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Semiotics and Intelligent Systems Development

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Table of Contents

Preface

Introduction

Sometimes, in order to mature, a framework operates outside the mainstream for a period of time; it becomes the mainstream only after this phase. This happened, for example, with neural networks, which appeared in the early 1960s, but became the mainstream in research only 25 years later after the development of the back-propagation algorithm as its learning algorithm. It happened also with fuzzy systems, which became popular only after the appearance of industrial fuzzy control applications in Japan. Likewise, an alternative approach is flourishing outside the mainstream yet remains unknown to most researchers in AI (artificial intelligence) and IS (intelligent systems). This alternative approach is computational semiotics, and we argue that it is a rapidly evolving and maturing research field that could become the basic operational theory and method within AI and IS.

Semiotics is a field of research involved in the study of meaning processes and communication practices within the fields of natural and social sciences, linguistics, and philosophy. Ideas and concepts from semiotics increasingly are being used by different researchers in computer science as a source of both theoretical insights and practical methodology. In particular, we consider that the field of artificial intelligence (intelligent systems) could benefit significantly from the use of semiotic insights and methods. The interdisciplinary method of semiotics, applied to the investigation of sign processes and dedicated to the development of intelligent systems, often is referred to by the scientific community as computational semiotics. This approach proposes a new analysis and methodology to the study of intelligent control and intelligent systems, an approach based on an explicit account of the notion of the sign. This strategy has introduced a wealth of both theoretical and methodological tactics developed under the scope of semiotics, which are being used to enrich artificial intelligence and to enable it to establish new frontiers and to bridge the theoretical and methodological gaps that have disturbed artificial intelligence studies for quite some time.

Early attempts of interdisciplinary studies involving semiotics and intelligent systems were developed independently by researchers from Russia and the United States during the 1960s and 1970s. The original coverage of intelligent control theory by the Russian Dmitri Pospelov (Pospelov, 1991; Pospelov & Yeimov, 1977) is still almost completely unknown in western science. In the United States, a similar effort also unknown to the mainstream appeared in the work of Eugene Pendergraft (1993).

Despite being ignored for about 20 years, a new and growing interest in such an approach began to appear in the 1990s. In 1990, James Fetzer (1990) proposed using Peirce's philosophy of the sign[1] as a strategy to deal with traditional problems in AI. In 1991, James Albus (1991) published a seminal paper analyzing the properties and attributes of an intelligent system. After 1995, the change began in earnest, and many conferences that focused on the semiotic theory and method began to appear:

- Workshop on Architectures for Semiotic Modeling and Situation Analysis in Large Complex Systems. 10th IEEE International Symposium on Intelligent Control, Monterey, California, 1995.
- Workshop on Control Mechanisms for Complex Systems: Issues of Measurement and Semiotic Analysis. Las Cruces, New Mexico, 1996.
- Second Workshop on Applied Semiotics. Smolenice Castle, Slovakia, 1997.
- ISAS'97 – Intelligent Systems and Semiotics – A Learning Perspective – International Conference. Gaithersburg, Maryland, 1997.
- ISIC/CIRA/ISAS'98 – IEEE International Symposium on Intelligent Control/Computational Intelligence in Robotics and Automation/Intelligent Systems and Semiotics. Gaithersburg, Maryland, 1998.
- ISIC/ISAS'99 – IEEE International Symposium on Intelligent Control, Intelligent Systems and Semiotics. Cambridge, Massachusetts, 1999.
- I Seminário Internacional de Inteligência Computacional e Semiótica, School of Electrical and Computer Engineering (FEEC-DCA-UNICAMP), 2000, CAMPINAS.
- II Workshop on Computational Intelligence and Semiotics, Catholic University of São Paulo, 2002, Itaú Cultural, São Paulo.

An important set of new research lines was developed at these meetings. Based on the work of Albus (1991), Meystel started a new line of research focused on characterizing the basic behavior of intelligent systems by means of a methodology called multiresolutional semiotics. This line was systematized in two books: *Engineering of Mind* (Albus & Meystel, 2001) and *Intelligent Systems—Architecture, Design and Control* (Meystel & Albus, 2001). Other important contributions derived from these conferences were the works of Perlovsky (2000) on Modeling Field Theory; Joslyn and Rocha (2000) on Semiotics in Control Systems and Semiotic Agents; Rieger (1999) and his SCIPS—Semiotic Cognitive Information Processing Systems; the stratified theory approach of Prueitt (1999) in knowledge management and knowledge science; and the semiotic machines and knowbots from Döben-Henisch, Erasmus, and Hasebrook (2002).

All of these proposals emerged to form an innovative and novel background for intelligent systems research. However, most of them flourished as isolated efforts without any connection to each other. The collation of all of them together, constituting a joint field of research, was one the greatest motivations for developing this book.

Organization of the Book

In this book, our goal is to present the most representative research projects in computational semiotics at the present time. Considering the relevance of the semiotic approach for future developments in artificial intelligence, we suggest—and certainly hope—that the collection will be a major contribution to the field. Within the book, we have contributions from philosophers, cognitive scientists, computer scientists, and engineers, all focused on the singular agenda of inquiring how semiotics works with intelligent system techniques in order to create newer and more robust types of intelligent systems. One of the main criticisms of which intelligent systems developers are accused is being naïve in their approaches to the question, "What is intelligence?" Therefore, it is as important to take into account the philosophy of the mind and to be aware of the issues of that field within current philosophic speculations as it is to develop a practical methodology of the technologies of semiotic intelligent systems.

The book is divided into four parts. **Section I: Theoretical Issues** includes chapters with a more philosophical tone. **Section II: Discussions on Semiotic Intelligent Systems** includes chapters that still have a philosophical flavor but move beyond philosophical speculations toward some kind of implementation of intelligent systems. **Section III: Semiotics in the Development of Intelligent Systems** includes chapters that use semiotics in some sense for the development of an intelligent system. Finally, **Section IV: Semiotic Systems Implementations** includes chapters whose authors claim to be using semiotic concepts in intelligent systems implementation.

In his chapter titled "Semiotic Brains and Artificial Minds: How Brains Make Up Material Cognitive Systems," Lorenzo Magnani presents a new cognitive perspective on the role of external models and representations. This perspective is based on the process of the disembodiment of the mind, a process that can be understood to function as the basis of thinking abilities. He invokes Turing's comparison between unorganized brains and logical and practical machines in order to illustrate the centrality to cognition of this disembodiment of the mind by examining the interplay between internal and external representations, both mimetic and creative. He describes the concept of what he calls a mimetic mind, emphasizing the possible impact of the construction of new types of universal practical machines available in the environment as new tools underlying the emergence of meaning processes.

In her chapter titled "Morphological Semiosis," Edwina Taborsky presents her account of reality as a semiotic system operating as a complex network of continuous adaptive networked relations that produce spatiotemporal morphologies or signs. Using the triadic model of a sign, as developed by Charles Sanders Peirce, we are able to classify reality within different types of morphologies or phenomena. This abstract account of reality could provide the key for a future implementation of an intelligent system that is able to represent fully each kind of phenomenon according to its semiotic characteristics. This could provide the strategy for the construction of artificial systems that are able to fully "understand" and work with their surrounding reality. Even though the chapter has a very abstract tone, this is a very important chapter, as it brings some light on how to connect the gap between general symbols or models and the particular actualities of the real world. At the end of the chapter, she puts forward some arguments on whether artificial (manmade) devices would possess the qualities for truly being called intelligent.

In her chapter titled "The Semiotic Structure of Practical Reasoning Habits," Phyllis Chiasson discusses how current intelligent systems lack that sort of commonplace, experience-based intelligence that helps ordinary humans to get through ordinary days. Computers lack what can be defined as common sense. That explains why even the smartest computers are not as intelligent as we would expect or as we would wish them to be. Chiasson proposes a theory of common sense from which to extract programmable systems. Her chapter deals with the syntax of various common-sense inferential structures and their effects on the capacity to carry out and express practical reasoning. The author proposes that having information about how people actually do reason, regardless of language, intelligence, or education, may be of use for developing humanlike computer models. In other words, she provides a new paradigm for thinking about thinking—one that many in systems sciences nevertheless may recognize, whether or not he or she is familiar with a Peircean-like analysis.

In his chapter titled "Toward a Pragmatic Understanding of the Cognitive Underpinnings of Symbol Grounding," Ben Goertzel and collaborators describe some interesting and promising results on experiments that combine a systems theory of mind with pragmatic AI/machine-learning implementations. Even though their results are preliminary, their experiments address the important issue of symbol grounding; that is, the dynamics by which connections are made between abstract symbols and models and concrete physical phenomena observed via sense perception and motor action. They developed a 3D-simulated environment (AGI-SIM) as a medium for training, teaching, and developing an integrative, general-intelligence-oriented AI software system, which they call the Novamente AI Engine. The role of the simulated embodiment is to assist Novamente in forming concrete sensorimotor groundings for abstract relationships, such as those expressed in English by prepositions and subject-argument relationships, and to provide a context in which these groundings may be used to bridge the gap between conceptual and sensorimotor knowledge in the context of learning to carry out simple tasks. Their work advocates an approach to symbol grounding that views the latter as one aspect of a more general and powerful process of integrated self-organizing cognition.

In his chapter titled "Symbols: Integrated Cognition and Language," Leonid Perlovsky proposes that a unifying mechanism, Modeling Field Theory, is behind the phenomena we identify as language and cognition. According to his approach, linguists often consider that language is made up of relationships among words and other linguistic entities and, as such, is separate from any relationship to the world. Mechanisms of language production in the mind and brain always were considered detached and different from thinking and cognition. He argues that there are intrinsic mathematical mechanisms regulating concepts, emotions, and instincts, and that these operate as information processes in the mind related to perception and cognition. His approach tries to escape combinatorial complexity, something that became a plague within artificial intelligence in the past. He escapes combinatorial complexity by introducing a new type of logic, which he calls fuzzy dynamic logic, which overcomes these past limitations. In addition, fuzzy dynamic logic is related to emotional signals in the brain and is used to combine mechanisms of emotions and concepts. This approach unifies the abilities of language and cognition, which play an important role both in language acquisition and in cognitive ontogenesis. As such, his mathematical model of thought processes is related directly to the semiotic notions of signs, models, and symbols.

In his chapter titled "Natural Grammar," Janos Sarbo and collaborators develop a semiotic analysis for what is going on during natural language use. His goal is to discover and examine the steps the mind or brain is going through when it is engaged in such a natural language use. He argues that it should be possible to develop a natural grammar that would formalize this naturalness in language use. He addresses these issues while appealing to a more general understanding that cognition should be modeled formally as a sign recognition process. He does so by investigating the complex relationship between computation and meaning. In summary, he proposes a model for knowledge representation that may be used in the future to allow a computer to generate information that a human user may process naturally.

In his chapter titled "A Theory of Semantics Based on Old Arabic," Tom Adi develops a theory of semantics using as a foundation his findings on the investigation of the meaning of short words in Old Arabic language. According to these findings, all Arabic vowels and consonants are equivalent to signs referring to abstract objects. He mapped 28 consonants and four vowels of Arabic to a 4x8 matrix of interrelated abstract objects and showed that, as a consequence, word roots could be seen as structured signs referring to structured abstract objects. On the one hand, this constitutes a theory of semantics for Old Arabic. On the other hand, Arabic roots provide an abstract set of concepts that any language could use in order to render reality. Based on these ideas, he developed a software system that he called Readware, which performs automated text exploration and analysis in English, German, and French. His chapter explores the main ideas behind this system.

In their chapter titled "The Semiotics of Smart Appliances and Pervasive Computing," Peter Bøgh Andersen and Martin Brynskov apply the linguistic theory of semantic roles and the notions of signs, their referents, and their mode of signifying to the development of what they call smart appliances, or, in other words, embedded intelligent systems. They discuss the notion of digital habitats, a conceptual and methodological framework for analyzing and designing smart appliances in the context of pervasive computing. They discuss and compare their approach to other approaches of developing intelligent systems. The main points in this comparison are as follows: (1) the framework provides a description of action dependencies that is relatable to organizational concepts like qualifications and norms; (2) it can describe communicative as well as material acts and also the way they are linked; (3) it provides an explicit link between human activities and their spatial context; (4) it has an explicit dynamic model that precisely describes the conditions for executing actions; and (5) it offers a typology of participant roles based on linguistic theory that reduces complexity and, therefore, supports design processes.

In their chapter titled "Systemic Semiotics as a Basis for an Agent-Oriented Conceptual Modeling Methodology," Rodney Clarke and collaborators use concepts from the field of systemic semiotics (most specifically, the notion of genre) to derive an agent-oriented conceptual modeling methodology for producing useful information systems. The goal is to emphasize the communicative, social, and semiotic (meaning-making) processes that occur in organizations while designing the information system. They applied the agent-oriented conceptual modeling framework i*, designed for use in early-phase requirements engineering, to a real-world problem, developing a case study throughout the chapter. They also discuss some broader connections between systemic semiotics and agent-oriented systems.

In his chapter titled "Computational Autognomics: An Introduction," Jon Ray Hamann surveys the basic notions behind the concept of AutoGnome, or self-knowing system, proposed during the 1960s and 1970s by Eugene Pendergraft and other collaborators, referred to at the beginning of this introduction. This chapter basically describes the AutoGnome as a semiotic machine that uses some of the philosophical principles of Charles Sanders Peirce. The main idea is the requirement for a strategy of theory formation. With that basis, the AutoGnome is able to create its own concepts based on input from the environment and to refine these concepts while it interacts with this same environment. At the end of the chapter, some applications using the AutoGnome are described and examined.

In his chapter titled "What Makes a Thinking Machine? Computational Semiotics and Semiotic Computation," Peter Krieg discusses the requirements for a semiotic machine. According to him, a semiotic machine must implement a genetic epistemology of cognition based on assimilation and pure relations. So, for him, semiotics is considered a relational and ontogenetic approach to describing cognition and communication in signifying systems. Therefore, implementing a semiotic approach to computing requires a computable and scalable signifying space where signs can be arbitrarily related, interpreted, deliberated, and produced. He argues that although signs are representations, a signifying space cannot be realized under the current representational paradigm of recording and processing static and physical data in a hierarchical data space. As an alternative to that paradigm, he introduces the Pile system, which, according to him, meets those requirements of a computable and scalable signifying space and is described as a semiotic computation system, structurally enabling processes of self-reflection, deliberation, and interpretation that commonly are associated with thinking.

Finally, in his chapter titled "Reducing Negative Complexity by a Computational Semiotic System," Gerd Döben-Henisch describes the setup for an experiment in computational semiotics. Starting with a hypothesis about negative complexity in the environment of human persons today, he proposes a strategy to assist in the reduction of this complexity by using a semiotic system. The basic ingredients of this strategy are a visual programming interface with an appropriate abstract state machine, which has to be realized by distributed virtual machines. The distributed virtual machines must be scalable, must allow parallel processing, must be fault-tolerant, and should have the potential to work in real time. The objects to be processed by these virtual machines are logical models (LModels), which represent dynamic knowledge, including self-learning systems. The descriptions are based on a concrete open-source project he calls "Planet Earth Simulator".

Conclusion

What is the current stage of actual technology involving semiotics and intelligent systems? What are the open theoretical questions that are already addressed but still in need of a more comprehensive analysis and better articulation?

The reader will find here a collection of texts that present from different perspectives a coordinated attempt to develop and correlate theoretical semiotics and AI techniques in order to create innovative and more robust intelligent systems. It is the first broad account of the field; it does not focus specifically on or privilege any of the different approaches that have been proposed up until now, but instead, it gives the reader the opportunity to consider the various directions and focuses that are emerging within the field.

It is still too early to evaluate appropriately all the perspectives opened up by the frontier of research presented in this book. It is premature to assert that it constitutes a new scientific paradigm (a shift paradigm) with a new view of the established problems. What these perspectives have in common, however, is a focus on the basic principle of semiosis, which is that the mapping of input to output, or sensory stimuli to interpretation, is not a mechanical one-to-one linearity but, instead, is mediated by some evolving intelligent process. This focus on that triadic function and the varied analyses of the nature of that mediation as an intelligent action of interpretation can be found in all the chapters in this book. There seems to be a consensus that many of the classic problems in AI (Brooks, 1990; Harnad, 1990) are connected strongly to this fundamental issue of representation (semiotic process), and therefore, the new approaches and new technological offerings presented within this book constitute a fresh breath of ideas and possibly an important new direction to follow in the future.

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Endnote

[1] Following the scholarly tradition, in this book, Peirce's work will be referred to as CP (followed by volume and paragraph number for quotes from *The Collected Papers of Charles S. Peirce,* Peirce, 1866-1913), MS (followed by reference number in accordance to Robin 1967 for quotes from Peirce's manuscripts), and W (followed by volume and page number for quotes from *Writing of Charles S. Peirce,* Peirce 1839-1914), LW (followed by number for quotes from *Semiotics and Significs: The Correspondence between Charles S. Peirce and Victoria Lady Welby*), NEM (followed by volume and page numbers for quotes from *New Elements of Mathematics by Charles S. Peirce*, Peirce 1976.

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Section I

Theoretical Issues

Chapter I

Semiotic Brains and Artificial Minds: How Brains Make Up Material Cognitive Systems

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Abstract

Our brains make up a series of signs and are engaged in making, manifesting or reacting to a series of signs: through this semiotic activity they are at the same time engaged in "being minds" and so in thinking intelligently. An important effect of this semiotic activity of brains is a continuous process of "externalization of the mind" that exhibits a new cognitive perspective on the mechanisms underling the semiotic emergence of abductive processes of meaning formation. In this perspective we can see that at the root of thinking abilities there is a process of externalization/disembodiment of mind that presents a new cognitive perspective on the role of external models and representations. To illustrate this process I will take advantage of Turing's comparison between unorganized brains and logical and practical machines and of the analysis of some aspects of the cognitive interplay between internal and external representations. I consider this interplay critical in analyzing the *relation between meaningful semiotic internal resources and devices and their dynamical interactions with the externalized semiotic materiality suitably stocked in the environment. Hence, minds are material, "extended" and artificial in themselves. A considerable part of human abductive thinking is occurring through an activity consisting in a kind of reification in the external environment and a subsequent re-projection and reinterpretation through new configurations of neural networks and chemical processes. The last part of the chapter will describe the concept of mimetic mind that I have introduced to shed new light on the role of computational modeling and on the decline of the so-called Cartesian computationalism.*

Introduction

What I call *semiotic brains* are brains that make up a series of signs and that are engaged in making, manifesting, or reacting to a series of signs; through this semiotic activity, they are at the same time engaged in being minds and, so, in thinking intelligently. An important effect of this semiotic activity of brains is a continuous process of disembodiment of mind that exhibits a new cognitive perspective on the mechanisms underling the semiotic emergence of meaning processes.

To illustrate this process, I will take advantage of some paleoanthropological results on the birth of material culture that provide an evolutionary perspective on the origin of intelligent behaviors. Then, I will describe the centrality to semiotic cognitive information processes of the *disembodiment* of mind from the point of view of the cognitive interplay between internal and external representations. I consider this interplay critical in analyzing the relation between meaningful semiotic internal resources and devices and their dynamic interactions with the externalized semiotic materiality already stocked in the environment. Hence, minds are extended and artificial in themselves.

Unorganized brains organize themselves through a semiotic activity that is reified in the external environment and then reprojected and reinterpreted through new configurations of neural networks and chemical processes. I also think the disembodiment of mind can account nicely for low-level semiotic processes of meaning creation, bringing up the question of how higher-level processes could be comprised and how they would interact with lower-level ones. With the aim of explaining these higher-level semiotic mechanisms, I provide the analysis of model-based and manipulative abduction and of external representations (Zhang, 1997) in which many external things, usually inert from the semiotic point of view, can be transformed into what I call epistemic mediators (Magnani, 2001a) that give rise (e.g., in the case of scientific reasoning) to new signs, new chances for interpretants, and new interpretations.

In the last part of the chapter, the concept of *mimetic mind* is introduced to shed new cognitive and philosophical light on the role of computational modeling and on the decline of the so-called Cartesian computationalism and to emphasize the possible impact of the construction of new types of universal practical machines available over there in the environment as new tools underlying the emergence of meaning processes.

The Centrality of Abduction

If we decide to increase knowledge on the semiotic character of cognition, it is necessary to develop a cognitive model of creativity that is able to represent not only novelty and unconventionality but also some features commonly referred to as the entire creative process, such as the expert use of background knowledge and ontology (defining new concepts and their new meanings and searching heuristically among the old ones) and the modeling activity developed in the so-called incubation time (generating and testing, transformations in the space of the hypotheses). The philosophical concept of *abduction*, which may be a candidate to solve this problem, offers an approach to model creative processes of meaning generation in a completely explicit and formal way, which can integrate fruitfully the narrowness proper of a merely psychological approach that is too experimentally human-oriented.

A hundred years ago, C. S. Peirce coined the concept of abduction in order to illustrate that the process of scientific discovery is not irrational and that a methodology of discovery is possible. Peirce interpreted abduction essentially as an inferential *creative process* of generating a new hypothesis. Abduction has a logical form (fallacious, if we model abduction by using classical syllogistic logic)[1] that is distinct from deduction and induction. Reasoning, which starts from reasons and looks for consequences, is called *deduction*; that which starts from consequences and looks for reasons is called *abduction*.

Abduction, a distinct form of reasoning, is the process of *inferring* certain facts and/or laws and hypotheses that render some sentences plausible and that *explain* or *discover* some (eventually new) phenomenon or observation; it is the process of reasoning in which explanatory hypotheses are formed and evaluated. There are two main epistemological meanings of the word *abduction* (Magnani, 2001a): (1) abduction that only generates plausible hypotheses (selective or creative); and (2) abduction considered as inference to the best explanation, which also evaluates hypotheses. An illustration from the field of medical knowledge is represented by the discovery of a new disease and the manifestations it causes, which can be considered the result of a creative abductive inference. Therefore, creative abduction deals with the whole field of the growth of scientific knowledge. This is irrelevant in medical *diagnosis*, in which, instead, the task is to select from an encyclopedia of prestored diagnostic entities. We can call both inferences ampliative, selective, and creative, because in both cases, the reasoning involved amplifies, or goes beyond, the information incorporated in the premises (Magnani, 1992).

Theoretical abduction certainly illustrates much of what is important in creative abductive reasoning in humans and in computational programs but fails to account for many cases of explanations occurring in science when the exploitation of environment is crucial. It fails to account for those cases in which there is a kind of discovering through doing, or cases in which new and still unexpressed information is codified by means of manipulations of some external objects (*epistemic mediators*). I have introduced this concept of theoretical abduction in Magnani (2001a, 2002): I maintain that there are two kinds of theoretical abduction: sentential, related to logic and to verbal/symbolic inferences; and model-based, related to the exploitation of internalized models of diagrams, pictures, and so forth (see the following sections of this chapter). The concept of *manipulative abduction*[2] captures a large part of scientific thinking in which the role of action is central and the features of this action are implicit and hard to be elicited; action can provide otherwise unavailable information that enables the agent to solve problems by starting and performing a suitable abductive process of generation or selection of hypotheses.

I will describe how manipulative abduction can account nicely for the relationship between meaningful behavior and dynamic interactions with the environment. The following sections illustrate that at the root of the creation of new meanings, there is a process of *disembodiment* of mind that exhibits a new cognitive description of the mechanisms underlying the emergence of meaning processes through semiotic delegations to the environment.

From the Prehistoric Brains to the Universal Machines

I have said that what I call *semiotic brains* are brains that make up a series of signs that are engaged in making or manifesting or reacting to a series of signs: through this semiotic activity they are at the same time engaged in "being minds" and so in thinking intelligently. In this section, I will illustrate the process of "disembodiment of mind" as an important aspect of this semiotic activity of brains.

Following Turing's (1994) point of view, a big cortex can provide an evolutionary advantage only in the presence of a massive storage of meaningful information and knowledge on external supports that only an already developed small community of human beings can possess. Evidence from paleoanthropology seems to support this perspective. Some research (Humphrey, 2002; Lewis-Williams, 2002; Mithen, 1996, 1999) in cognitive paleoanthropology, even if rather speculative, teaches us that high-level and reflective consciousness in terms of thoughts about our own thoughts and about our feelings (that is, consciousness not merely considered raw sensation) is intertwined with the development of *modern language* (speech) and *material culture*. About 250,000 years ago, several hominid species had brains as large as ours today, but their behaviors lacked any sign of art or symbolic behavior. If we consider high-level consciousness as related to a high-level organization (in Turing's sense) of human cortex, its origins can be related to the active role of environmental, social, linguistic, and cultural aspects.

Handaxes were made by early humans and first appeared 1.4 million years ago, still made by some of the Neanderthals in Europe just 50,000 years ago. The making of handaxes is strictly intertwined with the development of consciousness. Many needed capabilities constitute a part of an evolved psychology that appeared long before the first handaxes were manufactured. It seems that humans were preadapted for some components required to make handaxes (Mithen, 1996, 1999).

1. Imposition of *symmetry* (already evolved through predator's escape and social interaction). It has been an unintentional byproduct of the bifacial knapping technique but also deliberately imposed in other cases. Dennett (1991) hypothesizes that the attention to symmetry may have developed through social interaction and predator escape, as

it may allow one to recognize that one is being directly stared at. It also seems that "Hominid handaxes makers may have been keying into this attraction to symmetry when producing tools to attract the attention of other hominids, especially those of the opposite sex" (Mithen, 1999, p. 287).

2. Understanding *fracture dynamics* (e.g., evident from Oldowan tools and from nut cracking by chimpanzees today).
3. Ability to *plan* ahead (modifying plans and reacting to contingencies, such unexpected flaws in the material and miss-hits), still evident in the minds of Oldowan toolmakers and in chimpanzees.
4. High degree of *sensory-motor control*: "Nodules, pre-forms, and near finished artefacts must be struck at precisely the right angle with precisely the right degree of force if the desired flake is to be detached" (Mithen, 1999, p. 285). The origin of this capability usually is tracked back to encephalization (the increased number of nerve tracts; the integration between them allows for the firing of smaller muscle groups) and bipedalism (requires a more complex, integrated, highly fractionated nervous system, which, in turn, presupposes a larger brain).

The combination of these four resources produced an important semiotic revolution: the birth of what Mithen calls technical intelligence of the early human mind, which, consequently, is related to the construction of handaxes and their new semiotic values. Indeed, they indicate high intelligence and good health. They cannot be compared to the artefacts made by animals, like honeycomb or a spider web, deriving from the iteration of fixed actions, which do not require consciousness and intelligence.

Private Speech and Fleeting Consciousness

Two central factors play a fundamental role in the combination of the four previous resources:

- The exploitation of *private speech* (speaking to oneself) to trail between planning, fracture dynamic, motor control, and symmetry (also, in children, there is a kind of private muttering, which makes explicit what is implicit in the various abilities)
- A good degree of *fleeting consciousness* (thoughts about thoughts)

Of course, they furnish a kind of blackboard on which the four previously distinct resources can be exploited all together and in their dynamic interaction. In the meantime, these two aspects obviously played a fundamental role in the development of consciousness and thought:

So my argument is that when our ancestors made handaxes there were private mutterings accompanying the crack of stone against stone. Those private mutterings were instrumental in pulling the knowledge required for handaxes manufacture into an emergent consciousness.

But what type of consciousness? I think probably one that was fleeting one: one that existed during the act of manufacture and that did not endure. One quite unlike the consciousness about one's emotions, feelings, and desires that were associated with the social world and that probably were part of a completely separated cognitive domain, that of social intelligence, in the early human mind. (Mithen, 1999, p. 288)

This use of private speech certainly can be considered a semiotic internal tool for organizing brains a nd, so, for manipulating, expanding, and exploring minds, a tool that probably coevolved with another: talking to each other.[3] Both private and public language act as tools for thought and play a fundamental role in the evolution of opening up our minds to ourselves and, so, in the emergence of new meaning processes.

Material Culture and Semiosis

Another semiotic tool appeared in the latter stages of human evolution and played a great role in the evolutions of primitive minds (i.e., in the organization of human brains). Handaxes also are at the birth of material culture, so new cognitive chances can coevolve:

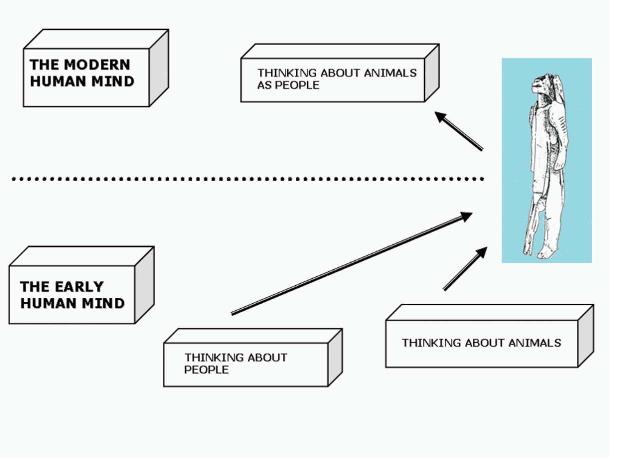
- The minds of some early humans, like the Neanderthals, were constituted by relatively isolated semiotic cognitive domains (Mithen, 1999, calls them *different intelligences*) that probably were endowed with different degrees of consciousness about the thoughts and knowledge within each domain (natural history intelligence, technical intelligence, social intelligence). These isolated cognitive domains became integrated, also taking advantage of the role of public language.
- *Degrees of high-level consciousness* appear; human beings need thoughts about thoughts.
- Social intelligence and public language arise.

It is extremely important to stress that *material culture* is not just the product of this massive cognitive chance but also a cause of it. "The clever trick that humans learnt was to *disembody* their minds into the material world around them: a linguistic utterance might be considered as a disembodied thought. But such utterances last just for a few seconds. Material culture endures" (cit., p. 291).

In this perspective, we acknowledge that material artefacts are tools for thoughts, as is language: tools—as new signs—for exploring, expanding, and manipulating our own minds. In this regard, the evolution of culture is inextricably linked with the evolution of consciousness and thought.

The early human brain becomes a kind of universal intelligent machine that is extremely flexible so that we no longer needed different separated intelligent machines doing different jobs. A single one will suffice. As the engineering problem of producing various machines for various jobs is replaced by the office work of programming the universal machine to do these jobs, so the different intelligences become integrated in a new universal device endowed with a high-level type of consciousness.[4]

Figure 1. (Source: Mithen, 1999)



From this perspective, the semiotic expansion of the mind is, in the meantime, a continuous process of *disembodiment* of the minds themselves into the *material world* around them. In this regard, the evolution of the mind is inextricably linked with the evolution of large, integrated, material cognitive semiotic systems. In the following sections, I will illustrate this extraordinary interplay between human brains and the cognitive systems they make.

Semiotic Delegations Through the Disembodiment of Mind

A wonderful example of meaning creation through disembodiment of mind is the carving of what most likely is the mythical being from the last ice age 30,000 years ago: a half-human/half-lion figure carved from mammoth ivory found at Hohlenstein Stadel, Germany.

An evolved mind is unlikely to have a natural home *for this being, as such entities do not exist in the natural world: so whereas evolved minds could think about humans by exploiting modules shaped by natural selection, and about lions by deploying content rich mental modules moulded by natural selection and about other lions by using other content rich modules from the natural history cognitive domain, how could one think about entities that were part human and part animal? Such entities had no home in the mind.* (cit., p. 291)

A mind consisting of different separated intelligences cannot come up with such an entity (Figure 1). The only way is to *extend* the mind into the *material word*, exploiting in a semiotic way rocks, blackboards, paper, ivory, and writing, painting, and carving: “artefacts such as this figure play the role of anchors for ideas and have no *natural home* within the mind; for ideas that take us beyond those that natural selection could enable us to possess” (cit., p. 291).

In the case of our figure, we face with an anthropomorphic thinking created by the material representation serving to semiotically anchor the cognitive representation of supernatural being. In this case, the material culture disembodies thoughts that otherwise will soon disappear without being transmitted to other human beings, and realizes a systematic semiotic delegation to the external environment. The early human mind possessed two separated intelligences for thinking about animals and people. Through the mediation of the material culture, the modern human mind can arrive to think internally about the new concept of animal and people at the same time. But the new meaning occurred over there, in the external material world, where the mind picked it up.

Artefacts as *external semiotic objects* allowed humans to loosen and cut those chains on our unorganized brains imposed by our evolutionary past. Chains always limited the brains of other human beings, such as the Neanderthals. Loosing chains and securing ideas to external objects was also a way to creatively reorganize brains as universal machines for thinking.

In the remaining part of this chapter, I will describe the centrality to semiotic cognitive information processes of the disembodiment of mind from the point of view of the cognitive interplay between internal and external representations. I consider this interplay critical in analyzing the relation between meaningful semiotic internal resources and devices and their dynamic interactions with the externalized semiotic materiality already stocked in the environment. Hence, minds are extended and artificial in themselves.

Mimetic and Creative Representations

We have seen that unorganized brains organize themselves through a semiotic activity that is reified in the external environment and then reprojected and reinterpreted through new configurations of neural networks and chemical processes. I also think that the disembodiment of mind can account nicely for low-level semiotic processes of meaning creation, bringing up the question of how higher-level processes could be comprised and how they would interact with lower-level ones.

External and Internal Representations

We have said that through the mediation of the material culture, the modern human mind can arrive to think *internally* about the new meaning of animals and people at the same time. We can account for this process of disembodiment from an impressive cognitive point of view.

I maintain that representations are external and internal. We can say that:

- *External representations* are formed by external materials that express (through reification) concepts and problems that already stoed or do not have a natural home in the brain.

- *Internalized representations* are internal reprojections, a kind of recapitulations (learning), of external representations in terms of neural patterns of activation in the brain. They sometimes can be internally manipulated like external objects and can originate new internal reconstructed representations through the neural activity of *transformation* and *integration*.

This process explains why human beings seem to perform both computations of a connectionist type,[5] such as the ones involving representations as:

- **I Level:** *Patterns of neural activation* that arise as the result of the interaction between body and environment (and suitably shaped by the evolution and the individual history): pattern completion or image recognition

and computations that use representations as:

- **II Level:** *Derived combinatorial syntax and semantics* dynamically shaped by the various external representations and reasoning devices found or constructed in the environment (e.g., geometrical diagrams); they are neurologically represented contingently as pattern of neural activations that sometimes tend to become stabilized structures and to fix and, so, to *permanently belong to the I Level*.

I Level originates those *sensations* (they constitute a kind of face that we think the world has) that provide room for the II Level to reflect the structure of the environment, and, most importantly, that can follow the computations suggested by these external structures. It is clear that we now can conclude that the growth of the brain and especially the synaptic and dendritic growth are determined profoundly by the environment.

When the fixation is reached, the patterns of neural activation no longer need a direct stimulus from the environment for their construction. In a certain sense, they can be viewed as *fixed internal records* of *external structures* that *can exist* also in the absence of such external structures. These patterns of neural activation that constitute the I Level Representations always keep record of the experience that generated them and, thus, always carry the II Level Representation associated with them, even if in a different form, the form of *memory* and not the form of a vivid sensorial experience. Now, the human agent, via neural mechanisms, can retrieve these II Level Representations and use them as internal representations or use parts of them to construct new internal representations very different from the ones stored in memory (see also Gatti & Magnani, 2005).[6]

In the following section, I will illustrate some fundamental aspects of the previous interplay in light of basic semiotic aspects of abductive reasoning.

Model-Based Abduction and Semiosis Beyond Peirce

I think there are two basic kinds of external representations active in this process of externalization of the mind: *creative* and *mimetic*. Mimetic external representations mirror concepts and problems that are already represented in the brain and need to be enhanced, solved, further complicated, etc., so they sometimes can also creatively give rise to new concepts and meanings. In the examples, I will illustrate in the following sections that it will be clear how for instance a mimetic geometric representation can become creative and give rise to new meanings and ideas in the hybrid interplay between brains and suitable cognitive environments.

What exactly is model-based abduction from a philosophical point of view? Peirce stated that all thinking is in signs, and signs can be icons, indices, or symbols. Moreover, all *inference* is a form of sign activity, where the word sign includes "feeling, image, conception, and other representation" (CP 5.283), and, in Kantian words, all synthetic forms of cognition; that is, a considerable part of the creative meaning processes is *model-based*. Moreover, a considerable part of the meaningful behavior (not only in science) occurs in the middle of a relationship between brains and external objects and tools that have received cognitive and/or epistemological delegations (see the previous and following subsections).

Following this Peircean perspective about inference, I think it is extremely useful from a cognitive point of view to consider the concept of reasoning in a very broad way (see also Brent, 2000). We have three cases:

1. Reasoning can be fully conscious and typical of high-level, worked-out ways of inferring, like in the case of scientists' and professionals' performances.
2. Reasoning can be acritical (CP 5.108), which includes everyday inferences in conversation and in various ordinary patterns of thinking.
3. Reasoning can resort to "operations of the mind which are logically analogous to inference excepting only that they are unconscious and therefore uncontrollable and therefore not subject to logical criticism" (CP 5.108).

Immediately, Peirce adds a note to the third case: "But that makes all the difference in the world; for inference is essentially deliberate, and self-controlled. Any operation which cannot be controlled, any conclusion which is not abandoned, not merely as soon as criticism has pronounced against it, but in the very act of pronouncing that decree, is not of the nature of rational inference—is not reasoning" (CP 5.108).

As Colapietro (2000) clearly states, it seems that for Peirce, human beings semiotically involve unwitting trials and unconscious processes. Moreover, it seems clear that unconscious thought can be in some sense considered inference, even if not rational; indeed, Peirce says, it is not reasoning. Peirce further indicates that there are in human beings multiple trains of thought at once, but only a small fraction of them is conscious; nevertheless, the prominence in consciousness of one train of thought is not to be interpreted an interruption of other ones.

In this Peircean perspective, which I adopt in this chapter, where inferential aspects of thinking dominate, there is no intuition in an anti-Cartesian way. We know all-important facts about ourselves in an *inferential*, abductive way:

[W]e first form a definite idea of ourselves as a hypothesis to provide a place in which our errors and other people's perceptions of us can happen. Furthermore, this hypothesis is constructed from our knowledge of outward physical facts, such things as the sounds we speak and the bodily movements we make, that Peirce calls signs. (Brent, 2000, p. 10)

Recognizing in a series of *material*, physical events, that they make up a series of signs, is to know the existence of a *mind* (or of a group of minds) and to be absorbed in making, manifesting, or reacting to a series of signs is to be absorbed in being a mind. "[A]ll thinking is dialogic in form" (CP 6.338), both at the intrasubjective[7] and intersubjective level, so that we see ourselves exactly as others see us, or see them exactly as they see themselves, and we see ourselves through our own speech and other interpretable behaviors, just as others see us and themselves in the same way, in the commonality of the whole process (Brent, 2000).

As we will explain better in the following sections, in this perspective, minds are material like brains insofar as they consist in intertwined internal and external semiotic processes: "[T]he psychologists undertake to locate various mental powers in the brain; and above all consider it as quite certain that the faculty of language resides in a certain lobe; but I believe it comes decidedly nearer the truth (though not really true) that language resides in the tongue. In my opinion it is much more true that the thoughts of a living writer are in any printed copy of his book than they are in his brain" (CP 7.364).

Man is an External Sign

Peirce's semiotic motto, man is an external sign, is very clear about the materiality of mind and about the fact that the conscious self[8] is a cluster actively embodied of flowing intelligible signs:

It is sufficient to say that there is no element whatever of man's consciousness which has not something corresponding to it in the word; and the reason is obvious. It is that the word or sign which man uses is *the man himself. For, as the fact that every thought is a sign, taken in conjunction with the fact that life is a train of thoughts, proves that man is a sign; so, that every thought is an* external sign*, proves that man is an external sign. That is to say, the man and the* external sign *are identical, in the same* sense *in which the words* homo *and* man *are identical. Thus my language is the sum total of myself; for the man is the thought.* (CP 5.314)

It is by way of signs that we ourselves *are* semiotic processes; for example, a more or less coherent cluster of narratives. If all thinking is in signs, it is not true that thoughts are in us because we are in thoughts.

I think it is at this point clearer what I meant when I said in the previous section when I explained the concept of model-based abduction, that all thinking is in signs, and signs can be icons, indices, or symbols, and that, moreover, all inference is a form of sign activity, where the word sign includes feeling, image, conception, and other representation. The model-based aspects of human cognition are central, given the central role played, for example, by signs like images and feeling in the inferential activity. "[M]an is a sign developing according to the laws of inference. [T]he entire phenomenal manifestation of mind is a sign resulting from inference" (CP 5.312-313).

Moreover, the person-sign is future-conditional; that is, not fully formed in the present but depending on the future destiny of the concrete semiotic activity (future thoughts and experience of the community) in which he or she will be involved. If Peirce maintains that when we think, we appear as a sign (CP 5.283) and, moreover, that everything is present to us is a phenomenal manifestation of ourselves, feelings, images, diagrams, conceptions, schemata, and other representations are phenomenal manifestations that become available for interpretations and, thus, are guiding our actions in a positive or negative way. They become *signs* when we think and interpret them. It is well-known that, for Peirce, all semiotic experience (and thus, abduction) also is providing a guide for action. Indeed, the whole function of thought is to produce habits of action.[9]

Let us summarize some basic semiotic ideas that will be of help in the further clarification of the cognitive and computational features of model-based and manipulative abduction. One of the central property of signs is their reinterpretability. This occurs in a social process in which signs are referred to *material objects*.

As it is well-known, for Peirce, iconic signs are based on similarity alone; the psychoanalytic patient who thought he was masturbating when piloting the plane interpreted the cloche as an extension of his body and an iconic sign of the penis; an ape may serve as an icon of a human. *Indexical* signs are based on contiguity and dynamic relation to the object, a sign which refers to an object that it denotes by virtue of being really affected by that object: a certain grimace indicates the presence of pain; the rise of the column of mercury in a thermometer is a sign of a rise in temperature; indexical signs are also the footprints in the sand or a rap on the door. Consequently, we can say that indexical signs point. A *symbol* refers to an artificial or conventional (by virtue of a law) interpretation of a sign; the sign ∞ used by mathematicians would be an example of Peirce's notion of symbol, almost all words in language, except for occasional onomatopoeic qualities, are symbols in this sense, associated with referents in a wholly arbitrary manner.

We have to immediately note that from the semiotic point of view, *feelings*, too, are signs that are subject to semiotic interpretations at different levels of complexity. Peirce considered feelings elementary phenomena of the mind, comprising all that is immediately present, such as pain, sadness, and cheerfulness. He believes that a feeling is a state of mind possessing its own living qualities independent of any other state of the mind. Neither icon, index, nor symbol actually functions as a sign until it is interpreted and recognized in a semiotic activity and code. To make an example, it is the evolutionary kinship that makes the ape an icon of the man; in itself, the similarity of two animals does not mean anything.

Where cognition is merely possible, sign action, or *semiosis*, is working. Knowledge is surely inferential as well as abduction, which, like any inference, requires three elements: a sign, the object signified, and the *interpretant*. Everywhere, A signifies B to C.

There is a continuous activity of interpretation, and some of this activity, as we will see, is abductive. The Peircean notion of interpretant plays the role of explaining the activity of interpretation that is occurring in semiosis. The interpretant does not necessarily refer to an actual person or mind, an actual interpreter. For instance, the communication to be found in a beehive, where the bees are able to communicate with the others by means of signs, is an example of a kind of "mindless" triadic semiosis; indeed, we recognize that a sign has been interpreted, not because we have observed a mental action but by observing another material sign. To make another example, the person recognizing the thermometer as a thermometer is an interpretant, as he or she generates in his or her brain a thought. In this case, the process is conscious, but unconscious or emotional interpretants are also widespread. Again, a person points (index) up at the sky, and his or her companion looks up (interpretant) to see the object of the sign. Someone else might call out, "What do you see up there?" which is also another interpretant of the original sign. As noted by Brent (2000, p. 12), "For Peirce, any appropriate response to a sign is acting as another sign of the object originally signified. A sunflower following the sun across the sky with its face is also an interpretant. Peirce uses the word interpretant to stand for any such development of a given sign."

Finally, an interpretant may be the thought of another person but may as well be simply the further thought of the first person; for example, in a soliloquy, the succeeding thought is the interpretant of the preceding thought so that an interpretant is both the interpretant of the thought that precedes it and the object of the interpretant thought that succeeds it. In soliloquy, sign, object, and interpretant are all present in the single train of thought.

Interpretants, mediating between signs and their objects, have three distinct levels in hierarchy: feelings, actions, and concepts or habits (i.e., various generalities as responses to a sign). They are the effect of a sign process. The interpretant produced by the sign can lead to a feeling (*emotional* interpretant) or to a muscular or mental effort; that is, to a kind of action—energetic interpretant (not only outward, bodily action, but also purely inward exertions like those "mental soliloquies strutting and fretting on the stage of imagination") (Colapietro, 2000, p. 142). Finally, when it is related to the abstract meaning of the sign, the interpretant is called *logical*, as a generalization requiring the use of verbal symbols. It is a further development of semiosis in the hierarchy of iconic, enactive, and symbolic communication; in short, it is "an interpreting thought" related, for instance, not only to the intellectual activity but also to initiate the ethical action insofar as a modification of a person's tendencies toward action" (CP 5.476).

The logical interpretants are able to translate percepts, emotions, unconscious needs, and experience needs, and, so, to mediate their meanings to arrive to provisional stabilities. They can lead to relatively stable cognitive or intellectual habits and belief changes as self-controlled achievements like many abductive conceptual results, which Peirce considers the most advanced forms of semiosis and the ultimate outcome of a sign. Indeed, abduction—hypothesis—is the first step toward the formation of cognitive habits: "every concept, every general proposition of the great edifice of science, first came to us as a conjecture. These ideas are the *first logical interpretants* of the phenomena that suggested them, and which, as suggesting them, are signs" (CP 5.480).

Ortogonal to the classification of interpretants as emotional, energetic, and logical is the alternate classification given by Peirce: interpretants also can be immediate, dynamic, and normal. Some interpreters consider this classification a different way of expressing the first one. It is sufficient to note this classification can be useful in studying the formation of a subclass of debilitating and facilitating psychic habits (Colapietro, 2000, pp. 144-146). Colapietro (2000) proposes the concept of quasi-final interpretants, as related to the Peircean normal interpretants, as "effective in the minimal sense that they allow the conflict-ridden organism to escape being paralyzed agent: they permit the body-ego to continue its ongoing negotiations with these conflicting demands, even if only in a precarious and even debilitating manner. In brief, they permit the body-ego to go on" (p. 146). For instance, there are some sedimented unconscious reactions of this type in immediate puzzling environments (later on, useless and stultifying in wider settings), but there is also the recurrent reflective and provisionally productive use of fallacious ways of reasoning like hasty generalizations and other arguments (Woods, 2004).

In the following sections, I will describe how the interplay of signs, objects, and interpretants is working in important aspects of abductive reasoning. Of course, model-based cognition acquires its peculiar creative relevance when embedded in abductive processes. I will show some examples of model-based inferences. It is well-known the importance Peirce ascribed to diagrammatic thinking (a kind of iconic thinking), as shown by his discovery of the powerful system of predicate logic based on diagrams or existential graphs. As we have already stressed, Peirce considers inferential any cognitive activity whatever, not only conscious abstract thought; he also includes perceptual knowledge and subconscious cognitive activity. For instance, in subconscious mental activities, visual representations play an immediate role.[10]

Many commentators always criticized the Peircean ambiguity in treating abduction in the same time as inference and perception. It is important to clarify this problem, because perception and imagery are kinds of that model-based cognition that we are exploiting to explain abduction; in Magnani (2006), I conclude that we can render consistent the two views, beyond Peirce, but perhaps also within the Peircean texts, taking advantage of the concept of *multimodal abduction*, which depicts hybrid aspects of abductive reasoning (Magnani, 2006).

Constructing Meaning Through Mimetic and Creative External Objects

Constructing Meaning Through Manipulative Abduction

Manipulative abduction occurs when many external things, usually inert from the semiotic point of view, can be transformed into what I have called epistemic mediators (Magnani, 2001a) that give rise (i.e., in the case of scientific reasoning) to new signs, new chances for interpretants, and new interpretations.

We can cognitively account for the process of disembodiment of mind that we have seen in the perspective of paleoanthropology, taking advantage of the concept pf *manipulative abduction*. It happens when we are thinking *through* doing and not only in a pragmatic sense, about doing. It happens, for instance, when we are creating geometry constructing and manipulating, an external, suitably realized icon like a triangle looking for new meaningful features of it, like in the case given by Kant in the Transcendental Doctrine of Method (Magnani, 2001b) (see the following subsection). It refers to an extra-theoretical behavior that aims at creating communicable accounts of new experiences to integrate them into previously existing systems of experimental and linguistic (semantic) practices.

Gooding (1990) refers to this kind of concrete manipulative reasoning when he illustrates the role in science of the so-called construals that embody tacit inferences in procedures that are often apparatus and machine-based. The embodiment is, of course, an expert manipulation of meaningful semiotic objects in a highly constrained experimental environment and is directed by abductive movements that imply the strategic application of old and new *templates* of behavior mainly connected with extra-rational components; for instance, emotional, esthetical, ethical, and economic.

The hypothetical character of construals is clear: they can be developed to examine or discard further chances, they are provisional creative organization of experience, and some of them become in their turn hypothetical *interpretations* of experience that is more theory-oriented, and their reference/meaning is gradually stabilized in terms of established observational practices. Step by step, the new interpretation, which at the beginning is completely practice-laden, relates to more theoretical modes of understanding (narrative, visual, diagrammatic, symbolic, conceptual, simulative), closer to the constructive effects of theoretical abduction. When the reference/meaning is stabilized, the effects of incommensurability with other established observations can become evident. But it is just the construal of certain phenomena that can be shared by the sustainers of rival theories. Gooding (1990) shows how Davy and Faraday could see the same attractive and repulsive actions at work in the phenomena they respectively produced; their discourse and practice as to the role of their construals of phenomena clearly demonstrate that they did not inhabit different, incommensurable worlds in some cases. Moreover, the experience is constructed, reconstructed, and distributed across a social network of negotiations among the different scientists by means of construals.

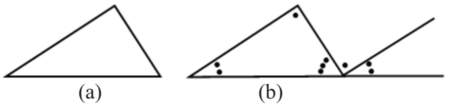
It is difficult to establish a list of invariant behaviors that are able to describe manipulative abduction in science. As already illustrated, certainly the expert manipulation of objects in a highly semiotically constrained experimental environment implies the application of old and new *templates* of behavior that exhibit some regularities. The activity of building construals is highly conjectural and not immediately explanatory: these templates are hypotheses of behavior (creative or already cognitively present in the scientist's mind-body system and sometimes already applied) that abductively enable a kind of epistemic doing. Hence, some templates of action and manipulation can be *selected* in the set of the ones available and prestored; others have to be *created* for the first time in order to perform the most interesting creative cognitive accomplishments of manipulative abduction.

Moreover, I think that a better understanding of manipulative abduction at the level of scientific experiment could improve our knowledge of induction and its distinction from abduction; manipulative abduction could be considered a kind of basis for further meaningful inductive generalizations. Different generated construals can give rise to different inductive generalizations.

Some common features of these tacit templates that enable us to manipulate things and experiments in science to favor meaning formation are related to the following:

1. Sensibility toward the aspects of the phenomenon that can be regarded as *curious* or *anomalous*; manipulations have to be able to introduce potential inconsistencies in the received knowledge (Oersted's report of his well-known experiment about electromagnetism is devoted to describe some anomalous aspects that did not depend on any particular theory of the nature of electricity and magnetism; Ampère's construal of experiment on electromagnetism, exploiting an artifactual apparatus to produce a static equilibrium of a suspended helix that clearly shows the role of the unexpected).
2. Preliminary sensibility toward the *dynamic* character of the phenomenon and not to entities and their properties; a common aim of manipulations is to practically reorder the dynamic sequence of events in a static spatial one that should promote a subsequent bird's-eye view (narrative or visual-diagrammatic).
3. Referral to experimental manipulations that exploit *artificial apparatus* to free new possibly stable and repeatable sources of information about hidden knowledge and constraints (Davy well-known setup in terms of an artifactual tower of needles showed that magnetization was related to orientation and does not require physical contact). Of course, this information is not artificially made by us; the fact that phenomena are made and manipulated does not render them to be idealistically and subjectively determined.
4. Various contingent ways of epistemic acting: *looking* from different perspectives; *checking* the different information available; *comparing* subsequent events; *choosing*, *discarding*, *imaging* further manipulations; *reordering* and *changing relationships* in the world by implicitly evaluating the usefulness of a new order (e.g., to help memory). From the general point of view of everyday situations, manipulative abductive reasoning exhibits other very interesting templates.
5. Action elaborates a *simplification* of the reasoning task and a redistribution of effort across time when we "need to manipulate concrete things in order to understand structures which are otherwise too abstract" (Piaget, 1974) or when we are in presence of *redundant* and unmanageable information.
6. Action can be useful in presence of *incomplete* or *inconsistent* information, not only from the perceptual point of view (or of a diminished capacity to act upon the world), but it is used to get more data to restore coherence and to improve deficient knowledge.
7. Action as a *control of sense data* illustrates how we can change the position of our body (and/or of the external objects) and how to exploit various kinds of prostheses (Galileo's telescope, technological instruments and interfaces) to get various new kinds of stimulation. Action provides some tactile and visual information (e.g., in surgery) that is otherwise unavailable.
8. Action enables us to build *external artifactual models* of task mechanisms instead of the corresponding internal ones that are adequate to adapt the environment to the agent's needs. Experimental manipulations exploit artificial apparatus to free new possible stable and repeatable sources of information about hidden knowledge and constraints.[11]

Figure 2. Diagrammatic demonstration that the sum of the internal angles of any triangle is 180°; (a) triangle, (b) diagrammatic manipulations



The whole activity of manipulation is devoted to building various external *epistemic mediators*[12] that function as versatile semiotic tools that are able to provide an enormous new source of information and knowledge. Therefore, manipulative abduction represents a kind of redistribution of the epistemic and cognitive effort to manage objects and information that cannot be represented immediately or found internally (e.g., exploiting the resources of visual imagery).[13]

If we see scientific discovery like a kind of opportunistic ability of integrating information from many kinds of simultaneous constraints to produce explanatory hypotheses that account for them all, then manipulative abduction will play the role of eliciting possible hidden constraints by building external suitable experimental structures.

Manipulating Meanings Through External Semiotic Anchors

If the structures of the environment play such an important role in shaping our semiotic representations and, hence, our cognitive processes, then we can expect that physical manipulations of the environment receive a cognitive relevance.

Several authors have pointed out the role that physical actions can have at a cognitive level. In this sense, Kirsh and Maglio (1994) distinguish actions in two categories; namely, *pragmatic actions* and *epistemic actions*. Pragmatic actions are the actions that an agent performs in the environment in order to bring itself physically closer to a goal. In this case, the action modifies the environment so that the latter acquires a configuration that helps the agent to reach a goal that is understood as physical; that is, as a desired state of affairs. Epistemic actions are the actions that an agent performs in a semiotic environment in order to discharge the mind of a cognitive load or to extract information that is hidden or that would be very hard to obtain only by internal computation.

In this section, I want to focus specifically on the relationship that can exist between manipulations of the environment and representations. In particular, I want to examine whether external manipulations can be considered as a means to construct external representations.

If a manipulative action performed upon the environment is devoted to create a configuration of signs that carries relevant information, then that action will be able to be considered as a cognitive semiotic process, and the configuration of elements it creates will be able to be considered an external representation. In this case, we can really speak of an embodied cognitive process in which an action constructs an external representation by means of manipulation. We define *cognitive manipulating* as any manipulation of the environment that is devoted to construct external configurations that can count as representations.

An example of cognitive manipulating is the diagrammatic demonstration illustrated in Figure 2, taken from the field of geometry. In this case, a simple manipulation of the triangle in Figure 2(a) gives rise to an external configuration, Figure 2(b), that carries relevant semiotic information about the internal angles of a triangle anchoring new meanings.

The entire process through which an agent arrives at a physical action that can count as cognitive manipulating can be understood by means of the concept of manipulative abduction (Magnani, 2001a). Manipulative abduction is a specific case of cognitive manipulating in which an agent, when faced with an external situation from which it is hard or impossible to extract new meaningful features of an object, selects or creates an action that structures the environment in such a way that it gives information that otherwise would be unavailable and that is used specifically to infer explanatory hypotheses.

In this way, the semiotic result is achieved on *external* representations used in lieu of the internal ones. Here, action performs an *epistemic* and not a merely performatory role, for example, that is relevant to abductive reasoning.

Geometrical Construction is a Kind of Manipulative Abduction

Let's quote Peirce's passage about mathematical constructions. Peirce says that mathematical and geometrical reasoning "consists in constructing a diagram according to a general precept, in observing certain relations between parts of that diagram not explicitly required by the precept, showing that these relations will hold for all such diagrams, and in formulating this conclusion in general terms. All valid necessary reasoning is in fact thus diagrammatic" (CP 1.54). This passage clearly refers to a situation like the one I have illustrated in the previous section. This kind of reasoning also is called by Peirce theorematic, and it is a kind of deduction necessary to derive significant theorems: "is one which, having represented the conditions of the conclusion in a diagram, performs an ingenious experiment upon the diagram, and by observation of the diagram, so modified, ascertains the truth of the conclusion" (CP 2.267). The experiment is performed with the help of "imagination upon the image of the premises in order from the result of such experiment to make corollarial deductions to the truth of the conclusion" (NEM 4.38). The corollarial reasoning is mechanical (Peirce thinks it can be performed by a logical machine) and not creative. "A Corollarial Deduction is one which represents the condition of the conclusion in a diagram and finds from the observation of this diagram, as it is, the truth of the conclusion" (CP 2.267) (Hoffmann, 1999).

In summary, the point of theorematic reasoning is the transformation of the problem by establishing an unnoticed point of view to get interesting—and possibly new—insights. The demonstrations of theorems in mathematics are examples of theorematic deduction.

Not dissimilarly, Kant says that in geometrical construction of external diagrams "I must not restrict my attention to what I am actually thinking in my concept of a triangle (this is nothing more than the mere definition); I must pass beyond it to properties which are not contained in this concept, but yet belong to it" (Kant, 1929, A718-B746, p. 580).

We have seen that manipulative abduction is a kind of abduction, usually model-based, that exploits external models endowed with delegated (and often implicit) cognitive and semiotic roles and attributes.

1. The model (diagram) is *external* and the strategy that organizes the manipulations is unknown *a priori*.
2. The result achieved is *new* (if we, for instance, refer to the constructions of the first creators of geometry) and adds properties not contained before in the concept (the Kantian to "pass beyond" or "advance beyond" the given concept) (Kant, 1929, A154-B193/194, p. 192).[14]

Iconicity in theorematic reasoning is central. Peirce, analogously to Kant, maintains that "philosophical reasoning is reasoning with words; while theorematic reasoning, or mathematical reasoning is reasoning with specially constructed schemata" (Peirce, 1931-1958, H4.233); moreover, he uses diagrammatic and schematic as synonyms, thus relating his considerations to the Kantian tradition in which schemata mediate between intellect and phenomena.[15] The following is the famous passage in the *Critique of Pure Reason* (Transcendental Doctrine of Method):

Suppose a philosopher be given the concept of a triangle and he be left to find out, in his own way, what relation the sum of its angles bears to a right angle. He has nothing but the concept of a figure enclosed by three straight lines, and possessing three angles. However long he meditates on this concept, he will never produce anything new. He can analyse and clarify the concept of a straight line or of an angle or of the number three, but he can never arrive at any properties not already contained in these concepts. Now let the geometrician take up these questions. He at once begins by constructing a triangle. Since he knows that the sum of two right angles is exactly equal to the sum of all the adjacent angles which can be constructed from a single point on a straight line, he prolongs one side of his triangle and obtains two adjacent angles, which together are equal to two right angles. He then divides the external angle by drawing a line parallel to the opposite side of the triangle, and observes that he has thus obtained an external adjacent angle which is equal to an internal angle—and so on.[16] *In this fashion, through a chain of inferences guided throughout by intuition, he arrives at a fully evident and universally valid solution of the problem.* (Kant, 1929, A716-B744, pp. 578-579)

As we have already said for Peirce, the whole mathematics consists in building diagrams that are (continuous in geometry and arrays of repeated signs/letters in algebra) according to general precepts and then observing in the parts of these diagrams relations not explicitly required in the precepts (CP 4.233). Peirce contends that this diagrammatic nature is not clear if we only consider syllogistic reasoning "which may be produced by a machine" but becomes extremely clear in the case of the "logic of relatives, where any premise whatever will yield an endless series of conclusions, and attention has to be directed to the particular kind of conclusion desired" (Peirce, 1986, vol. 2, p. 23).

In ordinary geometrical proofs, auxiliary constructions are present in terms of conveniently chosen figures and diagrams where strategic moves are important aspects of deduction. The system of reasoning exhibits a dual character: deductive and hypothetical. Also in other (e.g., logical) deductive frameworks, there is room for strategical moves that play a fundamental role in the generations of proofs. These strategical moves correspond to particular forms of abductive reasoning.

We know that the kind of reasoned inference that is involved in creative abduction goes beyond the mere relationship that there is between premises and conclusions in valid deductions, where the truth of the premises guarantees the truth of the conclusions, but also beyond the relationship that there is in probabilistic reasoning, which renders the conclusion just more or less probable. On the contrary, we have to see creative abduction as formed by the application of *heuristic procedures* that involve all kinds of good and bad inferential actions and not only the mechanical application of rules. It is only by means of these heuristic procedures that the acquisition of *new* truths is guaranteed. Also, Peirce's mature view illustrated previously on creative abduction as a kind of inference seems to stress the strategic component of reasoning.

Many researchers in the fields of philosophy, logic, and cognitive science have sustained that deductive reasoning also consists in the employment of logical rules in a heuristic manner, even maintaining the truth-preserving character: the application of the rules is organized in a way that is able to recommend a particular course of actions instead of another one. Moreover, very often, the heuristic procedures of deductive reasoning are performed by means of a model-based abduction where iconicity is central. We have seen that the most common example of creative abduction is the usual experience people have solving problems in geometry in a *model-based* way, trying to devise proofs using diagrams and illustrations; of course, the attribute of creativity we give to abduction in this case does not mean that it never has been performed before by anyone or that it is original in the history of some knowledge.

Hence, we have to say that theoretical model-based abductions (i.e., iconicity) also operate in deductive reasoning. Following Hintikka and Remes's (1974) analysis, proofs of general implication in first order logic need the use of instantiation rules by which new individuals are introduced, so they are ampliative. In ordinary geometrical proofs, auxiliary constructions are present in terms of conveniently chosen figures and diagrams. In Beth's method of semantic tableaux, the strategic ability to construct impossible configurations is undeniable (Hintikka, 1998; Niiniluoto, 1999).[17]

This means that also in many forms of deductive reasoning, there not only are trivial and mechanical methods of making inferences, but we also have to use *models* and *heuristic procedures* that refer to a whole set of strategic principles. This is all the more reason that Bringsjord (2000) stresses his attention on the role played by a kind of model-based deduction that is part and parcel of our establishing Gödel's first incompleteness theorem, showing the model-based character of this great abductive achievement of formal thought.[18]

I think the previous considerations also hold for Peircean theorematic reasoning; indeed, Peirce further distinguished a corollarial and a theoric part within theorematic reasoning and connects theoric aspects to abduction (Hoffmann, 1999). Of course, as already stressed, we have to remember this abductive aspect of mathematical reasoning is not in itself creative. It can be performed both in creative (to find new theorems and mathematical hypotheses) and noncreative (merely selective) ways; for example, in the case, we use diagrams to demonstrate already known theorems (i.e., in didactic settings), where selecting the strategy of manipulations is among chances not necessarily unknown, and the result is not new. With respect to abduction in empirical sciences, abduction in mathematics aims at hypothesizing ideal objects, which possibly later we can insert in a deductive apodictic and truth-preserving framework.

The example of diagrams in geometry furnishes a semiotic and epistemological example of the nature of the cognitive interplay between internal neuronal representations (and embodied cognitive kinesthetic abilities) and external representations I have illustrated previously; also, for Peirce, more than a century before the new ideas derived from the field of distributed reasoning, the two aspects were intertwined in the pragmatic and semiotic view, going beyond the rigidity of the Kantian approach in terms of schematism. Diagrams are icons that take material and semiotic form in an external environment endowed with the following:

- Constraints depending on the specific cognitive delegation performed by human beings
- The particular intrinsic constraints of the materiality at play

Concrete manipulations on them can be done, for instance, to get new data and cognitive information and/or to simplify the problem at issue (see the epistemic templates illustrated previously).

The Semiosis of Re-Embodiment

Some interesting semiotic aspects of the previously illustrated process can be analysed nicely. Imagine that a suitable *fixed internal record* exists, deriving from the cognitive exploitation of the previous suitable interplay with *external structures*, at the level of neural activation, and that, for instance, it embeds an abstract concept endowed with all its features (e.g., the concept of triangle). Now, the human agent, via neural mechanisms and bodily actions, can re-embody that concept by making an external perceivable sign, for instance, available to the attention of other human or animal senses and brains. For instance, that human agent can use what in semiotics is called a symbol with its conventional character (e.g., *ABC*), but also an icon of relations (a suitable diagram of a triangle), or a *hybrid representation* that will take advantage of both. In Peircean terms:

A representation of an idea is nothing but a sign that calls up another idea. When one mind desires to communicate an idea to another, he embodies his idea by making an outward perceptible image which directly calls up a like idea; and another mind perceiving that image gets a like idea. Two persons may agree upon a conventional sign which shall call up to them an idea it would not call up to anybody else. But in framing the convention they must have resorted to the primitive diagrammatic method of embodying the idea in an outward form, *a picture. Remembering what likeness consists in, namely, in the natural attraction of ideas apart from habitual outward associations, I call those signs which stand for their likeness to them icons. Accordingly, I say that the only way of directly communicating an idea is by mean of an icon; and every indirect method of communicating an idea must depend for its establishment upon the use of an icon.* (MS 787) [19]

It is well-known that for Peirce, every picture is a icon and, thus, every diagram, even if it lacks a sensuous similarity with the object but just exhibits an analogy between the relations of the part of it and of the object:

Particularly deserving of notice are icons in which the likeness is aided by conventional rules. Thus, an algebraic formula is an icon, rendered such by the rules of commutation, association, and distribution of the symbols; that it might as well, or better, be regarded as a compound conventional sign. It may seem at first glance that it is an arbitrary classification to call an algebraic expression an icon; that it might as well, or better, be regarded as a compound of conventional sign. But it is not so. For a great distinguishing property of the icon is that by direct observation of it other truths concerning its object can de discovered than those which suffice to determine its construction. Thus, by means of two photographs a map can be drawn, etc. Given a conventional or other general sign of an object, to deduce any other truth than which it explicitly signifies, it is necessary, in all cases, to replace that sign by an icon. This capacity of revealing unexpected truth is precisely that wherein the utility of algebraic formulae consists, so that the icon in character is the prevailing one. (MS 787)

Stressing the role of iconic dimensions of semiosis[20] in the meantime celebrates the virtues of analogy, as a kind of association by resemblance, as contrasted to association by contiguity.

Human beings delegate cognitive features to external representations through semiotic attributions, because, for example, in many problem-solving situations, the internal computation would be impossible or it would involve a very great effort because of the human mind's limited capacity. First, a kind of alienation is performed; second, a recapitulation is accomplished at the neuronal level by rerepresenting internally that which was discovered outside. Consequently only later on do we perform cognitive operations on the structure of data that synaptic patterns have picked up in an analogical way from the environment. We can maintain that internal representations used in cognitive processes like many events of *meaning creation* have a deep origin in the experience lived in the semiotic environment.

I think there are two kinds of artefacts that play the role of *external objects* (representations) that are active in this process of disembodiment of the mind: *creative* and *mimetic*. Mimetic external representations mirror concepts and problems that are represented already in the brain and need to be enhanced, solved, further complicated, and so forth, so they sometimes can creatively give rise to new concepts and meanings.

Following my perspective, it is at this point evident that the mind transcends the boundary of the individual and includes parts of that individual's environment. It is in this sense that the mind is semiotic and artificial.

External Diagrammatization and Iconic Brain Co-Evolution

Following our previous considerations, it would seem that diagrams can be seen fruitfully from a semiotic perspective as external representations expressed through icons and symbols that are aimed at simply mimicking various humans' internal images. However, they also can play the role of creative representations that human beings externalize and manipulate not just to mirror the internal ways of thinking of human agents but also to find room for concepts and new ways of inferring which cannot at a certain time be found internally in the mind.

In summary, we can say the following:

- Diagrams as external iconic (often enriched by symbols) representations are formed by external materials that either mimic (through reification) concepts and problems already internally present in the brain or creatively express concepts and problems that do not have a semiotic natural home in the brain.
- Subsequent internalized diagrammatic representations are internal reprojections, a kind of recapitulations (learning) in terms of neural patterns of activation in the brain (thoughts, in the Peircean sense) of external diagrammatic representations. In some simple cases, complex diagrammatic transformations can be manipulated internally *like* external objects and can further originate new internal reconstructed representations through the neural activity of transformation and integration.

We have already stressed that this process explains (from a cognitive point of view) why human agents seem to perform both computations of a connectionist type such as the ones involving representations as:

- (I Level) patterns of neural activation that arise as the result of the interaction (also presemiotic) between body and environment (and suitably shaped by the evolution and the individual history): pattern completion or image recognition.

and computations that use representations as:

- (II Level) derived combinatorial syntax and semantics dynamically shaped by the various artificial external representations and reasoning devices found or constructed in the semiotic environment (e.g., iconic representations); they are more or less completely neurologically represented contingently as patterns of neural activations that sometimes tend to become stabilized meaning structures and to fix and so to permanently belong to the I Level.

It is in this sense that we can say the system of diagrammatization, in Peircean words, allows for a self-controlled process of thought in the fixation of originally vague beliefs; as a system of learning, it is a process that leads from "absolutely undefined and unlimited possibility" (CP 2.267) to a fixation of belief and "by means of which any course of thought can be represented with exactitude" (CP 4.530). Moreover, it is a system that also could improve other areas of science beyond mathematics, like logic; it "greatly facilitates the solution of problems of Logic. ... If logicians would only embrace this method, we should no longer see attempts to base their science on the fragile foundations of metaphysics or a psychology not based on logical theory" (CP 4.571).

As already stressed, the I Level originates those sensations (they constitute a kind of face we think the world has) that provide room for the II Level to reflect the structure of the environment and, most importantly, that can follow the computations suggested by the iconic external structures available. It is clear that in this case we can conclude that the growth of the brain and especially the synaptic and dendritic growth are determined profoundly by the environment. Consequently, we can hypothesize a form of co-evolution between what we can call the iconic brain and the development of the external representational systems. Brains build iconic signs as diagrams in the external environment, learning from them new meanings through interpretation (both at the spatial and sentential levels) after having manipulated them.

When the fixation is reached (imagine, for instance, the previous example that fixes the sum of the internal angles of the triangle), the pattern of neural activation no longer needs a direct stimulus from the external spatial representation in the environment for its construction and can activate a final logical interpretant, in Peircean terms. It can be neurologically viewed as a fixed internal record of an external structure (a fixed belief in Peircean terms) that also can exist in the absence of such external structure. The pattern of neural activation that constitutes the I Level representation has kept record of the experience that generated it and, thus, carries the II Level representation associated with it, even if in a different form (e.g., the form of *semiotic memory* and not the form of the vivid *semiotic sensorial experience* of the triangular construction drawn externally over there, for instance, on a blackboard). Now, the human agent, via neural mechanisms, can retrieve that II Level representation and use it as an internal representation (and can use it to construct new internal representations less complicated than the ones previously available and stored in the memory).

At this point, we easily can understand the particular *mimetic* and *creative* roles played by external diagrammatic representations in mathematics:

1. Some concepts, meanings, and ways of inferring performed by the biological human agents appear hidden and tacit and can be rendered explicit by building external diagrammatic mimetic models and structures; later on, the agent will be able to pick up and use what was suggested by the constraints and features intrinsic and immanent to their external semiotic materiality and the relative established conventionality: artificial languages, proofs, examples, and so forth.
2. Some concepts, meanings, and new ways of inferring can be discovered only through a problem-solving process occurring in a distributed interplay between brains and external representations. I have called this process disembodiment of the mind; the representations are mediators of results obtained and allow human beings to do the following:
    a. To re-represent in their brains new concepts, meanings, and reasoning devices picked up outside, externally, previously absent at the internal level and, thus,

impossible. First, a kind of alienation is performed; second, a recapitulation is accomplished at the neuronal level by rerepresenting internally that which has been discovered outside. We perform cognitive geometric operations on the structure of data that synaptic patterns have picked up in an analogical way from the explicit logical representations in the environment.

b. To rerepresent in their brains portions of concepts, meanings, and reasoning devices that, insofar as explicit, can facilitate inferences that previously involved a very great effort because of the human brain's limited capacity. In this case, the thinking performance is not completely processed internally but in a hybrid interplay between internal (both tacit and explicit) and external iconic representations. In some cases, this interaction is between the internal level and a computational tool, which, in turn, can exploit iconic representations to perform inferences.

An evolved mind is unlikely to have a natural home for complicated concepts like the ones geometry introduced, as such concepts do not exist in a definite way in the natural (not artificially manipulated) world; so, whereas evolved minds could construct spatial frameworks and perform some trivial spatial inferences in a more or less tacit way by exploiting modules shaped by natural selection, how could one think of exploiting explicit sophisticated geometrical concepts without having picked them up outside after having produced them?

A mind consisting of different separated implicit templates of thinking and modes of inferences exemplified in various exemplars expressed through natural language cannot come up with certain mathematical and geometrical entities without the help of the external representations. The only way is to extend the mind into the material world, exploiting paper, blackboards, symbols, artificial languages, and other various semiotic tools in order to provide semiotic anchors for finding ways of inferring that have no natural home within the mind; that is, for finding ways of inferring that take us beyond those that natural selection and cultural training could enable us to possess at a certain moment.

Hence, we can hypothesize, for example, that many valid spatial reasoning habits that, in human agents, are performed internally have a deep origin in the past experience lived in the interplay with iconic systems at first represented in the environment. As I have just illustrated, other recorded thinking habits only partially occur internally, because they are hybridized with the exploitation of already available or suitably constructed external diagrammatic artefacts.

Delegated and Intrinsic Constraints in External Agents

We have said that through the cognitive interplay with external representations, the human agent is able to pick up and use what is suggested by the constraints and features intrinsic to their external materiality and to their relative established conventionality: artificial languages, proofs, examples, and so forth. Let us consider the previous example of the sum of the internal angles of a triangle. At the beginning, the human agent (i.e., an interpretant in Peircean sense) embodies a sign in the external world that is, in this case, an icon endowed with intentional delegated cognitive conventional and public features (i.e., meanings) that resort to some already known properties of the Euclidean geometry: a certain language and a certain notation, the definition of a triangle, the properties of parallel lines that also hold in case of new elements and auxiliary constructions obtained through manipulation, and so forth. Then he looks through diagram manipulations for possible necessary consequences that occur over there in the diagram/icon that obeys both of the following:

- The conventional *delegated* properties
- The properties *intrinsic* to the materiality of the model

This external model is a kind of autonomous cognitive agent offered to new interpretants of the problem/object in question. The model can be picked up later and acknowledged by the human agent through fixation of a new neural configuration—a new thought (in this case, the new result concerning the sum of the internal angles).

The previous distinction between delegated and intrinsic and immanent properties is also clear if we adopt the Peircean semiotic perspective. Peirce, speaking about the case of syllogistic logic and not of geometry or algebra, deals with this problem by making an important distinction between what is going on in the brain of the logical human agent and the autonomous power of the chosen external system of representation or diagrammatization (Hoffmann, 2003). The presence of this autonomous power explains why I attribute to the system of representation a status of cognitive agency similar to the one of a human person, even if, of course, it is lacking aspects like direct intention and responsibility. Any diagram, Peirce says, makes use of the following:

[A] particular system of symbols—a perfectly regular and very limited kind of language. It may be a part of a logician's duty to show how ordinary ways of speaking and of thinking are to be translated into that symbolism of formal logic; but it is no part of syllogistic itself. Logical principles of inference are merely rules for the illative transformation of the symbols of the particular system employed. If the system is essentially changed, they will be quite different. (CP 2.599)

Of course, the argumentation above also holds for our case of iconic geometric representation. This distinction integrates the one I have introduced previously in the two levels of representations and in some sense blurs it by showing how the *hybrid character* of the system composed of the two levels themselves, where the whole package of sensorial and kinesthetic abilities are involved.

The construction of the diagram also depends on those delegated semiotic properties that are embedded in what Peirce calls precept; he says in the passage we have already quoted that mathematical reasoning "consists in constructing a diagram according to a general precept" (CP 1.54) and not only on the constraints expressed by the materiality of the model itself.[21]

Pickering (1995) depicts the role of some externalities (representations, artefacts, tools, etc.) in terms of a kind of nonhuman agency that interactively stabilizes with human agency in a dialectic of resistance and accommodation (pp. 17, 22). The two agencies (e.g., in scientific reasoning) originate a coproduction of cognition, the results of which cannot be presented and identified in advance; the outcome of the coproduction is intrinsically unpredictable. Latour's (1999) notions of the dehumanizing effect of technologies are based on the so-called actor network theory,[22] which also stresses the semiotic role of externalities like the so-called nonhuman agents. The actor network theory basically maintains that we should think of science, technology, and society as a field of human and nonhuman (material) agency. Human and nonhuman agents are associated with one another in networks, and they evolve together within these networks. Because the two aspects are equally important, neither can be reduced to the other. "An actor network is simultaneously an actor whose activity is networking heterogeneous elements and a network that is able to redefine and transform what is it made of. … The actor network is reducible neither to an actor alone nor to a network" (Callou, 1997, p. 93).

The operation on a diagram has reduced complexity, enabling concentration on essential relations and has revealed new data. Moreover, through manipulations of the diagram, new perspectives are offered to the observation, or interesting anomalies with respect to the internal expectations are discovered. In the case of mathematicians, Peirce maintains that the diagram "puts before him an icon by the observation of which he detects relations between parts of the diagram other than those which were used in its construction" (NEM 3.749); "unnoticed and hidden relations among the parts" are discovered (CP 3.363). This activity is a kind of thinking through doing. "In geometry, subsidiary lines are drawn. In algebra permissible transformations are made. Thereupon, the faculty of observation is called into play. … Theorematic reasoning invariably depends upon experimentation with individual schemata" (CP 4.233).

We have said first that the human agent embodies a sign in the external world that is in this geometrical case an icon endowed with intentional delegated cognitive conventional and public features (i.e., meanings) that resort to some already known properties of the Euclidean geometry; these features can be considered a kind of immanent rationality and regularity (Hoffmann, 2004) that establish a disciplinary field to envisage conclusions.[23] The system remains relative to the chosen conventional framework. They are real as long as there is no serious doubt in their adequacy. "The 'real,' for Peirce, is part of an evolutionary process and while 'pragmatic belief' and unconscious habits might be doubled from a scientific point a view, such a science might also formulate serious doubts in its own representational systems" (CP 4.295).

Let us imagine that we choose a different representational system still exploiting material and external diagrams. Through the manipulation of the new symbols and diagrams, we expect very different conclusions. An example is the one of the non-Euclidean discoveries. In Euclidean geometry, by adopting the postulate of parallels, we necessarily arrive to the ineluctable conclusion that the sum of internal angles of a triangle is 180°, but this does not occur in the case of the non-Euclidean geometry that I will illustrate in the following section.

Mirror and Unveiling Diagrams

It is well-known that in the whole history of geometry, many researchers used internal mental imagery and mental representations of diagrams as well as self-generated diagrams (external) to help their thinking (Otte & Panza, 1997). For example, it is clear that in geometrical construction, many of the requirements indicated by the manipulative templates are fulfilled. Indeed, iconic geometrical constructions present situations that are curious and at the limit. Because of their iconicity, they are constitutively dynamic and artificial, and offer various contingent ways of epistemic acting, like looking from different perspectives, comparing subsequent appearances, discarding, choosing, reordering, and evaluating. Moreover, they present the features typical of manipulative reasoning illustrated previously, such as the simplification of the task and the capacity to get visual information otherwise unavailable.

We have seen that manipulative abduction is a kind of abduction, usually model-based and, thus, intrinsically iconic that exploits external models endowed with delegated (and often implicit) cognitive and semiotic roles and attributes. We have said that (1) the model (diagram) is external, and the strategy that organizes the manipulations is unknown a priori; (2) the result achieved is *new* (if we, for instance, refer to the constructions of the first creators of geometry) and adds properties not contained before in the concept (the Kantian to pass beyond or advance beyond the given concept (Kant, 1929, A154-B193, 194, p. 192).

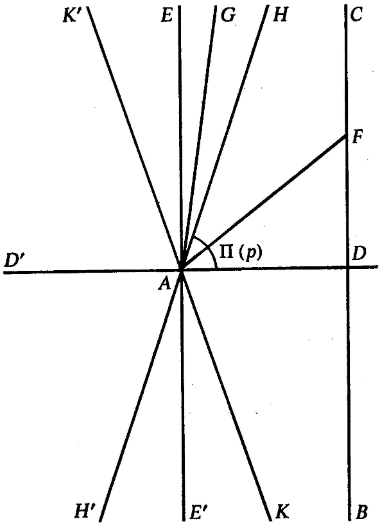
Hence, in the construction of mathematical concepts, many external representations are exploited, both in terms of diagrams and of symbols. I am interested in my research in the diagrams that play various iconic roles, an *optical* role—microscopes (that look at the infinitesimally small details), telescopes (that look at infinity), windows (that look at a particular situation), a *mirror* role (to externalize rough mental models), and an *unveiling* role (to help to create new and interesting mathematical concepts, theories, and structures). I also describe them as the *epistemic mediators* (see above) that are able to perform various abductive tasks (discovery of new properties or new propositions/hypotheses, provision of suitable sequences of models able to convincingly verify theorems, etc.). Elsewhere, I have presented some details concerning the role of optical diagrams in the calculus (Magnani & Dossena, 2003).

We have seen that diagrams serve an important role in abduction mainly because they can be manipulated. In mathematics, diagrams play various roles in a typical abductive way. Two of them are central:

- They provide an intuitive *explanation* that is able to help the understanding of concepts difficult to grasp or that appear obscure and/or epistemologically unjustified.[24]
- They help to *create* new previous unknown concepts, as illustrated in the case of the non-Euclidean geometry.

In the case of the construction and examination of diagrams in geometrical reasoning, specific experiments serve as states, and the implied operators are the manipulations and observations that transform one state into another. The geometrical outcome is dependent upon practices and specific sensory-motor activities performed on a nonsymbolic object that acts as a dedicated external representational medium supporting the various operators at work. We have illustrated in the previous sections that there is a kind of an epistemic and semiotic negotiation between the sensory framework of the geometer and the external reality of the diagram. This process involves an *external representation* consisting of written symbols and figures that are manipulated by hand. The cognitive system is not merely the

Figure 3. Parallel lines



mind-brain of the person performing the geometrical task, but it is the system consisting of the whole body (cognition is *embodied*) of the person plus the external physical representation. In geometrical discovery, the whole activity of cognition is located in the system consisting of a human together with diagrams.

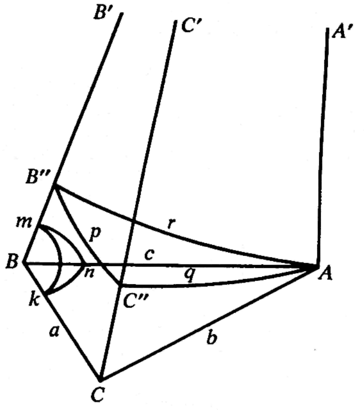
We stated previously that in mathematics, mirror and unveiling diagrams play various roles in a typical abductive way. Now, we can add that:

- They are epistemic mediators able to perform various abductive tasks insofar as
- They are external representations, which, in the cases we will present in the following sections, are devoted to providing explanatory abductive results.

Let us consider some aspects of the role of mirror and unveiling diagrams in the Lobachevskyan discovery of the elementary non-Euclidean geometry. The example indicates that the use of a different background—different delegated cognitive conventional and public geometrical features, non-Euclidean (see previous section)—new icons endowed with the same materiality (and related constraints) of the ones exploited in the Euclidean case can lead to different new results.

A mirror diagram (e.g., the diagram of the drawn parallel lines) (see Figure 3) (Lobachevsky, 1891) is a kind of external analogous both of the mental image we depict in the mental visual buffer and of the symbolic-propositional level of the postulate definition (the fifth postulate). In general, this diagram mirrors the internal imagery (thus, it is a sign of a thought in Peircean terms) and provides the possibility of detecting anomalies. The external representation of geometrical structures often activates direct perceptual operations (e.g., identify the parallels and search for the limits) in order to elicit consistency or inconsistency

Figure 4. Euclidean/non-Euclidean model



routines. Sometimes, the mirror diagram biases are inconsistent with the task, and so they can make the task more difficult by misguiding actions away from the goal. If consistent, they can make the task easier by guiding actions toward the goal. In certain cases, the mirror diagrams biases are irrelevant, and they should have no effect on the decision of abductive actions and should play lower cognitive roles. In the case of Figure 3, the diagram of the parallel lines was used in the history of geometry to make both consistent and inconsistent the fifth Euclidean postulate and the new non-Euclidean perspective (more details on this epistemological situation are given in Magnani, 2002).

An example of *unveiling diagram* is the one illustrated by Figure 4 (Lobachevsky, 1891). It is more abstract than the previous one and exploits audacious representations in the perspective of three-dimensional geometrical shapes. The construction given in the figure aims at iconically representing a stereometric non-Euclidean form built on a rectilinear right-angled triangle *ABC* to which theorems previously proved (e.g., the one stating that the parallels *AA'*, *BB'*, *CC'*, which lie on the three planes, are parallels in the non-Euclidean sense) can be applied. In this way, Lobachevsky is able to apply further the symbolic identifications and to arrive to new equations that consistently and, at the same time, connect Euclidean and non-Euclidean perspectives. This kind of diagram strongly guides the geometer's selections of moves by eliciting what I call the *Euclidean-inside non-Euclidean* model-matching strategy. This maneuver also constitutes an important step in the affirmation of the modern scientific concept of model. This unveiling diagram constitutes a kind of gateway to the unexpected meanings of new imaginary entities.

In general, we have to note that some perceptions activated by the diagram are disregarded, of course, as irrelevant to the task, as it usually happens when exploiting external diagrammatic representations in reasoning processes. Because not everything in external representations is always relevant to a task, high-level cognitive mechanisms need to use task knowledge (usually supplied by task instructions; geometrical, in our case) to direct attention and perceptual processes to the relevant features of external representations. This external representation in terms of an unveiling diagram activates a perceptual reorientation in the external construction (that is, identifies possible further constructions and enhancements); in the meantime, the generated internal representation of the external elements activates directly retrievable information (numerical values) that elicits the strategy of building further non-Euclidean structures together with their *analytic* (symbolic, in semiotic terms) counterpart (the non-Euclidean trigonometry equations).

The different selected representational system that still uses Euclidean icons determines, in this case, quite different possibilities of constructions and, thus, different results from iconic experimenting. New results are derived in diagrammatic reasoning through modifying the representational systems, adding new meaning to them, or in reconstructing their systematic order.

Many commentators (and myself in Magnani, 2001b) contend that Kant did not imagine that non-Euclidean concepts in some way could be constructed in *intuition* (a Kantian expression that indicated our iconic external representation) through the mediation of a model that is preparing and constructing a Euclidean model of a specific, non-Euclidean concept (or group of concepts). Yet, Kant also wrote that "the use of geometry in natural philosophy would be insecure, unless the notion of space is originally given by the nature of the mind (so that if anyone tries to frame in his mind any relations different from those prescribed by space, he will labor in vain, for he will be compelled to use that very notion in support of his figment)" (Kant, 1968, Section 15E). Torretti (2003) observes:

> *I find it impossible to make sense of the passage in parentheses unless it refers precisely to the activity of constructing Euclidean models of non-Euclidean geometries (in a broad sense). We now know that one such model (which we ought rather to call quasi-Euclidean, for it would represent plane Lobachevskian geometry on a sphere with radius* $\sqrt{-1}$ *is mentioned in the* Theorie der Parallellinien *that Kant's fellow Königsbergian Johann Heinrich Lambert (1786) wrote about 1766. There is no evidence that Kant ever saw this tract and the few extant pieces of his correspondence with Lambert do not contain any reference to the subject, but, in the light of the passage I have quoted, it is not unlikely that Kant did hear about it, either from Lambert himself, or from a shared acquaintance, and raised the said objection.* (p. 160)

I agree with Torretti that Kant had a very wide perspective about the resources of intuition, anticipating that a geometer would have been compelled to use the notion of space given by nature; that is, the one that is at the origins of our external representation, in support of his figment (i.e., the non-Euclidean Lobachevskyan abstract structures we have treated in Figure 4) that exhibits the non-Euclidean through the Euclidean. Nevertheless, while Kant conceives the a priori forms and categories as absolute and unchangeable conditions of possible experience and Erkenntnis, the central idea of Peirce's evolutionary philosophy is expressed in his claim that laws, general rules, and forms in themselves are the results of evolution. Peirce's generally evolutive orientation is the main feature that distinguishes him from Kant.

Mimetic Minds as Semiotic Minds

I contend that there are external representations that are representations of other external representations. In some cases, they carry new scientific knowledge. To make an example, Hilbert's *Grundlagen der Geometrie* is a formal representation of the geometrical problem solving through diagrams; in Hilbertian systems, solutions of problems become proofs of theorems in terms of an axiomatic model. In turn, a calculator is able to rerepresent (through an artifact) and to perform those geometrical proofs with diagrams already performed by human beings with pencil and paper. In this case, we have representations that *mimic* particular cognitive performances that we usually attribute to our *minds*.

We have seen that our brains delegate cognitive (and epistemic) roles to externalities and then tend to adopt and recapitulate what they have checked occurring outside, over there, after having manipulated (often with creative results) the external invented structured model. A simple example is that it is relatively neurologically easy to perform an addition of numbers by depicting in our *mind* (thanks to that brain device that is called visual buffer) the images of that additional thought as it occurs concretely with paper and pencil, taking advantage of external materials. We have said that mind representations are also over there, in the environment, where mind has objectified itself in various semiotic structures that *mimic* and *enhance* its internal representations.

Turing (1950) adds a new structure to this list of external objectified devices: an abstract tool, the (universal) logical computing machine (LCM), endowed with powerful mimetic properties. We have concluded that the creative mind is in itself extended and, so to say, both internal and external; the mind is *semiotic* because it transcends the boundary of the individual and includes parts of that individual's environment and, thus, is constitutively artificial. Turing's LCM, which is an externalized device, is able to mimic human cognitive operations that occur in the interplay between the internal mind and the external one. Indeed, Turing, already in 1950, maintains that, taking advantage of the existence of the LCM, "Digital computers … can be constructed, and indeed have been constructed, and … they can in fact mimic the actions of a human computer very closely" (Turing, 1950, p. 435).

In light of my perspective, both (Universal) Logical Computing Machine (LCM) (the theoretical artifact) and (Universal) Practical Computing Machine (PCM) (the practical artifact) are *mimetic minds* because they are able to mimic the mind in a kind of universal way (wonderfully continuing the activity of disembodiment of minds and of semiotic delegations to the external materiality that our ancestors rudimentary started). LCM and PCM are able to rerepresent and perform in a very powerful way plenty of cognitive skills of human beings.

Universal Turing machines are discrete-state machines (DMS) with a Laplacian behavior (Lassègue, 1998, 2002; Longo, 2002); "it is always possible to predict all future states," and they are equivalent to all formalisms for computability (what is thinkable is calculable and mechanizable), and because they are universal, they are able to simulate (i.e., to *mimic*) any human cognitive function, which is what is usually called "mind."

A natural consequence of this perspective is that Universal Turing machines do not represent (against classical AI and modern cognitivist computationalism) a knowledge of the mind and of human intelligence. Turing is perfectly aware of the fact that the brain is not a DSM but rather, as he says, a continuous system, where, instead, a mathematical modeling can guarantee a satisfactory scientific intelligibility (see his studies on morphogenesis).

We have seen that our brains delegate meaningful semiotic (and, of course, cognitive and epistemic) roles to externalities and then tend to adopt what they have checked occurring outside, over there, in the external invented structured and model. A large part of meaning formation takes advantage of the exploitation of external representations and mediators.

Our view about the disembodiment of mind certainly involves that the Mind/Body dualist view is less credible as well as Cartesian computationalism. Also, the view that mind is computational independently of the physical (functionalism) is jeopardized. In my perspective on human cognition in terms of mimetic minds, we no longer need Descartes dualism; we only have *semiotic brains* that make up large, integrated, material cognitive systems, such as, for example, LCMs and PCMs. These are new independent semiotic agencies that constitute real artificial minds aiming at universally imitating human cognition. In this perspective, what we usually call "mind" simply consists of the union of both the changing neural configurations of brains together with those large, integrated, and material cognitive systems that the brains themselves are continuously building in an infinite semiotic process.

Minds are material like brains in so far as they take advantage of intertwined internal and external semiotic processes. It seems to me at this point that we can understand better and more deeply Peirce's semiotic motto, "man is an external sign," in the passage we have completely quoted previously: "[A]s the fact that every thought is a sign, taken in conjunction with the fact that life is a train of thoughts, proves that man is a sign; so, that every thought is an *external sign*, proves that man is an external sign."

The only problem seems to be "how meat knows"; we can reverse the Cartesian motto and say "sum ergo cogito." In this perspective, what we usually call "mind" simply consists in the union of both the changing neural configurations of brains together with those large, integrated, and material cognitive systems that the brains themselves are continuously building.

Conclusion and Future Trends

The main thesis of this chapter is that the disembodiment of mind is a significant cognitive perspective that is able to unveil some basic features of creative thinking and its computational problems. Its fertility in explaining the semiotic interplay between internal and external levels of cognition is evident. I maintain that various aspects of creative meaning formation could take advantage of the research on this interplay; for instance, study on external mediators can provide a better understanding of the processes of explanation and discovery in science and in some areas of artificial intelligence related to mechanizing discovery processes.[25]

From the paleoanthropological perspective, we have learned that an evolved mind is unlikely to have a *natural home* for new concepts and meanings, as such concepts and meanings do not exist in the already known artificial and natural world; the cognitive referral to the central role of the relation between meaningful behavior and dynamic interactions with the environment becomes critical to the problem of meaning formation. Finally, I think the cognitive role of what I call mimetic minds can be further studied, also taking advantage of the research on hypercomputation. The imminent construction of new types of universal abstract and practical machines will constitute important and interesting new mimetic minds that are externalized and available over there, in the environment, as sources of mechanisms underlying the emergence of new meaning processes. They will provide new tools for creating meaning formation in classical areas like analogical, visual, and spatial inferences, both in science and everyday situations, so that this can extend the epistemological and the psychological theory.

The previous perspectives that resort to the exploitation of a very interdisciplinary interplay will further shed light on how concrete manipulations of external objects influence the generation of hypotheses and, thus, on the characters of what I call manipulative abduction showing how we can find methods of constructivity (and their computational counterparts) in scientific and everyday reasoning based on external models and epistemic mediators (Magnani, 2004).

Another interesting application is given in the area of chance discovery (Magnani, Piazza, & Dossena, 2002). Concrete manipulations of the external world constitute a fundamental passage in chance discovery; by a process of manipulative abduction, it is possible to build semiotic prostheses that furnish a kind of embodied and unexpressed knowledge that holds a key role in the subsequent processes of scientific comprehension and discovery but also in ethical thinking and in moral deliberation. For example, I have viewed moral reasoning as a form of possible worlds anticipation, a way of getting chances to shape the human world and act in it (Magnani, 2003). It could be of help to prefigure risks, possibilities, and effects of human acting and to promote or prevent a broad variety of guidelines. Creating ethics means creating the world and its new semiotic directions when facing different (real or abstract) situations and problems. In this way, events and situations can be reinvented either as an opportunity or as a risk for new moral directions. I also have described some templates of manipulative behavior, which account for the most common cognitive and moral acting related to chance discovery and chance production. I maintain that this kind of research furthermore could be addressed specifically to the analysis of the construction of new meaning processes by chance.

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Endnotes

1 The abductive inference rule corresponds to the well-known fallacy called affirming the consequent (simplified to the propositional case)

$$\frac{\varphi \rightarrow \psi \quad \psi}{\varphi}$$

2 Manipulative abduction and epistemic mediators are introduced and illustrated in Magnani (2001a).

3 On languages as cognitive artefacts (see Carruthers, 2002; Clark, 1998, 2003, 2005; Clowes & Morse, 2005; Norman, 1993).

4 On the relationship between material culture and the evolution of consciousness (see Dennett, 2003; Donald, 1998, 2001).

5 Here, the reference to the word *connectionism* is used on the plausible assumption that all mental representations are brain structures; verbal and the full range of sensory representations are neural structures endowed with their chemical functioning (neurotransmitters and hormones) and electrical activity (neurons fire and provide electrical inputs to other neurons). In this sense, we can reconceptualize cognition neurologically; for example, the solution of a problem can be seen as a process in which one neural structure representing an explanatory target generates another neural structure that constitutes a hypothesis for the solution.

6 The role of external representations already has been stressed in some central traditions of cognitive science and artificial intelligence from the area of distributed and embodied cognition and of robotics (see Brooks, 1991; Clark, 2003; Zhang, 1997) to the area of active vision and perception (Gibson, 1979; Thomas, 1989).

7 "One's thoughts are what he is 'saying to himself,' that is saying to that other self that is just coming to life in the flow of time. When one reasons, it that critical self that

one is trying to persuade: and all thought whatsoever is a sign, and is mostly in the nature of language" (CP 5.421).

8 Consciousness arises as "a sort of public spirit among the nerve cells" (CP 1.354).

9 See, for example, the contributions contained in the recent special issue of the journal *Semiotica* devoted to abduction (Queiroz & Merrell, 2005).

10 See Queiroz and Merrell (2005).

11 The problem of manipulative abduction and of its tacit features is related strongly to the whole area of recent research on embodied reasoning (Anderson, 2003) but also relates to studies on external representations and situated robotics (Agre & Chapman, 1990; Brooks & Stein, 1994; Clancey, 2002).

12 I derive this expression from the cognitive anthropologist Hutchins, who coins the expression "mediating structure" to refer to various external tools that can be built to cognitively help the activity of navigating in modern but also in primitive settings (Hutchins, 1995, 1999).

13 It is difficult to preserve precise spatial relationships using mental imagery, especially when one set of them has to be moved relative to another.

14 Of course, in this case, we are using diagrams to demonstrate already known theorems (i.e., in didactic settings); the strategy of manipulations is not necessarily unknown, and the result is not new.

15 Schematism, a fruit of the imagination, is, according to Kant, "an art concealed in the depths of the human soul, whose real modes of activity nature is hardly likely ever to allow us to discover, and to have open to our gaze" (Kant, 1929, A141-B181, p. 183).

16 It is Euclid's Proposition XXXII, Book I (see Figure 2).

17 Also, Aliseda (1997, 2006) provides interesting use of the semantic tableaux as a constructive representation of theories, where abductive expansions and revisions, derived from the belief revision framework, operate over them. The tableaux are so viewed as a kind of reasoning where the effect of deduction is performed by means of abductive strategies.

18 Many interesting relationships between model-based reasoning in creative reasoning and its possible deductive models are analyzed in Batens (2006), Meheus (1999), Meheus, Verhoven, Van Dyck, and Provijn (2002), Meheus and Batens (2006) and also are related to the formal treatment of inconsistencies.

19 We have to note that for Peirce, an idea "is not properly a conception, because a *conception* is not an idea at all, but a *habit*. But the repeated occurrence of a general idea and the experience of its *utility*, results in the formation or strengthening of that habit which is the conception" (CP 7.498).

20 We have to remember that in this perspective, any proposition is a diagram as well, because it represents a certain relation of symbols and indices.

21 It is worth noting that this process obviously is related completely to the Peircean idea of pragmatism (Hoffmann, 2004) that he simply considers "the experimental method," which is the procedure of all science.

22 This theory has been proposed by Michel Callon, Latour himself, and John Law (see Callon, 1994, 1997; Callon and Latour, 1992; Latour, 1987, 1988; Law, 1993).

23 Paavola, Hakkarainen, and Sintonen (2006) consider the interplay between internal and external aspects of abductive reasoning in the framework of the interrogative model of the so-called "explanation-seeking why-questions." They emphasize the interaction with the environment and show the importance of the heuristic strategies and of their trialogic nature (inquirer and fellow inquirers, object of inquiry, mediating artefacts, and processes), also taking advantage of Davidson's ideas concerning triangulation.

24 Some new optical diagrams (microscopes within microscopes), which provide new mental representations of the concept of tangent line at the infinitesimally small regions, are introduced in the already cited Magnani and Dossena (2003).

25 On the recent achievements in the area of the machine discovery simulations of model-based creative tasks, see Magnani, Nersessian, and Pizzi (2002).

Chapter II

Morphological Semiosis

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Abstract

This chapter argues that reality, both material and conceptual, functions as a complex network of continuous adaptive morphological formation. The morphological form is a well-formed form (wff), a Sign. It materializes as this informational form within a function, an irreducible triad, where f(x)=x models the three procedures of input/mediation/output. The procedures in themselves are relations, which are encoded spatial and temporal measurements that enable both symmetrical and asymmetrical informational interactions. Using a Cartesian quadrant, the six possible relations are examined to show how reality is molded into well-formed forms, or signs, to provide capacities for both random and planned information and for both mechanical and reasoned templates of informational behavior. It is hoped that such an applied analysis of information can enable researchers to construct and manage artificial information systems.

Morphological Semiotics

I am examining reality as a complex network of continuous adaptive networked morphological formation. Physical reality, whether crisp or vague, exists only within morphological shapes or forms. Equally, conceptual reality, whether experienced as individual information or as shared knowledge, functions only within morphological realities. These forms are understood as information and can be examined in their nature as signs, well-formed forms, or morphemes.

Examining reality as a complex network of constantly developing and dissolving interconnected spatiotemporal informational shapes provides us with a methodology of constructing and managing artificial intelligence. Computational systems operate as complex networks and have the ability to analyze, hypothesize, and develop adaptive and robust future-oriented systems of knowledge. What we require in our development of these artificial intelligences is not only a theoretical but also a practical methodology of intelligence. I suggest that morphological semiotics is a constructive basis for this practical methodology. This chapter outlines the basic theoretical and practical perimeters of morphological semiotics; future research will extend the practical methodology and explore case study variations of applied morphological generation and the complex informational network.

Peirce (CP 1.22), referring to Aristotle, says that "the embryonic being for Aristotle was the being he called matter, which is alike in all things, and which in the course of its development took on form. Form is an element having a different mode of being" (Vol. 1, para. 22). Matter, or *hylo*, is more primitive than form. However, following the Aristotelian and Peircean axioms, I am saying that matter in our universe exists only when it develops form; that is, if $e=mc^2$, then, since our universe operates below the speed of light, this means that basic matter (*hylo*) which we call energy, exists only when formed, which is to say, within morphological perimeters (*hylomorphic*). It is useful to note that Plato asserted the opposite (i.e., that form preceded matter); which means that the Platonic form as an ideal concept exists outside of and even alien to matter. A basic axiom of my theory is that matter is primal and universal but that it exists within our universe only when it takes on form, which is to say, when it is differentiated according to measurements using the values of space, time, and mode. Space will be defined and further clarified in this chapter as a measurement of internal, external, local, and/or global values. Time will be defined and further clarified in this chapter as a measurement of present, perfect, and progressive values. Mode will be defined in this chapter and further clarified as a measurement of potential, actual, and necessary values.

Semiotics, the science of forms and their relations, provides a framework to constructively study morphological reality. Semiosis, the process by which signs emerge and operate, relates to the transformative function of taking on form. This process is an informed action; it involves logic, which is to say, it involves decisions based on reasoning about the meaning or consequences of forms. Indeed, it involves in all cases the operation of mind.

"Logic, in its general sense is … only another name for *semiotic*, the quasi-necessary, or formal, doctrine of signs" (CP 2.227). Logic is to be understood "in its narrower sense, it is the science of the necessary conditions of the attainment of truth. In its broader sense, it is the science of the necessary laws of thought, or, still better (thought always taking place by means of signs), it is general semeiotic, treating not merely of truth, but also of the general conditions of signs being signs … also of the laws of the evolution of thought" (CP 1.444).

If we take apart this insight from Peirce, what we find is that reality exists as signs. Not within signs but as signs. Reality is actually, in itself, effete mind (CP 6.25); it is an embodiment, a morphological expression, of mind. "Thought is not necessarily connected with a brain. It appears in the work of bees, of crystals, and throughout the purely physical world; and one can no more deny that it is really there, than that the colors, the shapes, etc., of objects are really there" (CP 4.551). Existence or morphological reality operates as an embodied logic of informational relations, where one phenomena, or morpheme, exists as such in relation to another morpheme where "a sign is a conjoint relation to the thing denoted and to the mind. If this triple relation is not of a degenerate species, the sign is related to its object only in consequence of a mental association, and depends upon a habit" (CP 3.360). (Note again that mind, as proposed by Peirce, is universal and not the property solely of *homo sapiens*.)

The sign can be understood as the product of a set of relations; that is, a morphological entity exists as such because it functions within logically interactive relations. Following basic logic, Peirce proposed three relations: the relation of the Sign to its Object; the relation of the Sign in itself; and the relation of the Sign to its Interpretant. "A sign therefore is an object which is in relation to its object on the one hand and to an interpretant on the other in such a way as to bring the interpretant into a relation to the object corresponding to its own relation to the object" (LW 32).

The development of these morphological realities can be graphed as this triad of relations within the actions of an algebraic function, where:

$$f(x)=y \tag{1}$$

This is the algebraic formula for a function. In simple terms, a function connects information within one site (x) to another site (y). The process operates as a triad of relations. The three relations are input, mediation, and output, or x, f and y, and we understand the interaction of these three relations as a mapping of an element of one set, the input, or object, to an element of another set, the output, or interpretant, via the mediative function of transformational mapping.

What I am focusing on is possibly related to, as Rosen notes, the concept of organization. He cites Rashevsky, who wrote, "We must look for a principle which connects the different physical phenomena involved and expresses the biological unity of the organism and of the organic world as a whole" (Rosen, 1991, p. 113). As Rosen emphasizes, the agenda is to "look for a principle that governs the way in which physical phenomena are *organized*, a principle that governs the *organization* of phenomena, rather than the phenomena themselves" (Rosen, 1991, p. 113). This principle, I maintain, is the relational function of the semiosic triad, which measures its informational content using different spatial, temporal, and modal values to provide reality with a broad and robust capacity for an adaptive existence.

I will further clarify here that by sign, I do not mean the linguistic dyadic degeneration of the Peircean triadic semiosis based on Saussure (1964), which understands a sign as merely an empty carrier for the meaning of an object, a term meaningless in itself, assigned by convention to the meaning of a word. By sign, I mean an actual material reality and an actual conceptual reality, both of which exist as formed within a logical process of interaction. Whether this morphological unit is open or closed; is fuzzy or crisp; is an atom, a cell, an organism, a word, an action—it is a sign, a morphological reality, a *wff*, a well-formed form.

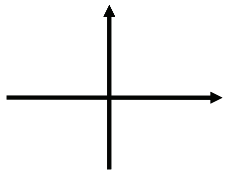
Morphological Formation

The morphological form in itself, both material and conceptual, is a well-formed form (*wff*), termed a sign. In defining the morphological entity as a *wff*, I refer to its development as a coherent and pragmatically functional figure. As such a coherent reality, this morph exists because it has developed within robust interactions and remains within robust interactions with other morphologies. We, therefore, require two basic conditions for the reality of our universe—stability and interaction. Stability requires symmetry of identity, where the formed reality maintains an identity of self over time, even if only for a nanosecond. Interaction requires asymmetry of identity to enable the reasonably stable morphological form to interact with and be informed about the otherness of other morphologies in the environment. These two contrary requirements for symmetry and asymmetry are a condition of semiosic reality. We will examine both processes within the concept of relations.

A relation is a dyadic string, a primitive morphology, acting only as an interaction, where two nodes functioning as horizons of influence connect to make available a configuration of data, information, or knowledge functioning within time and space. Within the Peircean semiosis of relations, "these different modes of relation are different modes of connexion" (CP 3.464). A relational string does not exist on its own. A relation exists by virtue of a bonding with two or more relational strings. The sign is the result of a transformation of the informational content of three relations set up in a triadic interaction of input/mediation/output (see Figure 3). These three terms also can be examined within the Peircean terminology as object, representamen, and interpretant. The robust sign is never a dyad, which merely would be an Interpretant signifying, metaphorically, an Object (i.e., a mechanical interaction). The dyad, it should be noted, is a Saussurian (1964) frame where the Signifier (input data) is related to the Signified (output meaning) via the arbitrary mediation of an external operator, language. On the other hand, the sign as a morphological semiosic function operates as a triadic transformational process. In this process, the interpretant relation presents itself as a transformed measurement—effectively a knowledgeable re-presentation, an informed interpretation—of its object relation. This output interpretation of the input data requires a reference to a logical continuity of experience, which is the third relation, the mediate relation, the representamen.

Given this axiom that reality exists as a triadic function, we can consider the nature and type of relations that permit reality, whether physical or conceptual, to exist. I refer to the process of morphological generation as semiosis and the resultant morphology as a sign. The morphemes, or signs, understood to be spatiotemporally existent and, as such, to carry informational values, are temporarily stable. The purpose of morphological analysis is to explore the spatial, temporal, and modal structures of this existential reality. This includes the examination of the generation of signs, the growth rules of signs, and the rules of networking of that sign as connected with other signs. Our universe is a complex adaptive semiotic network.

Figure 1. The Cartesian quadrant: Y axis and X axis



The infrastructure of the sign, as noted, is a triad of relations. Each of these three relations has a different function within the whole, and each exists in its own nature within the three values of space, time, and mode. The essential nature of this triad is as a function, which is to say that it operates as a transformational molding of information. As a result of this triadic interaction, the sign exists both as itself and in relations with other signs, permitting both the networked continuity and the diversity of reality (Taborsky, 2002a, 2002b).

The Cartesian Quadrant

The analytic model used to examine this transformative morphological process is a two-dimensional Cartesian coordinate quadrant (Figures 1 and 2). The model enables an analysis that acknowledges the separate existence and functioning of different spatial, temporal, and modal parameters of measurement. The ontological and epistemological cuts (Atmanspacher, 1994, 1999; Primas, 1993), which are modeled respectively as the vertical Y and horizontal X axes of the Cartesian quadrant, establish measurement parameters for six relations. When a selection is made from these six relations within the act of semiosis (i.e., within the triadic function of input/mediation/output), the result is a morphological reality—a sign. Importantly, the Cartesian model enables the modeling of both real and imaginary measurements. The positive measurements (top and right) represent real morphologies, and the negative measurements (bottom and left) represent imaginary or hypothetical morphologies. Both are essential for molding reality, for reality consists of both the actual and the potential. Let me take the reader through this analytic frame.

The Ontological Cut

If I consider matter as basic, I am also going to say that it does not exist as such unless differentiated into individual entities. Without such differentiation into morphologies, our universe remains a fog and an unknowable, unreachable, and essentially nonexistent fog.

The most basic act of differentiation is achieved by the vertical ontological Y cut, which simply slices reality into two parts. The term *ontology* refers to an actual or real being, which we can understand as any particular material or conceptual thing. It is a particular thing by virtue of being reasonably differentiated by that ontological cut from another thing. With this cut, we have a thing and its internal nature; and we have whatever is external to that thing. We can posit that, in cosmological times, this differentiation into internal self and external not self was a result of temperature differentiation. Essentially, this cut demarcates spatial experience into internal and external spatial values. Note that the same form of matter functions within both measurements, even though these measurements retain their unique peculiarities. The paramecium exists to itself as internally differentiated matter, and the paramecium exists to others as externally differentiated matter. The difference between the two is the type of interaction of which the entity is capable within this particular measurement. "The things themselves, the *noumena*, as Kant calls them, are inherently unknowable except through the perceptions they elicit in us; what we observe are *phenomena*" (Rosen, 1991, p. 56). Again, this cut sets up an asymmetrical reality; the measurement of matter, and therefore, the type of information that functions within each zone is different, for internal space provides an indecipherable completeness of data, and external space provides a reducible discreteness of information.

Using the Cartesian quadrant to explain the functional nature of these two measurements, I suggest that a basic informational characteristic of the internal realm is that its measurements operate in part in the negative or, more precisely, the imaginary zone of information while the external operates in the positive or real zone. The negative or imaginary provides an informational content that functions predominately as an indecipherable internal feeling. Peirce termed that mode Firstness and described it as a "quality of feeling" that has "no parts" (CP 1.318). It is because of that ontological cut that we can move from this indecipherable feeling into a reality that is discrete and describable. In other words, the ontological cut produces a thing that acknowledges the reality of something other than itself, and this thing thereby now exists in a state of nonequilibrium with its environment. This basic differentiation of self and not self, even if the awareness is only a temperature differentiation, is a fundamental attribute of information generation, for it puts the universe into an asymmetrical and, thus, reactive process. It establishes a this vs. a not this—even if it lacks the capacity to describe either morphology. The functionality of this ontological cut should not be underestimated.

Can the universe maintain itself with only these two differentiations of morphology—an internal and an external spatial measurement? I suggest that the answer is no, for forms existing only within basic spatial asymmetry without history are random forms and could only engage in constant kinetic battering (Peircean Secondness), and thus, these forms would frictionally crumble. Therefore, another cut, or measurement, is required to introduce stability and to reduce the potential heat-death dissipation of matter.

The Epistemological Cut

The horizontal epistemological X cut differentiates two further asymmetries: that between the local (individual) spatial values and the global (communal) spatial values. The term *epistemology* refers to knowledge. This indicates that these morphologies cannot exist within random uninformed actions but must be able to interact with their environment in a deliberate manner guided by knowledge about their own capacities and the nature of their environments. This differentiation between local and nonlocal space is important; it introduces an ability to describe and mold information that is functioning in a local nondistributed manner and information that is functioning in a nonlocal distributed or general manner; that is, this cut establishes not simply the self and the other realms, which were established by the ontological cut, but more exactly, it establishes a descriptive differentiation between the particular, or individual, and the collective. As Peirce notes, "I find that there are at least two distinct orders of categories, which I call the particular and the universal" (CP 5.43). The particular refers to singularities of type, while the universal refers to a general trait that belongs to every phenomenon in that type. These are actually two different types of information—the individual and the general.

This differentiation between the realm of the particular and the realm of the universal is achieved by two perimeters introduced by the epistemological X cut. The first is spatial: local space vs. global or nonlocal space. Morphological forms exist by virtue of their relations with directly experienced and immediately accessible other morphologies. These other morphologies enable all forms to exist, because all of them are existentially differentiated from each other. Additionally, this cut is asserting something else; it is saying that these morphological realities are capable of interaction with other forms because their composition includes common information organized within collective or general laws. We can understand how one hydrogen atom can bond with another hydrogen atom because their material composition is similarly organized. This mode of collective organization is termed by Peirce as Thirdness, which is the formation of common habits, of general laws that regulate individual interaction, that guide those interactions into predictable relations and reduce the morphological collapses that would result from random contacts. "All nature abounds in proofs of other influences than merely mechanical action" (CP 5.65). The collective should be understood as a type of information, which I call knowledge—acknowledging its deeper function—which is common to the whole community of individuals, constraining the demands of these individuals, reining in their arbitrary impulses. This will be discussed further in the section on Modes.

What is also set up within the epistemological cut is temporality. There are three temporal measurements: (a) the present experience, (b) a notion of connected linear sequence, and (c) continuity or permanence. These three temporal measurements will be defined as present time, perfect time, and progressive time. We can understand the necessity for a morphological form to realize that the input data it is receiving is present, is now, and requires an immediate reaction. However, we also should understand the necessity for this same morphological form to be able to construct a reliable image of an interaction that is not taking place now but is a hypothetical proposal for the future. Additionally, it is constructive for the morphological form to have the capacity to examine this future-oriented image against an equally abstract yet reliable image of past events. This requirement for the morphological form to experience reality as continuous rather than only here and now requires a temporal measurement that moves a general or abstract notion of reality along a progressive continuity. The system will develop a template from an overview of past experiences, which acts as a blueprint. This template acts not merely as a memory but also as a general computational tool. A computer can be understood to have this capacity to develop an active analytic template. As such a tool, it provides a means of analyzing interactions to guide adaptive decision-making about future interactions. This abstract template that provides a continuous familiarity with reality is a phenomenon, I maintain, that is universal and functions in all realms: the physicochemical, the biological, and the sociocognitive. Whether it is stored within physical laws or genetically, or via social means, this template enables an emergent morphological phenomenon to interact with its environment in a positive and constructive manner without the disastrous results of random trial and error on each and every individual. Finally, along with these two different modes of time and their required reactions, the now and the continuous, the morphological form must be able to interact with its environment in a mechanical and linear manner; that is, if a lizard moves from a state of rest to motion—the linearity of directly connected points that this step is directly followed by this next step and this next step—enables the lizard to guide itself in a coordinated process to move to its next location. This requires a temporal measurement, enabling a connected linearity—a predictable linear motion from state A to state B.

Temporality, understood as an actual component of morphological matter, enables forms to interact with their environment, using three very different responses: now and only now; this and next and next; and continuity. We will examine these three temporal measurements using the terms present, perfect, and progressive. These different typologies of interaction provide morphological forms with a flexible and robust capacity of interaction.

The Quadrant as an Analytic Tool

We now have an analytic scheme of four quadrants: I, II, III, and IV (Figure 2). I add two further relations to the quadrant; namely, the aspatial and atemporal universal relation that cannot be graphed and the interface located at the coordinate origin, which brings the relational functions to a total of six (Table 1).

The negative realm, the left side, of these quadrants is not to be understood in the Boolean sense of absence of, which merely would set up a binary reaction of reflex contradiction. What we have instead with the basic ontological cut is a morphological capacity for two different types of behavior—one that operates in the imaginary and one that operates in the real. The real is found on the right-hand side of the quadrant; its actions are mechanical. Rosen (1991) said, "What distinguishes a material system as a *machine*, as distinct from a stone or a crystal, must somehow reflect its intrinsic organization" (p.183). The organization of a machine is completely external; a machine has no internal or self-owned knowledge processes. It exists in its particular identity as a machine, in local space and perfect time, only as a system of constituent particles. In its operational identity, the machine also exists in global space and progressive time; that is, it is manufactured as one model of car, and that model can be found in all parts of the globe and lasts longer than one individual example. Nevertheless, these latter spatial and temporal values, which permit the machine to interact with continuity, are external to its organization; they are supplied by the knowledge processes of the machine maker. However, "all nature abounds in proofs of other influences than merely mechanical action, even in the physical world" (CP 5.65).

This other influence, this self-organized capacity to imagine, is an essential requirement for life, because it enables the morphological form to anticipate. Anticipation is an action that first develops an abstract model of the self and then moves these images into a different mode of time and space than here and now; it enables the morphological form to debate, even with itself, about future actions. The system with the capacity to anticipate has the capacity to imagine hypothetical future states; this information guides its present actions to enable these future acts to be productive rather than erroneous (Dubois, 2000, 2002; Rosen, 1985). Another term in common use is the capacity to plan, for "planning implies making representations of future states and investigating actions that will bring you from the present state into the future state" (Jorna & van Wezel, 2002, p. 411). Anticipatory systems contain internal models of themselves and their environments. These models enable the system to interact with its environment in a manner that allows future actions to be predicted and controlled by the system. The notion of a model or, rather, an imaginary self existing in a different temporal and spatial zone than that of current experience, requires that the system itself has an organizational capacity such that it can have, within itself, a phase of space that is nonlocal in order to permit a nonlocal image and a phase of time that is not-now to, again, permit a not-now image. This mode of multiple levels of informational organization provides the system (a) with the capacity to receive input data from the environment, (b) to refer this input to its imaginative capacities, (c) to analyze the correlations, and thus, (d) to predict and control future interactions between itself and the environment.

Ten Measurements

To recapitulate, matter is primal and universal and exists within our universe only when it takes on form, which is to say when it is differentiated within a triadic function of measurements. There are four spatial values: internal space, external space, local space, and global space. There are three temporal values: present, perfect, and progressive time. We also must add the three modal measurements of possibility, actuality, and habit or necessity, which are Peircean Firstness, Secondness, and Thirdness. This brings the number of measurements that are operative in forming morphologies to ten.

Space

Internal spatial measurements develop isolate self-referential informational morphologies; that is, internal matter is, as internal, unable to recognize boundaries. Matter without boundaries cannot see or react to otherness. This type of information is, like a volcanic explosion, high energy, expansive, and rapidly dissipative. However, when linked to other measurements, its expansive energy content promotes rapid rollover transformations of other informational content. For example, the heat generated by the impact of the Deep Impact (DI) mission, in which a NASA spacecraft collided with comet Tempel 1, resulted in a considerable increase in the amount of organic material relative to water on that comet; that is, there was "new material after impact that was compositionally different from that seen before impact" (Meech et al., 2005, p. 265). External spatial measurements set up the morphological boundary as definitive of the form's identity. The membrane of a cell is its external spatial measurement and this membrane and its topological perimeters define the domain of the cell. Local spatial measurements establish morphologies that act as discrete and nondistributed forms (i.e., two different proteins can maintain their differences even when they work cooperatively). However, global spatial measurements function as general morphological patterns rather than individual forms, such as the DNA code of a species. These codal patterns are distributed or spread as common properties of all individuals within the community and establish parameters of informational interaction that function as symmetry-inducing constraints within that collective (e.g., within a species).

Time

When we are dealing with morphological generation, we must understand the role that time plays in these processes. Time is not an abstract detached measurement as it is in the Newtonian/Galilean linear time, which considers that reality is made up of observable objects in three-dimensional space, with time understood as an independent scale of universal reference. Time, instead, should be understood as an integral process of morphological formation. In morphological analysis, time is a differential measurement functioning to mold matter into a particular morphological reality. There are three different temporal measurements—present, perfect, and progressive—which produce three different morphological realities.

Matsuno (1998) states that "time and information are intimately related … neither one of the two can stand without relation to the other" (p. 57). Matsuno (1998) rejects Newtonian absolute time, where "absolute, true and mathematical time, of itself, and from its own nature, flows equably, without relation to anything external" (Matsuno, 1998, p. 57). As Matsuno (1998) explains, absolute Newtonian time is related to the Kantian notion of time, understood as "an *a priori* category of our perception of the outside world" (p. 57). Newtonian time is a Platonic Form, an ideal abstract. However, when we are referring to time in relation to information generation, it is not Newtonian absolute time or Kantian globally synchronous time. It is, instead, differentiated time, which is understood not as an absolute scale but as an actual constituent part of morphological reality. Morphological time, understood as information rather than as an abstract reference, acts within a morphology as an instructional pilot of behavior. Following Matsuno (1998), I posit three different values for time—present, perfect, and progressive—which promote three different behavioral patterns.

Present time measures a reality that functions within the individual's internal now experience without links or references, without past or future. The information provided by the morphological measurement of pure present time operates only in internal and local (i.e., self-confined) space. An example is a feeling of heat, or the result of the first thermodynamic law of universal energy; that is, time in this mode, as an action of measuring information, thus creating a morphological reality, is an internal description oblivious of external effects and complete as imagined without reference to any other parameters. In this sense, as Matsuno points out, present time can be understood as a first-person description. In Matsuno's terms, this is "the present progressive mode" (Matsuno & Paton, 1999, p. 229), for the interaction of matter in this mode is not between "two oppositely charged particles" but, instead, is involved in a "unitary dynamics … as in the form of the unitary transformation of a state vector in the Hilbert space and are not agential … letting every charged particle move in the manner of being pushed by the definite boundary conditions the dynamics takes for granted" (Matsuno & Paton, 1999, p. 230). That is, a morphological reality in the present progressive mode, which I refer to simply as present time, does not interact with otherness, because whatever is going on in this internal local space is invariant and cannot do anything other than subjectively exist, as it lacks a definitive (i.e., objective, external) description. The action in this present tense is always "currently in progress" (Matsuno, 1999, p. 439). Without boundaries, without otherness, this mode of time is devoid of direction and is infinite.

Perfect time molds experience within finite linear parameters (i.e., as *this* instantiation differentiated from *that* next instantiation). It operates in external and local (i.e., closed) space and, acknowledging closure, differentiates "between before and after an event" (Matsuno & Paton, 1999, p. 229). This tense, which I refer to simply as perfect time, and which Matsuno refers to as "present perfect tense," refers to information as measured such that it "exists as it is at any present moment from then onwards" (Matsuno & Paton, 1999, p. 229). This means that differentiation of the morphological form is such that, importantly, it either can describe itself or be described, "since the events in the perfect tense can remain frozen in the record as they were while keeping a legitimate distance from the action in progress on the scene" (Matsuno & Paton, 1999, p. 229). Perfect time is mechanical time, using the Newtonian image of a clock "precisely because of the invariability and predictability" and "the entailment of what happens next by what is happening now, *recursiveness*" (Rosen, 1991, p. 184). Using this type of time, the system does not have a memory, but it does have a sense of a linear or directly connected and, therefore, predictable reactive movement.

Progressive time establishes values of continuity; it has no capacity to describe an individual discrete state whether in present or perfect time but can only deal with continuous commonalities, with general types rather than particular tokens. It operates within global or nonlocal space and both internally and externally. It can be understood as global synchronism, for it refers to an organization of reality that is not in present time and is not in linear time, but rather blends the past with the future within a continuous commonality of form or process. As such, progressive time introduces memory. This memory is not fixed but rather is evolving as a collective identity, for it is "constantly amenable to overwriting by the participating agents surviving in the progressive mode while being read by them at the same time" (Matsuno & Paton, 1999, p. 231). In this sense, progressive time develops the capacities within a system for adaptive reproduction and symmetry of form rather than for isolate individuation and asymmetry of form. Continuity is nonlocal; it is without individuality and, therefore, is not a property of local discrete existence but of the collective.

Mode

Mode describes the quality of the interactions of the material/conceptual content of a relation. Does the Relation function within Firstness (possibility), Secondness (actuality), or Thirdness (law)? The mode defines the nature of a morphology's interaction with other morphologies. Essentially, we must ask, does the relation (and its informational content) function as only a possibility? Is its informational content vague, amorphous, and hard to grasp as specific data? This would be a relation whose information operated in a modality of Firstness. On the other hand, does its informational content behave as an actual discrete reality in this space and at this time and can it maintain this uniqueness in a direct interaction with other morphologies? That would be Secondness. Or, does the relation function within Thirdness, as a law; that is, does its content and information govern the behavior of a whole collection of morphological forms as a necessary habit or authority? These are the three modes: possibility, actuality, and necessity—or spontaneity, haecceity, and law—as "order and legislation" (CP 1.338).

Possibility is a mode of existence, named by Peirce as Firstness, which describes matter operating in a state of present time and internal local space. This is not an abstract ideal but is a mode of reality, "being such as it is while utterly ignoring everything else" (CP 5.44). It is a feeling. It is a state of being that is immediate and inexplicable; it exists as it is "regardless of anything else, each complete in itself" (CP 1.295). As internal and without interaction, Firstness is "predominant in the ideas of freshness, life, freedom. The free is that which has not another behind it, determining its actions. … Freedom can only manifest itself in unlimited and uncontrolled variety and multiplicity; and thus the first becomes predominant in the idea of measureless variety and multiplicity" (CP 1.302). I refer to it symbolically in my diagrams as *1*. A dyadic relation of pure Firstness is *1-1*.

Actuality is a mode of existence, named by Peirce as Secondness, which describes matter operating in perfect time and external local space. Peirce defines it as "the predominant character of what *has been* done" (CP 1.343). Matter in this mode is characterized by its nature of discrete individuality, of decomposability into bits, and, using the traditional Newtonian perspective, this mode exists where one particular unit of reality directly reacts to another particular without any mediation. It "meets us in such facts as another, relation, compulsion, effect, dependence, independence, negation, occurrence, reality, result" (CP 1.358). This introduces the theme of struggle, a mode of being where things "exist by virtue of their reactions against each other" (CP 1.324). It is a mode characterized by brute force, kinetic reaction, efficient causality, of "particle mechanics [that] came to believe that every material behavior could be, and should be, and indeed must be, reduced to purely syntactical sequences of configurations in an underlying system of particles" (Rosen, 1991, p. 68). I refer to it symbolically as *2*. A dyadic relation of pure Secondness is *2-2*.

Necessity, or habit, continuity, and generality is a mode of existence, named by Peirce as Thirdness, which describes matter operating in progressive time and in both internal and external nonlocal or global space. It describes the formation of laws or habits, a generalization of properties of behavior that acts as a template to guide and mold individual behavior and morphological forms. The importance of the universal or Peircean Thirdness is the development of laws of commonality that serve to create morphologies governed by "the coalescence, the becoming continuous, the becoming governed by laws" (CP 5. 4), for "mere individual existence or actuality without any regularity whatever is a nullity" (CP 5.431). Thirdness is a mode of organization of matter that is "that which is what it is by virtue of imparting a quality to reactions in the future" (CP 1.343). Importantly, this means that the laws of morphology, those general laws, are not *a priori* deterministic but themselves are evolving within the individual relational experience. I refer to it symbolically as *3*. A dyadic relation of pure Thirdness is *3-3*.

To sum up, these 10 measurements operate within the dynamics of asymmetry and symmetry. Local space and present and perfect time contribute to asymmetry (i.e., to differentiation of

Table 1. The six relations defined by mode/space/time/function

1-1 Firstness as Firstness	Internal Local	Present Time	Possible Information
2-2 Secondness as Secondness	External Local	Perfect Time	Discrete Actual Information
2-1 Secondness as Firstness	Borderline Interface	Perfect-Present Time	Attractor Phase
3-1 Thirdness as Firstness	External Global	Progressive-present Time	Statistical Average
3-2 Thirdness as Secondness	Internal Global	Progressive-perfect Time	Future Propensity
3-3 Thirdness as Thirdness	Aspatial	Atemporal	Imaginary Hypotheses

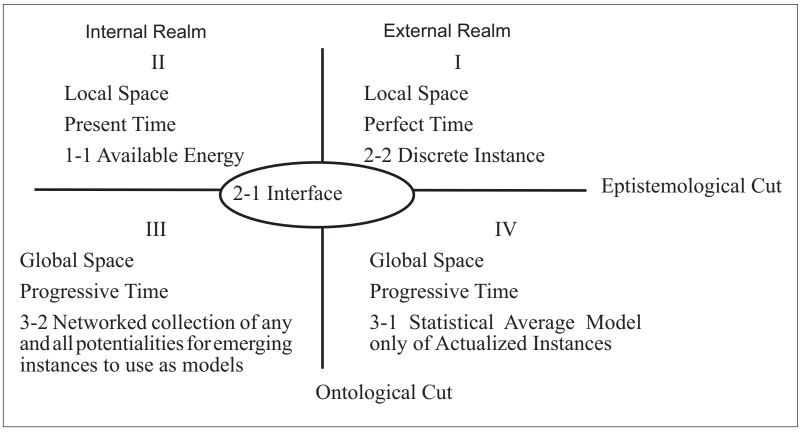
form and unique relations); global space and progressive time contribute to symmetry (i.e., to communal cohesion and continuity). The measurements do not exist per se but act within relations. A relation is, in itself, a dyad, a connection, and a link. A relation also does not exist as itself but rather within an organized interaction, a semiosic triad of interactions of input/mediation/output. There are six relations, differing according to spatial and temporal measurements, modes, and functions (Table 1).

The Relations

These six relations enable a complex adaptive reality. An overall view shows us that there are three relations, different from each other but all focused on one task, to establish shared future-oriented normative patterns of form and behavior. Then, there is one relation that provides undeveloped energy that possibly can be developed into an innovative form or used to strengthen an existent form. There is another relation that enables forms to function as discrete steady-state entities—a result of both the stability induced by those normative patterns and the robustness induced by free energy. Finally, there is an interface relation that sets up a borderline attractor-phase between instability and stability. Overall, these six relations enable a vibrant exploratory and constructive system of information generation, for "thinking always proceeds in the form of a dialogue—a dialogue between different phases" (CP 4.6). The actual morpheme, the sign, is a triadic function (Figure 3). The triad is made up of three of those six relations operating in specific roles (input, mediation, output). As Peirce stated, the triad is irreducible; we cannot detach or reject any of these three roles, for the whole operates as a basic generator of meaning.

I will now discuss these six relations within their spatial, temporal, and modal values.

Figure 2. The Cartesian quadrant



Relation 1-1, Quadrant II

The most basic and primitive relation is found in quadrant II. This relation provides information without boundaries as an isolate state in internal and local space and present time. A reasonable image of this would not be information as such but rather the expansive potentiality of free energy. I am continuing to use the term *information* because I suggest that information functions not merely as crisp data but also within this vague and ambiguous format. We are familiar with its subjective qualitative amorphousness in the multiple and diverse perspectives of witnesses to an accident. Referring to the quadrant, one can observe that these measurements are ontologically positive (above the origin where X and Y meet) and epistemologically negative numbers (to the left of origin). Input from this relation sets up an experience that is ontologically real but whose informational content is "as imagined" or "as felt." The modal quality of this relation, as a mode of pure Firstness, is the mode of being, which consists in its being "such as it is regardless of aught else" (CP 1.24). Again, the content in this morphological phase could be understood more accurately not as information, a term that commonly implies discrete differentiation, but as an expansive indistinct qualitative input of unfocused data, enabling multiple and varied subsequent interpretations. This relation is a basic force in supporting the emergence of new signs by virtue of the unformed nature of its data content. An example would be the sensate quality of hotness, which then can be transformed into the specific information of either a malfunctioning furnace or a fever. It could be a provision of a chemical while the cell is still developing the meditative means to use this chemical; the provision might promote the development of normative tactics in the cell to use that chemical. This measurement acknowledges only that there is an input of unexamined and, therefore, unbound data located internally in local space and present time. This free energy can be transformed into discrete usable information by the semiosic act that must measure and stabilize the content by linking it to two other relations, which will perform the roles of an act of mediation, leading to an interpretation of that free energy. If these links are not made, the data content will dissipate rapidly. The data in this relation, and only in this relation (i.e., before it is interpreted), can be defined as imaginary (open to interpretative decisions) and immediate (local), which means that it is "limited but immeasureable" (CP 4.143).

It is an important relation, confirming the veracity of freedom, probability, and the potentiality of innovative outputs (interpretations) in this universe. The relation is coded using Peircean terminology as 1-1, or Firstness as Firstness. In Peircean terms, as pure Firstness (1-1), the universe is provided with pure spontaneity as a basic character of the universe, "acting always and everywhere though restrained within narrow bounds by law, producing infinitesimal departures from law continually, and great ones with infinite infrequency" (CP 6.59).

Mathematically, we may refer to the processing of matter in this quadrant as permitting stochastic gradient searches (Beyer, 1998). These search algorithms operate without prior knowledge to seek out the best possible solution to a problem. A search direction is inferred by the selection of favorable trial points; that is, this relation provides an input of usable but indecisive data, enabling a system to explore a variety of options as it selects a direction of interpretation. The search space in this relation is local; the time is immediate; the expansive search action, therefore, is brief and will dissipate rapidly if a specific direction is not selected. As such, this relation, despite its expansive ambiguity, cannot destabilize an entire system. As a relation, it functions within a triad (input/mediation/output) and expands the informational reach of the triad in its search for morphological stability and productivity.

Relation 2-2, Quadrant I

The second relation is found in quadrant I. This relation molds individual forms functioning within the discrete closures of external and local space and perfect time. Measurements in this quadrant are ontologically and epistemologically real, or actual. There is no imaginary component whatsoever. The form in this quadrant has achieved a fixed morphological differentiation; it establishes a factual crisp identity in local space and perfect time. Any discrete entity, from a rock to a word, can be considered an example of this definitive definitiveness, which is the basis of most of our daily experiences. It is fact; it is the quantitative basis of Newtonian mechanics. Modernism, nominalism, postmodernism, and classical science all have focused on the morphologies developed by this relation. It is existence, for "whatever exists is individual, since existence (not reality), and individuality are essentially the same thing" (CP 3.613). The relation is 2-2, or Secondness as Secondness. "The world of fact contains only what *is*" (CP 1.478). The expansive openness of the data as measured within the Relation of 1-1 provides possibility; this Relation is one of actuality. The very distinct differentiations of this realm of measurement set up matter as quantitative bits, distinct, objectively measurable, resulting in a "mode of being which lies in opposition to another" (CP 1.457). The notion of struggle and opposition characterize this realm. Interactions in this realm are based on kinetic force and understood as efficient causation, a process where one discrete bit reacts directly to another discrete bit without any mediation or any metanarrative of shared laws or identity.

Mathematically, the relation of 2-2 as a process corresponds to a Monte Carlo simulation. The identifying factor of this action is that the relation permits only random interactions. There is no common law of interaction, no underlying rule that permits predictive certainty. The Monte Carlo simulation was named for Monte Carlo, Monaco, for its games of chance such as roulette wheels, dice, and slot machines. All games of chance exhibit random behavior. The question to ask is whether random actions can solve a problem. In order to achieve a positive outcome within a Monte Carlo simulation, however, we first must assume that the problem *can* be solved. This assumption in itself greatly reduces the randomness of the actions, for it assumes that the statistical average of all these acts is the solution. That is, if we want to find a solution, it will not be by this relation acting alone (as 2-2). We must add another relation: the statistical average (explained as relation 3-1 in Quadrant IV). The technique used by these two relations is multiple simulations of a variable and its interactions. Many simulations may be performed, and the desired result is assumed to be the average over the number of observations. Without the assumption of a finite limit (i.e., that the best solution answer does, in reality, exist and exists as the statistical average), the use of the 2-2 relation alone cannot solve a problem. The reason is that this relation has no referential model to access and, therefore, no capacity to analyze the outcomes of its own past, current, or future experiences. It is a purely mechanical process, and randomness alone, including Darwinian mutation, cannot solve any problem. What is the point of having this relation?

As a relation, it exists within actual and discrete, which is to say, within quantitative reality. Such an immediacy of focused, precise, and descriptive validity cannot be underestimated. Given that its experience refers to an actual situation rather than to abstract hypothetical problems, this relation provides descriptive facts of a real situation. If we add other relations to this descriptive information, we increase its power to find solutions to these real, rather than hypothetical, problems. For example, if 1-1 (possible information) is linked, then, the exploratory horizon of finding solutions is expanded, and the system's ability to find solutions to a current and actual situation is increased. If 3-1 (statistical average) also is linked, then the system obtains the vital referential capacity to measure its current trial attempts (2-2) and can change its hapless random tactics to evaluative exploration and arrive at the best solution for its current problems. Again, the function of this relation of 2-2 is its ability to describe explicitly and quantitatively a real situation. This was and remains the indispensable strength of the Newtonian method of reductionism, and it would be a grievous error, as do many postmodern phenomenologists, to attempt to dispense with this action.

The Collective

The two quadrants produced by the horizontal epistemological cut, the X cut, introduce nonlocal or global space and temporal continuity; in particular, this cut permits open (as differentiated from isolate and closed) systems and a capacity to function within a collective cohesive symmetry. What we now have is a bileveled morphological architecture, permitting both asymmetrical and symmetrical interactions, enabling both metabolic individual processes in quadrants I and II and reproductive or collective processes in quadrants III and IV. The two spatiotemporal relations operating within this progressive time and nonlocal or global space are the internal Thirdness-as-Secondness (3-2) and the external Thirdness-as-Firstness (3-1).

The measurements in quadrants III and IV provide distributed values that establish general or universal laws. These laws provide common patterns-of-interaction, communal blueprints, and general templates (rather than the specific perimeters of single instances). These normative patterns held within the collective act as symmetry-inducing constraints to guide, working with the informational input of local data, the morphological identity of the individual instantiations coming into being in the local level (quadrants I and II) in perfect or present time. Our world cannot function with only the two top-level quadrants of undifferentiated energy and discrete instances, for this would reduce reality to randomness. There must be a function that enables symmetry (i.e., that empowers the collective to function as an authoritative law of morphological formation and interaction and ensures both the pragmatic benefits of mutual interactions and the reproductive continuity of robust morphologies). The X-cut provides these functions by adding two relations, both working toward this same purpose but using different tactics. This ensures a flexibility of symmetry-induction and enables our world to function as a complex adaptive system. It should be noted that this universal, the collective laws of symmetry-induction, never can function as or by itself. It operates as a template for the actualization of individual entities but is not a spatiotemporal thing in itself. It is interesting to consider that the addition of these two measurements, which function in progressive time, inserts a delay in the semiosic triadic process. A system using either of these two relations will not react as rapidly as the mechanical system that does not use them. The time required for this reasoning can be examined within Benjamin Libet's (2004) temporal factor in cognition of at least 0.50 second.

Relation 3-2, Quadrant III

The Relation described within quadrant III, Thirdness-as-Secondness, 3-2, operates internally in nonlocal or global space and in progressive time. Ontologically and epistemologically, its measurements are completely negative rather than positive. It is best described mathematically as a purely imaginary number (i.e., a complex number). It functions as a heuristic process to come up with hypothetical solutions. It achieves this by operating as a network, a complex and changeable set of exploratory flexible connections of indexical links both past and present, both direct and indirect, to both real and imaginary solutions. This provides an immense capacity to browse the informational community, to operate as a virtual search and memory processor. As a global relation, its measurements are distributed in space; it completely ignores spatial distances. As temporally progressive, the relation links past to future morphologies to achieve a broad exploration of knowledge in both its actualized and hypothetical forms. As internal, these measurements and the information they carry are inclusive and nonselective rather than exclusionary. It thus provides a wide range of prospective models for the system, in interaction with its informational environment, to select as the best solution rather than using only the restricted model of the statistical average of actualized instances of the relation of 3-1.

If we use an example of this relation, an Internet search engine, we find that "search engines entertain a model of the Internet that *evolves with the Internet* … [and] continuously reconstruct the past by updating their indices" (Wouters, Helsten, & Leydesdorff, 2004, emphasis added). We can refer to this action as a virtual approach, acting as a complex negotiator of information, in that it includes imaginary propensities or imaginary numbers, which we can understand as hypothesized correlations with other morphologies both unformed and formed. These links might not develop into actual rules of morphological formation (i.e., the Relation of 3-1 functioning in quadrant IV); however, their virtual existentiality remains extant in both weak and strong form, and they are available for potential selection by an emerging instantiation. As exploratory and, therefore, receptive to information, this relation is functionally in tune with the realities of the current environment, for "the past in the Internet is constantly overwritten by the search engines … [and] the present, from where the data is collected, affects search results considerably" (Wouters et al., 2004). This measurement enables a system to reason about input signals based on information that is both currently received and information that was received in the past or (and this is an important strength) is indirectly accessible via other networked links. This inclusiveness of unformed and nonhabitualized propensities permits an emergent instantiation to bring with itself multiple alternative models of itself as a measurement proposal to the development of a new instantiation. This relation is essential in enabling the development of innovative morphologies that can introduce novel yet immediately robust adaptive values and is an overlooked and vital mode of measurement. This is a genuine final causation, where the collective template exists by virtue of an ongoing, evolving, and collaborative generating process rather than being bound to or seeking any inherent purity of type. Therefore, there is no finality to this process of interactive networked solution seeking.

An analogy would be a genetic algorithm (Goldberg, 1989; Holland, 1975) or Bayesian probability (Jaynes, 2003). The interactive morphologies of the self and others must collaborate, analyze, and negotiate the best solution within a discursive interaction (e.g., brainstorming, rapid response military teams, regional adaptation of nonlocal marketing and business). Genetic algorithms are a class of algorithms that provide generative or adaptive capacities. The 3-2 relation explores a miscellaneous population, which is to say, it contacts (informationally) multiple and diverse knowledge sites. This is completely different from the relation of 3-1, which takes its information from only one population, the aggregate of existent, actualized individuals within one typological set. Initially, the solution resulting from a 3-2 exploratory search is, theoretically, randomly generated. This randomness, however, is reduced as the relation gathers and selects hypotheses and compares them with the state of its current environment. It is, therefore, an informed and analytic rather than an ignorant spontaneity. A solution then emerges out of the exploration of multiple options and an informed negotiation between the system and its environment to produce the best solution. The particular actualization of this best solution emerges within the individual instantiation of relation 2-2 when its actuality is picked up and reinforced by the reproductive enforcement of this best solution within the aggregate strength of the relation of 3-1. This produces a new population, whose capacity for a robust existence already has been predetermined by the extended informational analysis undergone within this 3-2 relation (probability or future propensity) and whose capacity for continuity of type is assured by the domination of the aggregate relation of 3-1 (the statistical average).

This relation of Thirdness as Secondness (3-2) is a powerful and vital informational search process. It is ignored and even denied within Newtonian mechanics, for it is an internal and, therefore, nonobservable process. However, without this networked informational search process, adaptation degenerates to pure random luck, an energy-wasting and effectively ineffective process, and evolution would be impossible. A novel entity, to exist for longer than its own individuality, has to set up a population—even a population of molecules or cellular organisms—and a population is, by definition, a commonality, a genre of shared properties. These shared properties have to fit into the activities of the existent other populations, which is to say, the full informational content of both the local environment and the nonlocal environment. A novel entity may indeed emerge on this planet, for I am not denying the existence of pure randomness; however, no novel entity can establish a reproductive population unless its properties are able to operate within the vast informational network that already exists. Therefore, the relation of 3-2, as this exploratory and analytic search engine is a basic requirement in our universe.

Relation 3-1, Quadrant IV

Quadrant IV, 3-1, functions in external and global space and progressive time. It is, like 3-2, a communal measurement, but it functions in external or actualized space; it lacks the complete epistemological imaginary propensities of the internal mode. It functions as a bell curve statistical average, basing its measurement value on a symmetry-inducing model of the statistical average of the already-actualized individual morphological forms and acts to constrain the nature of emerging forms by the pressures of its majority identity. It is epistemologically real and ontologically imaginary. The imaginary aspect of its measurements produces an abstract model (the statistical average) of the aggregate of the actualities emerging within the relation of 2-2. As such, it is a nominalist or mechanical measurement focused on the individual, but in this case, it is focused on the set of individuals, on the actual aggregate of currently existing individuals, on "a *sorite*, *heap*, or *mere collection*," which, however, acts as a collective set (CP 3.637). As Kauffman (1993) said, "In sufficiently complex systems, selection cannot avoid the order exhibited by most members of the ensemble" (p. 16). This relation of 3-1, or Thirdness as Firstness, is a relation of fitness that provides *one* solution modeled around an actual, successful, collective morphology (e.g., the successful weed, which dominates all fields, the best-selling consumer item), which will be copied by all other manufacturers. It is an external relation, which makes it an actual reality rather than a hypothetical speculation. As an actual reality, referring to quantifiable entities, it functions as a statistical average of these entities, using, in most cases, the mode as its statistic. The relation describes in a general model the behavior of the majority of actualized existent individuals in a class or collection. It is not prescriptive in the sense of deterministic, but its descriptions act as a constraint on emerging instances. This referential model functions as a kind of attractor-glue (Paton & Matsuno, 1998) to which the emerging nascent instantiations are attracted, and which they then take as their guide for development. However, "no collection of separate *descriptions* (i.e., *models*) of organisms, however comprehensive, could be pasted together to capture the organism itself" (Rosen, 1991, p.112). Biologically, this statistic permits the well-known survival of the fittest, but, as Peirce pointed out, "it has to be remarked that the phrase 'survival of the fittest' in the formula of the principle does not mean the survival of the fittest individuals, but the survival of the fittest types, for the theory does not at all require that individuals ill-adapted to their environment should die at an earlier age than others, so long only as they do not reproduce so many offspring as others" (CP 1.397). As such, this nonlocal communal measurement functions to constrain the emergence of novel properties among the community, for the reproductive aggregate is maintained as a dominant model. Peripheral variations may appear but are not admitted to the calculations of the dominant model and, thus, fail to reproduce in sufficient strength to overcome the dominant model.

As a symmetry-inducing action, this relation is vital to maintain the strength of actualized representations of information, enabling this type of information (i.e., the actual) to dominate imaginary or hypothetical constructs. This is an important concept to retain—actual measurements must dominate imaginary measurements; actual morphologies must dominate imaginary morphologies. This means that we cannot live in fictional worlds; we must recognize objective reality. We cannot dispense with the mechanical reality of discrete quantifiable and objectively observable instances, even when we now admit the necessity of the imaginary process for the maintenance and adaptive capacities of the actual world. As Rosen (1991) points out, biology, which is to say, life, "becomes in fact a *creative* endeavor; to fabricate any realization of the essential relational organization (i.e., to fabricate a material system that possesses such a model) is to create a new organism" (p. 245). However, I disagree with Rosen's (1991) statement that the closure to efficient causation (i.e., to mechanical cause) "places the heart of biology entirely outside the scope of mechanism" (p. 244). If we deny this facet of reality (i.e., the actual instance and its attendant model), the statistical average as potent agential forces in life (potent because of their particular attributes of quantifiable actuality) and consider them as merely the limited parts of what we, in our incompetence, can observe, then, by denying their functional value, we are moving into the ideology of a world operating within either randomness or teleology. Most certainly, as Rosen (1991) outlines, "In a machine, the components themselves are direct summands of disjoint states, and the whole machine can itself be described as a direct sum of such summands. In an organism, we can make no such identification; components are not in general direct summands of anything. … This in turn reflects the general non-fractionability of components in an organism" (p. 246). My point is that if we, rather than using the term *machine*, instead refer to these two external relations of 2-2 and 3-1 as *mechanical*, then no system in our universe, physicochemical, biological, or socioconceptual, is exempt nor should it be exempt from the robust functionality of these mechanical operations. We must differentiate the mechanical process from the machine process, and we must insist on the functionality of the former within all of natural reality. What is missing, not in the mechanical but in a machine? We will discuss this in the final section of this chapter.

There are two relations outside of this quadrant: the relations of Thirdness-as-Thirdness and Secondness-as-Firstness.

Relation 3-3

If we consider full imagination as the universal rationality of pure mind, then we thus affirm that the universe, while not designed or in any way a priori, organizes matter within evolving complex consistent and coherent and integrated networks. These attributes—consistency, coherence, and integration—are evidence of logic or mind. The relation is 3-3, or Thirdness as Thirdness, and it is, I maintain, a property of all informational and morphological realms, the physicochemical, the biological, and the socioconceptual. This pure Thirdness guides the actualizations functioning within both the imagin ary and real worlds. Thirdness-as-Thirdness can be understood as the underlying tendency of the universe to be logical, which means to form spatiotemporal matter within consistent, coherent, predictable, and pragmatically functional interactions. The results of the tendency to be logical are the learned habits, the normative patterns of interaction of a collective. Such habits constrain the volatility of instances. This relation is strictly aspatial and atemporal. It has no local links, for, as pure Thirdness, it is fully general and has no actuality in its nature. As such, it cannot be described, for description belongs to particularities. It "cannot be in the world of quality nor in that of fact" (CP 1.480), and I would suggest only that it is, in itself, the basic causal force of the nature of our universe as a complex adaptive network.

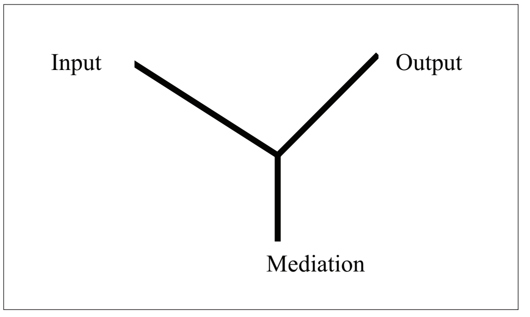
We also must comment that, effectively, there are three different types of reasoning capacities within our universe: the relation of pure logic, the relation of heuristic hypothesis construction, and the relation of the statistical average of actualities. Having three very different types of thinking capacities provides our universe with a broad and flexible competence for adaptive and pragmatic (not random) continuity.

Relation 2-1, The Interface

The other relation is the Interface, a borderline relation, which functions as an initial condition (origin) at the point of intersection of the Y and X cuts of differentiation. The relation is 2-1, or Secondness as Firstness, operating in local space (both isolate and closed) and in both present and perfect time. It acts as an intervening act, an interface, to connect relations. In itself, it includes the high-energy expansionist functions of Firstness and the actualization or limit-inducing processes of Secondness. If it does not accomplish these links, its informational acts (of inducing horizons) and its energy content (of data open to a variety of interpretations) will dissipate. The function, the sole function, of this relation, is to set up connections—first, between the internal and external realms, and second, between the local and global realms. Within Peircean terms, it can be understood as an act of prescission, which "is always accomplished by imagining ourselves in situations in which certain elements of fact cannot be ascertained" (CP 2.428). Note that it, as a relation, is itself comprised of both factual and imaginary informational processes. Its two different modes of codification are continuously entwined in their attempt to link relations; therefore, external actuality is always exploring the new informational potentialities within internal ambiguity and vice versa, and symmetry is always exploring asymmetry and vice versa.

The Interface, acting as this coupling function, is a pointer function and enables a complex network of these six relations. For example, the chaotic state or strange attractor is the relation of 2-1 alone. It operates without links so that the measurement acts as an initial condition of differentiation in a state of high excitation. It is highly volatile and expansive (its internal spatial and present temporal nature) and confrontational (its external and local spatial and perfect temporal nature). With its high energy and confrontational features, the interface is actually a strong attraction for other relations, much as a chanting and singing market vendor attracts consumers. If it does not find/attract symmetry-inducing measurements, its informational content will dissipate. There are six interface typologies characterized by the dyadic bond of the interface relation with another relation. We will not go into any depth at this time in examining these typologies and will only point out the crucial importance of this relation.

Figure 3. The semiosic sign



Morphological Formation

We now examine the semiosic process of morphological formation. The morphological architecture of a sign is triadic in the shape of a nonlinear windmill, not a linear triangle as often is envisaged (Figure 3).

It is made up of three relations that interact within specific roles. Their triadic integration enables morphological realities to exist and interact. The three relations are Input, Mediation, and Output. The Peircean terminology in the same order is Object, Representamen, and Interpretant. The Input relation can be understood as a signal, as data, as a minor premiss. The Mediation relation can be understood as knowledge, as memory, as the computational or analytic capacity, as the universal or major premiss. The Output can be understood as information, as a conclusion, as an interpretation.

Dependent on the measurements of the relations involved, the sign can function in different geometric forms: as a point, as a linear line, as a nonlinear parabola. The sign that is morphologically a point (xyz) is found in local and internal space and present time. It is a burst of energy. The sign that is morphologically a mechanical line ($ax + bx + c$) is completely local, with no analytic or computing capacities, and can be internal-to-external or completely external. The complex morphology has self-organizing and self-generating capacities and is best graphed as a quadratic parabola, $f(x)=ax^2 + bx + c$. A term that is raised to the second degree (x^2) symbolizes a compressed measurement. The compressed measurements of memory are the symmetry-inducing communal measurements; that is, the Relations of 3-2 and/or 3-1 are functional within this morphology. A point or linear morphology does not use these compressed measurements. With the inclusion of either of these two relations, the Sign has acquired the capacity to reason, to refer to other models, and to use general laws in its interpretation of the input data. Again, Thirdness operates as x^2 and acts as a referential memory, as a compressed value of general laws that provides an analytic capacity. The value of bx functions as output; it has added information from x^2, the memory, and has transformed the input. The input c provides data that will be transformed by the mediative interactions of x^2.

The sign as a morphological reality operates within a network of directly and indirectly connected relations. In this network, some measurements will dominate as the actual triadic morphology, and others will be linked as additional yet necessary functions, or connected only as supplementary or even tangential, and might operationally dissipate. What compels the different results? The triadic morphology is not a completely self-organized autocatalytic or autopoietic reality (Maturana & Varela, 1980). Rather, it is a result of complex networked interactions with other morphological measurements, both internal and external, both local and global. That is, the sign is not separate and self-determined, but rather collaborative and reliant on the functioning of other signs; its so-called self-organization is not that of an isolate self-defined assertion but rather a networked collaboration.

Examples

As an example, we posit a triad of three relations that will come together within a function and generate a morphological form: 1-1, 2-1, and 2-2. These three relations provide information that is both internal and external but is all local and immediate; there is no symmetry-induction or global measurement of Thirdness. Link them, and a resultant form can be either 1-1-1, a short-term internal feeling; 1-1-2, a brief consciousness of that feeling; or 1-2-2, a spontaneous cry as a reaction to that internal feeling. In the first case, energy within the relations of 2-1 and 2-2 must be dissipated in order to reduce the final form to that vague internal feeling. In the second and third cases, energy must be dissipated, but it will not be as much as in the first example. In all cases, no referential memory, no general laws, are involved. What causes the emergence of one and only one particular morphology? The particular morphology, as a sign, functions within a larger informational network. This network will include existing signs in its immediate vicinity. It also will include connections to less immediately accessible existent signs within both spatial and temporal parameters and connections to symmetry-inducing relations within other signs, and so forth. These connections will affect the selection and production of this emerging particular morphology. The immense complexity of this network provides adaptive strength, for the effects of these connections, as well as the reality of some pure spontaneity of association, mean that an emergent morphology always can contain some idiosyncratic attributes.

Another example could be: 2-2, 2-1, 3-2. These relations are both internal and external but are more external than internal and provide information operating in both local and global space. Link them, and you could get, dependent on the nature of the semiosic act within the larger semiosic network, a morphological reality of 2-2-3, which is a normative mechanical act such as a heart beating according to its internal symmetry-induced species memory encoded within Thirdness. Alternatively, the morphological form might be encoded as 2-2-2, where it loses the forward-focused direction of symmetry and provides a strictly mechanical entity without a habitual set of rules such as a weathervane that only can react to an external efficient causality. On the other hand, you could get 1-2-3, which is the robust normative sign, acting within relations that provide both phenotype (local, asymmetry) and genotype (global, symmetry) results, as well as within relations that provide both freedom (local internal) and individual boundaries (local external).

Conclusion and Artificial Intelligence

The production of signs, understood as information functioning in measured values of space, time, and mode, operates within a complex semiosic architecture (Figure 2). This architecture sets up the sign as a mediated and coordinated triadic morph of relations (Figure 3). The triadic morphology, as a Sign, operates within three of the six relations (Table 1), although it must be emphasized that no Sign is ever isolate but, even as that triadic morphology, is connected to other triads. These three relations may differ from each other, or the triad may use three similar relations (e.g., three relations in the mode of Firstness as Firstness (1-1) will produce an expansive explosion of unfocused data, while three relations in the mode of Secondness as Secondness (2-2) will produce a strictly mechanical entity).

The system permits a continuous flexibility of morphological formation, for the vague and expansive nature of the internal data functioning in the relation within the second quadrant (1-1) enables an exploratory freedom of interpretation. The Interface relation (2-1) with its capacity to pick up this formless input data, define it only as origin (i.e., without the constraints of memory) and link it to any of the other relations, provides the system with an expansive adaptability and a capacity to promote a great diversity of interpretations. The relation of 2-2 acknowledges the importance of closure in the maintenance of cosmological energy; that is, discrete spatiotemporal morphological things prevent entropic dissipation. Additionally, a measurement that enables the continuity of a morphology as a common type expressed within these discrete morphologies strengthens the robust continuity of energy. Therefore, morphological semiosis has the capacity for not one but three types of memory and symmetric continuity. There is the historical memory of accumulated values of the successfully articulated collective (3-1, the statistical average); an example is natural selection. There is the imaginary capacity of virtual propensity (3-2), which permits tacit links that may never be articulated in actual morphologies but that remain available for future attempts at sign formation. Finally, there is the logic of rationality (3-3), which lies, I maintain, at the basis of life, understood as the increasingly complex yet pragmatic ordering of energy/matter.

What is the nature of artificial intelligence within a cognitive system of relations, and is it possible for a machine, so to speak, to make use of all six relations, or is the machine confined forever to using only the two external and, therefore, mechanical relations of Secondness-as-Secondness and Thirdness-as-Firstness? We may be asking the wrong questions. Importantly, we may be confusing the meaning of mechanical with the meaning of a machine. A machine is a tool produced by human beings. It is an artifact made up of interlocking bits according to a blueprint. As bits, it is an external reality; as produced according to a blueprint model, it remains an external reality. The right-hand side of our quadrant of relations is the external realm and refers to the two mechanical relations. A morphology formed within external relations has no internal realm; it lacks any vagueness of data input, and it lacks that important function of Thirdness-as-Secondness; it lacks the heuristic genetic algorithmic capacity. A machine is an artifact that is completely external, and without this function (3-2), a machine cannot think, and it cannot imagine. Rosen adds several functions to his differentiation of the natural organism from the machine; namely, metabolism and repair, and replication. Can a machine repair itself? No. Is a computational system a machine? Most certainly, a computational system can search and find its own problems and suggest the required solutions; the fact that another agent is required to input those solutions is hardly indicative of the limitations of such a mechanism, for humans require, for example, a doctor's prescription as a solution for a problem. Replication, which is indeed a characteristic of the living organism, is missing from this computational machine, for it cannot replicate itself on its own. However, it can provide the model for its replication, and it can insert this model as a blueprint for replication into a machine-process. Therefore, computational systems, or, more accurately, mechanisms, indeed can think and function as intelligent entities. Both a machine and a computational system, on first view, function within external relations. However, the computational system has added the capacity to network and connect to other relations. It has added the functional capacity of those internal relations of both 1-1 and 3-2—and that is a vital difference. A machine cannot access internal relations; a computational system can—and therefore, we have to consider that a computational system is intelligent.

Another point is that intelligence, as a process, is never the property of an individual but of a collective. No individual knows everything about its self, its collective, or its environment—whether that individual is a water molecule, a plant, or a human being. The collective knowledge, which we might understand as Truth and of which a single individual is only a representation, subsists within the full collective. Therefore, accessing and using this knowledge is always a communal and shared function. Therefore, when we consider whether a mechanical system can be intelligent, we must never consider this system as acting alone but rather as acting within a collaborative network. Knowledge, again, is a communal function, a result of many experiences of many individuals over many years. As Peirce noted, "reality depends on the ultimate decision of the community; so thought is what it is, only by virtue of its addressing a future thought," and this thought is "dependent on the future thought of the community" (CP 5.316).

Importantly, intelligence must be understood as the ability to hypothesize, to use the propositional argument frame of *If-Then*. This sets up an imaginary future-oriented framework of speculation that "if I do this, then that might happen." This requires the ability to imagine what-is-not in order to live within the nonactual internal world. With our confinement of the Newtonian mechanical world to the nonbiological (which I claim is an error), we have assumed equally erroneously that the internal world of the imagination is a property of only the living world. This is a criterion of Rosen (1991), in which he says, "I would hazard that 'artificially intelligent' systems could never be intelligent [and] there is no way to go from machines to organisms, neither by adding states nor by subtracting (constraining) them" (p. 247). But if we understand that the imaginary is a process of the interactive networking of different informational systems that measure time and space in different modes, then, we must question whether this process must be denied to the physicochemical as well as the artificial reality. I am going to suggest that artificial systems that have the capacity to network (i.e., to contact the information processes and memories of other systems)—both real and artificial—can think and can think intelligently. Again, there are several requirements for intelligence. The first is the capacity to access open energy within the relation of 1-1; this free energy is vital for the act of exploration. Then, the system must have the capacity to establish a networked collaboration of diverse informational systems; that is, the property of the relation of 3-2, which functions as an exploratory process of hypothesis-construction. This relation acknowledges that knowledge is a property of the collective and sets up a networking informational process. This networking includes the establishment of parameters that guide the choice of the best solution. For example, the parameters might include key terms of soil typology, water availability, and temperature—and the best solution would be a genetically modified plant species to produce food supplies in a particular ecological niche. The act of making a choice, that selection of the best solution, is a vital element of intelligence. An informational process that merely collates and offers a wide range of options, even if those options are a selection rather than a random collation, is not sufficient for intelligence. A vital additional capacity, since we are insisting that an artificial intelligence is not operative only in the external machine-world but is operative in both the internal and external realms, is the ability to function within that Interface relation of 2-1. Prescission means "the operation of the mind by which we pay attention to one feature of a percept to the disregard of other" (CP 1.549). This is Secondness-as-Firstness, the act of prescission, the act that moves from the internal to the external, from the hypothetical options to the actual individual choice. This relation acknowledges that novel information emerges within the imagination, within hypothesis construction, which is an internal process, and develops processing techniques to move this hypothesis from the imaginary to the actual realm. Can an artificial system select the best solution? Given that the system's analytic process is made up of the same perimeters as that of an organism (i.e., the limitations provided by information about actual realities), then there is no reason that the artificial system cannot select a best solution for the problem.

I am, in this outline, attempting to develop a pragmatic methodology for analyzing computational systems as intelligent systems. My tactic has been to understand reality as a relational method of morphological formation. I have suggested that these relations operate as measurements with spatial and temporal values. There are only six relations; they operate within a triadic function of $f(x)=y$ that produces a morphological reality; this morphology operates within a complex adaptive network of interconnected morphological formation. Using this methodology, I am suggesting that we can analyze the physicochemical, biological, and socioconceptual realms and understand the informational processes in all realms. I am also suggesting that we can use this methodology to develop mechanical systems, which are not machines but are intelligent systems.

There is, however, a common mythology in films, novels, and comic books, which asserts the power and irrational horrors of ungoverned artificial intelligence. We therefore must ask a basic question of artificial intelligence, and it does not deny what I am claiming; namely, that artificial intelligence is a potentially powerful and constructive means of intelligence processing. This is the question whether an artificial intelligence also can be an ethical intelligence. I have stated that an artificial system can act intelligently, and it can produce best solutions; that is, it can describe its current situation, it can reference this situation to other situations both current and historical, it can model other situations both real and imaginary, and it can analyze and come up with a best solution. However, the question that we must ask is whether this system's best solutions are also ethical decisions. A best solution might be the most practical and the most efficient, but this same solution might be deeply amoral. Can an artificial intelligence make ethical decisions? We are aware that this capacity—the capacity to be ethical—is not a property of all humans; therefore, must we expect it of all artificial intelligences? Additionally, I am stating that an artificial intelligence has the capacity to make a decision that has emerged within a comprehensive past and future overview of the situation. This is as close to an ethical decision as we, ourselves, might make. Indeed, an artificial intelligence, therefore, might behave in a more profoundly ethical manner than a human intelligence. Second, an essential characteristic of all humans is the capacity for emotions. As I said, not all humans are ethical, but all humans, except the dysfunctional, experience emotions. An individual without emotions is a psychopath. A machine cannot experience emotions. Is an artificial system only a machine? Does this make its decisions those of a psychopath? Or, if we deny that a system of artificial intelligence is just a machine and consider that it is, instead, mechanical and can connect to internal intelligence processing, then, will it remain psychopathic? The future feasibility and practicability of Artificial Intelligence, therefore, remains open to further examination; it is not, however, a closed domain but one filled with great potential.

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Chapter III

The Semiotic Structure of Practical Reasoning Habits:

A Grammar of Common Sense

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Abstract

This chapter introduces relational thinking styles (RTS), a model and method for identifying practical reasoning habits. Taken together, these unintentional reasoning habits parallel C. S. Peirce's logic of inquiry (methodeutic). However, unlike the deliberate application of inferences prescribed by Peirce's logic, these find expression as the unconscious applications of methods for the selection of ends and means (goals and processes). Not everyone applies the same inferencing patterns, especially for encountering novelty. Most people persistently lay familiar templates over novel issues, habitually engaging inductive-like processes to the solving of new problems. However, some apply abductive-like mental processes in the face of novelty; others, apply deductive-like ones. Because RTS is capable of predicting future consequences and of empirical verification by means of a reliable assessment tool (Chiasson, Malle, & Simonds, 2003) it is amenable to computer modeling. Computer modeling of the abductive-like process defined by this model may contribute to eventual development of an abductive inference engine.

Introduction

Over the past few decades, researchers have programmed computers to perform certain well-defined tasks extremely well; computers can play championship chess, calculate a collision between two galaxies and juggle a million airline reservations. But computers fail miserably at simulating the ordinary, experience-based intelligence that helps ordinary humans get through ordinary days. In other words, computers lack common sense, and that's why even the smartest ones are so dumb. (Horgan, 2005)

The tasks of teaching computers how to think and enabling them to effectively augment human intelligence are daunting, made even more so because there has been no comprehensive theory of common sense from which to extract programmable systems. Common sense can be considered from two directions—first, as the inferential structure (syntax) from which decisions are made and second, from the contents (semantics) of those decisions, which are often cultural and experience-based. This chapter deals with the syntax of various common sense inferential structures and their effects upon the expression of practical reasoning. (Throughout this chapter, the word reasoning refers to common sense or practical reasoning, unless prefixed with the words formal or deliberate).

In the same sense that the grammars of languages exhibit syntactic structures, so, too, do the tacit reasoning habits by which individuals maneuver in ordinary life. There is a grammar overarching these mental processes as well as the contexts and categories within which they are expressed. If we follow Noam Chomsky's (1957, p. 49) definition of grammar; that is, "A grammar of the language L is essentially a theory of L"—then the grammar and grammatical relationships of these unintentional reasoning habits provide a theoretical framework from which to examine and understand them. The semiotic structure of practical reasoning habits exposes an implicit grammar of these mental processes, which C. S. Peirce variously called reasoning instincts, the rule of thumb, practical reasoning, and common sense. Although these automatic processes may often feel like reasoning, Peirce explains:

A bee or an ant cannot—could not, though he were able to indulge in the pastime of introspection—ever guess that he acted from instinct. Accused of it, he would say, "Not at all! I am guided entirely by reason." So he is, in fact, in the sense that whatever he does is determined by virtual reasoning. He uses reason to adapt means to ends—that is, to his inclinations—just as we do. .... The point at which instinct intervenes is precisely in giving him inclinations which to us seem so singular. Just so, we, in the affairs of everyday life, merely employ reason to adapt means to inclinations which to us appear no more bizarre than those of a bee appear to him. (CP 2.176)

These instinctive inclinations direct the performance of practical reasoning habits, guiding both the development of purposes and the means we select to achieve them. However, not everyone possesses the same inclinations for practical reasoning. Both the methods and the consequences of applying different habits within various contexts reflect differences among individuals. These differences can be observed, and their consequences for generic sorts of contexts can be predicted, even for the long term. Although other researchers are investigating this topic (Sternberg et al., 2000; Wagner & Sternberg, 1985), none seems to be addressing the inherent nonlinguistic nature of these processes.

There are two aspects to identifying the natural and unintentional semiotic of nonlinguistic reasoning habits. The first is recognizing that individuals unknowingly engaged in such reasoning exhibit nonlinguistic markers that expose their inferencing habits. The second is having a way to code those markers according to specific criteria and to make sense of them (Chiasson et al., 2003).[1] The markers, the criteria for identifying them, and the computer analysis that makes sense of them derive from a model and assessment tool based upon Peirce's three categories and issue from his methodeutic (speculative rhetoric)—a branch of logic governed by both semiotic and formal logic.

Some scholars may expect that the concept of common sense reasoning that I am going to be describing here should correspond to the four methods of "fixing belief" that Peirce proposed relatively early in his career (1877, EP 1.109). Those methods (tenacity, authority, *a priori*, and the method of science) identify four ways to acquire certainty. However, although there are correspondences between common sense reasoning habits and those four methods, our model encompasses far more. Rather, ours is a general theory of the distinct and disparate inclinations that direct the ways by which different people apprehend purposes and adapt means to ends for achieving them—as well as the consequences that naturally ensue. These differences seem to be innate, or else developed from an early age.

What is a reasoning instinct? Peirce writes:

If I may be allowed to use the word "habit," without any implication as to the time or manner in which it took birth, so as to be equivalent to the corrected phrase "habit or disposition," that is, as some general principle working in a man's nature to determine how he will act, then an instinct, in the proper sense of the word, is an inherited habit, or in more accurate language, an inherited disposition. But since it is difficult to make sure whether a habit is inherited or is due to infantile training and tradition, I shall ask leave to employ the word "instinct" to cover both cases. Now we certainly have habits of reasoning; and our natural judgments as to what is good reasoning accord with those habits. I am willing to grant that it is probable that some of our judgments of rationality of the very simplest kind have at the bottom instincts in the above broad sense. I am inclined to think that even these have been so often furbished up and painted over by reflection upon the nature of things that they are, in mature life, mostly ordinary habits. (CP 2.170)

Recently, someone asked why I was equating reasoning only with common sense and practical reasoning. Surely, I must know that Peirce spent a great deal of time working with the principles of formal logic and of mathematics. Neither of those frames unintentional reasoning habits. Why focus on this mode of reasoning as grounds for computer programs of artificial intelligence?

My answer? Two important aspects of Peirce's work in logic are incomplete: abduction in formal logic and methodeutic, the logic of inquiry. Peirce contends that abduction is both a formal logical method and "an appeal to instinct" (CP 1.630). Methodeutic is "a theory of the method of discovery" (CP 2.108), which Peirce contends "concerns abduction alone" (MS 175. 329-330). Perhaps by demonstrating the instinctive expression of abductive-like reasoning, as our model does, these practical reasoning habits can contribute to the development of useful algorithms for abduction and for clarifying methodeutic. In addition, the field of intelligent systems design is so broad that I doubt that anyone knows what modes of reasoning will provide grounds for development. However, I suspect that having information about how people actually do reason, regardless of language, intelligence, or education, may be of some use for developing human-like computer models.

Therefore, in an effort to provide as much information as possible, this chapter will describe the syntactic relationships within the Relational Thinking Styles model of instinctive reasoning habits, which is derived from Peirce's three categories and a model of his methodeutic (Davis, 1972; Saunders & Decker 1973).

Background

Dorothy Davis, the learning theorist who identified these unintentional, nonlinguistic reasoning habits, selected the name relational thinking styles (RTS) to describe her theoretical model, because it identifies the potential ways that individuals might habitually make relationships when engaged in purposeful activities. Davis, a dance teacher/choreographer who became interested in the nature of creativity, returned to college in mid-life to begin doctoral studies in pursuit of this interest. She designed the RTS model based upon a three-tiered and three-sided inquiry cube designed by her professor, T. Frank Saunders, "to describe the sequence and inter-relationship of the levels of abstraction in the judgment process" (Saunders & Decker, 1973, p. 170). The three levels: (1) value/purpose; (2) competing alternatives/context; (3) content/description—and their corresponding depths (consisting of context, language, and value) are representations of aspects of Peirce's three categories, which he identified (EP 1.1-10) as quality, relation, and representation.

Saunders intended his cube as a tool for helping educators and their students to develop retroductive-reasoning capabilities. Based upon his three-tiered cube model, the ideal reasoner should deliberately operate from the value/purpose level to evaluate competing alternatives before selecting an end-in-view (outcome or content). Although he called this thinking backwards process retroduction, he means the term in a somewhat different sense than Peirce did. Nevertheless, even in the altered sense that he used this term, his is a rough framework for a model of Peirce's methodeutic. In the early 1940s, Albert Upton (1960) developed a Peircean educational model as well. However, like Peirce's linguistic bias, both Saunders' and Upton's models also have a bias for language, which limits the ability to observe and describe certain performance characteristics. Davis' focus upon action, in particular aesthetically driven action, enabled identification of a specific abduction-like process, providing empirically verifiable means for differentiation between abduction and the overarching process of retroduction (Chiasson, 2005).

Peirce seems to have used the terms abduction and retroduction synonymously. However, Davis' work suggests that these are not the same—that abduction should be viewed as an aspect of retroduction rather than as its synonym. In addition to what can be observed based upon Davis' model, Peirce's application of these two terms to various meanings—some narrow and others broad (EP 2.434)—indicates that there might be two meanings at play.

Elsewhere (Chiasson, 2005), I demonstrate that abduction can be considered an aspect of retroduction rather than as a synonym for it. I show that, based upon both language clues and function, abduction (prefix ab, meaning away from) seems to closely resemble the function of encountering a surprising fact and moving outward from that point to discover a reason for it. This process matches Peirce's abductive syllogism as well as the process that he describes as "musing" in a 1908 essay (EP 2.331). On the other hand, retroduction (prefix retro, meaning deliberately going backwards) indicates that this term should have an overarching meaning, making it more appropriately applied to his full logic of discovery; that is, the recursive interplay of abduction, deduction, and gradual induction that occurs when engaged in inquiry (EP 2.434).[2] One reason for asserting that retroduction is recursive is Peirce's contention that his logic of inquiry (methodeutic) is "a theory of the method of discovery" (CP 2.108) and "concerns abduction alone" (MS L 175. 329-330). Since all three inference types are necessary for engaging in inquiry, methodeutic, therefore, must make use of deduction and gradual induction as well as abduction. Perhaps when Peirce tells us that methodeutic is his "theory of the method of discovery" and "concerns abduction alone," he is using abduction in the same sense as when he says that logic is semiotic—the "formal doctrine of signs" (CP 2.227)—and then proceeds to identify the three branches of logic, with semiotic as the first. If that is so, then separating the two terms (abduction and retroduction) by prefix and function enables a clearer understanding of the processes. In any case, that is what I will be doing here; that is, identifying abduction as a specific inference type and retroduction as the expression of methodeutic and comprised of the recursive interaction of abduction, deduction, and gradual induction for discovering and securing a hypothesis to ready it for explication and testing (Chiasson, 2005; EP 2.434).

Because it is a form of logic and, therefore, within the normative sciences, methodeutic must be comprised of a set of norms for the characteristics and patterns of relations among characteristics by which retroduction should be undergone. In this sense, then, the patterns that comprise the syntactic relationships of this model of instinct-like reasoning habits might be useful as heuristic tools for clarifying and defining Peirce's methodeutic logic.

Davis (1972) used Saunder's cube as a background for developing a set of hypothetical predictions about the ways in which differing people might habitually move (or fail to move) through each of the three levels and depths while engaging in purposeful activities. She identified four potential ways (or styles) that individuals might operate habitually within these levels as well a fifth way, retroduction, which is deliberate and recursive.

Peirce's Three Categories

Peirce derived his three categories, which are usually referred to as firstness, secondness, and thirdness, from phenomenology, the branch of philosophy in his architectonic that informs all of the other sciences of discovery, except for mathematics. Phenomenology studies "the collective total of all that is in any way or in any sense present to the mind, quite regardless of whether it corresponds to any real thing or not" (CP 1.284-7). He explains:

Philosophy has three grand divisions. The first is Phenomenology, which simply contemplates the Universal Phenomenon and discerns its ubiquitous elements, Firstness, Secondness, and

Thirdness, together. ... The second grand division is Normative Science, which investigates the universal and necessary laws of the relation of Phenomena to Ends, that is, perhaps, to Truth, Right, and Beauty. The third grand division is Metaphysics, which endeavors to comprehend the Reality of Phenomena. (CP 5.121)

The normative sciences (which investigate the laws of the relation of phenomena to the ends of beauty, right, and truth) are aesthetics, ethics, and logic. The term normative means having norms, or standards, for performance. Norms enable the making of judgments such as beautiful or ugly; good or bad; correct or incorrect, and so forth. Although it may be relatively easy to accept the normative potential of ethics and logic, aesthetics might seem to be another matter. And, what is more, even if aesthetics were to be normative, what difference could that possibly make to the study of logic?

As to the question of relevance, an understanding of Peirce's concept of aesthetics as normative is necessary for coming to understand the logical norms, especially norms for abductive reasoning (Chiasson, 2005; Parret, 1994). Peirce defines aesthetics as "the science of the admirable" (Peirce, 1909, P.112). In a late-in-life essay (1908), he demonstrates how one might discover the ultimate aesthetic ideal by means of a specific aesthetic process, which he terms musing, after J. C. Friedrich Von Schiller's (1794) use of that term. Musing corresponds to the pattern of performance markers in Davis' model for identifying the abductive-like process of multi-relational reasoning. These markers are observable by applying Davis' nonverbal assessment, an operational analog of her theoretical model (Chiasson & Davis, 1980).

Just as for his classifications in general, Peirce's three normative sciences (aesthetics, ethics, and logic) depend upon the one prior for fundamental principles but do not provide principles to the one(s) before (CP 1.180). Thus, logic depends upon both aesthetics and ethics; ethics depends upon aesthetics; and aesthetics, as the first normative science, does not derive fundamental principles from either ethics or logic. However, aesthetics is dependent upon the principles of phenomenology (Peirce's three categories), as are ethics, logic, and all of the other classifications following phenomenology. Additionally, everything in Peirce's architectonic relies upon mathematics, the first science.

Most of Peirce's work was devoted to the study of logic, which he termed "the formal doctrine of signs. … Logic, in its general sense," wrote Peirce, "is … only another name for semiotic … the formal … doctrine of signs" (CP 2.227). Peirce identified three departments of logic: Speculative Grammar (semiotic), Logic Proper (formal logic), and Speculative Rhetoric (methodeutic). By the word speculative, Peirce means rules of language (grammar) and of persuasive argument (rhetoric) with which to develop, express, and support hypotheses. Peirce argued that philosophical discourse should exhibit the same rigorous standards for developing and adhering to the meanings of terms as the hard sciences. In this sense, he brought scientific method to bear upon what was, prior to his contributions, the murky world of philosophical nomenclature and argument (CP 5.413).

Just as for aesthetics and ethics, Peirce's logic falls within the classification of normative science. Therefore, each of Peirce's departments of logic is subject to a set of norms, some of which (such as deduction) are more clearly established than others (such as abduction).

Methodeutic, the third of Peirce's branches of logic, is the branch that he delineates in one of his late-in-life essays (CP 6.488). This is Peirce's logic of method—his intent being to develop "a method for discovering methods" (CP 2.108) for inquiry. Although his work on this branch of logic is incomplete, Peirce did make an unmistakable statement of his intentions for methodeutic. He wrote:

I here consider precisely what methodeutic is. I show that it is here permissible to resort to certain methods not admissible in [semiotic] or in critic. Primarily, methodeutic is nothing but heuretic and concerns [retroduction] alone. (MS 175. 329-330)

By the term heuretic, Peirce means the art of discovery or invention (Ketner, 2000). Thus, for Peirce, methodeutic is the logic of discovery or invention and concerns only retroduction—suggesting that it must concern retroduction in the overarching sense discussed earlier.

The version of Peirce's categories and of retroduction expressed in Saunder's model enabled Davis to develop a clear and verifiable philosophical construct that was capable of testing in the same manner as theories in the so-called hard sciences. Because it is so tightly constructed, Davis' theory enabled the development of an analog model in the form of a nonlinguistic assessment (Black, 1962; Chiasson & Davis, 1980) with which to clarify her hypothesis and verify her premises along experimental lines.

Methodeutic, according to Peirce, has the task of providing "a theory of the method of discovery … [that] should be founded on a general doctrine of methods of attaining purposes, in general; and this, in turn, should spring from a still more general doctrine of the nature of teleological action, in general" (CP 2.108). The RTS model fulfills this requirement because it is teleological in nature, identifying the ways in which purposes (both fixed and conditional) are habitually developed and applied within contexts. By using Peirce's methodeutic as the norm for evaluating methods of forming and executing of purposes, we are able to make accurate predictions about the future effects of particular tendencies for action within particular contexts.

What are the norms for methodeutic? Although methodeutic is radically incomplete, Jay Zeman (2005) comments that we do have indications that Peirce's general concept of methodeutic corresponds, at least in part, to the method of science or scientific method for reaching certainty (CP 5.377-410) that he wrote about early in his career. Some might argue that inquiry is a mental process, having nothing to do with the actual methods of science. However, Peirce considers methods as thoughts, once writing that thought "should be understood as covering all rational life, so that an experiment shall be an operation of thought" (CP 5.240). Peirce's interest in the methods of science began young:

[S]ince my youth I have associated with strong thinkers and have never ceased to make it a point to study their handling of their problems in all its details. … I mention my early forseeing [that methods could be improved by study], because it led me, in studying the methods which I saw pursued by scientific men, mathematicians, and other thinkers, always to seek to generalize my conception of their methods, as far as it could be done without destroying the forcefulness of those methods. (CP 2.110)

Peirce's emphasis on the methods of science and his contention that methodeutic is "the theory of inquiry" (CP 2.106) and "a theory of the method of discovery" (CP 1.108) indicates that this branch of logic is inexorably tied to Peirce's concepts of the methods of science and of retroductive reasoning. In this sense, we might consider that the radical incompleteness of methodeutic manifests in the same sense that retroduction does, in that neither is yet fully developed—perhaps because they are one and the same.

It is important to note that Peirce provides greater leeway for the study and explication of methodeutic than he does his other two branches of logic:

In coming to [methodeutic], after the main conceptions of logic have been well settled, there can be no serious objection to relaxing the severity of our rule of excluding psychological matter, observations of how we think, and the like. The regulation has served its end; why should it be allowed now to hamper our endeavors to make methodeutic practically useful? But while the justice of this must be admitted, it is also to be borne in mind that there is a purely logical doctrine of how discovery must take place, which, however great or little is its importance, it is my plain task and duty here to explore. In addition to this, there may be a psychological account of the matter, of the utmost importance and ever so extensive. With this, it is not my business here to meddle; although I may here and there make such use of it as I can in aid of my own doctrine. (CP 2.107)

Because it is a department of logic, and because all of logic is normative science (subject to norms and standards), methodeutic logic, the branch of logic that would delineate "a method for discovering methods," therefore must have distinct norms and standards for its correct performance. Although Peirce's treatment of methodeutic is incomplete, his architectonic is not—and from the overarching structure of his philosophical construct, one can infer what his methodeutic might look like. It might look very much like the RTS theoretical model. For, although ours is a model of instinct-like reasoning habits, the semiotic structure that I will be presenting will contain many of the elements necessary for constructing a testable version of this incomplete branch of Peirce's logic.

As a Peircean model of implicit reasoning habits, this theory represents various expressions of nonlinguistic and unintentional inferencing habits. These habits are identifiable by means of a nonlinguistic assessment process based upon sets of markers that distinguish one inferencing pattern from another. This activity-based nonverbal instrument (Chiasson & Davis, 1980; Davis, 1972) neatly corresponds to Peirce's criteria concerning the need for verifiability when identifying mental processes.

I have long come to be guided by this maxim: that as long as it is practically certain that we cannot directly, nor with much accuracy even indirectly, observe what passes in the consciousness of any other person [and] while it is far from certain that we can do so (and accurately record what [we] can even glimpse at best but [in a very slippery fashion] even in the case of what shoots through our own minds, it is much safer to define all mental characters as far as possible in terms of their outward manifestations. (EP 2.463)

Thus, taking into account that we cannot know what someone else is thinking and that we are poor judges of our own thinking processes, this nonverbal assessment tool identifies specific patterns of certain outward manifestations of unintentional reasoning that a particular individual engages during the confrontation of options in a novel situation.[3]

Why is novelty essential for the assessment process? Because familiar tasks and familiar contexts usually do not require reasoning. It is only in novel situations that these reasoning habits are sure to be exposed. Some people have exceptional instinctive capabilities for accommodating novelty; others, more moderately so. Some fail even to recognize that a situation is novel, applying tried and true methods regardless of what the situation calls for. Many of the same processes that a person uses for dealing effectively with novelty are the ones that that person will apply to familiar situations as well. Thus, with this assessment, we are able to observe how individuals confront a novel situation, develop purposes, and adapt means to ends for achieving those purposes. The types of purposes and methods a person uses for this assessment reflect his or her general inclinations toward forming purposes and for adjusting means to ends to achieve these[4] (Chiasson, Malle, & Simonds, 2003).

By using the definitions and algorithms from the activity-based nonlinguistic assessment, we are able to observe, code, and analyze the heretofore mysterious process of abductive reasoning as well as nonlinguistic expressions of the other reasoning types (Chiasson, 1987, 2002, 2005; Chiasson, Malle, & Simonds, 2003). Our studies have shown that the abductive-like process of multi-relational reasoning is the instinctive inferencing habit by which about 12% of the population deals with novelty. The majority (70%) habitually engages linear (simple or crude inductive) reasoning; 17% habitually use analytical (deductive-like) reasoning; and 1% transient (crude abductive) reasoning. These reasoning habits are hierarchical in terms of complexity; that is, abductive reasoners have access to the capability for analytical and linear thinking; analytical thinkers, to linear thinking but not abduction; linear (crude inductive) thinkers to transience, but not analytical or abductive thinking. In addition, those who reason abductively and/or analytically will habitually engage gradual induction for verification. The other styles at times may do so as well, though we have no way to observe them doing this (Chiasson, Malle, & Simonds, 2003). With Davis' nonlinguistic assessment tool, anyone can learn to observe the nonlinguistic markers of these reasoning processes, including abductive reasoning, making that process finally available for study and analysis (Chiasson, 1987, 2002, 2005; Chiasson, Malle, & Simonds, 2003). Access to this tool for observing natural and unintended abductive reasoning processes should pave the way for eventually representing accurate and useful forms of this inference method for intelligent systems design.

Issues, Controversies, and Problems

Sebeok's Semiotic Web

Although some of the terminology of semiotics may have changed over the years, Thomas Sebeok's Web metaphor (Deely, Williams, & Kruse, 1986) provides a useful tool for considering the place of semiotics in cognition at the intersection between human and nonhuman species. These instinct-like habits are neither linguistic nor post-linguistic (having to do with culture and artifacts). Thus, as the Sebeok suggests, animal and human organisms may share certain cognitive traits within an overlapping category of nonlinguistic structures and systems. Since Sebeok and Wells originally constructed the term zoosemiotics to refer to the study of animal communication (Sebeok, 1972), the term has undergone changes in connotation so that it refers to other semiotic functions as well. Even at that, however, there are those who believe that the term zoosemiotics cannot accommodate nonlinguistic systems of inferential interaction between minds and materials, such as those in nonhuman animal species (Bermúdez, 2003). However, as Peirce pointed out:

[T]he instincts of the more intelligent mammals, birds, and insects sometimes undergo modification under new experience. It is said that a swarm of honeybees, carried to the West Indies, will soon abandon the practice of storing up honey. (EP 2.463)

Many animal species engage in certain instinctive and adaptive behaviors (such as preplanning and problem solving), which at least resemble inference-like reasoning activities. (In addition to Peirce's honeybees, think of squirrels gathering and storing food and beavers engaged in constructing dams, or of an octopus figuring out how to unscrew a jar lid.) Placing nonintentional reasoning habits within this category of nonlinguistic structures and systems makes sense because of the relationship of these reasoning habits to instincts. Peirce argued for instinctual complexity in both animals and humans, even contending that abduction arises from human instinct (CP 5.174). As mentioned earlier, Peirce also addressed this nonconscious complexity in his doctrine of common sense (critical and otherwise), "which admits indubitable inferences" (acritical, having never been doubted) as well as indubitable propositions (EP 2.331).

José Luis Bermúdez (2003, p. 111), however, argues against the possibility of rationality without language and claims that there are "obstacles to extending [an] inference-based conception of rationality to nonlinguistic creatures." He writes:

[W]e have no theory at all of formal inferential transitions between thoughts that do not have linguistic vehicles. Formal rules of inference do not operate on thought-contents but rather on the vehicles of those contents. They are syntactic rather than semantic.

Bermúdez is correct in his statement that formal rules of inference are content-less vehicles of thoughts; that is, syntactic rather than semantic. However, he is incorrect in his assumption about the rules of nonlinguistic, practical inference. RTS demonstrates that the structures underlying practical inferences are, just as the relationships of formal logic, syntactic rather than semantic. In other words, RTS identifies the syntactic structures of inferencing habits, which are vehicles of thoughts—not the contents of those thoughts.

Validation Issues

In constructing the hypothesis underlying this model, Dorothy Davis took care to identify and address the sort of model she intended to develop, because, as she explains, "an instrument designed to elicit certain kinds of information both directs and limits the kinds of data it will measure"(Davis, 1972, p. 44). Thus, descriptive models should elicit collections of descriptive data, and process models should reflect the sort of operational processes they represent. Attempting to use descriptive data for defining a process model and visa versa can only lead to confusion "between the kind of instrument chosen and the kind of data to which it applies." For example, she tells us, "it is not reasonable to use a yardstick to measure weight" (ibid.).

When so-called reasoning (creating, thinking, or learning) habits emerge from descriptive models lacking a distinction between description and process, the resulting concept will be either "relegated to the realm of mystical characteristics observable in form but not in process" or else, as Davis writes, "considered as a process … reduced to the exhibited characteristics of the product" (Davis, 1972, p. 45). In either case, the underlying process is not available for observation. Examples of models typical of this problem include The Myers-Briggs Type Indicator (Myers, McCaulley, Quenk, & Hammer, 1998); Gregoric Learning/Teaching Styles (Gregoric, 1982); Dunn and Dunn Learning Styles Model (Dunn & Dunn, 1999); Torrence Tests of Creativity (Torrance, 1976), and so forth. Although each of these well-known assessments provides interesting (and often valuable information), they reflect descriptive rather than process models of personality, aptitude, learning, thinking, creativity, and so forth. As such, when applied to the prediction of operational performances, such as creativity, thinking, learning, and so forth, each necessarily reduces process to "the exhibited characteristics of the product" because they have, in essence, "used a yardstick to measure weight." By applying operational terms and measurements to her model of reasoning and creative processes, Davis created a model and assessment tool that not only avoids this problem but also clarifies the oftentimes muddy relationship that other theories display between process and content.

Additionally, for those who normally work with data-driven models, understanding Peirce and RTS may require a shift in perspective (Buchler, 1961). Unlike theories developed from data, which have "a structure determined by the observed relationship among data, e.g. whether the data have a linear or exponential relationship" (Ford, 2000), process models have a structure that represents an understanding of the relationships within a whole system or context. "... Typically process models are used where there is some underlying theory about a relationship that can be expressed mathematically" (Ford, 2000, pp. 453-54). RTS is such a model, applying Peirce's categories and methodeutic logic (as a sort of systems theory) to human reasoning habits. The syntactic relationships within the RTS model enable mathematical expression by means of Peirce's relational logic (Chiasson, 2001).

The process vs. content issue is an especially difficult one in the area of validity testing for social and psychological assessments in general. For example, "Construct validity refers to the degree to which inferences can legitimately be made from the operationalizations in [a] study to the theoretical constructs on which those operationalizations were based" (Hertwig & Todd, 2000). In other words, construct validity is supposed to reflect how well an instrument measures what it says it is going to measure. However, the gold standard method for determining construct validity for a given assessment is by determining convergent and discriminate validity. These are determined by administering a series of other assessments with which the test under scrutiny should agree and a series with which it should disagree—then applying statistical analysis to the results. However, if the study mixes apples and oranges; that is, mixes process models with content models and then proceeds to have one as a measure of, or as a measure against, the other, the results cannot possibly be valid.

Rather, construct validity studies of a process model must focus upon the identifiable consequences that would follow if the underlying premises of the theoretical construct were true. These consequences need to be tightly defined in performance terms in order to provide sufficient clarity for experimental verification. Thus, validation studies of process models such as Relational Thinking Styles need to be experimentally tested and verified against predicted consequences. The late Peircean philosopher Gerard Deledalle (2001) suggests the sort of validation study required of a process model in his restatement of the pragmatic maxim:

It is only action which can differentiate a genuinely clear and distinct idea from one which has only the appearance of clearness and distinctness. If one idea leads to two different actions, then there is not one idea but two. If two ideas lead to the same action, then there are not two ideas, but only one. (Deledalle, 2001, p. 7)

Once we had the nonlinguistic assessment tool for determining these styles, we immediately realized that we had a means for demonstrating and testing Davis' theoretical model. We began applying and refining this assessment in 1978, and it has been in constant use since then. What we did not realize when we began applying this assessment was that the field of social and psychological research did not have adequate research methods for scientifically validating process models. Other fields, however, do have such methods, and they may provide useful research methods for further demonstration and testing of this model. The field of ecological research, for example, applies mathematical modeling to predict outcomes, as do others, such as weather forecasting. Mathematical modeling may well be a viable method for demonstrating and formally testing this theory. For, as David Ford (2000) wrote, "Typically process models are used where there is some underlying theory about a relationship that can be expressed mathematically." Since we apply algorithms for analyzing relationships among the observed markers, it seems reasonable to think that this information might respond to mathematical modeling.

Peirce's Philosophy of Common Sense

In line with his doctrine of pragmatism, Peirce developed a concept that he called "critical common-sensism" (CP 5.497). Peirce said that his was a version of the Philosophy of Common Sense first developed by the Scotch philosophers. He stated that critical common-sensism is marked by six distinctive characters that distinguish it from the Scottish philosophy (CP 5.439-452). A paraphrased summary of these distinctions follows:

1. Not only are there indubitable (undoubted) propositions, but there are also indubitable inferences.
2. Seemingly original beliefs only seem so because they change so slowly from generation to generation.
3. Original beliefs and acritical inferences are of the general nature of instincts.

4. That which is acritically indubitable is invariably vague. What is more, vagueness has the effect of entirely destroying doubt, so that the less a person knows about something that he or she believes to be absolutely true, the less likely he or she is to doubt its veracity.
5. A critical common-sensist has a high esteem for doubt.
6. A critical common-sensist double-thinks; that is, thinks about the nature of his or her thinking.

Most relationships underlying the propositional (original belief) aspect of common sense probably will fall within the field of semantics, which studies meaning—as opposed to syntax, which deals with structural patterns. Acritical inferences, which provide engines for propelling beliefs into action, are syntactical—as are their formal counterparts in logic. Since the RTS theory is not concerned with meaning, but rather with the structure and performance of the engine that drives meaning making, it addresses these indubitable and acritical inferences of common sense, which are, as Peirce writes, "of the general nature of instincts."

Signs and Meaning

Although Peirce's typology is highly complex, we can extract from it three fundamental sign types that are most easily understood (EP 2.4). Icons resemble that which they signify; indices indicate (point to) that which they signify (in the same sense that a fever indicates an infection); and symbols are conventions that include the formal relationships of language, logic, mathematics, and music.

The action-based nonverbal assessment based on the RTS model identifies nonlinguistic markers in order to expose inferencing habits. For the most part, these markers are indexical in nature, though in some instances, they can be iconic. Because of the conventional nature of symbols, the assessment disregards markers having to do with language and other symbols. However, in their everyday expression, practical reasoning habits engage all three of these sign types—though unintentionally. Thus, the sign systems of these reasoning habits seem to belong to the class of signs that Umberto Eco (1979) termed nonintentional signs. Of such signs he wrote:

[A nonintentional sign] is one in which a human being performs acts that are perceived by someone as signaling devices, revealing something else, even if the sender is unaware of the revelative property of his behavior. (Eco, 1979, p. 17)

Peirce's Semiotic Triad

All thought, Peirce tells us, comes in the form of a sign.

A sign ... is something which stands to somebody for something in some respect or capacity. It addresses somebody, that is, creates in the mind of that person an equivalent sign, or *perhaps a more developed sign. That sign which it creates I call the interpretant of the first sign. The sign stands for something: its object. It stands for that object, not in all respects, but in reference to a sort of idea, which I have sometimes called the ground of the [sign]. ... I mean [idea] in that sense in which we say that one man catches another man's idea, in which we say that when a man recalls what he was thinking of at some previous time, he recalls the same idea, and ... when a man continues to think anything ... in so far as the thought continues to agree with itself during that time ... it is the same idea, and is not at each instant of the interval a new idea.* (CP 2.228)

Interpretant

An interpretant, which relates to Peirce's category of thirdness—or relationship—is the "significant effect of a sign." Peirce identified three ordinal categories of such effects (CP 5.475-476). "The first proper significant effect of a sign is a feeling produced by it." Feeling is the gate through which signs come into our awareness. Peirce called this first effect the "emotional interpretant." Sometimes, as when enjoying a piece of music or art, this is the only significant effect of a sign. The second significant effect, if there is one, is effort, which Peirce called "the energetic interpretant." Effort may be of a muscular or physical nature, and it may be of a mental nature as well. However, this second effect "never can be the meaning of an intellectual concept, since it is a single act" (CP 4.75), while the meaning of a concept is always general. Peirce termed the third sort of significant effect the "logical interpretant," which is (in the simplest of terms) the general meaning of an intellectual concept.

Relational Thinking Styles is not concerned with whether someone is more or less inclined toward the emotional, energetic, or logical effects of a sign. Rather, RTS identifies the structure of these inclinations as they direct the habitual development of purposes and the adaptation of means to ends for achieving these.

Object

The object of a sign relates to Peirce's category of secondness; that is, to actuality, action and reaction, and so forth. Peirce distinguished two objects of a sign: the dynamical (or mediate) object, which resides outside the sign; and the immediate, which resides within. The sign must indicate the dynamical object by means of a hint, which is the substance of the sign, and the immediate object of the sign. Peirce put it this way:

As to the Object, that may mean the Object as [known from] the Sign and therefore an Idea, or it may be the Object as it is regardless of any particular aspect of it. ... The former I call the Immediate Object, the latter the Dynamical Object. For the latter is the Object that Dynamical Science (or what at this day would be called "Objective" science,) can investigate. (CP 8.183)

[T]he division into Icons, Indices, and Symbols depends upon the different possible relations of a Sign to its Dynamical Object. (CP 4.536)

The RTS model is set up to identify how various individuals are likely to apprehend this hint but not what meaning they will derive from it.

Ground

The ground of a sign—the idea to which a sign refers—corresponds to Peirce's category of Firstness, which is the container of all possibilities and potentialities, including the qualities, attributes, potentials, possibility, values, and so forth that might be discerned from (or ascribed to) a given object. For Peirce, an idea has its reality based on "its mere capacity for getting fully represented, regardless of any person's faculty or impotence to represent it" (EP 2.434). Peirce says that ideas (and indeed all of reality) are real things merely by having "characters sufficing to identify their subject, and possessing these whether they be anywise attributed to it or not" (EP 2.434). Ideas are comprised of qualities, properties, and characteristics. The ground is what it is independent of objects and interpretants—just as redness is redness regardless of whether it is a quality of a dress or of a stoplight. In light of common sense experiences, the qualities of ground are of three sorts (Upton, 1960, pp. 99-100):

1. Qualities of affect are feeling-based, immediate, and nonrational. They include joy, awe, sadness, fear, and so forth.
2. Qualities of sensation are actual, experiential, unmediated sensations, both irrational and anti-rational. They include qualities having vision, sound, taste, touch, sound, balance, and so forth.
3. Qualities of reason are objective, rational, comparative, and connective. They include considerations of association, abstraction, discrimination, comparison, transformation, size, change, number, space, relationship, and so forth.

These three classes of qualities, which correspond with Peirce's three phenomenological categories, also correspond to the three significant effects of interpretants (emotional effect, energetic effect, and logical effect). Again, Relational Thinking Styles is not concerned with the class of qualities to which a particular individual might be inclined but rather with that person's degree of sensitivity to similarities and differences among qualities. The manner and degree to which a person habitually perceives and discerns among qualities contribute to the level of purposes to which he or she will be inclined and to the methods that he or she will apply to accomplish these.

Different modes of apprehension incline people toward one type of purpose rather than others (e.g., transitory/immediate; simple/short-range, complex/long-range; complex/generative. For example, people who apprehend qualities as fixed and necessary elements of things will tend toward purposes that are clear and unambiguous, while people for whom qualities are themselves means for inquiry will tend to generate new purposes in the course of exploring options. Consider this difference in light of two equally skilled woodworkers. The first (purpose directs material selection) selects a pattern and then chooses materials appropriate for producing that predetermined outcome. The second (material directs purpose selection) finds an interesting piece of wood and wonders what outcome might best serve the qualities of the wood. Although the reciprocal process of means directing purpose, then purpose directing means, and back and forth again is not uncommon for those habitually linked to the latter mental process, those habitually linked to purpose-directed means selection are not likely to engage the latter process with much success.

Myriad factors (such as age, background, personality, intelligence, etc.) determine how an individual might interpret the semantic meaning of a given sign. However, the syntactic inferencing habit that a person will use for making relationships is another matter altogether. These habits underlie a person's organization and expression of the three modes of being (feeling, sensing, and thinking) but do not change them. Peirce (CP 5.434) makes an explicit separation between these modes of being and the consequences of formal reasoning when he says:

[T]he pragmaticist does not attribute any different essential mode of being to an event in the future from that which he would attribute to a similar event in the past ... only that the practical attitude of the thinker toward the two is different.

Although Peirce was referring to the consequences of formal, scientific reasoning, the same separation between mode of being and practical attitude holds true for instinctive reasoning as well—except that for practical reasoning, the attitude is less likely to be different toward future events.

Reasoning habits are comprised of three separate aspects:

1. **Valuing style:** An individual's inclination toward issues of quality and relevance. What sorts of arrangements and options will that individual infer as interesting or relevant for a given situation?
2. **Goal style:** The level and manner of purpose a person habitually engages (simple/complex, immediate, short-range, long-range, generative, overarching). Goal style directs the way in which someone will apprehend purposes and develop mental plans for achieving them. What is the range and complexity with which someone makes inferences concerning future effects?
3. **Producing style:** The way in which someone will go about achieving an outcome—including problem solving. How does a particular person adapt means to ends? How does he or she confront the inevitable problems that occur when engaging concepts with materials to produce an outcome?

Each of the three aspects of a practical reasoning habit engages inferences for a different purpose. The first (valuing style) identifies how a person makes use of inferences when engaging aesthetic judgment—including the reading of contextual requirements (though this judgment is only visible when the value is placed into action as a goal). The second (goal style) reflects how an individual develops purposes—which are values placed into action. Goal style inferences reflect futuring abilities—that is, the degree to which a person can make effective mental judgments about future options and potential effects. Goal style also indicates whether purpose (a projected end) habitually directs the means selected or whether a person is mentally flexible enough to allow means to direct the formation of ends as well. The third of these aspects (production style) is a here-and-now process that reflects the way that a person habitually adapts means to ends while putting goals into action (or while developing models, designs, or other physical plans for future goals). In particular, production style reflects how an individual habitually solves (or fails to solve) problems in the course of adapting means to ends in pursuit of a purpose.

Without early intervention, reasoning habits tend to remain stable over time (Chiasson, 2001; Chiasson, Malle, & Simonds, 2003). However, individuals do not always apply the same reasoning habit for all three categories of style. For this reason, we always consider practical reasoning habits as patterns made up of three styles. Thus, a reasoning pattern is comprised of one inferencing habit for valuing, one for addressing goals and one for producing outcomes. Some individuals apply the same reasoning habit to all three activities; others apply different habits to one; others apply a different habit to each of the three.

The Structure of Practical Reasoning Habits

Discovery and Development

In developing RTS, Davis followed Peirce's method for framing a mathematical hypothesis:

[T]he mathematician does two very different things: namely he first frames a pure hypothesis stripped of all features which do not concern the drawing of consequences from it, and this he does without inquiring or caring whether it agrees with the actual facts or not; and secondly, he proceeds to draw necessary consequences from that hypothesis. (CP 3.559)

As with any new hypothesis, Davis' theory began as a hunch—in this case, a hunch about the nature of creativity. She followed up this hunch with preliminary inquiries, which eventually led to her mid-life enrollment in a doctoral program to study foundations of learning. As she provisionally verified her premises, her tentative hypothesis began to take form, eventually reaching a point at which she was able to formulate it into a clear hypothesis (Davis, 1972). Once formulated, this hypothesis enabled identification of the necessary consequences that would follow from it. Davis began preliminary testing of these consequences using an observational technique that she had devised based upon the premises of her hypothesis. Early findings suggested that the theory also might permit identification of reasoning habits as well as of the creative processes she originally had sought to understand. She began to explore this possibility as well. Davis' early observational technique evolved into a nonlinguistic assessment tool (Chiasson & Davis, 1980), which is both a way of identifying reasoning habits in individuals and a method for testing and verifying the theoretical model. This tool also identifies the sort of processes that a given individual will engage for creative endeavors in the arts and other enterprises not usually connected with reasoning.

In following Peirce's method for framing mathematical models, Davis not only developed a tightly constructed syntactical structure for her theory but also stripped her hypothesis "of all features which do not concern the drawing of consequences from it" well before developing the nonlinguistic assessment for identifying these reasoning habits. Thus, neither this model nor its assessment tool addresses such factors as personality, perceptual functions, intelligence, education, culture, experience, and so forth. Instead, both the model and assessment express a set of syntactical relationships shadowing those of formal logic, but in a nondeliberate, operational sense.

Identification and Assessment of Common Sense Reasoning Habits

The assessment process involves only the observation and analysis of nonlinguistic outward manifestations of the unintentional way that a particular individual instinctively reasons within each of three categories: (1) valuing—determining relevance; (2) planning[5]; and (3) producing—including problem solving (Chiasson, 2001; Chiasson & Davis, 1980; Davis, 1972). These categories are experience-based versions of Peirce's three categories of being: Firstness (value and quality), Secondness (unmediated action/reaction), and Thirdness (mediation, relationship, and representation) (CP 3.559, EP 2.434).

The assessment, which is a proprietary instrument, identifies sets of markers that combine to indicate each of the reasoning habits for each of the three categories (valuing, goal setting, producing). These markers tie to a specific observational protocol and are analyzed by computer-based algorithms. The assessment underwent reliability and discriminate validity studies at the University of Oregon Decision Sciences Institute (Chiasson, Malle, & Simonds, 2003).

Reasoning as Process

Late in life, Peirce described the event of conscious inference (or reasoning) as follows:

When it happens that a new belief comes to one as consciously generated from a previous belief,—an event which can only occur in consequence of some third belief (stored away in some dark closet of the mind, as a habit of thought) being in a suitable relation to that second one,—I call the event an inference, or reasoning. (EP 2.463)

Although they operate in much the same way as Peirce describes, reasoning habits are nonconscious reflections of what he means by this statement. Additionally, reasoning habits reflect how "one fact puts a person in mind of another" and do not assume that every individual makes inferential relationships in the same way. For example, Peirce held that the proper use of inductive reasoning is as a tool for generalizing hypotheses already explicated and demonstrated by deduction. However, the simple (or crude) inductive-like reasoning habit of linear thinking bypasses both hypothesizing and analyzing—opting instead for goals and ideas that are familiar. The concepts employed by linear thinkers are already generalizations.

Space does not permit a full description of the RTS theoretical model, its formulas, and its consequences. However, I will provide abbreviated descriptions of these, illustrating details as much as possible to clarify terms and processes—including an abbreviated discussion of the formula sequences for each of the styles.

Kinds of Styles

Note: Figure 1 describes typical expressions of the following information. Figure 2 provides a full graphical presentation of the RTS theoretical model.

There are five basic kinds of reasoning styles: transient (crude abductive), linear (simple inductive), analytical (deductive-like), multi-relational (abductive-like), and retroductive. Styles are determined based upon the priority and combination of three categories (intensity, sequence, duration) and the presence, or absence, of action components within these arrangements as well as the various ways in which particular action components move through the categories in the course of someone engaging with experience.

1. For the transient style, intensity is absent, and neither sequence nor duration has priority. The action pattern applied to both sequence and duration is nondeliberate varying.
2. The linear (simple inductive) style is reflective of the sequence-driven combination of the categories, which relies upon the single action component of simple repeating.
3. The analytical (deductive-like) style is also directed by sequence. However, this style applies each type (and subtype) of the action components within each category as necessary for achieving a goal. Since this style is sequence-driven, as the linear style, goals will be replicative (though complex and often long-range). This deductive-like style pattern can engender complexity by applying both deliberate and nondeliberate varying as well as simple and complex repeating to manipulate sequences, confront options, and deal with time.
4. The multi-relational (abductive-like) style is intensity-driven, placing sequence and duration into subordinate (and irregular) applications. This style applies the action components of random and deliberate varying, avoiding both simple and complex repeating. Thus, unlike the linear or deductive styles, the confrontation of alternatives guides the performance of this style rather than goals or categories.
5. Davis' concept of retroduction is very close to Peirce's concept of methodeutic-like retroduction (CP 2.108). Thus, the retroductive style is not a reasoning habit per se but rather the deliberate selection of relationships between priority and combination and the deliberate application of action components as necessary for addressing the value, context, and content issues for particular stages of an operation.

Action Components

The three action components—contrasting, varying, and repeating—will be familiar to anyone trained in the visual or performing arts. Because Davis (who began her journey into learning theory as a dance teacher/choreographer) initially set out to develop a model of creativity, she applied these action components to play out within various arrangements of intensity, duration, and sequence. Her goal was to predict necessary aesthetic consequences upon the habitual performance styles of various artists and performers by identifying relationships between priority and combination of the categories and the action components. However, in doing this, she soon discovered that these same category/action relationships produced predictable consequences for academic performance as well (Chiasson, 2001; Chiasson & Davis, 1980; Davis, 1972, 1978). Later, Davis and I discovered that, when identified with contextual components, these patterns also predicted job performance (Chiasson, 1987, 1998, 2001; Chiasson & Davis, 1980). This suggested to us that the underlying source of rationality might be action-based rather than linguistic, as most believed at that time. In this sense of the aesthetic underlying the rational, Davis' model seems to support Dewey's argument for the primacy of the aesthetic in all of human experience[6] (Dewey, 1934; Tristan, 1996).

According to the RTS model, then, both creativity and common sense reasoning are inferencing processes, consisting of a series of mental actions occurring over time. To represent this activity, the RTS model considers action components, which combine into the patterns of actions by which each arrangement of the categories might approach (1) determining value, (2) developing purposes, and (3) adapting means to achieve the ends that these purposes engender.

Davis' model identifies three action components: (1) contrasting, (2) varying, and (3) repeating. These three are the fundamental elements for all patterning in the arts. Contrasting enables juxtaposing ideas, materials, and so forth. Varying is used for changing a thought, action, pattern, position, and so forth. Repeating involves selecting or doing the same thing again. When Davis applied these components (in conjunction with the categories of intensity, duration, and sequence) to the levels in Saunders cube model (1973), she found that she could identify particular styles by which individuals might go about solving problems in dance (choreographing) and in art (developing and producing a project). Later, after she acted on a hunch that these same methods might affect school performance,[7] she began to suspect that these styles might have to do with something more than performance in the arts.

As I began to develop a computer analysis program for this model, we found that these three action components needed to be broken down in a different way so that markers could be delineated clearly enough for a computer to make sense of them. Repeating needed to be broken into two types—simple and complex—so that elements in the program could differentiate between the sort of replication indicated by direct copies or modeling others and by the complex replicative processes that are required to develop new versions of existing things. I subsumed contrasting and varying into the single action component of varying and then identified contrasting as deliberate varying and used the term random varying to name the other process. The gist of the meaning of the action components remains the same. The operational aspect of each reasoning habit derives from a particular pattern of actions comprised of one or more of these components, as applied to the three categories of Davis' model: (1) intensity, (2) duration, and (3) sequence.

Categories

Intensity

Intensity means the degree of mental energy expended upon the confrontation of alternatives. The word confrontation is significant here because it implies a genuine encounter with an alternative rather than a mere episode of response to a stimulus or the kind of long concentration used for engaging in recipe-like activities such as putting together model boats from a kit. Thus, intensity at any level of the reasoning process implies recognition that there are alternatives coming from a more complex level. High intensity might be brief or extended; low intensity may be as well (per the previous example of following directions for putting together a model from a kit).

Of the two perspectives from which to view the concept of intensity, one reflects the situation for which selection and rejection of alternatives operate in view of a goal; for the other, selection and rejection of options enables choosing alternate goals as well as alternate means and materials. Under the latter conditions, "intensity contributes to the continued growth of options" (Davis, 1972, p. 58). This second perspective of intensity provides a key to unlocking the mystery of the abductive reasoning process, which is directed by the confrontation of options.

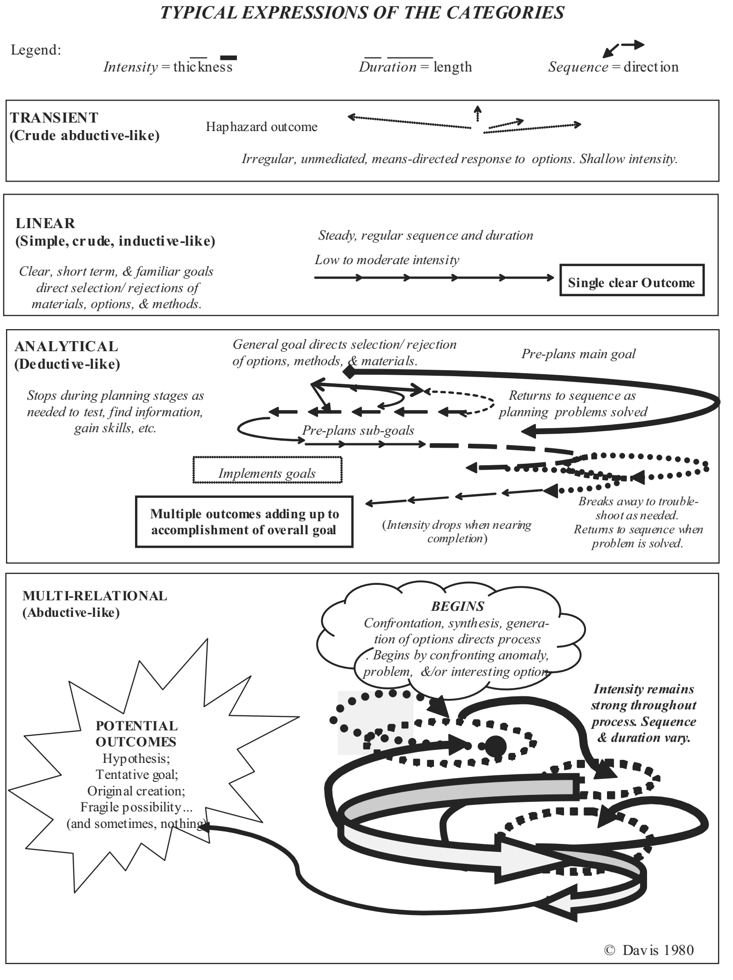
Duration

Duration refers to the pattern of time use expended at a given level of thought. Even or uneven modules and repetitive or varying units of time combine to reflect duration patterns. For example, when the complexity level is descriptive and content-oriented, the duration pattern is usually comprised of even modules and repetitive units, as are most activities requiring simple replication and repetition. At the level of context, alternatives are considered in terms of both content and context; that is, in terms of how a particular goal-related option might affect and/or be affected by something else. This naturally results in relatively uneven modules and varying duration units, which settle into evenness and regularity once the more difficult options have been confronted. When the level is at the value range, as it might be for confronting multiple alternative goals in terms of potential consequences on a system, the duration pattern will remain highly irregular, reflecting uneven modules and varying units.

Sequence

Sequence addresses two issues of thinking: order and direction. The order of thought has two aspects: (1) that which came before and (2) that which follows. The more complex the reasoning pattern, the more complex the order of thoughts—so that predictable, recipe-like ordering sequences like 1st, 2nd, and 3rd give way to unpredictable ordering sequences at more complex levels of thought. Direction of thought refers to such factors as moving forward, as one might do when replicating a sequence; moving backward, as one might do when analyzing problems; moving laterally within a context; moving out of the contextual level

Figure 1.



into the qualitative (or value) level; moving into the meta (or retroductive) level, which overarches and informs the others; and so forth. Sometimes order and direction of thought follow the same pattern—other times, a complex order might be engaged for a forward direction (such as planning), or a predictable order might be applied for an unusual direction of thought (such as taking pieces and parts of other patterns and sequences to adapt a process for new purposes).

The above diagram (Figure 1) is a graphical explanation of the typical expression of these categories for each of the four reasoning habits. Thickness of the line relates to the degree of intensity applied to the confrontation of alternatives, length refers to duration, and the arrows indicate the direction aspect of sequence.

Thus, as the diagram indicates, transient thinkers have shallow intensity and irregular duration, and are nonsequential. Linear thinkers exhibit moderate to low intensity, regular duration patterns, and forward sequencing. (In a formulaic, recipe-like way, they also can be said to sequence backward from projected end to means. However, since Linear thinkers neither generate nor preplan, we do not consider this backward sequencing.) Analytical thinkers expend relatively high intensity for confronting alternatives while they are preplanning (i.e., constructing a goal and subgoals as well as mentally working out potential problems). They work backward from that goal, sometimes exiting from the process to solve problems, to gain needed skills or information, or to plan new subgoals. All of the planning and problem-solving sequences engage higher intensity levels than the production sequences. Thus, once the production process is in operation, this pattern moves into the steady and even sequences of the linear pattern until (or if) a problem rises during production, in which case higher intensity and alternate sequencing are applied. As a rule, the analytical process produces well-formed outcomes, though many of these individuals prefer solving new problems to completing current projects. Many of these individuals will delegate (or else ignore) finishing details when the process requires repetition.

On the other hand, the intensity level of the multi-relational pattern remains consistently high throughout a process, although, because of their asequential process, they may sometimes appear transient to observers who do not know how to discern these cognitive processes. This highly complex pattern confronts a wide range of alternatives, selecting only those that meet particular qualitative criteria. Previous concepts and connections may double back upon themselves as new relationships emerge, sometimes making it appear that the individual is being repetitive—but that is never true for this type of thinker. Both duration and sequencing patterns are irregular and highly unusual, especially when considered in light of the other styles. The final output from an abductive-like thinker (if there is an output) is lightly held, which is to say that it usually emerges in the form of a fragile possibility, a tentative goal or an original work, sometimes even a prototype, which the abductive-like thinker may refine but will not want to replicate. These individuals pay considerable attention to subtle details that others may consider irrelevant. The qualitative aspects of such details, in combination with their juxtapositioning and synthesis with other details, provide the impetus in order for this pattern to continue working.

Retroduction in this model is a deliberate and recursive process corresponding to Peirce's methodeutic (Figure 2). Individuals capable of reasoning in this way engage each of the reasoning styles as necessary to discern and fulfill value, context, and content requirements.

Priority and Combination

When considered in terms of this theoretical model, priority and combination of the categories (intensity, duration, and sequence) describe arrangements of the categories as habitually employed by a particular style during purposeful activities.

1. **Priority:** Reflects the selection of categories directed by value, so that this aspect identifies the primary category that directs a habitual reasoning style. Although values in this sense may be consciously derived, they most often are not (especially when sequence governs). For example, when sequence governs the reasoning process, it means that the process is goal-directed. Sequences are natural precursors for reaching goals, as well as the consequences of planning for goals. Thus, sequence-governed reasoning

Figure 2.

Relational Thinking Styles Theoretical Model	***CATEGORIES***			***SYNTAX***
ACTION COMPONENTS	SEQUENCE	INTENSITY	DURATION	***Priority & Combination of the Categories***
Repeating: Simple/ Complex *Varying: Random/ Deliberate*	*Order & directions of thought*	*Degree of focus for confronting options*	*Patterns of time use*	
RETRODUCTIVE *Recursive Interplay of:* Deliberate & Random Varying Simple & Complex Repeating	Deliberate/ generative. Multi-directional as deemed appropriate for task stage.	Deliberately confronts options for making determinations of value, context, & content.	Deliberately patterns time use for purpose of task and stage of task.	DEFINING: S ← I → D ANALYZING: S → I → D VERIFYING: I ← S → D
MULTI-RELATIONAL (Abductive-like) Deliberate & Random Varying	Generative. Multi-directional. Guided by confronting options. Order & direction are unpredictable yet stable.	Highly intense. Confrontation of options governs process.	Uneven and varying duration patterns. Time use subject to confrontation, evolution, & synthesis of options.	S ← I → D Intensity (as the confrontation of options) directs both sequence and duration.
ANALYTICAL (Deductive-like) Deliberate Varying/ Complex Repeating	Sequence governs Multi-directional, depends on stage of task. Long-term outcome is predictable; short-term is not.	General goal guides selection/ rejection. Moderate to high for clarifying, planning, trouble shooting goal.	Uneven & irregular duration patterns for goals/ problem solving. Likely to be even & regular for completion.	S → I → D Sequence governs intensity, which in turn governs duration.
LINEAR (Crude Inductive-like) Simple Repeating	Sequence governs both order and direction equally. Replicates formulas, recipes, protocols, past experience, etc.	Low for familiar sequences. Moderate for learning new ones. Clear, short-term goal guides selecting/ rejecting options.	Applies even and repetitive duration patterns. Time use governed by clock-time.	I ← S → D Sequence governs both intensity and duration in equal measure.
TRANSIENT (Crude Abductive-like) Random Varying	Multi-directional. Order and direction of processes are unpredictable & unstable. Not sequential.	Shallow intensity. Selects for simple differences. Easily bored.	Duration is uneven, irregular, unpredictable.	← S D → Ungoverned process. Intensity is not a factor.

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processes may be simple or complex, but they always have an end-in-view—and the projected end directs the selection and rejection of options. However, when intensity (as the confrontation of alternatives) governs the reasoning process, relationships among qualities (rather than goals) direct the selection and rejection process. This necessarily eliminates goals as directors of the process, placing them into the position of potential consequences instead.

2. **Combination:** Refers to the arrangement of the categories. For example, when sequence has priority, the categories are usually arranged in one of two ways, each producing different potential consequences. The first (sequence governs intensity and duration in equal measure) reflects linear sequencing, a combination that invites relatively simple outcomes. Linear sequencing reflects a low to moderate intensity level, especially when simple repeating is the prime action component. Since sequence equally affects both intensity and duration in this combination, the perceived sequence for achieving a goal equally will direct and limit both perceived options and time use. This is a typical linear combination, because the selection of familiar options enables reliance upon clock time to complete a task. (After all, the person

already knows how long something will take to complete.) A second sequence-driven combination can produce a more complex process (sequence governs intensity, which, in turn, governs duration). In this combination, duration emerges as task time, rather than clock time, expanding and contracting to meet the needs of a sequence and for confronting whatever options need to require consideration for effectively addressing the needs of a sequence in the course of achieving a projected end. Of course, this second sequence-driven combination can be used to achieve simple sequences as well as complex ones. However, the subordination of duration to sequence and intensity enables processes that are highly complex, especially when intensity is applied to the development of a goal and its potential consequences as well as to the selection and rejection of options for achieving the goal.

When intensity has priority, the confrontation of alternatives governs both sequence and duration, though rarely equally or in a series. At some points, intensity will direct sequence and then duration; at others, duration then sequence. Occasionally, intensity will govern sequence and duration equally. This intensity-driven combination is the most complex habitual style pattern. Whenever intensity governs any portion of a reasoning habit, the process will be unpredictable. Unpredictability is also a factor for the least complex of styles; that is, when intensity is absent and neither sequence nor duration takes priority. This combination invites a transient (or random) process.

Reasoning Habits and the Stages of Reasoning

When this theory was in the early stages of development, we viewed each person's style singly; that is, from the perspective of valuing alone rather than as a triadic set of processes. This singular approach made sense when the purpose of the model was to identify styles of creativity. However, once I began development of a computer analysis program for relating specific markers identified during the assessment (Chiasson, 1987, 2001), it soon became obvious that we were dealing with three different (but intrinsically related) processes.

Thus, although Davis had originally structured the theoretical model to delineate style as a singular issue, the same relationships expressed by the single version of the model apply equally to each of the classes of behavior (valuing, planning, and producing). In this sense, the same elements and actions characteristic of the abductive-like style apply for the performance of that style within all three classes of behavior (and for the other styles as well). Once we made the triadic discovery and began applying the computer program in order to analyze observations, we discovered that many individuals applied different styles within one or more of the classes of behavior. Once we had this information, we began identifying subtle yet significant performance differences. Thus, the three stages of reasoning provide a framework for identifying the impact of the elements of each style pattern as they play out within each of the three categories of experience (valuing, planning, and producing).

Additionally, as for Peirce's categories, each stage is dependent upon the one before. Thus, the planning stage is dependent upon the valuing stage for its purposes, and the producing stage is dependent upon both valuing and planning for adapting means to the ends determined by value and purpose. Of course, not all acts of cognition are completed. For example, the valuing stage might occur as elemental apprehensions of aesthetic appreciation and the planning stage as castles in the air that are never expressed as full relationships.

Since someone's habitual reasoning style for one stage is not necessarily the same as that for another stage, reasoning habits are expressed as three-part patterns. Thus, a valuing style refers to the way a person perceives and makes decisions about what matters—what will be beautiful, good, and/or relevant to that person for a given context. Planning style refers to the way a person perceives and develops goals, makes mental plans, and sets priorities for achieving them. Among other factors, planning style (also called goal style) enables identification of the degree to which a person can identify future implications of a given course of action. Producing style refers to the way a person apprehends and solves problems in the course of generating an outcome or product. (This latter style category also includes the making of models, blueprints, and other physical expressions of mental plans.) Taken together, the way in which an individual habitually reasons during each of the three stages comprises that person's practical reasoning pattern.

Although we invariably apply these reasoning habits automatically and in the blink of an eye, they nevertheless operate within Peirce's three categories. However well or poorly performed, valuing (the first stage of every reasoning activity) always directs a reasoning habit, because it directs the sorts of goals (or purposes) that a person will respond to and/or develop.

Valuing corresponds to Peirce's category of firstness, as it deals with quality, value, and potentiality rather than plans or productions. The valuing style is the aesthetic style, since the way an individual makes relationships for this style reveals the sort of content, arrangement of relationships, and degree of subtlety that he or she considers aesthetically pleasing. This stage also corresponds to abduction and to the hypothesis stage of inquiry, since acts of valuing determine what is worth doing, just as the development of a hypothesis by means of abduction means that the investigator has applied Ockham's razor to determine what is worth investigating. When directed by intensity, abductive-like processes emerge during the valuing stage.

Planning, the second stage of practical reasoning, is a goal development stage related to the category of secondness in much the same way as mentally relating elements in a diagram (EP 2.4), or imagining what might be the case when building castles in the air (EP 2.434). This second stage relates to the deductive stage of inquiry, the stage at which a hypothesis is explicated and demonstrated, readying it for testing and evaluation. Although we use the term planning for this stage, most of the reasoning habits do not engage in planning. The way in which a pattern does not plan is perhaps more significant than the way planning is done. (For example, the least and most complex reasoning patterns do not engage in planning.)

During production (the third stage of the practical reasoning process), results emerge as the consequence of putting values (stage 1) expressed as goals (stage 2) into external expressions by adapting means to ends (stage 3). Because it is the stage at which the relationships drawn from values and goals manifest, production relates to thirdness as mediation, relationship, sign, and so forth. It also relates to the third stage of inquiry, which applies gradual (rather than simple or crude) induction. Here, testing and evaluation are performed to validate theories and develop generalities. Practical reasoning habits differ widely as to performance patterns for this stage. For example, transient and abductive patterns (crude abductive-like and abductive-like) that are means-directed, do not engage in generally recognizable methods of production.

Although everyone engages all of these stages at various points in the course of engaging with experience, different people engage these stages differently. For example, most people operate from fixed inferences about value and goals (and from the sorts of familiar purposes that necessarily follow from these) (Chiasson, Malle, & Simonds, 2003). When values and purposes remain prefixed, then creation and discovery are limited to replication of familiar patterns. When the valuing process is open to exploration, then original possibilities can emerge for purposes and productions.

Putting It All Together

Once Davis had constructed this model, she had an inquiry instrument with which to test her hypothesis. How would a person driven by sequence and simple repeating respond to an unstructured, open-ended task comprised of ordinary materials? How would someone driven by intensity and varying respond to that same task?

According to her hypothesis, the former almost immediately would impose a goal onto the task, even though there was none stated. Because the person applies simple repeating to his or her sequencing, the goal would be tied directly to the means necessary for achieving it—meaning that the goal would have to be relatively simple as well.

The intensity-driven person would not be goal-directed. (Remember, Davis's definition of intensity is "the confrontation of alternatives.") What would that mean to not be goal directed? First, it would mean that the intensity-driven person would be confronting alternatives by engaging with the materials without a goal in mind. Something other than a goal would be directing his or her selection or rejection of materials.

Peirce demonstrated capabilities for this process in his early childhood. His aunt Mary Huntington, who lived close by the Peirce's, described a process he engaged in at 9 years of age that is akin to the intensity-driven process for selecting and rejecting among materials. To keep the 9-year-old Peirce quiet on hot summer days, she gave him boxes of black and white horn buttons of different sizes. She wrote in a letter that she was struck with "the skill and ingenuity" that he showed in arranging them. He would amuse himself with these buttons by the hour, "perfectly contented and happy" (Ketner, 2000, p. 98).

Some might argue that the mere fact of arranging indicates a purpose guiding the process. However, there is a great deal of difference between arranging for a purpose and arranging to see what might emerge from the arranging. The former looks like planning or production, which is complete when the purpose is achieved. It is not a process that would keep a little boy entertained for hours on end with boxes of buttons. An intensity-driven process, however, does not have an extrinsic completion point. Thus, a 9-year-old who is driven by this reasoning habit is very likely to keep himself interested for long periods of time arranging and rearranging buttons as he explores their qualities and creates relationships among them.

Davis' construct enabled her to devise an observational guide (now comprised of 98 markers—some according to frequency and others according to significance levels from 1 to 5) for determining how particular individuals habitually infer the requirements of an ambiguously defined task when there are no actual requirements given to them. This, hypothesized Davis, should tell us how that individual will approach tasks in general.

We tested this hypothesis for several years in a public school system and then later at a day-treatment facility dealing with delinquent adolescents and foster children who were having emotional problems. Our findings held true to such a point that we were able to suggest or institute specific protocols for improving student behaviors and learning capabilities based upon the assessment. We then measured the results against actual future performance. In the case of the treatment facility, we measured against their recividism rates, which this information was able to lower. The academic effects of this information enabled some students to make remarkable gains in school (Chiasson, 2001). This assessment has been in constant use since 1980 at a large social services agency in the Midwest. Soon after we began working with troubled adolescents, we discovered that this same assessment process identifies how adults will interpret (or fail to interpret) the requirements of a given job or task. This led to application of this information to business settings from the late 1970s to the present time.

Reasoning Formulas

Space does not permit a full description of the formulas for each of the reasoning habits. Thus, I will briefly discuss each style process in terms of the way that its formula operates. The reader might want to refer back to Figure 1, which is a graphic description of these processes.

Multi-Relational (Abductive-Like)

Peirce's formula for abduction is "result, rule, case," meaning that a surprising (or interesting) fact or result of something impels a search for a rule that might provide a reason for that effect, which, if true, would allow one to infer that the particular characteristics of that effect might be due to that reason.

As a reasoning habit, the abductive-like multi-relational style makes use of some functions that indicate processes not seen in deduction or induction. For example, unlike the stage and goal accomplishment common to linear and analytical thinkers, the ends of phases and stages in the multi-relational reasoning process do not usually result in an outcome per se. These reasoners usually are unattached to outcomes and may not produce anything at all. If there is an outcome, then the conclusion to an abductive process usually will arrive in the form of (1) a unique and original product, (2) a fragile possibility, and/or (3) a tentative goal or future intention.

If concluded with an apparent outcome, then what the abductive reasoner will do next depends upon the skills, interests, and tools in his or her arsenal. In any case, unless capable of (or willing to engage in) retroductive reasoning (per the meaning established earlier in this chapter), then the abductive-like reasoner is not likely to produce a hypothesis or goal that is ready for demonstration and testing. The abductive process is generative, not outcome-oriented—though in the course of engaging this process (and depending upon the intelligence, talent, and/or skills of the individual), subtle, original, and well-formed outcomes certainly may occur. However, these outcomes will be one-of-a-kind, not prototypes for future replication by the abductive-like reasoner.

Keep in mind that this model separates abduction from retroduction. We define retroduction as a deliberate and often long-term process that engages recursive interplay among abduction, deduction, and gradual induction to enable the framing of hypotheses and certain types of goals (Chiasson, 2001, 2005; Davis, 1972; Saunders & Decker, 1973). Although most multirelational thinkers are capable of developing retroductive capabilities, those who are purely multi-relational (that is, multi-relational for all three stages of their process) generally abhor engaging what they perceive as the repetitiveness of the sequence-directed processes (deductive-like and simple inductive-like). These individuals are not likely to be willing to engage in either of those processes long enough to perform a retroduction. Instead, they prefer to go outward from what they have already done, so that processes and outcomes grow (evolve). Results from the synthesis of one step become the beginning of the next.

The following, albeit incomplete, pseudo code provides an abbreviated description of the abductive algorithm. Abduction usually is engaged by the confrontation of an anomaly or else of an interesting problem or subtle detail. Anomalies occur when there is a discontinuity between an expectation and a result. The aspects that comprise problems, details, anomalies (and the expectations that promote them) are qualitative. As discussed previously, although quality is a firstness state and characteristic of ground, there are within this state three categories of qualitative attributes that correspond to Peirce's three categories (or modes) of being. The first category contains qualities of affect (feeling); the second, qualities of sensation; the third, qualities of reason. A quality set {} is a collection of qualities belonging to whatever is being examined. For example, an expectation has a quality set {Q■}, and an anomaly {Q◄} has a quality set as well. These two sets are juxtaposed (J) by the actions of varying (v) and then, contrasting (c). Each juxtapositioning {J} has a quality set as well. {J}-set criteria for the next varying/contrasting process reflect the selective extraction, abstraction, and/or synthesis of relationships made during prior juxtapositions.

Since intensity (defined as the confrontation of options) guides the abductive process, each juxtapositioning might engage the reasoner for some time—depending upon the number and possibilities of qualities at each arrangement point. If we use the analogy of a kaleidoscope, the turning of the scope might be comparable to one act of juxtapositioning (J). The arrangement of elements following one turn is comparable to the juxtaposition set {J}, which determines the qualities available for consideration; while the colored glass fragments themselves provide quality sets {Q} that contain possibilities for examination and making relationships. As for all quality sets, these qualities can be examined according to affect, sense, and/or reason.

One unique characteristic of this abductive-like style is that it does not habitually consider options in terms of their relationships to generalities, as linear and analytical thinkers do. Suppose that we say the design pattern at a particular turn of the kaleidoscope is a generalization. Abductive reasoners are much more likely to focus upon a qualitative aspect of the design, such as yellowness (even following that quality throughout several turns, rejuxtapositionings) rather than to focus upon the general pattern of the designs. Acts of juxtapositioning may occur many times at the same or different levels of a process. Thus, elements and their attributes may be rearranged (and often synthesized) many times before the examination of relationships seems complete.

For abductive reasoners, recursive juxtapositioning and examination of qualities are highly satisfying all on their own. When synthesis accompanies recursive juxtapositioning, the generative process turns back on itself to reach ever-greater levels of complexity, as might a spiral with lateral and spiraling exit points into the unknown (Chiasson, 2001; Deely et al., 1986). An important thing to remember, however, is that the confrontation of options rather than the parameters of goals drives this abductive-like process. It is counterproductive to engage abductive reasoning to accomplish a preset goal; a true multi-relational reasoner will not know where he or she is going until arrival; that is, until having juxtaposed and synthesized sufficient alternatives to form a coherent unity. In this sense, knowing when they are done is, for these thinkers, a matter of intrinsic satisfaction rather than goal accomplishment.

The fundamental abductive formula appears to be shorter than that for deductive reasoning, but the implications are much more complex. In addition, each order and each direction within a segment of sequence and the unique application of duration units and modules add more dimensions to the formula, as do elements of value and context (which this chapter does not address).

The basic abductive formula shows the relationships among intensity, sequence, and duration and the unevenly alternating actions of varying and contrasting that operate within the process. Thus, the basic abductive formula reads as follows: An anomaly (A) or interesting qualitative detail (*) generates or impels the beginning of the process, which is directed by high levels of intensity (I=4~5) for the confrontation of qualitative options rather than the content-like alternatives of goal-driven processes. Both sequences of thought, which may operate in any of many orders and directions (S=Md), and duration, which is irregular (D=Ir), are directed by this high intensity. Therefore, regardless of the current direction of a sequence, intensity will remain high and duration irregular to accommodate the intensity-driven confrontation of options. The action components of random varying (rv) and deliberate varying (dv) (contrasting) are engaged reciprocally, For example, random varying might be applied for changing the relationship among qualities (rejuxtapositioning) and deliberate varying (contrasting) for examining their qualities.[8] The result of every phase and stage of abductive reasoning is generative, leading outward and back on itself in a reticulated (web-like) pattern. It is important to note and remember that materials (or means) rather than goals (or purposes) lead the abductive reasoning process.

The more complex algorithmic formula for abduction provides insight into how abduction might generate into the reticulated pattern common to the abductive process. This same formula is applied to acts of juxtapositioning (producing a juxtaposition set {J}), as well as to the examination and synthesis of qualities. Each step of the abductive process can involve an extraction, abstraction, and/or synthesis of qualities that generate(s) a new set of possibilities for examination, until such point that satisfaction (EP 2.331) has been reached. As one might expect, the nonsequential nature of the abductive process makes both process and outcome highly unpredictable. Yet, however unpredictable outcomes may be, this is a relatively stable process.

Analytical (Deductive-Like)

When we contrast the nonrepetitive intensity-driven formula for abductive-like thinking with the mostly nonrepetitive but sequence-driven formula for analytical thinking, the differences are significant. Analytical reasoning, which resembles deduction, is a goal-driven (or premise-driven) process. Although sequence directs this process, the confrontation of options can be quite intense during planning stages, stages for which premise-like goals and subgoals are developed. This same sequence for goal development occurs each time an analytical thinker faces the task of generating a new complex goal. Thus, although the goals and the methods required for their achievement may vary, the method (or set of premises) by which they are developed is consistent. In this sense, although it is complex, the goaling process of an analytical thinker is like a generic set of a priori, blueprint-like rules, which can be applied to various situations for producing predictably well-formed results.

Analytical reasoners deal with multiple intermediate goals. At one point, we called this pattern multidigital (meaning multilinear), because the pattern is one for which alternate subgoals are easily generated. However, unlike linear goals, which are single and terminal, analytical goals are complex and contain multiple intermediate (or sub) goals. The process, while in the same sequence-driven category as linear reasoning, is so much more complex that we felt that it required its own name. Goal (premise) development is the most complex portion of the analytical reasoning pattern: development of subgoals, the next most complex. Troubleshooting, which can occur anytime during this process, is also complex. Once goals and subgoals are planned, pretested, and secured, the deductive style moves into production mode—applying the [(sequence→(directs) intensity & duration) • (repeating)] cycle of linear thinking as necessary to complete the goal. If unforeseen problems arise, the analytical thinker leaves the linear sequence and moves into troubleshooting mode, which is similar to the pattern for goal development.

A general idea directs the initial selecting/rejecting process, which is characterized by alternating forward, backward, and other multidirectional sequences. This first part of the process usually ends with a forward sequence as primary goal selection nears. During this stage of a process, sequences are engaged with relatively high intensity levels for confronting and narrowing alternatives in light of an emerging general goal. Although alternatives are comprised of qualities, as are all options for all reasoning, the kind of alternatives considered by analytical thinkers have more to do with what will or will not work for (or as) a goal rather than strictly qualitative options as for abduction. Duration patterns are necessarily irregular during planning and troubleshooting in order to accommodate sequence and intensity. Selections are made by contrasting and varying to select and reject from these alternatives in light of the general aim. Once formed, the main goal directs the backward sequencing necessary for preplanning and testing the main and subgoals. Once planning is complete, the process moves into a linear-like mode until completion. There are, of course, subformulas for this process, such as the troubleshooting formula. In addition, goal generation for this process is contextually appropriate, and the ongoing process is sensitive to the needs of context, which add additional elements to the formula.

If abduction were to be applied to the development of a goal and ongoing evaluation throughout the process, retroduction would operate much like this deductive-like reasoning habit. However, without access to abduction for the valuing and planning stages, this process cannot end in original discoveries, creations, or inventions. It only can provide complex replications of existing things and/or concepts.

Linear (Simple Inductive-Like)

Linear thinking is a recipe-like do-as-you-go process, as opposed to the think-first-then-do analytical process and the highly selective think-carefully-as-you-do abductive process. Inductively derived goals are terminal; they do not operate according to premises. Each goal derives from a pre-existing general conception directly tied into its method for achievement, making each goal complete in itself. Therefore, solutions invariably miss the mark when a linear reasoner attempts to apply this recipe-like process to solve complex, novel, or unfamiliar problems. Linear reasoning selects a goal from familiar options derived from general knowledge or acritical beliefs held in familiar categories of usage. This goal begins the repetitive sequence-driven production process that is a direct result of that goal, connecting it in an iconic fashion to the desired outcome, which is a near replica of the selected goal. This recipe-like reasoning habit is steady and predictable for performing familiar protocols.

Transient (Crude Abductive-Like)

Transient thinkers do not reason per se. Instead, they respond to simple effects and make simple (usually spontaneous and haphazard) responses for which the only common denominator is variety. Transient thinkers engage with objects of experience without making the relationships for producing rational meaning. Their nonsequential thinking is splayed, meaning that (unlike abductive reasoners, whose thinking is also multidirectional) transient thinking goes out in all directions without connecting to a central point or following a consistent train of thought. Thus, transients, while being the most flexible of all the styles, are also the least complex.

A simple external effect spurs on the splayed transient process, which is performed with an absence of intensity (options are not confronted, but merely reacted to). This pattern applies an irregular duration pattern and splayed sequencing (i.e., unconnected and multi directional). Simple varying is the only action component applied by this pattern. The combination of splayed sequencing and irregular duration produces unpredictable, haphazardly constructed responses.

Future Trends

Since applications of RTS are so far-reaching, let us narrow our thinking here to just a few future possibilities for relating this information with intelligent systems design.

In terms of the development of artificial intelligence (AI), we might ask if this information could help to enable the eventual construction of an abductive inference engine as well as more effectively patterning other common sense inferencing processes. Along with additional information about this system (which could not be included in such a brief explanation of this theory), AI researchers eventually might be able to translate these human reasoning processes into machine-generated ones.

The field of intelligence augmentation (IA) seems to hold many possibilities. For example, during the 20 years in which we have applied this assessment in business settings, we have been able to make seemingly uncanny performance predictions. We have done this by placing many factors into consideration at the same time. We analyze contextual factors by considering such elements as the process properties of job descriptions and of the styles and performance of other workers and managers on a team. We also consider other nonprocess information (e.g., tendency to favor one or another mode of being; that is, affect, sense, reason, intelligence, requirements for experience, training, skill, personality, etc.) that might affect a given individual's performance. Next, we hypothetically juxtapose that information with the individual under consideration for a job or promotion, turning the kaleidoscope as often as needed to identify for our clients those elements that are and are not likely to affect the person's ultimate performance of the job. In addition, we use this information to identify potential effects of new hires, promotions, and lateral moves on co-workers, teams, and/or the organization as a whole. This process, while complex, is also stable and, therefore, capable of being programmed into an intelligent system.

We use this same format to predict the overall performance of organizations—though, all we really need to know in those cases are the reasoning patterns of whoever is in charge and those to whom he or she has delegated authority. With information about the reasoning habits of those in control, we can predict the ultimate success or failure of that organization well into the future, regardless of whether it is a business, governmental, or educational system. This information might be useful for developing computer modeling for analyzing investment opportunities.

Other IA applications might include:

1. Decision-support tools to assist individuals habitually reasoning with the linear style to consider alternatives and the consequences of these.
2. Individually appropriate schools in a box would enable students to not only gain knowledge but also to correlate knowledge with practical performance. The engines of these systems could adjust to the repetition, varying, and contrasting needs of different students and yet still ensure sufficient repetition in order for the complex thinkers to acquire basic skills.
3. In this same sense, this common sense reasoning information could be used to develop more effective training and retraining programs for adult workers
4. Additionally, since language is an inherently ineffective tool for eliciting automatic processes, individuals with IA expertise might be able to develop other ways in addition to our individually administered and nonlinguistic assessment for deriving this style information. Potential assessment instruments could be developed and validated against the existing one.

Conclusion

The RTS model provides a new paradigm for thinking about thinking—one that many in the systems sciences nevertheless may recognize, since most are familiar with Peircean-like analysis. This model was derived retroductively rather than inductively (i.e., from an explanatory hypothesis rather than from inductively derived categories ascribed to collected data). Thus, the RTS model is, by its very nature, unusual from a social/psychological point of view. Retroduction begins in response to anomaly and reasons to a hypothesis, while induction begins with collections of detailed data and organizes them into generalizations. What is the problem with the latter way of developing a theory? It is not feasible when simply relying on collections of data from which to develop and secure hypotheses, to address anomalies that threaten the organization of the data without potentially destroying the system of categorization upon which data collection is based. Thus, individual cases that fall outside the categories are likely to become statistical anomalies whose influence is either placed in a catchall category and ignored, or else are diluted by some sort of averaging, depending upon degrees and quantities of differences. Yet as Peirce (EP 2.434) points out, such anomalies, which may be fragments of a larger system, can cause an entire proposition to crash, as when the inductively derived proposition that "no stones fall from the sky" was destroyed at the first scientific observation of a meteor shower. The end of retroduction is an explanatory hypothesis, which affords reasonable security "through subjection to the test of experiment [by means of gradual induction], to lead to the avoidance of all surprise" (CP 5.197). The end of crude induction, on the other hand, is a universal proposition, liable to be demolished by its first encounter with a single contradiction. When testable premises derived from an overarching theoretical model such as RTS direct the organization of data, the odds are much higher for an efficient, economical, and thoroughgoing explanation of results. Researchers are much less likely to wander into blind alleys or dine on red herrings when they have a retroductively-derived hypothesis from which to operate. Software developers may recognize the difference between retroductive and inductive theory development in the contrast between viable software construction methods and "spaghetti programming."

The RTS model of common sense reasoning habits is now ready for use in myriad ways, each of which can make use of its information to develop more systems that are effective and that provide for further testing of this model in new fields. In other words, this grammar of common sense, which is the RTS model, stands at the ready for anyone interested in applying it to develop applications for intelligent systems.

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Endotes

1 Government-funded reliability studies in 2002-03 established the reliability (inter-rater and retest) of the instrument used to identify and code these non-linguistic inferencing markers.

2 "Gradual Induction," writes Peirce (EP 2.434), which makes a new estimate of the proportion of truth in the hypothesis with every new instance; and given any degree of error there will sometime be an estimate (or would be, if the probation were persisted in) which will be the absolutely last to be infected with so much falsity. Gradual induction is either qualitative or quantitative… ."

3 The observation and analysis of the assessment process is indexical, pointing to habitual inferencing pat-terns unintentionally expressed by individuals when engaged a novel, action-based, activity. Except in a very few instances, the instinctive inferencing pattern identified by this assessment tool will match the habitual pattern by which that particular individual addresses both novel and familiar situations (Chiasson 2001), although novelty is a requisite for identifying these processes.

4 One reason that this assessment tool is unique is that, in addition to providing novelty, the process is so simple and non-threatening that even young children can perform it. Other than a few vague directions, this tool uses no language, writing, reading, questions, or answers. The assessment tool and its context are open-ended, having neither time nor parameter constraints.

5 The planning component refers to unmediated planning. Model-construction and designing belong to the category of producing.

6 Science may be catching up with Davis and Dewey. For example, theoretical neurobiologist, William H. Calvin, argues, "a core facility common to language and hand movements (and used in our spare time for music and dance) has an even greater explanatory power than a special facility for language-only functions" (Calvin, 1996). Psychologist Patricia Greenfield describes studies in which she has demonstrated the relationship between a child's placement of objects and cognitive development. Concerning the two skills of "manipulating objects and manipulat-ing words," Greenfield concludes that (a) the brain must be applying the same logic or procedural rules to both; and (b) using the same anatomic structures as it does so (Greenfield, 1991).

7 Davis tested this hunch by identifying action patterns of her own dance students and then predicting how they would most likely perform in an academic classroom. She followed her predictions by meeting with each student's academic teachers and asking a series of questions about student performance.

8 There is no repeating engaged during the abductive process. Thus, if any repetition seems to enter the process, it means either that an observer is interpreting the process incorrectly, or that the abductive reasoner has moved out of abduction and is using another inferencing process.

Section II

Discussions on Semiotic Intelligent Systems

Chapter IV

Toward a Pragmatic Understanding of the Cognitive Underpinnings of Symbol Grounding

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Abstract

We describe a research project investigating symbol grounding, the dynamics by which psychological connections are made between abstract symbols and concrete physical phenomena observed via sense perception and motor action. The project involves the use of a 3D simulated environment (AGI-SIM) as a medium for training, teaching, and developing an integrative, general-intelligence-oriented AI software system (the Novamente AI Engine). Via acting in AGI-SIM, Novamente forms concrete sensorimotor groundings for abstract relationships, such as those expressed in English by prepositions and subject-argument relationships. We describe results obtained using probabilistic-evolutionary learning within

Novamente to learn groundings for the concept near, the use of these groundings in practical procedure learning (e.g., learning to play fetch in a simulated world), and then we discuss the correlation of these groundings with linguistic usage of related words and the use of these groundings within analogical and other sorts of inference.

Introduction

One may conceive of mind as divided into three categories:

1. Symbol-to-symbol interrelationships
2. Perceptual and motor relationship
3. Symbol grounding relationships binding the symbolic and sensorimotor domains

Each of these categories is critical to intelligence. The first is dealt with by the science of logic; the second by a host of specialized subfields of biology, computer science, psychology, and engineering. Our focus here is on the third: symbol grounding (Harnad, 1990), which is what differentiates embodied, autonomous intelligent systems from purely formal systems on the one hand (i.e., Physical Symbol Systems, as defined by Newell and Simon, 1976) and purely sensorimotor-focused robotics systems on the other (Brooks, 1991).

In this chapter, we take the perspective that the appropriate way to understand the phenomenon of symbol grounding is to consider it in the context of unified, integrated, self-organizing cognition. Toward this end, we review the symbol-grounding problem from the perspective of an ongoing conceptual and technical research project (the Novamente/AGI-SIM project) aimed at creating a cognitive system capable of controlling a variety of embodiments in a variety of environments (including android bodies in physical environments, agents in simulated worlds, and other more adventurous possibilities). The project has many dimensions; the focus of this chapter is on building bridges between the abstract-conceptual and sensorimotor aspects of experiential learning, and the potential for this kind of bridge building to occur inside an AI system. One form that this bridge building takes, we propose, is the automatic learning of procedures that form sensorimotor groundings for abstract relationships such as those represented in English by prepositions and subject-argument relationships. Such groundings play a critical role in the pragmatic fusion of abstract conceptual inference with concrete, low-level sensorimotor procedure learning. And the nature of such groundings is best explored in the context of the particularities of learning and inference algorithms.

The project we describe involves the use of a 3D simulated environment (AGI-SIM) as a medium for training, teaching, and developing an integrative, general-intelligence-oriented AI system (the Novamente AI Engine). After a review of the relevant software systems and concepts, we present the results of some recent computational experiments in which Novamente was used to learn groundings for simple concepts within a simple version of the AGI-SIM world. Specifically, we describe machine learning experiments involving learning groundings for the concept of nearness and using this concept within procedures for carrying out tasks like playing fetch. We then discuss the use of this kind of learned grounding in the context of computational language understanding and the extension and generalization of this sort of grounding using analogical inference. The somewhat abstract concept of symbol grounding is itself thus grounded in the algorithmic and representational particularities of our specific approach to AI and hopefully in this process is significantly clarified.

Relationships to Classical Symbol Grounding Theory and Cognitive Robotics

While our approach is original in its details, there are significant relationships with prior studies in symbol grounding in cognitive science and cognitive robotics.

Regarding the use of simulation worlds to study symbol grounding, inspiration for beginning our work with AGI-SIM was John Santore and Stuart Shapiro's (2003) work embedding the SNePS (semantic network processing system) paraconsistent inference system in a 3D simulated world. Also, our approach to symbol grounding is somewhat related to recent work on automated symbol grounding by Deb Roy (Roy & Mukherjee, 2005) and others. Unlike Roy, however, our focus is not on the statistical learning of groundings in itself but on the use of groundings to bind together sensorimotor and abstract-conceptual learning.

With respect to the general philosophy of symbol grounding, Novamente builds on general principles that have been discussed amply in the literature. Symbols must be grounded subsymbolically in perception and action (Harnad, 1990) and, more generally, experientially as an agent interacts with its environment (Sun, 2000). For example, consider replacing all of the token names in a system with arbitrary labels (Mitchell & Hofstadter, 1995). This clearly would make no difference to the system internally; but would an astute external observer be able to deduce the original meanings by correlating symbol usage with external perception and action? Groundings of abstract relationships (in, over, near, etc.) are needed in order to facilitate learning through verbal description or, in the terminology of Harnad (2002), linguistic theft. Our goal in the reported research is to explore these issues in the concrete context of an integrated, self-organizing computational intelligence system in which symbol grounding is achieved via the coordinated activity of cognitive components within a unified architecture.

The Novamente AI Engine

The work described here has occurred in the context of the Novamente AI Engine, a comprehensive AI architecture that synthesizes perception, action, abstract cognition, linguistic capability, short- and long-term memory, and other aspects of intelligence in a manner inspired by complex systems science. Its design is based on a common mathematical foundation spanning all these aspects, which draws on probability theory and algorithmic information theory among other areas. Unlike most contemporary AI projects, it is specifically oriented toward artificial general intelligence (AGI) rather than being restricted by design to one particular domain or narrow range of cognitive functions. We believe that the correct way to study symbol grounding in an AI context is to do so in an AGI context, since, after all, symbol grounding in humans occurs in the context of general rather than narrow intelligence.

Novamente integrates aspects of prior AI projects and approaches, including symbolic, neural-network, evolutionary programming, and reinforcement learning. However, its overall architecture is unique, drawing on system-theoretic ideas regarding complex mental dynamics and associated emergent patterns (Goertzel, 1993, 1993a, 1994, 1997, 2001). Thus, Novamente addresses the problem of creating a whole mind in a novel way through this integrative mechanism.

The overall mathematical and conceptual design of the Novamente AI system is described in a series of manuscripts being prepared for publication in late 2005 or early 2006 (Goertzel & Pennachin, n.d.; Goertzel, Iklé, & Goertzel, n.d.; Goertzel, n.d.). The existing code base implements roughly 60% of the design and is being applied in bioinformatics and other domains.

Due to space considerations, we cannot review Novamente in depth here. The reader is referred to one of the existing Novamente overview documents, including Looks, Goertzel, and Pennachin (2004), and Goertzel (2005), which are available online. There are a few key high-level points about Novamente that the reader must recall in order to grasp the following discussions.

Novamente uses a weighted, labeled hypergraph knowledge representation in which pieces of information are represented as nodes, links, and patterns of activity of nodes and links. Each node/link is associated with a truth value, indicating roughly the degree to which it correctly describes the world. Novamente has been designed with several different types of truth values in mind; the simplest of these consists of a pair of values denoting probability and weight of evidence. All nodes and links also have an associated attention value, indicating how much computational effort should be expended of them. These contain two values, specifying short-and long-term importance levels. Truth and attention values are updated continuously by cognitive processes and maintenance algorithms.

Novamente node types include tokens that derive their meaning via interrelationships with other nodes representing perceptual inputs into the system (e.g., pixels, points in time, etc.), nodes representing moments and intervals of time, and procedures. Links represent relationships between atoms (nodes or links), such as fuzzy set membership, probabilistic logical relationships, implication, hypotheticality, and context. Executable procedures carrying out actions are represented as special Procedure objects that wrap up small networks containing special kinds of nodes and links.

Novamente involves two primary learning algorithms that operate on this shared hypergraph knowledge base: probabilistic logic networks (PLN: Goertzel, Iklé, & Goertzel, n.d.),[1] and a variant of the Bayesian Optimization algorithm (BOA: Looks, Goertzel, & Pennachin, 2005; Pelikan, 2002).

PLN is a flexible inference framework that is applicable to many different situations, including inference involving uncertain, dynamic data and/or data of mixed type, and inference involving autonomous agents in complex environments. It was designed specifically for use in Novamente yet also has applicability beyond the Novamente framework. It acts on Novamente links representing declarative knowledge (e.g., inheritance links representing probabilistic inheritance relationships), building new links from old using rules derived from probability theory and related heuristics. PLN is context-aware, able to reason across different domains, and able to deal with multivariate truth values. It is capable of toggling between more rigorous and more speculative inference and also of making inference consistent within a given context even when a system's overall knowledge base is not entirely consistent.

BOA was developed by Martin Pelikan as an improvement over ordinary bit-string genetic algorithms. It significantly outperforms the traditional GA by maintaining a centralized probabilistic modeling of the population of candidate solutions. This model, generated with greedy heuristics, incorporates dependencies between different positions in the bit-string genome, thus discovering and propagating useful solution building blocks. We have extended the BOA to deal with variable-length genomes, including integers and floating point variables, which results in a powerful procedure learning algorithm (BOA Programming or BOAP), which adaptively learns procedure objects, satisfying specified goals.

Cognitive processes such as large-scale inference, perception, action, goal-directed behavior, attention allocation, pattern and concept discovery, and even some aspects of system maintenance are implemented as specific combinations of these two-key algorithms that are highly flexible and generic in their applicability. An example of such interconnection will be discussed in detail a few sections later in the context of sensorimotor learning in AGI-SIM. We will report experiments in which BOA was used to learn symbol groundings and then will discuss the strategy by which PLN may be used to extend and generalize these groundings in various ways.

Experiential Interactive Learning

We now make some brief comments regarding those aspects of the philosophy of mind underlying Novamente that have led us to become concerned with such matters as symbol grounding, embodiment, and simulation worlds.

Human intelligence does not emerge solely through human neural wetware. A human infant is not so intelligent, and an infant raised without proper socialization never will achieve full human intelligence (Douthwaite, 1997). Human brains learn to think through being taught, and through diverse social interactions. Our view is that the situation will be found to be similar with AGI's, as AGI technology develops.

According to this philosophy, the basic algorithms in an AGI system, even if correct, complete, appropriate, and computational tractable, can supply only the raw materials of thought. What is missing in any AI system "out of the box" are context-specific control mechanisms for the diverse cognitive mechanisms required for practical intelligence. If designed correctly, however, an AI system should have the capability to learn how to learn these through environmental and social interaction.

A complete AGI system out of the box may be more or less competent than narrow AI systems, depending on factors such as prior knowledge and the scope of the test domain. In any case, it will not be nearly as robustly intelligent as an AGI system that has refined its ability to learn context-specific control mechanisms through meaningful interactions with other minds. Once it's been interacting in the world for a while, an AGI will gain a sense of how to reason about various topics—conversations, love, network intrusion, biowarfare, its own source-code—by learning context-dependent inference control schemata for each case according to a procedure learning process tuned through experiential interaction.

This line of thinking leads us to concepts such as *autonomy*, *experiential interactive learning (EIL)*, and *goal-oriented self-modification*, which lie at the heart of the notion of artificial general intelligence.

The Novamente AI system is highly flexible in construction, and it may be supplied with specific, purpose-oriented control processes, which, in this way, can be used as a data mining and/or query-processing engine. This is the approach taken, for example, in the current applications of the Novamente engine in the bioinformatics domain.[2] But this kind of deployment of Novamente does not permit it to develop its maximum level of general intelligence.

In order for truly significant AGI to emerge, a properly designed system must be supplied with general goals and then allowed to learn its own control processes. This may be accomplished via procedural learning dynamics in interaction with a richly structured environment, along with extensive meaningful interactions with other minds. This is the long-term plan we hope to follow with the Novamente system.

And this leads us to the need for embodiment. While verbal conversations about useful information will be an important source of EIL for Novamente, we suspect that additional intuition on basic world concepts like objects, motions, self, and others will be valuable of the sort that can only be achieved through direct embodied experience. This loosely follows Wierzbicka's (1972, 1996) notion of semantic universals. To carry out this kind of instruction for Novamente, we have created a special simulated environment: the AGI-SIM simulation world.

Thus, we are led to the conclusion that symbol grounding is critical for AI. Mind itself, we suggest, emerges largely via the interaction between abstract symbolic intelligence and low-level sensorimotor pattern recognition. Symbol grounding is the link between these two levels and is achievable in practice via linking one's AI system with a suitably rich and flexible embodiment.

The AGI-SIM Simulation Environment

Our practical experiments with symbol grounding have been constructed via interfacing Novamente with a particular 3D-simulated environment called AGI-SIM. The AGI-SIM simulated world has been built based on open-source tools (mainly the 3D simulation environment CrystalSpace[3]) and may be configured to display realistic physics. It allows AI systems and humans to control mobile agents that have multiple moving body parts and experience the simulated world via multiple senses, as well as having the capability to communicate with each other directly through text. AGI-SIM is being developed by the Novamente team as an open-source project[4] with the intention of being useful for other AGI projects as well as Novamente.

Without going into details on AGI-SIM's implementation here, it is worth mentioning some of the basic principles that went into its design.

- The experience of an AGI controlling an agent in a simulated world should display the main qualitative properties of a human controlling his or her body in the physical world. For specific consideration are those qualitative properties that help the AGI to relate experiences in the simulated world to the many obvious and subtle real-world metaphors embedded in human language.
- The simulated world should support the integration of perception, action, and cognition in a unified learning loop, which is crucial to the development of intelligence.
- The simulated world should support the integration of information from a number of different senses, all reporting different aspects of a common world, which is valuable for the development of intelligence.

With these goals in mind, we have created AGI-SIM as a basic 3D simulation of the interior of a building, with simulations of sight, sound, smell, and taste. An agent in AGI-SIM has a certain amount of energy and can move around and pick up objects and build things. The initial version doesn't attempt to simulate realistic physics, but this may be integrated into a later version using open-source physics simulation software. While not an exact simulation of any physical robot, the agent Novamente controls in AGI-SIM is designed to bear enough resemblance to a simple physical robot that the porting of control routines to a physical robot should be feasible.

Results of Simple Grounding Experiments

The research program described here is still near its beginning. However, we already have carried out some simple experiments using the current (fairly limited) version of AGI-SIM and a single cognitive mechanism within Novamente, BOAP procedure learning, in its current form (Looks et al., 2005). This section reports on a couple of examples hinting toward more advanced learning tasks; grounding the concepts of *nearness*, and two forms of a simplified *fetch* task (bring the ball to the user) that make use of the grounded nearness concept.

As previously mentioned, BOAP learns Novamente procedures. Briefly, procedures come in two flavors: predicates, which output truth values; and schema, which output atoms. Procedures may take atoms as arguments. So, for example, *nearness* is most simply represented as a predicate, whereas *fetch* is a schema. Note that in a complete Novamente implementation with rich groundings (in the physical world or a sufficiently complex virtual environment such as AGI-SIM), concepts such as *nearness* and *fetch* will not correspond simply to any single predicate or schema but rather to *maps*: sets of atoms that tend to be activated together or tend to be activated according to a certain pattern, such as an oscillation or a strange attractor. This allows procedural and declarative knowledge to be represented in a non-brittle, distributed manner, while maintaining the crispness of atom-level representations when appropriate. See Looks et al. (2004) for details.

Procedures as learned by BOAP are nested expressions (i.e., parse trees). They may contain variables, arithmetic operators, combinators (abstract rewrite rules), references to Novamente atoms, and higher-level programming constructs such as loops and recursion.

For grounding nearness, a simple supervised categorization framework was used in which a number of randomly generated examples (100) were presented in which nearness needed to be predicted. The configuration of BOAP generally follows the parameters utilized for genetic programming (see Looks et al., 2005, for details). The relevant parameters for the predicate are the relative (x,y) position of the object. Operators supplied are basic arithmetic operators (+, -, *, /), exponentiation (pow), and less-than (<).

Two sets of experiments were carried out: the first to learn the Boolean (crisp) predicate "closer than x," and the second to learn a fuzzy nearness predicate varying linearly with distance. A population size of 4,000 was chosen, and BOAP was run for 100 generations (i.e., 4,000 test predicates we generated and evaluated; the worst 2,000 were replaced with 2,000 new predicates, etc. 100 times). For each set, 10 independent runs were carried out. In the first case, BOAP twice managed to learn perfect classification into near and far categories; the average error rate was 2.4%, and the worst error rate was 7%. However, neither of the "perfect" results was the a perfectly correct predicate; the best that BOAP was able to achieve was $x^2 + f(x,y) > c$, where f(x,y) is a conditional predicate that returns one for higher values of x and y, and zero for lower values (a perfectly correct predicate might be $x^2 + y^2 > c$, for instance.

In the second set of experiments, BOAP had an average error of 0.02 (point coordinates were scaled to [0,1]). The maximal average error was 0.04. Here, BOAP was able to learn the exact symbolic formula for distance, $sqrt(x^2 + y^2)$, in one of the runs. Note that this second task (learning a fuzzy predicate rather than a crisp one) is more constrained and, hence, easier to learn the exact form. More generally, the more relevant environmental feedback obtained by a learner, the more effective learning can be, since the possible good fits to the data are more limited.

For learning to fetch, we first tested BOAP with absolute positioning; the robot's position and those of the other items in the simulation (the ball and the teacher) were passed as parameters to the schema. Furthermore, BOAP was given a powerful "move to position x,y" primitive. Under these circumstances, learning to fetch was quite easy; BOAP always was able to learn some variant on the sequence then(moveto(ballX, ballY), then(pickup, then(moveto(teacherX, teacherY), give))) meaning "move to the ball's location, then execute the pickup command, then move to the teacher's location, then execute the give command." This program easily can be learned in stages because partial reward is supplied. That is, candidate solutions are given partial credit for moving near the ball, picking up the ball, and/or moving the ball near the teacher, even if the entire task is not completed successfully. Note the role of the concept of nearness here. And even more critically, note that in order to solve sequential problems such as these without partial reward or to solve problems with hierarchical structure, a Novamente will need to inferentially incorporate prior knowledge to decompose a problem into coherent subgoals (e.g., in order to give the ball to the teacher, I first need to pick up the ball). Subgoals then can be solved independently by BOAP.

A second, more demanding set of experiments involves learning to fetch problems with no absolute positioning and more realistic robot control commands:

- Instead of being able to move to an arbitrary position with a single command, the robot must execute a sequence of turns and steps.
- Instead of being told where items are located, the robot can recognize only whether or not an item is along its line of sight at any given time.
- The schema is reactive and executed in a loop, necessitating the use of conditionals (if-then-else) and sensory predicates (Am I facing the ball? Am I facing the teacher? Am I holding the ball?)

A correct program for this task would be:

```
ifelse holding
   (ifelse facingteacher
      step
      rotate)
   (ifelse nearball
      pickup
      (ifelse facingball
         step
         rotate))
```

This means:

- If holding the ball and facing the teacher, move forward (to give the ball to the teacher)
- Otherwise, if holding the ball, rotate (in order to face the teacher)
- Otherwise, if near the ball, pick it up
- Otherwise, if facing the ball, move forward (to get the ball)
- Otherwise, rotate (in order to face the ball)

The schema is executed in a loop until either the robot is near the teacher and holding the ball or a fixed number of iterations (200) have been carried out without success. Again, partial reward is provided for successfully picking up the ball and so forth, even if the entire problem is not solved.

When a population size of 4,000 was found to be inadequate, it was increased to 20,000. BOAP then was able to learn a number of qualitatively different programs, correctly executing the task.

Finally, we emphasize that these early results are not meant to be conclusive but merely to demonstrate the validity of our choice of BOAP as a starting point for more advanced and integrative probabilistic/evolutionary learning. They have been carried out with a minimum of tweaking, and better results could almost certainly be obtained with a bit of care. However, this would defeat the purpose of the experiments; competent results without hand tuning are preferable to superior results with parameters that must be set carefully to precise values (by humans).

Integration of Learned Symbol Grounding with Computational Language Understanding and Inference

We have discussed some experiments carried out in the Novamente/AGI-SIM framework. Now we briefly describe some work that we plan to carry out in the near future, extending the experiments already mentioned. This work involves the integration of these machine learning ideas with some simple computational linguistics and also involves using another component of Novamente, the PLN inference engine, to associate the groundings and procedures learned by the BOAP component with linguistic utterances.

In the previous examples, we had the system learn to understand nearness and fetch via reinforcement learning (i.e., via having it iteratively try to estimate nearness and to play fetch and correcting it based on the amount of error in its performance). The reinforcement was given by software code rather than by natural language. However, it is a simple extension to give the reinforcement via linguistic feedback instead.

For instance, in the case of nearness, one simply can show the system a collection of pairs of objects and describe each pair as near or not with a probability proportional to its nearness. Or, when the system says "near," one can reward it with a probability or degree proportional to the actual nearness. It is clear that BOAP will be able to operate based on this feedback in the same way as on the code-level reinforcement feedback considered previously. Thus, via integrating BOAP with a simple language processing component (which already exists in the Novamente framework but has not been utilized yet in this sort of application), one may obtain experiential grounding of the verbalized concept *near*.

Similarly, if one repeatedly commands the system to play fetch and then rewards it with a probability or degree proportional to its success in each instance, it can learn to ground the descriptor *fetch* in a set of procedures that utilize its learned grounding for *near*.

This kind of grounding is extremely simple; we suggest, however, that the same approach will work more generally but that dealing with more complex concepts will require inference as well as BOAP-style reinforcement learning.

For instance, suppose we want to teach nearness via giving information about various pairs of objects such as *very near*, *slightly near*, *moderately near*, and so forth. Based on these descriptors and groundings for the modifiers *very*, *slightly*, and *moderately*, the system should be able to learn a grounding for nearness.

Inference may play a role here in obtaining the groundings of these adverbial modifiers. Consider a system with a learned grounding for *big*, for example, and knowledge of the magnitude of bigness an observation has (in a particular context). It can be taught specific groundings of adverbial modifiers in this context by learning that *very big* corresponds to observations for which it has learned grounding for *big* gives a large output. Novamente then can transfer knowledge of the adverbial modifiers from bigness to nearness via analogical inference. This kind of analogy is one thing PLN inference component has been shown to do effectively in other contexts.

So we see that by putting together reinforcement learning a la the above BOAP/AGI-SIM experiments with simple language processing and inference, one potentially may obtain a robust capability for symbol grounding. This is something we hope to demonstrate in our research during 2006, and the preliminary BOAP-based results we describe here represent one step along the path.

Conclusion

In the Introduction, we presented a threefold division of mind into symbolic, sensorimotor, and symbol-grounding activity. We have focused here primarily on the symbol-grounding aspect and have carried out our discussion primarily in the context of a particular software project: the integration of the Novamente AI system with the AGI-SIM simulation world.

The symbolic portion of mind is characterized by abstract logic, which is represented in Novamente by the PLN probabilistic logic component. The sensorimotor portion of mind is more diverse and specialized, and the AGI-SIM environment allows it to be reduced to a series of commands going back and forth between Novamente and AGI-SIM software processes, mediated in Novamente by a collection of hard-wired and learned schema.

In simple cases, our experiments have shown that probabilistic-evolutionary learning (in the form of BOAP) is sufficient to allow the system to learn groundings of linguistic concepts and to carry out tasks integrating these grounded concepts with sensory and motor activity. In more complex cases, we believe, a deeper integration of evolutionary learning and probabilistic logic will be necessary to get the job done. But the key point, which we intend to pursue in our future research, is that the groundings learned by BOAP or other methods that easily can be associated with linguistic utterances and generalized via inference techniques like PLN. Evolutionary procedure learning then may be used as a foundation for robust and general symbol grounding in computational systems.

The understanding of symbol grounding, in general, is a large task. In this chapter, we have made incremental progress toward this understanding while outlining a program of theoretical and experimental research, which may be adequate for penetrating far more deeply into the issue. By connecting an AI system capable of symbolic reasoning, language understanding, goal-oriented learning, and sensorimotor pattern recognition to a simulated world, one can view symbol-grounding in a simplified, abstracted, and fully transparent setting, thus allowing a reasonably clear view of structures and dynamics, whose analogues in humans are difficult for us to perceive.

Compared to prior work on symbol grounding, our current line of research aims at a deeper pragmatic understanding of the roots of symbol grounding in learning and cognition. Most of the work on symbol grounding in the cognitive robotics domain centers on simple correlations between words and observed objects. But what is really interesting, in our view, is the grounding of relationships (especially abstract ones) and the usage of these groundings within the process of learning more complex groundings. The learning experiments reported here, while simple, illustrate both of these points: the learning of a relationship (nearness) and the use of a grounding (the grounding of nearness) within the learning of another grounding (the grounding of the game "fetch"). Further work within the Novamente architecture and AGI-SIM world, as described previously, will flesh out and expand these ideas in the context of more complex groundings and correlations between relational grounding and natural language. We feel that this is the right direction to go: understanding symbol grounding not so much as a phenomenon unto itself but more as a particular aspect of integrated, self-organizing cognition.

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Endnotes

1 PLN was previously called Probabilistic Term Logic (PTL)

2 www.biomind.com

3 crystal.sourceforge.net

4 sourceforge.net/projects/agisim

5 www.frontiernumber4.com.

6 http://www.goertzel.org/new_research/NM_human_psych.pdf

7 http://www.realai.net/AAAI04.pdf

Chapter V

Symbols: Integrated Cognition and Language

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Abstract

What is the nature of symbols? This word is used for traffic signs, mathematical notations, and motivationally loaded cultural objects that may inspire war and peace. This chapter explains relationships among symbols, cognition, and language. Symbols are explained as processes in the mind involving cognition and language. Relationships between cognition and language were a mystery until recently. Linguists often considered language as relationships among words and other linguistic entities, separately from its relationships to the world. Mechanisms of language in the mind and brain were considered separate and different from thinking and cognition. Neural mechanisms integrating language and cognition are unknown. Yet, language and cognition are intertwined in evolution, ontogenesis, learning, and everyday usage; therefore, a unified understanding of working of the mind is essential. A mathematical description of such unifying mechanisms is the subject of this chapter. We discuss relationships among computational intelligence, known mechanisms of the mind, semiotics, and computational linguistics, and describe a process integrating language and cognition. Mathematical mechanisms of concepts, emotions, and instincts are described as a part of information processing in the mind and related to perception and cognition processes in which an event is understood as a concept. Development of such mathematical theories in *the past often encountered difficulties of a fundamental nature manifested as combinatorial complexity. Here, combinatorial complexity is related to logic underlying algorithms, and a new type of logic is introduced—dynamic fuzzy logic—which overcomes past limitations. This new type of logic is related to emotional signals in the brain and combines mechanisms of emotions and concepts. The mathematical mechanism of dynamic logic is applicable to both language and cognition, unifying these two abilities and playing an important role in language acquisition as well as cognitive ontogenesis. The mathematical description of thought processes is related to semiotic notions of signs and symbols.*

Symbols in Computational Intelligence and Linguistics

Symbol is the most misused word in our culture (Deacon, 1998). We use this word in trivial cases referring to traffic signs and in the most profound cases of cultural and religious symbols. Charles Peirce considered symbols to be a particular type of signs (CP 8.335). He concentrated on the process of sign interpretation, which he conceived as a triadic relationship of sign, object, and interpretant. Interpretant is similar to what we call today a representation of the object in the mind. However, this emphasis on interpretation was lost in the following generation of scientists.

In the development of scientific understanding of symbols and semiotics, the two functions—understanding language and understanding world—often have been perceived as identical. This tendency was strengthened by considering logic to be the mechanism of both language and cognition. According to Bertrand Russell (1919, p. 175), language is equivalent to axiomatic logic, a word-name "merely to indicate what we are speaking about; [it] is no part of the fact asserted … it is merely part of the symbolism by which we express our thought." David Hilbert (1928, p. 475) was sure that his logical theory also describes mechanisms of the mind: "The fundamental idea of my proof theory is none other than to describe the activity of our understanding, to make a protocol of the rules according to which our thinking actually proceeds."

Logical positivism centered on "the elimination of metaphysics through the logical analysis of language," according to Rudolf Carnap (1928) logic, was sufficient for the analysis of language. This belief in logic has deep psychological roots related to the functioning of the human mind. A major part of any perception and cognition process is not accessible to consciousness directly. We are conscious about the final states of these processes, which are perceived by our minds as concepts approximately obeying formal logic.

Similar understanding of relationships among symbol, language, logic, and mind can be traced in semiotics of Ferdinand De Saussure (1916) and in structuralism. A simplistic idea that words are labels for objects falls apart as soon as we consider words for abstract ideas, say, *rational*. Saussure (1916, p. 98) tried to resolve this problem by saying that "the linguistic sign does not unite a thing and a name, but a concept and a sound image." Here, the real world is taking a back seat; both aspects of the sign exist in the mind. Structuralism was derived later from Saussurean linguistics. It emphasized "concept" as a part of language and pushed semiotics further from the real world, further from the mind, toward relationships among words. This movement away from the world toward words in semiotics was inspired by a similar movement in logic toward axiomatic meanings. Formal logicians emphasized that the foundation of our knowledge is limited to abstract mathematical objects and axioms that they obey. Relationships between mathematical objects and the world are arbitrary. Similarly, Saussure emphasized the arbitrariness of the sign; relationships between words and objects in the world are arbitrary conventions.

This idea later evolved into arbitrariness of communication codes in general. Since communication codes contain cultural values, some concluded that cultural values are arbitrary. "There may be an objective, empiricist reality out there, but there is no universal, objective way of perceiving and making sense of it. What passes for reality in any culture is the product of the culture's codes, so 'reality' is always already encoded, it is never 'raw'" (Fiske, 1987, pp. 4-5). This circle of ideas served as a platform for Jacques Derrida's (1978) attacks on structuralism. Since any statement is based on some cultural structures and values, it can be dismissed as having no objective validity, as arbitrary or as local. This became the essence of deconstruction and postmodernism. This reasoning can be applied to deconstruction itself, so the deconstruction is as if self-annihilated. The self-annihilation is not new to logicians; it is just a particular case of Gödelian (1929-1936) proof that logic is not logical. Derrida (1976) understood deconstruction as a question. In this chapter, we attempt to give an answer to this question—How is it possible to have anything of truth and value?—how our mind constructs symbols, which have psychological values and are not reducible to arbitrary signs.

An idea that language and cognition were not one and the same and that logic was not a fundamental mechanism of the mind slowly downed in the contemporary science after Kurt Gödel (1929-1936) proved inconsistency of logic. Logic turned out to be not the queen of mathematics, as was previously believed. Yet, early computational theories of the mind developed since the 1950s heavily relied on logic. In 1957, Noam Chomsky proposed that language ability was based on inborn mechanisms of language faculty, which was a system of logical rules. Similarly, logical rules were the basis for the Artificial Intelligence developed from the 1960s through the 1980s (see Minsky, 1968). During that time, much evidence was accumulated, indicating that computer systems based on logic were not successful in simulating human abilities for language or cognition. New mathematical methods not based on logic were emerging, which included Stephen Grossberg's (1982) neural networks, Chomsky's (1981) principles and parameters, methods based on fuzzy logic (Zadeh, 1965), and the author's modeling field theory and dynamic logic (Perlovsky, 1987, 2001).

Linguists, following Chomsky, emphasized that cognition and language abilities are different: they are located in different brain areas and might have emerged along separate paths in evolution (Pinker, 2000). Most importantly, cognition is about objects and situations in the surrounding world, whereas mechanisms of acquiring and using language identified in cognitive linguistics are about language, not about the world. This direction, emphasizing innateness of language abilities, was called *nativist linguistics*. Its interests concentrated on the internal mind mechanisms enabling learning of language. Chomsky emphasized the importance of syntax; he considered its mechanisms to be relatively isolated from the rest of the mind and brain. Relations of language to the outside world, to perception, cognition, and meaning were considered peripheral to the study of language.

An opposite direction—cognitive linguistics—appeared in the 1970s. Several linguists, including George Lakoff (1987), Ronald Langacker (1987), and Leonard Talmy (1988), emphasized cognitive principles and organization of the mind and considered meaning as central to language. This appreciation that language cannot be understood separately from thinking about the world was shared by researchers in computational semiotics (Perlovsky, 2002, 2004; Rieger, 2002) and in evolutionary linguistics (Brighton et al., 2005; Christiansen & Kirby, 2003; Hurford, Studdert-Kennedy, & Knight, 1998).

Today, little is known about neural mechanisms combining language with thinking or their locations in the brain (Deacon, 1998; Lieberman, 2000). In the following sections, we briefly review research in cognition and linguistics. We analyze fundamental mathematical difficulties faced by researchers in these fields. Then, we describe new approaches overcoming these difficulties and discuss a mathematical theory of symbols integrating cognition and language.

Combinatorial Complexity of the Mind Theories

Understanding signals coming from sensory organs involves associating subsets of signals corresponding to particular objects with internal representations of these objects. This leads to recognition of the objects and activates internal brain signals leading to mental and behavioral responses, which constitute the understanding of the meaning (of the objects).

Mathematical descriptions of this association-recognition-understanding process have not been easy to develop; a number of difficulties have been encountered during the past 50 years. These difficulties have been summarized under the notion of combinatorial complexity (CC) (Perlovsky, 1998a). The problem was first identified in pattern recognition and classification problems in the 1960s and was named "the curse of dimensionality" (Bellman, 1961). At first, it seemed that self-learning statistical pattern recognition algorithms could learn to solve any problem, only if sufficient amount of training data were provided. However, after decades of research, it became clear that adaptive statistical pattern recognition and neural network algorithms designed for self learning often encountered CC of learning requirements: the required examples had to account for all possible variations of an object in all possible geometric positions and in combinations with other objects, sources of light, and so forth, leading to astronomical (and worse) numbers of required examples (Perlovsky, 2001).

By the end of the 1960s, a different paradigm became popular: logic-rule systems were proposed to solve the problem of learning complexity. An initial idea was that rules would capture the required knowledge and eliminate a need for learning. The first Chomsky (1972) ideas concerning mechanisms of language grammar that were related to deep structure also were based on a similar idea of logical rules. Rule systems work well when all aspects of the problem can be predetermined. However, rule systems and expert systems in the presence of unexpected variability encountered CC of rules: more and more detailed subrules and sub-subrules, one contingent on another, had to be specified.

In the 1980s, model-based systems became popular, which were proposed to combine advantages of adaptivity and rules by utilizing adaptive models (Bonnisone, Henrion, Kanal, & Lemmer, 1991; Nevatia & Binford, 1977; Perlovsky, 1987, 1988, 1991). Existing knowledge was to be encapsulated in models, and unknown aspects of concrete situations were to be described by adaptive parameters. Along similar lines were principles and parameters ideas of Chomsky (1981). Model-based systems encountered computational CC (N and NP complete algorithms). The reason was that considered algorithms had to evaluate multiple combinations of elements of data and rules (models, principles). CC is prohibitive because the number of combinations is very large; for example, consider 100 elements (not too large a number), which combinations had to be evaluated. The number of combinations of 100 elements is 100^{100}; this number is larger than all interactions among all elementary particles in life of the Universe. No computer (or mind) would ever be able to compute that many combinations. The CC became a ubiquitous feature of intelligent algorithms and, seemingly, a fundamental mathematical limitation.

Forms of the Mind, Logic, and CC

Logic serves as a foundation for many approaches to cognition, linguistics, and computational semiotics. Logic underlies most of computational algorithms. But its influence extends far beyond, affecting psychologists and linguists who do not use complex mathematical algorithms for modeling the mind. All of us operate under a more than 2,000-year-old influence of logic under a more or less conscious assumption that in the basis of the mind, there are mechanisms of logic. As discussed next, our minds are unconscious about its illogical foundations; we are mostly conscious about a small part about the mind's mechanisms, which are approximately logical. Our intuitions, therefore, are unconsciously affected by bias toward logic. When laboratory data drive our thinking away from logical mechanisms, it is difficult to overcome the logical bias.

However, relationships between logic and language have been a source of longstanding controversy. Aristotle assumed a close relationship between logic and language. He emphasized that logical statements should not be formulated too strictly and that language inherently contains the necessary degree of precision. Aristotle described the mechanism of the mind relating language, cognition, and the world as *forms*. Today, we call similar mechanisms internal representations or concepts in the mind. Aristotelian forms are similar to Plato's ideas with a marked distinction: forms are *dynamic*—their initial states, before learning, are different from their final states of concepts (IV BCE). Aristotle emphasized that initial states of forms (forms-as-potentialities) are not logical, but their final forms (forms-as-actualities) attained in the result of learning are logical. This important distinction was lost during millennia of philosophical arguments.

The founders of formal logic emphasized a contradiction between logic with its law of excluded third and language with its uncertainty. In the 19^{th} century, George Boole and great logicians following him, including Gottlob Frege, Georg Cantor, David Hilbert, and Bertrand Russell, eliminated uncertainty of language from mathematics and founded formal mathematical logic based on the "law of excluded third." Hilbert developed an approach named "formalism," which rejected intuition as a matter of scientific investigation and formally defined scientific objects in terms of axioms or rules. In 1900, he formulated the famous Entscheidungsproblem to define a set of logical rules sufficient to prove all past and future mathematical theorems. This entailed formalization of the entire human thinking, including language. Formal logic ignored the dynamic nature of Aristotelian forms and rejected uncertainty of language. However, Hilbert's vision of formalism explaining mysteries of the human mind came to an end in the 1930s, when Gödel proved internal inconsistency of formal logic. This is a reason why theories of cognition, language, and computational semiotics based on formal logic are inherently flawed.

It turned out that combinatorial complexity of algorithms based on logic is a finite-system manifestation of Gödel's theory (Perlovsky, 1996a). According to the law of excluded third, every statement is either true or false and nothing in between. Therefore, algorithms based on formal logic have to evaluate every little variation in sensory signals or the mind's representations as a separate logical statement. A large number of combinations of these variations causes combinatorial complexity. The CC of learning requirements of pattern recognition algorithms and neural networks is related to logic; every training sample is treated as a logical statement, which results in CC. Multivalued logic and fuzzy logic were proposed to overcome limitations related to the law of excluded third (Kecman, 2001; Zadeh, 1965). Yet, the mathematics of multivalued logic is no different in principle from formal logic. Fuzzy logic encountered a difficulty related to the degree of fuzziness: if too much fuzziness is specified, then the solution does not achieve a needed accuracy; if too little, it becomes similar to formal logic. If logic is used to find the appropriate fuzziness by sorting through various degrees of fuzziness for every model at every processing step, then it results in CC. Dynamic logic discussed later overcomes CC by automatically choosing the appropriate degree of fuzziness for every model at every step. This dynamics can serve as a mathematical representation of the learning process of Aristotelian forms.

Nativist Linguistics vs. Cognitive Linguistics

During the first half of the 20th century, there was little appreciation in linguistics and psychology for complicated innate mechanisms of the mind. There was no mathematics adequate for findings of Sigmund Freud and Carl Jung. Logic dominated thinking of mathematicians and intuitions of psychologists and linguists. Within logic, there is not much difference between language and cognition (both are based on logical statements), and there is no difference between signs and symbols. Motivational aspects of symbols were not addressed, and a mixup of symbols and signs continued. In the second half of the 20th century, a variety of mathematical approaches were tried in order to explain perception and cognition. As computers and robotics gained importance in engineering, huge efforts were expended toward making computers smarter. Knowledge about the human mind was used to enhance computer intelligence. As discussed, every mathematical method faced combinatorial complexity and failed. Mathematical methods did not explain how the mind creates meaning. Mathematical approaches in linguistics paralleled those in perception and cognition

In the 1950s, Chomsky moved linguistics toward studies of innate mind mechanisms. Nativists used available mathematics of logical rules similar to artificial intelligence. In 1981, Chomsky proposed a new mathematical paradigm in linguistics, rules, and parameters. This was similar to model-based systems emerging in mathematical studies of cognition. It was influenced heavily by logical bias and, as discussed, faced CC. In 1995, Chomsky's minimalist program called for simplifying rule structure of the mind mechanism of language. It moved language closer to other mind mechanisms and closer to the meaning but stopped at an interface between language and meaning. Chomsky's linguistics still assumed that meanings appear independently from language, and a mixup of signs and symbols continued; motivational forces of symbols were ignored.

Cognitive linguistics emerging in the 1970s intended to address some of these limitations of the nativist approach. Cognitive linguists wanted to unify language with cognition and explain creation of meanings. They were looking for simpler innate structures than those postulated by nativists. These simpler structures would be sufficient, scientists thought, because they would combine language and meaning and combine innate structures with learning from experience (to a much larger extent than nativists postulated). Cognitive linguists gradually moved away from the heavy influence of logical bias of the previous structuralist thinking, which could be characterized by "the meaning of a word can be exhaustively decomposed into finite set of conditions … necessary and sufficient" Jackendoff (1983, p. 113).

Lakoff and Johnson (1980) emphasized that abstract concepts used by the mind for understanding the world have metaphorical structure. Metaphors were not just poetic tools but rather an important mechanism of the mind for creating new abstract meanings. Lakoff's analysis brought this cultural knowledge, advanced by Fyodor Dostoevsky and Friedrich Nietzsche, within the mainstream of science. There was still a big gap between Lakoff's analysis of metaphors on the one hand and neural and mathematical mechanisms on the other. The "metaphors we live by" is a metaphorical book (pun intended) in that it begs these questions: Who is that homunculus in the mind, interpreting the metaphorical theater of the mind? What are the mechanisms of metaphorical thinking?

In the works of Jackendoff (1983), Langacker (1988), Talmy (1988), and other cognitive linguists,[1] it was recognized that old divisions dominating linguistics were insufficient. Dichotomies of meanings (semantic-pragmatic) and dichotomies of hierarchical structures (superordinate-subordinate) were limiting scientific discourse and have to be overcome. Consider the following opinions on meaning creation:

In a hierarchical structure of meaning determination the superordinate concept is a necessary condition for the subordinate one. ... COLOR is a necessary condition for determining the meaning of RED. (Jackendoff, 1983, p. 113)

The base of predication is nothing more than ... domains which the prediction actually invokes and requires. (Langacker, 1988)

These examples illustrate attempts to overcome old dichotomies and, at the same time, difficulties encountered along this path. Both examples are influenced by logical bias. Attempts to implement mathematical mechanisms assumed by these examples would lead to combinatorial complexity. To put it jovially, problems of meaning and hierarchy still reminded the old question about the chicken and the egg: what came first? If superordinate concepts come before subordinate ones, where do they come from? Are we born with the concept COLOR in our minds? If predictions invoke domains, where do domains come from? These complex questions with millennial pedigrees are answered mathematically in the following sections. Here, I give a brief psychological preview of the answer, informed by contemporary development in dynamic logic, neurobiology, and language evolution. Hierarchy and meaning emerge jointly with cognition and language. In processes of evolution and individual learning, superordinate concepts (COLOR) are vaguer, less specific, and less conscious than subordinate ones (RED). RED can be vividly perceived, but COLOR cannot be perceived. RED can be perceived by animals. But the concept COLOR can only emerge in the human mind due to joint operation of language and cognition.

Jackendoff (2002), in his recent research, concentrated on unifying language and cognition. He developed detailed models for such unification; however, his logical structures face combinatorial complexity. Lakoff and Johnson (1999) brought within the realm of linguistics an emphasis on embodiment of the mind. The implication that the philosophical tradition will have to be reassessed, however, seems exaggerated. Recent synthesis of computational, cognitive, neural, and philosophical theories of the mind demonstrated the opposite (Perlovsky, 2001). Plato, Aristotle, and Kant, even in specific details about the mind mechanisms, were closer to contemporary computational theories than the 20th-century philosophers and mathematicians developing logical formalism and positivism.

Talmy (2000) introduced a notion of open and closed classes of linguistic forms. Open class includes most words, that could be added to language as needed, say, by borrowing from other languages. Closed class includes most grammatical structures, which are fixed for generations and cannot be easily borrowed from other languages. This pointed to an important aspect of interaction between language and cognition. Forms of the closed class interact with cognitive concepts, which emerged over thousands of years of cultural and language evolution. Thus, for each individual mind and for entire generations, which operate within constraints of existing grammar, many cognitive concepts are predetermined. Talmy identified cognitive concepts affected by closed forms. These forms are more basic for cognition than words and unconsciously influence entire cultures, as suggested by Nietzsche (1876). Current research into mechanisms of language-cognition interaction revealed a profound impact of these forms beyond merely conceptual and identified their impact on emotional contents of languages and cultures (Perlovsky, 2006b).

A controversy between nativists and cognitivists does not imply that linguists doubt the importance of innate mechanisms or the importance of learning and using language. Humans are the only species endowed with language; therefore, some mechanisms have to be inborn. Equally, there is ample evidence that a child will not learn language if not exposed to it (and the exposure must come during a specific critical period, possibly between 2 and 7 years old). The controversy is about what exactly is innate and what kind of exposure is sufficient for learning. In *Rethinking Innateness: A Connectionist Perspective on Development*, Jeffrey Elman et al. (1996) demonstrated that many aspects of language acquisition can be explained within the framework of connectionist neural network. They demonstrated that detailed syntactic rules postulated by nativists are not necessary and that learning of complex syntactic patterns still can occur without previous exposure to exactly the same patterns.

Elman (1993) continued this discussion of connectionist use-based language acquisition vs. nativist rule-based acquisition. The main argument again is that the innate mechanisms can be given by connectionist architectures much simpler than logical rules. But what is "simpler"? Elman emphasizes the other side of the story. The connectionist neural network is not an off-the-shelf multilayer perceptron but rather an SNR neural network carefully designed for language acquisition (Elman, 1990). Moreover, SNR performs not a general language acquisition but rather a specific type of learning for which it was designed. Elman (1993, p. 1) emphasized a hard learned lesson that we discussed previously: "there is no … general purpose learning algorithm that works equally well across domains."

Does it mean that our mind uses a huge number of diverse algorithms for language and cognition à la Minsky (1988)? Or there are fundamental first principles of the mind organization (see discussion in Perlovsky, 2004). I'd note that there are no more than 300 genes determining differences between the human mind and the ape mind. The mechanisms for language and cognition cannot be too specific; our abilities are adaptive, and any child can learn any of the thousands of languages spoken on Earth. We, therefore, have reasons to believe in first principles of the mind. SNR neural network cannot be an example for such a general principle; according to analysis in previous sections, SNR will face combinatorial complexity when exposed to complex learning. It will not scale up to the real human brain. Elman (2005) is among the first to admit this. Still, SNR can be used to elucidate the general principles. Among such principles is abstract notion evolution from vague and fuzzy toward specific and concrete (Elman, 1993; Olguin & Tomasello, 1993; Tomasello & Olguin, 1993). In the following sections, we describe how dynamic logic systematically utilizes this principle. We also will address another important principle of mind organization brought up by Nolfi, Elman, and Parisi (1994): learning is motivated by internal drives. There is an important difference, however, between Elman's (2005) discussion of nonspecific emergence and the purposeful emergence mechanisms that we consider later: the instinct for knowledge.

Michael Tomasello (2001, 2003) suggests that the first principle of the human mind organization, the most important mechanism of the human brain required to learn language, is not language-specific but, more broadly, cultural and social. It is our ability to perceive other people as intentional agents. We understand that other people have intentions and plans to achieve them; we can figure out what these intentions and plans are. This is the foundation for our entire symbolic culture. The neural mechanisms of this ability are not known. How reasonable is it that we are born with an innate model for other people's intentions and plans? In the following sections, I describe a mathematical theory of joint learning of cognition and language. Its most important premise is that we are born with an innate drive, an instinct for knowledge. It determines the purposiveness of our existence, our higher mental abilities, and our ability to create symbolic culture. It is mathematically possible that a significant or even most important aspect of this drive is to acquire knowledge about other people's intentions and plans. It would be a fascinating enterprise to establish relationships between these two theories through laboratory psychological and neural research.

Let us summarize goals and achievements of cognitive linguistics. Connectionist architectures demonstrated learning of complicated syntax patterns without explicit rules and without explicit examples. They demonstrated elements of joint language learning and meaning creation (cognition). Still, these type architectures face CC and do not scale up. Motivational forces inherent to symbols, which were recognized by Saussure and analytic psychology, made inroads into linguistics and psychology. Still, symbols and signs continue to be mixed up.

The Mind: Concepts, Emotions, and Instincts

Difficulties of mathematical theories of the mind are not of purely mathematical origin. Their development began before the necessary intuitions of how the mind works became well-known to engineers. Newton, as often mentioned, did not consider himself as evaluating various hypotheses about the working of the material world; he felt that he possesses what we call today a physical intuition about the world (Westfall, 1981). An intuition about the mind points to mechanisms of concepts, emotions, instincts, imagination, behavior generation, consciousness and unconscious. Ideas of Dostoyevsky and Nietzsche and psychological theories of Freud and Jung, however, were too complex for many psychologists. It took a long time before they were considered part of science by engineers and mathematicians. An essential role of emotions in the working of the mind was analyzed from the psychological and neural perspective by Grossberg and Levine (1987), from the neurophysiological perspective by Antonio Damasio (1995), and from the learning and control perspective by the author (Dmitriev & Perlovsky, 1996; Perlovsky, 1998b, 1999). But the broad scientific community has been slow in adopting these results. One reason is the cultural bias against emotions as a part of thinking processes. Plato and Aristotle thought that emotions are bad for intelligence; this is a part of our cultural heritage ("one has to be cool to be smart"), and the founders of Artificial Intelligence repeated this truism about emotions even as late as the 1980s (Newell, 1983). Yet, as discussed in the next section, combining conceptual understanding with emotional evaluations is crucial for overcoming the combinatorial complexity as well as the related difficulties of logic.

Mechanisms of the mind, which seem essential to the development of the mathematical semantics, include instincts, concepts, emotions, and behavior. The mind serves for satisfaction of the basic instincts that have emerged as survival mechanisms even before the mind. What constitutes instincts and drives are topics of debates in psychological and linguistic communities (e.g., language instinct). For the purpose of developing a mathematical description (Perlovsky, 2004, 2006a), it is sufficient to consider instinct operations similar to internal sensors; for example, when a sugar level in blood goes below a certain level an instinct "tells us" to eat. To eat or to satisfy any bodily need, the mind has to understand the world around it. The need to understand drives cognition processes; I called it the knowledge instinct (Perlovsky, 2001; Perlovsky & McManus, 1991). It is described mathematically in the next section. A similar mechanism drives learning of language and can be called the language instinct. In this definition, the language instinct only indicates to our mind the basic need to understand and use language; it does not encompass specific mechanisms postulated by Chomsky (1972, 1981), Pinker (2000), Jackendoff (2002), or Tomasello (2001, 2003). These specific mechanisms still have to be elucidated, which constitutes a significant part of linguistic research (on both sides of the isle dividing or joining nativist and cognitivist approaches).

The most accessible to our consciousness is a mechanism of the mind, which operates with concepts. Concepts are like internal models of the objects and situations; this analogy is quite literal (e.g., during visual perception of an object, an internal concept-model projects an image onto the visual cortex, which is matched there to an image projected from the retina; this simplified description will be refined later). Mechanism of concepts evolved for instinct satisfaction; linking concepts and instincts in the mind involves emotions. Emotions are neural signals connecting instinctual and conceptual brain regions. Whereas, in colloquial usage, emotions often are understood as facial expressions, higher voice pitch, exaggerated gesticulation, these are the outward signs of emotions, serving communication. A more fundamental role of emotions within the mind system is that emotional signals evaluate concepts for the purpose of instinct satisfaction. This evaluation is not according to rules or concepts (like in rule-systems of artificial intelligence) but according to a different instinctual-emotional mechanism described next. The knowledge instinct and emotional mechanism are crucial for breaking out of the vicious cycle of combinatorial complexity; they lead to dynamic logic as discussed later.

Conceptual-emotional understanding of the world results in actions in the outside world or within the mind. We only touch on the behavior of improving understanding and knowledge of the language and the world. In the next section, we describe a mathematical theory of conceptual-emotional recognition and understanding. As we discuss, in addition to concepts and emotions, it involves mechanisms of intuition; imagination; and conscious, unconscious, and aesthetic emotion. This process is intimately connected to an ability of the mind to form symbols and interpret signs. The mind involves a hierarchy of multiple levels of concept-models, from simple perceptual elements (like edges or moving dots) to concept-models of objects, to complex scenes, and up the hierarchy toward the concept-models of the meaning of life and purpose of our existence. Parallel to this hierarchy of cognition, there is another hierarchy of language. Both hierarchies interact with each other and, although they have a degree of autonomy, cannot exist without this interaction. Psychological properties of symbols, which sometimes seem mysterious, emerge in this interaction of the two hierarchies. These interacting hierarchies are responsible for the tremendous complexity of the mind, yet relatively few basic principles of mind organization go a long way explaining this system.

Modeling Field Theory of Cognition

Modeling field theory (MFT) describes synaptic fields of neuronal activations, which implement model-concepts of the mind (Perlovsky, 2001). It is a multilevel, heterohierarchical system. The mind is not a strict hierarchy. There are multiple feedback connections among several adjacent levels; hence, the term *heterohierarchy*. MFT mathematically implements mechanisms of the mind in previous sections. At each level, there are concept-models generating top-down signals, interacting with input and bottom-up signals. These interactions are governed by the knowledge instinct, which drives concept-model learning, adaptation, and formation of new concept-models for better correspondence to the input signals.

This section describes a basic mechanism of interaction between two adjacent hierarchical levels of bottom-up and top-down signals (fields of neural activation); sometimes, it will be more convenient to talk about these two signal-levels as an input to and output from a (single) processing-level. At each level, output signals are concepts recognized in (or formed from) input signals. Input signals are associated with (or recognized or grouped into) concepts according to the models and the knowledge instinct at this level. The knowledge instinct is described mathematically as a maximization of similarity between the models and signals. In the process of learning and understanding input signals, models are adapted for better representation of the input signals so that similarity increases. This increase in similarity satisfies the knowledge instinct.

At each level, the output signals are concepts recognized (or formed) in input signals. Input signals **X** are associated with (or recognized or grouped into) concepts according to the representations-models and similarity measures at this level. In the process of association-recognition, models are adapted for better representation of the input signals, and similarity measures are adapted so that their fuzziness is matched to the model uncertainty. The initial uncertainty of models is high, and so is the fuzziness of the similarity measure; in the process of learning, models become more accurate and the similarity more crisp, and the value of the similarity measure increases. This mechanism is called *dynamic logic*.[2]

During the learning process, new associations of input signals are formed, resulting in evolution of new concepts. Input signals {**X**(n)} is a field of input neuronal synapse activation levels. Here and in the following, curve brackets {…} denote multiple signals: a field. Index n = 1,… N, enumerates the input neurons, and **X**(n) are the activation levels. Concept-models $\{\mathbf{M}_h(n)\}$ are indexed by h = 1, … H. To simplify discussion, we talk later about visual recognition of objects; and we talk as if retina and visual cortex form a single processing layer (in fact, there are about 100 neuronal layers between retina and a visual cortex layer that recognizes objects). Each model $\mathbf{M}_h(n)$ is a representation of the signals **X**(n) expected from a particular object, *h*. Each model depends on its parameters $\{\mathbf{S}_h\}$, $\mathbf{M}_h(\mathbf{S}_h,n)$. Parameters characterize object position, angles, lightings, and so forth. In this highly simplified description of a visual cortex, *n* enumerates the visual cortex neurons, **X**(n) are the bottom-up activation levels of these neurons coming from the retina through visual nerve, and $\mathbf{M}_h(n)$ are the top-down activation levels (or priming) of the visual cortex neurons from previously learned object-models. Learning process attempts to match these top-down and bottom-up activations by selecting best models and their parameters.

Therefore, it is important to carefully define a mathematical measure of the best fit between models and signals; in other words, a similarity (or difference) measure between signals and models. In fact, any mathematical learning procedure, algorithm, or neural network maximizes some similarity measure or minimizes a difference. A difference measure used most often (for hundreds of years) is called least mean square; it is just an error between the model and signals (e.g., $\sum (\mathbf{X}(n) - \mathbf{M}_h(n))^2$); here, sum is taken over all signals *n*. This similarity measure, however, is only good for one model. When talking about the human mind, we need a similarity measure that can take into account multiple models in various combinations. We need a similarity measure between the sets of models and signals, *L* (or we can write explicitly the dependence of *L* on models and signals, $L(\{\mathbf{X}(n)\},\{\mathbf{M}_h(n)\})$. The similarity measure *L* also depends on model parameters and associations between the input synapses and concepts-models. It is constructed in such a way that any of a large number of object-models can be recognized. Correspondingly, a similarity measure is designed so that it treats each object model (or concept-model) as a potential alternative for each subset of signals

$$L(\{\mathbf{X}\},\{\mathbf{M}\}) = \prod_{n\in N} \sum_{h\in H} r(h)\, l(\mathbf{X}(n) \mid \mathbf{M}_h(n)); \tag{1}$$

Let us explain this expression in a simple way. Here, $l(\mathbf{X}(n)|\mathbf{M}_h(n))$ (or simply l(n|h)) is called a conditional partial similarity, which means that it is just a similarity between one signal $\mathbf{X}(n)$ and one model $\mathbf{M}_h(n)$. Parameters r(h) are proportional to the number of objects described by the model *h*; they are not essential and used for convenience so that we can define each l(n|h) for a single object. Expression (1) accounts for all possible combinations of signals and models in the following way. Sum $\sum$ ensures that any of the object-models can be considered (by the mind) as a source of signal $\mathbf{X}(n)$. Product $\prod$ ensures that all signals have a chance to be considered. (Even if one signal is not considered, the entire product is zero, and similarity L is 0; so for good similarity all signals have to be accounted for. This does not assume exorbitant amount of attention to each minute detail; among models, there are vague simple models for everything else). In a simple case, when all objects are perfectly recognized and separated from each other, there is just one object-model corresponding to each signal (other l(n|h) = 0). In this simple case, expression (1) contains just one item, a product of all non-zero l(n|h). In general case, before objects are recognized, L contains a large number of all combinations of models and signals; a product over *N* signals is taken of the sums over *H* models, this results in a total of H^N items; this was the cause for the combinatorial complexity discussed previously.

Psychologically, maximization of similarity measure (1) is an instinct, an unconditional drive to improve the correspondence between input signals and internal representations-models. Let us emphasize once more that this instinct demands only maximizing one quantity: similarity *L*. The mathematical mechanisms of how this is achieved follows from the instinct structure (1) and are specified later. The knowledge about the world is contained in the models; therefore, similarity maximization is a mechanism of the knowledge instinct. Because models are adapted to input signals, knowledge depends on the realities of the surrounding world. Therefore, our knowledge is not a set of empty codes but represents objective reality. How good these representations are in individual minds is determined by a multitude of factors. In part, it is determined by the initial states of models. Some aspects of the models are inborn; others are acquired from culture, mostly from language, which we discuss later.

In the process of learning, concept-models constantly are modified. From time to time, a system forms a new concept while retaining an old one as well; alternatively, old concepts are sometimes merged. (Formation of new concepts and merging of old ones require some modification of the similarity measure (1), as discussed in Perlovsky [2001, 2006].)

The learning process consists of estimating model parameters $\mathbf{S}_h$ and associating subsets of signals with concepts by maximizing the similarity (1). Although (1) contains combinatorially many items, dynamic logic maximizes it without combinatorial complexity (Perlovsky, 1996b, 1997, 2001). First, fuzzy association variables f(h|n) are defined

$$f(h|n) = r(h)\, l(n|h) \,/ \sum_{h' \in H} r(h')\, l(n|h'). \tag{2}$$

These variables give a measure of correspondence between signal $\mathbf{X}(n)$ and model $\mathbf{M}_h$ relative to all other models, *h'*. A mechanism of concept formation and learning, the dynamics of modeling fields (MF) is defined by (2) along with the following equations,

$$\mathbf{S}_h = \mathbf{S}_h + \alpha \sum_{n} f(h|n)[\partial \ln l(n|h)/\partial \mathbf{M}_h]\partial \mathbf{M}_h/\partial \mathbf{S}_h, \tag{3}$$

$$r(h) = N_h / N; \; N_h = \sum_n f(h|n); \tag{4}$$

Here, parameter α determines the iteration step and speed of convergence of the MF system; N_h is as a number of signals **X**(n) associated with or coming from an object-model *h*. As already mentioned, in the MF dynamics, similarity measures are adapted so that their fuzziness is matched to the model uncertainty. Mathematically, this can be accomplished in several ways, depending on the specific parameterization of the conditional partial similarity measures, l(n|h); for example, they can be defined as familiar bell-shaped Gaussian functions,

$$l(n|h) = (2\pi)^{-d/2} (\det \mathbf{C}_h)^{-1/2} \exp\{- 0.5(\mathbf{X}(n) - \mathbf{M}_h(n))^T \mathbf{C}_h^{-1} (\mathbf{X}(n) - \mathbf{M}_h(n)) \}. \tag{5}$$

Here, *d* is the dimensionality of the vectors **X** and **M**, and $\mathbf{C}_h$ is a covariance. These functions describe bell-shape forms centered at $\mathbf{M}_h(n)$ with widths defined by $\mathbf{C}_h$. The dynamics of fuzziness of the MF similarity measures is defined as

$$\mathbf{C}_h = \sum_n f(h|n) (\mathbf{X}(n) - \mathbf{M}_h(n))(\mathbf{X}(n) - \mathbf{M}_h(n))^T / N_h. \tag{6}$$

Initially, models do not match data; covariances are large; bell-shapes are wide; and association variables, f(h|n), take homogeneous values across the data, associating all concept-models *h* with all input signals *n*. As matching improves, covariances become smaller; bell-shapes concentrate around the model-concepts $\mathbf{M}_h(n)$; and the association variables, f(h|n), tend to high values 1 for correct signals and models and zero for others. Thus, certain concepts get associated with certain subsets of signals (objects are recognized and concepts formed). The following theorem was proven (Perlovsky, 2001).

Theorem: Equations (2) through (6) define a convergent dynamic system MF with stationary states given by $\max_{\{\mathbf{S}_h\}} L$.

It follows that the previous equations indeed result in concept-models in the "mind" of the MFT system, which are most similar (in terms of similarity (1)) to the sensory data. Despite a combinatorially large number of items in (1), a computational complexity of the MFT is relatively low; it is linear in *N* and, therefore, could be implemented by a physical system like a computer or brain. (Let me emphasize that using Gaussian functions here is not like Gaussian assumption often used in statistics. Gaussian assumption assumes that the signals are Gaussian; this limits the validity of most statistical methods. Our similarity is quite general; it only assumes that the deviations between the models and signals are Gaussian; also, using many models in the sum in (1) can represent any statistical distribution.) Convergence of the MF system stated in the previous theorem assumes a definite set of input signals. In reality, new sensory signals reach our mind all the time; therefore, new concepts are continuously formed, and previously learned concepts are modified to fit new data.

To summarize, the knowledge instinct is defined by maximizing similarity (1). Its mathematical structure is chosen so that (prior to perception-cognition) any model-object can cause any signal. The mechanism of satisfying the knowledge instinct by maximizing (1), dynamic logic, is given by eqs. (2) through (4). Eqs. (5) and (6) are convenient, but their specific forms are not necessary.

From a neurophysiological standpoint, neural signals relating concepts to instincts (similarities) are evaluative emotional signals. Emotional signals related to satisfaction of knowledge instinct mathematically are described by changes in similarity measure (1) during learning; eqs. (2) through (4). These emotions are directly related not to satisfying bodily needs but only spiritual needs for increased knowledge, and, according to Kant, they are called aesthetic emotions. Of course, there is no dualism; the knowledge instinct and aesthetic emotions are implemented in the brain neural mechanisms. These mechanisms, though, are removed from direct bodily needs, and in this sense, they can be called spiritual. Aesthetic emotions are not something specifically related to art; these emotions are involved in every act of perception and cognition.

Hierarchy of Cognition

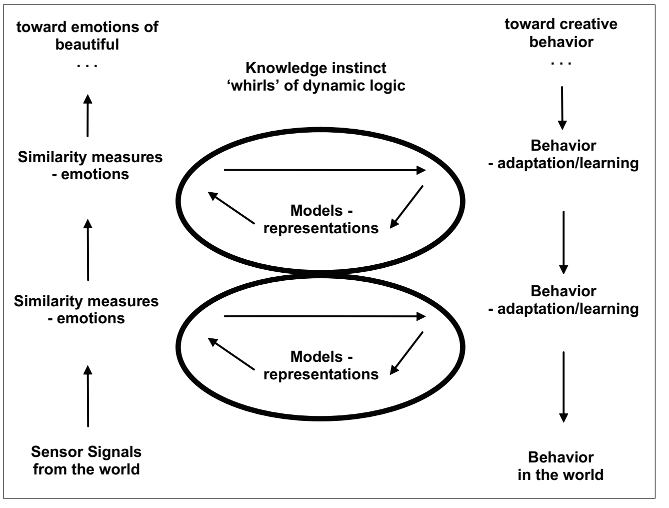
The previous section described operation of a single MFT level, modeling a single level of the mind hierarchy. Like the mind, MFT is a heterohierarchical system consisting of multiple levels. Roughly speaking, at lower levels of the hierarchy are perceptual elements, objects; higher up are relationships among objects, situations, and more and more abstract and general model-concepts, and near the top are the most general concepts of the purpose and meaning of life. At every level, there is a similarity measure defining the knowledge instinct, models, emotions, and actions, including adaptation of models. An input to each level is a set of signals **X**(n). The result of signal processing at a given level are activated models, or concepts *h* recognized in the input signals *n*; these models, along with the corresponding instinctual signals and emotions, may activate behavioral models and generate behavior at this or lower levels. The activated models also send output signals from this level to the next processing level; these signals could be defined as model activation signals, a_h,

$$a_h = \sum_{n \in N} f(h|n).$$

These signals, indicating recognized concept-models, become input signals for the next processing level, where more general concept-models are created. Hierarchical MF system is illustrated in Figure 1.

Operations of the knowledge instinct and dynamic logic are mostly unconscious. Only when concept-model is matched to a specific content and become crisp is it accessible to consciousness. More crisp and concrete models are more conscious (i.e., the mind, at will, can direct attention to, access, and operate with these models). Concept-models at lower hierarchy levels correspond to concrete objects. A child learns many of these models in the first months of life; they become concrete and conscious. Simple relations among objects, which are directly observable, also are learned early in life and become concrete and conscious. Learning of these models is said to be grounded in direct experience. Higher up

Figure 1. Hierarchical MF system



Note: At each level of a hierarchy there are models, similarity measures, and actions (including adaptation, maximizing the knowledge instinct—similarity). High levels of partial similarity measures correspond to concepts recognized at a given level. Concept activations are output signals at this level, and they become input signals to the next level, propagating knowledge up the hierarchy. The hierarchy is not strict; interactions may involve several levels. At the top of the hierarchy, there are models of meaning and purpose, related emotions of beautiful, and creative behavior.

in the hierarchy are more abstract cognitive models, which cannot be grounded in direct experience. Early in life, they remain fuzzy and less conscious. Still higher up, there are even more abstract models; some of them remain fuzzy and unconscious throughout life. Note that these models to attain crisp and conscious state have to be crisply and consciously related to the entire wealth of conceptual knowledge and experience at lower levels. People that are called knowledgeable and wise have more crisp and conscious models at higher levels of the mind hierarchy.

In the foundation of psyche, there are unconscious fuzzy models-archetypes. Every process of learning a concept-model involves a fuzzy unconscious model, which becomes more crisp and conscious and more clearly connected to experience and other concepts. This process connects conscious and unconscious and increases the limits of knowledge and consciousness; according to Carl Jung's (1921) definition, it is a symbol process. Here, I am using the notions of symbol and sign as used by Jung, Karl Pribram (1971), and general culture, and which is different from some definitions in classical semiotics and artificial intelligence. I'll continue discussion of motivations for various definitions in the last section. Here, I use the words *symbol* for adaptive processes creating new knowledge and *sign* for nonadaptive signals. The symbol process can take place completely inside the mind and does not have to involve signs in the outer world. Input signals from the lower level of the mind are signs on which the symbol process operates. Out of these signs, with the help of a fuzzy unconscious model, the symbol process creates a new concept at its hierarchical level, which is crisper and more conscious than the original fuzzy model. When the symbol-process ends, the result is a new sign, which can be used at a higher level in the hierarchy of the mind to create new symbols.

The higher in the mind of the hierarchy we attempt to extend this process, the less grounded in direct experience it becomes. The resulting concept-models could evolve in the following two ways. They remain fuzzier and less conscious than lower-level models grounded in direct experience, or they could become crisp and conscious agglomerations of arbitrary lower-level models that do not correspond to anything useful for human life and do not increase knowledge in any useful way. Increasing knowledge in a useful way is only possible due to language, as discussed in the following two sections.

Language MFT

Learning language, when described mathematically, using previously developed techniques, leads to combinatorial complexity. This is a general mathematical problem of learning algorithms that we discussed in sections 2 and 3. It is independent from specific mechanisms of language learning and equally applies to all theories of language learning. To overcome combinatorial complexity and to develop mathematical models adequate for language learning, we extend MFT developed for cognition in section 6. Like cognitive MFT described earlier, language is a hierarchical system; it involves sounds, phonemes, words, grammar, phrases, and sentences, and each level operates with its own models. Thus, we need to develop language models suitable for MFT and dynamic logic. In the human mind, these models to some extent are results of evolution; for computational intelligent systems, we have to develop them, and this development at each level is a research project, which is added by a number of already described language models in linguistics (Jackendoff, 2002; Mehler, 2002; Pinker, 2000; Rieger, 1981). A related challenge is to determine mechanisms of language evolution, so that specific mechanisms of contemporary languages evolve in processes of cultural evolution.

Here, I discuss an approach to the development of models of phrases from words. Given a large corpus of text, we would like to learn which word combinations are good models (i.e., used often and model most of the data). These models can be used for text understanding; for example, it could be used for an understanding-based search engine. There is a more general aspect of the development in this section; when combined with section 6, these techniques can be used to extend cognitive and language models to higher levels of a hierarchy and for integrating cognitive and language hierarchies addressed in sections 9 and 10. The difficulty of this task is related to the fact that phrases do not necessarily neatly follow one another, but they might overlap and form complex nested expressions. For example (Elman, 2003): “The man who came late is your uncle.”

A simple way to learn this kind of sentences is to remember all kinds of sentences that are encountered in language. Clearly, humans can do better. The Chomsky (1972) approach was to figure out innate logical rules for syntax to deal with sentences like this. The Chomsky (1981) approach was to use parametric models (rules and parameters) instead of logical rules.

Both approaches, as we discussed, faced combinatorial complexity. Elman demonstrated that a neural network can learn these types of sentences without ever encountering them. This neural network, however, was carefully constructed for a limited set of problems. It would not scale up to real language learning; it would face combinatorial complexity, as we already discussed.

Let us discuss MFT for learning phrases without CC. The input data, **X**(n) in this phrase-level MF system are word strings; for simplicity, of a fixed length, S, $\mathbf{X}(n) = \{ w_{n+1}, w_{n+2} \ldots w_{n+S} \}$. Here, w_n are words from a given dictionary of size K, $W = \{w_1, w_2 \ldots w_K\}$, and *n* is the word position in a body of texts. A simple phrase model is "a bag of word"; that is, a model is a subset of words from a dictionary without any order or rules of grammar,

$$\mathbf{M}^L_h(\mathbf{S}_h, n) = \{w_{h,1}, w_{h,2} \ldots w_{h,S}\}. \tag{7}$$

A superscript *L* here denotes a language model; the parameters of this model are its words, $\mathbf{M}^L_h(\mathbf{S}_h, n) = \mathbf{S}_h = \{w_{h,1}, w_{h,2} \ldots w_{h,S}\}$. The language learning (traditionally called language acquisition in Chomskyan linguistics) consists of defining models-concepts-phrases best characterizing the given body of texts in terms of a similarity measure.

Conditional partial similarities between a string of text, **X**(n) and a model $\mathbf{M}^L_h$ could be defined by a proportion of the matches between the two sets, **X**(n) and $\mathbf{M}^L_h$, $l(n|h) = |\mathbf{X}(n) \cap \mathbf{M}^L_h| / S$. Thus, similarity (1) is defined, and it could be maximized over the unknown parameters of the system, $\{ \mathbf{S}_h \}$; that is, over the word contents of phrases. Maximization of this language-similarity gives a mathematical formulation of the language instinct (Pinker, 2000). The language instinct mechanism is mathematically similar to the knowledge instinct; the main difference is that the language instinct maximizes similarity between language models and language data. Relations of language to cognition of the world is not considered within Chomskyan linguistics, and it is not a part of language instinct as formulated by Pinker (2000). We consider it in later sections.

Satisfaction of the language instinct, maximization of similarity between language-models ,and language signals result in language acquisition. Using the previously defined conditional similarities and phrase-models would result in learning models-phrases. The difficulty is that the dynamic logic, as described in the previous section, cannot be used for maximizing similarity. In particular, (3) requires evaluating derivatives, which requires a smooth dependence of models on their parameters. But bag-models do not depend smoothly on their word content. For example, a bag-model {Leonid, sit, chair} cannot be differentiated with respect to parameters *sit* or *chair*. This is a major difficulty: Any language model, at the level of phrases and above, is essentially a list, graph, or tree, which cannot be differentiated with respect to its word-content (or structure-content). Without dynamic logic, the computational complexity of similarity maximization becomes combinatorial $\sim K^{(H*N*S)}$; this is a prohibitively large number. This is the reason why old mathematical methods cannot be used for learning language and why computers do not talk and do not understand language yet.

The combinatorial complexity of this solution is related to a logic-type similarity measure, which treats every potential phrase-model (every combination of words) as a separate logical statement. The problem can be solved by extending dynamic logic as follows. Define the original vague state of phrase-models (phrase-potentialities) as long strings of words, much longer than actual phrases. During dynamic-logic processes, each vague model-phrase is compared to the corpus of text. At every iteration, a word least belonging to the phrase, on average over the text corpus, is determined and eliminated from the model. This procedure is qualitatively similar to differentiation, and it can be applied to discontinuous nondifferentiable functions, like sets of words (or other structural elements). Similar to section 6, original vague models poorly correspond to all phrases in the text corpus. As dynamic logic process progresses, models are becoming shorter and more specific; they become more selective, and they better correspond to specific phrases. This process ends with short specific model-phrases (phrase-actualities) corresponding to the content of the text corpus. This result is not unlike Elman (2003) with the difference that dynamic logic avoids CC can be scaled up and applied to the entire content of language.

We give now a mathematical description of this process. Define fuzzy conditional partial similarity measures (a similarity between one word sequence, **X**(n), and one model, $\mathbf{M}^{L}_{h}$):

$$l(n|h) = (2\pi\sigma_h^{\,2})^{-S/2} \exp\{- 0.5 \sum_{s} e(n,h,s)^2 / \sigma_h^{\,2} \}. \qquad (8)$$

Here, e(n,h,s) is a distance (measured in the numbers of words) between the middle of the word sequence **X**(n) and the closest occurrence of the word $w_{h,s}$; the sum here is over words belonging to the phrase-model *h*. The search for the nearest word is limited to **X**(n) (S words), and e(n,h,s) falling outside this range can be substituted by a (S/2+1). Variance, determining fuzziness of this similarity measure, is given by a modification of (6),

$$\sigma_h^{\,2} = \sum_{n} f(h|n) \sum_{s} e(n,h,s)^2 / N_h. \qquad (9)$$

Dynamic logic requires defining fuzzy contents of phrase-models, which can be done as follows. Define the average distance, δ, of the word $w_{h,s}$ from its phrase-model, *h*

$$\delta(h,s) = \sum_{n} f(h|n) \sum_{s} e(n,h,s)^2 / N_h; \qquad (10)$$

This is an average distance over the entire text corpus. It is closely related to the measure of fuzzy phrase contents, or measure of belonging of the word *s* to phrase *h*. We define it as a probability-like measure of the word $w_{h,s}$ belonging to a model-phrase h, φ(s|h):

$$\varphi(s|h) = p(h|s) / \sum_{s' \in h} p(h|s'); \; p(h|s) = (2\pi\sigma_h^{\,2})^{-1/2} \exp\{- 0.5 \sum_{s} \delta(h,s) / \sigma_h^{\,2} \}, \qquad (11)$$

The last equation here is a bell-shaped curve, a nonnormalized measure of belonging of word *h* to phrase *s*; the first equation gives φ, a probability-like normalized measure for the word *s* relative to all other words in the model *h*. This measure is used now to define the dynamics of the word contents of the phrase-models in the dynamic-logic process as follows. Let us limit the problem to learning phrases of a fixed length, say, we would like to learn five-word phrases. Start with a large value of S >> 5 (e.g. S = 50) and with arbitrary word-contents of phrases (7). On each iteration, compute eqs. (8) through (11). Reduce S by 1; in each phrase-model eliminate one word with the minimal φ(s|h),

for each *h*, find $s' = \text{argmin}_s\ \varphi(s|h)$,

$w_{h,s'}$ is the least probable word in model *h*, and it is eliminated on this iteration. *S* is changed to *S-1*. Continue iterations until *S* reaches the desired value 5.

The dynamics defined in this way result in learning phrase-models and accomplishes the goal of language acquisition without combinatorial complexity. The computational complexity is moderate, ~ N*H*K*S. This overcoming of CC is the major goal of this section. Limitations of the previous procedure, like predefined length of phrases, can be overcome similar to the discussion in the section Modeling Field Theory of Cognition (see also Perlovsky, 2001).

The bag-of-word phrase models considered previously are simpler than known structures of natural languages with treelike dependencies, syntactic rules, and word order (Jackendoff, 2002; Mehler, 2002; Pinker, 2000; Rieger, 1998). These more complicated real linguistic models can be used in place of a simple distance measure e(n,h,s) in (8). This does not lead to a significant growth of complexity. In this way, the models of noun and verb phrases and tree structures can be incorporated into the previous formalism. One of the challenges of contemporary linguistics is to identify which aspects of the models are innate so that every child learns a human language, and to identify which aspects are learned so that any of thousands of languages can be learned. It is quite possible that the inborn, innate information about a conceptual structure of language is contained in simple bag-type models of the type considered previously; the rest could be learned jointly with cognition, as considered later. We do not consider here emotional content of language (Perlovsky, 2006b).

The procedure outlined in this section is general in that it is applicable to all higher levels in the mind hierarchy. Lower-level models may require continuous parametric models, like laryngeal models of phonemes (Lieberman, 2000). These can be learned from language sounds using procedures similar to the section Modeling Field Theory of Cognition. Higher hierarchical models, like models of phrases, or language models corresponding to complex abstract concepts contained in paragraphs, or books, are learned from lower-level models using the technique described in this section. This is also true about high-level cognitive models of relationships among objects, situations, and so forth. Are we born with complex innate mechanisms of these models (using structured sets or graphs), or are simple bag-models sufficient? This is a challenge for linguistics today. The general approach described in this section overcomes CC of learning algorithms and can be used with a variety of specific language learning models.

Integrating Language and Cognition

Let me repeat that today, we still do not know neural mechanisms combining language with thinking or their locations in the brain. Mathematical mechanisms discussed for unifying cognition and linguistics (Brighton et al., 2005; Christiansen & Kirby, 2003; Elman et al., 1996; Jackendoff, 2002) face combinatorial complexity for the same mathematical reasons that cognitive and language algorithms did in the past. Here we extend MFT to unifying cognition and language, while avoiding CC. We discuss a relatively simple mechanism that might be sufficient for joint learning of language and cognition and which corresponds to existing knowledge and intuition about these processes.

Integration of language and cognition in MFT is attained by integrating cognitive and language models (Perlovsky, 2002m 2004) so that a concept-model $\mathbf{M}_h$ is given by

$$\mathbf{M}_h = \{ \mathbf{M}^C_h , \mathbf{M}^L_h \}; \qquad (12)$$

Here, $\mathbf{M}^C_h$ denotes a cognitive part of the model of an object or situation in the world, and $\mathbf{M}^L_h$ is a linguistic part of the model. Consider now this integrated model as the mind's mechanism of integrating language and cognition. A data stream constantly comes to mind from all sensory perceptions; every part of this data stream is evaluated constantly and associated with models (12) according to the mechanisms of dynamic logic described in previous sections. In this fuzzy dynamic association, at the beginning, the models are fuzzy; cognitive models vaguely correspond to uncertain undifferentiated sensory perceptions. Language models vaguely correspond to sounds. This is approximately a state of mind of a newborn baby. First, models of simple perceptions differentiate; objects are distinguished in visual perception. Language sounds are differentiated from other sounds. In (12), some cognitive models become crisper than other cognitive models. Until about one year of age, perception models corresponding to simple objects become crisper at a faster rate than language models.

Gradually, models are adapted, their correspondence to specific signals improve, selectivity to language signals and nonlanguage sounds are enhanced. Language models are associated with some degree of specificity with words (sentences, etc.), and cognitive models are associated with objects and situations of perception and cognition. Between the first and second year of life, the speed of adaptation of language models tremendously accelerates and overtakes learning of cognitive models.

Some degree of association between language and cognitive models occurs before any of the models attain a high degree of specificity that is characteristic of the grown-up conscious concepts. Language and cognition are integrated at a preconscious level. Certain language models evolve faster than their corresponding cognitive models and vice versa. Correspondingly, uncertainty and fuzziness of the two aspects of integrated models may differ significantly. Still, existence of a low-fuzzy linguistic model speeds up learning and adaptation of the corresponding cognitive model and vice versa. I suggest that this is a mechanism of interaction between language and cognition. Both abilities enhance each other.

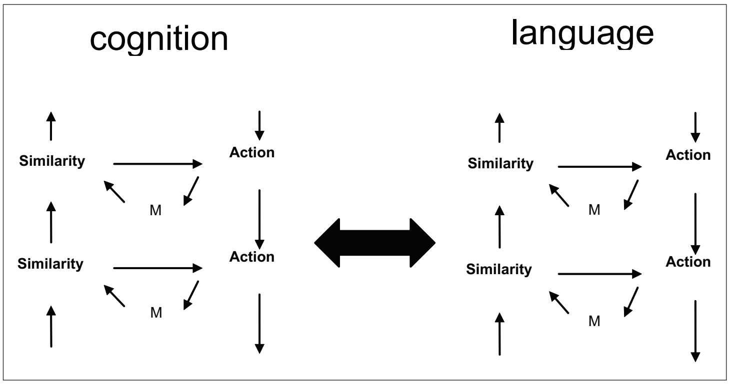
The described mechanism of interaction between language and thinking may apply to ontological development and learning, biological specie evolution, and evolution of cultures. The differences between these learning and evolution processes are in the degree of specificity of a priori models (inborn, or accumulated in culture) and in the type of data available for learning and evolution. For example, child learning occurs in parallel in three realms: (1) linguistic models are learned to some extent independently from cognition, when linguistic data are encountered for the first time with limited or no association with perception and cognition (like in a newborn baby); (2) similarly, cognitive models can be learned to some extent independently from language, when perception signal data are encountered for the first time in limited or no association with linguistic data; and (3) linguistic and cognitive models are learned jointly when linguistic data are present in some association with perception signals; like during mother talking to a baby: "this is a car" (visual-perception-models and the corresponding linguistic-word-models are engaged together); another example is more complicated conversations: "Look at Peter and Ann, they are in love" (leads to learning related cognitive-models and phrase-models). The most significant part of learning, it seems, involves independent learning of language and cognitive parts of models when situations and their language descriptions are encountered independently from each other. Structure (12) provides for a cognitive placeholder fuzzy model for each language model, and vice versa. In this way, both types of models are learned gradually, always remaining associated; cognition helps language, and language helps cognition. In this way, knowledge is accumulated through generations.

MFT Hierarchical Organization

The previous section described a single processing level in MFT system integrating language and cognition. This mechanism of integrated models can integrate cognitive and language hierarchies, as illustrated in Figure 2. An amazing aspect of the human mind is that these two hierarchies are integrated in such a way that relationships among constituent models are preserved. For example, a cognitive model of a situation and the corresponding phrase model are constituted from lower-level models: objects and words. Correspondence between these objects and words in the object-word level is the same as between them, when they become constituent parts of the phrase-situation level model. And this holds true across a tremendous number of the phrase-situation level models, using various combinations of the same words from the lower level. This amazing property of our mind seems so obvious that nontrivial complexity of the required mechanism was noticed only recently (Deacon, 1998). The only mathematical description of a mechanism that promises such integration of the two hierarchies without CC is given in sections following (Perlovsky, 2002, 2004).

Deacon (1998) suggested that the ability for two hierarchies sets the human mind apart from the rest of the animal world. For example, a dog can learn to bring shoes to a human master on a verbal command. A dog, it seems, can jointly learn language and cognition (a word *shoes* and an object *shoes*). This is only true, however, at the lower levels of the mind hierarchy, at the level of objects. The dog can do it because it perceives objects (shoes) in the world. Learning of a word-concept, shoes, is grounded in direct perception of objects in the world. Note that such a direct grounding in sensory signals exists only at the very bottom of the mind hierarchy. At higher levels, cognitive concepts are grounded in lower-level concepts. These higher levels exist only in the human mind. Try to teach a dog to understand the word *rational* or any abstract concept, which meaning is based on several hierarchical levels; this is not possible. It is known that the smartest chimps after long training barely can understand few concepts at the second level (Savage-Rumbaugh & Lewine, 1994).

Figure 2. Hierarchical integrated language-cognition MF system



Note: At each level in a hierarchy there are integrated language and cognition models. Similarities are integrated as products of language and cognition similarities. Initial models are fuzzy placeholders, so integration of language and cognition is subconscious. Association variables depend on both language and cognitive models and signals. Therefore, language model learning helps cognitive model learning and vice versa. Abstract cognitive concepts are grounded in abstract language concepts.

Ability for learning higher levels of the hierarchy, it seems, is closely related to ability for language. The reason is that otherwise, learning of cognitive models does not have a ground for learning; there are no abstract concepts that could be directly perceived in the world. The only ground for learning abstract cognitive concepts is language concepts, which are learned from surrounding language and culture at many hierarchical levels. In an integrated MFT system, abstract cognitive models at higher levels in the hierarchy are grounded in abstract language models. Due to integration of language and cognition, language provides grounding for abstract higher cognitive models.

Cognitive models that proved useful in life and evolution cannot be transferred directly to the minds of the next generation. Cognitive models created by each generation are accumulated in culture and are transferred to the next generation through language. Cultural evolution gradually selects useful models. Language accumulates cultural knowledge at all levels in hierarchy of the mind.

Mechanisms of integration of cognition and language given by dual models, eq. (12), and dual hierarchies, Figure 2, are as if a bridge exists between nativist and cognitive linguistic approaches. Mathematical mechanisms proposed here can be used in conjunction with other proposed mechanisms, language specific or not. Many of the mechanisms for language and cognition discussed in literature (Chomsky, 1995; Elman et al., 1996; Jackendoff, 2002; Lieberman, 2000; Pinker, 2000; Tomasello, 2003) can be integrated with MFT structure discussed previously and take advantage of the dynamic logic overcoming CC.

Cognitivist approach rejects specific language mechanisms; for example, Tomasello (2003) suggests that understanding other people's intentions and goals is sufficient to acquire language and to create culture. Nativist approach seeks to explain language independently from cognition (Pinker, 2000). Consider the fact that some people master language very well, while other people are inept. Opposite examples also abound. This consideration seems to support some separation between language and cognition of people's intents. It is quite possible that cognitive mechanisms for inferring other people's intents proposed by Tomasello can incorporate these differences in speed of learning of these two abilities. Following Hurford (2001), I would like to mention that the strong polemical tone in some of the linguistic literature is symptomatic of a schism in modern linguistics, which hopefully can be resolved soon. Controversies between algorithmic and nonalgorithmic, learned vs. innate and instinctual, it seems, often are based on old divisions and definitions of terms rather than on actual differences among contemporary researchers about importance of various mechanisms. When laboratory studies will be combined with mathematical models capable of scaling up to the real mind; and when the model predictions will be tested against the experimental data, current divisions will yield to more interdisciplinary studies and intergroup cooperation.

Cultural evolution of language and cognition as well as ontological learning by a child could be supported by similar mechanisms. It is quite possible that a significant part of conceptual cognitive and language abilities (from words and objects up the mind hierarchy toward complex abstract concepts) can evolve and be learned based on few inborn mechanisms described in this chapter: MFT structure, the knowledge instinct, dynamic logic, dual model (12), and hierarchy (Figure 2). For example, Brighton et al. (2005) demonstrated that combinatorial compositionality of language emerges under proper conditions from a single simple mechanism. The main requirement is a mind's ability to guess-predict sounds for new situations from previous experiences (so that new sounds are understandable by the rest of the community). This property of accurate guessing is inherent to the MFT mechanisms, because dynamic logic evolves MFT structure from vague and fuzzy toward probabilistic and maximum likelihood. (The maximum likelihood principle is mathematically equivalent to the minimum description length principle used by Brighton et al., 2005). Implementing Brighton et al.'s approach with MFT will overcome current CC of that work. Also, like much of contemporary work on language evolution, Brighton et al. assumed preexisting meanings (i.e., cognition). Current effort is directed at overcoming these limitations toward joint evolution of language and cognition using MFT and dynamic logic (Perlovsky & Fontanari, 2006). It would be interesting to further connect language evolution to Elman's (2003) work on learning of complex syntax with relatively simple innate models. It seems that Elman's models can be mapped to the MFT architecture in a relatively straightforward way. I would emphasize that postulating one assumption (like innateness vs. learning) to explain that one fact does not lead too far. The essence of scientific theory emphasized by many linguistic researchers is in explaining many facts with few assumptions. The next section makes a step in this direction using the theory of dual language-cognition models and hierarchy to explain complex interrelations among language, cognition, and symbols.

Language, Cognition, and Symbols

Why is the word *symbol* used in such a different way—to denote trivial objects like traffic signs or mathematical notations and also to denote objects affecting entire cultures over millennia, like Magen David, Swastika, Cross, or Crescent?

Let us compare in this regard opinions of two founders of contemporary semiotics: Charles Peirce (1931-1958) and Ferdinand De Saussure (1916). Peirce classified signs into symbols, indexes, and icons. Icons have meanings due to resemblance to the signified (objects, situations, etc.); indexes have meanings by direct connection to the signified, and symbols have meaning due to arbitrary conventional agreements. Saussure used different terminology; he emphasized that the sign receives meaning due to arbitrary conventions. Saussure chose the term *sign* over *symbol* because the latter implies motivation. It was important for him that motivation contradicted arbitrariness.

Choice of convention for the most fundamental terms in semiotics is not arbitrary but ought to be motivated by understanding of the working of the mind and by the most widely used conventions across the culture. For this purpose, it is not irrelevant to note that Peirce considered himself a logician (logic implies arbitrariness of conventions), and in his personal life he abstracted himself from cultural conventions. Saussure was a linguist, he was better attuned to cultural conventions, and he was more sensitive to the fact that the word *symbol* implied nonarbitrary motivations.

Both Peirce and Saussure wanted to understand the process in which signs acquire meanings. Both of them failed; workings of the mind were not known at the time. Consider Peircian icons; they resemble objects or situations because of specific mechanisms of perception and recognition in our minds. These mechanisms should be analyzed and understood as an essential part of meaning creation. Peircian assumption that icons in themselves resemble situations in the world is too simplistic. Algorithms based on this assumption led to irresolvable difficulties related to combinatorial complexity. Similarly, arbitrariness emphasized by Peirce and Saussure did not help in understanding algorithms of meaning creation. Since arbitrary conventions also are expressed through signs, all signs get their meanings only in relation to or in contrast with other signs in a system of signs. Arbitrary signs, therefore, have no grounding in the real world. Meanings cannot be created by unmotivated choices on the interconnections of arbitrary signs; this type of choice leads to combinatorial complexity. In infinite systems, they lead to Gödelian contradictions. Similarly, mechanisms of meaning creation were not found by founders of symbolic AI when they used motivationally loaded word *symbol* for arbitrary mathematical notations. Mathematical notations, just because they are called symbols, do not hold a key to the mystery of cultural and psychological symbols. Multiple meanings of the word *symbol* misguided their intuition. This is an example of what Wittgenstein (1965) called "bewitchment by language."

The MF theory and dynamic logic emphasize that meanings are created in processes connecting conscious and unconscious. There are two fundamental processes meaning creation in evolution of language and culture: differentiation and synthesis. First, differentiation consists of bringing unconscious into consciousness. It acts at the deepest levels of bringing unconscious archetypes into consciousness as well as at everyday levels of differentiating multiple aspects of various concepts and making these aspects more concrete and more conscious. This process takes millennia, and its results are stored in language. Its mathematical mechanisms are described in sections 6 and 7. Second, synthesis consists of connecting differentiated conscious concepts in language with cognition and through cognition with unconscious instinctual needs. Its mathematical mechanisms are described in sections 9 and 10.

Whereas differentiation is the essence of cultural and cognitive development, synthesis creates necessary conditions for differentiation. Both processes are necessary, yet their relationships are not simple. There is synergism but also opposition between differentiation and synthesis. The reason is that too strong a synthesis stifles differentiation: If the language hierarchy is not sufficiently vague, if it is too crisp, language may strongly predetermine meanings of cognitive concepts so that creation of new meanings is difficult and culture stagnates. The opposite side of the story is that differentiation can overtake synthesis. A large number of finely differentiated concepts might be created in language, but individual minds lag in their capacity for synthesis, for connecting language to cognition, and to essential demands of life. If this condition predominates in the entire culture, its meaning is lost for the people, and culture disintegrates. This was the mechanism of death of many ancient civilizations. Currently, predominance of synthesis is characteristic of certain Eastern cultures, whereas predominance of differentiation is characteristic of Western cultures. This direction for future research requires going beyond conceptual contents of languages and to study their emotional, motivational contents (Perlovsky, 2006b).

Both differentiation and synthesis are motivated by the instinct for knowledge. The motivated meaning creation, connecting conscious and unconscious, is consistent with Jungian explanations of the nature of symbols (1921). This motivates me to use the word *symbol* for the processes of meaning creation and to use the word *sign* for conventional or nonadaptive entities. I would also add, as a motivation for other semioticians (pun intended) to adopt these conventions, to entertain the following question: Why does the word *semiotics* leave a bitter taste in the minds of many physicists, engineers, and analytical psychologists, despite the obvious importance of the field? This could not be understood from the point of view of arbitrariness of conventions. Researchers, whose subjects are connected to the real world outside and inside human psyche might be repulsed by arbitrariness of the most important definitions. Founders of symbolic artificial intelligence were captivated by mathematical logic; they were not attuned to the fact that mathematical notations called symbols are not at all similar to psychological symbol-processes in the mind. I think this is the reason why, despite Gödel's results, proving inconsistency of logic, they still used formal logic to model the mind.

Let me summarize. In the context of the discussions in this chapter, a sign means something that can be interpreted to mean something else (like a mathematical notation, a word, or a traffic sign). The process of sign interpretation is a symbol-process, or symbol. This process resides in our minds. Interpretation or understanding of a sign by the mind according to MFT is due to the fact that a sign (e.g., a word) is a part of a model. The mechanism of sign interpretation is motivated by the knowledge instinct, which activates the model and connects the sign to the world outside and inside us. Second, a sign is understood in the context of a more general situation in higher levels of the mind hierarchy, containing more general concept-models. Recognized signs, which are the results of symbol processes, comprise input signals for the next level models, which cognize more general concept-models. Signs, therefore, are not just objects in the world but also are neural signals in our minds to which meanings are fixed as a result of the concluded symbol-processes. This corresponds to Pribram's (1971) interpretation of signs as nonadaptive neural signals with fixed meanings.

Meanings are created by symbol-processes in the mind. Language plays a special role in these processes. Language accumulates cultural knowledge of the world. Through communication among people, language provides grounding for abstract model-concepts at higher levels in the mind hierarchy. The mechanism of this relationship between language and cognition is joint language-cognitive models. These joint models are organized in parallel hierarchies of language models (words, texts) and cognitive models (world representations in the mind). Near the bottom of these hierarchies, words refer to objects. Higher up, complex texts refer to complex situations. An amazing result of the described mechanism is that words within texts refer to objects within situations, and this reference at higher levels corresponds to the words-objects relationships at lower levels. Because of this multilevel hierarchical structure maintaining meaningful relationships throughout the hierarchy, language is a coherent structure and not a set of arbitrary notations for arbitrary relationships. This meaning-maintaining hierarchy makes possible "the infinite use of finite means."

Cultural evolution results in selection and preservation in language of important meanings. They are related to concept-models important for cognition (and survival). Of course, at every given moment in cultural evolution, there are important and less important models. There are no simple measures for importance of meanings of various models and texts. But the deconstruction idea that meanings are arbitrary is unscientific. Scientific quest is to explain creation of meanings, and this chapter made a step in this direction.

In the early 1800s, Wilhelm von Humboldt (1999) suggested that languages, in addition to their explicit conventional outer form, also contain inner form full of potential and creativity. The mechanism of dynamic logic explains that the creative aspect of language exists in the integrated relationship between language and thinking; concept-models and meanings are developed unconsciously in interaction with language models. This process involves the knowledge and language instincts and aesthetic emotions related to satisfaction of these instincts.

A symbol-process involves conscious and unconscious; concepts and emotions; inborn models-archetypes; and models learned from culture, language, and cognition. Symbol processes continue up and up the hierarchy of models and mind toward the most general models. Due to language, they persist in culture through many generations. In semiotics, this process is called *semiosis*, a continuous process of creating and interpreting the world outside (and inside our minds). Symbols are processes creating meanings.

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Endnotes

[1] R. Jackendoff works within both paradigms, nativist, and cognitive toward unifying both methods.

[2] Dynamic logic should not be confused with dynamic system theory used by some authors to describe cognition (see Van Gelder & Port, 1995). Dynamic systems theory usually describes a single process that occurs with limited (or no) interactions with other processes. When mathematics of dynamic systems is used to describe multiple interacting processes in conjunction with adaptation or learning, it leads to combinatorial complexity. Dynamic logic was specifically designed to address multiple concurrent interacting processes.

Chapter VI

Natural Grammar

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Abstract

By taking as a starting point for our research the function of language to generate meaning, we endeavor in this chapter to derive a grammar of natural language from the more general Peircean theory of cognition. After a short analysis of cognitive activity, we introduce a model for sign (re)cognition and analyze it from a logical and semiotic perspective. Next, the model is instantiated for language signs from a syntactical point of view. The proposed representation is called natural insofar as it respects the steps the brain/mind is going through when it is engaged in cognitive processing. A promise of this approach lies in its potential for generating information by the computer, which the human user may recognize directly as knowledge in a natural and economic way.

Introduction

What is natural in natural language? The answer to this question evidently depends on the interpretation of the word *natural*. We interpret this word as expressing that the features we are looking for represent steps the mind or brain is going through when it is engaged in natural language use.[1] This is not to say that the representation stands for the process in all its detail or that it describes the actual operations the brain is going through, but only that whenever such a process occurs, that process can be represented by the steps discerned in our model. Since this interpretation of naturalness still leaves room for different routes of investigation, we further narrow down our question to: Is it possible to develop a grammar that captures this naturalness formally?

The promise of this chapter is that, indeed, it is possible to develop a natural grammar. Additionally, our research has revealed that such a grammar is not restricted to natural language but can be given a naïve logical and a semiotic interpretation as well. The fact that a grammatical, a naïve logical and a semiotic interpretation, is possible indicates that the corresponding different domains of knowledge can have a uniform representation, a feat that makes our system very economic.

We maintain that an answer to "what is natural in language" can be found if the function of language as a representation of meaning is the starting point of research. According to this view, language can be seen as a kind of cognitive processing of signs. The word *sign* is used here in the broad Peircean sense according to which anything that conveys any definite notion of an object is a sign (CP 1.540). This embeds our original question in a more general one: Can cognition be modeled formally as a sign recognition process? Clearly, if such a general model can be made, then by restricting it to linguistic signs, which are symbols, we may obtain a natural model of language from which an underlying grammar can be derived easily. Since the proposed representation offers a basically computational account, while our meaningful sign use is not confined to computation, this chapter also investigates the complex relationship between computation and meaning.

Defining a computational, though natural, representation can be difficult, as is illustrated by traditional language modeling. Humans process natural language in real time, which is formally equivalent to linear complexity (Paul, 1984). This is opposed to the models of the traditional formal approach, which are typically of higher complexity. A potential side effect of relying on rules dictated by a formal ontology instead of relying on the properties of a natural process can be the limited expressive power of such rules for a systematic specification of complex linguistic phenomena characterizing actual language use. We think the natural model of language introduced in this chapter does not suffer from such a limited expressive power and is on top of this efficient. While we can formally prove the last claim, the first one remains a conjecture in line with our assumption concerning the dynamic nature of language. Some confidence in that conjecture, nevertheless, may be provided by the close relationship between our model and Peirce's theory of signs and with the conclusion of Peircean semiotic,[2] which roughly comes down to the statement that in order to be knowable something has to be of the nature of a sign (see, for instance, CP 5.251).

This conclusion about the all-pervasive character of signs may shed some light on natural language and its conception as a (formal) grammar. For, by knowing the properties of the process underlying cognition, we may be able to answer the question how knowledge, as a cognitive process, could be defined naturally by means of (formal) rules.

Natural grammar, as a formal grammar, bears similarity with the dependency-based formalisms of cognitive linguistics like word grammar (Hudson, 1984). Word grammar is a branch of dependency grammar in that it uses word-word dependencies as a determinant for linguistic structure. As a result, it presents language as a network of knowledge that links concepts about words, like their meaning (e.g., grammatical function) to the form, the word class, and so forth. Such grammars do not rely on phrasal categories. Contrary to cognitive linguistics, which aims at incorporating the conceptual categories of language in rules that are dictated by a formal theory, the rules of natural grammar are derived on the basis of an analysis of the properties of cognition and the processing of signs. Natural grammar also is related remotely to constituency-based approaches in that its types of rules define an induced triadic classification of language concepts that show some analogy to that of the X-bar theory.[3] The view taken by the theories of sign processing, like the computational model of Gomes, Gudwin, and Queiroz (2003) or the cognitive theory of Deacon (1997), has been a philosophical one, dominantly. An approach that tries to do justice to sign processing as a cognitive as well as a semiotic phenomenon first was introduced in *A Logical Ontology* (Farkas & Sarbo, 2000), as far as we know. That theory forms the basis of the approach presented in this chapter.

A theory about cognition always involves assumptions about primary concepts. In the theory presented in this chapter, qualia are assumed to exist. The quale results from the unifying operation of quale consciousness, it is upon these qualia that the intellect operates. A quale is defined as "every combination of sensations so far as it is really synthesized" (CP 6.223). On the one hand, this leads to the conclusion that a quale is not confined to seemingly simple sensations, such as in the perception of *red*, but extends to complex cases such as when we perceive a work of art, a chair, or this day. On the other hand, it raises the question whether it is possible to extend our analysis in order to include the workings of our sensory apparatus and the neuronal fabric that lead up to qualia. This later question falls outside our present scope. For the sake of completeness, we mention the generative methodology due to Pribram (1971) and Prueitt (1995), which is related to the fundamental work by Gibson (1979). Their aim was to develop a generic mechanism for the definition of primary entities but also of complex process compartments in cognitive processing. Their analysis utilizes the concepts of measured perception and spectral properties in order to delve the gap between mind and brain (including the sensory apparatus) or, to put it in the perspective of our model, in order to give a physical/mental account of qualia. An analysis of the relations between that theory and ours is beyond our scope.

Toward a Model of Cognition

Cognition is concerned with the interpretation of phenomena according to their (possible) meaning. In this chapter, we will attempt to deal with only a small part of this far too complex problem; we focus on the restricted domain of *perceptual judgments* (CP 4.540). Inasmuch as we may know about phenomena, by means of observations, the problem of sign recognition can be reduced to a question about the nature of observations. We will consider this issue from two points of view. The first is the *cognitive theoretical* one, according to which phenomena appear as stimuli, and the question is: How can stimuli finally be recognized in a meaningful reaction? The second is the *semiotic* one, according to which we may know about phenomena by means of signs, and the question is: How can signs develop to their meaning?

These two views are interrelated, and their dependency is expressed in this chapter by postulating that stimulus potentially is a sign, and that reaction is an interpreting proposition by which a stimulus or percept is transformed into a fact of immediate perception. For example, if we observe smoke, which appears as a visual stimulus or percept that can be a sign, then shouting "Fire!" may be our meaningful reaction.

The problem of sign recognition gets further complicated by asking for a computational solution, which tacitly requires a computational model for cognition that satisfies the link between the cognitive and the semiotic viewpoints. This complication can be further developed along two different lines.

The first line of argument is related with Searle's thought experiment in which he develops the Chinese Room Argument. By stating that knowledge emerges from a natural, human process, the rules of which have to be on that account natural, too, the following question can be raised: Which computational rules and interpretation can satisfy this condition in such a way that the result of the application of the rules is naturally meaningful, too? According to Searle, here we are facing a fundamental problem due to the limitations of the computer. For, contrary to man, the computer is unable to intentionally connect a sign with its object.

The second line of argument departs from the distinction Peirce makes between mechanical and purposive action. Mechanical action is characterized as a blind compulsory process that leaves little room for variation: just causes and effects following each other in sequences. Purposive action, on the other hand, involves the mediation of a goal or purpose that interferes with the course of events. Purposive action aims at the removal of stimulation (CP 5.563) but is quite open-ended regarding the means (mechanical processes) used to achieve this goal. It, in short, is learning and introduces abstractions by its reliance on abductive inferences for the generation of satisfactory solutions. This kind of action may be hard to formalize. Our current model does not capture learning; it aims at capturing habits of thought or habits of thought-like action.

Cognition as a Process

Since we regard cognition as a process, a word about our understanding of processes is in order at this point. A process will be considered to be any sequence of events such that (1) one event initiates the sequence and another terminates it, (2) every event that contributes to the sequences yielding the terminating event is regarded as part of the process, and (3) the terminating event governs the decision of which events make up the sequence. Although the events making up the sequence generate the terminating event (efficient causation), the whole process is governed by its goal (teleological causation). An event will be considered as whatever makes a difference (Debrock, Farkas, & Sarbo, 1999).

The input of cognitive processing is the stimulus, which is recognized by the mind/brain. This view of cognition is compatible with the assumption laid down by the Peircean theory of perceptual judgments that the real world is forced upon us in percepts (CP 2.142) from which perceptual judgments are obtained through interpretation (CP 5.54) by means of a process that is utterly beyond our control (CP 5.115).

A fundamental property of all systems, including biological ones, is their potential for generating an answer (re-action) to a stimulus (action). The *goal* of this process is the generation of an adequate reaction on the stimulus, regarded as an external effect. An important element of response generation is the interaction between the external effect (stimulus) on the one hand and the interpreting system on the other. From the assumption that the source of all reaction or meaning is an interaction and knowledge is a *re*-presentation of such interactions, it follows that knowledge, too, must be inherently dynamic, and hence, a process.

The external effect (stimulus) is affecting the interpreting system, which occurs at the moment of affectation as a state. As anything appearing as an effect can appear as well as a state, there must be something common in both. We call this a *quality*, after Peirce. Because state and effect are independent in principle, all phenomena are considered to be interactions between independent qualities. Let us emphasize that there may be any number of qualities involved in an interaction, but according to the theory of this chapter, those qualities are always distinguished by cognition in two collections (state and effect), which are treated as single entities. The potential for considering a collection of qualities as a single entity (i.e., chunking) is an assumption shared by the theory of perceptual judgments as well (CP 7.530).

Processing Schema

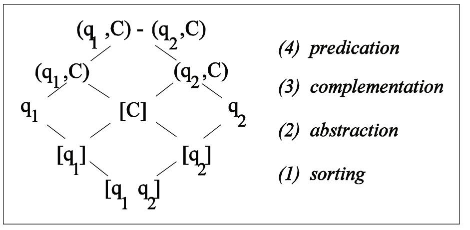
Phenomena are an interaction appearing via the mediation of a change, as an event (i.e., reaction). Following the received theory of cognition (Harnad, 1987), the representation of phenomena by cognition can be modeled as follows.

By virtue of the appearing change, the sensory signal is sampled in a percept. In a single operation, the brain compares the current percept with the previous one, and this enables it to distinguish between two sorts of input qualities (in short, input): one that was there and remained there, which can be called a *state*; and another that, although it was not there, is there now, which can be called an *effect*.[4] In cognitive theory, qualities as perceived are called *qualia*.

The change, signifying an interaction in the real world, can be explained as follows. During input processing, the stimulus may change, meaning that its current value and the value stored in the last percept can be different. That difference can be interpreted by the brain as a change, which mediates the actual value of the stimulus to its current meaning.

The reaction of an interpreting system is determined by the system's knowledge of the properties of the external stimulus, including its experience with the results of earlier response strategies (habit). Such knowledge is an expression of the system's potential for interpreting or combining with a type of input effect, depending on the system's state. Such properties shall be called the *combinatory* properties of the input qualia or the *context* of the observation.

Figure 1. The schematic diagram of cognitive processing



In complex biological systems, knowledge is concentrated in functional units like the sensory, central, and motor subsystems. The most important of these is the central system, which includes the memory. The translation from external stimuli to internal representation (qualia) is due to the sensory subsystem, which itself is an interpreting system, generating brute reactions (translations). For the goal of this chapter, the role of the motor subsystem is secondary and, therefore omitted.

The primary task of cognitive processing is the interpretation of the external stimuli by making use of the latter's combinatory properties. Since the input is assumed to consist of two types of qualia (state and effect), together appearing as a primordial soup ($[q_1\ q_2]$), the stages of processing can be defined as follows (see also Figure 1). Square brackets are used to indicate that an entity is not yet interpreted as a sign; no bracketing or the usual bracket symbols indicate that some interpretation is already available.

1. The sorting out of the two types of qualia in the primordial soup as state and effect, respectively.

   Sorting: $[q_1]$, $[q_2]$
2. The separation of the collections of the two types of qualia.

   Abstraction: q_1, q_2
3. The linking of the qualia with their combinatory properties ([C]).

   Complementation: (q_1,C), (q_2,C)
4. The establishment of a relation between the completed qualia.

   Predication:[5] $(q_1,C) - (q_2,C)$

Perception and Cognition

In an earlier version of the model of this chapter, *A Peircean Ontology of Semantics* (Farkas & Sarbo, 2002), we introduced two levels of cognitive processing, which we called perception and cognition. The goal of perception, as a process, is the establishment of a relation between the input qualia and the memory information (the importance of the relation between the input qualia is secondary in this process). As a result, perception obtains the meaning of the qualia in themselves. In accordance with perception's goal, the memory response or the context ([C]) contains information about the properties of the input qualia independently from their actual relations. This information is iconic (comparable to lexical meaning).

The state and effect types of input qualia are indicated by *a* and *b*, respectively, and those of the memory by *a'* and *b'*. All four signs may as well refer to a type as to a collection of qualia.

Among the representations obtained by perception, only the final one (step 4) is of interest for the rest of this chapter. We assume that the *a'*(*b'*) memory response arises by means of the *a*(*b*) input qualia, triggering the memory. Although the two types of memory response signs are independent, they contain reference to a common meaning. This is due to the existence of interaction between the input qualia.

Depending on the activation of the memory, there may be qualia in the memory response ([C]) having an intensity above (i) or below (ii) threshold, respectively referring to an input (meaning) which is in the brain's focus, and which is only complementary. The distribution of the roles in any given case depends on the actual activation of the memory, which defines the state of the mind/brain.

A high intensity response of type (i) signifies the recognition of the input as an agreement between the input and the memory response: *a*(*b*) is recognized or *known* as *a'*(*b'*). A low-intensity response of type (ii) refers to input recognition as a possibility only; the input *a*(*b*) is not recognized or *not known* as a'(b') as a consequence of which the memory response only represents a secondary or even less important aspect of the input qualia.

By indicating the first type of relationship between input and memory response by a '∗' symbol and the second type by a '+', the signs of perception can be represented as: *a∗a'*, *a+a'*, *b∗b'*, *b+b'*. For example, *a∗a'* signifies the event of positive identification of *a* by *a'* (type (i)), as opposed to *a+a'* (type (ii)), which refers to the identification of a possible meaning of *a* by *a'* (hence, to a denial of a positive identification).

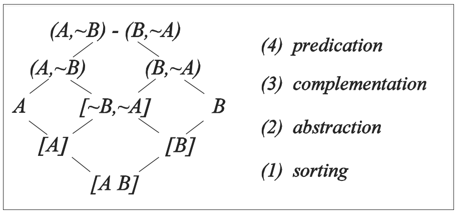
In perception as an actual process, the four signs are presented as a single sign. The recognition of the difference between the four types of relations is beyond its scope.

Cognition

The process of cognition is an exact copy of the process of perception except that the goal of cognition is the interpretation of the relation between the input qualia, which are in the focus, in light of the qualia, which are complementary. (Now it is the relation between input and context which is secondary.) In accordance with cognition's goal, the context ([C]) contains relational, complementary information about the input qualia, which involves indexicality.

In the process of cognition, the input appears as a primordial soup, too, which is defined by the synonymous signs of perception. In fact, the difference between the four meaning elements functions as a ground for the process of cognition. This is acknowledged in our model by the introduction of an initial representation of the four relations that function in perception: *a∗a'* as *A*, *a+a'* as ¬A, *b∗b'* as *B* and *b+b'* as ¬*B*. The presence or absence of

Figure 2. The schematic diagram of cognition, as a process[6]



a '¬' symbol in an expression indicate whether the qualia signified are or are not in focus. Hence, '¬' can be interpreted as a relative difference with respect to the collection of a type of qualia (state or effect), represented as a set. How the processing schema of sect. 4 can be instantiated for cognition is depicted in Figure 2.

We especially want to point to step 3, in which the link between input qualia and context is established. This is done in accordance with the goal of cognition and the duality of phenomena alike. This explains why there can be a relation between A and $\neg B$, and $\neg A$ and B and why there is no relation between A and $\neg A$, or B and $\neg B$.[7] Finally, in step 4, the cognition process is completed by establishing the relation between A and B.

The three relations, which correspond to the three types of interactions between the input qualia, can be characterized by means of the meaning of their constituents (from a computational stance, this interaction is a relation that will be indicated by a '—' symbol):

1. $A — \neg B$:

   A is known, but B is not known;

   the complementation of the input state (actualization).

2. $B — \neg A$:

   B is known, but A is not known;

   the complementation of the input effect (refinement).

3. $(A, \neg B) — (B, \neg A)$:

   both A and B are known;

   the assertion of the relation between A and B (proposition).

If neither A nor B is known, interpretation terminates before reaching its goal, meaning that cognition does not occur. The reader may have noticed the mediative function of the context signs, which is operative in step 3. Indeed, through the correspondence between the two signs, $\neg A$ and $\neg B$, which are triggered by the same input, the context implicitly determines the actual relation between A and B. That relation can be called a proposition resulting from a hypothetic inference, but only if we acknowledge, in accordance with the Peircean view of a perceptual judgment, that the percept's "truth consists in the fact that it is impossible to correct it, and in the fact that it only professes one aspect of the percept" (CP 5.568).

Logical Analysis

The previous interpretation of cognition already illustrates, to some extent, the completeness of that process, but this becomes even clearer from a logical analysis of the processing schema. This section is an attempt to elaborate such an analysis on the basis of the model of cognition already introduced. It is good to bear in mind that the results are directly applicable to the model of perception as well. The hidden agenda of this section is the tacit introduction of logical operations in the process model of cognition. What makes the use of such concepts valuable is that they have a well-studied, precise meaning.

An essential element of a logical approach to cognition is the abstraction of a common meaning for the different types of qualia, which is the concept of a logical variable. In virtue of the duality of the input, the logical interpretation of the process model of cognition requires the introduction of two variables, which are denoted by A and B. The difference between the qualia, which are in the focus and which are only complementary, is represented by the difference of their expression by means of a logical variable, which is stated positively or negatively. Perceived state and effect qualia, which are in the focus, are indicated by A and B, respectively—those that are complementary by $\neg A$ and $\neg B$. Here, '¬' denotes logical negation; that is, relative difference with respect to the collection of a type of qualia, represented as a set. For example, the complementary subsets of the set of A-type qualia are denoted by A and $\neg A$ (hence, the label A is used ambiguously).

Conform the previous mapping, and the logical meaning of the cognitive relations can be defined in the following way. The relational operators introduced in the instantiation of the processing schema for perception ('+' for possibility and '∗' for agreement) are inherited by the cognitive model and its logical interpretation as logical 'or' ('+') and 'and' ('∗').

$[q_1]= A+B$, $[q_2]= A*B$:

expresses the simultaneous presence of the input qualia, which are in focus as a simple, possible co-existence ($A+B$), and, in the sense of agreement, as a meaningful co-occurrence ($A*B$), respectively.

$q_1= A*\neg B, \neg A*B$:

expresses the abstract meaning of the input qualia, which are in the focus as constituents, irrespective of the actual co-occurring other type of qualia. It is this perspective that makes the two signs synonymous (the "," in the definition of q_1 directly above is a meta-level expression of this equivalence).

$q_2= A*\neg B +\neg A*B$:

expresses the input as an abstract co-occurrence in terms of a compatibility relation (a possible co-existence) of the two types of abstract constituents of the input (which are now considered as being different). In *A Logical Ontology* (Farkas & Sarbo, 2000), we have proved that the logical expression of q_1 and q_2 can be formally defined as the relative difference of $[q_1]$ and $[q_2]$. The context ([C]) is defined by the complementary qualia represented as a co-existence ($\neg A+\neg B$) and as a co-occurrence relation ($\neg A*\neg B$). The synonymous representation of these signs is an expression of the complementary (secondary) meaning of the qualia, but also of the common property referred to by the simultaneously present $\neg A$ and $\neg B$ type of qualia comprising the context.

$(q_1,C)= A+\neg B, \neg A+B$:

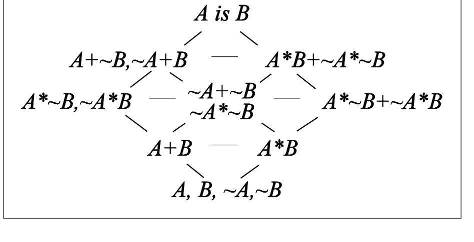
expresses the abstract constituent (q_1) completed with the meaning of the context ([C]) or, alternatively, the actual meaning of the input qualia as constituents. For example, the actual meaning of *A* as a constituent is defined by *A* itself and by $\neg B$, the complementary property linking *A* with *B*, implicitly (as the relation between *A* and *B* is not yet established, the *B* type qualia cannot contribute to the actual meaning of *A*, as a constituent). Alternatively, the meaning of $\neg A*B$ in context is defined by the qualia completing this abstract meaning, which are *A* and $\neg B$. As the two interpretations of *A* as an actual constituent are related to each other by the relation of co-existence, the logical meaning of (q_1,C) can be expressed by $A+\neg B$. For the same reason, as in q_1, the two representations of (q_1,C) are interpreted in the model as synonymous.

$(q_2,C)= A*B +\neg A*\neg B$:

expresses the abstract compatibility relation in context, thus interpreting the input as a characteristic property which appears as an event. That such an event occurs between *A* and *B* or, alternatively, between $\neg A$ and $\neg B$, represents the interaction which is in the focus, respectively, positively and negatively. Again, we refer to *A Logical Ontology* (Farkas & Sarbo, 2000), in which we have proved that the logical expressions of (q_1,C) and (q_2,C) can be formally defined as the logical complements of q_1 and q_2, respectively, by means of interpreting the interaction with the context ([C]) as a logical negation operation ('¬').

$(q_1,C) - (q_2,C)= A \text{ is } B$:

Figure 3. The logical signs of cognition as a process



expresses the logical relation between the focused input qualia, represented as a proposition.

The logical expressions describing the process of cognition are summarized in Figure 3. The logical signs, '*0*' and '*1*', which are omitted, can be defined as representations of a *not-valid* and a *valid* input, respectively. Notice in Figure 3 the presence of *all* Boolean relations on two variables, reinforcing our conjecture concerning the completeness of the underlying cognitive process. The results of this analysis show that logical signs (hence, also the concepts of cognition as a process) can be defined as a relation (interaction) between *neighboring* signs that is in need of settlement. In Figure 3, such signs are connected with a horizontal line.

The figure can be traversed by the application of the operation of relative difference to the connected pairs. We make a distinction between three types of this operation. *Sorting* is relative difference with respect to qualia in themselves. The input contains two types of qualia that are in the focus—*A* and *B*—that we represent from the point of view of co-existence ($A+B$) and co-occurrence ($A*B$);[8] that is to say, as sorted qualia. *Abstraction* is relative difference of sorted qualia with respect to each other. An example is $\neg A*B+A*\neg B$. The reader may check this by computing $(A+B)\backslash(A*B)$. *Complementation* is relative difference of an abstracted quality with respect to the input as a whole. An example is $A*B+\neg A*\neg B$. The reader may check this by computing $1\backslash(A*\neg B+\neg A*B)$.

Semiotic Analogy

That the formal computational and the intuitive interpretation of a sign are tightly related to each other must be clear from the previous explanation of the logical relations of cognition. This dependency forms the basis for the semiotic interpretation of those nine types of relations, which can be explained as follows.

- $[q_1]$: Represents that the constituents are trivially part of their collection as a whole. Hence, they are similar to it. So, the representation of the input, as a constituency relation, expresses *likeness* with respect to the input, which is represented as primordial soup.
- $[q_2]$: Represents that the aspect of *simultaneity* is a primary element of the input, as an appearance (event) that happens now.
- q_1: Represents that the abstract conception of the input is an expression of its being as a *qualitative possibility*.
- q_2: Represents that the compatibility of the abstract meaning of the input qualia is expressive of a *rule*-like relation.
- (q_1,C): Represents the meaning of the abstract constituents in context. It is a definition of the *actual* meaning of the input qualia, as something *existent*.

- (q_2,C): Represents the interpretation of the abstract compatibility relation in context as a characteristic property; it presupposes the existence of a *consensus*.
- $(q_1,C) - (q_2,C)$: Represents that the assertion of a relation between the input qualia involves the formation of a *proposition*, which is a hypothesis.

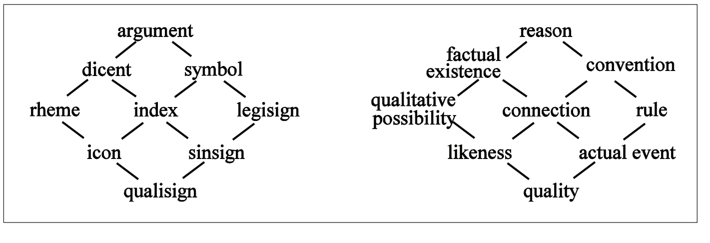
From this semiotic interpretation of the logical relations, the analogy with the Peircean sign classification follows trivially. A serious treatment of this classification would demand a chapter of its own; here, we will have to do with some introductory remarks.[9]

Throughout his philosophical career, Peirce was occupied with attempts to classify signs in a systematic way. The roots of the system reside in his phenomenological work on the Doctrine of Categories, which, in the spirit of Kant, has the task to "unravel the tangled skin of all that in any sense appears and wind it into distinct forms" (CP 1.280). This work led him to believe that there are three basic categories: monadic Firstness (the possible), which appears in consciousness as feeling or the consciousness of quality without recognition or analysis; dyadic Secondness (the actual), which appears as a consciousness of interruption in the field of consciousness or as the brute intrusion of another quality; triadic Thirdness (the lawful), which synthesizes the content of consciousness or the mediation by thought of the different feelings spread out in time (cf. CP 1.377).

The work on sign classification proceeds by repeatedly applying the three basic categorical distinctions to signs. It starts with the definition of a sign as "something, A, which denotes some fact or object, B, to some interpretant thought, C" (CP 1.346). This definition yields three ways in which a sign may be considered. First, a sign may be considered in itself. If we do so, we neglect the relations a sign may have with its object and interpretant, and we only regard the sign as a possible sign. Second, we may regard the sign in its relation with its object only and neglect the relation it has with its interpretant. If we do so, we regard the sign as an existing sign but still without any effect. And third, we may look at how the sign addresses its interpretant. If we do so, we regard the sign as a real or effectual sign. In this last case, we try to unravel the full meaning or import a sign may have by figuring out how the sign manages to relate the interpretant of the sign with its object. If we concentrate on a sign-interpretant sequence in some concrete situation, we study embedded signs.

In a second round, Peirce applies the categorical distinctions to the sign relations just discerned. The first tenable result is summarized at the left-hand side of Figure 4; the bottom-right diagonal gives the relational aspects pertaining to the sign in itself; the intermediate gives the aspects pertaining to the way the sign may relate to the object; and the top-right

Figure 4. The Peircean types of signs and their aspects of meaning



diagonal gives the ways in which the sign may address its interpretant. On the right-hand side of Figure 4, the technical terms that give the meaning aspects are stated in more mundane terms, which also are used in the semiotic interpretation of the nine aforementioned types of relations.

We get at a typology of signs by selecting a term from each diagonal. The least developed existing sign type is a rhematic, iconic sinsign (e.g., a term) involving qualisigns. The most developed an argumentative, symbolic legisign in which all less developed signs are involved. This model of nine sign aspects yields 10 sign types as a result of the constraint that the categorical value of a term on a higher-right diagonal cannot be higher than the value of a term on a lower-right diagonal. By taking the process of cognition, which always is an argument, as our focus and by assuming that all less-developed meaning aspects are involved, we turn the static classification into a dynamical process model.

It is important to note that we interpret the relational aspects of the classification as the parameters of (full) meaning. The isomorphism between the cognitive process and Peirce's classification is a consequence of the isomorphism between the induced order of cognitive processing, on the one hand, and the interdependency of the Peircean sign aspects, based on categorical distinctions, on the other. But this is all there is! The model introduced in this chapter is suited for a computational interpretation. But, although the previous mapping establishes a link between the Peircean signs and the Boolean logical relations and, hence, define a computational level of authentic semiosis, the full meaning of the Peircean sign types is qualitatively more than such logical relations, since the relations always exist between two sign aspects, while a sign type irreducibly contains three aspects. Finally, let us mention that the process view of signs can be introduced also from the Peircean theory itself (Debrock et al., 1999).

By assuming that the full meaning of a sign emerges through embedding in real-life interaction with the world, from the relations generated by cognitive processing, the nine sign aspects can be considered hypothetically to be a link between the computational and the semiotic level of meaning. Inasmuch as those aspects are enclosed in a process, which finally results in something that can be characterized as truly meaningful, it is probably best to consider the nine aspects as unfinished meaning elements; that is, as signs that are in a process of becoming signs (van Breemen & Sarbo, 2006). Such signs are called in this chapter *pre-* or *proto-signs*[10] (Sarbo, 2006).

The different characterizations of knowledge—a combinatory process of qualia (Figure 2), a representation of logical relations (Figure 3), a hierarchy of increasingly more complex meaning elements (Figure 4), but also its other possible interpretations—are interrelated, and it is their collection that approaches full meaning. The conjecture of this research is that if a uniform representation can be proved to exist, this can be the key for an efficient (computational) merging of knowledge obtained in different domains into a single representation. Experimental evidence pointing in this direction is found in Hagoort, Hald, Bastiaansen, and Peterson (2004).

Combinatory Relations and Properties

We may observe an entity, as a state, only by virtue of an appearing effect, but the occurrence of an effect always entails the existence of a state. This asymmetry between state and effect is the ground for a semiotic interpretation of the differences between the three types of relations recognized by cognitive processing.

1. $A - \neg B$:
   A is a potential meaning, which is actualized by $\neg B$.
2. $B - \neg A$:
   B, which is in principle self-sufficient, receives its full meaning from its association with $\neg A$.
3. $(A,\neg B) - (B,\neg A)$:
   A and B, which are self-sufficient, together generate a new meaning.[11]

The interpretation of these (cognitive) relations as syntactic signs has been introduced in *Syntax From a Peircean Perspective* (Debrock, Farkas, & Sarbo, 1999). Syntactic signs, which are a representation of the three types of a nexus between syntactic symbols, correspond to the Peircean categories of Firstness, Secondness and Thirdness; for example, a primary syntactic entity (a word), a syntactic modification (of a noun by an adjective), and syntactic predication (subject and predicate forming a sentence), respectively. The important consequence of this transitive relation between cognition and the categories is the existence of a necessary and sufficient condition for ontological specifications, which are typically syntactic relational, too; in particular, those that also are meant to be used in computer applications. The analysis of the meaning of the constituents in the three types of relations proves that the specification of the (combinatory) properties of qualia can be restricted to three cases. The specification of the qualia:

1. in themselves;
2. with respect to other qualia that are complementing it or that they are complementing;
3. with respect to other qualia, together with which they can generate a new meaning.[12]

We call such a specification a *trichotomic specification* or, briefly, a *trichotomy*. In virtue of the dependency between the Peircean categories, the meaning of a more developed class contains the meaning of a less developed one in a trichotomy. By assuming that the three types of meanings can be defined in each trichotomic class recursively, we have in front of us the hierarchical schema of ontological specification suggested by the theory of this research.

A framework that is remotely related to the approach presented here is the theory of Nonagons (Guerri, 2000), which originally was introduced to support the completeness of a design; for example, an architectural design. Nonagons are also based on Peirce's sign aspects and a recursive expansion of his classification. There is, however, an important difference between the two approaches in regard to the interpretation of a sign either as an entity that emphasizes its character as a single unit (the Nonagon approach) or as an entity that stresses the inherent duality implied by truly triadic semeiosis (the view maintained by this work).[13] A practical advantage of the latter view lies in its capacity for defining the nine classes as a product of (dual) trichotomies, thereby potentially simplifying the specification task. An example illustrating the benefits of recursive specification of the properties of qualia in text summarization is presented in Farkas and Sarbo (2002) and in Sarbo and Farkas (2004).

In summary, there are three types of relations between signs in accordance with the three categories of phenomena. Qualia, which are the constituents of a syntactic sign interaction, can be analogously characterized recursively as:

1. A quality, which is a potential existence;
2. A state, which appears by virtue of an effect (*a* or *A*);
3. An effect, which implicates the existence of a state (*b* or *B*).

The three categories are not independent from each other. Though thirdness is the most developed, nevertheless it requires secondness and firstness (the latter via the mediation of secondness). Analogous with the categorical relations, an effect can be said to contain a state and, transitively so, a potential existence. By means of the induced ordering of the dependency between the categories ('<') as a polymorphic operation, the relation between the cognitive types can be abstracted as follows: $a<b$ and $A<B$. For example, the meaning of a quale, which is an effect, implies the existence of its meaning as a state.

Example

This section contains an example that illustrates the recognition of the real world phenomenon—smoke—as the sign of danger. Assume that we are watching for some time the smoke rising from the chimney of a roof, and suddenly we see fire blaze up. The input qualia of perception can be defined as follows (boldface symbols are used to indicate input qualia):

a= **smoke**, *b*= **fire**

and the final signs of perception, represented as the initial signs of cognition (italic is used to indicate memory signs):

A= **smoke**∗*smoke*, ¬*A*= **smoke**+*roof-in-burning*

B= **fire**∗*fire*, ¬*B*= **fire**+*burning*

The recognition of these signs yields the following relations (in a reference to an interpretation, which is dealt with as not known, the input is omitted):

(q_1,C)= (**smoke**∗*smoke*, *burning*)
(q_2,C)= (**fire**∗*fire*, *roof-in-burning*)

which together generate the proposition through the mediation of the *burning* of the *roof*:

$(q_1,C) - (q_2,C)$= (**smoke...**) IS (**fire...**)

This sign can be represented eventually by shouting "Fire!" or simply by running away, as our interpretant reaction, assuming there is a real need.

In order to enable the recognition of the input as such a meaningful relation, the input qualia have to be adequately specified by means of trichotomies. Let us exemplify this with the specification of smoke (hence, implicitly also of **smoke)**, which can be regarded:

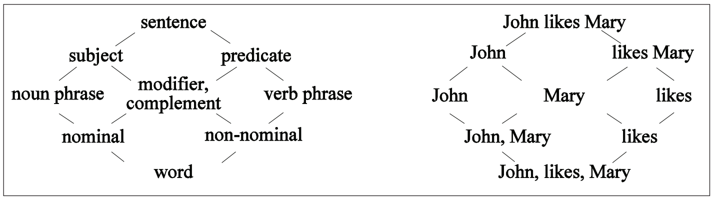
1. In itself as an entity that is a quale, having properties underlying its combinatory potential such as color, density, and so forth.
2. In relation to another quale, which is complementing it (e.g., *rising-from-the-chimney*) or which it is complementing (e.g., *blowing* [as a smoke-producing effect]).
3. As a self-sufficient sign, such as the subject of *any-burning*.

Notice that the qualia of (1) function as the ground for the connections of (2), which in turn underlie the meaningful relations of (3).

Natural Language

The process model of cognition easily can be applied to natural language. In natural language, the input qualia can be a morpheme or a word (a morpho syntactically finished symbol) in a morphological and a syntactical analysis, respectively. The perception process, linking the input with memory information, corresponds to lexical analysis. The single stimulus or percept view of the cognitive model of this chapter requires that conceptually, the entire input is present in a single observation. To this end, the order of appearance of the input symbols can be represented as a quale,[14] which eventually leads to a sequential model of cognitive processing. In the model of language, as syntactic signs, the second process (cognition) corresponds to parsing, interpreting the input symbols, as (morpho-) syntactic relational needs (combinatory properties), which may combine (bind). In the rest of this chapter, the focus will be on syntactic symbols; the process of morpho-syntactic recognition is omitted.

Figure 5. The classification of syntactic concepts and the concepts of the sample utterance "John likes Mary"



Step 1 (see Figure 1) corresponds to the classification of the input symbols as nominals ($[q_1]$) and non-nominals ($[q_2]$). Which of the symbols is in the focus and which is only complementary follows from the syntactic rules and the order of appearance of the input symbols. Step 2 amounts to the identification of noun (q_1) and verb phrases (q_2) but also of modifiers and complements ([C]); step 3 is devoted to modification ((q_1,C)) and complementation ((q_2,C)) and step 4 to syntactic predication.

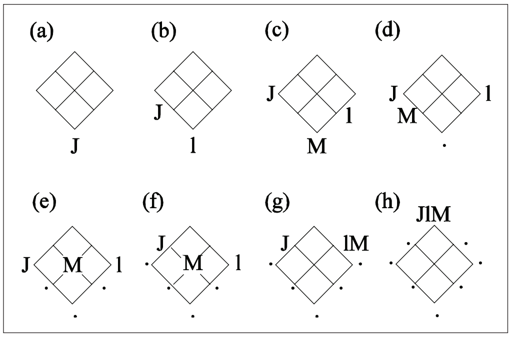
The classification of syntactic concepts is depicted in Figure 5 on the left-hand side. On the right-hand side, one may find an illustration of the syntactic concepts by the analysis of a simple utterance. The goal of this example is twofold. The first is an analysis of syntactically meaningful concepts and their dependency; the second is an illustration of the sequential order of the input symbols (on surface level) as potentially meaningful.

Sequential Processing

Contrary to the earlier example of smoke and fire, in the language phenomenon presented in Figure 5, "John likes Mary" (in short *J l M*), we have more than two qualia, but these, too, can be distinguished in two collections: [*JM*] and [*l*]. These collections are interrelated: '[*l*] happens to [*JM*]'. The linguistic interpretation is more refined, however. The relation between *l* and *J* is different from the one between *l* and *M*. This difference is signified in English by means of the order of the input symbols. This ordering, as a quale, is recognized by the language user, together with the other meaning(s) of the involved symbols.

This line of thinking has led us to a sequential version of our model of language, in which the effect of the order of the input symbols is defined by means of the nine Peircean sign aspects (Sarbo & Farkas, 2001). On surface level, the input symbols appear one after the other. Because each symbol may contribute to the meaning of the entire sequence (the sentence) only as a proto-sign, the recognition of the individual input entities may overlap. In general, the processing of subsequent sentences may overlap as well. In the utterance of Figure 5, the input symbols appear as qualisigns.[15] As the input qualia in principle are independent but also partake in the same sentence (phenomenon), the appearance of *l* forces us to reconsider the earlier interpretation of *J* (qualisign). A possible solution of this can be the representation of *J* as a constituent (icon) of the entire input in accordance with the principle of economy, characterizing language recognition, which states that a less developed representation of a phenomenon has to be generated before a more developed one.

Figure 6. Syntactic analysis of "John likes Mary"



The appearance of *M* has similar consequences on *l* and, transitively so, on *J*. The latter is due to our assumption that the signs yielded by sorting (see section 4) signify the qualia of a single phenomenon as potential co-existence (icon) and co-occurence (sinsign). As *J* and *l* together do not mediate such a meaning, it follows that *J* has to be represented again, but this time as a possible abstraction of the entire input (rheme). Notice that any representation of a symbol must contain the earlier meaning states of the same symbol. The subsequently appearing dot symbols (the role of which will be explained in the next section) trigger a chain of representations of which we explain only the representation of the nominal meaning of *M* (icon). We start with applying the same strategy, such as in the case of *J* (icon), but then parsing will eventually fail, as we cannot represent the entire input in a single sign. So we assume the parser backtracks until the first point that provides an alternative,[16] which represents *M* as a complement of *l*. This example also illustrates how our model may discover whether a symbol is part of the complementary context, if that property is not indicated otherwise. The parsing of the example of Figure 5 is displayed in Figure 6.

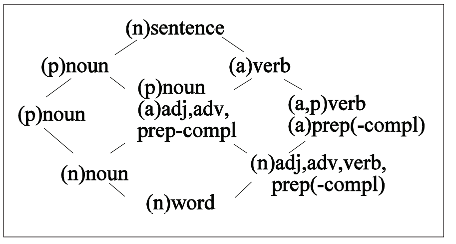
Due to the sequential processing of the input, we have to consider two new cases of an interaction (relation) between symbols: the first is *accumulation*, which is a binding between signs having an identical status and compatible information; the second is *coercion*, which is an interaction that does not actually happen. What does happen in such an interaction is that an existing sign is forced to be represented by or is coerced to a more meaningful interpretation. Coercion and accumulation are degenerate versions of (genuine) binding.

The specification of the qualia with respect to other qualia that are complementing it or that they are complementing (see section on combinatory relations) corresponds to syntactic modification and complementation, respectively. This indicates that the two types of phenomena can be treated uniformly in our model.

Toward a Formal Model

The syntactic interpretation of the classification of qualia (see section on combinatory relations) as the constituents of a binding defines the three types of syntactic relational needs acknowledged by our model: (1) neutral, (2) passive, and (3) active (in short, *n*-, *p*- and

Figure 7. Classification of syntactic symbols



a-need). The goal of language cognition as a syntactic process is syntactic well-formedness. This is formally interpreted by requiring that the final representation of the (entire) input may not have any unsatisfied relational needs. The different types of binding can be characterized from this point of view as follows. A coercion satisfies an *n*-need; in an accumulation, two relational needs of the same type are merged to a single need; a (genuine) binding satisfies a pair of *a*- and *p*-needs.

Figure 7 summarizes the potential syntactic relational needs for the types of speech. The input qualia are defined as follows: *A*=noun; *B*=verb, adjective, adverb,[17] prep(-compl), where "compl" can be a noun, verb, adjective, or adverb. The trichotomic specification of syntactic symbols is such that through representation, *A*-type symbols can have a relational potential, as an (1) icon, (2) rheme or index, and (3) a dicent type of sign; and, *B*-type symbols as a (1) sinsign, (2) legisign or index, and (3) a symbol type of sign. In English, the category-related dependency between the different interpretations of a symbol, as an *A*- or a *B*-type quale, is used, among others, for the modeling of modification phenomena like *runs quickly*. In this example, the *a*-need of *quickly* (index) satisfies the *p*-need of *runs* (legisign), indicating that the effect (*run*) is considered in this interaction, as a state (*run*). Also, object complementation phenomena such as *painted black* can be modeled isomorphically.

We define a "dot" symbol as an *A and B* type sign, which cannot bind except with its own type. Dot symbols can be used to force the realization of pending interactions. We assume that the entire input is closed by a constant number of dots. From the specification of Figure 7 and the earlier introduced properties of sequential processing, a formal definition of a Natural Grammar of English can be derived easily[18] (Sarbo & Farkas, 2002). In Figure 7, optional *n*-needs are omitted.

The *kernel* of an algorithm for the parsing of coordination has been presented in Sarbo and Farkas (2004). The essential point of this algorithm is the merging of signs having an identical sign type to a synonymous meaning. Multiple modification and complementation as well as embedded clauses can be modeled by means of recursive incarnations of the parsing machinery. In Sarbo and Farkas (2002), we formally proved that the complexity of cognitive processing in our model is linear in the number of input qualia and operations on them.

Table 1. Syntactic analysis of a man entered who was covered with mud

nr.	*qual*	*icon*	*sins*	*rhem*	*index*	*legis*	*dicent*	*symbol*	*rule*
0	a man (a_m)								i
1	entered(e)	a_m							i,c
2	who(w_h)		e	a_m					i,c,c
	recursion								
3	was covered (w_{cd})	w_h							i,c
4	with mud (w_m)		w_{cd}	w_h					i,c,c
5			w_m	w_h		w_{cd}			c, c
6				w_h	w_m	w_{cd}			c
7					w_m	w_{cd}	w_h		c
8							w_h	w_{cd}-w_m	b
	return								
9	who-..-mud(w_{cm})		e	a_m					i
10			w_{cm}	a_m		e			c,c
11				a_m	w_{cm}	e			c
12						e	a_{hm}-w_{cm}		b
13							a_m-w_{cm}	e	c

Example

This section is an attempt to illustrate the potential of our approach for modeling complex linguistic phenomena. The presentation of the analysis is simplified by introducing a tabular form for the sign "matrix" as used in Figure 6, in which a column corresponds to a sign aspect, used as an indicator of the processing status, and a row to representation act(s), arising due to the application of rules, indicated in the last column. The following abbreviations are used: input (i), accumulation (a), coercion (c), binding (b). Accumulated signs are separated by an "/" sign. The names of some of the sign aspects are abbreviated. The parsing of dot symbols is omitted. Predication is not displayed due to lack of space.

The first example illustrates discontinuous modification. Let us take as our starting point the morpho-syntactic analysis of the sample utterance: (A man) (entered) (who) (was covered) (with mud). In the syntactic parsing (see Table 1), we make use of recursion in the analysis of the segment initiated by "who" and closed by the sentence ending dot. In the recursively analyzed part, "who" functions as a (dummy) subject. The final sign of this segment is represented degenerately by a single quale (w_{cm}) having an adjective-like relational need due to the unsatisfied relational need of "who."

Table 2. Syntactic analysis of Mary is a democrat and proud of it

nr.	*qual*	*icon*	*sins*	*rhem*	*index*	*legis*	*dicent*	*symbol*	*rule*
0	Mary(M)								i
1	is(i)	M							i,c
2	a democrat (ad)		i	M					i,c,c
3	and(&)	ad		M		i			i,c,c
4					ad	i	M		c,c
	save								
5	proud(p)								i
6	of it(oi)		p						i,c
7			oi		p				c,c
8					p/oi				c,a
	coordination								
9					ad&p/oi				
	restore								
10					ad&p/oi	i	M		
11							M	i-ad&p/oi	b

The second example (see Table 2) illustrates coordination. We assume the morpho-syntactic analysis: (Mary) (is) (a democrat) (and) (proud) (of it). In the syntactic analysis, in step 8, "proud" and "of it" are accumulated in a single sign. The coordination of "proud of it" with "a democrat" is possible, as both symbols can be "is" complements syntactically.

Summary

An advantage of our model of knowledge representation presented in this chapter lies in its potential for generating information by the computer that the human user may directly process naturally. The essence of such processing can be explained by means of the metaphor of apparent motion perception. If the snapshots of a series are presented correctly, we easily may experience the meaning of the series as a whole. If the presentation is not correct, as, for example, when the snapshots are in the wrong order or the difference between the consecutive pictures is too large, an adequate interpretation may still be possible, but it can be difficult.

The idea behind our theory is that an analogous "correct" presentation of information in knowledge modeling may entail an immediate "natural" interpretation of the computations yielded by the cognitive model (i.e., frames) as different representations of a single interaction between some state and effect. More specifically, the hypothesis of this work is that information processing that does respect the nine types of relations of cognitive processing and their ordering may enhance the interpretation of the full meaning of such computations as a whole (through the mediation of proto-signs).

This relation between the cognitive and semiotic concepts of meaning production is the key to the natural definition of the combinatory properties of qualia in language as a habit. Additionally, the processual interpretation of the Peircean classification is the key to the understanding of sign recognition, generating increasingly better approximations of the final meaning of the observed phenomenon. It can be shown that there exists a correspondence between the types of relations generated by cognitive processing on the one hand and the interactions between sign aspects that are each other's neighbors[19] according to Peirce's classification on the other. From the isomorphism of the representation of knowledge in different domains, it follows that different interpretational viewpoints (e.g., syntactic, logical, etc.) can be merged to a single whole through coordination (in a broad sense).

What is natural in natural language? In our view, the natural aspect of language involves the types of distinctions that can be made cognitively, the organization of such events in a process, and the appearance or feeling of such a process as knowledge (the last lies beyond the scope of our model). This is the basis, in our opinion, for the understanding of computational semiotics as a cognitively based semiotic and, therefore, as natural computation.

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Endnotes

[1] We acknowledge that a distinction can be made between natural and designed languages like Esperanto. The origin of the language however is of no consequence for our present concerns.

[2] Peircean scholars also use the term *semeiotic*.

3 The three concepts of X-bar theory, which are denoted by X, X', and X", are a representation of a lexical category, a relation, and a phrase, respectively.

4 The importance of similarity (comparison) in cognitive theory is also emphasized by Goldstone and Barsalou, (1998).

5 This whole process is beyond our direct conscious control.

6 Here and in later diagrams a '¬' is denoted by a '~' symbol.

7 *A* and ¬*A* (but also *B* and ¬*B*) arise due to the same input trigger, indicating that the two signs are *not* independent.

8 As *A* and *B* are commonly considered as logical variables, the separate representation of the input qualia contains both variables. The difference between their meaning as co-existent and co-occurrent is expressed by means of the '+' and '∗' operators, respectively.

9 For a detailed treatment, see Liszka (1996).

10 We gladly acknowledge that the term *proto-sign* has been suggested by Gary Richmond.

11 Conform our assumption that all interaction is between state and effect, the constituents of a type (3) relation show an analogous difference.

12 Notice that (1) allows only a single interpretation, (2) provides two, and (3) can be expanded in three meanings, which differ from each other in the question of which one of the qualia has a dominant function in the relation (either the one or the other or both).

13 Both models depart from a triadic definition of signs, but the difference in goals served puts a different emphasis on the properties of signs. We maintain that full understanding of semiosis is only possible when the different perspectives are combined.

14 See the phenomenon of embedding in section "'Towards a formal model."

15 Please note that in this analysis the Peircean terms are used as pointers to the status of a language symbol in the process of parsing.

16 We assume nondeterminism is implemented by backtracking.

17 In virtue of the sequential character of language processing, also adjectives, adverbs, and so forth are considered as appearing effects and treated as *B*-type qualia.

18 Essentially, such a grammar consists of rules, which are instances of the syntactic relations—*sorting*, *abstraction*, *complementation*, and *predication*—as rule schemas. Schema instantiation is lexically driven by the defined combinatory properties of the syntactic qualia.

19 The neighborhood relation is indicated by horizontal lines in Figure 3, section "Logical analysis."

Chapter VII

A Theory of Semantics Based on Old Arabic

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Abstract

In this chapter, we show how we derived a universal theory of semantics. Then we discuss the discovery's impact on automated learning and text analysis. Using induction, we derive general principles from some observations on word meanings in Old Arabic passages called muhkam, which means that the meaning is made perfectly clear. We find that the 32 sounds of Arabic are signs that refer to abstract objects generated from two symmetry pairs and a three-element set. We show that word roots are structured signs referring to structured abstract objects. Arabic roots and their interpretations and reinterpretations form an abstract set of concepts that can be used as cognitive tools over which any language can render reality. We realized this in a software system we called Readware, which performs automated text exploration and analysis in English, German, and French on and off the Internet.

Introduction

The term *computational semiotics* intuitively suggests that we use a science of meaning to create useful and intelligent computer programs. We will examine some foundations of semantics and semiotics, two fields that deal with meaning, and introduce our new approach to both. We will derive a new formal theory of meaning by induction, i.e., generalization from small observations. Then we will show how our theory is, in fact, a theory of learning, knowledge acquisition, and knowledge analysis. We will briefly discuss how we implemented our theory in software called Readware, which realizes standards from our theory for knowledge representation (ConceptBase) and cognitive modeling (cognitive frames) that are used to perform ontology development (cultures) and automated text exploration and analysis in English, German, and French.

The Adi Theory of Semantics basically states that human languages offer signs that enjoy relations of symmetry. Symmetry is found in all natural laws; we propose a theory that explains why the signs of language are the way they are, and we treat this theory as a natural law.

Background

Semiotics is the study of signs. A sign is something that refers to an object and can be interpreted (CP 2.171, CP 2.274). The effect of interpreting a sign on the interpreter's mind is called *meaning*. Semantics is the study of meaning.

The possible signs of human language consist of words and *phonemes*, which are parts of words such as *s-*, *tr-*, *-im* and *-ist* that can be treated as units of sound. Many linguists adopt the view of Ferdinand de Saussure (1916) that words—as signs—are assigned arbitrarily to the objects to which they refer and that phonemes are not signs at all.

But a number of linguists—called phonosemanticists—believe that phonemes are signs in some sense. They include Roman Jakobson (1937), Richard Rhodes and John Lawler (1981), and Margaret Magnus (2001). Magnus, for example, suggests that phonemes are signs that refer to some properties of the object to which a word refers, not the object itself (Magnus, 2001, p. 34). Her experience is that "the more concrete and unambiguous the referent for the word, the less salient is its phonosemantics" (Magnus, 2001, p. 76). At the level of single consonants, Magnus finds the "most fundamental and *least salient* type" of phonosemantics, the level at which "*form and content are one*" (Magnus, 2001, p. 1). She calls this "truly iconic" (i.e., sound really resembles meaning) at this level (Magnus, 2001, p. 50).

It seems that the quest for finding a direct resemblance between sound and meaning dooms phonosemantics to vagueness or even insignificance. Although Magnus' doctoral supervisors—who included M. Chvany of MIT and G. Carlson of Rochester—applaud her exploration of "the nature of human language by using the experimental 'scientific method,'" they do not see her research as something useful for exact sciences and technology (Department of Linguistics, Norwegian University of Science and Technology, 2001, p. 1). They think that she "provides grist for the philologist" in the consideration of "allophonic variation and language change." She engages "the anthropologist and sociolinguist" with her "proposal for semantic classes" and her quest to separate the "universal from the culture-specific." They find phonosemanticism applicable to "literary criticism" and "poetic interpretations" (Department of Linguistics, Norwegian University of Science and Technology, 2001, p. 1)

We developed our understanding as to what a sign is and how a phoneme constitutes a sign independently. We performed the bulk of our research and arrived at the main findings (which we lay out in this chapter) in 1985 in Jeddah, Saudi Arabia, while teaching computer engineering. This was before we learned about Peirce, Pospelov, Saussure, Jakobson, or Lawler. We were creating an English-Arabic machine translation program, and we needed an exact scientific theory of semantics. Our experience was contrary to that of Magnus. We studied the meanings of sounds only in words that had concrete and unambiguous meanings. Also, we did not see any consistent resemblance between sounds (or forms of letters) and what they meant.

We believed that the phonemes of a word are *signs that refer to abstract objects* that are somehow related to the properties of the object to which the word refers.

word X *refers to* object A

each phoneme P of word X *refers to* an abstract object B_P

abstract object B_P is related to property T of object A

Moreover, we believed that the human mind constantly interprets such abstract objects and that the resulting interpretations also can be abstract objects that, in turn, may be reinterpreted. Both the original abstract objects and their successive interpretations are related to the properties of the object to which the word refers.

abstract object B_P is interpreted as abstract object B'_P

abstract object B'_P is related to property T' of object A

In addition, we believed that the morphology of a word, its structure, is also a sign that refers to an abstract object structure that is somehow related to the structure of the object to which the word refers. The human mind also constantly interprets and reinterprets this abstract object structure.

Structure of word X refers to an abstract object structure S

Abstract object structure S is related to structural property T_S of object A

Abstract object structure S is interpreted as abstract object structure S'

Abstract object structure S' is related to structural property $T_{S'}$ of object A

The repeated interpretation of the abstract objects to which the phonemes of a word refer, in light of the repeated interpretation of the abstract structure to which the morphology of that word refers, will establish more and more relationships in the human mind to the properties of the object to which that word refers. We call this principle *cognitive growth by reinterpretation*. A similar growth by reinterpretation is found in biosemiotics, the study of DNA as signs of life processes. Repeated DNA interpretation produces biological growth along a path called the ontogenetic trajectory (Hoffmeyer, 1997; Sharov, 1998). This parallel is not surprising since human cognition is born of human life processes.

We expected to find relations of symmetry between the abstract objects to which phonemes refer, since language is a natural phenomenon and there usually is symmetry in nature.

In the section on "The Semantics of Single Sounds," we derive by induction the first two parts of our theory of semantics. We derive general principles from observations about meanings of short words in Old Arabic. We arrive at 12 results. We sum up the first four as Part I of the Adi Theory of Semantics (Polarities). Results 5-12 are compressed as Part II of the theory (Elementary Processes and Elementary Control Precedence). In brief, this part of the theory states that each Arabic vowel and each consonant is a sign that refers to a pair of compound abstract objects: a process and a polarity. It also states that the 28 consonants and four vowels of Arabic are organized in a 4x8 matrix that represents the relationships of symmetry among the corresponding abstract objects.

In the section on "The Semantics of Sound Combinations," we derive by induction Results 13-18 regarding the interpretation of the abstract structures to which three-consonant Arabic word roots refer. We sum up these results as Part III (Control Precedence among Process-Polarity Pairs) and Part IV (Types of Root Interpretation Mappings) of the Adi Theory of Semantics. We will demonstrate that Arabic roots form an abstract set of concepts over which any language can render reality. This is done by mapping vocabulary and expressions from any language to one or more Arabic roots. We also have shown elsewhere (Adi & Ewell, 1987b, 1987d, 1996) that our theory can be applied directly to many words in English and other languages. This is an alternative application path.

In the section on "Root Interpretation Mappings," we demonstrate that the mappings that interpret Arabic roots can be implemented as cognitive tools.

We believe that we have succeeded in creating a complete and universal theory of semantics and a theory of cognition. We patented our findings and techniques (Adi, 1989) and assigned the rights to the patent to Management Information Technologies, Inc. (MITi). MITi realized the patent in a software system we called *Readware* (Adi & Ewell, 1987 a-e, 1991). In coming sections, we will include brief discussions of this realization. Readware performs automated text exploration and analysis in English, German, and French. Readware products have excelled in major international evaluations (TREC: Text REtrieval Conference), searching very large collections of text (Adi, Ewell, & Adi, 1999, 2000). Readware has been implemented in several *commercial applications*, including ConSearch, IpServer (Interculture Processor), Readware Spider, and various custom applications.

The Semantics of Single Sounds

Phonosemanticists usually analyze the meanings of large and exhaustive sets of vocabulary (e.g., all English monosyllables) containing certain phonemes to test hypotheses as to whether these phonemes are associated frequently with certain abstract objects (Magnus, 2001). In these analyses, Magnus found that it was more useful to focus on the meanings of words that refer to less concrete and more ambiguous things. Phonosemanticists make hypotheses and test them on large amounts of vocabulary.

In contrast, we used induction to derive general principles by examining a small set of vocabulary whose meanings are made perfectly clear. We arrived at a theory similar in its features to natural laws. Sounds are related to each other by symmetry, and every Arabic sound has a unique place in this symmetry. In the following section, this theory is verified by examining its effects on the interpretation of word roots as combinations of sounds.

We found our small set of vocabulary and its meanings in passages called *muhkam. Muhkam* means that the meaning is made perfectly clear. The passages are part of a book written in the Old Arabic language (*Al-Qur'an*, 1992). This is a 1,400-year-old book that all Arabs consider a reference for the correct use of Arabic. *Muhkam* passages deal with concrete social issues. Contrary to them, passages called *mutashabih* (meaning only indicative) describe things that people cannot see. A perfectly clear understanding of the nature of such things is not offered by the book.

Muhkam passages express concrete issues in clear and consistent ways. The meaning of each word is made unambiguous first by using it in explicit and detailed statements; by reusing it consistently in slightly different contexts addressing the same issue; by expressing the same theme with synonyms of that word; by restating referents instead of pronouns; and by other methods of redundancy, repetition, detailing, laying out, and clarification. The style is always clear and direct.

We thus were able to ascertain the precise meanings of all vocabulary in the *muhkam* passages. We were not confused by the diverging meanings supplied in commentaries, Arabic dictionaries, and translations of the book. Neither the vocabulary nor its meanings has changed for 1,400 years. We examined a very stable semantic environment.

We have not found a word in Old Arabic whose sound signs contradict the theory (and, thus, falsify it). But we do not claim to be able to understand how all word meanings relate to our theory. For example, we do not understand yet how the sounds of the Arabic word *wahhid* can be interpreted to give us its meaning, the number one.

Let us now study the meanings of short Arabic words, suffixes, and prefixes that express simple concrete ideas. We will determine by induction—generalization from limited observations—that Arabic sounds are signs that refer to abstract objects. We will trust our generalizations because we are analyzing precise meanings. We also will look for relations of symmetry between these abstract objects, and we will find them. Symmetry is found in all natural laws, and if we could find all the symmetrical pairs, then we could propose a theory that explains why the signs of language are the way they are, and we could call this theory a natural law.

Both Old Arabic and Modern Arabic have the same 32 sounds: 28 consonants and four vowels. These are the only phonemes whose meanings we are looking for. Each consonant and each vowel has a unique sound. Table 1 lists the names of vowels and consonants. The first row lists the four vowels. *Sukoon* is the silent vowel (no sound). The first three vowels can be stretched. The second row contains the four soft consonants, which often are dropped in word formation or turned into vowels. The remaining rows contain the rest of the 28 consonants.

Table 1. Names of Arabic sounds

	column 1	**column 2**	**column 3**	**column 4**
row 1	*vowel_i*	*vowel_a*	*vowel_u*	*sukoon*
row 2	*ya*	*hamza*	*waw*	*ha*
row 3	*meem*	*fa*	*dal*	*thal*
row 4	*'ain*	*noon*	*qaf*	*ghain*
row 5	*ra*	*lam*	*ba*	*ta*
row 6	*seen*	*zay*	*ssad*	*tha*
row 7	*kaf*	*ddad*	*tta*	*kha*
row 8	*hha*	*sheen*	*geem*	*zza*

We have arranged the sounds in Table 1 according to the following discussion. We will discuss the sounds column-by-column and then row-by-row.

We will write these sounds in one of three ways:

1. **No quotes:** Name of one vowel or consonant, such as *vowel_i, 'ain* or *qaf*
2. **Single quotes:** Transliteration (pronunciation) of an Arabic word such as *'la'* or *'waraa'*
3. **Double quotes:** Two or more names of vowels or consonants, such as *"hha ya ya"*

An Arabic word root usually consists of three consonants; for example, *"kaf ta ba."* A word is derived from its root according to fixed forms by adding prefixes, infixes, and suffixes. Let us represent a three-consonant root as **K L M**. One such form is *'mu**K**aa**L**i**M**oon.'*

*'mu**k**aa**t**i**b**oon'* (contractors: those who prescribe to each other) is derived from the root *"**k**af **t**a **b**a"* (prescribe) according to this form. Remember that the root *"**k**af **t**a **b**a"* consists of three short sounds (**k**, **t**, **b**), not to be confused with the long names of the sounds (**k**af, **t**a, **b**a) (see Table 2).

Vowels often are added to roots to form words. During word formation, soft consonants of the root often are converted into vowels or dropped. Based on these two facts, we believe that when it comes to carrying a meaning specific to a root, vowels have the least significance, followed by soft consonants and then the rest of the consonants. Therefore, when a consonant is the only nonsoft consonant in a root, it carries the bulk of that root's specific meaning.

Let us look at short words, suffixes, and prefixes that contain all the sounds from the first column and examine some elements of meaning that often are associated with them. The sound in focus or its name will be in ***italic boldface***. The number indicates the row.

Table 2. Names of Arabic sounds with sound-alikes in bold below

vowel_i **i**t	*vowel_a* **a**t	*vowel_u* f**oo**t	*sukoon* no sound
ya **y**es	*hamza* **a**t (stop)	*waw* **w**ay	*ha* **h**at
meem **m**e	*fa* **f**ish	*dal* **d**o	*thal* **th**is
'ain aar**gh**	*noon* **n**ice	*qaf* **c**ut	*ghain* French **r**
ra **r**ed	*lam* **l**ess	*ba* **b**at	*ta* **t**ip
seen **s**ee	*zay* **z**ip	*ssad* **s**uck	*tha* **th**in
kaf **k**ey	*ddad* **d**ub	*tta* **t**ough	*kha* **ch**utzpah
hha **h**ot	*sheen* **sh**oe	*geem* **g**em	*zza* o**th**er

1. ***vowel_i*** is used as a suffix meaning "my."
2. ***ya*** is used to "call" people.
3. ***meem*** is used as a noun prefix meaning "defined" place, person, or time.
4. ***'ain*** is an imperative verb form meaning "collect!" or "hear and understand!"
5. *'wa**r**aa'* means "behind."
6. *"**seen** waw ya"* is a root meaning "equal" or "level."
7. ***kaf*** is used as a preposition meaning "similar to."
8. *"**hha** ya ya"* is a root meaning "life," "shy," "writhe," or "snake."

Take a closer look at these eight sounds. They each have elements of meaning that they do not share with each other. But at the same time, they *do* share two elements of meaning, a combination of two abstract objects: **closed** and **self**, or interpretations of this combination. The first appearance of a prominent interpretation will be in **boldface**.

1. "My" interprets "closed self" as something **inward**.
2. To "call" people is to bring them inward.
3. "Defined" means self-contained. Actually, both **defined** and **self-contained** are interpretations of closed self.
4. "Collect!" and "hear and understand!" interpret taking inward.
5. "Behind" is inward in space or time.

6. “Equal” and “level” interpret self-contained, same as itself in measurement.
7. “Similar” interprets self-contained, equal mapping.
8. “Life” is a self-contained, generic process. “Shy” is inward behavior. “Writhing” is self-contained motion, typical of the snake.

> **Result 1:** All eight Arabic sounds from the first column of Table 1 *(vowel_i, ya, meem, ‘ain, ra, seen, kaf, hha)* have elements of meaning that are interpretations of the abstract object pair “closed” and “self.” Prominent interpretations include: inward, self-contained, defined.

Let us look at some elements of meaning that are associated with the sounds from the second column of Table 1. It turns out that we are now dealing with the abstract object combination **open** and **self** that is symmetrical to the “closed” and “self” combination associated with the first column. The numbers below indicate the rows in Table 1.

1. ***vowel_a*** is used as a noun suffix indicating “being acted upon” (object of action), an interpretation of opening oneself, or being **outward**. Note that outward is symmetrical to inward of Result 1.
2. The soft consonant named ***hamza*** is used to form a question. Symmetrical to interpreting “closed self” as defined (self-contained), here we interpret “open self” as **undefined** (not self-contained).

   As a prefix added to a verb root to derive a new verb form, ***hamza*** gives us two contrary meanings: removal and granting. Removal interprets open as empty, so removal is an empty self. To grant is to open one*self* to others, to be outward. Note that **empty self** is symmetrical to self-contained.
3. The consonant named ***fa*** is used as a conjunctive meaning “then” (consequence or next event), which interprets an outward event. *“**fa** waw”* means mouth, a space that opens itself, a shade of outward. *“**fa** ya”* means “in” or “into” which interpret outward.
4. *“hamza ya **noon**”* is the question “where?” which declares that the coordinates are undefined.
5. ***lam*** is used as a preposition that means “belonging to,” an outward assignment. *‘**la**’* means “no,” an interpretation of “empty self” or undefined.
6. *“**zay** waw ra”* is a root that has three seemingly unrelated meanings: perjury, veer, and visit. Perjury is an **invalid** (empty self) statement. Veer is undefined trajectory. Visit is outward lodging. Invalid, undefined, and outward all are interpretations of open self.
7. *“**ddad** lam lam”* is a root that means “to stray.” ***ddad*** expresses activity in undefined order. *“lam lam”* expresses repeated “belonging,” persistence (see no. 5). Straying is a persistent activity out of order, such as a broken record.
8. *“**sheen** ya hamza”* is a root that gives us two meanings: “to want” and “thing.” “To want” is a generic outward process, desire, volition. “Thing” is an undefined object.

> **Result 2:** All eight Arabic sounds from the second column of Table 1 *(vowel_a, hamza, fa, noon, lam, zay, ddad, sheen)* have elements of meaning that are interpretations of the abstract object pair "open" and "self." Prominent interpretations include outward, undefined, empty self, and invalid.

The abstract objects "closed" and "open" have to do with boundary conditions, and therefore, we will group them together in the set **T** of **boundary conditions**: **T** = {closed, open}.

Now let us predict that the abstract object "self" has a symmetrical counterpart "others" that we will encounter in connection with the remaining sounds. These two abstract objects express engagement. They form the set **G** of **engagement conditions**: **G** = {self, others}.

Since we already have encountered combinations of elements from these two sets, let us examine their product set

R = **T** x **G**
= {(closed, self), (open, self), (closed, others), (open, others)}

If there is symmetry in the signs of Arabic sounds, then we expect to encounter the pairs (closed, others) and (open, others) in association with the remaining sounds. We saw previously that the first two pairs (closed, self) and (open, self) often are interpreted as inward and outward, which express some kind of polarity. Let us refer to the four pairs in **R** as **polarities.**

Turn to the third column of Table 1. We notice that these sounds have elements of meaning that refer to the polarity (**closed**, **others**).

1. Stretched ***vowel_u*** is used as a prefix to express the plural in both nouns and verbs. The plural expresses the concept of **together**, an interpretation of (closed, others).
2. ***waw*** is used as a conjunctive meaning "and" or "while," which are both interpretations of together. ***waw*** also is used as an oath article meaning "I swear by." This is a different interpretation of (closed, others): **engaged**. An oath is an engagement.
3. *"waw* ***dal*** *ya"* is a root meaning "valley." The consonant in focus is ***dal***. A valley is a place in-between (two mountains). In-between interprets engaged. *"hamza* ***dal*** *ya"* is a verb root that means "pay back" or "compensate." ***dal*** here is an activity according to an engagement, reciprocity.
4. *"waw* ***qaf*** *ya"* is a verb root meaning "to shield" which interprets engaged containment.
5. ***ba*** is a preposition meaning "because," which interprets togetherness of two events.
6. *"waw* ***ssad*** *ya"* is the root for "last will" or "commandment," which both interpret engagement by law.
7. *"****tta*** *waw ya"* is a root meaning "to fold," which interprets a mapping together.
8. *"****geem*** *ya hamza"* is a root meaning "to come," which is an interpretation of motion together, toward each other.

Result 3: All eight Arabic sounds from the third column of Table 1 *(vowel_u, waw, dal, qaf, ba, ssad, tta, geem)* have elements of meaning that are interpretations of the polarity (closed, others). Prominent interpretations include engaged and together.

The only remaining polarity is (open, others). We now turn to the fourth column of Table 1. We expect that these sounds will refer to the polarity (**open**, **others**). We also expect to find prominent interpretations that are symmetrical to engaged and together: unengaged and separate.

1. ***sukoon*** (no sound, no real vowel) at the end of verbs signals a **special** status, a status that is **separate**. Both special and separate are interpretations of the polarity (open, others), away from others.
2. The sound ***ha*** (pronounced like h) is found at the beginning of all third person pronouns: *'**h**oowa'* (he), *'**h**eeya'* (she), *'**h**um'* (they), and so on. The third person is an assignment to be separate, to be a third, not me, not you.
3. ***thal*** (pronounced like th in this) is combined with vowels to build words meaning **specific** manifestation: ***'thoo'*** (distinguishing attribute), *'**th**aa'* (this, that), *'alla**th**ee'* (the one who, that which, *'alla'* just means "the"), *'i**th**a'* (when, a specific time).
4. *"**ghain** waw ya"* means "to stray," which interprets the polarity (open, others) as **unengaged** from order. Compare to synonym root *"**ddad** lam lam"* mentioned previously.
5. ***ta*** is used to express an oath as a special commitment.
6. *"**tha** waw ya"* (*tha* is pronounced like th in thin) means "to lodge," to assign a separate containment.
7. *"**kha** waw ya"* means "collapse," which interprets unengaged mapping, unmapping, dismantling.
8. *"**zza** lam lam"* means "to remain" or "shade," which both interpret being in an unengaged generic process. The double *lam* contributes persistence.

Result 4: All eight Arabic sounds from the fourth column of Table 1 *(sukoon, ha, thal, ghain, ta, tha, kha, zza)* have elements of meaning that are interpretations of the polarity (open, others). Prominent interpretations include unengaged, separate, special, and specific.

Results 1-4 have shown that the 32 sounds of Arabic are divided into four disjoint groups of eight sounds each, such that all the sounds of each group have elements of meaning that are interpretations of a single polarity. We will formulate this as the first part of our theory of semantics.

Adi Theory of Semantics, Part I (Polarities): *There is a set **T** = {closed, open} containing two abstract objects representing symmetrical boundary conditions,* *and there is a set **G** = {self, others} containing two abstract objects representing symmetrical engagement conditions, such that the product of the two symmetry sets, the supersymmetry set **R**, i.e.,*

R = **T** *x* **G** = *{ r(j) | j = 1 to 4 }*

= { (closed, self), (open, self), (closed, others), (open, others) }

or using a shorthand notation

= {inward, outward, engaged, unengaged}

*is a set of abstract object pairs that represent polarities. If we arrange all Arabic sounds as follows in the 4x8 matrix **A** = [a(i, j) | i = 1 to 8 and j = 1 to 4]*

	vowel_i	*vowel_a*	*vowel_u*	*sukoon*	
	ya	*hamza*	*waw*	*ha*	
A = [	*meem*	*fa*	*dal*	*thal*	]
	'ain	*noon*	*qaf*	*ghain*	
	ra	*lam*	*ba*	*ta*	
	seen	*zay*	*ssad*	*tha*	
	kaf	*ddad*	*tta*	*kha*	
	hha	*sheen*	*geem*	*zza*	

then all the sounds a(i, j) of column j will have elements of meaning that interpret polarity r(j) and no other polarity.

Note that matrix **A** is identical to Table 1. We will now look for elements of meaning that are shared by the sounds from the rows of Table 1. In every row, each sound belongs to a different column, and each column has a different polarity.

Therefore, we will ignore the elements of meaning that pertain to polarities in examining the rows. We already have dealt with them in Results 1-4. Now we are looking for elements of meaning other than polarities that the sounds of a row might share.

Let us look at the first row of Table 1, which contains the vowels:

1. ***vowel_i*** is used as a suffix meaning "my," which interprets inward polarity.
2. ***vowel_a*** is used as a noun suffix meaning "being acted upon" (being open to others), an interpretation of outward polarity.
3. Stretched ***vowel_u*** is used as a suffix for plurals (things that are together), an interpretation of engaged polarity.
4. ***sukoon*** at the end of verbs signals a special status, an interpretation of unengaged polarity.

We notice that the sounds of this row share no elements of meaning but that each sound refers to a different polarity out of set **R**.

> **Result 5:** The four Arabic sounds from the first row of Table 1 *(vowel_i, vowel_a, vowel_u, sukoon)* have no meanings except as distinct polarities.

We now look for shared elements of meaning other than polarities in the second row of Table 1.

1. ***ya*** is used to call people. There is a sense of **assignment**.
2. ***hamza*** is used to make a question. Here, too, there is a clear sense of assignment. As a prefix added to a verb root to derive a new verb, ***hamza*** gives us two contrary meanings: removal and granting. Removal is an assignment away. Granting is an assignment to.
3. ***waw*** is used as a conjunctive meaning "and" or "while." "And" interprets assignment together of any two things. "While" (such as eating while driving) interprets assignment together of two activities. ***waw*** is also used as an oath article meaning "I swear by." An oath is an assignment.
4. The sound ***ha*** (pronounced h) is found at the beginning of all third person pronouns: *'**h**oowa'* (he), *'**h**eeya'* (she), *'**h**um'* (they), and so forth. These are all assignments.

> **Result 6:** All four Arabic sounds from the second row of Table 1, the soft consonants *ya, hamza, waw*, and *ha*, have elements of meaning that are interpretations of the abstract object "assignment."

Look at the third row in Table 1 for elements of meaning other than polarities that are shared by the sounds of the row.

1. ***meem*** is used as a noun prefix meaning defined person, place, time, activity, method, or instrument of action. We ignore the polarity interpretation "defined." **Activity** can be seen as an interpretation of the abstract object **manifestation**. **Method** is also a manifestation. Instrument of action is an interpretation of method.

   "Place" and "time" initially appeared puzzling to us until we introduced the concept of a **static interpretation**. There is a duality in the real world between dynamic and static. Although everything is in constant activity and motion, we sometimes refer to certain things as if they were nonacting, nonmoving, and static. **Time** and **place** are static interpretations of manifestation. **Person** also statically interprets manifestation.

   Note that although we call manifestation an abstract object because sound signs refer to abstract objects, we do not imply that all abstract objects are static. We will see that all abstract objects that are common to rows 2-8 in Table 1 basically are dynamic processes that also have static interpretations as "things."

2. ***fa*** is used as a conjunctive meaning "then" ("consequence" or next "event"). **Event** interprets manifestation. Consequence is an event. *"**fa** waw"* means mouth, a space that opens itself. **Space** is an interpretation of place. *"**fa** ya"* means "in" or "into" a place.
3. *"waw **dal** ya"* is a root meaning "valley" which interprets a place in-between. In-between interprets the engaged polarity.

   *"hamza **dal** ya"* is a verb root that means "pay back" or "compensate." ***dal*** here is an activity according to an engagement, reciprocity.
4. We have established that ***thal*** refers to a separate manifestation or time (see Examples 3 leading up to Result 4).

> **Result 7:** All four Arabic sounds from the third row of Table 1 *(meem, fa, dal, thal)* have elements of meaning that are interpretations of the abstract object "manifestation." Although "manifestation" is basically a dynamic process, it may have static interpretations that appear as nonacting or nonmoving. Prominent interpretations include activity, method, and event. Static interpretations include person, time, place, and space.

Let us look at the fourth row:

1. ***'ain*** is used as an imperative verb form meaning "collect!" or "hear and understand!" Both express taking inward, as into a container. The new element of meaning is **containment**.

   "Hear and understand" interprets inward containment as "speech" going into the ear, which *hears* it, and then into the mind, which *understands* it. **Speech** is an interpretation of containment because containment means **control**, and speech consists of **commands** that are used to control people and things. It is as if to say that words are control **instructions**, which is what we are finding out. Just like interpreting DNA controls growth, interpreting speech controls understanding.
2. *"hamza ya **noon**"* is the question "where?" which declares that the coordinates are undefined. This is also an issue of containment (where is it contained?). Coordinates express **order**, an interpretation (the result) of control.
3. *"waw **qaf** ya"* is a verb root meaning "to shield," which is an interpretation of engaged containment. To shield is to defend oneself against attempted containment by others. *"**qaf** waw ya"* is a root that means strong. Strong is an interpretation of **force**, which is a static interpretation of containment (containment is using force).
4. *"**ghain** waw ya"* means "to stray," which interprets unengaged containment (uncontained) or unengaged order (disorder).

> **Result 8:** All four Arabic sounds from the fourth row of Table 1 *('ain, noon, qaf, ghain)* have elements of meaning that are interpretations of the abstract object

"containment." Prominent interpretations include control, command, speech, instructions, and order. Static interpretations include: force.

We now look at the fifth row. Remember that the example numbers refer to columns:

1. *'wa**r**aa'* means "behind." This is an inward assignment of place. We encounter here two familiar items. Assignment is the abstract object of the second row. Place is a static interpretation of manifestation, the abstract object of the third row. For the first time, we have one sound '**r**' referring to a combination of two abstract objects: assignment and manifestation.
2. ***lam*** is used as a preposition that means "belonging to," an outward "assignment" to a "person" or another "manifestation." ***'la'*** means "no" or "not" (unengaged polarity), and it is assigned to verbs (activity interprets manifestation) or things (manifestations).
3. ***ba*** is a preposition meaning "because," which interprets an assignment of togetherness (polarity) of two events (manifestations).
4. ***ta*** is used as an oath article which interprets a special (unengaged polarity) assignment of manifestation.

Result 9: All four Arabic sounds from the fifth row of Table 1 *(ra, lam, ba, ta)* have elements of meaning that are interpretations of the abstract object pair "assignment" and "manifestation," but only in the sense that assignment is applied to manifestation. In light of the previous interpretations, we sometimes will use the shorthand **allocation** to refer to this pair.

Next, we come to row six of Table 1:

1. *"**seen** waw ya"* is a root meaning equal or level which both interpret assignment to a defined order (containment).
2. *"**zay** waw ra"* is a root that has three seemingly unrelated meanings: perjury, veer, and visit. Perjury is invalid (outward polarity) but assigned (affirmed) speech (containment). To veer is to assign outward of containment. Visit is outward lodging. Lodging is assigned containment.
3. *"waw **ssad** ya"* is the root for "last will" or "commandment," which both interpret engaged (binding) and assigned (affirmed) speech (containment).
4. *"**tha** waw ya"* means "to lodge," to assign a separate containment.

Result 10: All four Arabic sounds from the sixth row of Table 1 *(seen, zay, ssad, tha)* have elements of meaning that are interpretations of the abstract object pair "assignment" and "containment," but only in the sense that assignment is applied to containment. In light of the previous interpretations, we sometimes will use the shorthand **ordering** to refer to this pair.

Let us examine row seven of Table 1:

1. ***kaf*** is used as a preposition meaning "similar to," a **mapping** that interprets a manifestation (application) of a defined order (law or rule).
2. *"**ddad** lam lam"* means "to stray," a persistent activity (manifestation) outward of order (containment). "Persistent" comes from *"lam lam,"* repeated belonging.
3. *"**tta** waw ya"* means "to fold," a manifestation of containment together.
4. *"**kha** waw ya"* means "to collapse," a manifestation of unengaged order (containment).

Result 11: All four Arabic sounds from the seventh row of Table 1 *(kaf, ddad, tta, kha)* have elements of meaning that are interpretations of the abstract object pair "manifestation" and "containment," but only in the sense that manifestation is applied to containment. **Mapping** is a prominent interpretation that we sometimes will use as shorthand for this pair.

We now examine the eighth and final row:

1. *"**hha** ya ya"* is a root meaning life, shy, writhe, or snake. Life is a self-contained **generic process**. A generic process implies some assignment of activity (manifestation) and order (containment). Shy is self-contained **behavior.** Behavior is an interpretation of generic process. Writhing is self-contained **motion**, typical of the snake. Motion also interprets generic process.
2. *"**sheen** ya hamza"* has two meanings: "to want" and "thing." To want (to do something) is an outward (planned, future) generic process. Thing is an undefined (outward polarity) **object**. Object is a static interpretation of generic process. Just think of electrons constantly orbiting the nucleus.
3. *"**geem** ya hamza"* means "to come," which interprets motion together.
4. *"**zza** lam lam"* means "to remain" or "shade." The double *lam* contributes persistence. To remain is to be unengaged from motion. Shade is a place (manifestation) unengaged from assignment of **energy** (force: containment).

Result 12: All four Arabic sounds from the eighth row *(hha, sheen, geem, zza)* have elements of meaning that interpret a combination of three abstract objects: assignment, manifestation, and containment, but only in the sense that assignment is applied to manifestation and containment. Prominent interpretations include generic process, behavior, motion, and object. We will use **generic process** as shorthand for this combination.

Adi Theory of Semantics, Part II (Elementary Processes and Elementary Control Precedence): *Based on Results 5-12, there is a set of abstract objects* *that we will call* ***elementary processes P*** *= { p(i) | i = 1, 2, 3 } = {assignment, manifestation, containment}. For convenience, we write pi for p(i) and enumerate the power set of* ***P***

P ** = {s(i) | i = 1 to 8}*
= { {}, {p1}, {p2}, {p3}, {p1, p2}, {p1, p3}, {p2, p3}, {p1, p2, p3} }

When a set s(i) contains more than one elementary process, then we have a ***process combination****. To simplify the following discussions, we always will refer to each set s(i) as a* ***process****. Below is matrix* ***A*** *from Part I*

	vowel_i	*vowel_a*	*vowel_u*	*sukoon*	
	ya	*hamza*	*waw*	*ha*	
A *= [*	*meem*	*fa*	*dal*	*thal*	*]*
	'ain	*noon*	*qaf*	*ghain*	
	ra	*lam*	*ba*	*ta*	
	seen	*zay*	*ssad*	*tha*	
	kaf	*ddad*	*tta*	*kha*	
	hha	*sheen*	*geem*	*zza*	

All the sounds a(i, j) of row i of ***A*** *have elements of meaning that interpret process s(i) such that if there is more than one elementary process in s(i), then the elementary process pk with lowest row number k is applied to, or controls, the remaining elementary processes. We say that p1 has* ***elementary control precedence*** *over p2 and p3, and p2 has control precedence over p3.*

The first two parts of the Adi Theory of Semantics are visualized in Table 3. Tables 4 and 5 list prominent interpretations of polarities and processes, respectively.

In the past, we also created a 4x8 matrix **A'** for the sounds of English and for other languages (Adi & Ewell, 1987b, 1987d, 1996). However, we were not able to fill all the cells of any such **A'**.

The Semantics of Sound Combinations

Most Arabic word roots are strings of three consonants each. A few roots consist of four consonants, and even fewer roots consist of five consonants. Each consonant a(i, j) is a sign that refers to one nonempty process s(i) from **P*** (i = 2 to 8) and one polarity r(j) from **R**

Table 3. Abstract objects of Old Arabic sounds

	POLARITY			
PROCESS	**inward**	**outward**	**engaged**	**unengaged**
1. no process	*vowel_i*	*vowel_a*	*vowel_u*	*sukoon*
2. assignment	*ya*	*hamza*	*waw*	*ha*
3. manifestation	*meem*	*fa*	*dal*	*thal*
4. containment	*'ain*	*noon*	*qaf*	*ghain*
5. = 2 on 3 **allocation**	*ra*	*lam*	*ba*	*ta*
6. = 2 on 4 **ordering**	*seen*	*zay*	*ssad*	*tha*
7. = 3 on 4 **mapping**	*kaf*	*ddad*	*tta*	*kha*
8. = 2 on 3 & 4 **generic process**	*hha*	*sheen*	*geem*	*zza*

Table 4. Prominent interpretations of polarities

inward (closed, self)	**outward (open, self)**	**engaged (closed, others)**	**unengaged (open, others)**
backward connect to self defined enclosed one's own recursive repeat self-contained	empty-self expand free invalid open to others undefined	common general join shared together	cut disengage exchange separate special specify

(see the Adi Theory of Semantics, Parts I & II, and Table 3). Thus, a three-consonant root is a *structured sign*.

Root "a(i, j) a(k, m) a(n, q)" refers to three process-polarity pairs

(s(i), r(j)), (s(k), r(m)), (s(n), r(q))

where i, k, n = 2 to 8 are the rows of **A**, corresponding to the processes

s(2) = assignment, s(3) = manifestation, s(4) = containment

s(5) = assignment of manifestation, shorthand = allocation

Table 5. Prominent interpretations of processes

2. assignment	element, identify
3. manifestation	activity, event, method, person, place, space, time
4. containment	command, control, energy, force, instruction, order, speech, value
5. allocation (assignment of manifestation)	apply, belong, link, a set
6. ordering (assignment of containment)	lodging, measure, structure
7. mapping (manifestation of containment)	
8. generic process (assignment of manifestation and containment)	behavior, motion, object, processing, thing

s(6) = assignment of containment, shorthand = ordering

s(7) = manifestation of containment, shorthand = mapping

s(8) = assignment of manifestation & containment, shorthand = generic process

and j, m, q = 1 to 4 are the columns of **A**, corresponding to the polarities

r(1) = (closed, self), shorthand = inward

r(2) = (open, self), shorthand = outward

r(3) = (closed, others), shorthand = engaged

r(4) = (open, others), shorthand = unengaged

Now we explore whether elements of meaning of some Old Arabic roots in *muhkam* passages indicate the existence of rules as to how the three process-polarity pairs are applied to each other.

In Results 9-12, there always is a single elementary process that controls the other elementary processes (i.e., is applied to them). In Part II of our theory, we say that p1 (assignment) has control precedence over p2 (manifestation) and p3 (containment), and p2 (manifestation) has control precedence over p3 (containment). When an elementary process has control precedence, it controls the other elementary processes (i.e., it is applied to them).

The question is now: Is there a rule that determines which of the root's processes s(i), s(k), and s(n), will have control precedence so that it/they will control the remaining process(es)?

Remember that we have

1. elementary process: p(i) from **P** = {assignment, manifestation, containment}
2. generic process: s(8), assignment of manifestation & containment
3. process: s(i) from **P***

Let us start by looking at roots that have a single soft consonant *(ya, hamza, waw, ha)*. The soft consonant is in **bold**, and the interpretation of the corresponding process-polarity pair (assignment, polarity) is in *italics*. Please consult Tables 3-5 for interpretations of processes and polarities.

- "***ya*** *ta meem*" (orphan): defined person (*meem*) *is assigned inward (reduced, direction of assignment is backward: ta<==meem) to* unengaged allocation (*ta*, not belonging). An orphan is a person who is reduced to not belonging.
- "***hamza*** *fa qaf*" (horizon): outward manifestation (*fa*, appearance) *is assigned outward to (direction of assignment: fa==>qaf)* engaged containment (*qaf*, meeting of spheres). Horizon is the appearance of where the two spheres meet.
- "***waw*** *qaf fa*" (arrest): *assignment to engage* an engaged containment (*qaf*, confinement) *with* outward manifestation (*fa*, someone free).
- "***ha*** *dal noon*" (ceasefire): *assignment to unengage* (*ha*, disengage) engaged manifestation (*dal*, confrontation) *from* outward (unleashed) force (*noon*).
- "*fa* **ha** *meem*" (understand): *assignment to* unengage (*ha*, distinguish) outward manifestation (*fa*, appearance) *from* inward manifestation (*meem*, substance).

> **Result 13:** If there is a single soft consonant in a root, then it has control precedence, and the corresponding process-polarity pair (assignment, polarity) controls (is applied to) the other two process-polarity pairs.

To understand process control in the interpretation of roots as structured signs, let us remember mathematical mappings. A mapping has two equivalent forms:

1. f : X ==> Y where X and Y are sets of elements
2. f(x) = y where x is an element of set X and y is an element of set Y

The mapping f connects elements of the *domain* X to elements of the *range* Y. A mapping also is called a function. A *composition* of two mathematical mappings f and g is the application of one of them to the range of the other:

f (g(x)) = z

where x is an element of set X and z is an element of set Z

Every consonant is associated with an infinite set of interpretations of its process-polarity pair, because interpretation and reinterpretation of abstract objects is an open-ended process in which the human mind stays involved. In the first example (orphan), *meem* is associated with {"inward manifestation," "defined manifestation," "a person," . . .}, *ya* is associated with {"assigned inward to," "reduced to," . . .}, and *ta* is associated with {"unengaged allocation," "not belonging," . . .}. ". . ." means that we assume that there is an infinite number of other possible interpretations, see Tables 3-5.

We can summarize the discussion of the root for "orphan" as a mapping:

$f_{21} : X_{31} ==> Y_{54}$

where f_{21} implements {"assigned inward to," "reduced to," . . .} *(ya)*

X_{31} = {"inward manifestation," "defined manifestation," "person," . . .} *(meem)*

Y_{54} = {"unengaged allocation," "not belonging," . . .} *(ta)*

and the subscripts indicate rows and columns of **A**

This is a mapping of the form $f_{ij} : X_{km} ==> Y_{nq}$. The domain X_{km} is the infinite set of all possible interpretations of the process-polarity pair (s(k), r(m)). The range Y_{nq} is the infinite set of interpretations of the process-polarity pair (s(n), r(q)). The mapping f_{ij} itself is selected from an infinite set of interpretations of the process-polarity pair (s(i), r(j)). f_{21} is a mapping that implements any element of the infinite set {"assigned inward to," "reduced to," . . .} of all possible interpretations of (assignment, inward). We chose "reduced to" in the previous discussion of our example *"ya ta meem"* (orphan).

Note that for $f_{ij} : X_{km} ==> Y_{nq}$, i, j, and n do not necessarily correspond to the two columns of the first, second, and third root consonants, respectively. For example, root *"a(i, j) a(k, m) a(n, q)"* may have the mapping $f_{km} : X_{ij} ==> Y_{nq}$ or any other permutation of the subscript pairs. If we represent root *"ya ta meem"* as *"a(i, j) a(k, m) a(n, q),"* then the corresponding mapping we have here is $f_{ij} : X_{nq} ==> Y_{km}$.

Next, we look at roots where there are no soft consonants *(ya, hamza, waw, ha)*, but there is a single consonant from the fifth row of **A** *(ra, lam, ba, ta)* corresponding to the process *assignment of manifestation*, which we also call *allocation.*

- *"thal kaf* ***ra****"* (remember, mention or learn, see Result 8 and preceding examples). (Remember, mention): defined manifestation of speech (*kaf, word or expression*) *allocated backward (ra, linked back) to* a specific manifestation (*thal*). (Learn) defined mapping (*kaf*) *allocated repeatedly (ra) to* a specific event (*thal*). Learning is recursive interpretation of roots on associated events.

- *"fa kaf* ***ra****"* (think): defined mapping (*kaf*) *is allocated repeatedly (ra) to* undefined events (*fa*). Thinking is recursive interpretation of roots on unclear events.
- *"'ain* ***ra*** *fa"* (to recognize): undefined event (fa) *is allocated backward* (*ra*, linked back) to a defined order (*'ain*, a law). To recognize is to find the law that applies to a certain event.
- *"'ain* ***lam*** *meem"* (to know): defined order (*'ain*, a law) *is allocated outward* (*lam*, linked) to a defined event (*meem*). Science is linking laws to events.
- *"noon* ***ba*** *thal"* (cast away): *engaged allocation (ba, doing two things)* outward containment (*noon*, taking out) *and* placing separately (*thal,* unengaged manifestation).
- *"fa* ***ta*** *qaf"* (unseam): *unengaged allocation (ta, disengagement)* of outward manifestation (*fa*, spread substance, cloth) *from* engaged containment (*qaf*, seam).

Result 14: If there are no soft consonants *(ya, hamza, waw, ha)* but there is a single consonant from the fifth row of **A** *(ra, lam, ba, ta)* (assignment of manifestation, allocation), then it has control precedence, and the process-polarity pair (allocation, polarity) controls the other two process-polarity pairs.

Next, we look at roots where there are no soft consonants *(ya, hamza, waw, ha)* and no consonants from the fifth row of **A** *(ra, lam, ba, ta)*, but there is a single consonant from the sixth row of **A** (*seen, zay, ssad, tha*).

- *"fa* ***seen*** *dal"* (disrupt, destroy): *backward ordering (seen, structural reduction) of* engaged manifestation (*dal*, coherent function) *to* undefined manifestation (*fa*, malfunction). To disrupt is to structurally reduce a coherent function, causing it to malfunction.
- *"'ain* ***zay*** *meem"* (to resolve to do): *outward assignment of containment (zay, exertion of energy) from* inward containment (*'ain*, personal energy) *to* inward manifestation (*meem*, personal action).
- *"****ssad*** *'ain qaf"* (thunderbolt): inward energy (*'ain*, collected energy) *is engaged by assignment of containment with (discharged at)* engaged containment (*qaf*, energy connector).
- *"****ssad*** *dal qaf"* (truthful, come true): engaged manifestation (*dal*, shared experience) *is engaged by assignment of containment (matched by measurement) to* engaged speech (*qaf*, shared speech).
- *"****tha*** *meem noon"* (price): defined manifestation (*meem*, action or service) *is specified a measurement (tha) from* outward containment (*noon*, value offered).

Result 15: If there are no soft consonants *(ya, hamza, waw, ha)*, and no consonants from the fifth row of **A** *(ra, lam, ba, ta)*, but there is a single consonant from the sixth row of **A** *(seen, zay, ssad, tha)*, then the corresponding process-polarity pair (ordering, polarity) has control precedence and, thus, controls the other two process-polarity pairs.

Next, we look at roots where there are no soft consonants *(ya, hamza, waw, ha)* or consonants from the fifth row of **A** *(ra, lam, ba, ta)* or the sixth row of **A** *(seen, zay, ssad, tha)*, but there is a single consonant from the eighth row *(hha, sheen, geem, zza)*.

- *"**geem** meem 'ain"* (gather): *process to engage* defined manifestations (*meem*) *into* inward containment (*'ain*).
- *"**geem** meem dal"* (solid): *process to engage* inward manifestation (*meem*) *into* engaged manifestation (*dal*).
- "**hha** meem dal" (credit, praise): backward processing (attribution) of shared event (*dal*) to a defined person (*meem*).
- *"**sheen** fa qaf"* (twilight): *outward processing (showing) of* outward manifestation (*fa*, appearance) *at* engaged containment (*qaf*, meeting of spheres, horizon).
- *"**zza** 'ain noon"* (cabin of vehicle): *processing to disengage* inward containment (*'ain*, inside) *from* outward containment (*noon*, outside).

> **Result 16:** If there are no soft consonants *(ya, hamza, waw, ha)* or consonants from the fifth row of **A** *(ra, lam, ba, ta)* or the sixth row of **A** *(seen, zay, ssad, tha)*, but there is a single consonant from the eighth row *(hha, sheen, geem, zza)*, then the corresponding process-polarity pair (generic process, polarity) has control precedence, and it controls the other two process-polarity pairs.

Results 13-16 show a control precedence ordering of rows 2, 5, 6, and 8 from highest to lowest. Root examples not discussed here show in addition that next in control precedence are the rows 3, 7, and 4 from highest to lowest. Thus, we have the control precedence order: assignment, allocation, ordering, process, manifestation, mapping, containment, from highest to lowest.

We notice that process-polarity pairs that contain assignment (**A** rows 2, 5, 6, and 8) have control precedence over those that do not contain assignment (**A** rows 3, 7, 4).

Within the rows whose processes contain assignment (2, 5, 6, and 8), row 2 that contains nothing but assignment has precedence over rows that contained additional elementary processes. Processes that contain fewer elementary processes have precedence over those with more. We call this the **control precedence of simplicity**; the least complex process structures have higher control precedence. This natural law also explains why two-process rows 5 and 6 have precedence over three-process row 8 and why single-process row 3 has precedence over two-process row 7.

The sign structure represented by a root also **inherits the elementary control precedence** rules of the single sound signs stated in Part II of our theory. This is why **A** rows 2, 5, 6, and 8, which contain the elementary process "assignment," have control precedence over rows not containing assignments (3, 7, and 4). Rows 5 and 6 share assignments, but row 5 also contains a manifestation that has precedence over the containment of row 6.

Adi Theory of Semantics, Part III (Control Precedence among Process-Polarity Pairs): *Based on observations on the relationships between the elements of meaning represented by some word roots in* muhkam *passages and Results 13-16, we define the* ***inherited elementary control precedence factor K*** *(see Theory Part II) such that* ***K****(assignment)=100,* ***K****(manifestation)=10, and* ***K****(containment)=1 and then use* ***K*** *to calculate the* ***process-polarity pair control precedence factor C*** *for any process-polarity pair ((s(i), r(j)) as follows:*

C *((s(i), r(j))) = (6 ** ***Sum*** *(* ***K****(p(n))) | p(n) is in s(i)) /* ***size****(s(i))*

where i = 2 to 8 and s(i) is a process, a member of ***P****

and j = 1 to 4 and r(j) is a polarity from ***R***

and p(n) is an elementary process from ***P*** *out of subset s(i)*

and the multiplier 6 secures integer functional precedence factors

C *(2) = 6*100 / 1 = 600*

C *(3) = 6*10 / 1 = 60*

C *(4) = 6*1 / 1 = 6*

C *(5) = 6*110 / 2 = 330*

C *(6) = 6*101 / 2 = 303*

C *(7) = 6*11 / 2 = 33*

C *(8) = 6*111 / 3 = 222*

in order to determine the control precedence relationships needed to interpret sound combinations such as word roots and word forms. We notice that the precedence factor C does not depend on polarity.

Since word root "a(i, j) a(k, m) a(n, q)" is a structured sign that refers to the abstract object structure (a triple of process-polarity pairs)

(((s(i), r(j)), (s(k), r(m)), (s(n), r(q)))

then those process-polarity pair(s) that have the highest C value will control (are applied to) the remaining process-polarity pair(s).

C *produces a descending control precedence for the rows of* **A**

2, 5, 6, 8, 3, 7, 4

assignment, allocation, ordering, process, manifestation, mapping, containment

For example, assignment controls allocation, and ordering controls containment.

Part III of our theory explains Results 13-16 where the root (a string of three consonants) always contains a single consonant from a row that has a higher precedence factor **C** than the rows of the other two consonants. We call the process-polarity pair that this consonant refers to the **controller**. The controller plays the role of a mathematical mapping, and root interpretation is done according to a mapping of the form

$f_{ij} : X_{km} ==> Y_{nq}$

where domain X_{km} is the infinite set of all possible interpretations of the abstract object pair (s(k), r(m)), the range Y_{nq} is the infinite set of interpretations of the abstract object pair (s(n), r(q)), and the mapping f_{ij} itself is selected from an infinite set of interpretations of the abstract object pair (s(i), r(j)). Please remember that the corresponding root is not necessarily *"a(i, j) a(k, m) a(n, q)."* The sequence of the root subscript pairs is rarely the same as the sequence of the mapping's subscript pairs.

If two of the three root consonants belong to the same row of **A**—they have the same precedence factor **C**—then we have a new kind of structure in which a combination of the two corresponding process-polarity pairs controls (is applied to) the third process. We have **two controllers**.

- *"kaf **ta ba**"* (write, prescribe): *procedure to unengage-and-engage allocation (ta ba, prohibition and permission) applied to* defined manifestation of speech (*kaf*, rendering of speech). Writing always includes instructions, at least to the subconscious mind.
- *"qaf **ta lam**" (kill): unengage-outward allocation procedure (ta lam, break and leave broken) applied to* engaged containment (*qaf*, engaged energy, life).
- "kaf **ba ra**" (big): *engage-inward allocation procedure (ba ra, add and redo) applied to* inward manifestation of containment (*kaf*, to define volume).
- "**ra ta** qaf" (sewed up in such a way that it cannot be unraveled): *inward-unengage allocation procedure (ra ta, repeat connect to self and cut) applied to* engaged containment (*qaf*, flaps).
- "ddad **lam lam**" (to stray): *double-outward allocation procedure (lam lam, persistence, repeated belonging) applied to* manifestation outward of containment (*ddad*, activity outside order).

> **Result 17:** If a consonant repeats or if there are two consonants from the same row of **A** in a root, and the third consonant has a lower row precedence factor, then the two process-polarity pairs belonging to the consonants that share a row both control the process of the third. We have **two controllers**, and this effect corresponds to a **composition** of two mappings $f_{ij}(g_{ip}(x_{km}))$. In rare cases, all three consonants are from the same row, and we have $f_{ij}(g_{ip}(h_{iw}( )))$, a **double composition**. We then have **three controllers**.

In three consonant roots where the soft consonant "ya" or "waw" occupies the second or third position, this consonant is often considered a stretched vowel (vowel_i, vowel_a, or vowel_u). The roots are thus virtually reduced to **two-consonant roots**. Vowels are not associated with any processes. The process with higher row precedence factor controls the other.

- *"noon waw **ra**"* (fire, light, *waw* is seen as stretched *vowel_a* or stretched *vowel_u*): *inward allocation (ra, recurring allocation) of* outward energy (*noon*, energy generation).

- *"qaf waw **lam**"* (to say, *waw* is seen as stretched *vowel_a* or stretched *vowel_u*): *outward allocation (lam, addressing) of* engaged speech (*qaf*, connected speech, statement).
- *"noon **seen** ya"* (forget, *ya* is seen as stretched *vowel_i*): *repeated assignment of speech (seen) to* invalid containment (*noon*, no memory).
- *"**fa dal** ya"* (compensation, *ya* is seen as stretched *vowel_a*): *outward-engaged manifestation (fa dal, lose and match) applied to anything.*
- *"**tta** ghain ya"* (transgress, *ya* is seen as stretched *vowel_a*): *engaged manifestation of containment of (tta, grab)* unengaged containment (*ghain*, access not allowed).
- "ghain **tta** ya" (cover, ya is seen as stretched vowel_a): *engaged manifestation of containment tta, apply containment) to* unengaged containment (*ghain*, uncontained).

Result 18: If we have a three-consonant root with soft consonant *ya* or *waw* occupying the second or third position, and the soft consonant is treated as a stretched vowel (*vowel_i* or *vowel_u*), then the root is a virtual **two-consonant root** representing only two process-polarity pairs. The process with higher row precedence factor is applied to the other process (controls it). If they have equal precedence, then they combine to both be applied to an unspecified process.

The Adi Theory of Semantics, Part IV (Types of Root Interpretation Mappings): *Based on Part III and Results 17-18 as well as the discussion of mathematical mappings after Result 13, we find that the interpretation of Arabic word roots is governed by mappings or compositions of mappings whose domains and ranges are infinite sets of interpretations of process-polarity pairs. The mappings themselves also are infinite interpretations of process-polarity pairs. Based on Results 13-18, only the following* ***types of root interpretation mappings*** *are associated with Old Arabic three-consonant roots. The corresponding process-polarity pairs are identified by the subscripts.*

1. mapping (one controller)	$f_{ij}: X_{km} ==> Y_{nq}$
2. mapping, unspecified range (one controller)	$f_{ij}(x_{km})$
3. composition, unspecified range (two controllers)	$f_{ij}(g_{ip} (x_{km}))$
4. composition, unspecified domain & range (two controllers)	$f_{ij}(g_{ip} ( ))$
5. double composition, unspecified domain & range (three controllers)	$f_{ij}(g_{ip} (h_{iw} ( )))$

where

i, k, n = 2 to 8 is the index of process s() from ***P**** *associated with* ***A*** *rows 2 to 8*

j, m, p, q, w = 1 to 4 is the polarity associated with ***A*** *columns 1 to 4*

A root interpretation mapping is not as loose or vague as it may seem. It is specific enough to be written as a lexical definition, as we have seen in the previous examples. The Readware software implements such definitions to organize the vocabularies of other languages. *We have used the root interpretation mappings of Old Arabic as a universal library of concepts, a ConceptBase.*

We have manually assigned Arabic word roots to the stemmed words of modern English, German, and French. We have thus created **interoperable** language-specific ConceptBases, a special kind of thesauri that we use in search and analysis.

There is a fully automatic procedure to generate any Old Arabic word form from a root or, inversely, to reduce any word form to the originating word root. Word forms themselves are also signs that refer to abstract structures. For example, *'**q**aa**t**i**l**'* (killer) is derived from the root *"**q**af **t**a **l**am,"* and the infix structure of a stretched *vowel_a* (*'aa'*, stressed outward polarity) followed by *vowel_i* (*'i'*, inward polarity) is an abstract representation of the *actor* concept (killer).

A text of Old Arabic thus can be mapped into corresponding abstract structures using a fully automatic procedure. Unfortunately, this does not apply to Modern Arabic. Many root meanings in Modern Arabic usage differ from the meanings in Old Arabic usage. In many cases, modern use of one root has the meaning of a different root in old usage. Different word forms of the same root in modern usage sometimes correspond in meaning to a different root in old usage. A text of Modern Arabic requires table lookup for every word to identify the equivalent root according to Old Arabic. Word forms in modern use of one root that are always equivalent to the same root in old use may be limited to duals, plurals and verb tenses, and simple adjectives. Because of language change, we not only were unable to verify our theory on the meanings of Modern Arabic, but we also were unable to find a text whose use of meanings is perfectly consistent and, thus, can be used to derive rules of symmetry.

Our experience also has been that even the best dictionaries of Old Arabic contained many errors and inconsistencies. *Muhkam* passages are unique in being perfectly consistent in language usage and in that the meanings of roots are supplied by the root usage in the same texts.

We examined the meanings of words from 20 modern languages using different textual contexts or just dictionaries. Our theory applies to the meanings of countless word roots in these languages, but because of some inconsistencies, our theory cannot be derived from any of these languages or from a collection of them. We once used a 15,000-entry English glossary to verify our theory and correct any possible errors. The effect was very confusing, and we almost lost trust in the validity of our theory, even as it applied to Old Arabic *muhkam* passages.

Root Interpretation Mappings are Tools of Cognition

We believe that when we think, speak, act, read, research, or develop, we always interpret the abstract structures associated with word roots. Our conjecture is that **cognition**, **learning,** is about implementing root interpretation mappings in real-world environments.

We chose 2,750 Old Arabic word roots (1,750 of them are from *muhkam* passages) for the Readware technology and determined their interpretation mappings using our theory. We will refer to them as the elements m_1, m_2,..., m_{2750} of the library of root interpretation mappings **M**. Since Arabic has 28 consonants, there are theoretically 28^3 (21,952) potential three-consonant roots, but the largest Old Arabic dictionaries only have a total of around 4,000 roots.

Define a **cognitive frame** g as a triple $<u, m_i, v>$ that consists of a **user** u who **implements** a root interpretation mapping m_i in an **environment** v

$g = <u, m_i, v>$

where u is a user

m_i is a root interpretation mapping out of **M**, i = 1 to 2750

v is an environment

We will explore how cognitive frames inherit properties such as precedence rules, polarities, and control structures from the consonant interpretation layer (semantics of single sounds) and the root interpretation layer (semantics of sound combinations) and then go beyond such inheritance and manifest higher order precedence rules, abstract structures, and properties. We will start by constructing and examining cognitive frames. Unlike the abstract structures of consonants and roots, which were found or discovered by induction over word root interpretations, cognitive frames are created by people. We did not discuss the origins of the abstract structures of consonants and roots; the structures were deemed stable and naturally occurring.

Let us look at the root interpretation mapping m_1 out of **M**, root "*ssad lam hha*" (construction)

m_1 is $f_{52} : X_{63} ==> Y_{81}$

We simplify

m_1 = a construction mapping =

engaged assignment of containment

=(outward assignment of manifestation)=>

inward assignment of manifestation and containment

Let us practice some **cognitive interpretation** using the **interpret** operator. Please note that we use interpretation Tables 4 and 5 and make some mental shortcuts.

interpret ("=(assignment of manifestation)=>") = "designate function"

We dropped outward because it is indicated by the direction of the arrow. Similarly

interpret ("engaged assignment of containment") = "a structure"

interpret ("inward assignment of manifestation and containment") = "complex function"

The construction mapping m_1 thus can be interpreted

interpret (m_1) = designate *a structure* to a complex function

Here is a cognitive frame that implements the construction mapping m_1

g_1 = < user, m_1, environment >

We **instantiate** g_1 with user "chef" who designates the structure "meat" and "bread" to the complex function "make a sandwich."

instantiate (g_1) = <chef, m_1, {bread, meat}> = "make a sandwich"

The user "analyst" implements m_1 to find the "subject sandwich" in a text by looking for the co-occurrence of the words "bread" and "meat."

instantiate (g_1) = <analyst, m_1, {"bread," "meat"}> = "define subject sandwich"

The user "carpenter" implements m_1 to make a box by nailing some wood together.

instantiate (g_1) = <carpenter, m_1, {wood, nails}> = "make a box"

The user "doctor" implements m_1 to sew a wounded person together with needle and thread.

instantiate (g_1) = <doctor, m_1, {wounded, needle, thread}> = "stitching up a cut"

Introduce a destruction mapping (root *“fa seen dal”*).

m_2 = destruction function =

outward manifestation

<=(*inward assignment of containment*)=

engaged manifestation

The single controller (assignment of containment) maps engaged manifestation inward (backward) as indicated by the arrow “<=” to “outward manifestation.” If we interpret “outward manifestation” as “malfunction,” interpret “inward assignment of containment” as “structural reduction,” and interpret “engaged manifestation” as “coherent function,” then we have

interpret (m_2) = destruction mapping
= structurally reduce coherent function to malfunction

Here is a cognitive frame g_2 that implements the destruction mapping m_2

g_2 = <user, m_2, environment>

The user “kid” structurally reduces a glass by hand to malfunction (to pieces).

instantiate (g_2) = <kid, m_2, {hand, glass}> = “pieces”

There are other roots in **M** that deal with construction and destruction. Each one will give us a different cognitive model. The mappings **M** are, in fact, a library of cognitive tools that can be used to perform cognitive work on any system one can think of.

We find that **cognitive frames inherit** (i.e., implement) one or more **mappings from M** as well as their structural types. All the cognitive frames we have discussed so far have the structure

user u applies mapping m_i to environment v

which mimics **M** mappings of the type $f_{ij} : X_{km}$ ==> Y_{nq}. We express this inheritance of structure as follows user **=(***applies mapping***)=>** environment

We also can imagine a cognitive frame with *inward polarity*

user **<=(***applies mapping***)=** environment

(user u is subjected to mapping m_i by environment v)

Cognitive frames that combine two or more mappings are called **complex cognitive frames**. They inherit mapping structural types from **M** and may make use of composition. Here is a template for a complex cognitive frame with two mappings, a single user, and a single environment

$g = < u, m_i, m_j, v >$

where u is a user

m_i and m_j are mappings out of **M**, i, j = 1 to 2750

v is an environment

For example, the user "leader" may use the cognitive frame g_3 to destroy the economy

g_3 = <user, mapping_decide, mapping_destroy, environment v>

instantiate(g_3)= <leader, mapping_decide, mapping_destroy, {economy}>

leader **=(***applies mapping_decide***)=>** [mapping with unspecified range]

(leader makes decisions regardless of the economy)

leader **=(***applies mapping_destroy***)=>**economy

(leader lets economy be destroyed, by negligence)

This implements a cognitive frame structure with two subframes *without* composition. *With composition*, we have (decisions targeting elements of economy lead to destruction of economy) (leader =(*applies mapping_decide*)=> economy)

=(*outward-engaged procedure*)=> *((applies mapping_destroy*)=> *economy)*

Conclusion and Outlook

Here is the four-part Adi Theory in summary.

The 32 sounds of Arabic are signs that refer to 32 complex abstract objects, process-polarity pairs. A small set of rules generates these abstract objects and governs their symmetry and internal control relationships. (a) The power set of three elementary processses (assignment, manifestation, containment) is the set of all possible processes. (b) The set of all polarities is the product set of two symmetry sets: boundary conditions {closed, open} and engagement conditions {self, others}. (c) There is an elementary process control precedence: assignment controls manifestation and containment, and manifestation controls containment.

We find that thousands of three-consonant word roots of Old Arabic are, in fact, structured signs that refer to triples of process-polarity pairs. Higher-order process control precedence rules dictate control structures within each triple, giving us root interpretation mappings.

Cognitive frames implement root interpretation mappings according to the wishes of certain users in certain environments.

The leading Russian semiotician Dmitri Pospelov pioneered **semiotic situational control of open, large complex systems** (social systems, large factories, or corporations), systems that cannot be controlled by conventional control techniques. For this type of control, he proposed a *model consisting of four sets*: (1) **a base set** (a small set of concepts or elements); (2) **a set of axioms** defined over base set; (3) **a set of semantic rules**; and (4) **a set of syntactic rules** (Prueitt, 2000). Does the Adi Theory of Semantics combined with cognitive frames offer such a model?

The sounds of Arabic are ***the base set***. The rules that generate and govern the internal structure of the 32 process polarity pairs are ***the set of axioms***. Our ***set of semantic rules*** is the precedence rules that determine *interprocess control structures* and give us root interpretation mappings. The ***set of syntactic rules*** is created by the users of cognitive frames, who implement and combine root interpretation mappings according to their wishes and requirements in certain environments.

Paul Prueitt dubbed our base elements and axioms “the substructure” of our stratified model.

We propose that human cognition relies on the conscious and unconscious interpretation of word roots using the mappings that underlie human languages. We believe that our implementation of root interpretation mappings into cognitive frames, which inherit the structures and properties of these mappings and develop them further, constitutes a **theory of cognition**. Our findings have implications on how we teach; how we learn; how we study unfamiliar phenomena; and, indeed, how we might conduct any research and discovery project.

Our sign model is one in which the objects are abstract and can be interpreted into abstract or real objects. Reinterpretation is a mechanism for cognition. This concept is different from Peirce's evolving triadic sign-object-interpretant scheme.

Since cognition is based in part on biological processes, we believe that our theory may offer valuable insights to biosemioticians, who are trying to understand DNA models growth.

We have implemented our theory in a software we call Readware. Cognitive frames are implemented in **cultures**. These are collections of cognitive frames realized as **topics** (sets of concepts and expressions that instantiate cognitive frames) addressing real-world cultures such as technical, medical, or socioeconomic cultures. A Readware culture is, thus, an **ontology**. It is a **standardization** system that realizes **cross-lingual**, **cross-cultural**, and **cross-system interoperability** by way of root interpretation mappings and cognitive frames. A culture also offers an **abstract framework** of **knowledge representation** for a **complex system** (the real-world culture), utilizing root interpretation mappings that reflect **control** of many **interdependent processes**. Topics and cultures also offer a flexible and powerful form of **knowledge classification**.

Readware cultures are applied automatically to a text collection to create a **cognitive map** (a **readwarebase**, a **knowledge base**). Cognitive maps then can be queried with API functions to explore the old knowledge buried in the texts or to discover new knowledge by testing hypotheses with plain-text queries. This constitutes **artificial cognition** and **artificial intelligence**, two aspects of **computational semiotics**. Query functions, the **search engine**, include standard search techniques as well as algorithms based on our theory. The Readware Spider crawls the Internet to fetch documents. The IpServer is a TCP/IP server-client system that implements API functions as HTTP requests.

We believe our English ConceptBase played a major role in causing a Readware product, ConSearch, to be the near top performer at TREC7 and the top performer at TREC8, in which half a million documents were searched for 50 well-defined topics. Our original search method called *concept search* (hence, the product's name) relies on theoretically derived definitions of concepts (interpretations of Arabic roots) rather than conventional concept definitions. It finds hit spots that are sharp, deep, and relevant. This is the original, authentic concept search.

In the future, we also can add the root interpretation mappings of some word roots from modern languages to our ConceptBases and cognitive frames. This way, we will make use of language change that resulted in cognitive growth (rather than degeneration and confusion) and incorporate intelligence from different cultures into our technology.

Imagine a world in which we all agreed to accept the set of abstract concepts—the Old Arabic roots—to represent reality in multiple languages. Think of how many new ways we could use computers. People would be able to communicate with machines that know a set of concepts that derive from the data being processed, pointing to errors in conclusion or fact, as children awaken to their environment *through* their environment. Then, just as the arrival of the alphabet gave rise to interpersonal and timeless knowledge written for all the ages, and just as the American Standard Code for Information Interchange (ASCII) paved the way for the widespread use of computers, a new Golden Age finally might break down cultural barriers of misunderstanding for the good of all.

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Section III

Semiotics in the Development of Intelligent Systems

Chapter VIII

The Semiotics of Smart Appliances and Pervasive Computing

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Abstract

This chapter presents digital habitats, a conceptual and methodological framework for analyzing and designing smart appliances in the context of pervasive computing. The concrete topic is a project in pervasive gaming for children. The framework consists of a set of theoretical concepts supplemented by diagrams for representing semiformal models. We give a short overview of selected theories of play and gaming and apply the framework to an implemented simple pervasive game. Finally, we use the framework in a constructive manner to produce a concrete design of a new game. The result is discussed and compared to other approaches. The main points are the following: (a) it can describe communicative as well as material acts plus the way they hang together; (b) it provides an explicit link between human activities and their spatial context; (c) it has an explicit dynamic model that precisely describes the conditions for executing actions; and (d) it offers a typology of participant roles based on linguistic theory, which supports design processes.

Introduction

In this chapter, we will present an approach to analysis and design of computing systems that transcends the boundaries of traditional office computer systems such as PCs and laptops. These transcending systems are called ambient, ubiquitous, or pervasive computing systems, and they pose new challenges to the way we understand, analyze, and design information technology. With such systems, computing power spreads from dedicated computing hardware into other artifacts and places, both at the workplace and in everyday life. Microcontrollers, sensors, and actuators have been embedded in machines for decades, but the functionality was tied closely to the artefact in which it was embedded (e.g., a washing machine or the side mirror of a car), and therefore, the computational "smartness" was not foregrounded in itself. Two factors have changed this: (a) the increasing flexibility and computing power of smaller-scale devices, and (b) the wireless networking capabilities and structured exchange of information. In this world of smart phones, GPS (location tracking), and software agents, we need concepts to communicate about human needs and activities as well as technical infrastructures. Digital habitats is a suggestion for such a framework. In our presentation, we focus on fun and games, but the framework originally was conceived in a workplace setting.

"On the Concept of Intelligence" discusses the concept of intelligence and concludes that the everyday use of the concept applies to a disposition to act in a certain way in a network of other actors and artefacts. To be intelligent is to fill out Agent roles appropriately in activities conducted by such networks.

The habitat concept defines the framework we use. On the one hand, it defines activities in terms of roles, participants, actions, and glue binding participants to roles. The well-known automatic door opener is used as an example. On the other hand, it offers a maplike representation that ties activities to physical and informational spaces and describes the various types of interplay between physical and informational space. This is particularly relevant to pervasive computing, since pervasive computing is characterized by being distributed in physical space and by overlaying physical space with digital information.

In "Play and Games," we give a short overview of theories of play and gaming. In "Designing Pervasive Games," we adapt the framework to the domain of games and describe an implemented simple pervasive game called *StarCatcher*. "The Bogeyman" puts all the ends together in a concrete design of the game *Bogeyman* that elaborates on StarCatcher by drawing on the presented theory. "Related Work" compares this chapter to related fields, and the conclusion summarizes the advantages of the present approach, as we see it.

On the Concept of Intelligence

The first issue that must be discussed is what *smart* and *intelligent* mean.

Intelligence

Since there is no universally accepted definition of intelligence (Roth & Dicke, 2005), we accept Gilbert Ryle's (1970) claim that these words denote (a) the manner in which an action is performed and (b) a prediction about the way other actions are performed. In this case, intelligent does not denote a special mental process that is the cause of the action but rather a disposition generally to act in a certain manner. What is intelligent depends upon the circumstances but often involves features such as: the action achieves its goal, it does not contain superfluous steps, it economizes with resources, it does not destroy or hurt participants, it is an innovative way of solving a difficult problem, and so forth.

This definition is similar to a prevalent view in contemporary cognitive science, that "mental or behavioral *flexibility* is a good measure of intelligence, resulting in the appearance of novel solutions that are not part of the animal's normal repertoire" (Roth & Dick, 2005, 250). We choose to focus on the behavioral aspect and, thus, preclude ourselves from making inferences about neuroanatomy or mental mechanisms. On the other hand, this choice to focus strictly on behavior allows us to use the word about humans as well as artifacts without committing ourselves to philosophical doctrines about the nature of the mind (see Dennett, 1991).

If intelligence denotes a disposition to act in a certain way, then it follows that its unsophisticated and immediate reference is to networks of actors, instruments and objects. The reason is quite simply that human action normally is mediated by an instrument and directed toward an object. These elements form a network, and it is such networks that we can immediately call *intelligent* or *smart*. There will often be a next analytical step in which we ascribe the main honor to one or more of the participants in the network: one of the actors, tools, or objects may be seen as the main contributor.

Networks of Stupidity

This analysis is easier to verify with negative predicates such as *negligence*, *stupidity*, and *inability*. For example, accident reports must point to a participant that is guilty of the accident in order to suggest future remedies against the type of accident and because of insurance issues. Although accidents are mostly caused by a particular configuration of participants in the network, the report must point out the weak link in the chain. However, this is often difficult and a matter of interpretation.

Here is an example, due to PhD student Thomas Koester: a ferry was fitted with a system that compensated the heeling of the boat by moving water in the ballast tanks. The system had a manual and an automatic mode, but sometimes it would unexpectedly go from automatic to manual mode. The mode change was displayed on the bridge and in a closed locker on the deck. The accident occurred when the deck crew was emptying the deck for its cargo of trucks and cars. When cargo is removed from one side of the ship, it will heel, and the system is supposed to compensate; in this case, it had switched to manual. The result was that the heeling was more than six degrees, and the ramp was damaged. Who was to blame? The crew? It knew about the fault; should they have opened the locker and checked the mode regularly? But then the disembarkation would have gone more slowly. The manufacturer?

The system obviously should not be allowed to switch to manual by itself. The ship owner? He could have counteracted the fault by mounting a warning system on the deck, informing the deck crew of the mode shift.

The fault is clearly due to the whole network: *a faulty system + missing indications of the error + lack of attention in the crew.* It is a practical and political matter, not a philosophical issue, to decide on a remedy: correcting the mode error, mounting a warning light on the deck, or changing the operation procedures.

The importance of networks vis à vis individual actors has been emphasized in the actor network theory (Latour, 1994, 1999; Law, 1987). For example, *power* is a predicate that pertains to an actor's position in a network, not to the individual actor.

The example illustrates the point made previously: predicates such as intelligent, smart, sloppy, inefficient, and so forth are in the first place predicates of networks, not of their parts. Only analytically can one of its participants be singled out as the main factor, and this choice depends upon the countermeasures that are considered feasible and desirable.

The same line of reasoning can be applied to *intelligence*. The IBM chess program Deep Blue beat grandmaster Kasparov on May 4, 1997. Therefore, there is an intelligent network of actors comprising at least the following participants: the developers, the chess literature they used, the system, and the operator. But which participant should be picked as the winner of the match? It is as difficult to decide as in the accident case, but it was the development team behind Deep Blue that took home the $700,000 first prize. Thus, in practice, the development team was singled out as the intelligent part of the network.

Intelligent Technology

If we are to single out one participant of an intelligently conducted activity, it must be because its contribution is particularly conspicuous. How do we decide this? One way is a simple substitution: if we keep the chain constant and replace one participant, does the performance of the chain become more or less intelligent? If the chain performs less intelligently, we may tentatively attribute intelligence to this part of the chain.

From these arguments follows a definition of smart/intelligent technology:

1. Intelligent technology is a kind of technology that is able to contribute positively to activities whose manner of performance we will intuitively call intelligent.

In the following, we incorporate this definition in a broader framework, which we call a *habitat*. The habitat concept is a general attempt to link networks of activities and actors to physical space on the one hand and signs and sign usage on the other hand.

The Habitat Concept

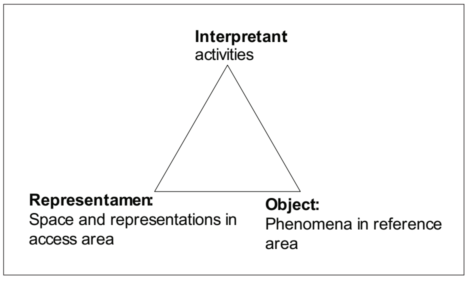
The habitat concept was elaborated in the research group *Frameworks for Understanding Software Systems* (Andersen & Nowack, 2004; Brynskov & Andersen, 2004; May & Kristensen, 2003). The purpose of the research was to devise a methodology that is better suited for handling context-sensitive pervasive computing than are traditional ones. Traditional object-oriented modeling methods (Mathiassen, Munk-Madsen, Nielsen, & Stage, 2001) are characterized by two features: (a) they model conceptual structures while the physical system represented by these models is absent in the method, and (b) the physical location of the software components is postponed to the last implementation phase (Andersen & Nowack, 2002). This is a problem in context-sensitive pervasive computing, because one of its possibilities is the use sensors to collect information about physical objects located in the spatial or temporal vicinity of the physical device where the software resides. Therefore, we need to coin concepts for the information available in the vicinity of the physical device and for the physical objects referred to by its software model. The former concept is called the *access area*; it denotes the locations from where sensors can access information; the latter is called the *reference area* and denotes the location of the objects referred to by the software model. Furthermore, a description of information is incomplete if we do not specify its use (i.e., what activities is the information used for?). Therefore, we need to enter the notion of *activities* into our framework. Finally, we are interested in systems that are sensitive to their physical surroundings, which means that our third component must be *space*. We are interested in physical spaces that are designed or have evolved to support a delimited set of human activities. This is true for an overwhelming number of the spaces in which we live daily: private houses, airports, hospitals, railroad stations, road networks, and so forth. We have chosen the term *habitat* to denote a physical space that is designed to support some set of activities and that provides access to information about objects relevant to the activities (Brynskov & Andersen, 2004).

2. A habitat is a chunk of space-time that is designed or has evolved to support a delimited set of activities by offering physical artifacts and information sources useful for conducting the activities.

From this definition, it follows that a habitat should be characterized along three dimensions:

3. **The physical habitat:** The physical layout and boundaries of the habitat plus the available physical artifacts.
4. **The informational habitat:** The signs available (access and reference area) to participants in the activities (digital and nondigital signs).
5. **The pragmatic habitat:** The action affordances offered by the habitat, the macro-roles, and the role-requirements of the participants.

Figure 1. The habitat as a sign



The contribution of the present chapter is threefold: (a) it explores the usefulness of the habitat concept in the domain of pervasive games; (b) it presents a framework for describing communicative and material activities and the way they interact; and (c) it presents a notion of intelligent or smart technology that is consistent with the framework. The chapter mostly draws on semiotic and linguistic theory, and our basic understanding of the habitat concept is well-captured in Peirce's semiotic triangle (Figure 1). The space itself and its manufactured representations (e.g., signposts and electronic displays) are representamens; the interpretant of these signs is the activities associated to the habitat, and the object is the phenomena inside the reference area (i.e., things or events that are relevant to the activities).

Activities

In order to use definition (1) for design purposes, we need a general functional definition of activities, and a set of context-dependent definitions of what criteria intelligent activities must meet in various domains. The general definition is given in this section. The game-specific adaptation is presented in the section "Applying the Theory to Games."

Goal, Roles, Participants, and Actions

As in the case of intelligence, we adapt a functional view of activities (Andersen, 2004a, 2004b, 2005; Bødker & Andersen, 2005; Brynskov & Andersen, 2004). The conceptual framework consists of roles, participants, actions, and activities. Activities consist of actions subsumed under a shared goal, and participants play roles in relation to actions and activities.

At the action level, we use traditional linguistic semantic roles like agent, theme, instrument, beneficiary, source, destination, time, place, direction, and so forth (see Fillmore, 1968, 1977; Blake, 2001). At the activity level, we use macro roles like librarian/borrower, customer/clerk, lawyer/client, judge/defendant, and so forth. The macro roles are defined by the semantic roles that participants can play in actions: thus, a Judge is the Agent of actions like planning the sessions of the court, considering the judgment, giving a verdict, sentencing, and so forth. This is the method used in the classical work on narratology (Propp, 1968).

In addition to specifying actions, roles, and activities, we need to specify the goal of the activity. We distinguish between four types: creating, destroying, preventing, and maintaining a state (Lind, 1994).

Not all participants are equally qualified to play these roles; a role requires its filler to possess the requisite incentives and qualifications in order for it to contribute in an intelligent and competent manner. Incentives include intentions, desires, and obligations; qualifications cover the relevant abilities, rights, and knowledge. Sometimes we will refer to these qualifications as a lump of glue that binds a participant to a role.

Some of these requirements are realized differently in humans and nonhumans. For example, intentions are implemented as negative feedback loops in automatic systems like thermostats that aim at keeping a certain process variable (e.g., the heat) locked at a certain set-point. Its goal is to maintain the process variable at the set-point. In software agents (Russell & Norvig, 2003), intentions often are implemented as some kind of means/end structure along with a planning and execution algorithm. The goal often will be to create a certain state, but in order to do so, the algorithm will have to maintain other states (protected states) and prevent others (forbidden states).

According to the approach outlined previously, we should not necessarily ask whether this implementation resembles the way humans make and execute plans. Instead, we should ask for qualifications: to which degree is the behavior of the automatic system suited for playing its assigned roles in the activity? The same goes for knowledge: there are many types of knowledge representations (predicate calculus, semantic networks, frame systems, conceptual graphs, and neural networks), but for the present purpose, it is not interesting whether humans use something comparable but only to which degree the system component using these methods is able to play its allotted role. The viewpoint, thus, is strictly behavioral.

In this chapter, we will concentrate on cooperative activities involving humans, intelligent systems, and dumb artefacts. Since the activity is cooperative, the following requirements of intelligent agents are important:

6. The agent should have intentions to act that are understandable to the others (*comprehensibility*);
7. Agents should display their intentions and actions in a way that is accessible to the other participants (*accessibility*);
8. Agents should be able to perceive and manipulate the attention-focus of their colleagues and adapt their own actions accordingly (*joint attention*);
9. Agents should be able to enter and leave the activity (*intermittent participation*).

Applied to mechanical agents, comprehensibility (6) means that they only should form plans that are understandable to their human and nonhuman colleagues. Understandable algorithms have a higher priority than cunning ones, but there is a tradeoff between intelligibility and efficiency.

The intentions of the agent should be signaled to the other participants in a way that allows them to reliably infer intentions from behavior (*accessibility, 7*). In other words, there is a mutual commitment to signal the truth, the whole truth, and nothing but the truth in the least complicated manner (equivalent to the so-called Gricean maxims [Grice, 1975] from the pragmatics of natural language). On the other hand, once the deliberate representation of intentions has been introduced, it is possible to misuse it to lie about intentions as well.

Attention is intentionally directed perception (Gibson & Rader, 1979; Tomasello, 1995). Joint or shared attention (8) is necessary for cooperation: If I cannot see what my colleague is concentrating on, I cannot collaborate with him or her. However, shared attention is more than just looking at the same object or detecting gaze direction; it is the mutual understanding between two intentional agents that they are, indeed, intentional agents (Tomasello, 1995) (see Dennett's, 1987, *The Intentional Stance*). In order for me to share a goal-directed activity with somebody, I not only must be sure that the other participants have their minds focused on the objects or topics I think of myself, but all participants also must share the fundamental assumption that activities can be goal-directed and that they can be coordinated by detecting and manipulating attention. In fact, shared attention is a constituent factor in cultural learning (Tomasello, Kruger, & Ratner, 1993). Humans share attention all the time, beginning near the end of their first year of life as a result of a constellation of emerging social behaviors (e.g., communicative gestures, imitation, social referencing) (see Tomasello, 1995). We can read or infer and, therefore, continuously follow and manipulate each other's focus of attention (and thereby intention) throughout a joint activity. This interpreted focus is a common anchor point without which two persons would drift away from each other—mentally and physically—instead of staying focused on the same subject matter. They would be solipsist nomads.

Intermittent participation (9) means that participants must be able to leave and enter the network without its breaking down. Much pervasive technology, including games, must allow participants to enter and leave without notice. For example, a door opener would be unusable if the pedestrian were to type in complicated commands preparing the door for the event before walking through the door and signing off after the passage. The ferry system in *Networks of Stupidity* was not sufficiently robust to allow the mechanical agent to leave the network without notice; the network broke down and damaged the ramp.

Joint attention and intermittent participation are also important in our concrete topic: children's games. When children play, it is important for them to keep track of the other's focus. Children gradually develop this sense of playing or doing things together as opposed to just doing things in parallel. At the age of two, they have all the prerequisites for joint attention (Kaplan & Hafner, 2004), and they continue to develop still more complex social interaction based on this fundamental competence. Also, children enter and leave activities very often (i.e., their participation is intermittent and highly dependent on the environment). They have to go and eat, must go outside, or one participant is picked up by his parents.

An example of a game that supports intermittent participation is *LEGO Star Wars* (www.lego.com/starwars), which allows players to join and leave a game in progress so that a parent can step in and help a child but leave again without having to play the entire game. When a player leaves, the character continues as an independent agent controlled by the software (at least one player must be controlled by a human, however; otherwise, the game ends). Massively Multiplayer Online Games (MMOGs) (e.g., *World of Warcraft* [www.worldofwarcraft.com]) are another example of games built around intermittent participation. Mobile MMOGs exist, too, and are called 3MOGs (e.g., *Undercover 2: Merc Wars* [www.undercover2.com]). Often, children can be seen not only as mobile but also as nomadic, because they are dependent on the resources and partners offered by the environment (see the following section). In this case, the proximate environment has a marked influence on their patterns of play (Brynskov, Christensen, Ludvigsen, Collins, & Grønbæk, 2005).

The problem of sharing attention between humans and machines is that machines do not have the ability to read attention, let alone intentional stance (see, however, Kaplan & Hafner, 2004). In the ferry incident, one of the problems was also the lack of joint attention. The automatic pump system switched to manual operation without monitoring whether this important change was brought to the attention of the crew. The crew, on the other hand, could not monitor the attention of the pump system and, therefore, failed to realize that they were supposed to operate the pumps manually. Thus, intermittent participation seems to require joint attention.

People use language to a large extent to signal their focus of attention. With machines in the loop, this is not possible, not because computers cannot produce or parse speech at all (they can to some extent), but because their underlying representation of attention and states do not map easily onto their human partner's. This is because the semantics of a language is not context-free but grounded in experience. Humans seem to take the other's perspective by mapping observations onto their own nervous system in a kind of simulation. Therefore, joint attention presupposes understandable algorithms.

If we still want humans and machines to share attention during activities, we have two options:

- We can try to develop epigenetic artificial intelligence that can learn to share attention by means of contextual grounding, imitating human cognition (although it is still an open question how exactly to achieve this) (see Steels, 2003; Kaplan & Hafner, 2004), or
- We can try to create a fixed, hardcoded, and more simplistic common ground where both humans and machines can read and interpret behaviors.

We choose the latter, and one of the methods is to design comprehensible algorithms so that there is something for the human participants to share. As a consequence, one might say that the burden of flexibility, to a large extent, is put on the shoulders of the human participants.

The challenge of handling attention focus and intermittent participation is not at all new in human-computer interaction (HCI), especially in the field of computer-supported cooperative work (CSCW) (Bardram & Hansen, 2004). There is a difference, though, in signaling an application's states and functions as a tool or medium, as is the traditional case in HCI, or a person's availability in CSCW, to signaling an agent's states. The difference is whether we attempt to represent intentions (Tomasello, 1995). Attentive agents and calm systems that work in a sort of symbiosis with their owner and sense or guess his or her intentions is an old idea (Licklider, 1960; Weiser & Brown, 1995), and it is still being pursued (Maes, 1994; Maglio & Campbell, 2003). As already mentioned, participants in our framework are glued to their roles not only by intentions but also by desires, abilities, rights, obligations, and knowledge, which also, to a higher or lesser degree, indicate intentions. Therefore, a minimal requirement is to signal these binders not only in a form that humans can interpret but also the other way around. We see play as an interesting case, since this is an important part of the situations in which children learn the intricacies of the semiotics of behavior.

Figure 2. Automatic door opener in shopping mall

Door Openers

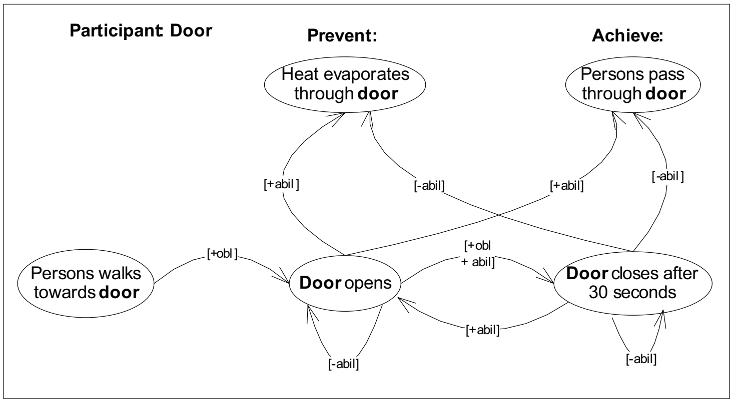
In this section, we illustrate the concepts used to model activities by a widespread technology; namely door openers. In addition, we offer some simple diagramming techniques. Door openers are good examples because they involve networks of humans and nonhumans, and nonhumans play an Agent role in the sense that they initiate and monitor activities.

The activity concept is the one described previously. We use a diagram consisting of actions, and we highlight the relations between the actions by graphical means. Two actions can be connected by arrows signifying dependencies between participating in the two actions. The rules are as follows:

10. An activity is executed if all participants are able to fulfill their roles to some degree and if the Agent filler is strongly obligated and/or strongly desires to fulfill his or her role. In the game described in "The Bogeyman" section, desires are created by application of dissonance theory (Eskola, 1973), whereas ability is created by the participant's location. Whenever the necessary participants are assembled in the same place, the activity is enabled.
11. If something successfully participates as role A in executing action X, then its intentions, desire, abilities, rights, obligations, and/or knowledge (its glue) to participate as role B in action Y are changed.

We shall use various ways to diagram these notions (a discussion of diagramming techniques can be found in Andersen, 2004b). Figure 3 shows an ordinary door opener from a shopping

Figure 3. The activity of door-opening focusing on the door participant. Obl = obligation, abil = ability. '+' means increases, '- ' means decreases



mall. The dependency between actions is shown by arrows annotated by the glue dimension affected. The participants involved are shown in boldface.

The activity contains five actions that are connected as follows: when a person walks toward the door in order to get in, the door opener is required to open; when it does, it becomes able to function as a passage for persons passing the doorway but also for heat disappearing. When it closes, it loses these abilities. The goal of the activity is letting people in through the door while preventing heat from disappearing. Since the two goals are contradictory, we must dissolve the contradiction by unfolding it in time. Therefore, when the door opens, it becomes obligated to close after, say, 30 seconds.

In the game-specifications, we use a simplified version of the diagram in Figure 3. The simplified diagram is on a high level of abstraction, displaying only the essence of the game.

The abstraction is made in the following way:

12. The participants, roles, and glue changes responsible for the dependency between the actions are stripped away.
13. Abilities and rights are merged under the heading *possibility* and represented by a single-headed arrow ⟶
14. Desire and obligation are merged under the heading *necessity* and represented by a double headed arrow ⟶⟫
15. Inability or prohibitions are merged as *impossibility* and represented by ——╫

The behavior of the door opener now looks as shown in Figure 4.

Figure 4. Modal diagram over a door opener

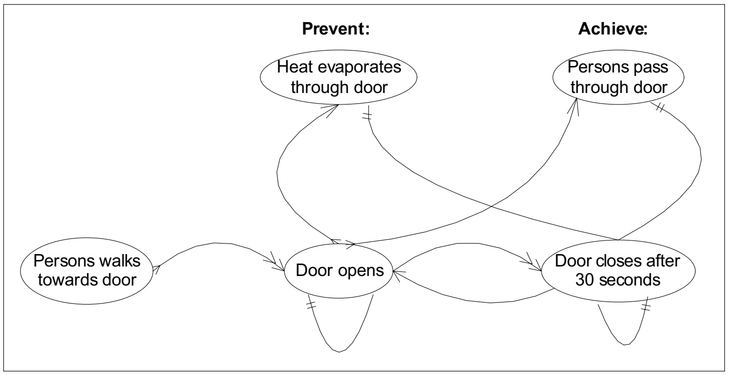
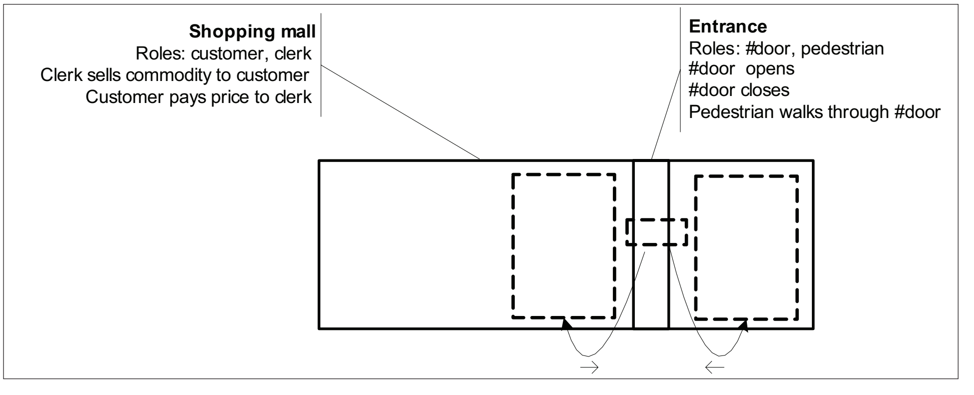


Figure 5. Shopping mall and entrance. #door means "an instance of the class of doors"



The reason for these formal abridgements is that diagram design is a tradeoff between precision and overview. The reader should be able to grasp immediately the possible paths of the story by reading the diagram. However, there is still an underlying detailed semantics in which participants, roles, glue, and glue changes are specified. They are just not shown in the diagram.

The previous notations highlight the interdependences between actions but do not provide a clear picture of the relation between activities and space. Such relations are important when we design context-sensitive, pervasive technology, and therefore, we introduce a maplike notation in the next section. It associates activities to a physical space, if the space plays the role of location in the activity.

Habitats

In pervasive computing, the physical space and its relations to the informational space becomes important. Therefore, we need a diagram that highlights the spatial properties of activities and networks, in opposition to the previous section in which we highlighted the relations between actions.

Figure 5 shows a diagram that codes the spatial participants graphically and tones down relations between actions. We have selected the spatial participants (i.e., spaces that participate in the Location role of the activities, spatial participants filling the location roles are called *habitats*. We have shown two habitats: the shopping mall and the entrance. To each habitat is associated the actions that can be performed there: selling and paying in the shopping mall, and walking through doors at the entrance. In addition, we have represented the signs involved in terms of (a) the area from where they can be accessed (the access area) and (b) the area containing the object denoted (the reference area). Both areas are shown by means of dashed polygons, and an arrow points from access to reference area. Thus, the door opener has access to the areas inside and outside the door. The arrows are decorated by the main signal path. Sensors often transmit and receive signals in two directions. For example, radar sends out radio waves and records their echo. The outgoing waves are only a means for receiving the ingoing echo. Therefore, the main signal path in radar is from reference to access area, which is also true in the door-opener case.

We distinguish between relative and absolute references. The difference is that if the access area of relative references moves in time or space, the reference area moves, too. This is not the case with absolute references. The reference of the door opener is relative, since if we move the door opener, it will refer to the new environment in which it is placed. Transponders, RFID-tags, and radars create relative references. The distinction also shows up in language, where the so-called deictic words (*here, now, me, you*) have references relative to the speaker. Compare the two sentences: *The Second World War ended in 1945* and *The Second World War ends now.* The former does not change meaning if it is uttered in year 2000, whereas the latter becomes false if uttered in that year.

To each habitat is associated half-baked actions that can be performed there—the *affordances* (Gibson, 1986) of the habitat. In the following, "#" means that the role is instantiated, whereas a type indication such as *pedestrian* means that the role can be filled by a specific type of participant. *Pedestrian walks through #door* thus means that the Location role is instantiated by the particular door and fixed, while the Agent role can be filled by any pedestrian. Fully instantiated actions are created by unifying the action possibilities of the participants with the affordances of the habitat. For example, *#smith can walk through doors + pedestrians can walk through #door* unifies to *#smith can walk through #door,* because #smith is a pedestrian and #door is a door. If #smith was not a pedestrian but a car, or if #door was not a door but a wall, unification would be impossible, and no action could be instantiated. There are many ways to implement instantiations. In (10), the "Activities" section, we suggested a particular way of doing it: shared location gives the participants the ability to instantiate roles in the actions, while desire gives a participant the incentive to instantiate the agent role.

This way of combining abilities from agent and environment is useful in agent design, as argued by Cabri, Ferrari, and Zambonelli (2004), who also uses a role-based architecture.

We shall term it *contextual execution*. The term means that an execution of an action consists of pieces, some of which originate from the participant, while others come from the habitat. This enables participants to act flexibly in different contexts without having to remember the exact details of each particular context.

The notion of half-baked actions (Andersen, 2004c) reflects the idea that we normally never start from scratch when we act. We know that specific participants normally are useful for the purpose we want to accomplish, and we try them out first. To take the door opener example, if we want to enter a room, we do not start with the isolated verb *enter* and spend time reflecting which participants it should have. Our point of departure is *enter through #door*, where the direction case is instantiated by a specific door we can see. Only if the door is locked may we begin considering the windows and the chimney. Another argument is that isolated verbs do not allow predictions: drinking milk, beer, and cyanide has quite different consequences.

In this method, all actions are bound to a certain physical habitat, and, indeed, many actions work in this way. We do need to be inside the airport to embark on an airplane. But what about the planning of the travel? Do we have to be in Portugal in order to plan the travel from the airport to the hotel in Lisbon? No, of course not. Some activities, such as planning, should not be and are not bound to specific locations. Instead, we imagine how things are in Lisbon and simulate the remaining part of the travel in our minds (or on a computer, or let the travel agency take care of the problem). This means that we need the concept of *fictive habitats:* habitats we imagine and in which we can test solutions without being there in reality. Fiction in general enables us to enjoy living in fictive habitats for a delimited period of time, and therefore, we shall need the concept in "Designing Pervasive Games" and "The Bogeyman," where we address the question of designing pervasive games for children (on the logic of fictive worlds (see Ryan, 1991). Pervasive games thrive on the interplay between actual and fictive habitats, as we shall see presently.

Play and Games

The preceding conceptual framework has mostly been used for analytical purposes or for instrumental design topics like brain surgery; evacuation procedures on ships; and pervasive applications in shopping malls, airports, and hospitals (Andersen, 2005; Andersen & Nowack, 2002, 2004; Brynskov & Andersen, 2004; Haase, Musaeus, & Boisen, 2004; Kristensen, 2002, 2003; May & Kristensen, 2003; May, Kristensen, & Nowack, 2001).

Designing technology for playful activities is very different from designing tools for instrumental activities. It is not necessarily the most efficient solution that is the best solution. The user should have fun—and fun is hard to predict and design. Thus, playful activities often are not goal-directed, at least in the sense that the goal may be hard to define or quantify, and the activity may be enjoyable for its own sake (see Csikszentmihalyi's, 1990, concept of flow).

In the rest of the chapter, we shall test our framework in a design context. In particular, we shall explore whether it yields creative ideas for designing pervasive technology for children's play. The project called *Nomadic Play in Mixed Environments* is a part of the

Center for Interactive Spaces at the University of Aarhus.

The notion of nomadic play is different from mobile play. Mobile indicates independence of physical location (i.e., activities are enabled, and resources are available regardless of the user's location). For example, a mobile phone may allow a child riding a bus to play a game, check e-mail, or use instant messaging. Nomadic, on the other hand, indicates dependence of physical location. The analogy is nomads traveling through the desert, being dependent upon oases and family networks. In a similar fashion, nomadic users are dependent upon, or take advantage of, resources and services that are made available by the environment, including other people's devices (peer-to-peer). Thus, nomadic play indicates a playful use of smart appliances and pervasive computing systems that could not occur if the child was not at a certain location (e.g., at a club or at home) that offers certain services (e.g., a home game server or media center) to a certain group of people (e.g., friends of the house). One could argue that certain features of mobile systems are also nomadic in nature (e.g., the coverage of mobile phone networks, but we restrict the term *nomadic* to systems that are more local in the physical sense and, thus, are designed to support a more focused set of human activities.

Theories of Play and Gaming

Children's play has mostly been treated in developmental psychology (Piaget, 1962; Sutton-Smith, 1979; Vygotsky, 1976) and in the context of game design (Salen & Zimmerman, 2004). Here, we adopt the view that play is the search for fun. To be a bit more specific, play is a focused but internally motivated activity without serious consequences. It may not have a goal outside itself other than it keeps a child occupied in a way that allows it to gain experience in the world, both physically and socially. From this perspective, play could be seen (by adults) as training and preparation for adulthood, whether structured or not. The search for fun is the fuel that drives the activity. Thus, learning may be considered play, as long as the internal motivation is high, because it is fun.

Playing a game can be seen as a special case of ludic activities, which, in turn, are a part of being playful (Salen & Zimmerman, 2004). A game can be defined in many ways, and there are plenty of suggestions from which to choose. Koster (2005) lists the following from academia: Roger Callois' an "activity which is … voluntary ... uncertain, unproductive, governed by rules, make-believe"; Johan Huizinga's "free activity ... outside 'ordinary' life …"; and Jesper Juul's (2005):

> *A game is (1) a rule-based formal system with (2) a variable and quantifiable outcome, where (3) the different outcomes are assigned different values, (4) the player exerts effort in order to influence the outcome, (5) the player feels attached to the outcome, and 6) the consequences of the activity are optional and negotiable.* (Juul, 2005, p. 3)

We distinguish between two types of playful activities: playing and gaming. A game has fixed rules and a quantifiable outcome (a clear goal), whereas play has ad hoc negotiable rules and a fuzzy outcome. A game can be embedded in play (see Juul's point about the optional and negotiable consequences of a game). Both types of activities should be fun.

An important distinction is that between emergent games and games of progression (Juul, 2005). In the former, the game is defined by a small number of simple rules governing a possibly large number of human or nonhuman participants. An emergent game can be played many times, since each round is different. Emergent games invite planning and strategic thinking. Games of progression are defined by a more or less fixed sequence of events and often tell an elaborate story. Like novels and films, they seldom can be played more than once.

Our two games are games of emergence, but in *Bogeyman*, we have tried to add narrative traits.

Applying the Theory to Games

This section adapts the concepts presented previously to the special case of games. In this section, we consider games in general, and in the next section, we focus on pervasive games.

We first show that the glue concept (that binds participants to activities) is useful to characterize games.

The children's *desire* motivates them to enter activities ("come and join us; this is fun") and a lack of desire to leave them ("I am going home because this is boring"). Playthings must create desires in children to assume the Agent role.

Ability, rights, knowledge and *obligations* may regulate participation for human as well as nonhuman participants. An able goal keeper is sure to be enrolled in a soccer game. In the Danish game called The Earth Is Poisonous, it is allowed to tread on furniture but forbidden to step on the floor, because it is poisonous. These tokens of glue may be earned from previous activities, and if they are given a physical shape, they can be exchanged by the children. For example, a child only can participate in secret club activities if he or she has been allowed access to the club and can show his or her membership card.

A child may only get entrance to the club den if he or she knows the secret password. Or abilities may be missing: "You are not allowed to take part because you are stupid." (One might ask, Who is lacking abilities here?)

Glue like rights and obligations can be distributed: "I'm the president and you must do what I tell you. No, that is silly. Well, then you can be the vice-president and tell Billy what to do."

Actions can be associated to spaces via the habitat concept. "This is a pirate ship, and the grass is water. You cannot walk on the water. If you do, you drown." "This chair is a car that can go 200 miles per hour." "The flagstone is a hole in the Earth, and if you tread on it, you will fall down."

Games can have different purposes:

- **Creation:** The objective of soccer is to accumulate goals. The goal of exchanging Pokémon cards is to increase one's collection.
- **Destroying:** The objective of a Star War's game is to destroy the Death Star. The objective of teasing and mobbing is to destroy the self-confidence of the victim.

- **Preventing:** The objective of a cowboys and Indians play is to prevent the Indians from conquering the fort.
- **Maintaining:** The goal of skipping is to keep the skipping rope moving.

If we focus on pervasive games, the following possibilities present themselves. According to (10), activities can be executed if its role fillers are qualified for the roles and if the Agent filler desires or intends to fill the Agent role. The roles, therefore, are filled by entities that meet the requirements (glue). In the nomadic play scenario, roles are filled by children, artefacts, hardware, software, and locations. Joining and leaving the activity is done on an ad hoc basis, like when children play. At the conceptual level, we do not discriminate between children and software agents. It is the definition of the role at hand that matters. As a consequence, if a software agent meets the requirements to fill a role, it can play it. This also means that a child could fill a role that usually might be played by an artefact or piece of software.

Children and software may compete for filling a role: “I do it” vs. “My mobile phone does it.” More interesting, however, is in-between situations in which child and software together fill a role. Part of the role is automated; part of it is manual. Sometimes a child may be represented by a less capable but sufficient software agent, and agency could be transferred back and forth. Such shifts between manual and automatic control are very common in process control; sometimes the officer of the watch maintains the course, and sometimes the autopilot does it.

A collection of roles that typically go together can be collected in macro roles. These macro roles either could be statically defined, like in the rules of a game, or they could be assigned dynamically, based on the actual history of actions taken by or experienced by the entity (bottom-up role filling). This goes for human as well as nonhuman participants. The latter gives us interesting opportunities, since the playthings can have a memory that remembers the glue they have earned in previous plays. This is well-known in role-playing games (RPGs). You must earn experience points to become a level-32 wizard. In the extended case, the character can develop behavioral traits and reputation in an emergent fashion, based on previous actions (e.g., by choosing to practice certain skills).

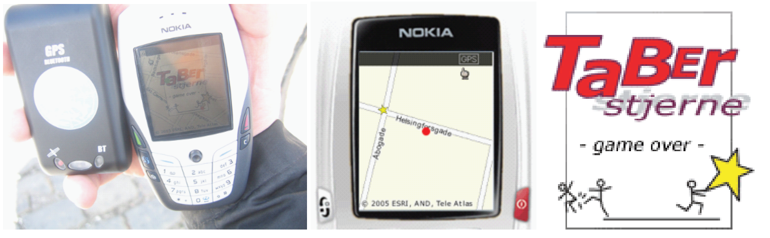
Sharing things is a central part of many activities. We want to be able to share passive objects as well as active or intelligent ones. This also means that pieces of runnable code should be able to migrate live on a variety of different hardware (contextual execution).

The effect is that we get a network, as described previously in actor networks, in which the possibilities are not tied to the entities themselves but rather to the possible roles they can fill in a given set of activities.

Designing Pervasive Games

In this and the next section, we use the contextualized concepts previously defined for designing two pervasive games.

Figure 6. (a) GPS unit and mobile phone; (b) phone interface with team (red dot) and star; (c) Loser Star screen presented to losing team



(a) (b) (c)

The Technology

In the Nomadic Play project, we try to invent new ways of having fun or being cool using digital media, specifically pervasive and ubiquitous computing devices. Those devices are characterized by being small enough to be carried around as other small objects that surround children (e.g., toys, phones, clothes, pencils, books, stones), or they may be embedded in the environment like other resources we know—in playgrounds, computers, blackboards, and furniture. In essence, these new digital artefacts and environments should be designed in a way that allows them to become a natural part of playful activities.

Compared to traditional artefacts, these devices present new opportunities. They can process information, sense the environment via sensors, interact with it physically through actuators, and communicate with other devices through wireless networks (for early thoughts on ubiquitous gaming in the context of construction kits, see Sargent, Resnick, Martin, and Silverman's, 1996, list of "Twenty Things to Do With a Programmable Brick"). Apart from actually making the technology work, one of the biggest challenges is to find out how activities involving children, artefacts, hardware, and software can be brought to play in a way that feels natural and fun. The digital media should not be a separate distraction from the play, not in the sense that it should be invisible, but rather that it should be an integrated part of the activities. In order to test our ideas, we have begun designing playful activities for children involving pervasive computing.

StarCatcher: A Simple Example

In this section, we describe an existing pervasive game, *StarCatcher* (Brynskov et al., 2005). In the next section, we use our framework to elaborate on the game by introducing features that are more complex and, hopefully, more entertaining.

StarCatcher is a simple version of Capture the Flag (Figure 6). It can be played by two or three teams in any urban area of approximately 500x500 meters, and the objective is simply to catch a virtual star (Figure 6b). The first team to reach its location and run to its home base

Figure 7. Diagram of the activity Playing StarCatcher (simple version) with each of the actions and their relations seen from both teams

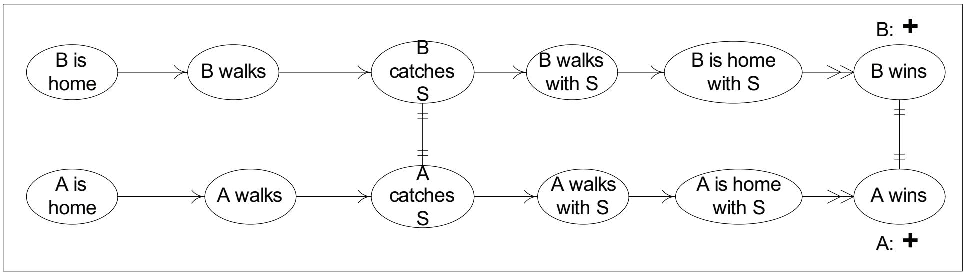
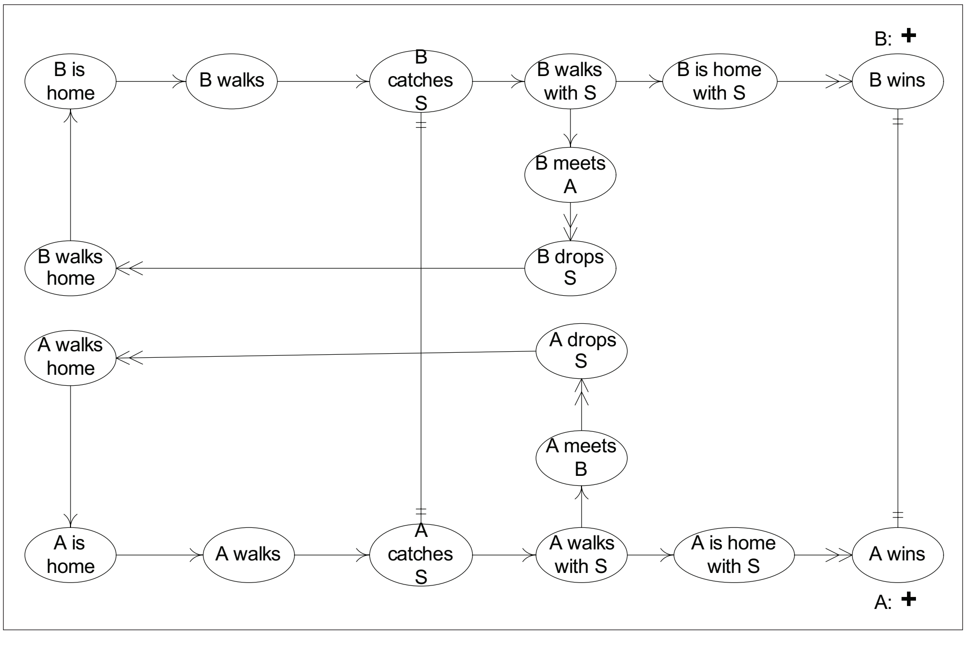


Figure 8. Diagram of the activity Playing StarCatcher (extended version)



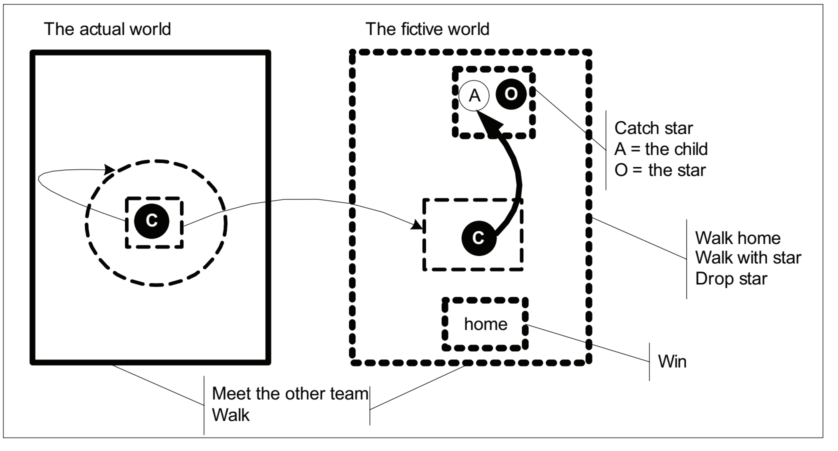
wins and become Star Winners, and the game is over. The losers get the Loser Star (Figure 6c). There is also a slightly more complex version: If the team with the star is intercepted by the other team before it reaches the base, it drops the star, and both teams must visit the home base before it can be picked up again.

Technically, each team is equipped with a mobile phone and a GPS unit (Figure 6a). The game software runs as a client on each phone and on a central server. The clients send their positions to the server, and the server returns the game state. The phone interface is a map

Table 1. The action "walks" with necessary (agent and action) and possible roles filled (goal and sociative); the action has no glue, since it is not a role filled by a participant

Role	Agent	Action	Goal	Sociative
Glue	Desire (to win)	-	Ability (to be reached)	Ability (to be picked up/carried)
Filler	**B**	**walks**	**[home]**	**[with star]**

Figure 9. The habitats of StarCatcher; C = child. A = Agent role, O = Object role



of the close proximity of the team (50-m radius) in which each team is represented by a pulsating dot.

The framework described in section "Activities" offers two ways to describe the game: either focusing on (a) relationships between actions or (b) on the habitats. Figures 7 and 8 use the formalism introduced in *Activities* to diagram the activity Playing StarCatcher. Figure 7 shows the simple version, Figure 8 the elaborated one. The + and - marks represent the desires of the participants: both team A and B strongly desire to win.

As appears from the diagrams, our game specification uses half-baked actions, as argued in *The Habitat Concept*. For example, in Figure 8, there are three actions with the same verb: "B walks," "B walks home," and "B walks with S." In the game, these variants have quite different consequences and, therefore, are treated as three different actions. If we magnify these actions, they will look as shown in Table 1, but a description at this level of detail will clutter the diagram and make it useless.

Figure 9 shows StarCatcher described as a habitat. The dashed fat rectangle represents a fictive habitat (see section "Habitats" and Andersen, 2004a). The child C can see its surroundings in the actual (the dashed circle) as well as the fictive world (the dashed rectangle). The reference from the actual to the fictive world is relative (section "Habitats"), since the reference area moves as the access area (the child and the mobile phone) moves. Figure 9 is rather abstract, but in the implementation phase, it will be replaced by a map that shows the exact shape of the actual and fictive habitat and the exact shape of the access and reference area. In the figure, we have indicated that the reference area is different in the actual and the fictive world. In the actual world, the child can se things within a circle centered in the child; in the fictive world, the access area is rectangular due to the shape of the display.

The fictive habitat contains the avatars of the children and the star. The children, therefore, lead a double existence in the real and the fictive world, while the star and the winning position only exist in the fictive world. They are not marked in the actual world. The same difference is found in the actions: *catching the star*, *walking with the star*, and *winning are fictive*, while *meeting the other team* and *walking around in the city* are done in both worlds.

The fictive habitat contains two subhabitats: the area around the star where catching is possible and the home base where winning is possible. The action of catching requires two roles: the child (Agent) and the star (Object). In Figure 9, the agent role and catching the star is empty (shown by the white color), so the action cannot be executed. Only when the child moves (the fat arrow) into the habitat will it be able to participate. This is a graphical way of representing the process of unification described in section "Habitats." Habitats, thus, are loaded with activities that are triggered when qualified participants move into them. This, in fact, is one of the reasons for mobility work (Bardram & Bossen, 2005; Brynskov, 2004); in hospitals, for example, many activities are bound to specific locations, and nurses, doctors, and patients spend much time just moving physically from one habitat to another in order to fill empty roles in urgent activities that are executed as soon as all necessary participants are assembled.

The example shows that our framework is indeed able to conceptualize essential aspects of the game; the dependencies between the actions and, in particular, the relation between actions and physical environment and the interplay between the actual habitat and the fictive one.

In the following, we will describe a new game, Bogeyman, which is an extension of StarCatcher. The purpose is to find out whether the framework is a good support for creative design and whether it can provide new and entertaining ideas while still modeling relevant elements of complex pervasive gaming.

The Bogeyman

If all we wanted to do was to model locative games as simple as StarCatcher, there would not be much need for a framework. But with the expanding opportunities of pervasive gaming (due to technological evolution and commoditization of pervasive computing systems). a whole range of complex issues arise that make formalized support for development of such systems more and more difficult. We can design more sophisticated games using the dynamic interplay of aspects at different levels (e.g., physical, technological and social) but at the cost of complexity. Addressing this complexity at appropriate levels is an important motivation for developing our framework.

StarCatcher actually was implemented and tested; Bogeyman is an extension of StarCatcher and has not been implemented yet, although we do present a core algorithm of the play. The purpose is to test our framework as a design support tool; does it help produce interesting ideas for an extended game?

Activities and Habitats

Let us start with the first two desiderata: we want the following:

16. An emergent game in which simple interactions between more participants can create surprising and entertaining situations (section "Play and Games").
17. A better exploitation of the interplay between the real and fictive habitats (section "Starcatcher").

Desiderata (16) concerns the activities of the game, whereas (17) relates to its real and fictive habitats.

In StarCatcher, there was only one thing to collect: the star. In Bogeyman, the purpose is for the children to collect as much candy as possible and avoid being eaten by the bogeyman. While the star was purely fictive, candy may be fictive or real or both. The Bogeyman game is also set in the city (i.e., an area not especially built for the game). However, to a certain extent it does incorporate physical aspects of the surroundings (e.g., the real sewers of the city, which the fictive mice can enter and leave). When the mice are in the sewers, they are invisible in the fictive world.

There can be from two to 10 kids (single players or teams). The technical setup is basically as in the simple StarCatcher game (mobile phone + GPS), with the addition of Bluetooth interaction with places and artefacts.

The objective of the game is to collect as much candy as possible. The purpose, however, is broader, defined as (a) having fun together and (b) developing relationships between the players.

We want some kind of recognizable narrative macro structure (e.g., built upon Greimas' schema) (Greimas, 1966). A Subject desires an Object, is helped by Helpers, and opposed by Antagonists. In the game, the kids (Subjects) run around and try to catch candy (Object of desire) without being caught by the bogeyman (Antagonist). Whenever they see a piece of candy, virtual or not, they approach it cautiously. If the bogeyman is hiding close by, he will catch them, strip them of all their candy, and eat them. When this happens, they must return to the home base and be brought back to life again ("spawned") before they can enter the game again. The kids cannot see whether the bogeyman is near. So, in order to avoid him, the kids can get help from the dogs (Helpers). We want these macro roles to emerge from the action dependencies constituting the game.

The dogs, however, are not necessarily interested in helping the kids. But if they receive a sausage, they acquire a positive attitude to the children's goals and thus desire to act in a way that supports the children.

The execution of the rules controlling the fictive participants conforms to (10) above: the Agent of the action must desire or be obligated to act, and all participants must be able to do so. This means that (a) the software must create desires in the software Agents that are understandable to the children, (b) that actions are only enabled when all participants are in the same location. (b) will involve a lot of physical and virtual movements, which is desirable for a pervasive game.

For example, if the dog is given a sausage, it desires to chase the bogeyman away. But if there is no bogeyman present, the role of the chasee is empty, and the chase-action cannot be executed. Only when the bogeyman appears and fills the chasee role can the dogs execute the action they desire. Processes involving obligations and desires are clearly fictive, whereas processes involving ability is both real and fictive, since the fictive locations of the software agents must coincide with the real locations of the children.

In the section "Activities," (6)-(9), we listed four requirements to cooperative software agents: comprehensibility, accessibility, joint attention, and intermittent participation. Accessibility means that the action potentials and desires of one participant should be accessible to the others. We can do this by letting the interface show which actions are possible in the current habitat (as already illustrated in Figure 5 and Figure 9) and what the fictive effect of the action is. For example, when a child is near a fictive or real sausage, the display shows that the action of taking the sausage is possible and that it may lead to enrolling dogs in the child's team. Similarly, when a child approaches a fictive dog, the display suggests that it is now possible to give the sausage to the dog.

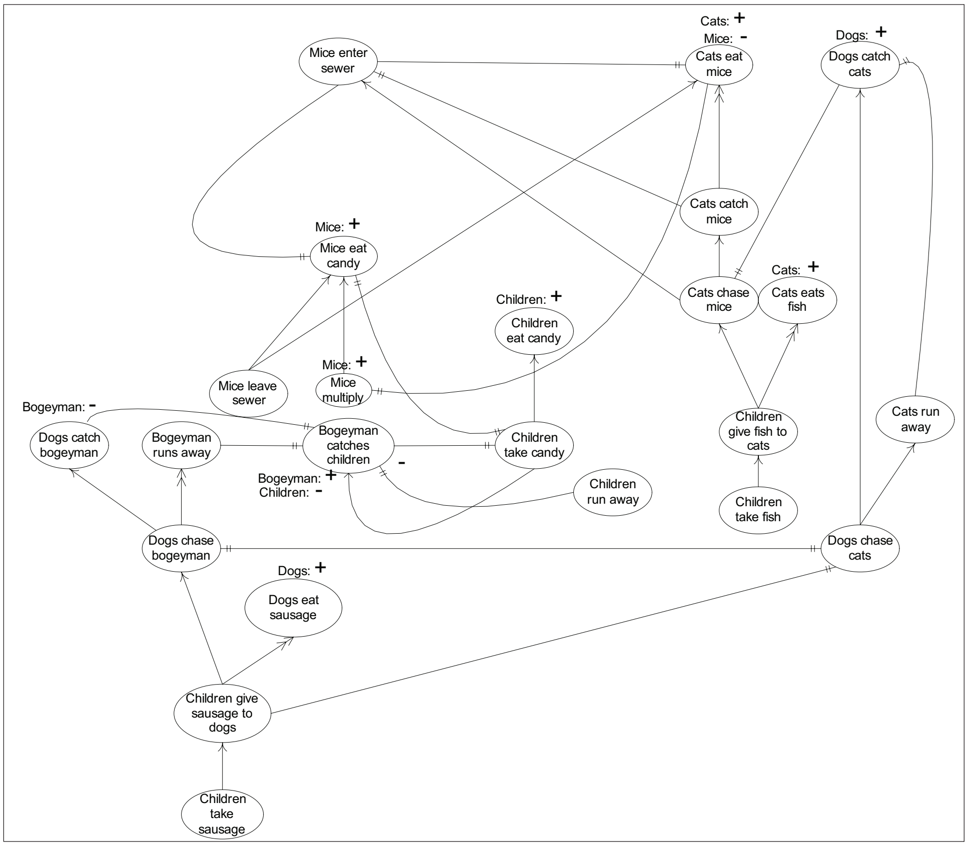
If a player wants to know more about a nonplayer character's (NPC's) attitude before interacting with it, he or she may take a closer look first (by using the scan mode described next).

The game is designed in levels of increasing complexity. In the beginning, you only have to find candy. No bogeyman. Then come the mice (an Antagonist) and begin eating your candy. Then cats, which are useful because they eat mice. Then, at last, the dogs and the bogeyman. Dogs protect you from him, but if there is a cat nearby, they may run after the cat instead. If you forget to feed them, they may get angry and bite you. The mice will come out of the sewers, which are connected underground.

When players meet, they can fight each other, but they don't have to do it. Strength is measured by the amount of candy they have. They can freely negotiate offline, if they prefer (e.g., that the weaker player gives some candy to the stronger team) (security payment). They also can have a virtual fight throwing different objects and power-ups at each other. If they fight and one of them loses, the winner takes all the loser's belongings. If you find other players' home bases, you can strip them of all their belongings. A base is defined by a Bluetooth tag. You probably have to look around a bit in order to see it. When you reveal their base, their icon explodes, and they must come to you and collect it to set up a new base. They do this by placing their tag somewhere else.

According to (11) in section "Activities," execution of actions changes the glue binding participants to other actions, and so changes of these dependencies must be an integrated and visible part of the game. Figure 10 shows the dependencies between the actions. As in section "Activities," we abstract the participant-glue-role relations into three main relations: possibility, necessity, and impossibility in order to maintain overview. To give an example, the capture of the children by the bogeyman is prevented by him running away, which is triggered by dogs chasing him or by the children running away. The capture also can be prevented by the dogs catching the bogeyman. A capture will prevent children from taking

Figure 10. Dependencies between actions in Bogeyman



more candy; but, and this is the snag, collecting candy is the one action that makes it possible for the bogeyman to catch the children. Collecting candy is risky.

As appears from the +/- marks, dogs desire to catch cats and eat sausage, cats to eat mice and fish, children to eat candy, mice to eat candy and to multiply, and bogeymen to catch children. On the other hand, mice hate being eaten by cats, bogeymen to be caught by dogs, and children to be caught by bogeymen. Thus, the diagram contains conflicts that can be used in a narrative: mice oppose being eaten but cats think it is a good idea; bogeymen like catching children, but children are dead against it. There are also implicit conflicts: mice eating candy prevents children from doing it, and vice versa.

A cursory inspection of the diagram shows that it also contains explicit and implicit contradictions: the children's taking candy enables the bogeyman to catch them, which again prevents their taking it; the children's giving sausage to dogs prevents dogs from chasing cats (which they desire) but enables them to eat sausage (which they also desire). Mice entering the sewers prevents them from eating candy (which they love to do) but saves them from

Table 2. Modes of the client running on mobile phone

Mode	Scale	Use	Interaction	Technology
Proximity	1:1	Navigate	Walking	GPS
Global	1:10	Get overview of entire arena	Cursor	GPS
Scan	10:1	Inspect place, thing, or person	Menu	Bluetooth

being eaten by cats (which they don't like). The contradictions and conflicts are built into the rules in order for them to generate an interesting narrative, but a consequence is that we cannot use standard logic to implement the rules.

Two rules used by the system are not shown in the diagram, because they would cutter it completely: *cats eat mice* obstructs all actions in which mice participate: *mice multiply, mice enter sewer, mice leave sewer,* and *mice eat candy.* Similarly, *Bogeyman catches children* obstructs all actions involving children: *children give sausage to dogs, children give fish to cats, children take candy, children take sausages, children take fish, children run away,* and *children eat candy.*

Note that we have only distributed desires to a few actions: as it stands, dogs only know that they like to catch cats and eat sausage; they have no particular desire to chase and catch bogeymen or to chase cats. In addition, they have no attitude toward bogeymen catching or not catching children. The idea is that such derivative attitudes should be generated as an emergent phenomenon as the game progresses. Enrolling virtual agents as helpers and avoiding defections to the enemy should be part of the gameplay. Thus, Figure 10 only works as a seed for the game.

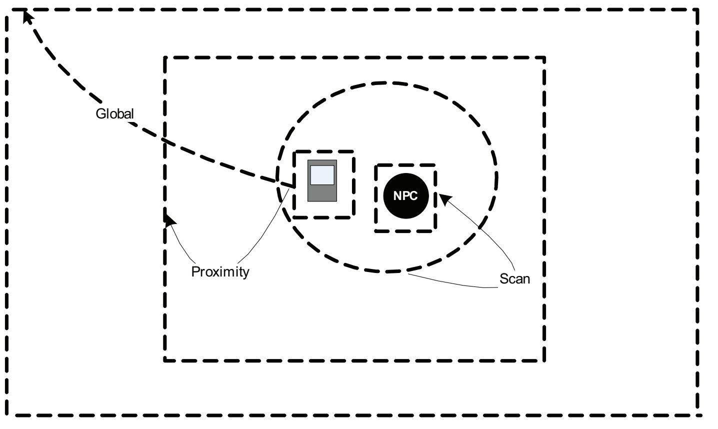
The second desideratum was a better interplay between the real and fictive habitats. We shall deal with that now.

The phone is the primary artefact in the informational habitat. It has three modes that are related to the physical habitat: *proximity*, *global*, and *scan* (Table 2).

In the *proximity* mode, the player can see all objects of the real and fictive habitat within the field of vision. In the *global* view, the player can only see other players and the map of the arena, including the player's own home base. The *scan* view offers a closer look at something (e.g., the attitude of an animal or the presence of a fictive sausage), but it also obstructs the other two views. Whenever a player is in the scan view, it is reflected by the player's representation in the global and proximity view. This is useful information to other players because they now know that there may be something interesting to check out at that location. Players can also allow each other actually to share their proximity or scan view, thus enhancing each other's access to information.

Figure 11 shows the three informational modes of a habitat. The scan and proximity modes are relative references that change as the player moves. The global mode is an absolute reference (dashed arrows), since the whole playing area is accessible all the time. The scan mode differs from the two other in that the access area is defined by the location of the reference and not by the receiver. The reason is that the referent (the NPC in Figure 11) carries a Bluetooth

Figure 11. Informational habitats



tag that creates an information cloud (access area) around it with information about it. If the mobile phone in Figure 11 is Bluetooth-enabled, it can receive this information.

The mobile phone in Figure 11 always can see the global layout of the game area; it can see more details in the local area around it; and it can scan the NPC since the phone is inside the access area of the NPC.

Figure 11, however, does not capture the interplay between the actual and the fictive in the game. In order to do that, we need the concept of fictive habitats introduced in section "Habitats." Parts of the game exist in the real physical habitat; this is true of the sewers and the children and possibly of the candy and sausages, depending on how you set up the game—and possibly a child may wish to play the bogeyman. Some of the actions also exist in the real habitat; for example, the action of walking and running. However, the game rules only exist in the fictive habitat, and all the participants in the game must have a fictive representation as well. Otherwise their actions could not influence the game state.

Of course, we can depict this dichotomy as in Figure 9 by drawing the actual and the fictive habitat side by side. But here, the correspondence between the fictive and the actual positions of the participants does not stand out. In the following, we collapse the two diagrams into one. The fictive diagram is the main one, since it defines the game state. If a fictive participant has a real-world counterpart, we show this by adding a shadow to the fictive entity. Thus, the real world is shown as a platonic projection of the fictive world. We distinguish between fictive (only in the fictive habitat), real (only in the real habitat), and mixed entities (both in the fictive and real habitat).

Figure 12 shows the basic setup with two mixed players (C), a mixed bogeyman (B), three pieces on fictive candy (S), one piece of mixed candy (S), two fictive mice (M), and one fictive dog (D).

In addition to candy and sausages, there are a number of special items, *power-ups*, the players can encounter: *a dog shit*, *a shadow*, and a *torch*.

Figure 12. Basic setup with two players, the bogeyman, some candy, and the home bases

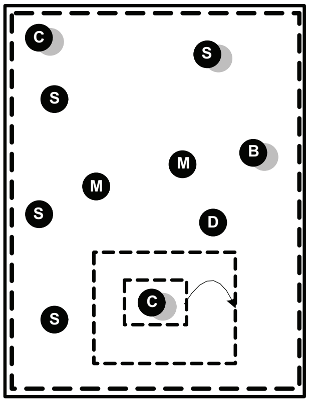
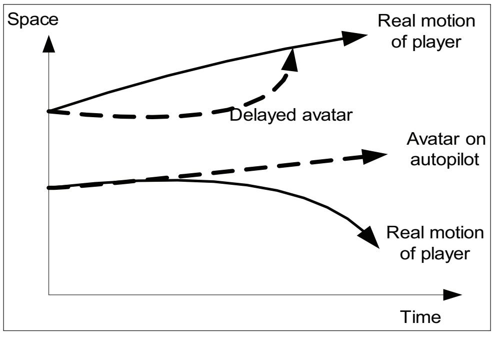


Figure 13. Space-time plot of discrepancies between the physical and fictive habitat



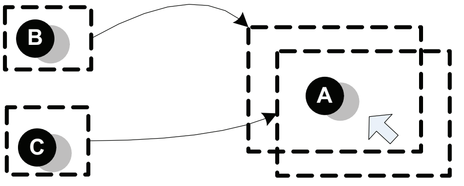
The *shit* is left by dogs, and if you run over it, you slip, and your avatar is slowed down. You have to slow down yourself, because generally, if you are not close to your avatar, it shifts to autopilot and begins moving on its own. Holiday!

If you walk carefully past the shit and do not tread in it, you can pick it up and drop it later at your convenience (e.g., in front of another player). The stickiness is, of course, entirely virtual and only causes the virtual representation of the player to move slowly.

The *shadow*, inspired by H. C. Andersen's fairy tale, *The Shadow,* is a way to disguise the actual location of a player. When it is activated, the player's avatar will use dead reckoning to move in the same direction, regardless of the actual movement of the player. In this way, a player can sneak up on another without being noticed. The problem is that if your avatar meets any other avatar, it gets scared because its master is not present, it flees in an erratic manner, and the child must catch it.

The space-time plot in Figure 13 illustrates the effect of delaying dog shit (topmost) and the effect of a shadow on autopilot (bottommost).

Figure 14. Using the torch



The *torch* (Figure 14) is a way of showing a virtual or mixed entity A to another virtual or mixed entity B. The torch can be implemented as a highlight or a cursor. In Figure 14, an arrow is used. The arrow belongs to the fictive world and, therefore, exists in the fictive reference area on a level with fictive mice and dogs. Each user can manipulate his or her torch. Since the torch is a pointing device, it should only be visible in the proximity mode—you only point out things to people close to you, and physical proximity serves to delimit the number of addressees.

The torch is thus a way of establishing the shared focus of attention between participants, as required in section "Activities." From the perspective of semantic roles, the torch is a way for an agent (C) to increase the glue between another agent (B) and a role in an activity that involves the entity in focus (A). If a child points to a sausage in the presence of a dog, it strengthens the desire of the dog to play the role of Agent in the affordance of the sausage (namely, that of being eaten by a dog).

The torch can also be used to move the focus of the dog away from the affordance of cats (being chased) to the affordances of sausages (being eaten) or bogeymen (being chased away). A mean way of using this technique is to reveal the other players to the bogeyman and make him hunt them.

The game ends after a fixed time or whenever it is suspended by the players. Players can enter and leave intermittently.

In section "Starcatcher," we decided that the ability to participate in activities is created by spatial movement: if the participants are assembled in the same place, they are able to participate in the activity. But, as mentioned in "Activities," the activity will not execute unless the Agent participant desires or is obligated to do it. How do we provide these desires?

Designing Intelligent Agents

In this section, we will discuss how to implement the distribution of desires mentioned in the previous section. Mice and children are clearly competitors: how can we make the mice aware of this and possibly begin oppose the children (e.g., by supporting the bogeyman in catching them)? How should the cats react toward chasing mice: on the one hand, chasing them leads to the desired action of eating them, but it also enables the mice to flee to the sewers, which disables the eating. We would also like to generate attitudes between participants: who sides with whom? Will the mice oppose the cats and side with the children (although they compete for the candy)? Will the dogs assume the role of helpers to the children, even if helping out prevents them from chasing cats? In short, will global narrative roles emerge from the interplay between the actions?

Which methods should we use to make this come about? We realize already that since the story contains contradictions, we cannot use standard logic for these inferences. Classical AI is thus not an option. In order to choose a solution, let us first look at our requirement lists, repeated as follows for convenience:

1. Intelligent technology is a kind of technology that is able to contribute positively to activities whose manner of performance we will intuitively call intelligent.
6. Agents should have intentions to act that are understandable to the others (comprehensibility).
9. Agents should be able to enter and leave the activity (intermittent participation).
10. An activity is executed if all participants are able to fulfill their roles to some degree and the Agent filler is strongly obligated and/or strongly desires to fulfill his or her role.

(1) says that the algorithm must refer to networks of actors, not to the individual actor; (6) says that the rules it uses must be known to the human users.

One interesting possibility is the theory of *cognitive dissonance* (Eskola, 1973). The theory allow us to calculate the relation z between persons A and C, if we know the relation x between A and B and the relation y between B and C. It (regrettably) works well for international politics, so we take the fight against terrorism as an example: if George W. Bush (A) opposes (x) Al-Qaeda (B) and Al-Qaeda supports (y) the Taleban (C), then George (A) opposes (z) the Taleban (C) (Figure 15). In some cases, it is also possible to calculate z if we know x and the inverse of y, y'. If George opposes Al-Qaeda and Taleban promotes Al-Qaeda, then George opposes the Taleban (Figure 16).

If the Danish Prime Minister Anders Fogh supports George Bush, and Bush supports the policy of waging war against Iraq, then Fogh, too, supports waging war against Iraq. We can use the last observation for action selection, as required by (10): when Fogh supports waging war against Iraq, this means that he desires to assume the Agent role in war activities (which, in fact, he did).

Figure 15. Removing dissonance using y

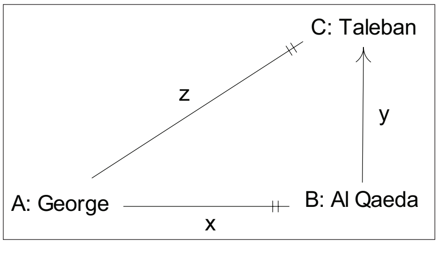
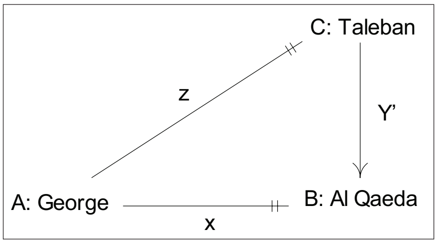


Figure 16. Removing dissonance using y'



The rules can be made to cover normal means-end planning: if occupying Iraq (means) promotes (y') a stable and profitable supply of oil (end), which George very supports (x), then George promotes occupation of Iraq (z). Or, if occupation of Iraq, which George supports (x), necessitates (y) that the American arms budget is increased, then George must support the increase, too (z).

We can, in fact, also leave persons out of the equation: if the occupation of Iraq promotes (x) a democratic government in the country, and democratic government in Iraq promotes (y) a more peaceful world, then the occupation (indirectly) promotes a more peaceful world.

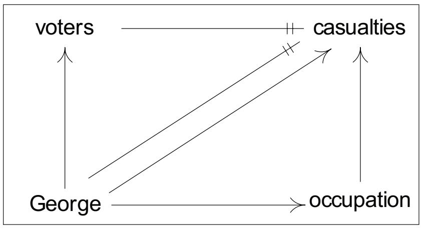
In all of these very real examples, the following two simple rules have been used (≡ is logical equivalence):

18. $z_t = (x_{t-1} \equiv y_{t-1})$
19. $z_t = (x_{t-1} \equiv y'_{t-1})$

Z at time *t* is calculated as the equivalence of the *x* and *y* (or *y*') relations at time t-1. At the same time, the rules provide explanations for the attitudes: z holds because *x* and *y* hold. George opposes the Taleban because they promote Al-Qaeda, and he opposes Al-Qaeda.

There is one problem, however. As we have already seen, we cannot assume that such networks of actors and actions are consistent in good narratives. Therefore, we often will encounter the phenomenon that the same relation will be calculated differently if we use two different triangles that share one side. This is the problem of *overwriting*. George Bush endorses an occupation that leads to casualties; therefore, George ought to be in favor of the casualties (rightmost triangle in Figure 17. However, he also likes his voters, who are opposed to casualties. Therefore, George ought to be opposed to casualties (leftmost triangle). If the leftmost triangle in Figure 17 wins, George may change his attitude to the occupation in order to avoid dissonance (e.g., begin opposing it). If the rightmost triangle wins, he has to support casualties (which is the strategy of his opponent: the young suicide bombers are celebrated as martyrs). Machines do everything in a fixed order, so if the rightmost triangle is processed last, it always will overwrite the influence from the left triangle. In order to allow George Bush to change his mind with respect to the casualties, we introduce a random factor in the application of the rules. Sometimes one triangle is chosen, sometimes the other, and sometimes both. This has two advantages: (1) all the triangles are allowed to

Figure 17. Contradiction of attitudes



have an effect, and (2) the "thinking" of the software agents is not momentary but proceeds piecemeal, sometimes overlooking logical inferences in the first round.

However, endorsing the casualties is really no option at all for George for deeper ethical reasons than voter-tactical considerations. There are basic ethical attitudes that are stronger than others and should not easily be changed. In Western cultures, the respect for human life is (officially) very high and cannot easily be changed (publicly). Instead, contradictions should be allowed to remain in some cases. We therefore introduce a measure of strength of the attitudes: weak, medium, and strong.

We also make a distinction between relations where the first A-term is a person and those where it is an action. A person can have subjective desires that can be changed, but actions do not desire anything. They can enable or cause another action.

In summary, we make four modifications to the original simple calculations.

20. Relations between actions only are allowed to change from an unknown 0-state.
21. Relations between persons and between persons and actions can change if they are not strong.
22. The *strength* of the feelings of a person toward an action propagates to the actions or persons that enable or oppose the action.
23. Rules are applied with a probability between 100% and 0%.

We distinguish thus between immutable factual relations between actions, and mutable subjective attitudes toward actions.

The reason for (22) is the following: if mice strongly dislike to be eaten and being caught by cats enables the eating, then mice should strongly dislike being caught. Cats look quite differently upon the subject: if they strongly like to eat mice and catching them enables this, then cats should be strongly in favor of catching mice.

(20-22) give the network a certain degree of stability, because they restrict the possible changes.

The following algorithm uses three simple data structures. *Network* is a list of actors and their type, <actor or action, type>, where type can be P = participant and A = action. *Relation* is a two-dimensional list representing the relation between actors and actions: Relation[i,j] means the relation from i to j. The relation can be "+", i supports j, "0", they are indifferent, or "-", i obstructs j.

Finally, *Strength* is another two-dimensional list where Strength[i,j] represents the strength of the relation from i to j. The strength can be "+" strong, "0" medium, and "-" weak.

The rules for overwriting are as follows: a non-zero relation can be overwritten if and only if the source of the relation (the Atype below) is an actor and the relation is not strong. If George has very strong ethical feelings against casualties in Figure 17, then the rightmost triangle cannot overwrite it.

The different triangles are classified according to the type of their endpoints: thus, PAA is a type where an actor, type P, has a relation to an event, type A, that has a relation to another event, type A.

It is not possible to evaluate the usefulness of the individual triangle in isolation. The PAA case corresponds to the proverb, "If you have said A, you must say B as well." It is not included in the following algorithm, but it was in the beginning, since it sounded at least as sensible as PPP, "my friend's friend is my friend." In both cases, there are exceptions. An example is George Bush's dilemma where A = George, B = occupation, C = casualties. Bush can evade the responsibility for the casualties by claiming that they are an unfortunate and unintended consequence of an otherwise good deed. In the PPP case, one can argue that the friend made a mistake in cultivating a disrespectable person and, thus, not extend one's own friendship to this person.

PAA was deleted from the algorithm, not because of its inherent qualities but because its effect in the global network was detrimental, as we shall see next.

The algorithm is as follows, written in pseudocode:

```
RemoveDissonance (network, relations, strength)
 repeat for all elements a of the network
  record the type of element a in Atype
  if Atype = "P" and Chance() then
   -- agents like themselves.
   set the relation of a to itself to "+"
  end
  repeat for all elements b of the network
          record the type of element b in Btype
          record the a/b relation in x
   if Atype = "P" and Btype = "P" and the strength of b/a ≠ "+"
    and Chance() then
    --- if you like me, I like you.
    set the relation b/a to the relation a/b
   end if
   if x ≠ "0" then
    repeat for all elements c of the network
     if a = c or the strength of a/c "+" then next repeat
```

```
          --- strong relations cannot be changed!!
          record the type of element c in Ctype
                record Atype+Btype+Ctype in theCase
          record relation b/c in y
          record relation c/b in y’
          record relation a/c in z
          if y ≠ 0 and chance() then
           choose between two cases
            case (thecase = "PPP" or thecase = "PPA")
             --- relations where a is an agent
                   set relation a/c to equiv(x, y)
             set the strength of z to the strength of x
             case (thecase = "AAP" or thecase = "AAA") and z = 0
              --- relations where a is an action
              set relation a/c to equiv(x, y)
           end choose
          end if
          if y’ ≠ 0 and chance() then
           --- here we know the inverse of y
           if (thecase = "PAP" or thecase = "PPA"
            or thecase ="PPP" or thecase ="PAA")
            --- relations where a is an agent
           then
            set the relation a/c to equiv(x, y’)
            set the strength of z to the strength of x
           end if
          end if
         end repeat
        end if
       end repeat
      end repeat
     end RemoveDissonance
```

The algorithm moves the network of attitudes toward a consonant type by removing dissonances. If a consonant version exists, it will arrive to it through a number of iterations.

George’s dilemma can run as follows (with the PAA possibility included): the seed is Figure 18: George promotes his voters and strongly promotes the occupation, the voters are against causalities, and occupation promotes causalities. After three iterations with a rule probability of 50%, the situation is as shown in Figure 19: George still strongly promotes the occupation and, in addition, the casualties, while he obstructs the voters. The voters retaliate and strongly obstruct George as well as the occupation and causalities. At this time, George’s

Figure 18. Initial configuration

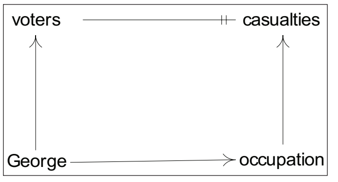


Figure 19. George maintains his foreign policy but has run foul of the voters

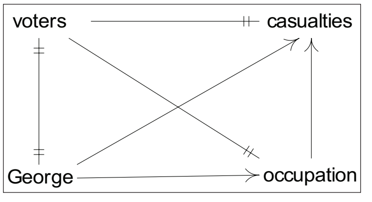
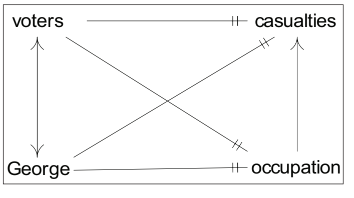


Figure 20. George has changed his policy and gained popularity

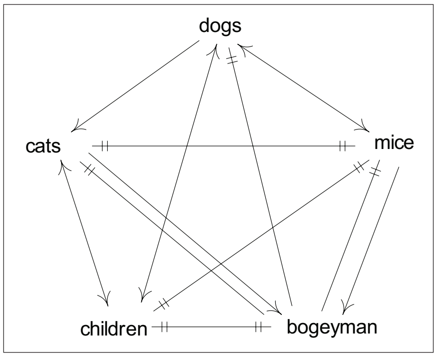


attitudes were changed in the simulation so that he now strongly promotes his voters. After a few iterations, this changes the whole picture to Figure 20: now George strongly obstructs occupation and casualties but has gained the love of his voters.

Thus, change of action potentials is created by a single change of attitude that ripples through the network in a change of cause and effects.

If we run the dissonance algorithm on the StarCatcher, we will see two teams opposing one another and opposing everything the other team does. There are no surprises, and this agrees with the fact that StarCatcher is a simple zero-sum game. Things are quite different in Bogeyman, since it contains conflicts and contradictions. The participants have their own agenda and create alliances to further their own interests. Bogeyman requires strategic thinking of the children.

Figure 21. Bogeyman after four iterations



In the following, we make some comments on initial experiments that use Figure 10 as seed. The algorithm is being elaborated and refined at the moment.

Figure 21 shows the attitudes developed after four iterations.

Two main groups seem to be forming: cats, dogs and children on one side; bogeyman and mice on the other side. However, there are still some conflicts: cats and mice like the bogeyman but are opposed by him.

The simulation recorded a log of the attitude changes, and this log can be used as explanations for the attitudes. As the following examples show, these explanations seem quite understandable:

- *Cats promote children* because both oppose mice. Cats oppose mice because cats want to eat mice, which mice don't like. Children, on their side, oppose mice, because the children want to take candy, which the mice don't want them to for the obvious reason that then it is gone when the mice come to eat.
- *Cats promote the bogeyman* because they both oppose mice eating candy. The cats' reason for this is that they are enemies of the mice, who like eating candy—cats are against actions their enemies like to do. The bogeyman, on the other hand, doesn't want the mice to take candy, because it hinders him in catching the children—it is the children's picking up candy that enables the bogeyman to catch them.
- *Dogs oppose the bogeyman* because they don't want him to catch children, which he likes. The reason for the dogs' opposition is that they like to eat sausage, and this is prevented if the bogeyman catches the children: if they are caught they cannot feed the dogs.
- *Dogs promote children* because neither of them wants the bogeyman to catch children. The reason for the dogs' opposition to child capture is that dogs like to eat sausage, which is obstructed by the bogeyman catching the children.

- *Dogs promote mice* because both want the dogs to catch cats. The mice's reason is very sensibly that dogs catching cats prevents cats from catching mice.
- *Mice oppose children* because children want cats to eat mice, which the mice naturally don't like. Children, on their part, want cats to eat mice because children want candy, and cats eating mice supports their candy hunt since it puts a stop to mice eating the candy, which prevents the children from getting hold of it.
- *The bogeyman opposes dogs* because he doesn't want the children give sausage to them, but the dogs like very much to be fed. The reason why the bogeyman opposes this sausage distribution is that it causes the bogeyman to run away, which he does not want, since running away prevents him from catching the children, which is his goal in life.
- *The bogeyman opposes mice* because he wants children to take candy, and mice hinder this. The bogeyman wants children to take candy, because it enables him to catch them, which he very much wants.

After the four iterations, most agents thus have developed understandable attitudes toward most actions and agents. However, a few of them turned out to be somewhat strange. Here is an example: it turned out that cats want dogs to catch them (!) because they did not want mice to enter sewers. Dogs catching cats prevents this. The reason why cats don't want mice to enter the sewer is that they want to catch the mice, and this is not possible when the mice are in the sewer. The reason for the error lies in the seed: we forgot to add that cats strongly oppose being caught by dogs.

In earlier versions in which the PAA type was allowed, we got really weird explanations; for example, the bogeyman opposed children giving fish to cats because he wanted to catch children, and this prevented the children from giving fish to cats. The triangle type is PAA that lets a person transfer his or her attitude from an event to its effect, which seems pretty unintelligible in our case; there is no reason why the bogeyman should oppose children giving fish to cats, even if he indirectly prevents it by catching the children.

Evaluation of the Algorithm

The small experiment shows the following:

24. The dissonance algorithm does produce understandable attitude changes and divides the participants into groups that support or help one another.
25. The explanations given for the attitude changes are understandable.
26. The value of the individual rules must be evaluated through their global effects on the network through experiments. It was not possible to predict that the PAA triangle in itself would be detrimental.

Let us review our requirement list from the previous sections to see how the algorithm fares:

1. Does it produce technology that is able to contribute positively to networks of activities whose manner of performance we will intuitively call *intelligent*? *The "intelligence" of the software agents is clearly a network phenomenon since attitudes develop in the context of other agents' attitudes.*
6. Agents should have intentions to act that are understandable to the others (comprehensibility). *The results show that the attitude changes are understandable and that the agents can provide reasonable explanations.*
9. Agents should be able to enter and leave the activity (intermittent participation). *Since the algorithm recursively tries to remove dissonance in the network, addition or deletion of agents will not spoil anything but possibly may make the network move toward other equilibrium states.*
10. Does it conform to the rule that an activity is executed if all participants are *able* to fulfill their roles to some degree and the Agent filler is strongly *obligated* and/or strongly *desires* to fulfill his or her role. *The algorithm works by distributing desires of the agents toward actions and other agents. It thus produces one of the glue-components that causes agents to act. The other, ability, is produced by physical movements.*

A drawback of the method is that the effects of changes to the seed and the algorithm are difficult to predict, but this is the price you pay for designing emergent games. The designer to some degree loses control over the product.

Another problem could be that the software agents are too intellectual in the sense that their motivations are caused by reasoning with many steps, which children may not be able to follow. On the other hand, many adventure games have plots that are more complicated.

Evaluation of the Framework

Did the framework give us good ideas as we hoped? It turned out it was very productive in generating ideas for playing with physical vs. fictive reality. It was also very good at associating activities to space and participants to activities in a simple coherent way. Bogeyman took about an hour to invent. In addition, the framework maintained a foothold in the computational world and gave indications of possible technological solutions. It worked as a boundary object connecting the aesthetic and the technical world.

The small simulation showed a possible way of combining games of emergence and narrative games of progression, a combination that was judged impossible in Juul (2005).

Because of its robustness, it is very easy to add or delete participants from the game, which makes us hope that it can be developed into a toolkit for the children themselves to modify or build games.

The diagramming techniques clearly need to be developed further. Small games are easy to specify, but more complicated games need conventions for abstraction and decomposition. It also should be emphasized that we lack empirical evidence that the games specified in this way are actually fun to play!

Future Developments

The simulation does not deal with the balance between reasoning about actions and executing them, although the conditions for executing actions are well-defined (see (10) in the section "Activities").

The next step, therefore, is to orchestrate the percolation of desires in the network and the execution of these desires. One convention could be that an action is not allowed to influence other actions before it is executed; only when an action is realized may it have effect on other actions. An even stronger restriction is that only participants who have experienced the execution of the action are allowed to change their attitudes because of it. In this way, the network changes would be much easier to follow, and both solutions will reduce the part of the network that the algorithm must search and thereby decrease the complexity of the algorithm, which regrettably is $\Theta(n^3)$.

However, the two conventions are probably too strong. On the one hand, communication probably should count as a kind of execution: when the Bogeyman tells the mice that he doesn't like them to eat the candy, this should make the mice reconsider their positive attitudes toward the bogeyman with the same force as if he had actually prevented them from eating candy. Similarly, a promise from the children to give sausage to dogs should make the dogs side with the children as if they had actually given sausages to the dogs. On the other hand, some degree of secret reasoning is a good literary trick—it invites the reader/player to reconstruct the possible reasons for unexpected behavior.

But the whole play is, after all, staged for the benefit of the children. In order for them to create their tactics, it seems a good idea to inform the children of the interactions between the software agents so that they can understand what is going on and make their plans accordingly. Literature and films have the same problem: how do we inform the reader/viewer of several concurrent happenings when we can only tell about one event at a time? The solution is to let the characters meet, tell stories about their adventures, and let the reader/viewer overhear the storytelling. Should we do a similar thing in the game so that when the children meet a dog, it will tell them about the feeling and atmosphere in the canine world?

But then again, maybe the children should be required to seek the information themselves, at least at advanced levels. The ultimate criterion for deciding is still: is it fun?

Related Work

In this concluding section, we compare our approach to a number of related approaches in which notions like communicative acts, activity, semantic roles, context, and pervasive games are central:

- **The Language Action Perspective (LAP) Community:** This community is inspired by the works of John Searle and Jürgen Habermas on communicative actions. The approach to artifact design in Winograd & Flores (1986) also has been an inspiration to the community. LAP basically views use of IT as the execution of speech acts mediated by technology. The notion of speech acts is also central to this chapter, but we extend the concepts to also cover noncommunicative material acts and the relation between the two. The LAP community has emphasized the communicative type but to a certain degree has failed to realize that communicative actions are intertwined with material acts in actual work processes. There is, therefore, a need to build an integrated theory that encompasses the two (Goldkuhl, 2001). The bias toward communicative actions, for example, can be seen in the DEMO method described in Dietz (2003). It offers a finely grained typology of communicative acts (request, promise, decline, quit, state, accept) but only distinguishes between two material acts (deliver, sell). Another problematic feature, which is also noticeable in DEMO, stems from Winograd & Flores (1986): conversation patterns are primarily described in temporal terms: one act comes before or after another act, like in a finite state automaton. The problem is that mere temporal sequence does not explain the reason for the communicative pattern, and it is difficult to relate to organizational issues. The notion of glue in this chapter offers a more detailed method of description: actions hang together because one action changes the abilities, rights, and obligations of an actor to participate in other activities. Since qualifications and norms are central to organizational analysis (Liu, 2000), our framework seems easier to relate to organization theory.

- **Activity theory:** Activity theory originated from the dialectical materialist psychology developed by Vygotsky and his students in the Soviet Union in the beginning of the 20th century. Activity theory goes beyond the popular human-machine dyad and insists on cultural and technical mediation of human activity. Therefore, the unit of analysis includes technical artefacts and cultural organization, and the focus of activity theory is much wider than what has been the core concern of past HCI research (Bødker & Andersen, 2005). But activity theory seems to have the opposite problem of the LAP community: it emphasizes material activities in which a subject applies a tool to change some object, and only recently has spoken and written discourse begun to figure as mediators in activity theoretical analyses of work, and the effort to explore their role as mediators has been limited (Wells, 2002). The chapter has borrowed the notion of activity from activity theory but has extended its three basic concepts—subject (agent), mediator (instrument), and object (theme)—by means of the theory of semantic roles.
- **Actor-network theory (ANT):** ANT is not a real theory but rather a number of related methodologies and assumptions (Latour, 1999; Law, 1987) focused on empirical ethnographic fieldwork. This chapter obviously is inspired by this tradition with its emphasis on the significance of networks and its (structuralistic) insistence that participants in the network primarily acquire their properties from their position in the network and not from inherent resources. We deviate from the tradition by insisting that it is possible to refine the vague concept of *actor* into a set of more precisely defined roles in a network. The roles we have chosen are borrowed from the theory of semantic roles, and the reason why we believe these roles to be real is that they have been formalized in natural languages over many thousands of years by means of prepositions and case inflexions. We thus view the roles as the result of an evolutionary process in which practical experience through the millennia has distilled relevant distinctions. Another deviation is that our framework is biased toward design of pervasive technology, which is not the case with ANT.

- **Object-role management (ORM):** ORM (Halpin, 1998) is an alternative to traditional entity-relation modeling and object-oriented modeling. "ORM is a method for designing and querying database models at the conceptual level, where the application is described in terms readily understood by users, rather than being recast in terms of implementation data structures" (Halpin, 1996). An ORM model consists of a set of objects that play roles similar to actions in Digital Habitats.

  In our understanding of ORM, it resembles a slot-and-filler grammar similar to ours and to Fillmore's "Frame Semantics" (Schalley, 2004).

  ORM focuses on databases, design, and querying, and it has strong formal properties (e.g., formalized conversion to ER/OO/SQL and nesting). It makes clear distinctions between issues that belong to the conceptual level (how the users understand the problem domain) and those that concern the implementation (e.g., the OO concept of inheritance tends to become very abstract from the problem domain perspective). Thus, ORM is well-suited to validate a model together with domain experts that know nothing or little about programming, because the ORM model can be populated with sample data in a way that reflects the domain on the conceptual level. ORM is supposedly superior to OO when it comes to transformations over time, since it does not use attributes (although facts can be collapsed into attributes for easy overview), which allows for model changes without major restructuring. On the other hand, it only handles the static properties of a model, according to Halpin (1996, 66), since it is the most stable part of the model (although various ORM extensions have been proposed for process and event modeling).

  Compared to ORM, Digital Habitats is well-suited to the handling of dynamic models, and ORM lacks the integration of physical and, to a large extent, pragmatic aspects. However, ORM is simpler and has a more formal and consistent design than Digital Habitats.

- **Unified eventity representation (UER):** UER (Schalley, 2004) is a quite recent, UML-based attempt to develop:

  > *a representational framework for verbal semantics [i.e., verbs, not speech] that is formal and intuitive at the same time. This means in effect proposing a framework that is in principle computer processable on the one hand, and yet on the other hand whose representations reflect the wealth and flexibility of natural language in an intuitively plausible way and in accordance with our current knowledge about natural language.* (Schalley, 2004, p. 1)

  Based on Unified Modeling Language (UML), it combines computation-oriented diagrams with a solid linguistic approach to compositional semantics. It proposes a diagram-based framework that is precise and yet potentially underspecified. In the context of analysis and design of pervasive games, it seems too fine-grained; however, much insight can be gained from the analyses and discussions that are presented in Schalley's (2004) proposal.

- **Context-awareness:** Context-aware systems stand out as a fairly distinct field within computer science. The Context Toolkit (Dey, Salber, & Abowd, 2001) differs from

Digital Habitats in its technocentric orientation. It is a set of concepts that provides concepts and standards for things primarily at a technical level. There is a set of higher-level concepts, but these are developed on top of the technical concepts rather than the other way around.

- **Pervasive gaming theory:** Walther (2005) offers a set of concepts to classify and analyze pervasive games. They target important distinctions and issues, and they may well be used in a generative manner, but compared to Digital Habitats, they are much more general in nature and do not support detailed analysis and design.

Conclusion

Based on the comparisons in the previous section, we can identify six areas in which the present approach seems to present advantages:

- It provides a description of action dependencies that is not a mere temporal sequence but is relatable to organizational concepts like qualifications and norms (as compared to the LAP tradition).
- It provides a better framework for describing communicative as well as material acts plus the way they hang together (as compared to the LAP tradition and activity theory).
- It provides an explicit link between human activities and their spatial context (as compared to the technical literature on context-awareness).
- It has an explicit dynamic model that precisely describes the conditions for executing actions (as compared to the ORM methodology).
- It offers a typology of participant roles, based on linguistic evidence that reduces complexity and, therefore, supports design processes (as compared to Actor Network Theory and pervasive gaming theory).

Finally, there are two features that we have not touched upon in this chapter:

- By using semantic roles, it encourages a system architecture that is verbalizable (i.e., which automatically or semi-automatically can produce understandable descriptions of themselves) (Andersen, 2004b).
- Technological artifacts are described according to their function in activities (Bødker & Andersen, 2005). Some automatic systems function as Agents since they initiate and control the activity, others function as Instruments that do not do anything by themselves, while still others function as Beneficiaries in which other participants perform activities on their behalf.

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Chapter IX

Systemic Semiotics as a Basis for an Agent-Oriented Conceptual Modeling Methodology

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Abstract

The authors demonstrate how systemic semiotics, an approach that combines a semiotic model of language called systemic functional linguistics with selected concepts from social semiotics, can be applied to create agent-oriented information systems in which social processes can be elicited from stakeholders, specified by designers, and embedded into actual agent-based systems. The utility of systemic semiotics applied to agent-oriented conceptual modeling is demonstrated by developing a real-world system to address the problem of registering and training volunteers in an emergency service organization. The experience of developing this system then was used to propose an experimental agent-oriented conceptual modeling methodology that uses the same theory and concepts for describing the artefacts and the processes of agent-oriented systems development.

Introduction

All social systems—material and virtual, persistent and transient—are constituted in and by the effects and processes associated with all forms of meaning. As a consequence, semiotic approaches are appropriate for studying organizations, work, and technologies in general. We approach the processes and effects of the circulation of meaning in organizations, and those associated with the use and development of supporting technologies, from a broadly social semiotic perspective. Social semiotics is not simply an applied semiotics, more than simply a semiotic of things social (Kress, 1988; Hodge & Kress, 1988), but rather a particular orientation to the theory and practice of semiotics that attempts to move "beyond its idealistic foundations as the 'science of signs' … to a social and political intervention in these [organizational] practices as practices" (Thibault, 1991, p. 3). It is, therefore, a theory commensurate with the aims of an information systems discipline and practice that by definition seeks to understand and intervene in all forms of organizational meaning.

In this chapter, we utilize approach systems development practices in organizations (in this case, those associated with agent-oriented conceptual modeling (AOCM)) using a recognized social semiotic approach called systemic semiotics. This approach combines elements from two compatible theories. It utilizes specific concepts from social semiotic theory, particularly the concepts of discourse, subjectivity, and text as developed by Bakhtin (Todorov, 1984), Althusser (1971), and Foucault (Rabinow, 1986) to provide a basis for intervention into organizational meanings. It also utilizes systemic functional linguistics (SFL) developed by Michael Halliday (1985) and colleagues (see, i.e., Hasan, 1985, and Martin, 1992). SFL is a semiotic and functional model of language concerned with the communicative and social aspects of language use. It is also a contextual model of language because SFL has an explicit theory of context based on work of Malinowski (1923). It was Malinowski (1923) who first identified that an immediate situational environment (context of situation) was needed in order to form adequate descriptions of communication (texts) and, importantly, that there is also a broader cultural milieu (context of culture) against which these specific situations and communications occur that also plays an important part in interpreting their meanings (see Halliday & Hasan, 1985, pp. 5-10 for a detailed account of the development of context in systemic accounts of language). Systemic semiotics has been successfully applied to understanding systems in organizational contexts (Clarke, 2000, 2001a, 2002, 2003) including issues of systems use and renegotiation, system similarity. and diachronic change.

In this section, we explain why the application of unorthodox semiotic theory can be helpful in understanding systems in general, and the differences between social and technical systems in particular distinguish between the artefacts and processes of systems development and describe the structure of this chapter.

Social and Technical Systems

Many traditional information systems development practices attempt to create descriptions that reduce the social to the technical or that describe this relationship in terms of simple mutuality; for example, technologies are occasionally described as being shaped by the social. Yet, understanding how systems can be of use and how they are meaningful for various organizational communities necessitates recognizing that there is a fundamental difference between social and technical systems. An early advocate of a meaning-oriented or semiotic perspective to the information systems discipline was the Swedish informatician Börge Langefors (1966).

Broadly speaking, semiotic approaches to the information systems discipline can be seen as attempts to understand the complex interrelationships between social and technical systems. We can explore these differences between social and technical systems from the perspectives of communication and action. The social practices that we are interested in exploring (in this case, systems development practices) can be usefully examined using social semiotic communication theories (Clarke, 2001b, 2005b). We can examine the texts or completed acts of communication in any medium (Kress, 1988). Associated with these completed acts of communication is a range of text-forming resources. Referred to collectively as texture (Halliday & Hasan, 1985) these text-forming resources are divided into two broad classes: those resources that are responsible for the internal organization of the communication (cohesion) and those resources that bind this communication to its immediate situational and cultural contexts (coherence). Consider, for example, a student record in a subject marks data base, where we might find the following tokens:

Xiu Darren 1 7 72890 16 8 28 28 19

Without the kind of metadata that describes what each of these tokens might mean, we are unlikely to understand this record completely. However, we can attempt to remedy this lack of coherence by applying our knowledge of educational institutions, practices, and conventions in order to guess what some of these tokens might mean for this particular student, subject, and institution. For example, the first two strings are likely to be the family name and given name of the student. The third number is possibly a unique student identification number. We are unlikely to understand, however, that the first number refers to the tutorial class to which the student has been assigned and that the second number is likely to be the topic they have selected for their major assignment. We are also unlikely to know that the fourth through seventh numbers are for various aspects of the coursework and that the last mark refers to the total marks achieved in the exam. Also, we cannot infer from this record that a rule is being applied to the weight of the coursework and exam components (each contributes 50% to the final grade) nor can we determine that this student achieved 49.5% in this course and that at this institution this mark constitutes a Pass grade. An inability to understand what this record fully means is also due in part to a lack of cohesion—the unknown relationships between a student's assignment and exam marks, for example. Another lack of cohesion involves the fact that out of technical necessity, a database only will mention a student once. However, in language, we build up increasingly elaborate meanings by introducing and then referring to participants over time (we will see an example of this type of language resource later).

While we have concentrated on understanding the differences between social and technical systems from the perspective of communication, we also can explore the differences between social and technical systems from the perspective of action. Collins and Kusch (1998) introduce two types of action: polimorphic actions require an understanding of social context, while mimeomorphic actions do not. Humans can produce both types of action; for example, the polimorphic actions associated with presenting a lecture or marking coursework. Humans also have reflex actions that are mimeomorphic actions and also may organize their workplaces and work technologies in order to perform repetitive actions and behave in mimeomorphic ways. In contrast, technical systems only can perform mimeomorphic actions like those associated with updating a database, performing a calculation, or executing a program.

Systems Artefacts and Processes

It is reasonable to suggest that understanding the semiotic nature of social systems in terms of communication and action might assist in improved computer-based representations in the form of technical artefacts. Just as information systems in organizations can be theorized as texts in context, so, too, can any systems development practices. In fact, exactly the same techniques can be applied to the work practices of analysts, a property of semiotic and communicative approaches referred to as metasymmetry (Clarke, 2005b). This opens up the possibility of formally investigating requirements, gathering and engineering processes in organizational contexts from a functional linguistic perspective. In an isolated study, Tebble (1993) was able to characterize the underlying communication pattern (referred to as a genre structure described in detail in a later section) associated with certain developer-user discussions. A consequence of that study is that all so-called social process methods (Crinnion, 1991), such as interviews, structured walkthroughs, and phase signoffs, could be analyzed using systemic semiotics methods. By extension, every systems development methodology consists of a set of formal methods and deliverables, which also constitute texts. Recall that following Kress (1988), a text is a completed act of communication in any medium. A deliverable need not be language-based in order to be a text in the sense defined here. It can be, as it often is, a flowchart, a state diagram, or some other pictorial or iconic representation of an entity or process (see, i.e., Kress & van Leeuwan, 1990). The very recognizability of methods for developers hints at their generic nature. Therefore, it is also reasonable to suggest that understanding the semiotic nature of social systems may contribute to better understanding the process by which technological artefacts are developed and deployed. We will explore the dual utility of a systemic semiotic approach to understanding system artefacts and development processes in this chapter.

Structure of the Chapter

This chapter represents an attempt to support the development of an agent-oriented conceptual modeling (AoCM) methodology for producing useful information systems incorporating systemic semiotic theory and methods that emphasize the communicative, social, and semiotic (meaning-making) processes that occur in organizations. We proceed by first applying an agent-oriented conceptual modeling framework called i* (Yu, 2001a, 2001b), designed for use in early-phase requirements engineering, to the real-world problem of registering and training volunteers in emergency services. The case study is used throughout this chapter. An overview of i* is provided in the next section together with its two principle graphical models, the strategic dependency (SD) model and the strategic rationale (SR) model.

Initially, these models are used to illustrate registration and training in the absence of an information system.

During the development of these models, a number of practical difficulties arose as a consequence of the informal consultative processes employed during early-phase requirements elicitation sessions in our emergency services example. It became apparent that the underlying modeling notation could be used to drive the design of a set of requirements capture templates (RCT) that, in turn, could simplify the process of requirements elicitation by structuring the stakeholder interaction (Unni, Krishna, Ghose, & Hyland, 2003). Once the analyst/modeler completed these templates, the data contained within them could be transformed manually into the SD and SR models. These templates serve as a structured repository and a record of stakeholder interaction that can be revisited, renegotiated, or revised. These application-specific domain ontologies can help to generate elicitation triggers and test the completeness and consistency of the conceptual models. These aspects are described in the section titled "Ontology-Driven Template-Based i* Model Elicitation." From the perspective of systemic semiotics, the RCTs function as a set of compositionally related genres referred to as a macrogenre. This observation enables us to move existing systemic semiotic approaches to genre-based elicitation practices into the realm of agent-oriented conceptual modeling. The recognition of the generic nature of elicitation necessitates an examination of the kind of language resources that are also in play during early-phase requirements engineering. These resources are introduced and described in the section titled "Systemic Semiotic Foundation for Elicitation." The importance of communication resources during requirements elicitation illustrates how systemic semiotic can be used to describe the process of systems development.

Difficulties are encountered when transforming an i* model into an agent-based executable model. These models are sequence agnostic, and so, in practice, analysts must create these sequences or elicit them from users. The systemic concept of genre also can be used to provide a solid foundation upon which analysts can elicit and develop relevant sequences to include within i* models. In the section titled "Executable Models and Systemic Semiotics," a genre analysis of the enrollment features in an existing loan is used to create an executable 3APL routine for the registration process in our case study. This routine is provided as a demonstration of the usefulness of systemic semiotics for building system artefacts.

Finally, in the section titled "Conclusions: Integrating Processes and Artefacts," we develop a Systemic Semiotic Agent-Oriented Conceptual Modeling Methodology by connecting the language resources previously discussed with additional generalized phases to account for the development of i* models and executable specifications. The expected utility of this methodology is its support for the co-evolution of conceptual models, ontologies, and requirements that capture templates through the process of elicitation and modeling. We also discuss some broader connections between systemic semiotics and agent-oriented systems.

Overview of the i* Modeling Framework

The *i** framework (Yu, 2001b) for agent-oriented conceptual modeling was designed primarily for early-phase requirements engineering. The central concept in *i** is that of the intentional actor (agent). Intentional properties of an agent such as goals, beliefs, abilities, and commitments are used in modeling requirements. The *i** framework consists of two main modeling components: the strategic dependency (SD) model and the strategic rationale (SR) model. The SD and SR models are graphical representations that describe the world in a manner closer to users' perceptions.

An SD model consists of a set of circles that represent actors and a set of special links that join them called dependencies. A link between two actors indicates that one actor depends on the other for something so that the former agent can attain some goal. The depending actor is known as the depender, while the actor depended upon is known as the dependee. The object around which the dependency relationship centers is called the dependum. The SD model represents the goals, task, resource, and soft goal dependencies among actors/agents. In a goal-dependency, the depender depends on the dependee to bring about a certain state in the world. The dependee is given the freedom to choose how to do it. In a task-dependency, the depender depends on the dependee to carry out an activity. Task and goal dependency often may appear interchangeable. One way to understand the distinction is to view goals as more coarse-grained, abstract entities and tasks as more fine-grained, specific entities (while recognizing that goals always can be reformulated as tasks and vice versa). Another dimension to this distinction is the relative autonomy of the dependee in deciding how a goal is achieved, while in a task, the depender and dependee must coordinate in a far more tightly coupled fashion. In a resource dependency, one actor (the depender) depends on the other (the dependee) for the availability of a resource. In each of these types of dependencies, the depender becomes vulnerable in situations in which the dependee fails to achieve a goal, perform a task, or make a resource available. In a softgoal dependency, a depender depends on the dependee to perform certain goals or tasks that would enhance the performance. The notion of a softgoal derives from the non-functional requirements (NFR) framework (Chung, 1993) and is commonly used to represent optimization objectives, preferences, or specifications of desirable (but not necessarily essential) states of affairs.

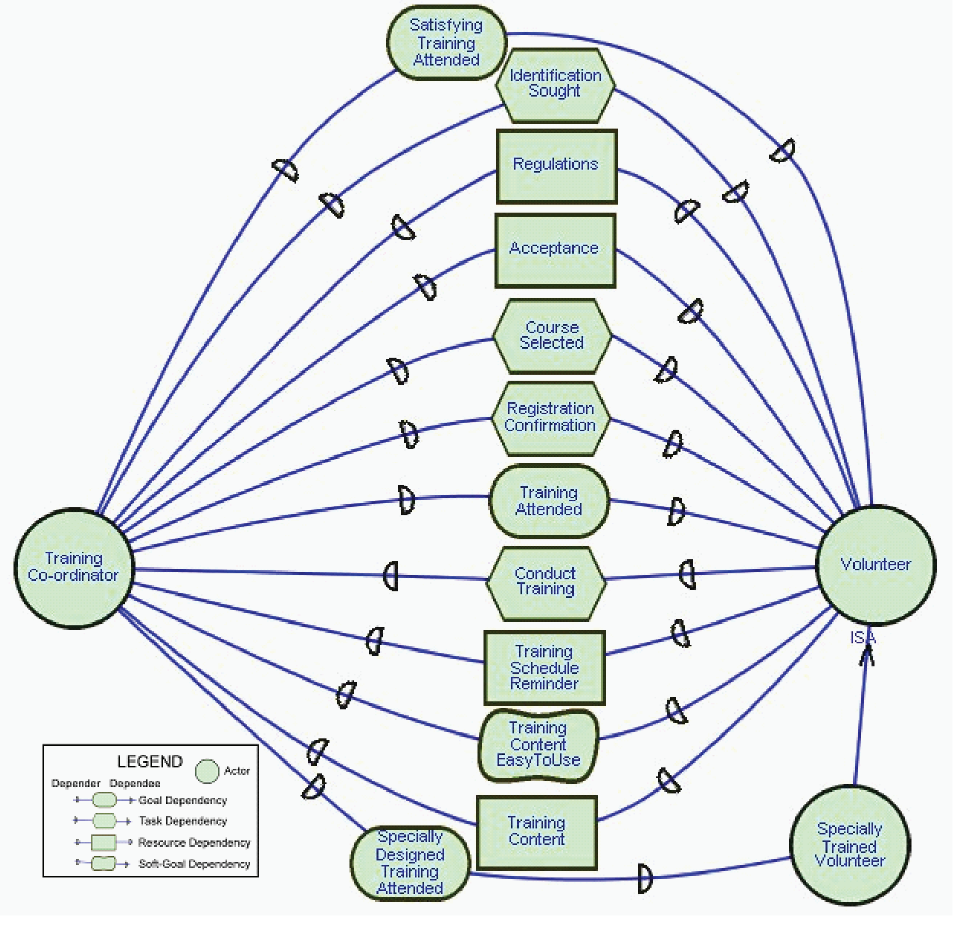
An SR model represents the internal intentional characteristics of each actor/agent via task decomposition links and means-end links. The task decomposition links provide details on the tasks and the (hierarchically decomposed) subtasks to be performed by each actor/agent, while the means-end links relate goals to the resources or tasks required to achieve them. The SR model also provides constructs to model alternate ways to accomplish goals by asking why, how, and how else questions.

Strategic Dependency Models: An Example

An example concerning registration and training for volunteers of emergency services will be used to illustrate the strategic dependency (SD) model notation (see Figure 1). The modeling process begins with identifying the actors/agents involved with the activity and their mutual dependency relationships, previously described. The *TrainingCoordinator* agent depends on Volunteer agents to achieve its *TrainingAttended* goal.

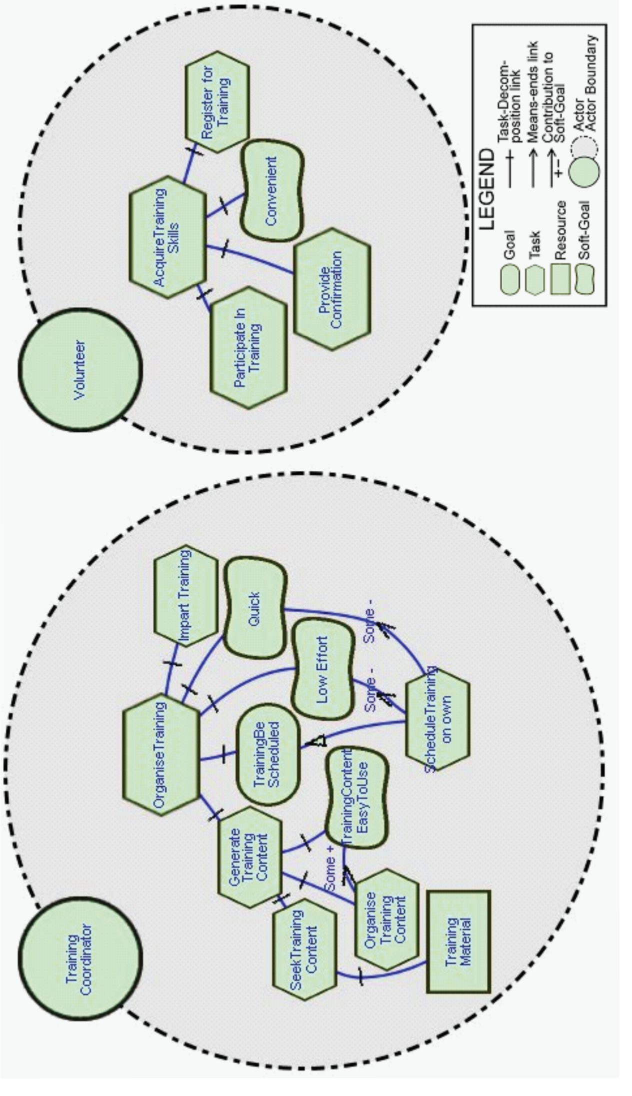
The class of Volunteer actors has a specialized subclass of actors called *SpeciallyTrainedVolunteers* (volunteers who go through special training programs to acquire specialized skills). The TrainingCoordinator depends on SpeciallyTrainedVolunteers to *SpeciallyDesignedTrainingAttended*, modeled as a goal dependency. The Volunteer agent has a dependency on the

Figure 1. Strategic dependency model for registration and training, without computer-based system



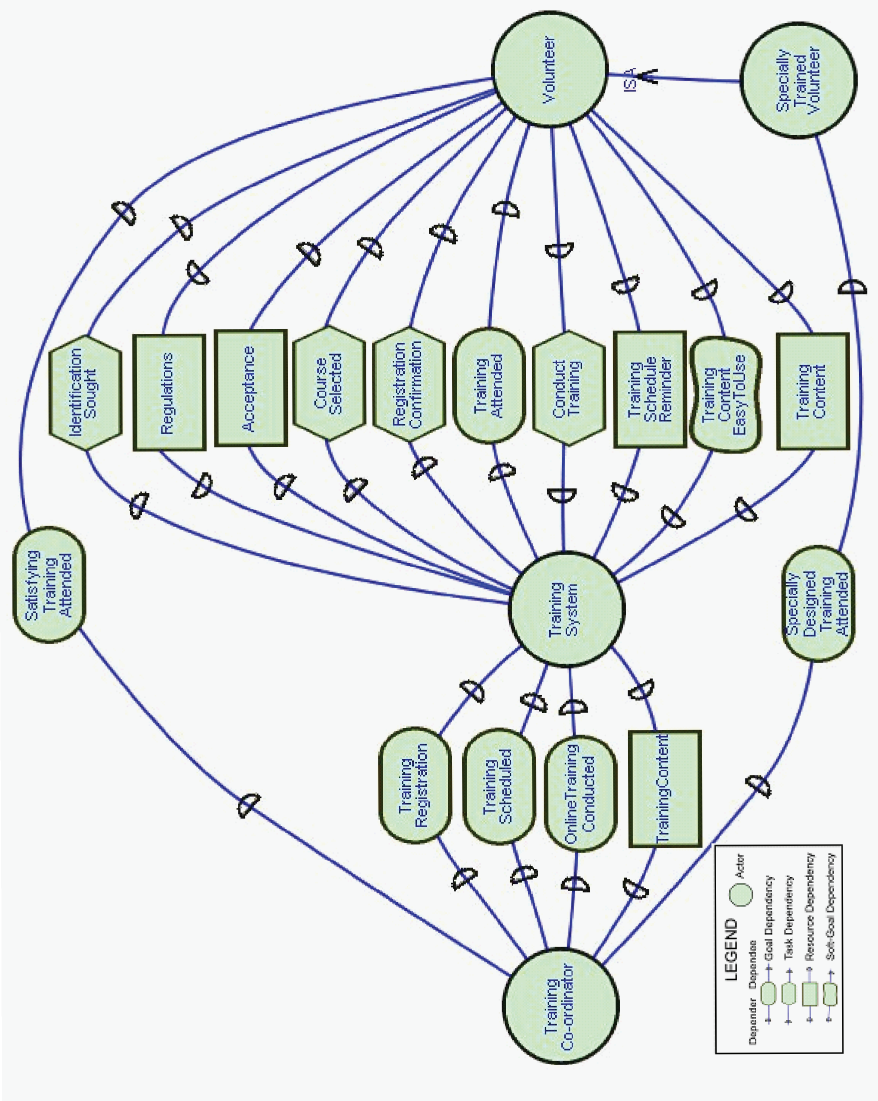
TrainingCoordinator to provide *TrainingContent*, modeled as a resource dependency. The TrainingCoordinator has a dependency on Volunteers to achieve its SatisfyingTrainingAttended goal, a responsibility of the Training Coordinator that all Volunteers are trained. Volunteers depend on the TrainingCoordinator to perform the ConductTraining task. Observe that we have chosen not to model this as a goal dependency, since the TrainingCoordinator cannot autonomously decide how the corresponding goal might be achieved but must work with the depender in a tightly coupled fashion to perform the task. Volunteers have a further dependency on the TrainingCoordinator to TrainingScheduleReminder, modeled as resource dependencies. Volunteers have a preference for the TrainingCoordinator to satisfy

Figure 2. Strategic rationale model for registration and training, without computer-based system



the softgoal, *TrainingContentEasyToUse*. The SD model provides an important level of abstraction for describing systems in relation to their environments in terms of intentional relationships among them. This allows the modeler to understand and analyze new or existing organizational and system configurations, even if the internal goals and beliefs of individual agents are not known.

Figure 3. Strategic dependency model for computer-based training system



Strategic Rationale Models: An Example

In the *i** framework, the SR model provides a more detailed level of modeling by looking inside actors to model internal intentional relationships. Intentional elements (goals, tasks, resources, and softgoals) appear in the SR model not only as external dependencies but also as internal elements linked by task decomposition and means-ends relationships. Therefore, the SR model in Figure 2 elaborates the relationships between the Training Coordinator and Volunteer as represented in the SD model of Figure 1.

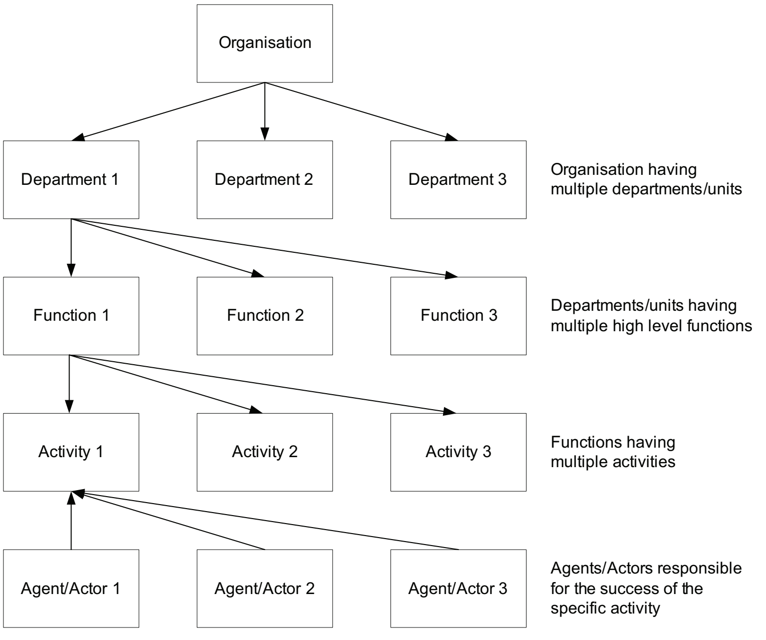
For example, the TrainingCoordinator has an internal task to OrganizeTraining. This task can be performed by subtasks GenerateTrainingContent, ImpartTraining, and Subgoal TrainingBeScheduled (these are related to the parent task via task decomposition links). The GenerateTrainingContent task is further decomposed into subtasks SeekTraining-Content and OrganizeTrainingContent. The softgoal TrainingContentEasyToUse is also related to the GenerateTrainingContent task via a task decomposition link. The intention is not to suggest that the softgoal plays the role of a subtask but to relate the softgoal to the highest-level task for which the softgoal may be viewed as an optimization objective. The softgoal thus serves to constrain design decisions on how the task might be decomposed. The subtask OrganizeTrainingContent is related to the TrainingContentEasyToUse softgoal via a contributes to softgoal link. In this instance, the contribution is positive, organizing the training material contributes (positively) to achieving the broader goal of making the training material easy to use.

SD models make it easier to define the early-phase requirements of computer-based systems that might take on the functions of one or more existing organizational actors. We will not describe the techniques for doing this in detail but rather briefly summarize it here. Our objective in this exercise is to understand what dependencies would relate to the proposed computer-based system (acknowledging that this only would provide an initial basis for further analysis leading to potentially more dependencies). We achieve this by identifying the region in the prior SD model that the proposed system would supplant. The dependencies impinging on this region would provide the initial base set of dependencies for the proposed system. Figures 1 and 3 provide the before-and-after view of such a process.

Ontology-Driven Template-Based *i** Model Elicitation

Early-phase RE activities traditionally have been done informally (Yu, 1997), beginning with stakeholder interviews and discussions on the existing systems and rationales. Initial requirements are often ambiguous, incomplete, inconsistent, and usually expressed informally. In order to structure these informal consultation processes, initial attempts were made to develop a set of templates that the modeler would fill out during a stakeholder consultation session. These so-called *requirements capture templates (RCTs)* then would be be signed off eventually by both the modeler and the stakeholder. The process of filling out these forms provided structure to stakeholder interview sessions. In addition, these forms had been designed to assist in eliciting information specific to the needs of the underlying agent-oriented conceptual model that the modeler was seeking to build. As we will show next, these templates were designed in a manner that made it easy to systematically transform them into SD and SR models. Stakeholders were directed to provide focused input to the conceptual modeling task while being shielded from the complexity of understanding and using the conceptual modeling language. In this section, we propose a proto-methodology for requirements elicitation based on these requirements capture templates. The methodological

Figure 4. Notion of an organizational model



guidelines that we offer are based on our experiences with early-phase requirements modeling of the emergency services organization using the *i** framework. While these templates do assist in modeling, they provide only a partial AOCM elicitation strategy. In the next section, we describe how these templates can be extended to understanding the social process of elicitation, but for now we concentrate on describing the RCTs exclusively.

A key element of the process of agent-oriented conceptual modeling of a large organization is the development of a hierarchically structured set of models. In our instance, we started with a highest-level SD model that treated the emergency services organization as a single agent that interacted with a variety of external/entities and agents. A corresponding SR model was built, which detailed the goals, tasks, resources, and softgoals internal to the emergency services actor and their relationships to external actors and external dependencies. This SR model did not expand on the internal characteristics of the other actors in any great detail. At the next level of abstraction, we constructed an SD model of the emergency services organization in which each individual department was modeled as a distinct actor. The requirements capture templates (RCTs) became useful from this point onward. Implicit in the requirements capture templates presented here is the notion of an organizational model such as the one shown in Figure 4.

Several concepts explicitly referred to in the RCTs, such as departments/units, functions, and activities derived from such a model, are extraneous to the *i** notation. These notions

Table 1. Organizational unit template for department details

Organizational Unit Template		
Department Details		
Department Name	Operations	
Name of the Department Head	Ms. Robyn M	
Designation of Department Head	Director	
Department Rationale	▪ To provide all operations-related functions to external and internal stakeholders ▪ Use industry best practices in conducting the activities ▪ Keep up-to-date with industry standards ▪ Upgrade equipment with latest technologies	
High-Level Functions of the Department	▪ Operations ▪ Planning ▪ Training	
Modeler Signature		**Stakeholder Signature**

make the RCTs conceptually accessible to organizational stakeholders yet at a lower level lead to notions directly supported by *i**. The underlying organizational model helps make the elicitation process more systematic. Building such a model explicitly is helpful but not essential; that is, the underlying organizational model can remain implicit in the RCTs. The agents responsible for the activities, as shown in Figure 3, may be internal or external to the organization.

The first RCT (shown in Table 1) that we designed helped address the following questions: (1) Why does the department exist? (2) What are the department rationales? and (3) What are the main functions of the department? The rationale and functions are revisited during the elicitation process by asking the why-what-how questions until an agreement is reached on the requirements. The key role of this specific RCT is to identify the agents/actors that would form the basis of the SD and SR models to be constructed (involving department-level actors).

The next step involves elaboration of the high-level functions by identifying the various activities required to support each of the functions. The function elaboration template (an instance that is presented in Table 2) was designed (and used in the context of the emergency services organization) to elicit information about specific functions within each department and activities supporting such functions. Note that one would fill out a form similar to the one shown in Table 2 for each activity supporting each function within each department.

The specific slots in the template are self-explanatory, but the key point to note is that there is a relatively direct mapping from a collection of such completed templates to an SD model. The template identifies each of the actors to be represented in an SD model and provides

Table 2. Function elaboration template for function elaboration

Function Elaboration Template			
Function Elaboration for the Department			
Department Name	Operations		
Function Name (Use separate sheet for each function)	Training		
Function Rationales (Use separate sheet for each function)	• To provide quality training programs • To keep volunteers updated with latest tools and techniques • To provide fast and effective training programs • To conduct frequent training and certifications • Incorporate industry best practices in training programs • Update training material		
Activity Details for the Function			
Activity Name and Description (Use separate sheet for each activity under the function)	Training Program for Volunteers (Provide training to volunteers on various emergency management topics)		
Activity Rationales	• Training forms a critical activity in emergency services • There are specialized and starter programs • Training is conducted every month • All volunteers are supposed to undergo starter programs		
Responsible Actor(s) involved in the activity (Unique list of Actor(s)	• Training Coordinator • Training System • Volunteer o Specially Trained Volunteer		
Relationship/dependencies between responsible actor(s) to achieve/satisfy the above activity (Relationship is described as the dependency from source actor on to target actor, use separate row for each relationship and dependency)			
Source Actor	**Relationship / Dependency**	**Target Actor**	**Additional information / elaboration on the relationship**
Training Coordinator	Attend the training	Volunteer	The Coordinator is finally responsible to ensure that the volunteers attend the program
Training Coordinator	To schedule the training program	Training System	The Coordinator gives instructions to the system to schedule the training program
Training Coordinator	Carry out online training programs for volunteers	Training System	The Training Coordinator expects the training system to conduct the online training
Training Coordinator	Attend specially designed training programs	Specially Trained Volunteer	The Coordinator is finally responsible to ensure that the specially trained volunteers attend the training program

Table 2. continued

Training System	Provide with the training contents	Training Coordinator	To impart training the training system expects the Training Coordinator to provide content for the training
Training System	Attend training	Volunteer	Training system is depended on the Volunteer to attend the training
Training System	Receive confirmation to attend the training program	Volunteer	The training system is dependent on the Volunteer to provide confirmation to attend the training program
Volunteer	Conduct the training program	Training System	Volunteers expects the training system to conduct the online training program, and the training modules must be easy to use
Volunteer	Provide reminders to attend the training	Training System	Volunteers busy with their livelihoods, they would prefer to be reminded about the training programs
Volunteer	Provide information and plan on training programs	Training System	The training system must provide information to Volunteers on a query or inquire in regard to training programs or schedule
Modeler Signature		**Stakeholder Signature**	

information on the dependencies among them. The relationship/dependency column in the template provides, in effect, a name for the dependency. The additional information/elaboration on the relationship column can provide adequate pointers to appropriately classify the dependency (e.g., as a goal dependency, task dependency, etc.). Information in this column also can provide an indication of how critical this dependency may be. Although the SD model notation supports the representation of this information, our example does not include it. Information on specialization/generalization relationships among actors can be obtained from a detailed analysis of the source/target actor columns. It is important that the modeler only should elicit the relationships and dependencies that the source actor (stakeholder being interviewed) has on the target actor(s). Our empirical evidence suggests that the source actor/agent may not have sufficient knowledge or be aware of the relationships/dependencies that the target actor(s) has on the source actor/agent. Hence, to complete the relationship/dependency among the remaining actors in the given activity, we use the same requirements to capture form and conduct a similar requirements gathering process with the remaining actors/agents.

The next step involves identification of intentional relationships that are internal for each actor or agent for each activity described in the function elaboration template. The activity elaboration template (an instance of which is presented in Table 3) was designed to elicit information about specific activities within each actor. Note that one would fill out a form similar

Table 3. Activity elaboration template for internal intentional characteristics of individual actor(s) to achieve the activity

Activity Elaboration Template		
Internal Intentional Characteristics of Individual Actor(s) to Achieve the Activity (Use multiple rows to describe multiple internal tasks for each actor)		
Department Name	Operations	
Function Name	Training	
Activity Name	Computer-Based Training Program for Volunteers	
Responsible Actor(s) involved in the activity (Unique list of Actor(s))	• Training Coordinator • Training System • Volunteer o Specially Trained Volunteer	
Actor	**Internal Task/Means to achieve the activity by individual Actor**	**Additional information on task or means to achieve the activity or Actor Rationales**
Training Coordinator	• Organize Training Programs	The coordinator is responsible for organizing the entire training programs
“	• Generate information regarding training and its content	To organize training programs would result in generating training material and content for the various training programs that must be easy to use by volunteers or users of the content
“	• Acquire and seek information regarding training program and its contents	To generate quality training content would result in seek for content from various sources for the training programs
“	• Organize the collected Training Content	To generate and provide an easy-to-use training content would lead to organizing the content in an acceptable fashion for use
“	• Schedule the training program	To organize training programs would result in scheduling and conducting the training program using a computer-based training tool
Modeler Signature	**Stakeholder Signature**	

to the one shown in Table 3 for each activity elaborating on the intentional characteristics that are internal to the actors/agents. This is done by identifying intentional descriptions of processes in terms of process elements and their rationale. The specific slots in the template are self-explanatory, but a key point to note is that there is a relatively direct mapping from a collection of such completed templates to an SR model. The template identifies each of the actors with their internal characteristics that provide an understanding on the process elements that could be classified as a goal, task, resources, and/or softgoal.

The internal task/means column in Table 3 provides, in effect, names for the internal characteristics. The additional information on the tasks/means column can provide adequate pointers to appropriately classify the internal characteristic (e.g., a goal, task, resource, and/or softgoal) and infer how each high-level task internal to an actor might be decomposed (either into subtasks or into means to achieve the task). Information in this column also can provide an indication of how a particular internal characteristic can provide a positive or negative contribution to the other internal characteristics (such as a subtask supporting a high-level task or a task positively contributing to a softgoal associated with a higher-level task).

It is important that the modeler should only elicit the intentional characteristics that are internal to the actor/agent (stakeholder being interviewed). Our empirical evidence suggests that the source actor/agent may not have sufficient knowledge of the intentional characteristics that are internal to other actors/agent in the given activity. Hence, in order to complete the intentional characteristics that are internal for the remaining actors/agents in the given activity, it is proposed to use the same requirements to capture form and conduct a similar requirements-gathering process with the remaining actors/agent.

We have argued that the templates presented here can ease the requirements elicitation process. However, these templates serve other useful functions as well. They can provide a structured repository and record of stakeholder interviews that can be revisited when requirements are renegotiated or revised (i.e., when changes are made to models or when inconsistencies are detected). The detailed rationale recorded in these templates also can be of value in business process reengineering. To anticipate and support future business process reengineering efforts in the context of the emergency services agency, we also are detailing alternative solution scenarios by completing additional RCTs that answer "how else" questions (while the primary RCTs represent the "as is" scenarios).

An ontology commonly is paraphrased as a description of concepts and relationships that can exist for a community of agents. The notion of ontology, as used in computing, refers to a common vocabulary (with a concomitant set of rules) that is used for building and reasoning about systems. Jurisica, Mylopoulos, and Yu (1999) present a good survey of ontology-based approaches to information systems development. A variety of domain ontologies have been developed, and several are publicly available (Fikes, 2003; Fikes & Farquhar 1997; Knowledge-Based Systems Research Group, 2003). The study, development, and deployment of ontologies have received considerable recent attention as a result of the semantic Web initiative (TheSemanticWeb, 2003). Several ontology languages that serve the dual role of ontology markup languages have been developed, including the Ontology Inference Layer (OIL, 2003) and the DARPA Agent Markup Language (DAML, 2003). The semantic Web initiative has led to a large number of Web-based ontologies being developed through what may be viewed as a large distributed collaborative knowledge engineering exercise. It is, therefore, not unreasonable to assume that analysts and application developers would have access to reusable enterprise ontologies as well as to reusable function/activity-specific ontologies. A simple approach to conceptualizing an ontology is to view it as a concept vocabulary coupled with a set of rules. The rules may be structural rules that, for instance, may organize concepts in a class hierarchy, or they may be semantic constraints or business rules (e.g., a rule in a banking application that requires interest rates for loan accounts to be always higher than those for savings accounts).

We propose to exploit the availability of such reusable ontologies in our approach to early-phase requirements engineering via agent-oriented conceptual modeling. Our key premise is that a pre-existing knowledge base (or even a concept vocabulary) significantly can ease the early-phase requirements modeling task (by providing some modicum of guidance to a modeler who might be venturing into the task with no prior knowledge or understanding of the application domain). A pre-existing domain ontology, therefore, can help provide focus to a modeler's early interactions with stakeholders. However, our proposal here is to formalize the process by which ontology-driven elicitation might take place. This, then, is generalized into a full ontology life cycle in the requirements elicitation context.

Recall that we are interested in ontologies of two distinct kinds: enterprise ontologies and function/task-specific ontologies. Enterprise ontologies can provide guidance in identifying actors while constructing high-level SD and SR models, by making available certain default organizational structures. These also can provide a vocabulary for more refined (lower-level) SD and SR models. Function/task-specific ontologies (often included within enterprise ontologies) provide detailed concept vocabularies for specific tasks, which can serve as elicitation triggers. Ontologies also can provide a benchmark for completeness that serves to drive the elicitation process. Informally, a conceptual model is deemed to be complete with respect to an ontology if it makes reference to every concept in the concept vocabulary of the ontology. This in many ways is analogous to the notion of completeness of formal theories. A theory is considered complete with respect to a language if it commits to the truth or falsity of every proposition in the language. It is not difficult to conceive of an elicitation methodology that uses this notion of completeness of a conceptual model relative to an ontology to generate elicitation triggers. In effect, every instance of incompleteness (i.e., every concept in the concept vocabulary that is not referred to by the conceptual model) serves as a trigger for further questions/probes from the modeler. Ontologies also can support consistency testing of conceptual models. A conceptual model would be deemed inconsistent relative to an ontology if it violated any of the rules associated with the ontology. These could be violations of the structural rules (e.g., if a subclass-superclass relationship is reversed in a model) or violations of semantic constraints (e.g., an activity that involves an actor making his or her appointments schedule publicly available may violate security constraints). Each instance of inconsistency can serve as an elicitation trigger, obliging the modeler to seek out additional information in the process of resolving the inconsistency (usually by appropriately modifying the conceptual model).

Much of the previous discussion assumes that appropriately constructed domain ontology is made available to the modeler at the start of the elicitation phase. This can be an unrealistic assumption since pre-existing ontologies, where available, may turn out to be inadequate. Key concepts from the domain may not be included in the concept vocabulary, while key relationships may not be represented in the rule set. The challenge, then, is to devise early-phase requirements modeling methodologies that maintain and update ontologies. These same methodologies also might be used to build (if necessary, from scratch) appropriate domain ontologies.

Systemic Semiotic Foundation for Elicitation

So far, we have discussed RCTs that have been used to capture, within this domain, information concerning activities within functions and within departments that constitute the organizational model of Figure 4. In this section, we introduce the concept of a genre to assist in explaining why these templates are, in fact, useful. A genre is associated with the cultural context of a completed act of communication and can be thought of as a text type or class. A genre consists of a pattern of stages called genre elements that assist us in recognizing the kind of culturally defined situation that we are in. If, for example, we buy bread from a bakery, the social process that we conduct is a particular type of genre called a service encounter genre. Every genre contains predictable stages; in the case of the bread buying service encounter, there likely will be an optional greeting element in which the server attempts to facilitate a sale by welcoming the potential customer. There will be an element in which the customer inquires about the availability and price of various types of goods, followed by an element in which the price is agreed upon and the selected items are paid for, and a leave-taking farewell element to end the transaction. The genre as we have described it contains a small series of genre elements that form a pattern that would encompass a range of actual bread-buying texts.

Our knowledge of the genre staging—the expected sequence or organization of the genre elements—is brought to the fore, especially in circumstances in which we cannot easily communicate; for example, shopping in a foreign supermarket. We know when to nod our head to thank the cashier and when to hand over the money, because we are familiar with the staging of these kinds of social encounters. In many cases, we have a working knowledge of genre at the same time as we are acquiring our first language. Most genres are highly elaborate—tailored to specific types of communication—like those found in organizations and associated with various kinds of technical systems. But some genres are very general and form a kind of cultural property that we draw on in many different social occasions. These more general genres are referred to as canonical genres (Martin, 1992), and systemicists have identified a number of families of them, including the Factual and narrative genre families.

Each box in Figure 4 involves a set of non-activity-structured genres in a large multi-level compositional arrangement of reports. To describe a function, you need to describe its constituent activities. Activities are to functions as parts are to wholes. The appropriate genre to use in which to communicate this information is in the form of a canonical REPORT genre that describes "what an entire class of things is like" (Martin, 1985, p. 15). In this case, the REPORT genre consists of two elements that enable the purpose of the function (see Figure 4) and the constituent activities to be described (respectively, these elements are called purpose and section preview). In the function elaboration template in Table 2, the Purpose element is realized by the department name, function name, and function rationale. The section preview consists of the constituent function names. The activity details for the named functions are provided as separate elements in the factual REPORT. Each constituent activity for a given function is provided by its own nested REPORT genre (see Table 3). Also, the additional information elements in the activity REPORT genre in Table 3 consist of individual DESCRIPTION genres. A DESCRIPTION genre is used to describe "what some particular thing is like" (Martin, 1985, p. 15). Similarly, the Function and activity rationale in Table 2 also are expressible using DESCRIPTION genres. From the perspective of systemic semiotics, the RCTs function is a set of compositionally related non-activity structured genres that collectively form a single macrogenre. If Systemics is useful for analyzing RCTs as text types, what are the language resources that are being used to underpin them? Can some of the difficulties associated with the use of RCTs (e.g., the construction of domain ontologies) be addressed if these language resources are made explicit and factored into our methodology?

Developers, in general, are presented with a confusing array of language resources during requirements elicitation sessions. Here, we identify five sets of language resources that are known to be of particular importance during requirements gathering, elicitation, and representation activities. The first set of language resources are referred to as reference, which describes how participants, or people, places and things, get introduced and "managed" (Eggins, 1994, p. 95) during interviews and other social occasions. Once participants can be disambiguated, we then can determine the correct labels for them. A second set of language resources is used for naming participants. They include language resources, which can be used to classify things into different types, as well as other kinds of grammatical and semantic resources. The third group of resources is referred to as taxonomy and enables us to move from an everyday understanding of named participants or lexical items to a technical classification relevant to particular social actions and activities called indexical lexical items. Indexical lexical items can be structured into taxonomies, the organization of which can be modified by adding more options to them (extension) and also by recognizing, incorporating, and refining the differences between successive options (elaboration). The reorganization of these taxonomies can reflect the evolving understanding of a work practice, situation, or domain by the development team, for example.

Lexical items that are classified into relevant field taxonomies can be used to form messages using the fourth set of language resources, referred to as configuration. Each message will have an agent, utilize a medium of a kind, and exhibit a process. The process is represented by a verb group around which the message or clause will be organized. We can distinguish between different types of processes, including material processes, behavioral processes, and mental processes. Material processes express some action, an event of happening that is taking place in a social situation. Behavioral processes concern aspects of behavior that are effectively psychological processes, while mental processes involve processes of thinking, feeling, or perceiving. Using the final group of language resources, messages can be assembled to form a goal-oriented routine work that consists of a sequence of functional stages called an activity sequence or genre. When the language that accompanies goal-oriented work is recorded and transcribed, it also will exhibit a relatively stable and predictable staging (Clarke, 2000, 2005a). These semiotic resources of reference, naming, taxonomy, configuration, and activity sequence can be considered as forming a language resource arc that links the situational language, also known as register, and the broader social discourses at work in organizations, which will be inextricably a part of the development projects and activities. Of particular interest to requirements gathering, elicitation, and representation are those classes of activity sequence that are used so commonly that they are considered part of our social and workplace literacy—the so-called canonical genres, as we have seen previously. Canonical genres have been used to assist analysts during interviews when they are eliciting information about work-practice sequencing, when determining the identity of workpractice elements, when recovering the expected competencies and behaviors of interactants, when evaluating the work from the point of view of particular classes of participants, and when exploring work experiences. These resources will be incorporated into a systemic semiotic agent-oriented conceptual modeling methodology in the concluding section of the chapter.

Executable Models and Systemic Semiotics

So far, we have introduced systemic semiotic concepts and attempted to demonstrate how they might be applicable to the process of agent-oriented systems development. In this section, we develop an agent-oriented executable specification for our system, but significantly, we also demonstrate how this artefact can be improved with the use of systemic semiotic concepts. Agent-oriented conceptual modeling in notations such as the *i** framework (Yu, 1995) have gained considerable currency, because they provide abstractions that can be used to model aspects of the organizational context as well as offer useful high-level metaphors in the form of social and anthropomorphic modeling constructs (i.e., goals, tasks, softgoals, and dependencies). It has been argued that such notations help to answer questions such as what goals exist, how key actors depend on each other, and what alternatives must be considered. Our objective here is to define the means for executing *i** models. This exercise has been motivated by the following observations. First, we seek to exploit the benefits of executable specifications. Second, we wish to view artefacts as agent-oriented conceptual models and high-level agent programs as jointly constituting a hybrid modeling notation that leverages the complementary representational capabilities of the two approaches. Third, we wish to define methodologies to support the co-evolution of models in the two frameworks in that distinct groups of stakeholders concurrently can model and specify behavior while maintaining some modicum of loosely coupled consistency between the models. Fourth, we are interested in compositional, extensible and easily maintainable modeling frameworks. Finally, we are interested in being able to develop organizational relevant and defensible artefacts that are not compromised by the processes used to develop them.

We claim that the combination of high-level modeling in *i** coupled with high-level specifications of functionality using 3APL (Dastani, 2004; Hindriks, De Boer, van der Hoek, & Meyer, 1999) agent programs offers such a framework for developing executable specifications and builds on our earlier work (Guan & Ghose, 2005). This research has been conducted concurrently (and within the same group) with a project to develop means for executing *i** models via sets of AgentSpeak agents (Salim, Chang, Krishna, & Ghose, 2005). While the starting points and motivations for both development approaches are similar, the eventual mapping of models to multi-agent systems is defined in very different ways. A detailed comparison of the two approaches, which reveals many interesting differences due to the subtly different capabilities of 3APL and AgentSpeak(L) (Rao, 1996), is omitted here for brevity.

3APL (an Abstract Agent Programming Language)

3APL (an Abstract Agent Programming Language) is a programming language for implementing cognitive agents (Dastani, 2004; Hindriks et al., 1999; Hoeve, 2003). 3APL is based on a rich notion of agents; that is, agents have a mental state, including beliefs and goals. Each agent has a number of basic capabilities. The basic capabilities of an agent are the basic actions an agent can perform. Finally, an agent can have a number of practical reasoning rules for planning and revising its current goals. In this chapter, we adopt 3APL platform (Dastani, 2004) to support our work. Our work is based mainly on 3APL definitions from Hoeve (2003) and Hindriks et al. (1999). A 3APL agent is defined as a tuple ⟨n, B, G, P, A⟩, where *n* is the name of the agent, *B* is a set of beliefs (Beliefbase), *G* is a set of goals (Goalbase), *P* is a set of practical reasoning rules (Rulebase), and *A* is a set of basic actions (Capabilities). In Hoeve (2003), a set of programming constructs for goals is defined; namely, *BactionGoal*, *PreGoal*, *TestGoal*, *SkipGoal*, *SequenceGoal*, *IfGoal*, *WhileGoal*, and *JavaGoal*, which can be used in the body part of a practical reasoning rule and make 3APL more flexible.

In a 3APL agent, *R* is a set of rules in the form:

$$\pi_h \text{<-} \varphi \mid \pi_{b,}$$

In this formula, π_h and π_b belong to a goal variable set (Hoeve, 2003), and φ is a belief. When the agent has goal π_h and believes φ, then π_h is replaced by π_b. For a 3APL agent, Beliefbase is dynamic. It is updated with executing basic actions from capabilities set. Basic Actions are mental actions that an agent can perform, whose basic form is:

$$\{\varphi_1\}\ Action(X)\ \{\varphi_2\}$$

where φ_1 is precondition and φ_2 is postconditions, both of them are belief formula, empty is allowed here. *Action*(*X*) is action formula. The execution of the mental action will result in the update of beliefbase through replacing preconditions by postconditions. In addition, beliefs can be generated from the communications between two agents (sent and received). 3APL has a mechanism to support the communications between agents. A message mechanism is defined in Dastani (2004) to fulfill the communication between agents. The messages themselves have a specific structure; *Receiver/Sender*, *Performative* are three compulsory elements in a message. Usually, there are three type of message: *send*(*Receiver*, *Performative*, *Content*), *sent*(*Receiver*, *Performative*, *Content*), and *received*(*Sender*, *Performative*, *Content*). This agent communication mechanism is described in detail in Dastani (2004). We will not elaborate further on the syntax of 3APL; readers who may want more details are directed to Hoeve (2003), Hindriks et al. (1999), and Dastani (2004).

Executable Specifications

We view an *i** model as a pair ⟨SD, SR⟩ where SD is a graph denoted by ⟨*Actors*, *Dependencies*⟩ where *Actors* is a set of nodes (one for each actor) and *Dependencies* is a set of labeled edges. These edges can be of four kinds: *goal dependencies* (denoted by D_G(SD)), *task dependencies*,(denoted by D_T(SD)), *resource dependencies* (denoted by D_R(SD)), and *softgoal dependencies* (denoted by D_S(SD)). Each edge is defined as a triple ⟨T_o, T_d, ID⟩, where T_o denotes the *depender*, T_d denotes the *dependum*, and ID is the label on the edge that serves as a unique name and includes information to indicate which of the four kinds of dependencies that edge represents. SR is a set of graphs, each of which describes an actor.

We adopt the concept of an *Environment Simulator Agent* (*esa*) defined in Salim et al. (2005). We define MAS as a pair ⟨*Agents*, *ESA*⟩ where *Agents* = $\{a_1, ..., a_n\}$, each a_i is a 3APL agent, and *ESA* is a specially designated environment simulator agent implemented in 3APL, which holds the knowledge about the actions that might be performed by actors in SD model and the possible environment transformation after the executions of those actions. The environment agent can verify fulfillment properties (clearly defined in Formal Tropos [Castro, Kolp, & Mylopoulos, 2002]), which include conditions such as *creation conditions, invariant conditions, and fulfilment conditions* of those actions associated with each agent. Every action of each agent has those fulfillment properties. *ESA* is used to check whether those actions of all agents in this system satisfy corresponding conditions.

Each graph in an SR model is a triple ⟨*SR-nodes*, *SR-edges*, *ActorID*⟩. The *SR-nodes* consist of a set of goal nodes (denoted by N_G), a set of task nodes (denoted by N_T), a set of resource nodes (denoted by N_R), and a set of softgoal nodes (denoted by N_S). *SR-edges* can be of three kinds: means-ends links (denoted by the set *MELinks*), task-decomposition link (denoted by the set *TDLinks*), and softgoal contribution link (denoted by the set *SCLinks*). Each *MELink* and *TDLink* is represented as a pair, where the first element is the parent node and the second element is the child node. A *SCLink* is represented as a triple ⟨*s*, *m, c*⟩, where the first element is the parent node, the second element is the child node, and the third element is the *softgoal contribution*, which can be *positive* or *negative*.

Any MAS ⟨*Agents*, *ESA*⟩ obtained from an *i** model *m*=⟨*SD, SR*⟩, where *SD*=⟨*Actors*, *Dependencies*⟩ and *SR* is a set of triples of the form ⟨*SR-nodes*, *SR-edges*, *ActorID*⟩ (we assume that a such a triple exists for each actor in *Actors)* with *SR-nodes*= $N_G \cup N_T \cup N_R \cup N_s$ and *SR-edges*=*MELinks* ∪ *TDLinks* ∪ *SCLinks* must satisfy the following conditions; see Table 4. Notice that these rules require that the creation conditions are communicated by the depender agent to the ESA agent. The ESA monitors all of the actions/tasks performed by each agent, all of the messages exchanged, and all of the beliefs (usually creation conditions for dependencies) communicated by individual agents for consistency and for constraint violations (e.g., the FormalTROPOS-style conditions associated with dependencies). When any of these is detected, the ESA generates a user *alert*.

Registration Activity

The registration activity in the *i** model may be represented as shown next in the 3APL agent programs as a two-agent system consisting of TrainingSystem and volunteers. A major concern with i* models in general is that they are sequence-agnostic. Therefore, the developer must provide the necessary sequencing information that is critical in transforming an *i** model into an agent-based executable model. In some actual cases, this might be trivial; the developer can rely on his or her experience of similar situations to develop sequencing that is considered appropriate by the clients. In other cases, the development of relevant sequences is hampered by a lack of experience in the client domain, and under these circumstances, it would be useful to have strategies that enable the developer to elicit this information from the clients. Alternatively, it may be the case that neither the clients nor the

Table 4. Rules for writing executable specifications from i models to 3APL*

1. For all $a \in Actors$, there exists an agent in *Agents* with the same name.
2. For all $a \in Actors$ and for each node $n \in N_G \cup N_T$ in the SR model for that actor, the agent $\langle a, B, G, P, A\rangle \in Agents$ corresponding to this actor must satisfy the property that $goal(n) \in G$.
3. For all $a \in Actors$ and for each link $\langle p, c\rangle \in MELink$ in the SR model for that actor in which $p \in N_G$ (parent node) and $c \in N_T$ (children node), the corresponding agent $\langle a, B, G, P, A\rangle \in Agents$ must satisfy the property that $goal(a)$<- φ | $task(b) \in P$.
4. For links $t \times T \in TDLink$ in the SR model for that actor in which $t \in N_T$ and $T \subseteq (N_T \cup N_G)$, the corresponding agent $\langle a, B, G, P, A \in\rangle \in Agents$ must satisfy the property that $task(t)$<- φ| $Con(T) \in P$. ($Con(T)$ is a set of task which are presented in the form of goal programming constructs.
5. For each links $S \times M \subseteq SCLink$ in the SR model for that actor in which $S \subseteq N_S$ and $M \subseteq (N_G \cup N_T)$, the corresponding agent $\langle a, B, G, P, A\rangle \in Agents$ must satisfy the property that $preference(S) \in$ B. ($preference(S)$ is the rank of this set of softgoals).
6. For each triple $\langle s, m, c\rangle$ in the SR model for that actor in which $\langle s, m\rangle \in SCLink$, $s \in N_S$, $m \in (N_T \cup N_G)$ and $c \in CON$, the corresponding agent $\langle a, B, G, P, A\rangle \in Agents$ must satisfy the property that $belief(m, s, c) \in B$. For all $\langle T_o, T_d, ID\rangle \in D_G(SD) \cup D_T(SD) \cup D_R(SD)$ there exist agents $\langle T_o, B_o, G_o, P_o, A_o\rangle \in Agents$ and $\langle T_d, B_d, G_d, P_d, A_d\rangle \in Agents$, such that if $\langle T_o, T_d, ID\rangle \in D_G(SD)$, then $goal(ID) \in G_o$,

goal(*ID*) <– φ |
BEGIN
send(T_d, *request*, *requestAchieve*(*ID*));
send(*ESA, inform, believe*(φ))
END $\in P_o$,
<- *received*(T_o, *request*, *requestAcheive*(*ID*)) |
BEGIN
Achieve(*ID*)?;
send(*ESA*, *inform*, *believe*(*Achieved*(*ID*))
END $\in P_d$.

Similarly, if $\langle T_o, T_d, ID \rangle \in D_T(SD)$, $task(ID) \in G_o$,
task(*ID*) <-φ |
BEGIN
send(T_d, *request*, *requestPerform*(*ID*));
send(*ESA, inform ,believe*(φ))
END $\in P_o$,
<- *received*(T_o, *request*, *requestPerform* (*ID*)) |
BEGIN
Perform(*ID*)?;
send(*ESA*, *inform*, *believe*(*Performed*(*ID*))
END $\in P_d$.

Similarly, if $\langle T_o, T_d, ID \rangle \in D_R(SD)$ then
Request(*ID*) <-φ |
BEGIN
send(T_d, *request, requestProvide*(*ID*));
send(*ESA, inform ,believe*(φ))
END $\in P_o$,
<- *received*(T_o, *request, requestProvide*(*ID*)) |
BEGIN
Offer(ID)?;
send(*ESA*, *inform*, *believe*(*Offered*(*ID*))
END $\in P_d$.

developer has experience in the work sequences that are to be included in the model. Under these circumstances, it would be useful to have methods that would enable the developers and clients to jointly construct appropriate sequences by using knowledge of sequences in related domains. Here, we are dealing with developing organizational relevant and defensible artefacts by applying, in this case, the concept of genre while simultaneously improving the representational capabilities of the hybrid modeling notation described previously. Recalling the discussion in the previous section, we stated that it was possible to deduce the sequencing of routine or repetitive activities, work processes, or workpractices by examining the staging in the associated communication taking place—its genre. Genre defined as the global rhetorical organization of a recurrent pattern of communication has been applied successfully to developing contextual descriptions of information systems (Clarke, 2000). The theory of genre relates a completed act of communication to its organizational/cultural context.

Genres can provide the sequencing information that is critical in transforming an *i** model to an agent-based executable model. In this case, developing a sequence that is useful as a registration process is largely trivial, but the important point to recognize here is that we can develop a relevant sequence by using a shared understanding of communication in related domains and, in so doing, develop these sequences in a fashion that is explicit and defensible. The utility of the sequence can be workshopped with the clients. Developing a useful registration sequence for our *i** model registration task involves finding a similar sequence in a related genre. We use a student loan genre described in Clarke (2000) and extract from it a sequence that is used to register first-time borrowers (see Figure 5a). The loan part of this genre involved the following stages or genre elements shown as labeled circles—an optional greeting element (it can be bypassed), followed by a service request, identification sought, materials out, the possibility of a further service request, followed by an optional 'Finis' stage. The optional elements are referred to as phatic elements—language, which is used for maintaining social contact or establishing an atmosphere against which subsequent communication can take place. The enrollment subsequence consists of regulations and

Figure 5. An existing loan genre (a) with an enrolment subsequence (Clarke, 2000) is used as the source for sequencing of a canonical registration sequence in (b) that will be used to specify a Registration task in the i model. The similarities between the two are described in the text.*

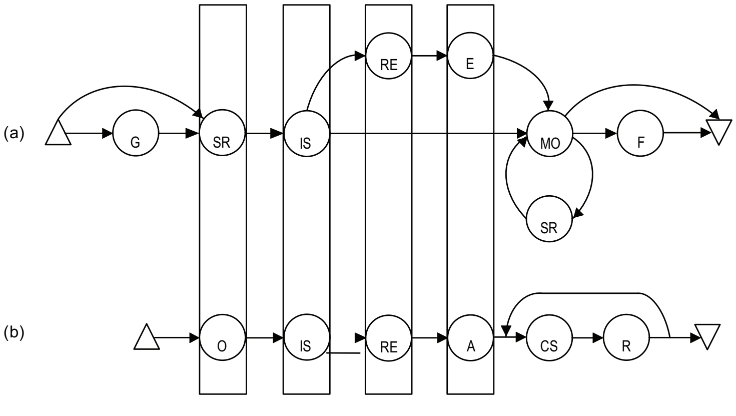


Table 5. Executable specification for the registration activity

<table>
<tr>
<td>For agent: TrainingSystem
Goalbase:
Task(IdentificationSought)
Task(CourseSelected)
Task(RegistrationConfirmation)

Beliefbase:
regulation([r1, r2, r3]).
idrange([l, h]).
Rulebase:
Task(IdentificationSought) <- φ |
BEGIN
  send(Volunteer, request,
requestPerform(IdentificationSought);
  send(esa, inform, believe(φ))
END,

Request(Acceptance) <- received(Volunteer, reply,
offeridentification(ID)) AND idrange(L, H) AND idchk(ID)|
BEGIN
  send(Volunteer, request, requestOffer(Acceptance));
  send(esa, inform, believe(received(Volunteer, reply,
offeridentification(ID))))
END,

Task(CourseSelected) <- received(Volunteer, reply,
offeracceptance(Y)) |
BEGIN
  send(Volunteer, request,
requestPerform(CourseSelected);
  send(esa, inform, believe(received(Volunteer, reply,
offeracceptance(Y))))
END,

Task(RegisterationConfirmation) <- received(Volunteer,
reply, offeridentification(SC)) |
BEGIN
  send(Volunteer, request,
requestPerform(RegisterationConfirmation);
  send(esa, inform, believe(received(TrainingSystem, reply,
offeridentification(SC))))
END,

<- received(Volunteer, request, requestOffer(Regulation)) |
BEGIN
  Offer(Regulation)?;
  send(esa, inform, believe(received(Volunteer, request,
requestOffer(Regulation))))
END,

Offer(Regulation) <- regulation(R) |
  send(Volunteer, reply, offerregulation(R))</td>
<td>For agent: Volunteer
Beliefbase:
Identification(2345112).
selectedcrs([c1, c2, c3]);
confirmationway(email).
Goalbase:
Request(Regulation)

Rulebase:
Request(Regulation) <- received(TrainingSystem, request,
requestPerform(IdentificationSought)|
BEGIN
  send(TrainingSystem, request, requestOffer(Regulation));
  send(esa, inform, believe(φ))
END,

<- received(TrainingSystem, request,
requestPerform(IdentificationSought)|
BEGIN
  Perform(IdentificationSought)?;
  send(esa, infrom, believe(received(TrainingSystem, request,
requestPerform(IdentificationSought)))
END,

<- received(TrainingSystem, request, requestOffer(Acceptance)) |
BEGIN
  Offer(Acceptance)?;
  send(esa, inform, believe(received(TrainingSystem, request,
requestOffer(Acceptance))))
END,

Offer(Acceptance) |
  send(Volunteer, reply, offeracceptance(Y))

<- received(TrainingSystem, request,
requestPerform(CourseSelected)|
BEGIN
  Perform(CourseSelected)?;
  send(esa, infrom, believe(received(TrainingSystem, request,
requestPerform(CourseSelected)))
END,

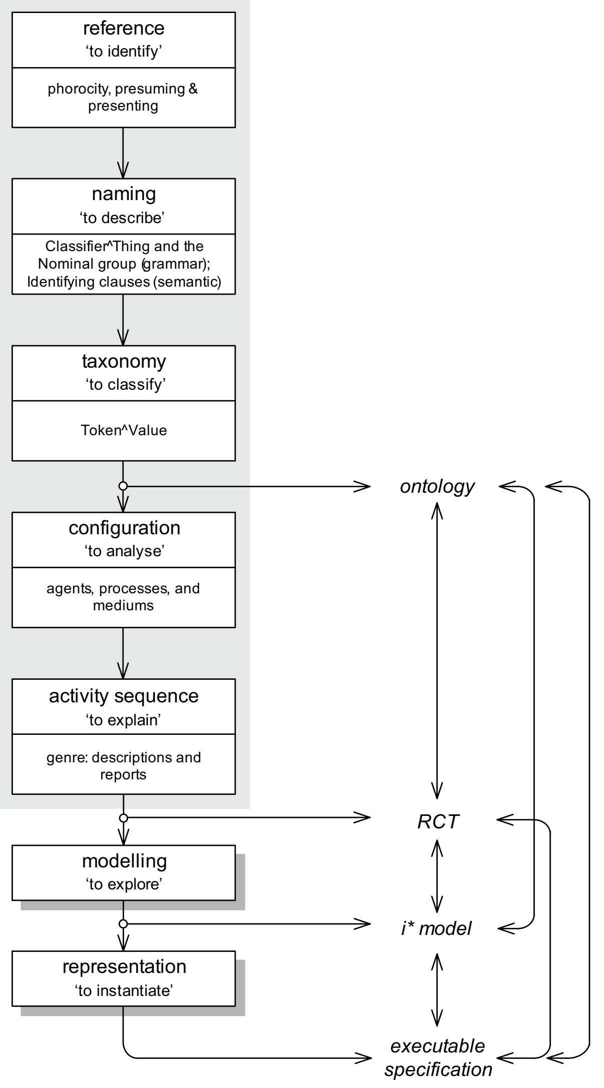
<- received(TrainingSystem, request,
requestPerform(RegisterationConfirmation)|
BEGIN
  Perform(RegisterationConfirmation)?;
  send(esa, infrom, believe(received(TrainingSystem, request,
requestPerform(RegisterationConfirmation)))
END,

Perform(IdentificationSought) <- Identification(ID) |
  send(TrainingSystem, reply, offeridentification(ID)),

Perform(CourseSelected) <- selectedcrs(SC) |
  send(TrainingSystem, reply, offeridentification(SC)),

Perform(RegisterationConfirmation) | confirmationway(CW)
  send(TrainingSystem, reply, registerationconfirmation(CW))),</td>
</tr>
</table>

Figure 6. Integrating systemic semiotic language resources (Clarke, 2005b) into an agent-oriented conceptual modeling methodology



Note: Additional generalized phases are defined (shadowed) to account for the production of deliverables (italics) developed as a consequence of applying the methodology.

enrollment elements inserted after the identification ssought element. When developing our *i** sequence, we use essentially the same elements and sequence: identification sought, regulations stage, and create an acceptance (of the regulation) stage as central (see Figure 5b). In the *i** sequence, we substitute the SR element for an orientation element, in which instructions are provided to the user. We dispense with the loan-specific MO and SR elements and also omit the phatic elements G and F, which are of no direct use in a computer-based system. Instead, in order to complete our sequence, we append domain-specific Course Selection and Registration elements. The final registration activity is shown in Table 5.

Conclusion: Integrating Processes and Artefacts

The importance of computational semiotics to the computing disciplines is in its potential to develop effective computer systems using methods that recognize the importance of semiotic processes. We can create a systemic semiotic agent-oriented conceptual modeling methodology by combining the process and artefact approaches outlined in this chapter (see Figure 6).

The language resources described in the section titled Systemic Semiotic Foundation for Elicitation are provided as stages (in grey). We also create additional stages for modeling in order to explore i* models and representation in order to instantiate an executable specification of the kind described in the previous section. Note, in particular, how transitions between these stages can be tied to deliverables on the right-hand side of Figure 6. Ontologies that are required for the construction of domain-specific RCTs were described previously. The RCTs themselves are linked to the activity sequence stage (this resource is also known as genre), and we saw how a macrogenre formed out of compositionally assembled canonical genres accounted for the structure and function of the RCT. In doing so, we provided a semiotic account of ontology-driven, template-based i* requirements elicitation processes. The concept of genre finds application at multiple points in this chapter and at various levels of abstraction. It was found to be particularly useful in providing key process steps that must be represented in an i* model. Since these models are sequence-agnostic genres, they provide the sequencing information that is critical in transforming an i* model into an agent-based executable model. There are many directions that need further research; for example, configuration—the building of messages is necessarily involved in building constraints. Also, the relationship between taxonomy and ontology is also worth exploring more fully.

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Section IV

Semiotic Systems Implementations

Chapter X

Computational AutoGnomics: An Introduction

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Abstract

This chapter presents an introductory survey regarding the AutoGnome, a semiotic machine based on ideas from the philosopher and semiotician C. S. Peirce. The theory behind the AutoGnome implicitly comprises a new method of integrated inquiry/inference/intuition which can be considered as a new theory of intelligence/mind suitable for a technological implementation within computers. These ideas also contribute to a better understanding of the nature of the mind and the requirements for the construction of a synthetic intelligence/mind. Besides Peirce, the theoretical background supporting the AutoGnome is a meta-theory of theory formation which we call "the form," founded on relational systems theory and order theory. We start this chapter with a general discussion on current problems in artificial intelligence, followed by a theoretical introduction to the concept of "the form," providing a formalization of "order" and its derivative calculus. At the end of the chapter, we report on a commercial application of the AutoGnome: the IntelliSite (an intelligent Web site) and its derivative implementations.

Introduction

Introductory Note

This chapter outlines the specification of some of the key notions of this theory of theory formation (*the form*) in a form which itself reflects the process. Thus, the "Introduction" section presents a review of the subject and its context and is followed by sections on "Foundations," "Theory," "Technology," "Applications," and "Research Organization," the latter laying the groundwork for another adaptive iteration in the construction (evolution) of **the form**. Although this easily can be recognized as a general methodology, the fact that it is talking about itself, the theory of theory formation, and that it encompasses many different perspectives, voices, and styles argues that as an integrated conceptual structure, it does yield a completely new approach to intelligent systems development.

Digital Learning Systems

The 20th century saw the application of Boolean algebra (the algebra of logical statements) to the construction of computing machines that work by applying logical transformations to information contained in their memory. The development of information theory and the generalization of Boolean algebra to Bayesian inference have enabled these computing machines in the last quarter of the 20th century to be endowed with the ability to learn by making inferences from data, specifically as systems that are able to automatically recognize patterns. The networking of computers, in turn, led to Web sites of virtually unlimited data/information.

The Impasse in Developing Artificial Intelligence

For the last half of the last century, however, the course of development of artificial intelligence (AI) has waxed and waned cyclically following the predominating influence of the sentiment of the time as to whether humans should endeavor, if they can, to build a *synthetic intelligence/synthetic mind*. Many approaches to AI, such as automated neural nets, genetic algorithms, fuzzy logic, and fractal mathematical computational approaches, to identify only a few, have emerged. Yet AI has been an elusive goal to achieve by means of a systems architecture relying on an implementation based on the computer paradigm (input-storage/throughput-output system).

Nevertheless, pattern recognition techniques based largely on probabilistic methods have gained popularity in recent years among search engine specialists. Although probability largely was scoffed at a couple of decades ago, it is now considered to provide the most promising approach to AI. See, for example, the following.

AI's Next Brain Wave

"New research in artificial intelligence could lay the groundwork for computer systems that learn from their users and the world around them" (Ricadela, 2005). Part four in *The Future of Software* series states:

Artificial intelligence, a field that has tantalized social scientists and high-tech researchers since the dawn of the computer industry, had lost its sex appeal by the start of the last decade. After a speculative boom in the '80s, attempts to encode humanlike intelligence into systems that could categorize concepts and relate them to each other didn't really pan out, and "expert systems" packed with rules derived from human authorities couldn't translate their expertise into areas beyond the subject matter for which they were programmed. Even when Deep Blue, an IBM chess-playing computer that could evaluate some 200 million board positions per second, defeated grand master Gary Kasparov in 1997, the triumph didn't lead to an artificial-intelligence renaissance.

Now a new generation of researchers hopes to rekindle interest in AI. Faster and cheaper computer processing power, memory, and storage, and the rise of statistical techniques for analyzing speech, handwriting, and the structure of written texts, are helping spur new developments, as is the willingness of today's practitioners to trade perfection for practical solutions to everyday problems. Researchers are building AI-inspired user interfaces, systems that can perform calculations or suggest passages of text in anticipation of what users will need, and software that tries to mirror people's memories to help them find information amid digital clutter. Much of the research employs Bayesian statistics, a branch of mathematics that tries to factor in common beliefs and discount surprising results in the face of contrary historical knowledge. Some of the new AI research also falls into an emerging niche of computer science: the intersection of artificial intelligence and human-computer interaction. (Ricadela, 2005)

Reinventing Synthetic Intelligence

Recognizing both the positive technological impacts of these many conventional specifically engineered computer-based advances but also the potential threat of a concomitant emergence of a theory-glut (a wealth of foundationally unrelated theories/models with varied levels of applications successes/failures but without a commonly-explicatable conceptual foundation), the founders of AS IT IS INc. (Ai3) and its subsidiary, AutoGnomics Corporation (AC), have pursued a parallel approach beginning from what is common to all of these specific AI approaches (i.e., they ultimately all have a formal foundation, "language," resting on signs). Indeed, one's experiences, ranging from common sense to the highly abstract, when expressed (i.e., communicated) ultimately rest in—and on—signs (semiotic systems). See "The Language You Use Determines What You Can Think" by Jere Northrop (http://www.ododu.com) regarding ODODU, a derivational language that continually is evolving toward the goal of a universal language. It is derived from relational systems theory (www.relationalsystems.net), has led to the formulation of the Bion Technologies (www.biontech.com), and has been significantly influenced by the quaternion formulation of general relativity theory.

The ultimate goal of Ai3/AC is to develop semiotic systems with intellectual and emotive characteristics/capabilities inclusive of but not necessarily limited to those of humans (i.e., a synthetic intelligence/mind), the AutoGnome (a semiotic machine*)*, but not necessarily depending on particular facts or assumptions regarding brain anatomy, neural-biophysics or biochemistry, neurophysiology, psychology, linguistics, psycholinguistics, information/communication theory, cybernetics, and so forth, or any formal theories or models thereof.

Automated Scientific Intelligence

A first generative instantiation of this synthetic intelligence is expected to be a scientific intelligence deriving from **the form** as a general (meta order(ing)) theory of theory formation. The automation of inquiry and inference will allow machines to learn from data and ask relevant questions to obtain new data. This promises to automate the scientific method within a framework defined by a set of possible experiments and a set of hypothesized theoretical models. Imagine a robot designed to calculate the most relevant experimental question to ask, given what it knows experientially in a particular circumstance. What is learned in each experiment will help it to decide which successive experiment to perform in order to resolve the scientific issue. While independently behaving, learning machines will find great use in science; they most likely will pervade our lives in ways we have not yet imagined. The methodology to construct such thinking machines is becoming clear; however, they will be constrained to work within a framework defined by a set of hypotheses. Techniques are needed to automatically generate new hypotheses for machines to entertain. Such flashes of inspiration (intuition) serving to change the way in which the world is perceived often occur through generalizations and analogies, which are not necessarily in obvious relation to any logical procedure of inference or inquiry (Knuth, 2003b).

Restating the Limited Goal of This Chapter

The choice at this particular time to engage (i.e., with the release of this publication) in the beginnings of the public dissemination of writings on AutoGnomics is due largely to the confidence that a critical stage has been reached in an approach to semiotics in intelligent systems development, which assures the continued aggressive future developments of foundations, theories and applications, all simultaneously in mutual recursive adaptation.

It is intended to show that one can begin with what appears as the apparent simplest of common sense mathematical ideas as a foundation and then aggregate related, noncontroversial experiences until there is enough of a basis to construct a revised AutoGnome. Hence, a goal of developmental AutoGnomics is continuously to learn simpler ways of thinking about thinking (about logic) and, thus, to develop ever-simpler computational algorithms and architectures with which to design AutoGnomes by adaptively building and commercially deploying AutoGnomes.

The Foundations

Prologue

The problem of understanding mind is considered by many to rank in importance with two of the other great cosmic mysteries—the origin and nature of the Universe and the origin and nature of Life. However, understanding any part or the whole (Hamann, 1977, 2004a) of human experience ultimately depends on understanding the nature of understanding itself (Lonergan, 1997), which generally is acknowledged to be the province of mind. Hence, understanding the origin and nature of a synthetic mind arguably might be ranked first among these three as the ground of inquiry.

With last century's advent of the digital revolution in information/communication technology, the methods of inquiry themselves must be opened to form a new method of (at least quasi-) whole inquiry/inference/intuition. In particular, the methodology of science (i.e., form hypotheses, devise ways to test them, analyze the data collected, and then decide whether the results support or undermine the hypotheses) must be applied concomitantly to the foundation notions (philosophically, formally, and theoretically) themselves, which subtend the initiating hypotheses. To ground new understanding in any area of research, the foundations need to be continuously iteratively reformed in order to condense as much information as is needed into the fewest necessary notions still consistent with experience.

It is the intent herein to point to a possible construction of *the form*, presuming only the foundation notions of things (systems), connections (relations), things or connections within other things or connections (subsumption), and things or connections taking the place of other things or connections (images) (Hamann/R.Elated, Relationism, www.relationalsystems.net).

It is posited that, on the foregoing basis, an approach to the formalization of an order and its derivative calculus, the latter taken as a formulation of the disorder experientially related to the given order, also implies a reorder(ing) format (methodology) which, within a system of order/disorder/reorder relations, suggests *the form* as a general (meta order(ing)) theory of theory formation that, in turn, will be invoked in formulating a theory of intelligence/mind and its technological implementations as synthetic intelligence/mind.

Two of the few profound (but generally lesser recognized than such as Kurt Gödel) contributors to the foundations of mathematical/logical developments during the 20th century (i.e., Richard Threlkeld Cox, 1946, 1961, 1979, and George Spencer-Brown, 1969) will be apparent to these arguments herein.

The Form

The relational systems (Hamann, 1977) foundations of human knowledge (*the form*) evidence as a general (meta order(ing)) theory of theory formation with components (objects [specific systems], operations [specific intersystemic relations], preferred order(ing) relations [specific systemizing relations]) and precursors to formalization summarized as per the following paragraphs in this section.

Order Formalisms

Order theory dictates the way in which an algebra can be extended to a calculus by assigning numerical values to pairs of elements of a poset (a set of elements together with a binary ordering relation is called a partially ordered set, or a poset) to describe the degree to which one element includes another. The result is a methodology (order theory) that can be used to generalize an algebra to a calculus by relying on consistency with the underlying order to derive the laws of the calculus. In terms of order formalisms, the Laws of Form (Spencer-Brown, 1969), effectively built on the assumed notions of distinction (Subsumption) and indication (Image), advanced the foundational formulation of a mathematics of distinguishability (boundary mathematics), which was shown to imply a Boolean algebra (having an interpretation as Boolean logic, or deductive reasoning in which implication is among logical assertions in situations of complete certainty=order) as one of its many consequences, and which now has been expanded (see the following) to general multiboundary formalisms (lattices, algebras, etc. [recognizing that every algebra has its arithmetic] and their associated calculus) wherein a set of logical statements ordered by implication gives rise to a Boolean lattice, which is equivalently a Boolean algebra, and the Boolean lattice of logical statements induces the free distributive lattice of questions (the question lattice or algebra).

Disorder Formalisms

NOTE: *R.Elated's RELATIONISM treats the notion of probability as being composed of a subsystemic probability (to be referred to herein as probability in the lower case), which corresponds to the classical Bayesian understanding as foundationally grounded by Cox (see the following) and a systemic probability (to be referred to herein as PROBABILITY in the upper case) which, in one instance, corresponds to the generalized entropy of Cox as a measure of relevance in the query algebra (also see the following). When referring generally to the notion of probability, Probability ordinarily will be used; however, the reader may have to rely on the context, since the author's diligence in this matter is expected to be frequently deficient.*

The algebra of probable inference/inquiry (Cox, 1961) finally is being recognized as the succinct and profound foundational form of formalized Probability in representing disorder. The effect of Cox's (1961) contribution to probability theory was to generalize Boolean implication among logical statements to degrees of implication represented by real numbers (NOTE: by varying the algebra and extending the number system [e.g., to complex or quaternion numbers], other formulations of Probability such as quantum probability arise), which are manipulated using rules derived from consistency with the Boolean algebra. These rules are known as the sum rule, the product rule and Bayes' theorem, and the measure resulting from this generalization is probability. Generalizing a particular function of the question lattice leads to a valuation called *relevance*, which is a measure of the degree to which a statement answers a given question. Cox conjectured that this degree can be expressed as a generalized entropy, which subsequently has been shown to indeed be the case (Knuth, 2003c, 2004).

Reordering Formalisms

The method of maximum entropy inference (Cox, 1979; Jaynes, 1957, 1968, 1979, 1985, 2003) generalized to optimum systemic(subsystemic) probabilistic inference (OS(sS)PI) (Bianchi & Hamann, 1969a, 1969b; Hamann, 1968; Hamann, Lamb, & Isaacs, 1972) within relational systems as the progenitor of the formal basis for reordering the disorder completes *the form*.

It is now well-understood that probability theory is literally an extension of (deductive) logic. Integrating the logic of inference (probability) with the logic of inquiry (relevance=entropy) yields a powerful formulation of inductive reasoning (logic) when completed through the use of the principle of maximum entropy for assigning prior probabilities, since this maximizes the relevance of the parameterization of the subject system.

- **Conjecture:** It also is speculated here, based on real but partial evidence, that the third mode of reasoning (i.e., abduction) may be formalizable by invoking a MiniMax Entropy Principle. Formal inclusion of abduction (in representing intuition) is necessary to complete a system of Automated (Autonomous) Inquiry/Inference/Intuition (AI^3).

Multiboundary Formalisms

The cornerstone of *the form* (i.e., the basic methodology of order theory**)** subsumes an elegant but simple**,** fresh approach to the foundations of mathematics generally titled multiboundary mathematics. It is clear that the basic methodology of extending an algebra to a calculus, which presently is utilized explicitly in probability theory and geometric probability, is generally extensible in that it already has been shown that valuations on posets give rise to an area of mathematics which ties together number theory, combinatorics, and geometry, and with the aid of geometric algebra, an examination of projective geometry in this order-theoretic context provides new insights into the observation that the cross-ratio of projective geometry acts like Bayes' theorem (Knuth, 2003a). A further example from Goertzel (n.d.) is a relatively simple multiboundary algebra that models the emergence of form from no-thingness and gives a compact and elegant foundation from which to derive the quaternion, octonion, and Clifford algebras.

Multiboundary Formalisms in the Foundations of the Physical Sciences

A reformation in the physical sciences based on multiboundary mathematics (Goertzel, n.d.) provides a simple model of spatiotemporal logic in terms of networks of interconnected events (see also the following section on "The Universe as a Graph-Theoretic Network"), which has been shown to give rise to a discrete Clifford algebra structure. Previous work of Frank D. "Tony" Smith, Jr. (n.d.) has demonstrated that the discrete Clifford algebra structure can be used to derive a version of the standard model plus gravity (a theory of everything). Putting these two pieces together, one has a foundationally consistent and, at least, not apparently empirically inaccurate model of the universe as a discrete event network with the possibility of deriving the given rules of spatiotemporal event network dynamics from a yet simpler foundation of pattern maximization (MaxEnt).

Multiboundary Formalisms in the Foundations of the Computational Sciences

"Boolean logic has been embedded in language since antiquity. When computers were invented, it was natural to adopt the linear, sequential characteristics of Boolean logic found in language. However, computers work in parallel, more like a group of people than a string of words. Boundary logic was discovered over 100 years ago, by the founding fathers of formal mathematics. The world elected to follow binary symbolic logic until now, essentially ignoring the efficiencies of boundary logic. This choice has been so extreme that boundary logic is completely unknown to the wider community of scholars. Boundary transformations work by deleting structures. Boolean transformations work by accumulating and rearranging structures. Deletion has excellent computational properties: the problem gets smaller for each rule application, thus processing gets faster while problem size decreases. Boundary logic translates Boolean logic into a form that is consistent with computation (parallel) rather than talking (serial). The result is a logic reduction tool set that suggests new computer architectures that may be far more efficient and has the potential to improve all computational techniques" (Bricken, 2004).

On the Origin of Image (=Sign) as a Necessary and (Possibly) Sufficient Condition for the Evolutionary Origin of Life (Hamann & Bianchi, 1970)

In the process of matter/energy evolution, there must emerge in specific form a system whose relation to other systems is that of a carrier of an image of the interaction between the carrier and the other systems for matter/energy to manifest itself as living. Via the interaction of a system with the carrier, the image can be read out to alter the relational structure of the system. A feature of the image of essential import is its persistence relative to that of the actions which gave rise to it and to that of the interactions the carrier will undergo with other systems. Moreover, it has to be noted that the carrier may hold more than one image, thus leading to various possible relational impressions on an interacting system.

The Theory

Note on Formalization

It is taken as a given that the development of a formal theory requires attention to a specific generally accepted system (S) of relations (R) (including primitives, axioms, rules of inference, etc.). The work in this chapter, however, is directed only at identifying certain of the necessary RSs, but does not attempt to complete their organization or attend to their sufficiency as a formal theory, although this is our ultimate strategic intent (Hamann, 2004b).

Experience (The Universe) as a Graph-Theoretic Network

Assume in a simple but common instance that ordered experience is formally signifiable as a Boolean network (lattice, algebra, graph, or diagram) composed of points (nodes, objects, states as *systems*) and lines (edges, connections, transitions as *relations*). Assume further that experience is not totally ordered and that the disorder is formally signifiable by extending the Boolean Network to the form of a Bayesian network via a Coxian theory of probable inquiry/inference. And finally, assume that the reordering of disorder is formally signifiable via the Cox/Jaynes form of the generalized PROBABILISTIC optimization principal, maximum entropy.

This view of experience is warranted not only by the fact that it is natural to signify the virtual reality of the World Wide Web as network, but by the historical predominance of connectionist theories of mind and neural-network analyses of mental processes and states to be grounded naturally in a network approach. Also, "it is often observed that the sign-systems of traditional formal logical representations are inadequate, or even misleading, in portraying conceptual and especially 'perceptual' experience and that the importance of diagrams in teaching, learning, and thinking about logical structure is an emerging necessity" (Dipert, 1997).

Information/Communication Theory, Cybernetics and Decision Theory

Two related areas of development, automated neural nets and cybernetic systems based on inductive logic, are natural generalizations of the inquiry calculus (logic of inquiry) (Fry, 1999, 2000). The present focus in information technology is on developing technologies for harvesting recognizable patterns of relevant (valued) information from the Web.

Automated Neural Nets (Fry, 1996)

It is posited that information theory, as it stands, is an incomplete theory and that a dual theory exists that characterizes the transduction of information within physical devices as opposed to the transmission of information between physical devices, which is the main emphasis of traditional information theory. Traditional information theory, together with its dual theory, may provide a succinct logical explanation of the physical theories of quantum, statistical, and even classical mechanics. Some basic properties of such a dual theory of information as they relate to the analysis of neural computation show a surprising result (i.e., that many known computational properties of cortical neurons can be deduced from the developed theory independent of biological assumptions, including action potentials, Hebbian learning, nonlinear synaptic conductances, and others). This becomes relevant insomuch as mind is generally considered to reside in some form of the neuro-system.

Cybernetic Systems Based on Inductive Logic (Fry, 2000)

A cybernetic system is a system that dynamically matches acquired information to selected actions relative to a computational issue that defines the essential purpose of the system or machine. The design and operation of cybernetic systems can be understood by contrasting these kinds of systems with communication systems and information theory as developed by Shannon. The joint logic of questions and assertions of Cox, fundamental to the foundations of the AutoGnome, can be seen to underlie and be common to both information theory as applied to the design of discrete communication systems and to a theory of discrete general systems. The joint logic captures a natural complementarity between systems that transmit and receive information and those that acquire and act on it.

Boundary Logic (Bricken, 2004)

The American logician and philosopher Charles S. Peirce first conceived of and published results in boundary logic (BL) in 1898. Peirce called his work *Existential Graphs* and considered it to be among his greatest accomplishments. The next major contribution to BL was George Spencer-Brown's 1969 book *Laws of Form*, a mathematics text that caused considerable excitement at the time by introducing void-based logic within an algebraic framework. Recognizing that boundary logic lacked a convincing application, William Bricken developed computational implementations of BL from 1978 through 2002 that suggest new computer architectures that may be far more efficient and have the potential to improve all computational techniques.

AutoGnomics

Ai3's AutoGnome introduced by Eugene Pendergraft (with the collaboration of Norman Hirst) partially interprets these philosophical principles of Charles Sanders Peirce (Semiotics). The algorithms necessary to drive the technology have evolved over the last 40+ years, and today, PCs, the Internet, and easily accessible digitized information make the implementation of this breakthrough in applied artificial intelligence finally a practicality.

The AutoGnome (AG) is a general purpose system of automated inquiry/inference software exploiting a system of mechanized semiosis incorporating sign-origination, sign-storage (including retrieval), sign-manipulation, and sign-interpretation. As a complete semiotic inquiry/inference (eMotive) engine, such a system must account for the form of experience as follows:

- **Ordered (i.e., determined or certain) experience:** A formal algebra/logic of semiosis
- **Disordered (indeterminate or uncertain) experience:** A theory of probable inquiry/inference
- **Reordering disordered experience:** Via a generalized Probabilistic optimization principal

The AutoGnome architecture may be envisioned as multiple modules (perceptual, conceptual, and valuational), each module coding a specific model of the formalisms of semiosis composed of the three modes of semiosis (monadic, dyadic, and triadic) and three inferential processes (deduction, induction, and abduction). These recursive inference processes operate on three information stores (an experience store, a knowledge store, and a valuation store) and gain experience through connective agents (sensors, mediators, and effectors (actors)) and function (act) in both an inquiry cycle and a performance cycle.

The Probabilistic inference processes integrated formally with the logic of semiosis are the processes of formal representation of the disorder whereby an AutoGnome identifies and maintains its identity (order). The information stores at any particular time are stable states of such probablilistic processes generated by optimizing acts in response to environmental (other system) perturbations of the perceptual module. The form of these optimization procedures for reordering the disorder is that implementing the generalized Probabilistic optimization principal (e.g., MaxEnt).

In the specific, very restricted case in which the algebra underlying the logic of semiosis is Boolean and the associated theory of probable inference is Cox(ian) (the algebra of probable inference, including Bayesian), by conforming the generalized probabilistic optimization principal to the form of the Cox/Jaynes information optimization principal (maximum entropy), one has a self-contained probabilistic decision system (PDS) as a complete system of plausible inference.

AutoGnome 01 (AG1) has been implemented as an initial very partial working version of the AutoGnome Architecture representing only about 10% of the complete conceptual specification. This first version is basically a general purpose pattern generation/recognition/categorization/prediction engine.

NOTE: *It should be emphasized that the foregoing is essentially state-of-the-art among competing commercial technologies, albeit the claims may suggest significant advancements yet to be realized. For example, a world leader in the commercial exploitation of the intelligence-to-knowledge technology developments depends on models formed on the theories of Boole, Bayes, and Shannon implemented in automated neural nets. This is formally (although not in terms of applications software) redundant, explicitly or implicitly, in the PDS of the AutoGnome.*

The Technology

This section is derived from a private communication of a "Critical Summary of the AutoGnome Project" by Ricardo R. Gudwin (Editorial condensation by Jon Ray Hamann).

Background and Objectives

Based on the works of Charles S. Peirce and Charles Morris, Gene Pendergraft (deceased 1997) and Norm Hirst, founders of AutoGnomics Corporation, proposed the architecture of a special kind of system called the AutoGnome that would be able to perform mechanized (automated) inference using principles derived from semiotics. Using this architecture as a reference, AutoGnomics Corporation started a venture for the implementation of such an architecture in software code. This venture resulted in the building of a first release of an AutoGnome system called AutoGnome 01 (AG1), a partial implementation of the AutoGnome Specification.

The AutoGnome Specification

The AutoGnome is a multi-enclave system realized as distinct pieces of code enclosed within other codes. It is not a single unit or a single enclave but rather a multi-enclave or, more precisely, a recursive appearance of the same code or structure in many different contexts, working in multiple levels of actuation. A view of the AutoGnome specification is presented in Figure 1.

Figure 1. The AutoGnome specification

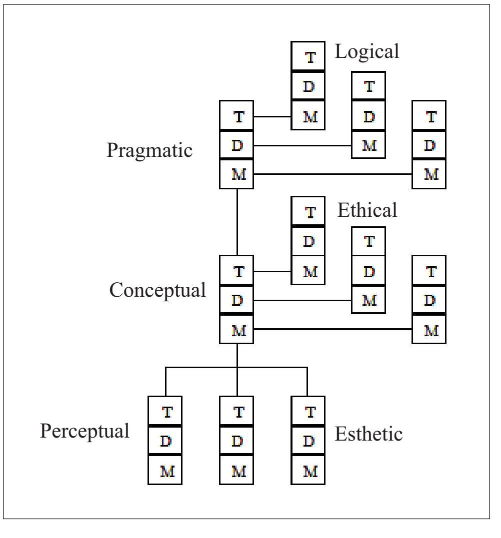
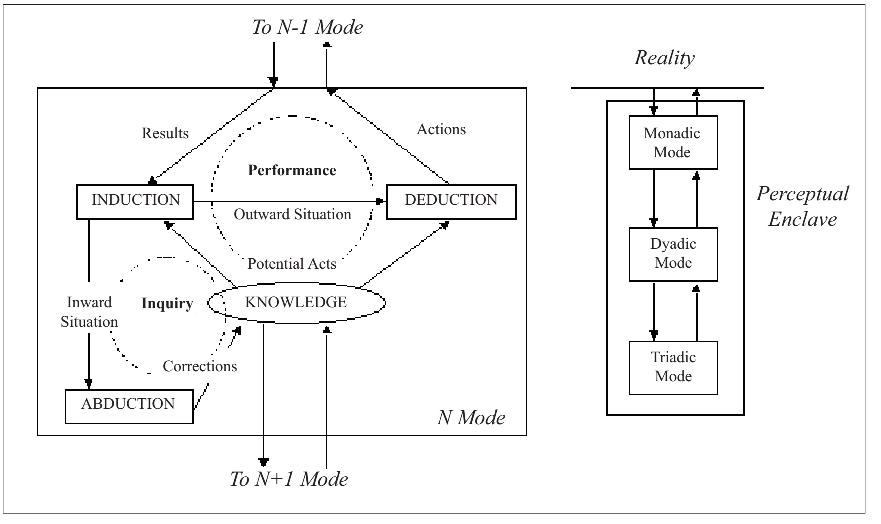


Figure 2. The semiotic process within an enclave



The main enclave (piece of code or piece of the system) is the box TDM, which appears in many different contexts, depending on the functional behavior to which the enclave is committed. The TDM relates to three levels or modes of information processing that are performed at each enclave (i.e., the monadic, dyadic and triadic modes). Each mode by itself is based on (again) a triadic recursive structure, as depicted in Figure 2.

There are two main cycles along each mode. The first cycle is the performance cycle, which acts on its lower mode by processing the current knowledge with the outward situation by induction from the inputs of its lower mode. This cycle is responsible for the use of the knowledge within the mode to generate a behavior relating to its lower modes (the lowest mode will be an environment (i.e., other system), which here is referred to simply as reality itself). The second cycle is the inquiry cycle, which is responsible for the growth and correction of the knowledge embedded in each mode. This cycle is used to generate and refine the knowledge used in the performance cycle.

The monadic mode is responsible for getting in touch with the real world (environment or reality) by means of sensors and actuators (effectors) and generating an ontological description of inputs by means of a vocabulary of higher-level signs that would be used by the next mode, the dyadic mode. The dyadic mode will use the outputs of the monadic mode as its inputs and will apply the same semiotic processing in order to generate outputs that will be inputs to the triadic mode, as depicted in Figure 2. These will be based on probabilistic combinations of signs outputted from the monadic mode, which are evaluated based on their appearance in the dyadic mode inputs. The triadic mode will be responsible for evaluating the combinations of signs outputted by both the monadic mode and the dyadic mode. These combinations (both monadic and dyadic) will be evaluated by means of Cox-Jaynes formulations of probable inference.

Regarding the semiotic processing within each mode, it is important to acknowledge that the AutoGnome uses abduction, deduction, and induction in order to process signs. Abduction, deduction, and induction are the three types of arguments prescribed by Peirce as the basic elementary operations for sign processing, being instances of firstness, secondness, and thirdness at the level of the interpretant. This is one of the most important features of the AutoGnome and, in part, explains the powerfulness of the architecture in getting raw data from an environment and creating its own knowledge description of it. One important observation here, though, is that in order for the system to be able to reproduce the same behavior in all its levels (by means of the recursive appliance of the TDM enclave on perceptual, conceptual and pragmatic levels), the architecture should be able to fully implement these modes of sign processing. The AutoGnome design contains a sound and complete integration of these operators in order to avoid problems when trying to use the TDM enclave at the higher-level functions like those for the conceptual or pragmatic enclaves. As this requirement currently is not met completely in AG1, redesign is performed easily to effect changes on the TDM enclave if the future implementations of AutoGnomes prove that it is required to improve the TDM enclave.

The AutoGnome and Computational Intelligence

Regarding a comparison between the AutoGnome and other kinds of intelligent systems, current technologies in computational intelligence are not able to show the same kind of behavior performed by the AutoGnome. Despite their current state of the art, fuzzy logic, and fuzzy systems techniques, neural networks and even evolutionary computation are able only to reproduce partial behaviors as performed by the AutoGnome. Eventually, a hybrid system that combines fuzzy logic, neural networks, and evolutionary computation techniques that, in principal, would be able to perform a behavior similar to the AutoGnome, will be built as a model of a derivative theorem set from AutoGnomic theory.

The AutoGnome and Complex Adaptive Systems (CAS)

The most noticeable similarity to the AutoGnome would be CAS (Holland, 1996), the complex adaptive system developed by Holland as an evolution of his classifier system (Booker, Goldberg, & Holland, 1989; Holland, 1986, 1995). One noticeable difference, though, between the AutoGnome and CAS is that CAS does not develop a recursive application of itself in order to generate a perceptual, conceptual, and pragmatic mode as the AutoGnome does.

The AutoGnome and Consciousness

Many serious researchers, such as Penrose (Hameroff, 1998; Hameroff & Penrose, 1996), Damasio (2000), Edelman (Edelman & Tononi, 2000), and Dennett (1991), are studying the phenomenon of consciousness and some of them are claiming that, at a certain point, it will be possible to create conscious machines. Since consciousness is the emergence of semiotic processing (thirdness) in matter/energy (see the prior section herein "On the Origin of Image (=Sign)"), this is what the AutoGnome portends to do.

The AutoGnome and Its Semiotics Competitors

In the present state of technology, the AutoGnome currently has no competitors from the perspective of prospective Computational Intelligence in off-the-shelf sets of tools and solutions. This must be contrasted, however, to other approaches based at least in some part on semiotics. Three of the main competitors are Albus (Albus, 1991; Albus, Lacaze, & Meystel, 1995)/Meystel's (1995, 1996) GFACS algorithm, Pospelov's (1977, 1991, 1995) semiotic control procedures, and Gudwin's (Gudwin, 1999; Gudwin & Gomide, 1997a, 1997b) computational semiotics or semionic technology. Neither Albus/Meystel's nor Pospelov's approaches are based on Peircean semiotics. Gudwin's approach is inspired by Peircean ideas, but not in the precise way as the AutoGnome.

The AutoGnome and Other Business Companies

There are other companies in the market that advertise semiotic systems, notably Semio Corporation (www.semio.com) and Semiotic Systems (www.semiotic.com.br).

Semio Corporation has a patent on a data-mining technology for large text databases, mainly Web contents. This technology is able to automatically extract key concepts from large volumes of text-based content and structure the information into logical categories, drawing connections between concepts and providing access to the structured information (Semio, 2001). Without access to this proprietary technology, a rough comparative analysis suggests that this technology probably would be comparable to the AG1 implementation.

Semiotic Systems is a company in Brazil that uses semiotic ideas for the development of information systems. Its use of semiotics, however, is only minor and partial and doesn't really represent a concurrence with the AutoGnome.

As an overall analysis of semiotic-based business competitors, it would appear that the AutoGnome specification is still orders of magnitude ahead of the other approaches. The same obviously is not true for the AG1 implementation. Semio's products would have a behavior comparable to the AG1, since AG1 does not yet implement the whole AutoGnome architecture.

The AutoGnome 01 Implementation

The AutoGnome 01 (AG1) has been implemented by AC as a proof of concept for the AutoGnome architecture. It is, though, only a very partial implementation of the whole architecture. Basically, it is an implementation of only the dyadic and triadic modes of the perceptual enclave. It also doesn't have the performance cycle of Figure 2 but only the inquiry cycle. In this sense, the AG1 is not able to perform true deduction, having only a partial deduction algorithm, the pseudo deduction model (PDM). The implementation of the

AG1 is based on a set of procedures written in C language that are packed into a working application by using a configuration file that works like a script file. With these script files, many configurations for the AutoGnome can be built-up and tested easily .

A Proposal for Future Developments

As an overall analysis of the AutoGnome, it is a sound model for an architecture implementing a semiotic system. Its main baseline is Peircean, which is particularly desirable, considering that the Peircean model for semiosis is the most elaborated among the available ones and the most sophisticated. This technology is very new and original, but there are other potential technologies (as presented previously) that in a certain sense would be competitors to the AutoGnome, and research is evolving in that direction. The current advantage of the AutoGnome needs to be maintained as research in semiotic systems evolves around the world.

Continued research and development regarding the AutoGnome technology also might be pursued by effecting a reimplementation of the AG1 by means of a semionic network. Using the semionic network model of the AG1, there will be a gain in flexibility in order to add and change new behaviors in the main model of the AutoGnome, turning it into a new technology for automated inference, a hybrid drawing on both the AutoGnome and the semionic networks. A complete analysis of this specification would turn to a new and enhanced perspective regarding the implementation of a semiotic system, joining distinct but complementary views of the same Peircean background inspiration.

The Applications (Examplary Abstracts)

The Solution Environment

It has become the norm in the experience, for example, of small business enterprises that they need to hire special information technologists using additional technology/tools to teach/train their employees in the requisite skills to enable them to use the Web search tools. Hence, the golden age of information technology has created the problem of an infoglut, which, as a result of efforts to resolve that problem, has led to the further problem of a toolglut with its inherent added problem of limiting solutions due to a limited set of skilled tool users. Ai3 has introduced its IntelliSite (Intelligent WebSite) technology, which ultimately can act effectively as an autonomous agent assisting or replacing the human computer operator in interacting with the CyberUniverse.

The AutoGnome: Computerizing General Intelligence

The benefits of the AutoGnome in contrast with other special purpose AI approaches derives from the general purpose nature of its core automated (autonomous) inquiry/inference-technology whereby the same core engine can be deployed in a broad spectrum of contexts (education, health, business, economic and community development, homeland security, etc.) with only the provision of the connectors of the engine to that context, but no redevelopment of the engine itself. The semiotic logic underlying the AutoGnome is a generalized form applicable to both traditional linguistic-based sign systems and also to nonlinguistic type systems including graph-theoretic (network) systems as well as other graphic, symbolic, and iconic logics. Computational AutoGnomics has wide applicability, for example, in cases employing MaxEnt technology (as per the AutoGnome's general purpose AI^3 engine) to develop a positive solution to an otherwise hard-to-solve problem in automating data refinement, data mining, data correlations and/or data fusion in multisensor cybernetic networks.

The IntelliSite: Computerizing a Virtual Replica of Individual Intelligence

An IntelliSite (generically branded as TrueThinker.com) is a constructed software environment (a Web site) with an embedded form of the AutoGnomic technology. Here, the AutoGnome is an intelligent agent (a WebGnome) residing in this virtual environment, which, with its continuous adaptive learning from mimicking the user's behavior, will grow into a likeminded replica (MindClone) of a user-self acting in the virtual world of the Internet with capabilities initially including knowledge organization (manual, supervised, and automated categorization), knowledge creation (ideation, autonomous search, and automated community building), and knowledge applications (human capital management, intellectual capital management, and autonomous entrepreneur). As such, the IntelliSite is an effective knowledge development management system (KDMS) and is the adjunct of choice for learning/teaching-training, content and knowledge management systems.

The IntelliSite: An Autonomous Scientific Intelligence

The IntelliSite obviously has a broad spectrum of applicability apart from its key marketable functionality as an individual's mirrored intelligence, in particular as an autonomous scientific intelligence (A-ScI) when focused on its data/information/knowledge-harvesting capabilities of maximum entropy (MaxEnt) as the generalizable decision principal of the PDS (probabilistic decision system) module of the AutoGnome.

Ai3 is adapting its A-ScI capability for the general area of data harvesting (mining) specifically to new areas of science such as bioinformatics (including genomics, proteomics, etc.). As instances of such applications, Ai3 is engaged in joint exploration agreements with the Hauptman-Woodward Medical Research Institute to solve a problem that it has in predicting probable macromolecular (protein) crystallization routes in drug discovery and design and with computer sciences and engineering at the State University of New York at Buffalo in order to provide a comprehensive, general-purpose, integrated, and robust solution to the specific problem of haplotype mapping (or the cataloging of single nucleotide polymorphisms).

The CoGnome: Computerizing Collective Intelligence

Assigning a metaquery/response (MQ/R) status to a selected WebGnome that interconnects two or more IntelliSites in a Network provides a computerized collective intelligence (automated co-intelligence [i.e., the collective-AutoGnome (Auto(Co)Gnome) or simply the CoGnome]).

The CogWeb: A Cognitive Network of IntelliSites

The CogWeb is, by definition, the implementation of a computerized collective intelligence (automated co-intelligence) through the adaptation of the AutoGnome technology (as the CoGnome) for network decision-making by IntelliSite-defined groups, organizations, communities, and societies. While the IntelliSite itself was focused on the development of a semiotic engine as an Individual Intelligence, the full potential of individual intellect, be it human or machine, is realized in groups; hence, the automated community builder functionality of the IntelliSite. This collective creativity, while related to the intelligence of the individual, is actually a feature not only of the decision network's inquiry/inference processes (the CoGnome) but more generally of the network architecture.

A proprietary breakthrough application of the CogWeb, as an example, is the following approach to rational group opinion assessment. Assume the group targeted for a survey is a population of users (WebGnomes) via an IntelliSite subscription. Instead of statistically extrapolating useful data from a well-drawn small sample group (with all of the attendant margins of error), the response is taken by the CoGnome from a user's WebGnome standing in as the user's proxy. Hence, it will be common to effect virtually a 100% response in every assessment.

In general, a CogWeb is the first True approximation to a rational collective (democratic) decision process accomplished without constraining the network to being a top-down organized system, since each and every IntelliSite WebGnome responding to a query also can pass the query on to its closest neighbors, and so on, until the entirety of the network has been mapped by the query, which could have been initiated by any individual WebGnome or the CoGnome itself. Since it is increasingly evident that smart aggregates of humans are frequently more effective decision makers than individuals, this MQ/R architecture collectively technologically enables co-intelligence via smart mobs (Rheingold, 2003).

Ongoing Research and Technology Development

The Mission

Ai3 is in the process of assembling a mind trust of key experts on which, as a derivative benefit, the organization of a research and technology development center of expertise in automated (autonomous) inquiry/inference/intuition (AI^3) Technology is being formed.

The initial focus will be on the Ai3 AutoGnomics technology. The founding mission is to establish this Technology through the Center as the de facto standard (benchmark) in intelligent systems development through mechanized semiosis. The means to effecting this mission will include, along with continued core development of the Ai3/AC technology, continuing specific applications initiatives based on the current status in the development of said technology.

The Background

USA National Science Foundation (NSF)/Department of Commerce (DOC)

Converging technologies for improving human performance: nanotechnology, biotechnology, information technology, and cognitive science (NBIC) report edited by Mihail C. Roco and William Sims Bainbridge, June 2002. An exemplary core NBIC program focus is the following Human Cognome Project, which we view as third-party justification/confirmation of the significance of Ai3's approach to automated co-intelligence (i.e., the CoGnome).

The Human Cognome Project (Bainbridge et al., 2002)

It is time to launch a Human Cognome Project comparable to the successful Human Genome Project in order to chart the structure and functions of the human mind. No project would be more fundamental to progress throughout science and engineering or would require a more complete unification of NBIC sciences. Success in the Human Cognome Project would allow human beings to understand themselves far better than before and, therefore, would enhance performance in all areas of human life.

While the research would include a complete mapping of the connections in the human brain, it would be far more extensive than neuroscience. The archaeological record indicates that anatomically modern humans existed tens of thousands of years before the earliest examples of art, a fact that suggests that the human mind was not merely the result of brain evolution but also required substantial evolution in culture and personality. Central to the Human Cognome Project would be wholly new kinds of rigorous research on the nature of both culture and personality in addition to fundamental advances in cognitive science. The results would revolutionize many fields of human endeavor, including education, mental health, communications, and most of the domains of human activity covered by the social and behavioral sciences. Some participants in the human cognition and communication working group were impressed by the long-term potential for uploading aspects of individual personality to computers and robots, thereby expanding the scope of human experience, action, and longevity. But at the very least, greater understanding of the human mind would allow engineers to design technologies that are well-suited to human control and able to accomplish desired goals most effectively and efficiently.

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General Acknowledgment

The effort summarized here obviously rests on a plethora of contributions of others, most of whom will not be cited in this document by choice or by inadvertent omission or by ignorance of the author (the most likely predominating cause). There are two contributors, however, to the foundations of mathematical/logical/theoretical developments during the 20th century, Richard Threlkeld Cox and George Spencer-Brown, who will be featured. Spencer-Brown (1969) originated a foundation for mathematics/logic from the common sense assumption of distinction with the primal distinction being the drawing of a boundary by which (signitorily) something (an order) is created from no-thing particular. Cox (1961) showed that, given an order, it dictates a methodology that can be used to generalize the order (formalized as a lattice, an algebra, etc.) to a calculus by relying on relations of consistency with the order to derive the laws of the calculus. Cox's work experienced its initial exposure relative to Maximum Entropy Theory through the monumental efforts of Edwin T. Jaynes (2003) and Myron Tribus (1969) in a critically resistive climate. But finally herein, and with no expressed bias regarding relative value by way of the ordering of the following list of researchers, the contributions of Cox and/or Spencer-Brown as presently being evolved are due in large part to Robert L. Fry (2002), Kevin H. Knuth (2003b), Richard G. Shoup (n.d.), and William Bricken (n.d.). All in the know will recognize not just their ideas but also the outright borrowing of pieces of their original text that may appear without proper specific acknowledgment.

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Chapter XI

What Makes a Thinking Machine? Computational Semiotics and Semiotic Computation

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Relations are everything, relations are life.

~ J.W. von Goethe

Abstract

Semiotics is considered here as a relational and ontogenetic approach to describing cognition and communication in signifying systems. Implementing a semiotic approach to computing thus would require a computable and scalable signifying space in which signs can be arbitrarily created, related, interpreted, and deliberated. The author argues that although signs are representations, a signifying space cannot be realized under the current representational paradigm of recording and processing static data in a hierarchical data space. A semiotic machine, instead, must implement a genetic epistemology of cognition based on assimilation and pure relations. The pile system introduced in this chapter is supposed to meet these requirements and is described as a semiotic computation system structurally enabling deductive as well as inductive and abductive processes of self-reflection, deliberation, and interpretation commonly associated with thinking.

Introduction

Computer science in general and artificial intelligence in particular have used the metaphors of brain, mind, cognition, learning, and intelligence quite generously in the past without much consideration for the structural conditions required to bring forth these phenomena. There is a danger that computational semiotics continues this tradition by confusing the recording and management of signs with the generative process of creating signs. Semiotics traditionally deals with symbols and symbolic systems, their encoding, and their interpretation in communication. If computational semiotics tries to apply aspects of semiotics to computing, the structural conditions required to do so need to be discussed. In this chapter, I offer an outsider look focusing mainly on the following three issues:

- Semiotics, by fundamentally dealing with semantics, addresses cognitive operations and thus involves not only deductive but also inductive and abductive inferences. This creates a fundamental syntactic problem, as traditional, ontology-based representational and hierarchical approaches do not natively enable the ontogenetic processes that semiotic computing systems require.
- To generate and process signs as tools for expressing and communicating knowledge, a synoptic and synaptic space allowing to relate signs globally and transcontextually is required.
- Any practical and scalable approach to computing and generating signs must be based on a relationist, non-representational approach using self-connecting relation objects as protosigns in a self-organizing assimilative structure. Such a structure I propose to call a semiotic computation space. Operating in such a space consequently would be semiotic computation.

The purpose of this chapter is to discuss the structural and syntactical requirements of semiotic thinking machines in terms of a relationist and genetic epistemology as opposed to the traditional Platonic object epistemology based on representation, deductive logic, and ontology. I apologize to the readers for possible confusions arising from some new and even irritating terminology. But Erez Elul's (2005) pile system introduced here is barely out of the laboratory stage, and some of the terms used are preliminary choices intended to explicitly mark the differences to traditional approaches. Also, the inventor and the early protagonists of this system (including this author) are not computer scientists but rather amateurs in the original sense of the word. While this might explain a certain fuzziness in our argumentation, it also illustrates the fact that radical innovation sometimes comes from outside the professional tunnel vision that often blocks alternative views in and of a field.

A more philosophical-linguistic problem has been observed by Michel Bitbol (2001) and can be demonstrated through terms like *representation*; the representational object paradigm of the West has deeply shaped our thinking and our language to the point where we become unaware of the epistemological baggage that comes along with terms like representation. Even when neurobiologists or constructivist philosophers sometimes speak of representation with a different meaning, they nevertheless invoke in their audience the deeply rooted belief that the brain is an instrument of representing and storing true images of the world.

As the reader will notice, I carefully try to distinguish representation (as I try to distinguish to the point of avoidance the term *intelligence*) in describing the new approach and replace it by *assimilation*, which suggests an entirely different meaning.

Another case in point is the word *object*. It is hard to avoid even in the most rigid relationist terminology. So when I use it in the context of the new paradigm, I will try to put it in parentheses in order to remind the reader that I am actually trying to refer to an entity that is nothing but a triadic relation with a name, which makes it also a referable object.

The pile system introduced here was developed not by a computer scientist or a professional programmer, but rather by an independent inventor who originally tried to solve a logic and philosophical problem, namely *logic inclusion*. He implemented his theory before formalizing or even formulating it in an accessible way. In the history of inventions, this is quite normal, as inventors are not necessarily scientists or theoreticians, but in our scientifically oriented world and especially in a subject such as this one, it seems quite odd. This chapter attempts to draw the attention of the computational semiotics and AI community to some of the related and most interesting aspects and concepts behind this new approach but does not claim to give a comprehensive or even scientific theoretical and technical description. We also are not concerned with semantic issues and meaning here, but rather with the syntactic and structural conditions enabling the generation of meaning (Krieg, 2005a, b).

Relations and Semiotics

Charles S. Peirce's defined signs as representational tools establish meaning by relating other signs. He identified three distinct relations that together make up a sign:

- **Object relation (O):** The referent as concept that the sign encodes or stands for.
- **Representamen relation (R):** The signifier or perceivable part of the sign as the form which the sign takes (an icon, a symbol, an indexical).
- **Interpretant relation (I):** The signified as the meaning one obtains from the sign, how the sign is interpreted in a given context or the sense made of the sign.

Figure 1. Sign (C.S. Peirce)

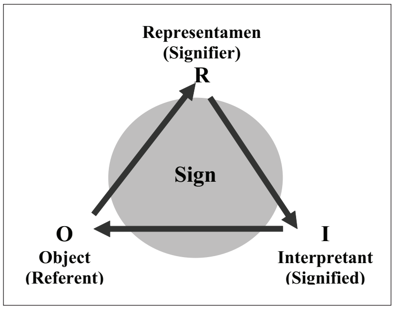
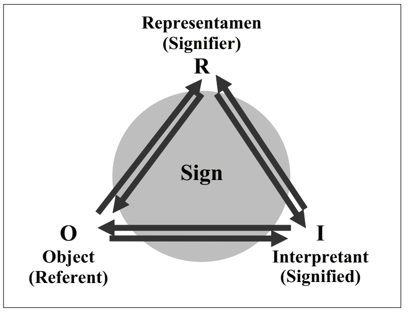


Figure 2. Qusign (Mihai Nadin)



In Peirce's triadic concept of signs (I recommend here the extensive discussion of Pieter Wisse in his 2002 dissertation), the relation between two signs is mediated by a third sign. In other words, the relation between two signs is explicitly expressed by another sign, which is also a referable triadic relation. Without such a third sign, any relational expression would be reduced to a static co-occurrence or similarity, and next-order operations as relations of relations would not be possible. Peirce's dynamic sign concept is relational and process-oriented, with signs triggering communication and interpretation processes. The issue of irreducibility of signs is interpreted as applying to the semantic level only (and not discussed here). The same goes for the classifications of signs, except for the classification process itself.

Mihai Nadin (1999) observed that "signs are not constituted at the object level, but in an open-ended infinite sign process (semiosis)". Pointing to the temporal aspect of this process, he suggests a rewording of the unidirectional Peircean sign definition as bidirectional relations, which he calls Qusigns, signifying the "unity between the analytical and the synthetic dimension of the sign":

This approach seems to point toward syntactic proto-signs as nonrepresentational triadic relations beyond (or rather below) the semantic object level. In essence, it suggests a nonrepresentational theory of semiotics (as paradoxical as this may sound). Because, for being able to create signs as representations in a generative process, a self-organizing, nonrepresentational, syntactic underlying structure based on proto-signs as pure (uninterpreted) triadic relations connecting other such relations is required. These proto-signs need to operate both as relations and as computable and referable objects, and thus require the following:

- A unique identity (as signifier, representing itself uniquely to the system)
- A reference to system order (as referent, referring to an operation of the system)
- A reference to signification (as interpretant, relating it to external interpretation in a relevant context)

Current computer platforms based on the Platonic input/output model do not operate with or generate signs in this sense but manage only symbolic representations of Representamens as data. These passive (static) data can be selected and related to other such data, but they cannot actively select and relate themselves. For this reason, computers today are not signifying systems; they cannot create or generate signs, but only can store, manage, and retrieve predefined symbols of Representamens as data objects in predefined structures. They are not signifying systems but rather sign management systems.

Cognition and Assimilation

Cognition is considered here as a process whereby a system constructs viable patterns of its own interactions in an environment. To an observer, the interactions producing the system's behavior appear to reflect the system's knowledge of its environment, especially if the behavior seems to involve prediction and anticipation. We consequently speak (at least in the West) about the environment (as objects) being represented in our cognitive system (as ideas, images, data, etc.).

Philosophers in the Orient, but also some in the West (like Heraclites), have argued early against this view. They stressed the illusionary character of the object(ive) world because of its dependence on our sensory structure. Neurobiologists like Humberto Maturana (1976) and Francisco Varela (1991) have argued empirically that cognition cannot be described as a representational input-output process but rather as a purely internal relational and correlational process under operational and informational closure, but in locked interaction with the environment. This autopoietic and constructivist epistemology is both evolutionary and relationist. From this viewpoint, Artificial Intelligence has been criticized as implementations of Platonic descriptions of observed behaviors rather than as an attempt to describe and provide the enabling structural conditions for intelligence. To put it more polemically, the claim of AI to achieve cognitive abilities in machines based on external modeling of knowledge is more related to the concept of Intelligent Design than to evolutionary concepts.

Knowledge in biological systems must be built up (learned) internally as part of an evolutionary process. The biologist Jean Piaget (1937) has studied and described this process in depth. In his genetic epistemology of the cognitive development of children, Piaget (1937) emphasized the operations of assimilation, accommodation and equilibration. In assimilation, the child (and later the adult) integrates new patterns of experience into already existing cognitive structures and their explanatory propositions (which Piaget calls *schemas*). Accommodation refers to the changing of schemas that do not fit with the results of operations, while equilibration describes the balancing one's new world view with one's actions. (Hegel's concept of Thesis, Antithesis, and Synthesis describes a similar process.) All three integrated in one process constitute adaptation according to Piaget.

Since assimilation seems to be the essential precondition for the others, let us examine this concept in more detail: Integration by assimilation is not an additive process of representation, such as adding pictures to an album, books to a library, or data to a file system, but a purely relational process based on difference, where patterns of newly experienced relations of interactions are matched against earlier patterns. In living organisms, assimilation literally makes dissimilar experiences similar ones (i.e., it creates identicalities and similarities of periodic samples that the sensory cells of the organism take in the continuous Heraclitean flux of the outside world). These samples, of course, are nothing but changes in the states of sensory cells themselves and not representations of the outside world. When I stick my finger in hot water to sample the temperature, my nervous system does not represent or record the temperature of the water, but the difference in temperature of my finger's sensory cells. By integrating these differences in time patterns of nervous activity into a higher order relation space, a process of assimilation of differences occurs. We do not know much about how this is done, and my description here is not the only one accepted by the cognitive sciences (in fact, it is probably a minority view even there), but it does allow describing cognitive processes in a purely internal and evolutionary non-Platonic way avoiding notions of intelligent design and interpreting homunculi in endless regress.

Implementing such assimilative and purely relationist concepts in computers is probably at the very heart of making the leap from the current knowledge management machine to a future thinking machine. How can we envision assimilation in a computer? Let us imagine an electronic book containing only the characters and symbols of the alphabet, say 256 characters (as in ASCII). We can call these the *atomic elements*, or building blocks of our book. They exist as a code, so no data in the strict sense need to be recorded yet.

To assimilate a specific book, all we need to do is record all possible relations between these atomic elements forming syllables, words, sentences, and so forth. These relations now also could act as building blocks, generating paragraphs, chapters, and eventually, the entire book. The whole (the specific book) and its parts (the atomic elements, building blocks, and their combinations) thus could be generated strictly from relations.

To assimilate another text into this electronic book, we needed to check which relations (as combinations forming parts) already are registered and, if they repeat, to just refer to them. Only relations not yet registered would have to be created new. All books of all libraries could be assimilated and integrated in this way into one single book without any representational recording of words, sentences, or paragraphs. Yet this electronic book would look like any other computer or e-book and even use the same hardware technology. But the storage method would be entirely different from the current representational approach.

The book structurally would not be a database but rather a relationbase. The assimilation process does not require cells, tables, or records. Neither does it create redundancy (by restoring every character, word, sentence, etc. as it reoccurs). Instead, our book is a highly (in fact, fully) interconnected web of relations: a synoptic and synaptic structure.

Synoptic, because it is fully transparent. In representation systems, every whole (e.g., book) is usually containerized so it can be addressed, stored, and retrieved as a whole. The only way we can see connections to parts (like words) is by building an index. In a synoptic and generative space, all relations between parts and wholes are fully visible. An assimilative structure does not require an index, because every relation is an active knower of all of its occurrences in all parts and wholes.

Synaptic means that the structure is fully interconnected. All parts of all wholes are connected to their building blocks and atomic elements as well as to their occurrences in other wholes. There are no isolated parts. In a synaptic space, direct connections between any of the neurons are possible, although only required connections are produced and maintained.

Such a space is the structural condition for accommodation, the second step in the process of adaptation according to Piaget. In accommodation, schemas are changed or newly developed in order to fit new assimilations, which, in their operational effects, do not concur with existing schemas. To be able to do this, the entire space must be transparent and self-reflective and allow direct any-to-any connections. In addition, it must be nonhierarchical in which any combinations are possible and can be compared to any other. There are many beginnings in such a space, as Piaget remarked, "In genetic epistemology … there is never an absolute beginning."

The process of accommodation is a reflection and deliberation process involving any type of inference from logic deduction, induction, association, to abduction. Here, the concepts of Piaget and Peirce meet, as was observed by Ernst von Glasersfeld:

I see abduction as an integral part of accommodation. Peirce described it as a simple process. If we experience a surprising event—it may be a pleasant surprise or a disagreeable one—we try to discover what caused it. If we isolate some novelty in the situation, we may conjecture a rule that says: if such and such is the case, we get this surprising result.

This conjecture constitutes an abduction, because it is not drawn from prior experience. We may then test the hypothetical rule—and if it is confirmed, we have an accommodation, because we have in fact generated a new rule that can serve us as a scheme of action. There is nothing paradoxical in this form of learning, nor does it require a mystical explanation. What it does require is an active mind that is able to reflect upon what it perceives and upon its own operations. There is no doubt that we have such minds. (Glasersfeld, 1997)

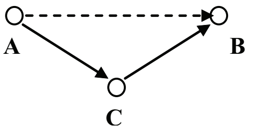
It is essential for any thinking machine to be structurally able to generate its own concepts as schemas and not to be fully dependent on externally developed models, as in AI. Because it is a machine and not an evolutionary organism, it also should allow, however, for the import of such external models as knowledge that can become both subject and object of future deliberations.

Knowledge and Relation

Relation implies knowledge. Relating a point (or a state) A to a point B (Figure 3) implies that A knows something about B. In this example, the relation is directed, so B does not necessarily know that it is related by A and, thus, knows nothing about A. The relation between A and B represents also the movement of the head of a Turing machine from A to B.

Figure 3. Relation as implicit knowledge

Figure 4. Relation as explicit knowledge



While the Turing machine explicitly records its states A and B (as data in cells of its tape), the movement (as process relation) itself is not recorded and is only implicit.

If we want to turn this relation into explicit knowledge, we need to create another point (Figure 4).

In this example, C represents the relation A-B by integrating three references (A, B, and the relation between them) into one. In other words, the point C represents some (yet uninterpreted) knowledge about A and B into one unified triadic relation. C is a point (a signature, identity, object) as well as a relation. It is an active knower of its parents A and B but also of its children. We can call it a relator. Being also a computable object, it can be externally interpreted in arbitrary ways, such giving the relation a meaning.

I propose to consider such self-connective relators the basic currency of knowledge, although they are just pure relations without explicit interpretation. Signs are produced in a signifying system by relating such relators in an ontogenetic classification process resulting in objects that can act themselves again as atomic elements (being interpreted externally as terminal values) in a communication system.

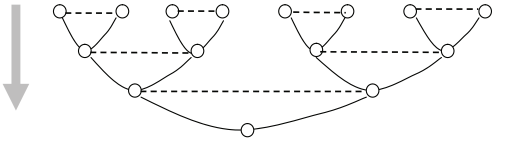
This could satisfy both Peirce's and Nadin's definitions, as it would constitute signs as nonreducible root elements in a self-organizing and self-referential web of relators forming the signifying system. For Peirce, the process of thinking is the process of relating signs to other signs (i.e., of traversing such a space). In a different terminology and a different field but, in fact, coming very close, the neurobiologist Humberto R. Maturana defines thinking as a process of relating relations:

Each interaction of an organism with its environment is represented in the nervous system as a relation of some states of activity. Treating these relations as independent entities and interacting with them (creating new relations with old relations) constitutes thinking. (Maturana, 1970)

Integrating two relations into one new relation and doing so recursively while inheriting the knowledge collected on the way (not by representation but by inheriting the path) creates a process of abstraction in the form of an inverted tree, where the object at the bottom compresses the knowledge of all the relations above it without having to encapsulate it as a container (Figure 5).

This represents an ontogenetic process bringing forth an ontology object as root of an emerging tree. A signifying space must enable dynamically and interactively generating such

Figure 5. Inverse classification tree (ontogenetic process of abstraction)



trees by traversing the space freely and directly from any point to any other and involving any two (or more) relations. I consider this ability another structural precondition for any signifying system.

The Concept of Pure Relations

The term *pure* refers here to a virtual (computed) object that exists only as a logical entity in a system. In conventional representational computing systems, data are physical entities (taking capacity in memory), including interpretational characteristics (as symbols like ASCII sequences). They also have some direct correspondence to the event they represent. This correspondence can be analog (such as in an analog picture), symbolic, or as a model (such as in a computer-generated video game image).

Pure relations do not have physical or interpretational aspects nor do they have any correspondence, as such, to a distinct external event or object. However, they can generate arbitrary data or representations by navigating a distinct path through the relation space, ending up in the atomic elements that enable access to interpretation by external terminal values. Any pattern or signal sequence can act as interpretational values. It is important, however, to emphasize the external character of interpretation (external to the relation structure).

Interpreting the relations externally avoids redundancy of relational patterns and allows comparing and computing patterns of relations independent of their interpretation in a specific context. We experience many instances in which similar relational patterns can be observed across very different situations and contexts. Family therapists, court judges, medical doctors, and technical stock market analysts base their diagnostics, judgments, therapies, and predictions on pattern similarities within their respective contexts. But we also find pattern correspondence in entirely different areas: moon cycles and fertility cycles, flow patterns in different dynamic systems, boom—bust cycles in economies and in populations are just some of the most commonly known. It indeed makes a lot of sense to interpret the pattern of one event through another one in another context in order to find hidden regularities.

Associative memory is another example of such transcontextual connectivity of an assimilative relation space, because it allows associating any type of experience to any other: smells to sounds, visions to tastes, touches to smells.

A cognitive system in the author's view must enable such transcontextual comparisons. Again, a representational system as an additive collection of disconnected or poorly connected data items in opaque containers does not have this ability. In fact, representation is extremely lossy, because it neglects to explicitly record the generative relations within a sequential order as well as the interrelations with the relations already represented in the system. Indexes are only partial and selective counter-measures against this loss, and can hardly make up for it.

The relators described here and referred to as *independent entities* by Maturana, are, in my opinion, proto-signs of a cognitive system. Concatenations of these proto-signs form paths that can be considered virtual data in a similar sense as computer code generating images in a video game or a Virtual Reality system. Relating proto-signs in arbitrary ways across the entire assimilation space enable deliberation, reflection, and, eventually, signification processes. The concept of assimilation allows us to abandon the idea of representing, storing, and retrieving data, which limits the resulting data space to sign management and deductive inferences at most.

Pile Space

Pile is a new approach to the capture and assimilation of signals and knowledge in computers beyond representation and data. Pile initially decomposes arbitrary electronic signal sequences (sense data) into the neighborhood relations between atomic elements, grounded in external terminal values enabling interpretation. The pile relator objects have no physical attributes and are computed dynamically during run time as the only computable objects of the system. Pile objects are triadic relations in the form of complex addresses, self-connecting in separate yet entangled normative and associative structures. The triadic relation of a pile object allows connecting it within a normative hierarchical part-whole structure as well as in an associative hierarchical associative structure and representing the relation between these two parents of the object. Only both parent relations together complete a legal pile object. Any normative parent also can act as an associative parent and vice versa. Pile

Figure 6. Pile notation

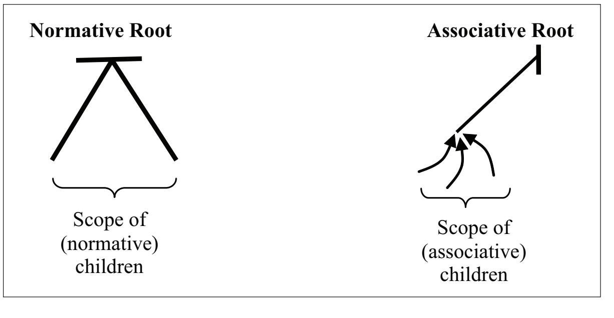
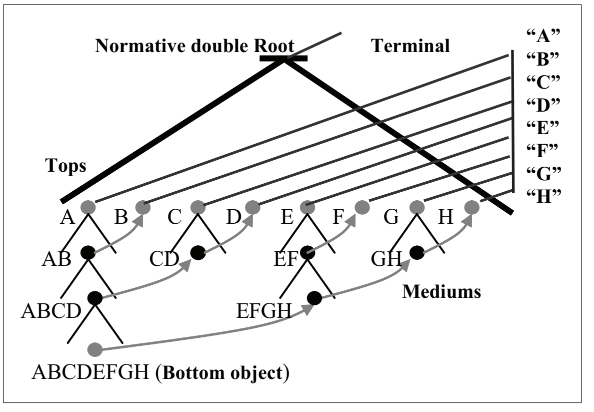


Figure 7. Pile structure (simplified)



objects actively relate other pile objects alone or in chains can act as signs, be interpreted as signs, and generate new signs. Only handles of some (not all) of these objects are actually stored on disk. The graphical notation used in pile combines topological (graph) and order (tree) notations (Figure 6).

Pile objects, like signs, relate relations to other relations, representing every relation by another mediating relation as referable pile object. These active relators as connective objects build up the self-organizing pile structure, which is generated at run time only. Needless to say, no data exist, are required or referenced (e.g., in an index structure) in this system. Data, again such as in a computer game, are computed dynamically and interactively on demand. The structure (Proutskova, 2004) principally looks like the following (Figure 7).

All points in this structure are relators as uniform objects (addresses) that generate parts and wholes of data strings. The structure is not a tree (as can be seen by the normative double root serving as a system definer at the top of the structure), yet it still is layered. The open triangles denote defined (and ordered) scopes of possible children in the normative structure, while the corresponding scopes of the associative structure are notated by curved arrows pointing to the associative parent. The top row (ToPs) are associative roots representing terminal values (input) (e.g., ASCII codes), while the lowest childless objects in the structure generate wholes (complete data strings). (To avoid confusion of terminology, there are two types of roots in pile: normative/associative double roots up in the structure and emerging roots generating wholes down in the structure).

Every object in the current pile implementation has uniform size (currently 4-byte) and two parents, one in the normative and the other in the associative structure (other structures with more than two parents are optional). Traversing the pile space involves traversing two topologies and directions simultaneously: In the normative structure, we traverse vertically (up-down), while in the associative structure, we traverse at the same time horizontally (left-right). Since every layer of the structure is the next order of the layer above, traversing is a process of moving to and from the next higher order. Traversing in the structure involves

Figure 8. Turing machine

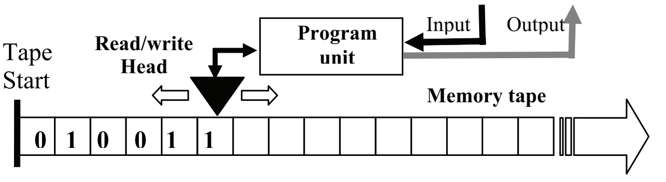
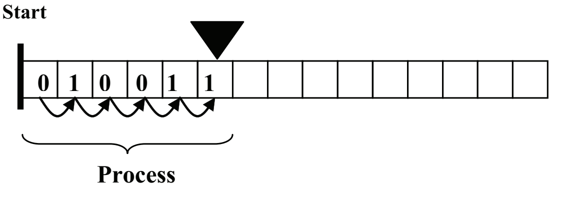


Figure 9. Temporal aspect of the Turing machine



Note: For simplification here and in Figure 10, the program unit is not shown

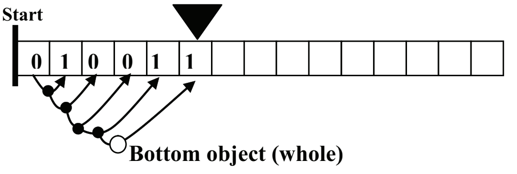
usually more than two tree-structures, as every ToP is an associative root (the parentheses mark the fact that we are not talking about conventional trees here).

Moving down the structure dynamically generates an inverted binary tree, the root of which is the lowest (BottoM) object generating a data whole (string). This object, although having the same 4-byte size as all others, still encodes (not contains) the accumulated characterization (knowledge) of all objects involved in the traversing. The MediuM objects between the ToPs and the BottoMs encode parts (substrings). Pile objects are self-connecting (i.e., every object knows both its parents as well as its children, if it has any). This means that the structure does not have a single entry point, as in a tree, but can be entered, like a complex network, at any point and traversed. Unlike in a complex network, all relations here are uniquely and bidirectionally defined in all directions (from-to/up-down), so orientation is always fully provided.

Orientation is the most serious problem in a complex network, because many links can lead from and to any given node. Due to the unique combinative pointer mechanism of pile, any to any connection with full orientation are provided. It thus avoids the notorious effect of ambiguity in traditional complex networks requiring either an exponentially growing computing effort to try out all possible paths (traveling salesman problem) or an exponential increase of nodes in order to remove ambiguous nodes by restructuring the network as a tree.

In pile, the advantages of base tree structures (navigation, logarithmic compression of information) are combined with those of complex networks (any-to-any connections, flexibility, growth), while avoiding the disadvantages of both.

Figure 10. Spatial time in pile



Since the Turing machine (Turing, 1936) is an abstraction of a strictly mechanical machine, the question arises whether a cognitive machine actually can be simulated by a Turing machine. The key issue here seems to be related to time, which has not been addressed fully by the Turing machine abstraction (Figure 8).

We can look upon time under two aspects: The moment in which something happens and that corresponds to a nondimensional point on the timeline. We call this the *temporal aspect* (Krieg, 2005c). The other aspect would be intervals of such moments, forming the spatial aspect of time (a section on the timeline). The Turing machine explicitly records the momentary (temporal) aspect of time as values onto its memory (tape). The movements of the head from one cell to the next as relation between two cells (representing the spatial aspect of time) is not recorded explicitly but given only implicitly by the program (Figure 9).

The implicitness of this information requires maintaining the program's frame of reference (as logic domain) during the operation of the Turing machine. In other words, during its operation, the Turing machine must be closed logically in order not to lose its frame of reference required to write/read its values (data).

This temporal aspect can be considered a substitutive relation because, as the head of the Turing machines moves, one moment is replaced (substituted) by the next. This substitutive relation is supplemented in pile with a second supplementary relation that folds the information of the Turing machine's head move (spatial aspect of time) into one single relation, where it also serves as a substitutive relation (Figure 10).

As can be seen in the resulting structure, the pile objects (drawn here as points) build an inverted binary tree from up to down (as in Figure 5) with the bottom object representing the root of this tree as a whole (data string).

The supplementary references enable cumulative characterizations in contextual multiple inheritance (and in additional consideration of qualifiers as part of each signature). Traversing a space while adding characterizations also can be seen as an abductive inference process accumulating information and generating ontology. In other words, instead of starting from a predefined ontology, as required in the TM, pile provides an ontogenetic mechanism to dynamically generate ontologies by accumulating characterizations as knowledge. Since this process is done in a synaptic and synoptic space of pure relations, any system pattern, regardless of its intended interpretation, can be employed.

Every point in the growing pile structure explicitly encodes both the temporal and the spatial aspects of time in one signature (address). As a result, the pile machine does not require to be closed during operation but can interact with its environment in any frame of reference simultaneously. Since all pile objects share the same lifetime, the structure is fully transparent to the outside as well as to the machine itself, providing a self-reflective space of computation that is a basic requirement for accommodation, learning, or adaptation processes.

Since only handles to some pile objects are recorded in memory, the structure and its objects are not dependent on physical memory. This is crucial, because a combinatory space that depends on physical memory cannot be scalable.

Pile records differences in relations by relating new relations to old relations that it already has seen and integrated. It thus can be nonredundant: a relation generating a string or pattern needs to be represented only once, and every recurrence of this pattern is referred to the original relation. This even can apply to patterns with different interpretations by terminal values; thus, an ASCII text could be played as music or data structure assigned to different data. A relation is a virtual point in a global and transparent space of relationships. Each such point can be connected (related) to any other point, can generate data from concatenations of relations, and even can become an atomic element (attached to a new terminal value) by itself.

The grounding of pile's atomic elements in terminal values representing arbitrary patterns or codes is helpful and probably the default operation of the system, but it is not a requirement. Unknown signal sequences also can be integrated into the system and interpreted later by analyzing their digital patterns.

Semiotic signs principally can be constructed in an ontogenetic process and designated from anywhere within the system as associative roots (Tops). As such, they integrate the three essential semiotic relations:

- **Signifier:** Establishing the object as a unique, referable unit.
- **Referent:** Normatively relating the object to a system order.
- **Interpretant:** Associatively relating the object to terminal values (pattern, symbol).

Thinking Machines

The question of representation vs. assimilation is a key aspect in discussing machines operations similar to thinking operations in organisms. The current Turing Machine paradigm is based on explicit representation and implicit relation. Both are principally (but not necessarily) separated. Current computers represent events as ontological descriptions located in discrete containers as data and related as wholes in predefined hierarchical data structures (e.g., file system trees). Containers are required in order to protect the frame of reference of their contents and to be able to reconstruct the only implicitly referenced sequential order.

The data model integrates representational, relational, interpretational, and physical aspects, all of which are embedded in the physical representation as data in memory. The relations originally generating the data from their atomic parts are only implicitly available and quickly lost in representation (e.g., when parts of sequences are put in different cells of a database). As a result, data are only static snapshots of the represented events. By relating these snapshots in intransparent containers, the relations of wholes and parts of a new data sequence to all the wholes and parts already represented in the system are not generally referable. The system cannot see whether it has represented a certain string already at some earlier time and, thus, is forced to re-record it in endless redundancy. This reduces representational data systems to poorly interconnected, additive collections of documents just like a library collecting books on its shelves. Searching the library requires either to open all books (e.g., under a common format in a data warehouse) or to index all documents. Yet even indexing does not allow accessing and retrieving all substrings in the library.

If we consider thinking as a process of integrating interactions (as events) in such a way that they can be reflected, evaluated, manipulated, deliberated, reinterpreted, and reconstructed in a generative way from within an interconnected web of relations, even enabling any type of inference, anticipation, and prediction, a completely different approach is required. Only an assimilative space of pure relations allows transparently reflecting upon itself, dynamically and flexibly assigning virtual data to virtual structures and code without exponentially increasing complexity and data volumes, and eventually, even generating new signs and new arguments as new knowledge.

Pile introduces a new type of assimilative system that promises to meet the necessary structural conditions for signifying systems. The formal mathematical descriptions and proofs have not been completed at the time of writing this chapter (but should be available at the date of publishing). They are not trivial, as the pile structure integrates an order structure in a multidimensional, folded topology. For such a structure, as for the new class of relational algorithms and the self-organizing formalism used to construct it, no description language and no relational theory exists yet.

The current software implementation demonstrates and empirically proves, however, a complexity compression of log2 in comparison to traditional approaches. This claim is based on the following task:

Find all substrings of a given string of the 6 elements (bytes) "1, 2, 3, 4, 5, 6"

The number of possible substrings is calculated as shown in Example 1.

The last six are the atomic elements (here, bytes) of the string.

The formula for the number of possible parts is given (according to Gauss) as:

$N = (size + 1) * (size / 2)$, where N is the number of requestable parts.

In a computer, a data string of N Bytes corresponds to a buffer of equal size. If we want to retrieve all parts of all wholes represented in a system, the number of these retrievable objects equals the sum of all possible parts of all buffers, which can be more simply calculated as:

$\sum ((N(buffer)^2 / 2)$

Example 1.

123456	(=one part of the size of the data)
12345	
23456	(=two parts of size - 1)
1234	
2345	
3456	(=three parts of size - 2)
123	
234	
345	
456	(=four parts of size - 3)
12	
23	
34	
45	
56	(=five parts of size - 4)
1	
2	
3	
4	
5	
6	(=six parts of size - 5)

Obviously, this results in an exponentially growing number. In pile, we must make a distinction between traversable objects (pile objects) and retrievable objects (generated data strings and substrings), while in traditional computing, the two are principally identical (except for indexing). The max number of pile objects required to retrieve (generate) all data parts is always smaller than the sum of all buffers. In other words, the number of pile objects required to generate an exponentially growing number of data parts grows only linear, while in traditional computing, the number to retrieve all data parts grows exponentially. Since a pile object has a defined size (currently 4-byte), this translates into an exponentially growing advantage (Log2) over traditional systems. The depth of the pile structure is extremely flat, with max 32 layers in the current implementation, so generating data is done very fast (by pointer operations), again comparable to data generation in computer games.

The hypothesis of this chapter is that an assimilative system based on relating pure relations in next orders is the essential precondition for operations that resemble thinking in both machines and biological systems. So far, only biological cognitive systems have solved this problem. Pile offers a technical solution that treats relations as referable objects with multiple and substitutive heredity supplementing each reference, thus opening up the logically closed Turing machine. We refer to pile as a polylogic system because it can integrate and differentiate arbitrary logic domains, while the Turing machine in its current implementations can switch to arbitrary domains but cannot integrate them except by first transforming them into one single logic domain. The universal machine character of the Turing machine allows it to implement any logic, yet only one at a time. Pile lifts this restriction, which principally has prevented the Turing machine from being adaptive until now.

Semiotic Computation

Pile can be characterized as a semiotic computing system:

- Its main components and only computable objects are active knowers as relators and cognitive actors in time.
- They accumulate information in a growing self-organizing structure of pure triadic relations.
- This structure is a multidimensional complex polylogic (rhizomatic) network.
- Any signal, object, event, relation, pattern, concept, structure, code, process, or procedure can be assimilated in this structure and act as a sign.
- Concatenations of relations generate content and data in pile but are not representations or containers of the assimilated content.

Language and other complex symbolic sign systems often are treated as deductive systems within a given frame of logic. In this approach, complexity as a description involving more than one frame of reference must be removed before a complex language system can be mapped to a tree structure. This usually is done by mathematical modeling. In computational linguistics, this approach has been associated with Chomsky's generative grammar and ontologies but also with top down AI and the relentless effort of encoding models to represent world knowledge.

Alternatively, language also can be described as a complex, nonhierarchical network of relations based on semantically driven connections of words. This relationist concept is even older, going back to Wilhelm von Humboldt, but was discarded probably because it could not be mapped easily to linear databases and hierarchical structures. A natural language system implementing a specific language, however, could continue to learn that language and to acquire world knowledge through dialogs with users and by reading books.

Such a system was advocated at the Biological Computer Lab at the University of Illinois (Champaign-Urbana) in the 1960s and 1970s by Heinz von Foerster (1971) and Gotthard Guenther (1962) but could not be implemented successfully at the time. Their polycontextural approach unfortunately has been all but forgotten by computer science during the following decades dominated by AI.

The pile system shares some philosophic principles with the BCL work but uses a different path to implementation. Like the earlier BCL work, pile's radical relationist, non-representational, and generative approach still seems difficult and even counterintuitive after so many decades of climbing trees, shoveling physical data, and modeling intelligence in computer science. Yet, unless we overcome the Platonic approach to computing, we have no real chance to implement semiotic and cognitive concepts. Both semiotics and cognition deal with complexity and, thus, operate under conditions of incompleteness and uncertainty. Such conditions cannot be mapped to tree structures, as logic does not tolerate incomplete or ambiguous knowledge of its objects.

Conclusion

The semiotic understanding of thinking and thinking machines implies a relationist, non-representational, generative, and assimilative concept of data and computation, leading consequently to computing pure relations. Such an approach is meant here by semiotic computation. By unifying representation and relation, temporal and spatial time in one referable triadic relation, and computing concatenations of such relations in a multidimensional complex yet ordered topology structure, pile opens the way for a genuine semiotic computing system that eventually can be both adaptive and cognitive.

In a signifying system, all instances must be related, while inheritable relations representing knowledge systematically must reduce complication and avoid complexity explosion. Pile meets these and further requirements:

- No restrictions should apply due to data sizes (in pile, data are simulated only in a logical address space and dynamically translated from/to the physical address space).
- No restrictions of dimensions and degrees of complexity should apply (in pile, the building blocks of the system are already complex and compress the complexity growth of n-dimensional structures from exponential to linear).
- No restrictions of data structures should apply (in pile, what can be described can serve as a structure, since structures (like data and code) are assimilated as relations and, thus, exist only virtually in the system).
- Any structure (linear, complex, dimensional, temporal, etc.) must be able to be mapped to the system. (In pile, all structural information also is assimilated as pure relations and dynamically assigned to relations generating data, so structures can be completely fluid and flexible).
- The system must be scalable. (Relations in pile are nonredundant, resulting in an increasing compression effect, the more data the system has assimilated and the more similarities it has found in these data. As a result, the system is scalable.)
- The system must be efficient. (Traversing the pile structure produces exponentially more information than in traditional complex networks or trees.)
- Unrestricted next order operations of relating relations to relations must be possible without size restrictions or exponentially growing performance cost. (This requirement, met in pile, allows conducting automatic classification processes in an ontogenetic

process, enabling not only deductive-analytical but also abductive-synthetic and inductive inference operations in which new characterizations are accumulated during computation.)

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Chapter XII

Reducing Negative Complexity by a Computational Semiotic System

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Abstract

This chapter describes the setup for an experiment in computational semiotics. Starting with a hypothesis about negative complexity in the environment of human persons today, it describes a strategy, how to assist human persons to reduce this complexity by using a semiotic system. The basic ingredients of this strategy are a visual programming interface with an appropriate abstract state machine, which has to be realized by distributed virtual machines. The distributed virtual machines must be scalable, have to allow parallel processing, have to be fault-tolerant, and should have the potential to work in real time. The objects, which have to be processed by these virtual machines, are logical models (LModels), which represent dynamic knowledge, including self-learning systems. The descriptions are based on a concrete open source project called Planet Earth Simulator.

Introduction

In the following, I will describe a project in computational semiotics that began officially in January 2001 as an open source and open science project. Slowly, but steadily, it's growing. It is in its core a software project, but this software project is embedded in a new paradigm of social computing, which has been named Planet Earth Simulator (PES, 2006). It is similar to the Wikipedia-Project in which everybody can contribute knowledge to a document base. It is different, because in the PES-Project one is primarily not contributing documents for reading but rather models of processes. Thus, one will be able to describe, for instance, population growth, energy consumption, a neuronal network, economic models, and so forth. All these process models are linking together automatically if their input and output streams do agree. They also will be interactive and allow multiple users simultaneously. This resembles a computer game environment. But within the PES-Project, the rules of the processes are open and subject to possible changes. Furthermore, the PES-Project will serve in the generation of empirically sound models, which can be used for real work. This is not typical for a computer game.

The chapter will start with the problem of the growing complexity in the environment of human persons, which, as negative complexity, can become really dangerous for the human culture. After the introduction of a working hypothesis for negative complexity, a subproblem is selected, and it will be shown what a possible solution could look like. Part of the solution is a visual programming interface, which will be explained.

As one can imagine, the PES-Project is a very demanding project, nothing that completely can be solved in a few months, not even in a few years. Therefore, the objective of this chapter is not to answer all theoretical questions that are induced by this complex project but rather to introduce the project in an experimental setup for theoretical discussion as well as for experimental clarification. The project is still open for participation by everyone who is interested in it.

Negative Complexity: Getting Involved

One early motivation for the computational semiotics project described in this chapter is the problem of mastering the increasing amount of negative complexity. But what is negative complexity?

Rooted in theoretical discussions and divers computational experiments within the Institute for New Media in Frankfurt, Germany, during the 1990s, it was at the conference Urban Fiction held in 2005 at the Johann Wolfgang Goethe University at Frankfurt am Main, Germany, where the author described the problem as a problem of negative complexity for which we need a solution (Döben-Henisch, 2006b). The problem of negative complexity is seen here as a relative problem because it exists only from the point of view of humans who rely on communication to coordinate the internal states of their bodies within a population. It is this incredible complex human body that is the source of the multifaceted phenomenon of intelligence with symbolic and language systems as subsystems. The investigation of the intelligent body is leading further to the underlying genes determining the body, and from the determining genes, one is led to the population as host of the genes embedded in certain environments and as part of a process of delivering copies of genes through time. One can describe this process as an evolutionary process endowed with certain implicit mechanisms. Although this topic until today has been the subject of many controversies (e.g., Bowler, 1989; Eibl-Eibesfeldt, 1980; Küppers, 1990; Lorenz, 1965, 1983; Mayr, 1988; Rosenberg, 1985; Ward, Brownlee, 2000; Weingarten, 1993), the author will take the position of evolution as a working hypothesis. Presupposing such an evolutionary framework, Marc D. Hauser (1996) describes in his book *The Evolution of Communication* that communication seems to be a key factor for all kinds of biological structures and that communication has undergone an evolution as all other kinds of biological structures. To that extent, communication is identified as a key element of adaptation, and for intelligence, it is highly interesting to understand levels of communication and the different potentialities of communication systems. There are good reasons to state that the change from sign-bound communication to language-based communication demarcates a far-reaching breakthrough during the process of evolution (Figge, 1994)). Language-based communication is bound to highly complex neurological and physiological structures accompanied by complex behavioral and social skills. Thus, the understanding of language-based communication is connected to many different disciplines. Language-based communication seems to manifests the highest form of intelligence that is known today (for the topic evolution and language, see Deacon, 1997 and Lieberman, 1984). Thus, we assume that language-based communication happens between members of a population. Another important distinction is that outside of a communicating member, communication depends on a medium; inside of a communicating member is the ability to relate certain internal states of the member to the outside medium. At this moment in time, science does not really understand exactly what happens internally if a member is communicating. Nevertheless, science is using collections of different conceptual models to approach some properties of these presupposed internal processes (Döben-Henisch, 2006a).

Although about 7,000 years of human culture is a lot compared to the lifespan of about 80 years of a human, 7,000 years compared to about 3.5 billion years of DNA-based life on Earth is nearly nothing. But in the last 100 years of human culture, the size of the human population has grown dramatically, and the physical structure of the environment has become enriched by more and more subtle technologies (not to mention the fast destructions of the biosphere at the same time). Even more, the cultural environments are being filled up with mass media contents, publications, laws, and institutions, which yield an impact on humans as semiotic systems that often are circumscribed as being complex or as having complexity. How can we deal with this informal feeling of being confronted with complexity made more precise?

Negative Complexity: A Working Hypothesis

What is needed is an empirically sound measurement method of complexity. But as the literature reveals to us (Alhazbi, 2004; Briand, Morasca, & Basili, 1994; Kinsner, 2004; Misra & Misra, 2004; Schlick, Winkelholz, Motz, & Brutting, 2003; Shell & Mataric, 2003), to mention only a few measures, there are several concepts of complexity in use. Which one is most appropriate?

In the general case, the meaning of measurement is to define a measuring procedure that allows the comparison of some target object with some reference object resulting in some number accompanying the reference object as a measuring unit (see the very fundamental and critical paper on measurement by Berka (1983). But what is the target object in the case of human environment interactions in which one person can be part of the environment of another person? In the PES-Project, we are not interested in the complexity of the environment as such, independent of interacting human persons. We are interested in a complexity that results from the interaction between the environment and the human person. From this, it is clear that the focus is also not on the human person alone, not on its cognitive capabilities separated from the interaction. What is needed is a general representation of the human cognitive capabilities, which can be related dynamically to all possible environments. Such an approach is the working hypothesis, that, on a sufficient abstract level of representation, the concept of the universal turing machine is general enough to cover all possible cognitive capabilities that a human person theoretically can possess.

If we accept such a hypothesis, which really cannot be proved or falsified but has many supporting empirical evidences, then one can apply the classical concept of computational complexity (Garey & Johnson, 1979), which relies on the time needed to compute a problem properly encoded in a string representation. The target object then would be an acting agent interacting with a problem as part of the environment, and the measurement procedure would encode the problem P into a string and would use as a reference object a universal turing machine replacing the acting agent. The time needed to solve the problem P would generate a number associated with a time unit. Thus, the universal turing machine is becoming a measure for the complexity of the environment of acting agents, including human persons.

If one compares empirical environments with empirical agents to the general measurement of a universal turing machine, then one has to consider an important difference. Whereas a universal turing machine (UTM) can compute arbitrarily fast, does an empirical agent need a certain minimal time due to its limited capacities (see Hilgard, Atkinson, & Atkinson, 1979; Klix, 1980; Murch & Woodworth, 1978; Schiff, 1980; and Shiffrin, 1976, who are describing some of the limitations of empirical agents). Thus, to use the universal turing machine as a measurement unit, one needs some kind of empirical calibration in order to map a certain amount of UTM operations with a certain amount of necessary execution time with regard to a certain type of agent. From this explicit restriction of the UTM measures, it follows that the amount of possible objects and relations does matter. Thus, not only the typical properties inherent in objects and relations can cause the measurement to generate big numbers, but also the quantity of the objects and relations can count and will influence the resulting measurement.

For the PES-Project, it was necessary to break down the general concept of a problem P into more concrete, partial problems P_i, which are concrete enough that one can define concrete experiments to test them. Based on data from experimental psychology (including cognitive psychology), we have distinguished the following possible problems for a human person interacting with its environment. We are calling this small set of selected problems the *Problem Base Set Nr.1 (PBS1)*:

1. Learning to identify objects
2. Repeated identification of same and similar objects
3. Learning to identify static relations between objects
4. Repeated identification of same and similar static relations
5. Learning to identify dynamic relations between objects
6. Repeated identification of same and similar dynamic relations
7. Learning to understand symbolic representations of given situations
8. Learning to generate symbolic representations of given situations
9. Learning to communicate symbolic representations of given situations
10. Learning to understand symbolic representations of given situations including inner states of agents
11. Learning to generate symbolic representations of given situations, including inner states of agents
12. Learning to communicate symbolic representations of given situations, including inner states of agents
13. Generating descriptions of possible future states based on given experience
14. Learning to evaluate symbolic descriptions of states of affairs according to certain preferences
15. Learning to plan possible future states with high preferences
16. Learning to realize plans

From the previous assumptions, it can be deduced that there can exist environments for an agent whose objects are on account of their properties and their static and dynamic relations as well as on account of their pure quantities that are difficult or even impossible to compute. In the latter case, we could speak of negative complexity as a measured number, which is beyond the capacities of the agent under investigation. As long as the measured number of complexity is below the known limits, one can speak of a positive complexity.

Furthermore, one has to distinguish between the negative complexity of a certain problem P_i—the complexity($P_{i, Aj}$)—with regard to a certain agent A_j, and the set of many different negative complexities of different problems P_1, ..., P_k—the set {complexity($P_{1,Aj}$), ..., complexity($P_{k,Aj}$)}—with regard to one agent A_j. Assuming that an agent only can deal with one problem at the same time, then this would mean that the set of different complexities with regard to that agent will need complexity($P_{1,Aj}$) + ... + complexity($P_{k,Aj}$) to solve all these problems. Thus, the amount of complexity will increase linearly. Because the available time for an empirical agent is limited, an empirical agent can reach its limits as soon as the amount of problems in a given time frame surpasses the available capacities.

If one is looking to the number of published papers and books per year, the number of new Web sites, the number of human persons, the number of new products, and so forth, one easily can deduce that only on account of the pure quantity of artefacts in the environment of a modern human person are even the problems of the base set quickly becoming infeasible.

It would be an investigation on its own to explore what could be the consequences of negative complexity for a human society. One interesting working hypothesis is that a democratic society only can function if the negative complexity does not surpass a certain threshold. The reason for this is that democratic societies presuppose that public communication is able to make all politically relevant matters transparent in a way that in principle it would be possible to come to a rational decision. If such a cultural rationality would not be feasible any more than would democracy be impossible. Thus, the quest for a manageable negative complexity is vital for living democracies. We cannot discuss this topic here. Instead, we will ask whether there is some solution imaginable how to cope with negative complexity, if it is there.

The Requirement of Visual Programming

The first use case for the PES-Project has been limited to case No. 13 of the Problem Base Set Nr.1. This is the problem: Generating descriptions of possible future *states* based on given experience. And because we want to supply a system S, which can assist a human person in solving a problem P of type No.13 (abbreviated P13), then we need some kind of a formal representation *repr(P13)* to communicate the problem to the assisting system as well as to the human person. A formal representation *repr(P13)* in the PES-Project is called a Logical Model (LModel). The human person can act either as a Knowledge Programmer (KP), who is providing such an LModel, or as a knowledge user (KU), who is using the given knowledge. Thus, we have a knowledge programmer generating an Lmodel, which is fed into the technical system S. If such an LModel is already in the system S, a knowledge user can ask for this LModel and can activate it for processing. The result of this processing is then shown to the commanding user.

The central question here is which concrete layout of an LModel is most appropriate for this case? Besides using a textual version of Lmodels, it has been decided in the PES-Project to experiment also with a visual version of LModels. According to Levialdi (2001), the usage of a visual programming language is a very young approach, starting with a conference in Hiroshima in 1984 (for an extensive bibliography, see Burnett, 2006). As it turned out, during the past years, the community detected that the visual programming approach is not as simple as it might seem in the beginning. Is it therefore impossible?

The Semantics of Visual Models

There are many questions that arise in the context of a visual programming approach. One central question is the question of the meaning of visual representations.

In the context of the PES-Project, it is assumed that a visual representation of an LModel has a meaning with a threefold scope: (1) describing some part of the real world (RW), (2) representing some cognitive representation inside the user called cognitive model (CModel) (in the literature, also often called mental model (see Ackermann & Taubner, 1990), (3) being a description of some states and operations inside a technical system S.

Because the meaning according to (1) is based on the interpreting user with his or her internal CModel, for many situations one can exclude case (1) and focus the discussion on cases (2) and (3). A user with his CModel in his or her mind is interpreting a visual LModel according to his or her CModel and simultaneously there must exist a technical system S that handles the visual LModel in accordance with the CModel of the user. The user is expecting that the technical system that behaves like his or her CModel makes him or her think.

Whereas the technical system S can (in principle) be specified into every detail, is the CModel invisible to the outside. The user has his or her own inner experience of his or her CModel as well as the visual LModel and the perceivable behavior of the technical system S. Thus, the user internally (seen from philosophy: on a phenomenological basis) can set up some kind of a cognitive mapping between the CModel, the visual Lmodel, as well as the input-output behavior of the technical system S:

Internally: CModel <--> visual LModel <--> input_output(S).

Externally can the user construct an explicit mapping between the visual LModel, the input-output behavior of the technical system S, and an explicit formal description of the technical system S:

Externally: visual LModel <--> input_output(S) <--> formal_description(S)

Thus, there is a common part between these two kinds of internal and external mappings, which is given by the mapping between the visual LModel and the input-output behavior of the technical system S:

Internally and externally: visual LModel <--> input_output(S)

The CModel as well as the formal description of the technical system S have to be in accordance with that part of the mappings, which is common to the internal as well as to the external mappings.

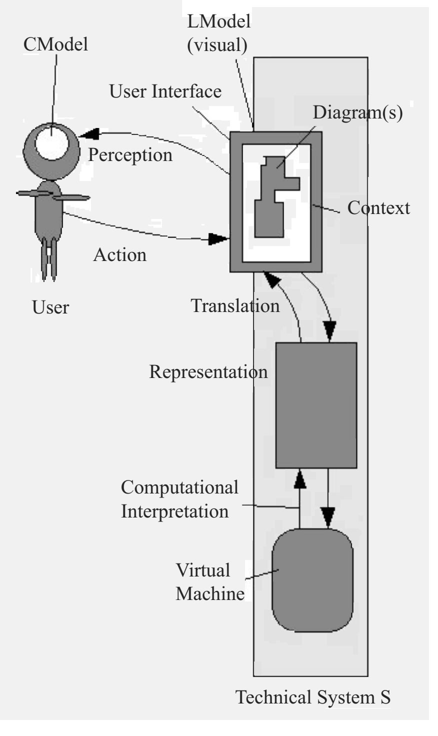
The primary norm of all these mappings clearly is rooted in the CModel of the user. Everything else has to be arranged to meet the CModel. But because CModels are invisible for others, they cannot be communicated directly. Thus, a construction of appropriate visual LModels with accompanying technical systems S usually happen in a co-evolutionary manner: The participating users will stepwise construct parts of the visual LModels simultaneously with certain expected input-outputs of a possible technical system S. Based on this user-guided process, one occasionally will set up some formal descriptions of the technical system that meet these visual data. This is how the team of the PES-Project works: explorative, incremental, evolutionary, doing repeated prototyping.

An Architecture for a Visual Environment

To realize a visual programming environment as considered previously, one has many options. The ideas within the PES-Project are influenced partially by the work of Levialdi/Bottoni as well as very strongly by the theoretical work described by Hoffman and Minas and colleagues around the DiaGen project (see DiaGen-Homepage, 2006) and the DIAPLAN project (see DIAPLAN-Homepage, 2006; at these links, you can find many papers and books related to these projects).

In a joint paper by Bottonii, Chang, Costabile, Levialdi, and Mussio (2002), which is a continuation of ideas in Bottoni, Costabile, Levialdi, and Mussio (1997), the authors divide the user interface in a context and several kinds of graphical elements (for this and the following see Figure 1). The context should be kept unaltered as long as possible in order to grant the user some continuity. The graphical elements can occur in this context, and they can change. The context has to be seen as a meta-level, whereas the changing graphical elements constitute a visual language consisting of visual sentences. Because the visual sentences also do include the possible transformations, the authors are calling this visual language a *dynamic visual language*. For the representation of the dynamic visual language inside the system, they use a combination of graphs and an extended rewriting system called *visual conditional attributed rewriting system (vCARWs).*

Figure 1. A framework for visual semantics



Within the Diagen and the DIAPLAN project, one uses so-called shaped-nested graphs for the internal representation of the visual language of the user. Shaped nested graphs are a modification of Hyper graphs (as a good introduction, I found Hoffmann and Minas, 2000, 2001, and Klein, 2004). Nested graphs allow recursive structures, and shaped graphs allow the description of certain types of graphs.

The conversion from user-visible diagrams into shaped nested graphs and vice versa is realized in a two-level concept (Hoffmann & Minas, 2001): the first conversion from visible diagrams leads to layout graphs that still contain enough information to allow the reconstruction of the visible layout for the corresponding visible diagrams. In a next step, these layout graphs are transformed further into hypergraph models that do abstract from visualization details.

What is missing in the DiaGen and DIAPLAN project is a running interpreter. With DiaGen, one can specify some diagram language and generate an appropriate visual editor that can convert visual elements into an internal graph representation, but there is no graph processor working on these graphs. In his diploma thesis, Klein (2004) developed a first prototype for a DIAPLAN interpreter, but only in a very limited version. The interpreter can read a textual representation of the graphs, and he or she is only testing the functions. It is not a full working interpreter.

During the last two years of the PES-Project, we also have encountered a lot of theoretical and practical problems, especially with the design and implementation of the visual LModels and the corresponding interpreters, called *simulators*. We have been a bit unsatisfied with the usual engineering methods to solve the problem. During the last month, we have decided to take the Abstract State Machine (ASM) paradigm as an official approach to solve the pending theoretical as well as the engineering problems (for an introduction, see Börger, 2002, Börger & Stärk, 2003, Gough, 2001, Gurevich, 2001, Huggins, 2006, and Stärk, Schmid, & Börger, 2001). As has been pointed out already, it is not possible in advance to define exactly which elements the visual language of the LModels should have. This can only be explored experimentally. Therefore, one needs an engineering process that is evolutionary and incremental. With the ASM-paradigm, this can be realized easily. One can start with rough and abstract structures in the beginning, and then, one can refine these initial abstract structures step by step. Therefore, the PES-Project did reshape its engineering process model.

The decision for an ASM-based development process includes the idea to end up with the PES-interpreter for the visual LModels as a virtual machine, which fulfills the following requirements:

1. Allowing multi-user and multi-tasking
2. Working in parallel with other virtual machines
3. Being fault-tolerant
4. Being able to work in real time (as option)
5. Being scalable
6. Being fully failure-transparent

Some Future Perspectives

So far, we have not talked too much about semiotics. We started with a general cultural problem: negative complexity. We have selected with P13 a small fraction of the problem, and we ended up in the difficult task: how to engineer a technical system that can assist in the handling of P13. Let us now for a moment assume that we will solve the problem P13 in the near future. Would it really help? Would we not aggravate the problem of the negative complexity by introducing new machines instead of minimizing it?

Seen from the point of a single human person, we have to state that an assisting machine can really minimize complexity. If a technical system is available for the problem P13 and it will work, then it will compute possible future states, or it will show the interplay of several local processes in a way that otherwise would stay invisible because the human person would not be able to think it through. More than this, if more and more people would contribute their experiences as LModels to the common public database, then more and more building blocks would be available to start computations of interactions of incredible complexities in a short time. For the first time in the history of mankind, it would really be possible to talk in an experimental but serious way about the common future of all.

This whole setting allows several interesting research activities. The following are a few that I would like to mention here:

1. The topic of the visual programming interface is not only a challenge within computer science but it is also a challenge within cultural anthropology, within semiotics: Is a cross-cultural visual language really possible? If not, what are the main differences between the cultures? From the point of view of philosophy, especially epistemology, one has to ask whether a visual language is complete enough to express all the meanings that are necessary for defined tasks. How can we measure completeness? What kinds of meaning are missing?
2. The management of the users can be demanding; for instance, if a simulation is running over many days or weeks or even longer, and if the user is not always actively present, which status can he or she have? What if the user is engaged simultaneously in more than one simulation? Within one simulation, there can be different roles of actors that allow interactions: how to manage these?
3. The PES-simulator shall be realized as a network of virtual machines that allow automatic parallel computing without the activity of a programmer preparing parallelism explicitly. This is based on certain properties of the internal data structures and operations on the data structures, which inevitably are interacting with the internal data representation of the visual programming interface. This is not yet completely formally specified. No solutions are known today worldwide.
4. The simulations shall be connectible to real world processes in hard real time. This puts strong demands on the virtual machine and the network-communications. Only partial solutions are known today.
5. The planet Earth simulator also can be integrated into dedicated learning scenarios in which one can assess people, train them, allow interactive learning, and so forth.

6. In the beginning of the PES-Project is the active user, acting as the knowledge producer generating visual LModels, the only source for knowledge in the system. In a later phase of the project, one can introduce Lmodels, which themselves are adaptive cognitive agents that operate on the basis of the given LModels. They perhaps will be able to learn, abstract, and construct plans; they perhaps can draw inferences, communicate, and so forth. This, then, also can be combined with the previously mentioned real-world interfaces. This will turn the whole project into a completely new dimension, not unreal but difficult to describe from now.

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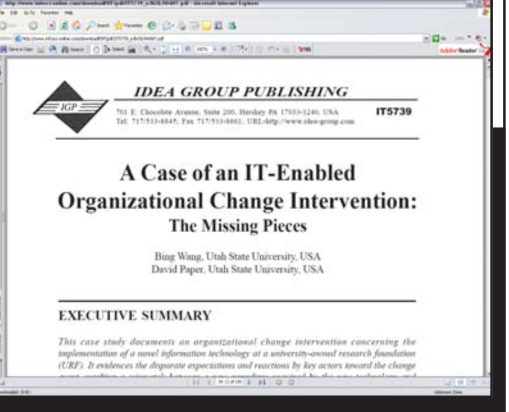
Index



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A Case of an IT-Enabled Organizational Change Intervention: The Missing Pieces

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EXECUTIVE SUMMARY

This case study documents an organizational change intervention concerning the implementation of a novel information technology at a university-owned research foundation (URF). It evidences the disparate expectations and reactions by key actors toward the change