Signs, Processes, and Language Games: Foundations for Ontology

John F. Sowa

> *Systems, scientific and philosophic, come and go. Each method of limited understanding is at length exhausted. In its prime each system is a triumphant success: in its decay it is an obstructive nuisance.*
>
> Alfred North Whitehead, *Adventures of Ideas*

Abstract. According to Heraclitus, *panta rhei* — everything is in flux. But what gives that flux its form is the *logos* — the words or signs that enable us to perceive patterns in the flux, remember them, talk about them, and take action upon them even while we ourselves are part of the flux we are acting in and on. Modern physics is essentially a theory of flux in which the ultimate building blocks of matter maintain some semblance of stability only because of conservation laws of energy, momentum, spin, charge, and more exotic notions like charm and strangeness. Meanwhile, the concepts of everyday life are derived from experience with objects and processes that are measured and classified by comparisons with the human body, its parts, and its typical movements. Yet despite the vast differences in sizes, speeds, and time scale, the languages and counting systems of our stone-age ancestors have been successfully adapted to describe, analyze, and predict the behavior of everything from subatomic particles to clusters of galaxies that span the universe. Any system of ontology that is adequate for defining the concepts used in natural languages must be at least as flexible as the languages themselves: it must be able to accommodate all the categories of thought that are humanly conceivable and relate them to all possible experiences, either directly by human senses or indirectly by whatever instrumentation any scientist or engineer may invent. As a foundation for such an ontology, this paper proposes the philosophies of three logicians who understood the limitations of logic in dealing with the both the flux and the logos: Charles Sanders Peirce, Alfred North Whitehead, and Ludwig Wittgenstein.

This is an extended version of an invited lecture presented in May 1999 at the International Conference on the Challenge of Pragmatic Process Philosophy at the University of Nijmegen.

1. The Aristotelian Synthesis

The primary task of ontology, as it was practiced by its founder Aristotle, is to bridge the gap between what exists and the languages, both natural and artificial, for talking and reasoning about what exists. Aristotle did not state that goal explicitly, but it is the unifying theme exemplified in his life's work: the analysis of the basic principles of every branch of knowledge and their organization in a system that shows how the diverse subjects are related to one another. Although Aristotle did not work out all the details himself, he laid the foundations for the science and technology of the Hellenistic era that followed him, the great flowering of Islamic civilization in the early middle ages, and the grand synthesis by the 13th century Scholastics in response to the clash of the Islamic, Jewish, and Christian cultures in Spain. In linguistics, the Scholastics developed Aristotle's correspondence theory of truth into an early version of model-theoretic semantics, which they applied to the analysis and definition of the quantifiers and logical connectives of Latin. In fact, the *Theory of Propositions* by William of

Ockham (1323) would still serve as a good introduction to model theory for linguists who are discouraged by Richard Montague's formidable notation.

Today, the goal of developing an ontology that can support natural language processing and knowledge sharing among heterogeneous computer systems requires such a synthesis. Following are three systems with the largest hierarchies of categories, all of which are defined by Aristotle's method of genus and differentiae:

- The Cyc system (Lenat & Guha 1990; Lenat 1995) was designed to accommodate all of human knowledge. Its very name was taken from the stressed syllable of the word *encyclopedia*. Over 700 person-years of effort have been spent in hand-crafting a hierarchy of 600,000 concept types with about two million associated axioms.
- The Electronic Dictionary Research project in Japan (Yokoi 1995) developed a dictionary with over 400,000 concepts, with their mappings to both English and Japanese words. Although EDR has nearly as many concepts as Cyc, the project has emphasized linguistic information rather than logical axioms.
- George Miller and his colleagues (Miller 1995; Fellbaum 1998) developed WordNet as a hierarchy of 166,000 word form and sense pairs. WordNet doesn't have as much detail as Cyc or as broad coverage as EDR, but it is the most widely used ontology for natural language processing, largely because it has long been freely accessible over the Internet.

The axioms for Cyc are expressed in full first-order logic with extensions for metalevel reasoning about the axioms themselves. But the rules of inference used for inheriting differentiae through the hierarchies of Cyc, EDR, and WordNet are based on the patterns of syllogisms defined by Aristotle and named by the Scholastics: Barbara for inheritance from genus to species, Darii for inheritance from species to individual, and the negative patterns Celarent and Ferio for detecting inconsistencies in the hierarchy.

Although Aristotle's logic and categories still serve as a paradigm for the ontologies used in modern computer systems, his grand synthesis began to break down in the 16th century. Aristotle's physics and cosmology were demolished by the work of Copernicus, Kepler, Galileo, and Newton. In philosophy, the skeptical tradition of antiquity was revived by the publication in 1562 of a new edition of the works of Sextus Empiricus, whose attacks on Aristotle were popularized by the essays of Michel de Montaigne (Annas & Barnes 1985). In responding to the skeptics, Descartes began his search for certainty from the standpoint of universal doubt, but he merely reinforced the corrosive effects of skepticism. The British empiricists responded with new approaches to epistemology, which culminated in Hume's devastating criticisms of the foundations of science itself. Two responses to Hume helped to restore the legitimacy of science: Thomas Reid's critical common sense and Immanuel Kant's three major *Critiques*. Kant (1787) adopted Aristotle's logic as the basis for his new system of categories, which he claimed would be sufficient for defining all other concepts:

> If one has the original and primitive concepts, it is easy to add the derivative and subsidiary, and thus give a complete picture of the family tree of the pure understanding. Since at present, I am concerned not with the completeness of the system, but only with the principles to be followed, I leave this supplementary work for another occasion. It can easily be carried out with the aid of the ontological manuals. (A:82, B:108)

Yet after two hundred years, Kant's easy task is still unfinished. His *Opus postumum* records the struggles of the last decade of his life when Kant tried to make the transition from his *a priori* metaphysics to the experimental evidence of physics. Förster (2000) wrote "although Kant began this manuscript in order to solve a comparatively minor problem within his philosophy, his reflections soon forced him to readdress virtually all the key problems of his critical philosophy: the objective validity of the categories, the dynamical theory of matter, the nature of space and time, the refutation of idealism, the theory of the self and its agency, the question of living organisms, the doctrine of practical postulates and the idea of God, the unity of theoretical and practical reason, and, finally, the idea of transcendental philosophy itself."

Before attempting a new synthesis, it is important to understand the strengths and weaknesses of the Aristotelian achievement and the lessons that can be learned from it. What, if anything, can be salvaged from it? What philosophical foundations might be better able to accommodate the breakthroughs in modern science, logic, linguistics, and computer science? What semantic foundations could support the highly technical languages of science, the colloquial speech of everyday life, and the problems of finding, sharing, and reasoning with knowledge scattered among millions of computers across the Internet? Should Kant's achievements be considered an encouraging step toward a new synthesis or a discouraging dead end?

Those questions were raised and answered by Peirce, Whitehead, and Wittgenstein — three logicians who understood the limitations of logic when applied to the problems of language and life. What set them apart from their contemporaries was their willingness to build the foundations of their philosophies on the recognition that logic, although important, is limited in what it can do. Section 2 of this paper reviews the difficulties encountered by the 20th-century analytic philosophers who either failed to recognize the limitations of logic or tried to bury their doubts under many layers of formalism. Section 3 analyzes the efforts in artificial intelligence to design logical systems that can cope with the limitations of logic. Sections 4, 5, and 6 show how Peirce, Whitehead, and Wittgenstein developed methods for accommodating the limitations, not eliminating them. Finally, Section 7 outlines the proposed new foundations: Whitehead's process philosophy as a theory of the flux, Peirce's semiotics as a theory of the logos, and Wittgenstein's language games as a theory of semantic change and adaptability. Together, they provide a foundation for ontology that is capable of any desired level of precision, while accommodating the inevitable discrepancies that occur when discrete symbols are used to approximate a continuous world.

2. A Static, Lifeless, Purposeless World

Using logic as a tool for knowledge representation is the chief characteristic of *analytic philosophy*. It began in a revolutionary spirit, which is most clearly defined by what it rejected. The founder, Gottlob Frege (1879), set out "to break the domination of the word over the human spirit by laying bare the misconceptions that through the use of language often almost unavoidably arise concerning the relations between concepts." Bertrand Russell shared Frege's contempt for natural language and sought refuge in a purified language of logic. The theory of *logical atomism*, which Russell (1918) developed in partnership with Ludwig Wittgenstein, was a natural outgrowth: predicate calculus has only two quantifiers, which range over a discrete set of individuals; therefore, the world should be describable by a logical combination of atomic facts about discrete atoms. The major achievements of analytic philosophy resulted from the application of symbolic logic to the analysis of language and the description of the world. Its major weaknesses stemmed from that same source. It focused on those aspects of language and the world that were easy to represent in logic. Unfortunately, everything else was systematically ignored — especially human purposes, intentions, society, and life.

To eliminate metaphysical assumptions, Russell (1924) formulated what he called "the supreme axiom in scientific philosophising": "Whenever possible, substitute constructions out of known entities for inferences to unknown entities" (p. 363). Among scientists, the behaviorists were the most enthusiastic in purging their theories of all traces of unobservable mental notions. They even dropped the name *psychology* because it implied an unobservable *psyche*. Physicists, however, ignored Russell's supreme axiom and happily constructed theories about unobservable fields, forces, particles, and waves. Albert Einstein (1944) criticized Russell's "fear of metaphysics" (Angst vor der Metaphysik) as a "malady (Krankheit) of 20th-century empirical philosophy." Contrary to Russell, Einstein maintained that "the concepts which arise in our thought and in our linguistic expressions are all — logically considered — free creations of thought which cannot be inductively derived from sense experiences." He believed that was just as true "for everyday thinking as for the more consciously and systematically developed thought in the sciences."

Russell and Wittgenstein had a strong influence on the Vienna Circle, including Rudolf Carnap, who had been one of Frege's few students. The Vienna Circle combined the *positivism* of an earlier Viennese, Ernst Mach, with the new language of logic to form *logical positivism*, whose primary thesis was the rejection of metaphysics and any theoretical terms that could not be explicitly defined in terms of observable data. To this mix, a visitor to the Vienna Circle, Alfred Tarski (1933, 1936) contributed model-theoretic semantics, which gave a formal definition of the truth of compound statements in terms of elementary facts about individuals. Tarski's combining rules for deriving the truth value of a compound sentence from its elementary clauses were equivalent to Ockham's. What was novel was the rejection of any aspect of meaning that could not be reduced to relations of individual objects.

Among the major achievements of analytic philosophy were *Der Logische Aufbau der Welt* by Rudolf Carnap (1928) and *The Structure of Appearance* by Nelson Goodman (1951). Both authors used symbolic logic to "construct" a description of the world in terms of observable entities. Carnap took the more challenging approach of reducing everything to primitive sensory data, which he called *Elementarerlebnisse* (elementary experiences). He showed how to use logic, set theory, and geometry to define physical objects in terms of sensory data. Goodman took an easier, but quicker approach by starting with physical objects and using *mereology* to combine them in larger structures. In both books, the primary emphasis was on the representation of static physical objects. For Carnap, psychological "objects" are physical objects that have a spatiotemporal location within an individual human object (§18). Carnap "clarified" the notion of *intention relation* by saying it is "nothing but" a relation between a psychological object and some other object (§164). Carnap recognized the importance of the *sign relation* and admitted "The construction of this relation is more difficult than any of the other relations which we have hitherto undertaken" (§141). In his later works, Carnap (1934, 1947, 1954) returned to the problems of representing signs, but only in formal languages. Richard Montague (1970) combined Carnap's approach with Kripke's model theory to develop a formal semantics for a 37-word "fragment" of English.

Analytic philosophy was criticized throughout the 20th century by philosophers who were partisans of other traditions. But the most serious criticisms were formulated by its own adherents or by philosophers who had been closely associated with the founders. Although Peirce invented the notation for logic that the logical positivists adopted, he had been a harsh critic of the attempt to eliminate metaphysics by the 19th-century positivists, Auguste Comte (1830) and Ernst Mach (1886). His criticism applies equally well to the logical positivists: "Find a scientific man who proposes to get along without any metaphysics... and you have found one whose doctrines are thoroughly vitiated by the crude and uncriticized metaphysics with which they are packed" (CP 1.129). As an example of the vitiating effect of his crude metaphysics, Mach fought a long, desperate battle against the assumption of unobservable atoms. He prevented his fellow Viennese, Ludwig Boltzmann, from receiving proper recognition for his brilliant theory of statistical mechanics (Lindley 2001). Einstein was even more blunt: "Mach was a good experimental physicist but a miserable philosopher"; he made "a catalog not a system" (quoted by Lindley, p. 219).

The most devastating criticism, which analytic philosophers have never been able to answer, was by Wittgenstein. In his first book, Wittgenstein (1922) presented the clearest formulation of logical atomism, which he and Russell had jointly developed before World War I. In his second book, however, Wittgenstein (1953) repudiated the "grave mistakes" in "what logicians have said about the structure of language," among whom he included Frege, Russell, and his earlier self. Instead of his direct mapping from language to the world, which was highly compatible with Tarski's model theory, Wittgenstein later developed the theory of language games, which are linguistically far more realistic, but far more difficult to reconcile with analytic philosophy.

Although Whitehead coauthored the *Principia Mathematica* with Russell, he was highly critical of Russell's approach to philosophy and rejected nearly all the basic assumptions of analytic philosophy. Whereas Russell emphasized static relations among things, Whitehead presented a dynamic theory of processes. Whereas Russell tried to avoid metaphysical entities, Whitehead boldly posited Platonic Forms, which he called *eternal objects*. Whereas Russell believed in absolute clarity, Whitehead (1937) maintained "In the focus of experience, there is comparative clarity. But the discrimination of this clarity leads into the penumbral background. There are always questions left over." When introducing Russell for his William James Lectures at Harvard, Whitehead said "This is my friend Bertrand Russell. Bertie thinks that I am muddleheaded, but then I think that he is simpleminded" (Lucas 1989:111). That remark is consistent with a statement attributed to Russell: "I'd rather be narrow minded than vague and wooly" (Kuntz 1984:50).

Another analytic philosopher, Nicholas Rescher, had a broad background in other traditions, including Arabic and medieval philosophy. While reviewing Quine's *Word and Object*, he was struck by the absence of any discussion of events, processes, actions, and change. After reviewing the literature, Rescher (1962) realized that Quine's static views were endemic in the tradition: "The ontological doctrine whose too readily granted credentials I propose to revoke consists of several connected tenets, the first fundamental, the rest derivative:"

1. "The appropriate paradigm for ontological discussions is a *thing* (most properly a physical object) that exhibits *qualities* (most properly of a timeless — i.e., either an atemporal or a temporarily fixed — character)."
2. "Even *persons* and *agents* (i.e., "things" capable of action) are secondary and ontologically posterior to proper (i.e., inert or inertly regarded) *things*."
3. "Change, process, and perhaps even time itself are consequently to be downgraded in ontological considerations to the point where their unimportance is so blatant that such subordination hardly warrants explicit defense. They may, without gross impropriety, be given short shrift in or even omitted from ontological discussions."

"It is this combination of views, which put the thing-quality paradigm at the center of the stage and relegate the concept of process to some remote and obscure corner of the ontological warehouse, that I here characterize as the 'Revolt against Process'." (p. 182)

Rescher found that the only analytic philosopher who bothered to defend the static view was Peter Strawson (1959), who claimed that "identifiability" and "independence" were sufficient criteria for ontological priority: "whether there is reason to suppose that identification of particulars belonging to some categories is in fact dependent on the identification of particulars belonging to others, and whether there is any category of particulars that is basic in this respect" (pp. 40-41). By applying that principle, Strawson concluded that physical objects are ontologically basic because processes cannot be identified without first identifying the objects that participate in them. Rescher, however, found Strawson's arguments unconvincing and presented three rebuttals, which can be summarized briefly:

1. Since people are commonly identified by numbers, such as employee numbers or social-security numbers, Strawson should grant numbers ontological priority over people. Alonzo Church (1958) observed that a similar argument could be made for the ontological priority of men over women because women are typically identified by the names of their fathers or husbands.
2. All physical things are generated by some process. Therefore, they owe their very existence to some process. Processes can generate other processes, but inert things cannot generate anything without some process.
3. The method of identifying an object is itself a process. Therefore, things cannot even be recognized as things without some process.

Undeterred by Rescher's rebuttals, Strawson (1992) published a textbook consisting of the introductory lectures on philosophy that he had used for twenty years to inculcate undergraduates with the thing-property doctrine. He mentioned *event semantics* as proposed by Donald Davidson (1967), but promptly dismissed it as "unrealistic" and "unnecessary." He took no notice of the rich and growing literature on event semantics in linguistics and artificial intelligence (Tenny & Pustejovsky 2000).

The thing-property ontology, which Russell (1918) pushed to the extreme of treating objects as nothing but "a bundle of properties," is derived from the substance-property-accident representation of Aristotle's early philosophy. In reviewing the development of Greek philosophy, Wolfgang-Rainer Mann (2000) observed that far from being common sense, the position Aristotle presented in the *Categories* was "a revolutionary metaphysical picture":

> To formulate it most starkly: before the *Categories* and *Topics*, there were no things. Less starkly, things did not show up *as* things, until Aristotle wrote those two works. (p. 4)

The fundamental issue is the nature of the 'beings' or 'entities' (*ta onta*) that are ontologically primary. Both Plato and Aristotle used the word *ousia* for those privileged entities. Plato considered the abstract *Forms* to be *ousiai* and physical entities to be imperfect copies that *participate* in the Forms. In the *Categories*, however, Aristotle considered physical *things*, of which his main examples were living things, to be *ousiai*, which Boethius translated into Latin as *substantiae*. But as Mann notes, Aristotle distanced himself from those early views in his later philosophy, especially the *Metaphysics* and *De Anima*. In those books, Aristotle's primary representation of physical entities is the form-matter composite, which is more compatible with Plato than with his own early philosophy. The main difference between Plato and the later Aristotle is over the nature of the combination: whether physical entities participate in the Forms or whether the Forms inhere in the physical entities.

Besides telling a fascinating story about the development of ancient philosophy, Mann raised serious questions about what views might be considered "common sense." He also observed that the presocratic philosophers had no single word that corresponds to the English word *thing*. The closest words in Greek were derived from verbs: *pragma* literally means *what is done*, and *chrêma* means *what is used*. Other languages also use verbal forms for "object": *objectus* in Latin and *Gegenstand* in German mean something that is thrown against or standing in the way. As Mann's analysis indicates, a revolutionary view that Aristotle once proposed and later abandoned can hardly be considered so obvious that no further justification is required.

During the course of the 20th century, many philosophers who were trained in the analytic tradition broadened their views in order to deal with human language, intentions, and society. Among them are John Searle (1969, 1982, 1995), who wrote several books on those subjects, Michael Bratman (1987), whose theory of beliefs, desires, and intentions has been formalized and applied to AI systems called *BDI agents*, and Barwise and Perry (1983), whose work on *situation semantics* has been influential in formal theories of propositional attitudes. In psychology, strict behaviorism began to decline with the publication of Edward Tolman's (1948) classic paper, "Cognitive Maps in Rats and Men." In that paper, Tolman showed that the behavior of rats running a maze cannot be adequately explained without assuming that they form a mental map of the maze in their brains. Thirty years later, O'Keefe and Nadel (1979) showed that the hippocampus is involved in building cognitive maps, and later evidence from neural imaging experiments provided further confirmation. In short, cognitive psychology has demonstrated that mental hypotheses are worthy of serious scientific study, neural evidence shows they are correlated with observable activity in the brain, and AI researchers collaborating with philosophers, linguists, and psychologists have formalized those hypotheses and implemented them in working computer systems.

Despite the growing acceptance of mental hypotheses in cognitive science, some philosophers have continued to observe Russell's supreme axiom. One example is Barry Smith (1995, 1998, 1999), who has struggled to eliminate mental notions by defining all aspects of human life in terms of mereological sums of physical objects and processes. His resulting ontology has two basic categories, *continuants* (physical objects) and *occurrents* (processes), which can be combined by mereology to form complex entities called *physical-behavioral units* and *social objects*:

- Smith considers Aristotle's early substance-property-accident view as "common sense" and accepts Strawson's claim that objects are ontologically prior to processes, because "occurrents require a support from continuants in order to exist." But as Rescher observed, one could with greater justification say that continuants are existentially dependent on the occurrents that generate them and maintain the conditions necessary for them to continue.
- Examples of physical-behavioral units include "Wendy's Friday afternoon class, Jim's meeting with his teacher, your Thursday lunch, Frank's early morning swim." These units are similar to Barwise and Perry's situations, but Smith prefers the hyphenated adjective because it makes them sound more "observable" and therefore more "objective."
- Examples of social objects include legal entities such as "juries, courts, contracts, lawsuits", cultural entities such as "works of music and literature", and human social groups such as "families and tribes, nations and empires, but also orchestras and chess clubs, battalions and football teams, as well as those more or less short-lived social groupings, which arise when strangers are formally introduced, or pair up on the dance floor." To ensure that these entities are purely physical, Smith defines them as mereological sums of rather disparate conglomerations. A contract, for example, includes not only the signed piece of paper, but also the people who signed it, the act of signing, and all the objects and processes involved in fulfilling the contract throughout its duration. The only things missing from Smith's definition are the intentions of the people who signed the contract and carry out its provisions.

Although Smith claims objectivity for his definitions, they violate the requirements for an effective operational test. His social objects, for example, include so many physical entities scattered over long intervals of time that itemizing them on paper is difficult and observing them in action is impossible. When arguing about a contract in a court of law, lawyers do not consult the mereological sum of physical actions, but the propositions stated on paper or uttered by witnesses. In every one of Smith's examples of social objects, the fundamental requirement that determines the nature and extent of the physical entities involved is some sign or structure of signs that may be written in symbols, uttered by some humans, or embodied in some artifact. In effect, the mereological sum of physical entities involved in any social object is "dependent" on the propositions entailed by the constitutive signs of that social object. A sounder formalization of Smith's approach should be based on the semiotic processes that involve the people (or other animals) who create the social objects, use them, and live with them and in them. As Carnap recognized, the "construction" of the sign relation from physical objects "is more difficult than any of the other relations which we have hitherto undertaken." An easier and more fundamental approach is to start with signs as the prerequisites for any social entity and to follow the signs to determine what other entities may be involved.

As this discussion indicates, analytic philosophy was "a triumphant success" at the beginning of the 20th century, but it became, in Whitehead's terms, "an obstructive nuisance" by the end of the century. In the early days, it served a useful purpose by promoting the development of logic as a tool for knowledge analysis and representation. Its weaknesses, however, resulted from the prejudices of its founders: Frege and Russell tried to replace natural languages with logic; Carnap, Neurath, and Hahn (1929) published a manifesto denouncing metaphysics; and Russell's "supreme axiom" excluded the most difficult and important problems from "scientific philosophizing." To bring those problems back into the province of science and philosophy, Frege's slogan should be turned on its head:

> We must break the domination of analytic philosophy over the human spirit by laying bare the misconceptions that through ignorance of goals, purposes, and intentions unavoidably arise concerning the relations of agents, concepts, and the world.

3. Artificial Intelligence

AI researchers are divided in two camps: the "scruffies" reject logic because of its limitations, and the "neats" try to apply logic along the lines advocated by analytic philosophers. One of the early successes of AI, the SHRDLU system by Terry Winograd (1972), was a classic implementation of the neat approach: it combined Russell's logical atomism with a Fregean compositional semantics, a Tarskian model theory, and a version of speech acts (Austin 1962). As an example, following is SHRDLU's response to a command:

- Input: *Find a block that supports a pyramid.*
- Translation to logical form:

```
(goal (and (is ?X1 Block)
           (is ?X2 Pyramid)
           (support ?X1 ?X2)))
```

- Response: SHRDLU finds a block that satisfies the conditions and points to it on the computer display.

One of the most impressive features of SHRDLU was its ability to accept definitions of new words. Following is a sample dialog between a human user (U) and SHRDLU (S):

```
U:  Are there any steeples?
S:  Sorry, I don't know the word "steeple".
U:  A "steeple" is a stack which contains two green cubes and a pyramid.
S:  I understand.
U:  Are there any steeples now?
S:  No.
U:  Build one.
S:  OK.
```

SHRDLU was freely distributed across Arpanet, and many people tried to use its extensibility features to build ontologies for new domains, but without much success. The following dialog illustrates the difficulties:

```
U:  I'll trade you a squirtgun for a big red block.
S:  Sorry, I don't know the word "trade".
U:  A "trade" is a free exchange of property.
S:  Sorry, I don't know the word "free".
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U:  A "free" act is done willingly, without being forced.
S:  Sorry, I don't know the word "act".
U:  "acts" are what people do on purpose and not by accident.
S:  Sorry, I don't know the word "people".
U:  Sorry, I thought you were smarter than you are.
S:  Sorry, I don't know the word "sorry".
```

The title of Winograd's book, *Understanding Natural Language*, was an exaggeration, which he recognized when he tried to extend SHRDLU to a broader coverage of language use. After some discussions with the phenomenologist Hubert Dreyfus, Winograd abandoned his earlier approach and adopted its diametric opposite, the phenomenology of Martin Heidegger. In their later book, Winograd and Flores (1986) explained the weaknesses of the SHRDLU approach: it makes no room for context, background, social commitment, discussion, negotiation, and the inevitable exceptions that cause a fragile formal system to break down. Since those issues were ruled outside the bounds of scientific philosophy by Frege, Russell, and Carnap, it's not surprising that Winograd should turn to Heidegger, their most vociferous opponent.

SHRDLU was considered a success in 1972 and a failure in 1980, but it was an interesting failure from which a great deal has been learned. Like many AI systems, SHRDLU implemented a limited version of intentionality. Each input or output statement could be represented as a pair (*p,m*), in which *p* is a proposition, and *m* is a marker that indicates the intended speech act, such as *assertion, question, answer, command, definition, warning,* or *apology*. To answer a question or obey a command, SHRDLU would derive a top-level purpose or goal. Then it would break that goal into multiple subgoals, which could be further subdivided into lower-level subgoals. If a subgoal failed, SHRDLU would try an alternative or ask for help. If the top-level goal failed, SHRDLU would apologize. That level of intentionality, although not very sophisticated, demonstrates that intentions can be formalized and analyzed with the same kind of logic used to represent observables.

Although intentions themselves are not directly observable, they may have observable effects. The most clearly visible effects result from activities, such as planning, problem solving, or game playing, which are directed toward some goal under the influence of certain constraints. As an example, Figure 1 shows two patterns that occurred during the play of the Japanese games of go and go-moku. Both games use the same board, the same pieces, and the same syntactic rules for making legal moves: the board is lined with a 19 by 19 grid; the pieces consist of black stones and white stones; and two players start with an empty board and take turns in placing stones on the intersections of the grid. A position from the game of go is on the left of Figure 1, and a position from go-moku is on the right.

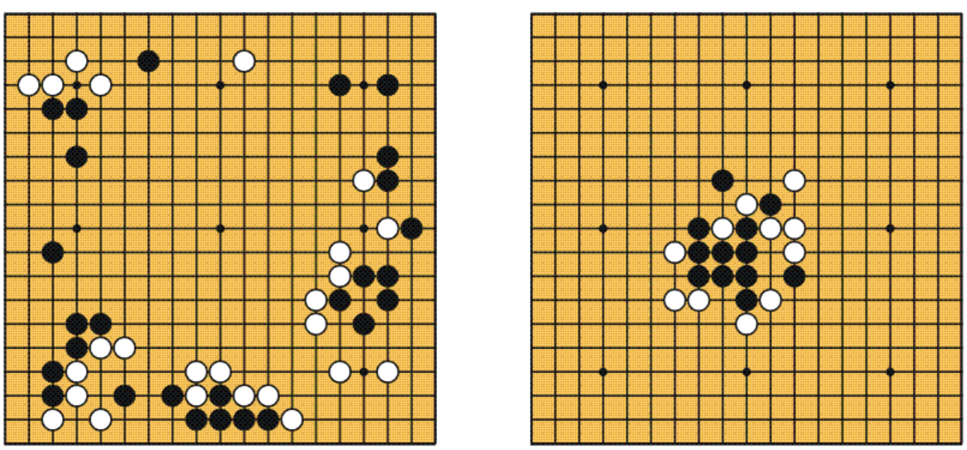

Figure 1: Positions from the games of go and go-moku

The most striking difference between the two board positions is that the go pieces are scattered around the edges, and the go-moku pieces are clustered in the middle. At a purely syntactic level, either position is legal in either game. But the intention of winning the game causes every move to be evaluated in terms of its potential effect on the final score, which is not computed until the end of the game. In go, the score is determined by the amount of territory each player has surrounded; therefore, the stones are viewed as competing "armies" that stand guard over their territory. In go-moku, the winner is the first player who forms a straight line with five stones of the same color; therefore, go-moku stones are placed in the middle, where they can form connected lines or block the opponent's lines. Intentionality is most easily formalized in game programs, but its effects are just as visible in anything that results from design and planning: buildings, highways, airplanes, orchestras, armies, businesses, and governments.

In computing the effects of intentions, AI systems routinely quantify and refer to events, potential events, and possible futures in ways that Strawson would not approve. To illustrate Davidson's event semantics, Strawson (1992) claimed that the sentence *John kissed Mary in the garden at midnight* would require a complex representation such as the following formula:

$$(\exists e)(\exists g)(\exists t)\ (\text{kiss}(e) \land \text{garden}(g) \land \text{midnight}(t) \land \text{agent}(e,\text{John}) \land \text{theme}(e,\text{Mary}) \land \text{location}(e,g) \land \text{pointInTime}(e,t)).$$

In an attempt to discredit Davidson's proposal, Strawson complained about the complexity of such formulas. As an alternative, he argued "What could be more simple and straightforward than the idea of a construction whereby we may tack on to the verbs of happening or action in such sentences a phrase which answers these when? and where? questions" (p. 104). Notations that "tack on" such qualifiers have long been used in AI; as an example, Figure 2 is a representation of Strawson's sentence as a *conceptual graph* (Sowa 1984, 2000).

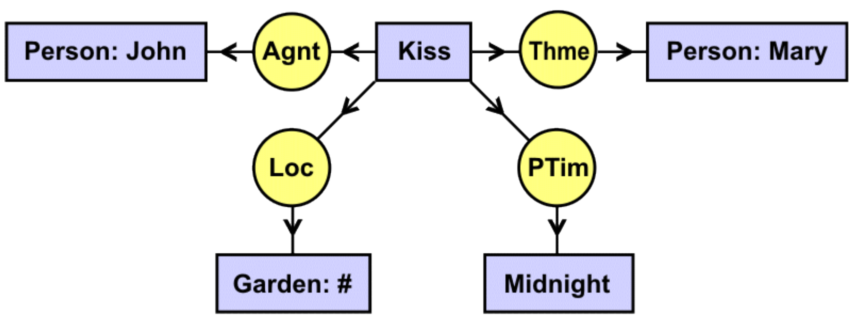

Figure 2: A simpler representation of Strawson's sentence

Figure 2 satisfies Strawson's criteria of simplicity, but it is a formal notation that is that is logically equivalent to Davidson's. Each box in Figure 2, which is called a *concept*, has an implicit existential quantifier. Each circle, which is called a *conceptual relation*, can be translated to a predicate, such as loc(e,g) or pTim(e,t). Although no one knows exactly what kind of representations occur in the human brain, Strawson is correct in saying that a graph-like connection is more likely than a formula in predicate calculus. But Figure 2 shows that graphs can express the equivalent information with Strawson's desired level of simplicity.

Model-theoretic methods for evaluating truth are most convenient when the elementary data can be stored in the tables of a relational database. They can also be adapted to simulated robots such as SHRDLU that have been designed to extract the equivalent information dynamically. As an example, consider the following command to SHRDLU:

- *Move Block X from A to B.*

This statement, which avoids all detail about how the block is manipulated and carried, has the same necessary and sufficient conditions for a human arm or a robot arm:

- *Preconditions*. Before the event, Block X is located at A, and the arm may be anywhere.
- *Postconditions*. After the event, both Block X and the grasping end of the arm are located at B.

These conditions would be equally true of a human arm, a robot arm, or a monkey arm, but they are stated at a high level of abstraction that ignores the details about the arm, the way it grips the block, and the trajectory from A to B. For SHRDLU, Winograd avoided those details by showing a simplified robot arm on the computer screen instead of controlling an actual robot, such as the aptly named Shaky.

Model theory breaks down when the high-level abstractions are "embodied" in the detailed motions of an animal or a robot. The arm must be transported from an arbitrary starting position to point A; its grasping mechanism must be aligned with the block; the grasp must be sufficiently tight to hold the block firmly, but without crushing it; the arm with the block must be moved to B, avoiding obstacles that might obstruct any part of the arm or the block; the motion must be stopped before the bottom of the block reaches the surface at B; the approach to the surface must be slow enough to avoid breaking the block or the supporting material; and finally, the grasp must be released. These detailed statements use verbs like *grasp, hold, crush, avoid, obstruct, reach, approach, break*, and *release,* whose truth conditions require information from sensors that are continuously monitoring the arm, the block, and the environment. Model theory, as defined by Tarski and extended by Kripke, Montague, and others, was never designed to accommodate dynamic information about interacting agents in a complex environment.

The weakness of model theory is not in the Ockham-Tarski combining rules for compound sentences, but in the methods for evaluating the truth of the elementary clauses. As an alternative, Lakoff and Johnson (1999) rejected neat approaches based on logic and advocated scruffy methods. Their work is part of a project called the *Neural Theory of Language* (NTL), which is being developed by Jerome Feldman, George Lakoff, Lokendra Shastri, and their students. As examples, the NTL group has undertaken several major tasks in language understanding and learning:

- For his dissertation on learning spatial relations, Terry Regier (1996) started with the cross-linguistic analyses of spatial relations by Len Talmy (1983). Regier failed in his first attempts to get a conventional PDP (parallel distributed processing) network to learn spatial relations, such as *above* and *in*. He later developed a hybrid system with a simulation of human perceptual mechanisms as a front-end to a PDP network for learning.
- For learning verbs of hand motion, David Bailey (1997) started with Jack, a computer simulation of the muscles and joints of the human body. To represent motor schemas, Bailey collaborated with another student, Srini Narayanan, to adapt Petri nets to represent the real-time control of hand motions. Then Bailey used a PDP network to learn which combinations of Jack's motions were associated with verbs in English, Farsi, Russian, and Hebrew.
- For motor control and abstract aspectual reasoning, Narayanan (1997) discovered systematic patterns of Petri nets that could be tailored to represent most, if not all bodily movements. Those patterns correspond to the aspectual features of verbs, which have long been studied by linguists. Then Narayanan showed how the same patterns used to interpret Jack's bodily motions could be used to interpret metaphors, such as *France falls into a recession, Germany pulls it out,* and *India releases the stranglehold on business*.

By showing the importance of the human motor and perceptual mechanisms for understanding verbs and spatial relations, these projects give concrete meaning to the catchphrase *embodied mind*. The "neural" metaphor, however, is not entirely justified, since the mechanisms that support these systems use conventional computations. Jack is based on methods used in virtual reality, Petri nets are a distributed-processing method commonly used to simulate multithreaded operating systems, and PDP networks are statistical computing systems that have only a remote resemblance to actual neurons. A more appropriate acronym might be VRTL, for Virtual Reality Theory of Language.

The possible motions of the bones and joints determine much more detailed, dynamic conditions for truth than the static relations of a traditional Tarski-style model. Imagine, for example, a basketball player shooting a ball through a hoop while running, jumping, and trying to avoid other players who are also running, jumping, and waving their arms in an attempt to obstruct the trajectory of the ball. Although the trajectories may be computable, the patterns of relationships are not given in advance, and they cannot be computed without modeling the three-dimensional interactions of multiple moving objects. Even slower interactions of just two objects may require considerable background knowledge. Consider how a human being or a computer might evaluate the truth conditions for the following sentences:

1. *Bob pushed the block across the room with his nose*.
2. *Bob pulled the block across the room with his tongue*.
3. *Bob lifted a 50 kg block with one finger and tossed it to point B*.

The first sentence is unusual, but possible if Bob gets into an awkward crouching position while pushing the block. The second one is impossible for most people, but it's conceivable if Bob happens to be a frog. The third sentence would normally be false, since such a block would be too heavy for anyone to lift with one finger. Yet if the environment contained a suitable system of pulleys and counterweights, such a motion might be possible. These considerations do not refute the Ockham-Tarski methods for deriving the truth value of a compound sentence in terms of its nested clauses. But by showing the complex methods required to determine the truth of elementary clauses, they discredit the oversimplified methods of analytic philosophy for relating language and logic to the world.

In summary, the only thing analytic philosophy has to offer is something AI already has in abundance: elegant formal techniques. In analyzing and representing knowledge about the world, AI researchers have been forced to address problems that analytic philosophers have deliberately ignored:

- Motion, change, processes, causality, and dynamic interactions.
- Independent agents that interact with the processes and communicate with each other about their interactions.
- Situations, contexts, and situated agents whose actions and communications are based on their beliefs, desires, and intentions.
- Planning, learning, negotiating, problem solving, and game playing in ever-changing environments.
- Defaults, exceptions, vagueness, continuity, granularity, and conflicting viewpoints on the same phenomena for different purposes.
- Full range of natural languages and their semantic underpinnings in terms of situations, contexts, and the world.
- Sharing and using knowledge expressed in any language, natural or artificial, among situated heterogeneous agents, both human and robotic.

These problems, which are individually difficult, have such overwhelming ramifications that they confirm the epigram by Alan Perlis (1982): "A year spent in artificial intelligence is enough to make one believe in God." Winograd's frustration is typical of many optimistic graduate students who later became discouraged and cynical. To design intelligent systems, AI researchers are willing to accept help from any branch of cognitive science, but oversimplified formulas from armchair philosophers merely divert attention from more promising approaches.

4. Peirce's Semeiotic

Peirce was no armchair philosopher. He published research in chemistry, astronomy, physics, mathematics, and logic. During the late 19th century, he had an international reputation as the leading expert both in symbolic logic and in methods of measuring gravity. Among his other achievements, he was the first person to propose a wavelength of light as a standard for length, and he demonstrated its practicality by designing the equipment for using light waves to measure the length of the pendulums he used to measure gravity. Independently of Frege, Peirce created the modern algebraic notation for logic, which Peano modified by replacing Peirce's symbols with special characters like ∃ and ∧. Unlike Frege and Russell, who sought to replace natural languages with logic, Peirce used logic as a tool for understanding language. In a letter to B. E. Smith, the editor of the *Century Dictionary*, Peirce wrote

> The task of classifying all the words of language, or what's the same thing, all the ideas that seek expression, is the most stupendous of logical tasks. Anybody but the most accomplished logician must break down in it utterly; and even for the strongest man, it is the severest possible tax on the logical equipment and faculty.

Peirce spoke as an associate editor of that dictionary, for which he wrote, revised, or edited over 16,000 definitions. With his background in language, logic, and mathematics, Peirce knew how to define words, write axioms, and prove theorems. With his background in science and engineering, he knew how to verify hypotheses by experiments and how to design artifacts that satisfy requirements.

In philosophy, Peirce was a voracious reader who studied all the philosophers from ancient Greece to 19th-century Europe. Unlike most of his contemporaries, he was especially well versed in medieval philosophy and logic. He once boasted that he had the largest collection of medieval books on logic in Cambridge (which included the Harvard libraries). In his lectures of 1898, he said that in his youth he had been "a passionate devotee of Kant":

> I believed more implicitly in the two tables of the Functions of Judgment and the Categories than if they had been brought down from Sinai.... But Kant, as you may remember, calls attention to sundry relations between one category and another. I detected some additional relations between those categories, *all but* forming a regular system, yet not quite so. Those relations seemed to point to some larger list of conceptions in which they might form a regular system of relationship. After puzzling over these matters very diligently for about two years, I rose at length from the problem certain that there was something wrong with Kant's formal logic.

What was puzzling to Peirce, as it was to Hegel and many others, was the underlying principle for deriving the categories. Starting with the four major groups Quantity, Quality, Relation, and Modality, Kant divided each group into triads in order to derive twelve categories. As an example, Kant divided the group of relations into three categories named Inherence, Causality, and Community. Peirce noticed that Inherence could be defined by a monadic predicate that characterizes something by what it has in itself, independent of anything else; Causality would require a dyadic predicate that characterizes some reaction between two entities; and Community would depend on a triadic relation that establishes new connections among the members of the community. Following is Peirce's summary of the principle:

> First is the conception of being or existing independent of anything else. Second is the conception of being relative to, the conception of reaction with, something else. Third is the conception of mediation, whereby a first and a second are brought into relation. (1891)

Peirce's trichotomy of Firstness, Secondness, and Thirdness is a metalevel principle that can be applied repeatedly to generate new categories. His first application was to analyze Kant's method of subdividing his four major groups, but he later applied it to any method of conceiving anything.

Throughout all these activities, Peirce viewed semiotics or as he spelled it, *semeiotic*, as the unifying theme that relates naturally occurring signs and conventional symbols to concepts and reality: language, logic, and science are systems for manipulating signs to represent relationships in and about the world. In classifying signs, Peirce used his trichotomy to subdivide the sign relation into the triad of *icon, index* and *symbol*: an icon represents an object by its inherent form, which resembles the intended object; an index represents its object by some causal relationship, such as a pointing finger, a weather vane, or a dial on a meter; and a symbol represents its object by a convention established by some community. By repeatedly applying the trichotomy to sign types, analyzing their interrelationships, and eliminating types that are ruled out by other constraints, Peirce showed how three trichotomies of signs would generate ten types of signs. He later extended the analysis to show how ten trichotomies would generate 66 types of signs.

Besides using the trichotomies to classify signs, Peirce also used them to classify mathematics, philosophy, science, and the study of signs themselves. He subdivided the field of semiotics into three subfields according to which aspect of signs is addressed by each:

1. *Universal grammar* is first because it studies the structure of signs independent of their use. The syntax of a sentence, for example, can be analyzed without considering its meaning, reference, truth, or purpose within a larger context. In its full generality, universal grammar defines the types of signs and patterns of signs at every level of complexity in every sensory modality.

2. *Critical logic*, which Peirce defined as "the formal science of the conditions of the truth of representations" (CP 2.229), is second because truth depends on a dyadic correspondence between a representation and its object. The Ockham-Tarski rules for evaluating the truth of compound sentences in terms of their constituents are a special case of those formal conditions. Although Peirce couldn't know of Tarski's work, he was familiar with Ockham's work, which he incorporated into his version of model theory, called *endoporeutic* (Peirce 1909). Hilpinen (1982) observed that Peirce's version is formally equivalent to *game-theoretical semantics*, which is a simpler, more elegant method than Tarski's, but which determines the same truth values. As usual, Peirce improved upon his successors.

3. *Methodeutic* or *philosophical rhetoric* is third because it studies the principles that relate signs to each other and to the world: "Its task is to ascertain the laws by which in every scientific intelligence one sign gives birth to another, and especially one thought brings forth another" (CP 2.229). By "scientific intelligence," Peirce meant any intellect capable of learning from experience, among which he included dogs and parrots. Methodeutic analyzes the methods of observation, experiment, and testing for relating signs to their referents in everyday life and in the most advanced applications of science and engineering.

Charles Morris (1946) popularized Peirce's classification under the headings *syntax, semantics,* and *pragmatics*. Unfortunately, Morris's choice of words has led to confusion, especially over the word *semantics*, which logicians use in much same sense as Peirce's term *critical logic*, but linguists use in a much broader sense. As an alternative, linguists have coined the term *lexical semantics*, which includes aspects of all three of Peirce's branches.

Peirce also applied his trichotomy to subdivide these subfields. In analyzing the methods of reasoning, he observed that induction exemplifies Secondness because it depends on a dyadic relation between propositions and reality. Deduction exemplifies Thirdness because it is determined by mediating laws that relate premises to conclusions. In looking for the missing Firstness, he discovered the principle of abduction, which generates new hypotheses, which are further tested by the methods of deduction and induction. The AI methods of heuristics (which Peirce spelled *heuretic*) are special cases of abduction.

The principle of searching for the missing third is a valuable heuristic (or heuretic) for developing ontological categories. Peirce's major criticism of the 19th century positivists was their failure to go beyond Secondness. That is also the major weakness of 20th century analytic philosophers. Following is a short list of the kinds of Thirdness they have either systematically ignored or failed to appreciate:

> Causality, Interaction, Communication, Planning, Intention, Agency, Duty, Responsibility, Obligation, Authorization, Penalty, Permission, Organization, Strategy, Business, Society, Life.

In commenting on life, Peirce observed "The problem of how genuine triadic relationships first arose in the world is a better, because more definite, formulation of the problem of how life first came about" (CP 6.332). In every living being, from bacteria to humans and perhaps beyond, semiosis is the crucial Thirdness that enables the organism to respond to signs by taking actions that serve to further its goals of getting food, avoiding harm, and reproducing its kind. For most life forms, those goals are unconscious, and most of them are built into their genes. But there is no difference in principle between the evolutionary learning that is encoded in genes and the individual learning that is encoded in neurons. Understanding life at every level and in every kind of organization from colonies of bacteria to human businesses and governments requires an understanding of signs, goals, communication, cooperation, and competition — all of which involve aspects of Thirdness.

The best way to appreciate the power of Peirce's trichotomy is to use it to analyze problems that are difficult to solve or even state without them. One problem is the classification of verbs according to what aspect is signified: some directly observable event (Firstness); some indirectly related effects (Secondness); or the agent's intentions (Thirdness). The next three sentences describe the same act in each of those ways:

1. Brutus *stabbed* Caesar.
2. Brutus *killed* Caesar.
3. Brutus *murdered* Caesar.

An act of stabbing can be recognized by objective criteria at the instant it happens. That is a classification by Firstness, since no other entities, events, or mental attitudes are involved. But an act of stabbing cannot be identified as killing unless a second event of dying occurs. Caesar had time to ask "Et tu, Brute?" before the stabbing could be interpreted as a killing (Secondness). Murder is Thirdness that depends on the intention of the agent. Determining whether an act of stabbing that resulted in killing should be considered a murder may depend on subtle clues, whose interpretation may require a judge, a jury, and a lengthy trial.

Many of the problems analytic philosophers have either ignored or debated without reaching a satisfactory conclusion could have been solved by an application of Peirce's semiotics. A typical example, which Russell (1905) thought he solved, is the problem of dealing with terms whose referents are nonexistent:

> The present king of France is bald.

People who had never studied philosophy would say that the phrase *the present king of France* has a meaning, even though no such person now exists. By his supreme axiom, however, Russell sought to replace unobservable entities, such as meaning, with observable signs that have observable referents. His solution was to paraphrase the sentence in a way that would enable its truth to be evaluated without raising questions of meaning:

> There is one and only one present king of France, and that one is bald.

Since the first conjunct is false, the entire sentence must be false, and the second conjunct can be ignored. The entire procedure can therefore be evaluated without attributing a "meaning" to terms that have no existing referents. Many people, including philosophers who wanted to avoid mental entities, felt there was something deeply unsatisfying about a solution that treated such terms as meaningless. Strawson (1950) tried to interpret the sentence in terms of English speakers' habitual usage, and Russell (1969) responded by reasserting a preference for his original approach. Meanwhile, Carnap (1947), Donellan (1966), and Kripke (1977) proposed different ways of interpreting the sentence without admitting mental entities. In his conclusion, Kripke said that a complete treatment of definite descriptions should "make it clear why the same construction with a definite article is used for a wide range of uses." But he admitted "I have not yet worked out a complete account that satisfies me."

In commenting on the endless debates about the present king of France, Sharon Kaye (1997) observed that William of Ockham's solution to the problems of nonexistent entities was logically equivalent to Russell's, but it was general enough to handle the criticisms by Strawson and others. Following Aristotle and earlier Scholastic logicians, Ockham considered logical terms that may be written, spoken, or conceived:

> A written term is part of a proposition written on some physical object, which is seen or can be seen by the bodily eye. A spoken term is part of a proposition spoken by the mouth and able to be heard by the bodily ear. A conceived term is an intention or passion of the soul naturally signifying or consignifying something and suited to be part of a mental proposition and to supposit for that which it signifies. (T, ch. 1)

Peirce considered these three kinds of terms, including mental terms, to be special cases of signs. Another Scholastic distinction, which Peirce adopted and generalized, was the distinction between the *significatio* of a term and its *suppositio* or what it stands for. For comparison, following is a definition of *sign* by Peirce:

> A sign, or *representamen*, 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 representamen. (CP 2.228)

In Peirce's terminology, the *significatio* of a term corresponds to its interpretant, and the *suppositio* of a term corresponds to its object. Frege made a similar distinction: the *Sinn* of a sign (*Zeichen*) is its *significatio*, and the *Bedeutung* of a sign is its *suppositio*. Following is Ockham's definition:

> *Suppositio* means taking the position of something else. Thus when a term in a proposition stands for something, in such a way that we use the term for the thing, and that the term (or its nominative case, if it occurs in an oblique case) is true of the thing (or of a demonstrative pronoun which points to the thing), then we say that the term supposits for the thing. This is true, at least, when the suppositing term is taken significatively. (T, ch. 63)

Ockham's definition accommodates the *supposito* of proper names, common nouns, and pointing words, which Peirce called *indexicals*. Peirce generalized the Scholastic distinctions and incorporated them into his classification of signs and signs of signs. Frege, however, never attained the breadth and depth of Ockham, let alone Peirce.

After presenting his theory of terms, Ockham applied it to the analysis of propositions. He started with simple propositions, consisting of a single subject and predicate, and continued with compound propositions. He formulated rules, which are logically equivalent to Tarski's, for deriving the truth values of compound propositions from the truth or falsity of the simple propositions contained in them. Ockham actually went beyond Tarski in analyzing modal, temporal, and fictional propositions. To analyze propositions about figments and negated terms, Ockham used paraphrases in Latin that were logically equivalent to Russell's paraphrases in symbolic logic. Following are two of his examples (P, ch. 12):

A donkey is a non-man. ⇒
A donkey is something, and that is not a man.

A chimera is a non-man. ⇒
A chimera is something, and that is not a man.

Ockham maintained that the first proposition is true because both parts of the conjunction are true. The second proposition is false because the first conjunct is false, and the second is therefore irrelevant to the truth value. Applying Ockham's method to Russell's sentence would produce the following paraphrase:

The present king of France is something, and that is bald.

In 1323, the first conjunct would have been true, and the truth of the second conjunct would depend on historical evidence about Charles IV. As Kaye pointed out, Ockham's solution, although equivalent to Russell's, had the advantage of assigning a meaning to each term, even in the case of fictional entities.

Unlike Frege and his followers, Peirce not only studied the medieval logicians, he delivered several lectures at Harvard on the logic of both Duns Scotus and William of Ockham, two of the last and greatest of the Scholastics. Where they disagreed, he usually preferred the realism of Scotus to the nominalism of Ockham. But he learned from both and incorporated their insights into his own broader and deeper theory of signs. Following is a brief summary of his theory of indexicals:

- Peirce coined the word *indexical* to characterize words such as pronouns and demonstratives that serve as a context-dependent index of their referent. He observed that adverbs such as *here* and *now* as well as tense markers on verbs are also indexicals.
- Instead of saying that a pronoun is used in place of a noun, Peirce claimed that a pronoun or other indexical directly indicates its referent and that a noun could more properly be considered a indirect symbol used in place of the more direct pronoun.
- By similarity, an icon such as  could represent a target for an arrow, but by convention or habitual use, it could become a symbol for an abstract goal. This example illustrates Peirce's point that the interpretant of a sign can grow over time and that symbols typically evolve from icons that are habitually used in a particular way. Without mentioning Peirce, Kripke (1977) said "I find it plausible that a diachronic account of the evolution of language is likely to suggest that what was originally a mere speaker's reference may, if it becomes habitual in a community, evolve into a semantic reference."
- Peirce maintained that a proper name, when first used to introduce someone or something, is an indexical. At subsequent uses, however, it becomes a symbol for the individual that had been introduced. Proper names of fictional entities, such as Sherlock Holmes, are signs that are introduced as indexicals for hypothetical individuals. Subsequently, they become symbols for

those hypotheses. Peirce's treatment of fictional terms was compatible with the Scholastic theory, which considered them to have *suppositio*, even though that *suppositio* did not have a physical referent.

- Unlike Russell, who considered the indexical use of the word *the* to be an ambiguous and therefore degenerate case, Peirce maintained that the indexical use of *the* is its basic use. That interpretation answers Kripke (1977): Russell's treatment of *the* as the mark of a globally unique referent is merely a special case where the context happens to be the entire universe for all time.
- Long before John Perry (1979) published his famous paper, "The problem of the essential indexical," Peirce observed that every proposition stated in any language, including any notation for logic, must contain at least one indexical in order to determine the referents of its symbols. This observation is true even when all referents are indicated by proper names, since as Peirce observed, every proper name is first introduced as an indexical and by convention it later becomes a symbol of an index.

As late as 1989, a group of 17 philosophers paid tribute to David Kaplan's analysis of demonstratives and indexicals, while discussing Frege's brief remarks on those topics in excruciating detail (Almog et al. 1989). None of them, however, mentioned Peirce or Ockham. In the concluding article of that collection, Kaplan (1989) admitted that he was not able to correct all the shortcomings of his earlier work: "I don't know exactly how to fix some of the sections that now seem wrong, and I don't yet see how to connect my current thinking, about propositional attitudes and proper names, with indexicals." In the writings of the last two decades of his life, Peirce achieved a wide-ranging synthesis of his thoughts in these areas, where Kripke, Kaplan, and others admit that their ideas are still tentative or incomplete. Perhaps they wouldn't agree with all of Peirce's conclusions, but they cannot afford to ignore them.

Even more recently, Barry Smith and John Searle debated some issues, or rather talked past one another about some topics, which could have been clarified by an application Peirce's trichotomy (Smith & Searle 2001). Smith began with a criticism of Searle's book *The Construction of Social Reality*, which he tried to interpret in terms of his own ontology of social objects. Searle replied

> I think in the end he makes many useful points, but I also believe that he misunderstands me in certain very profound ways. I believe his misunderstandings derive from the fact that he approaches this topic with a set of concerns that are fundamentally different from mine, and in consequence, he tends to take my views as attempts to answer his questions rather than attempts to answer my questions.

In Peircean terms, Smith was trying to use the dyadic *partOf* relation of mereology to represent fundamentally triadic relations of people, social institutions, and their purposes. Searle, however, recognized the need for a triadic relation, which he expressed in the pattern X *counts as* Y *in context* C. This relation gave Searle greater flexibility than Smith's dyads, but Smith criticized that flexibility as too loose and imprecise. In particular, Smith noted that a context itself is a social object that requires some independent definition. Both authors made valid points: Searle's book illustrates the power of triadic relations for analyzing social institutions, but Smith's criticism shows the need for greater precision in distinguishing different kinds of triads. Peirce's trichotomy is the key to resolving this dispute: instead of using a single triad, Peirce formulated a metalevel principle for generating different triads when applied to different phenomena.

When applied to the modes of existence, Peirce's trichotomy generates three fundamental ontological categories, which correspond to Kant's triad under Modality: Possibility, Actuality, and Necessity.

- Possibility includes everything that can be defined without an internal contradiction. It includes all mathematical structures, since the existential quantifier in a mathematical theory does not imply existence in the physical world, but only the possible existence of something that has a formal structure characterized by certain axioms. In effect, every consistent mathematical theory can be prefixed with the phrase “It is possible that there exists something that satisfies the following axioms.”
- Actuality includes everything that exists in the universe. It is the subject matter of the natural sciences: physics, chemistry, biology, geology, and astronomy.
- Necessity includes the general laws or principles that govern the universe and their implications. Although Peirce was a realist concerning the laws of nature, he was not a strict determinist. On the contrary, he believed in an irreducible residue of pure chance. He would have been delighted by the subsequent developments of quantum mechanics, especially Heisenberg’s uncertainty principle.

These three categories clarify the issues discussed by the physicist Eugene Wigner (1960) in his classic paper “On the unreasonable effectiveness of mathematics in the natural sciences.” Wigner marveled at the success of mathematics in describing the universe and predicting the outcome of experiments before they had been carried out. That success, however, is implied by Peirce’s theory: everything that is actual can be described by mathematics because the hierarchies of infinities envisioned by Georg Cantor include more than enough possibilities to describe the finite universe; mathematical theories can predict the future because the infinity of all possible theories includes the formulations of every law of nature. The goal of science is to search that infinity of possibilities to find theories that best characterize what exists and how it operates. What is truly marvelous is not the ability of mathematics to express accurate theories about the universe, but the ability of the human mind to discover those theories or at least useful approximations to them.

Peirce’s category of signs overlaps the categories of modality because every sign is a way of interpreting something that is possible, actual, or necessary. In fact, everything that exists can be interpreted as a sign in many different ways. The most basic interpretation is what Peirce called a *sinsign* — something that serves as a sign of its own existence. A weather vane on a steeple, for example, is a sinsign when it is considered as a sign of itself. It serves as an index when it is used to indicate the direction of the wind. An icon of a rooster on the weather vane is a sign of the bird it resembles, but it might also be interpreted as a sign of a bird facing into the wind because its streamlined shape reduces the resistance from that direction. A rooster is also used as a symbol of early morning because its habitual crowing makes it an index of dawn. A closer inspection of the weather vane could reveal many other signs: a trademark as a symbol of the manufacturer, the composition of the metal as an index of the manufacturing process and even the source of the ore, and the design as an index of the style or the period when it was made. Finally, a weather vane on a steeple, even when made in the 20th century, could be used as a symbol of a rural 19th-century village with its close ties to the natural forces of wind and weather.

A similar analysis of any physical object or activity, whether natural or artificial, would reveal many such interpretations. Even phenomena originating billions of light years away could be interpreted in different ways by different people at different times. A photograph of some distant light might be interpreted as an index of a black hole, even though the photograph was taken before the concept of black hole had been invented. In summary, the categories of signs do not classify the kinds of beings, but the ways in which phenomena caused by beings may be interpreted.

5. Whitehead's Process Philosophy

Like Peirce, Whitehead was a scientist, whose publications included groundbreaking research in algebra, geometry, theoretical physics, and logic. Also like Peirce, he was a voracious reader who studied and debated philosophy with topnotch philosophers throughout his adult life. But as he said in his autobiography, he never stepped inside a philosophy class until he became a professor of philosophy at Harvard at age 63. Whitehead's major contribution to philosophy is his system of *process philosophy* or *philosophy of organism*, which he published in several books that he wrote at Harvard.

In his magnum opus *Process and Reality*, Whitehead agreed with Heraclitus that "the flux of things is one ultimate generalization around which we must weave our philosophical system." But he considered the other ultimate generalization to be the "permanences amid the inescapable flux," which Plato tried to capture in his eternal, unchanging Platonic forms:

> Plato found his permanences in a static, spiritual heaven, and his flux in the entanglements of his forms amid the fluent imperfections of the physical world.... Aristotle corrected his Platonism into a somewhat different balance. He was the apostle of "substance and attribute," and of the classificatory logic which this notion suggests. But on the other side, he makes a masterly analysis of "generation." Aristotle in his own person expressed a useful protest against the Platonic tendency to separate a static spiritual world from a fluent world of superficial experience.

Whitehead's most significant achievement was the synthesis of Plato and Aristotle with the recent developments in relativity and quantum mechanics. His starting point was Plato's theory of forms, but with Aristotle's "correction" that the forms inhere in the physical entities. Then he updated the ancient conceptions of form and matter with the latest developments in physics and mathematics:

- *Matter.* The most serious flaw in Aristotle's theory of the form-matter composite was his incurably vague notion of matter. Like Peirce, Whitehead believed that physicists were the best qualified to characterize matter, energy, and the laws that govern their interactions. He assumed relativity and quantum mechanics as they were known in 1929, but the more recent developments in physics are, if anything, even better confirmations of his process philosophy.
- *Forms.* As a mathematician, Plato adopted geometrical patterns as his primary examples of forms. As a trained physician, Aristotle did his most significant experimental work in biology, and his most detailed examples were the forms of plants and animals. Like most mathematicians, Whitehead had a natural inclination toward a Platonic view of mathematical forms, which he called *eternal objects* or *forms of definiteness*. Physical objects are long-lasting aspects of processes or "recurring event types" characterized by the forms.

Whitehead's notion of eternal object was criticized by philosophers who were still under the influence of Russell's supreme axiom. However, the identification of forms with mathematical structures gives them the same ontological status as anything else in mathematics. Even professed nominalists, such as Quine, have admitted Cantor's hierarchy of infinite sets. Given set theory, the rest of mathematics, including Whitehead's forms, can be constructed from it. Today, computer simulations of virtual reality have used mathematical models to represent forms ranging in size from the astronomical to the subatomic levels. The patterns of tiny polygons used in VR simulations can represent biological forms with a photographic level of detail.

Among the many philosophers who have noted strong similarities between the philosophies of Peirce and Whitehead, the first were Charles Hartshorne and Paul Weiss, two of Whitehead's former students, who edited the first six volumes of Peirce's *Collected Papers*. Another was William Reese (1952), who wrote

In general, the logic of Peirce's thought modifies Whiteheadian cosmology by clearly identifying the basic philosophic categories with modes of being... The result of this mutual play of principle upon concept between the two systems is, we suspect, a position of philosophic realism combining the emphases of both...

In fact, the first six of Whitehead's "categories of existence" can be interpreted as two Peircean triads, as in Figure 3. The physical triad on the left subdivides the category of physical entities, which would correspond to Kant's category of Actuality. The abstract triad on the right subdivides the category of abstract entities, which would correspond to Kant's category of Possibility. Kant's category of Necessity could be added as a third branch to represent the laws, which Peirce subdivided into the laws of logical necessity, physical necessity, and intentional or subjective necessity.

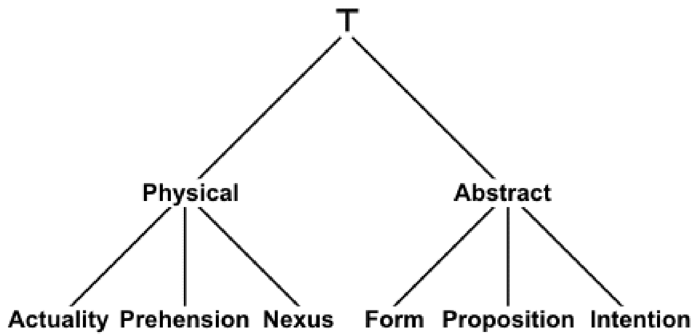

Figure 3: Whitehead's categories organized in Peircean triads

The physical categories on the left of Figure 3 represent what Whitehead (1929) called "the ultimate facts of immediate actual experience." The three categories Whitehead defined for *actual entities, prehensions,* and *nexûs* make up a triad of physical categories characterized by the Kantian triad under Relation: Inherence, Causality, and Community.

1. Actuality represents Whitehead's *actual entities* or *actual occasions*, which are characterized by Inherence or what they are in themselves, independent of anything else. They "are the final real things of which the world is made up. There is no going behind actual entities to find anything more real. They differ among themselves: God is an actual entity, and so is the most trivial puff of existence in far-off, empty space." (p. 18)
2. Prehension is Whitehead's category for "concrete fact of relatedness". It is broader than the Kantian category of causality, if interpreted merely as efficient causation; but if causality is interpreted as Aristotle's *aitia*, which also include final, formal, and material causes, then Whitehead's prehension would be very close to an Aristotelian version of causality. Whitehead explained "that every prehension consists of three factors: (a) the *subject* which is prehending, namely, the actual entity in which that prehension is a concrete element; (b) the *datum* which is prehended; (c) the *subjective form* which is *how* that subject prehends that datum." (p. 23) In other words, a prehension is a dyadic physical relation, in which the subjective form characterizes the type of relation.
3. Nexus is Whitehead's category that corresponds to Kant's category of Community. It represents an instance of connecting or binding together a community or society of actual entities: "Actual entities involve each other by reason of their prehensions of each other. There are thus real individual facts of the togetherness of actual entities, which are real, individual, and particular, in the same sense in which actual entities and the prehensions are real, individual and particular. Any such particular fact of togetherness among actual entities is called a *nexus*." (p. 20)

Besides the three physical categories, Whitehead maintained “All else is, for our experience, derivative abstraction.” He classified the abstractions in the categories of *eternal objects, propositions,* and *subjective forms*, which constitute a triad of abstract potentials for characterizing inherence, causality, and community (with the proviso that causality is interpreted a broad sense that is close to Aristotle’s *aitia*).

1. Whitehead’s eternal objects correspond to Plato’s forms, but in Aristotle’s sense that the forms are derivative abstractions rather than the ultimate reality. An eternal object is a “pure potential” that can only be described by its manner of “ingression” or instantiation in actual entities. A circle, for example, is an abstraction that can be realized or instantiated in a particular physical object, such as a dinner plate. Whitehead would agree with Aristotle that the potentiality of the circle is realized in the dinner plate, thereby contributing a definite form to the baked clay that becomes the plate.

2. For Proposition, both Whitehead and Peirce were influenced by Plato: “The *logos* comes to us by the interweaving (*symplokê*) of the forms with one another” (*Sophist* 259E5). For a simple proposition like cat(Yojo), the form named Cat is predicated of a single entity named Yojo. For a more complex proposition like *Yojo is chasing a mouse*, the syntax of the English sentence or a logical formula “interweaves” the forms named Cat, Chase, and Mouse with the relations that connect them. Peirce would agree with Whitehead that “The actual entities involved are termed the *logical subject*, and the complex eternal object is the *predicate*.” In this example, the complex pattern is predicated of three physical entities: Yojo, a mouse, and an act of chasing.

3. As abstract Thirdness, Whitehead’s *subjective forms* correspond to Peirce’s mediating intentions, which generate the community. Whitehead maintained “that there are many species of subjective forms, such as emotions, valuations, purposes, adversions, aversions, consciousness, etc.” As a synonym for subjective form, he also used the term *private matter of fact.* In Figure 3, that category is named Intention, a Scholastic term that was independently adopted by Peirce and Brentano.

Whitehead’s other two categories are principles for generating new categories: his Category 7 of *multiplicities* is made up of “pure disjunctions of diverse entities”; and Category 8 of *contrasts* is a source of distinctions that determine how entities are related in a prehension. Whitehead said “The eighth category includes an indefinite progression of categories, as we proceed from *contrasts* to *contrasts of contrasts* and on indefinitely to higher grades of contrasts.” These two principles may be viewed as special cases of Peirce’s methodeutic.

Although Whitehead understood the power of logic and the value of a good theory, he and Peirce would agree with Leibniz that only an infinite mind, such as God’s, could use logic to deduce all the implications of any initial state of the physical world. Even with the fastest computers, humans would be limited by the principle that Peirce called *finite fallibilism*. In his last book, *Modes of Thought*, Whitehead (1938) expressed similar concerns:

- “The conjunction of premises, from which logic proceeds, presupposes that no difficulty will arise from the conjunction of the various unexpressed presuppositions involved in those premises. Both in science and in logic, you have only to develop your argument sufficiently, and sooner or later you are bound to arrive at a contradiction, either internally within the argument, or externally in its reference to fact.” (p. 14)

- “It should be noticed that logical proof starts from premises, and that premises are based upon evidence. Thus evidence is presupposed by logic; at least, it is presupposed by the assumption that logic has any importance.” (p. 67)

- “The premises are conceived in the simplicity of their individual isolation. But there can be no logical test for the possibility that deductive procedure, leading to the elaboration of compositions, may introduce into relevance considerations from which the primitive notions of the topic have been abstracted.... Thus deductive logic has not the coercive supremacy which is conventionally conceded to it. When applied to concrete instances, it is a tentative procedure, finally to be judged by the self-evidence of its issues.” (p. 144)
- “The topic of every science is an abstraction from the full concrete happenings of nature. But every abstraction neglects the influx of the factors omitted into the factors retained.” (p. 196)

These cautionary notes are expressions of the limitations of logic by the senior author of the most influential treatise on logic ever written. They are not a rejection of logic, but a warning about the ways it can be misused. The theme of Whitehead’s book may be summarized in one sentence from it: “We must be systematic, but we should keep our systems open.”

6. Wittgenstein’s Language Games

Like Peirce and Whitehead, Wittgenstein was a system builder. Unlike Peirce and Whitehead, whose systems reached fruition in their later years, Wittgenstein presented his system in his first book and spent the remainder of his life pointing out the errors in it. For that reason, Wittgenstein is often called antitheoretical because he devoted so much effort to exploding his own and other people’s theories. Yet his method of criticizing theories is theoretical, but it is a metalevel theory about the limitations of any particular object-level theory. In the preface to the *Philosophical Investigations*, which was published just after his death, Wittgenstein wrote “I should have liked to produce a good book. This has not come about, but the time is past, in which I could improve it.” Although Wittgenstein despaired of ever presenting his later ideas in the elegant form of his first book, he still had a yearning for a grand synthesis, which he realized he could not achieve himself.

Wittgenstein made another intriguing remark in that preface: “I have been forced to recognize grave mistakes in what I wrote in that first book. I was helped to realize these mistakes — to a degree which I am hardly able to estimate — by the criticism which my ideas encountered from Frank Ramsey, with whom I discussed them in innumerable conversations during the last two years of his life.” Many philosophers, starting with Richard Rorty (1961), had noticed similarities between Peirce’s version of pragmatism and Wittgenstein’s later philosophy. After reviewing Ramsey’s published citations of Peirce, Jaime Nubiola (1996) concluded that Ramsey was certainly influenced by Peirce and he probably passed along some Peircean ideas, such as the notion of meaning as use. After those discussions, Wittgenstein dropped the assumption of context-independent meanings and treated language as a game, in which the meaning of a word is determined by its use. That view is consistent with Peirce’s maxim of pragmatism:

> Consider what effects that might conceivably have practical bearings you conceive the objects of your conception to have. Then, your conception of those effects is the whole of your conception of the object. (CP 5.438)

Grammarians have traditionally distinguished three uses for sentences: assertions expressed in the indicative mood, questions in the interrogative mood, and commands in the imperative mood. But as Peirce and Wittgenstein observed, every imaginable purpose can lead to a different kind of use. Wittgenstein (1953) said

> There are *countless* — countless different kinds of use of what we call ’symbols,’ ’words,’ ’sentences.’ And this multiplicity is not something fixed, given once and for all; but new types of language, new language games, as we may say, come into existence, and others

> become obsolete and get forgotten.

As examples of the multiple uses, he cited

> Giving orders, and obeying them; describing the appearance of an object, or giving its measurements; constructing an object from a description (a drawing); reporting an event; speculating about an event; forming and testing a hypothesis; presenting the results of an experiment in tables and diagrams; making up a story, and reading it; play acting; singing catches; guessing riddles; making a joke, telling it; solving a problem in practical arithmetic; translating from one language into another; asking, thanking, cursing, greeting, praying.

Inspired by Wittgenstein's list of uses, Austin (1962) developed his theory of speech acts, each of which represents a different way of using a sentence in natural language. Peirce had made a similar observation: every sentence in a natural language expresses a proposition and its intended use:

> A *proposition*, as I have just intimated, is not to be understood as the lingual expression of a judgment. It is, on the contrary, that sign of which the judgment is one replica and the lingual expression another. But a judgment is distinctly *more* than the mere mental replica of a proposition. It not merely *expresses* the proposition, but it goes further and *accepts* it.... One and the same proposition may be affirmed, denied, judged, doubted, inwardly inquired into, put as a question, wished, asked for, effectively commanded, taught, or merely expressed, and does not thereby become a different proposition. (EP 2.311-312)

Speech acts, as described by Austin, are an important aspect of natural language, but the different ways of using a sentence do not, by themselves, change the meanings of the words that occur in it. Both Peirce and Wittgenstein, however, observed that every symbol, not just the sentences, may have multiple uses. In addition to Austin's multiple uses for sentences, Wittgenstein's language games accommodate multiple uses for individual word types. As Peirce said, the "conception" that constitutes the meaning of a word is the totality of the "effects that might conceivably have practical bearings." When a word is used in a new way, it has new effects, and its corresponding conception is modified by the "practical bearings" of those new effects.

Wittgenstein compared grammar, which determines how words are used in a sentence, to the rules that determine how the pieces are used in a game of chess. The games of go and go-moku illustrated in Figure 1 are even better examples. Each game uses the same stones, the same board, and the same method of two players alternately placing stones on vacant points of the board. The only difference between the two games is in the scoring procedures. As Figure 1 shows, that difference leads to totally different patterns during the course of the games. At a syntactic level, the rules for placing stones are the same, but the meaning of the patterns of stones is determined by the scoring procedures, which are only applied at the end of a game. Besides go and go-moku, other games may be invented that use the same pieces and moves. In another kind of game, the player with the black stones might try to form a continuous path that connects the left and right sides of the board, while the player with white would try to connect the top and bottom. With the same stones and the same syntax, each change in the scoring rules changes the meaning of the patterns.

The practice of reusing old pieces and moves in new games corresponds to *metaphors*, which are language games that adapt familiar words and syntactic patterns to new subjects and ways of thinking. As an example, consider the metaphorical uses of the verb *support* in the following sentences:

```
Tom supported the tomato plant with a stick.
Tom supported his daughter with $10,000 per year.
Tom supported his father with a decisive argument.
Tom supported his partner with a bid of 3 spades.
```

The first sentence uses the verb *support* in its original sense of physically holding something up. The other sentences are metaphorical extensions that use the same verb and the same syntactic pattern to link the noun phrases in a more abstract domain of discourse:

`A person supported` NP_1 `with` NP_2.

Each use of the verb can only be understood with respect to a particular subject matter: physical structures, financial arrangements, intellectual debate, or the game of bridge. Just as the meaning of the pieces and moves in a game will change with differences in the method of computing the score, the meaning of the words in a sentence will change with differences in the subject matter. Metaphor is not a decorative element for expressing emotion in poetry, but an essential mechanism for extending a finite vocabulary to accommodate an open-ended range of subject matter.

As an example of the way meanings evolve, consider the English word *car*, which was originally an abbreviation of *carriage* and which came to mean "horseless carriage." But during the past century, that same word has come to represent computerized metal boxes that would be unrecognizable to the people who coined the term. Those changes were not caused by any linguistic events, but by changes in the subject matter. Over longer periods, even more drastic changes can occur.

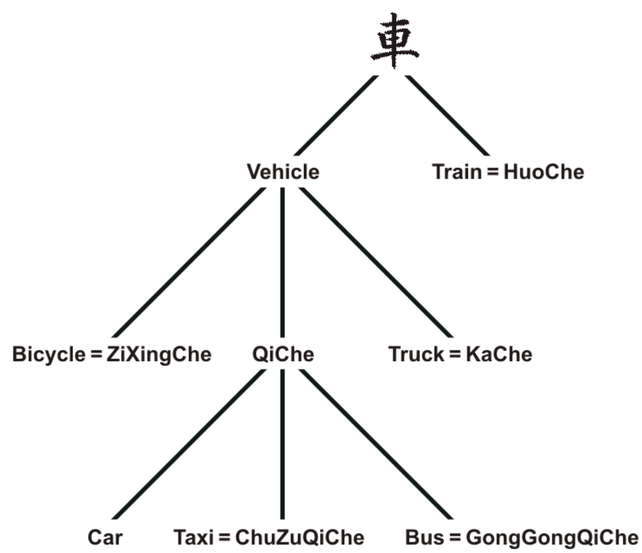

Figure 4: A hierarchy with the English *Vehicle* and the Chinese *Che*

Figure 4 shows a hierarchy of concept types that includes the English word *Car* and the Chinese *Che*, which is represented by the character at the top of the hierarchy. The English concept types *Car, Taxi, Bus, Truck=Lorry,* and *Bicycle* are subtypes of *Vehicle*. The Chinese types do not exactly match the English: *Che* is a supertype of *Vehicle* that includes *Train*, which is not usually considered a vehicle in English. The type *QiChe* (Energy-Che) has no English equivalent, and it includes *Car*, which has no Chinese equivalent.

The original meaning of the word *che* is illustrated by the icon used to represent it: a simple wagon consisting of a box, one axle (represented by the vertical line through the center), and two wheels (represented by the horizontal lines at top and bottom). That word has evolved to become the generic term, which can be qualified to represent any of the others: a train is a huo-che (fire-che), a bicycle is a zi-xing-che (self-powered-che), a taxi is a chu-zu-qi-che (for-hire-energy-che), and a bus is a gong-gong-qi-che (public-use-energy-che). Although specialized terms have been coined for various subtypes, the word *che*, by itself, can be used to represent any of them when the context is sufficient to distinguish the details. A Chinese speaker would normally say "Call me a *che*", "I'm waiting for the *che*", or "I parked my *che* around the corner." The listener would either infer the implied subtype from the context or ask a question to resolve the ambiguity.

Wittgenstein's theory of language games has major implications for both computational linguistics and semantic theory. It implies that the ambiguities of natural language are not the result of careless speech by uneducated people. Instead, they result from the fundamental nature of language and the way it relates to the world: each natural language has a finite number of words that are used and reused to represent an unlimited number of topics. A closed semantic basis along classical lines is not possible for any natural language. Instead of assigning a single meaning or even a fixed set of meanings to each word, a theory of semantics must permit an open-ended number of meanings:

- Words are like playing pieces that may be used and reused in different language games.
- Associated with each word is a limited number of lexical patterns that determine the rules that are common to all the language games that use the word.
- Meanings are deeper conceptual patterns that change from one language game to another.
- Metaphor and conceptual refinement are techniques for transferring the lexical patterns of a word to a new language game and thereby creating new conceptual patterns for that game.

Once a lexical pattern is established for a concrete domain, it can be transferred by metaphor to create similar patterns in more abstract domains. By this process, an initial set of lexical patterns can be built up; later, they can be generalized and extended to form new conceptual patterns for more abstract subjects. The possibility of transferring patterns from one domain to another increases flexibility, but it leads to an inevitable increase in ambiguity.

If the world were simpler, less varied, and less changeable, natural languages might be unambiguous. But the complexity of the world causes the meanings of words to shift subtly from one domain to the next. If a word is used in widely different domains, its multiple meanings may have little or nothing in common. As an example, the word *invest*, which originally meant to put on clothing, has come to mean either to surround a fortress or to make a certain kind of financial transaction. In Italian, the related word *investmento* has all the senses of the English *investment*, but with the added sense of traffic accident. As these examples illustrate, the mechanisms of natural languages not only permit, but actually facilitate shifts in meaning that can be arbitrarily large. They have enabled isolated tribes using stone-age implements to adapt to 21st-century cultures within the lifetime of a single generation, while continuing to speak what is called "the same language."

7. Foundations of a New Synthesis

According to Peirce and Whitehead, the new foundations for ontology are the same as the old foundations: the *philosophia perennis* as outlined by Plato and Aristotle, but updated with the more recent developments in science, mathematics, and logic. Whitehead said that all of western philosophy for the past 2,500 years has been a series of footnotes to Plato and Aristotle. Peirce made a similar point, but he expressed it in terms of his trichotomy: there are seven fundamentally different metaphysical systems, each characterized by the combination of Firstness, Secondness, and Thirdness that it recognizes (EP 2.179-195):

1. A metaphysics of pure Firstness would admit of quality or sensation without any further interpretation. As examples, Peirce mentioned "Nihilism, so-called, and Idealistic Sensualism."
2. Pure Secondness would be a philosophy of brute facts and nothing else. As an example, Peirce cited "Strict individualism."
3. As a metaphysics of pure Thirdness, Peirce cited "Hegelianism of all shades." In distinguishing

his triads from Hegel's, Peirce emphasized the equal status of all three categories and rejected the idea that "Firstness and Secondness must somehow be *aufgehoben*" (CP 5.91).

4. A combination of Secondness and Thirdness would recognize the reality of facts and laws while ignoring sensation. As examples, Peirce cited "Cartesianism of all kinds, Leibnizianism, Spinozism and the metaphysics of the physicists of today."
5. A combination of Firstness and Thirdness would recognize sensations and ideas, while ignoring facts. As an example, Peirce cited "Berkeleyism."
6. A combination of Firstness and Secondness would recognize sensation and facts, while denying the reality of generalizations, such as the laws of nature or the semiotic processes that support life at every level from bacteria to humans. As an example, Peirce mentioned "Ordinary Nominalism." It would include most 20th-century analytic philosophy, as described in Section 2 of this article.
7. For the metaphysics that puts equal emphasis on all three categories, Peirce mentioned Kant, Thomas Reid, and "the Platonic philosophy of which Aristotelianism is a special development." In characterizing his own philosophy, Peirce added "I should call myself an Aristotelian of the scholastic wing, approaching Scotism, but going much further in the direction of scholastic realism."

In stressing the continuity of their philosophy with Plato and Aristotle, Peirce and Whitehead were not retreating to a dogmatic repetition of old formulas. On the contrary, both of them were famous, if not notorious for creating novel formulations replete with neologisms that some people have found repugnant. Wittgenstein seldom cited or even mentioned any of his sources, but his early philosophy could be classified as "Ordinary Nominalism", and his later work could be considered a series of examples that probe the weaknesses of any philosophy that ignores Thirdness, including his own early work.

An ontology that synthesizes the insights of Peirce, Whitehead, and Wittgenstein would belong to the seventh system of metaphysics. It would therefore include Peirce's trichotomy and its use as a metalevel principle for generating all the triads needed for a complete theory of semiotics. It would also include Whitehead's process philosophy, but with the categories reorganized in Peircean triads. Although Wittgenstein never formalized his theory of language games, each language game could be identified with a kind of *microtheory* as used in many AI systems. Winograd's SHRDLU system implemented a simple, but rather limited example of a microtheory for a world consisting of blocks moved by a robot. R. V. Guha (1991) introduced collections of microtheories into the vastly more complex Cyc system in order to make it more modular and more adaptable to a wide range of applications.

Multiple Hierarchies. As a way of formalizing a structure of microtheories to accommodate an open-ended, possibly inconsistent *knowledge soup*, Sowa (1990c, 2000) proposed to organize them in an infinite lattice, which would be rich enough to include any possible language game that any finite reasoner (human, computer, or extraterrestrial) could ever invent. Central to the framework is a partitioning of the knowledge base into four separate hierarchies with appropriate mappings to link them. A multilingual system of N languages would have 2N+2 hierarchies.

1. *Words.* For each natural language, a hierarchy of words and word senses similar to WordNet and EDR or the more automated MindNet (Richardson et al. 1998; Dolan et al. 2000). Each word sense would be mapped to some type in the type lattice. EDR, for example, has separate hierarchies for Japanese words and English words, which are mapped to a single type hierarchy that contains the word senses of both languages.

2. *Types.* A lattice of concept and relation types, which are used to index the contents of the other three hierarchies. Some types may be expressible by word senses in several different languages, but others might be not expressible by single words in any of the N languages. A type that does not correspond to a single word sense in some language would have to be expressed by a multiword phrase in that language.
3. *Canonical graphs.* A partial ordering of conceptual graphs that express the *lexical patterns* and *thematic roles* of natural languages. Each canonical graph is indexed by the types that occur in it. The canonical graphs are generalizations of the more informal frame systems that are often used in computational linguistics to represent lexical patterns.
4. *Theories.* An open-ended lattice of theories, each of which axiomatizes the detailed knowledge about some subject from a certain point of view. Each theory is indexed by the types that occur in its axioms. The complete lattice of all possible theories is infinite, but only a finite subset could ever be implemented in any actual system. Any implementation, however, must make provision to accommodate any theory in the infinite lattice that might turn out to be useful.

Richardson and his colleagues have shown that most, if not all of the information in the hierarchies of WordNet or EDR can be derived by automated tools that process the dictionaries and encyclopedias written for human readers. Semiautomated tools can be used to aid in the development of the other hierarchies, but further research in linguistics, semiotics, and knowledge representation is necessary to support those tools.

Theories, Models, and the World. The problems of knowledge soup result from the difficulty of matching theories based on discrete concepts to the continuum of physical world. The AI techniques of fuzziness, probability, defaults, revisions, and relevance are different ways of measuring, evaluating, or accommodating the inevitable mismatch. Each technique is a metalevel approach to the task of finding or constructing a theory and determining how well it approximates reality. To bridge the gap between theories and the world, Figure 5 shows models as Janus-like structures, with an engineering side facing the world and an abstract side facing the theories.

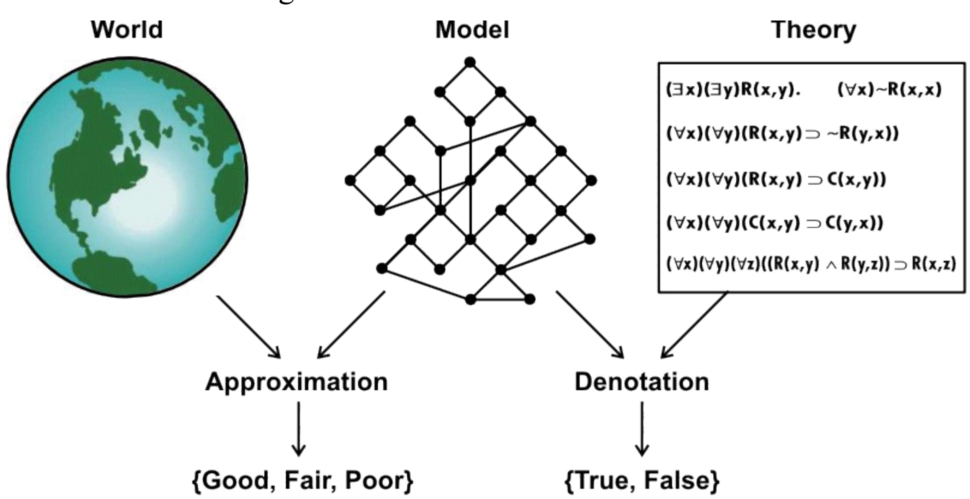

Figure 5: Relating a theory to the world

On the left is a picture of the physical world, which contains more detail and complexity than any humanly conceivable model or theory can represent. In the middle is a mathematical model that represents a domain of individuals ***D*** and a set of relations ***R*** over ***D***. If the world had a unique decomposition into discrete objects and relations, the world itself would be a universal model, of which all accurate models would be subsets. But as the examples of knowledge soup have shown (Sowa 1990c, 2000), the selection of a domain and its decomposition into objects depends on the intentions of some agent and the limitations of the agent's measuring instruments. Even the best models are approximations to a limited aspect of the world for a specific purpose. The statistician George Box expressed that point in a pithy slogan: *All models are wrong, but some are useful*.

The two-stage mapping from theories to models to the world replaces the direct mapping of sentences to the world as characterized by two diametrically opposed views of semantics: the Ockham-Tarski version of model theory, and the version of fuzzy logic by Lotfi Zadeh (1975). In the Ockham-Tarski approach, each sentence has two possible truth values: {true, false}. In fuzzy logic, a sentence may have a continuous range of possible values from 0.0 for certainly false to 1.0 for certainly true; intermediate values would represent hedging terms, such as likely, unlikely, very nearly true, or almost certainly false. Susan Haack (1978, 1996) was one of the early critics of fuzzy logic, and she has continued to sharpen her arguments against the claims that natural language justifies or even requires "degrees of truth." Her most serious criticism is not that fuzzy logic is vague, but that it is too precise: instead of modeling the way people talk and think about vagueness, fuzzy logic forces an unwarranted quantification of vagueness. The two-stage mapping of Figure 5, however, makes room for both kinds of reasoning: a rigorous two-valued logic for evaluating the truth of a mathematical theory in terms of a model; and a continuum of fuzzy values that measure the suitability of a particular model for a particular purpose in actions upon the world. Such two-stage mappings have long been used in science and engineering: a strict two-valued logic is necessary for mathematical reasoning, and a continuum of values is used for quantifying experimental error and degree of approximation.

Searching the Lattice of Theories. Although the world is bigger than any human can comprehend or any computer can compute, the sets of all possible theories and models are even bigger. The entire universe contains a finite number of atoms, but the lattice of all possible theories is infinite, and the set of models of those theories is uncountably infinite. The ultimate task of science is to search that vast infinity in the hope of finding a theory that gives the best answers to all possible questions. Yet that search may be in vain. Perhaps no single theory is best for all questions; even if one theory happened to be the best, there is no assurance that it would ever be found; and even if somebody found it, there might be no way to prove that it is the best.

Engineers have a more modest goal. Instead of searching for the best possible theory for all problems, they are satisfied with a theory that is good enough for the specific problem at hand. When they are assigned a new problem, they look for a new theory that can solve it to an acceptable approximation within the constraints of available tools, budgets, and deadlines. Although no one has ever found a theory that can solve all problems, people everywhere, from prehistoric times to the present, have been successful in finding more or less adequate theories that can deal with the routine problems of daily life. As science progresses, engineering techniques advance with it, but the engineers do not have to wait for a perfect theory before they can do their work.

From each theory, the partial ordering of the lattice determines the paths to more general theories above and more specialized theories below. Figure 6 shows four basic ways of moving along the paths from one theory to another: *contraction, expansion, revision,* and *analogy*. Each move corresponds to one of the four operators for *belief revision* or *theory revision*. The first three operators are defined by the AGM axioms (Alchourrón et al. 1985); the fourth operator, which revises a theory by renaming the labels of types and relations, is defined by Sowa (2000).

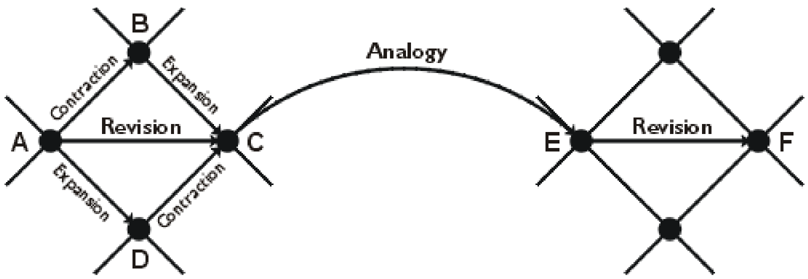

Figure 6: Four belief-revision operators

To illustrate the moves through the lattice, suppose that theory A is Newton's theory of gravitation applied to the earth revolving around the sun and that F is Niels Bohr's theory about an electron revolving around the nucleus of a hydrogen atom. The path from A to F is a step-by-step transformation of the old theory to the new one. The revision step from A to C replaces the gravitational attraction between the earth and the sun with the electrical attraction between the electron and the proton. That step can be carried out in two intermediate steps:

- *Contraction*. Any theory can be contracted or reduced to a smaller, simpler theory by deleting one or more axioms. In the move from A to B, axioms for the gravitational force would be deleted. Contraction has the nonmonotonic effect of blocking proofs that depend on the deleted axioms.
- *Expansion*. Any theory can be expanded by adding one or more axioms to it. In the move from B to C, axioms for the electrical force would be added. The net result of both moves is a substitution of electrical axioms for gravitational axioms.

Unlike contraction and expansion, which move to nearby theories in the lattice, analogy jumps to a remote theory, such as C to E, by systematically renaming the types, relations, and individuals that appear in the axioms: the earth is renamed the electron; the sun is renamed the nucleus; and the solar system is renamed the atom. Finally, the revision step from E to F uses a contraction step to discard details about the earth and sun that have become irrelevant, followed by an expansion step to add new axioms for quantum mechanics.

By repeated application of the four operators in Figure 6, any theory or collection of beliefs can be converted into any other. Multiple contractions would reduce a theory to the *empty* or *universal theory* $\top$ at the top of the lattice that contains only the tautologies that are true of everything. Multiple expansions would lead to the *inconsistent* or *absurd theory* $\bot$ at the bottom of the lattice, which contains all axioms and is true of nothing. The analogy operator allows short cuts that can jump across the lattice by a systematic relabeling of the types and relations. If the original theory is consistent, the analogy must also be consistent, since the axioms are identical except for a change of a change of names.

Each step through the lattice of theories is simple in itself, but the infinity of possible steps makes it difficult for both people and computers to find the best theory for a particular problem. Newton became famous for finding the axioms that explain the solar system, and Bohr won the Nobel Prize for revising them to explain the atom.

Abduction. Of the three reasoning methods in Peirce's methodeutic, abduction is the only one that can introduce a truly novel idea. It is the method that generates Einstein's "free creations of thought which cannot be inductively derived from sense experiences." In Peirce's system, abduction is the replacement for Descartes's innate ideas and for Kant's synthetic *a priori* judgments. Abduction may be considered a process of selecting chunks from the knowledge soup, evaluating their relevance to the problem at hand, and assembling them into a novel combination. Abduction may be performed at various levels of complexity:

- *Reuse*. Do an associative search for a previously used rule, pattern, or theory that can be applied to the current problem.
- *Revise*. Find a theory or fragment of a theory that approximately matches the problem at hand and apply the belief revision operators to adapt it to the current situation.
- *Combine*. Search for scattered fragments or *chunks* of knowledge and perform repeated steps of belief revision to combine them or modify them to form a theory appropriate to the current situation.

All these processes may be used iteratively. After a hypothesis is formed by abduction, its implications must be tested against reality. If its implications are not confirmed, the hypothesis must be revised in another stage of abduction. In Peirce's "logic of pragmatism," the free creations of thought generated by abduction are constrained at the two "gates" of perception and action:

> The elements of every concept enter into logical thought at the gate of perception and make their exit at the gate of purposive action; and whatever cannot show its passports at both those two gates is to be arrested as unauthorized by reason. (EP 2.241).

Note Peirce's word *elements*: abduction does not create totally new elements, but it can reassemble previously observed elements in novel combinations. Each combination defines a new concept, whose full meaning is determined by the totality of purposive actions it implies. As Peirce said, meanings grow as new information is received, new implications are derived, and new actions become possible.

Logic of Pragmatism. In its narrow sense, abduction is one of three methods of reasoning in Peirce's methodeutic. In its broader sense, which includes induction for discovering the elements and deduction for deriving the implications, Peirce identified abduction with the logic of pragmatism. To illustrate the relationships, Figure 7 shows an agent who repeatedly carries out the cycle of induction, abduction, deduction, and action.

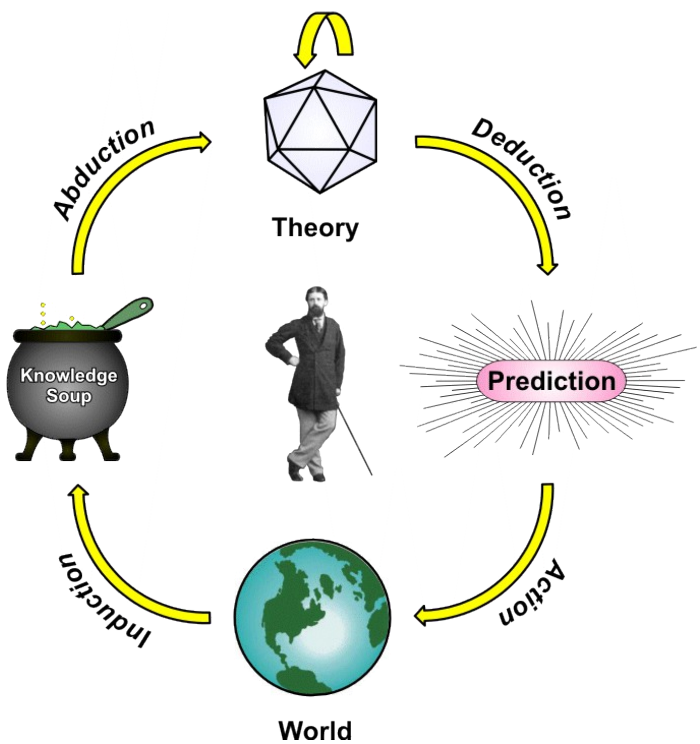

Figure 7: Peirce's cycle of pragmatism

The arrow of induction indicates the accumulation of patterns that have been useful in previous applications. The crystal at the top symbolizes the elegant, but fragile theories that are constructed from chunks in the knowledge soup by abduction. The arrow above the crystal indicates the process of belief revision, which uses repeated abductions to modify the theories by expansion, contraction, revision, and analogy. At the right is a prediction derived from a theory by deduction. That prediction leads to actions whose observable effects may confirm or refute the theory. Those observations are the basis for new inductions, and the cycle continues.

As Figure 7 illustrates, the chunks of knowledge in the soup enter through the gate of perception and are recognized as repeatable patterns by the process of induction. The crystalline theories at the top are hypotheses assembled by abduction. Those theories whose predictions lead to successful actions are added to the soup as chunks that become available for further abductions. The more often a chunk is used, the higher its *salience* or likelihood for future selections.

Learning is the process of accumulating chunks of knowledge in the soup and organizing them into theories — collections of consistent beliefs that prove their value by making predictions that lead to successful actions. Learning by any agent — human, animal, or robot — involves a constant cycling from data to models to theories and back to a reinterpretation of the old data in terms of new models and theories. Beneath it all, there is a real world, which the entire community of inquirers learns to approximate through repeated cycles of induction, abduction, deduction, and action.

Truth as the Aim of Inquiry. To evaluate the truth of his axioms and rules of inference, Peirce (1909) had developed a version of model-theoretic semantics, but he was dissatisfied with a definition of truth as a static correspondence between a sentence and a particular model of the world. Instead, he believed in a potential infinity of mathematical models, which could be applied to various aspects of the world, but he also rejected a relativistic view that all models are equally good. Instead, he defined truth as the ultimate goal of a search through an infinity of models that give better and better approximations to a wider range of phenomena. The denotation of a proposition in terms of a particular model must be supplemented with the scientific methods of experiment, observation, and test to determine whether the model is an adequate approximation to the world for the purpose at hand. Following are some quotations in which Peirce summarized that view:

- "The opinion which is fated to be ultimately agreed to by all who investigate is what we mean by truth." (CP 5.407)
- "Truth, what can this possibly mean except it be that there is one destined upshot to inquiry with reference to the question in hand." (CP 3.432)
- "Truth is that concordance of an abstract statement with the ideal limit towards which endless investigation would tend to bring scientific belief, which concordance the abstract statement may possess by virtue of the confession of its inaccuracy and one-sidedness, and this confession is an essential ingredient of truth." (CP 5.565)

Peirce's definition of truth and his logic of pragmatism, which supports that definition, are an elegant generalization of the practices of working scientists. Yet many philosophers who seized upon one brief quotation have failed to appreciate their full ramifications. In a survey of various theories of truth, Kirkham (1992) said

> Peirce's theory of truth is plausible only because it is parasitic on another, hidden theory of truth: truth as correspondence with reality. So why doesn't Peirce simply offer the latter as his theory of truth? (p. 83)

If he had read more of Peirce's writings, Kirkham might have found the answer to his question:

> That truth is the correspondence of a representation with its object is, as Kant says (1787, A58, B82), merely the nominal definition of it. Truth belongs exclusively to propositions. A proposition has a subject (or set of subjects) and a predicate. The subject is a sign; the predicate is a sign; and the proposition is a sign that the predicate is a sign of that of which the subject is a sign. If it be so, it is true. But what does this correspondence, or reference of the sign to its object, consist in? The pragmaticist answers this question as follows... if we can find out the right method of thinking and can follow it out, — the right method of transforming signs, — then truth can be nothing more nor less than the last result to which the following out of this method would ultimately carry us. (EP 2.379-380)

Quine (1960) is more subtle, but he hadn't read much more of Peirce's writings than Kirkham:

> But there is a lot wrong with Peirce's notion, besides its assumption of a final organon of scientific method and its appeal to an infinite process. There is a faulty use of numerical analogy in speaking of a limit of theories, since the notion of limit depends on that of "nearer than," which is defined for numbers and not for theories. And even if we by-pass such troubles by identifying truth somewhat fancifully with the ideal result of applying scientific method outright to the whole future totality of surface irritations, still there is trouble in the imputation of uniqueness ("*the* ideal result").... It seems likelier, if only on account of symmetries or dualities, that countless alternative theories would be tied for first place. (p. 23)

Quine's objection has three parts, each of which requires a separate answer:

1. Peirce made no "assumption of a final organon of scientific method," other than the repeated and unfettered cycles of induction, abduction, deduction, and testing illustrated in Figure 7. In rejecting Kant's claim that there is anything that could be inherently unknowable, Peirce maintained that for any question that science might ask, there exists a discoverable theory that could answer it. He admitted that discovering such a theory might take an indefinitely long time, but the existence of a theory in the infinite lattice does not depend on the method of search, its duration, or the nature of the minds that do the search.
2. The lattice of all possible theories provides a notion of "nearer than": a theory T_1 is nearer to a theory T_2 than it is to T_3 iff fewer belief revision steps (contraction, expansion, and analogy) are needed to convert T_1 to T_2 than to convert T_1 to T_3.
3. Peirce was well aware of the infinite number of symmetries, dualities, and other transformations that can change a statement's form without making any change in its implications. They can all be accommodated by grouping theories into equivalence classes (Sowa 2000). The ultimate goal of science is not a particular statement of a theory, but any statement within the equivalence class.

Conclusion. To deal with meaning, semiotics must go beyond relationships between signs to the relationships of signs, the world, and the agents who observe the world, interpret it in signs, and use the signs to plan further actions upon the world. Peirce's recognition of the ubiquity of signs enabled him to bridge the mind-body dichotomy: the mind itself is a sign formed by a complex structure of other signs, which are related by the methods of perception and action to the world and to all the people who communicate with each other in languages that express the multitudes of signs in their minds. Every living being, down to the level of single-celled bacteria, is a semiotic processor that responds to signs by generating more signs. The human brain is the most advanced of all known semiotic processors, but the signs it processes are simple compared to the signs encoded in DNA that generate every living thing including the human brain itself. This view by Peirce is compatible with the complementary positions by Whitehead and Wittgenstein. Together, the three of them provide the necessary counterbalance to the extreme nominalism of 20th-century analytic philosophy.

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