Peirce's Contributions to the 21st Century

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Abstract. Peirce was a precocious child, a 19th-century scientist who had an international reputation in both logic and physics, and a largely neglected philosopher in the 20th century. Peirce's research in logic, physics, mathematics, and lexicography made him uniquely qualified to appreciate the rigors of science, the nuances of language, and the semiotic processes that support both. Instead of using logic to understand language, the philosophers who began the analytic tradition — Frege, Russell, and Carnap — tried to replace language with a purified version of logic. As a result, they created an unbridgeable gap between themselves and the so-called Continental philosophers, they exacerbated the behaviorist tendency to reject any study of meaning, and they left semantics as an unexplored wilderness with only a few elegantly drawn, but incomplete maps based on Tarski's model theory and Kripke's possible worlds. This article reviews the ongoing efforts to construct a new foundation for 21st-century philosophy on the basis of Peirce's research and its potential for revolutionizing the study of meaning in cognitive science, especially in the fields of linguistics and artificial intelligence.

1 The Influence of Peirce and Frege

Charles Sanders Peirce is widely regarded as the most important philosopher born in America, and many of his followers consider him the first philosopher of the 21st century. An easy explanation for the neglect of his philosophy in the 20th century is that Peirce was "born before his time." A better approach is to ask what trends in the 20th century led to the split between analytic and Continental philosophy, and how Peirce's logic and philosophy relate to both sides of the split. The short answer is that his logic was adopted by the analytic philosophers, but the questions he addressed were closer to the concerns of the Continental philosophers. A longer answer is needed to show what Peirce's ideas can contribute to research and development projects in the 21st century.

Frege (1879) and Peirce (1880, 1885) independently developed logically equivalent notations for full first-order logic. Although Frege was first, nobody else adopted his notation, not even his most famous student, Rudolf Carnap. Schröder adopted Peirce's notation for his three-volume *Vorlesungen über die Algebra der Logik*, which became the primary textbook on logic from 1890 to 1910. Peano (1889) also adopted Peirce's notation, but he changed the logical symbols because he wanted to include mathematical symbols in the formulas; he gave full credit to Peirce and

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Schröder and criticized Frege's notation as unreadable. Whitehead and Russell (1910) cited Frege, but they adopted Peirce-Schröder-Peano notation for the *Principia Mathematica*.

To illustrate the differences in notation, consider the English sentence *John is going to Boston by bus*, which could be expressed in Peirce's algebraic notation as

$$\Sigma_x\Sigma_y\ (\mathrm{Go}(x) \bullet \mathrm{Person(John)} \bullet \mathrm{City(Boston)} \bullet \mathrm{Bus}(y) \bullet \mathrm{Agnt}(x,\mathrm{John}) \bullet \mathrm{Dest}(x,\mathrm{Boston}) \bullet \mathrm{Inst}(x,y))$$

Since Boole treated disjunction as logical addition and conjunction as logical multiplication, Peirce represented the existential quantifier by Σ for repeated disjunction and the universal quantifier by Π for repeated conjunction. Peano began the practice of turning letters upside-down and backwards to form logical symbols. He represented existence by $\exists$, consequence by $\supset$, the Latin *vel* for disjunction by $\vee$, and conjunction by $\wedge$. With Peano's symbols, this formula would become

$$(\exists x)(\exists y)(\mathrm{Go}(x) \wedge \mathrm{Person(John)} \wedge \mathrm{City(Boston)} \wedge \mathrm{Bus}(y) \wedge \mathrm{Agnt}(x,\mathrm{John}) \wedge \mathrm{Dest}(x,\mathrm{Boston}) \wedge \mathrm{Inst}(x,y))$$

Figure 1 shows a conceptual graph that represents the same information.

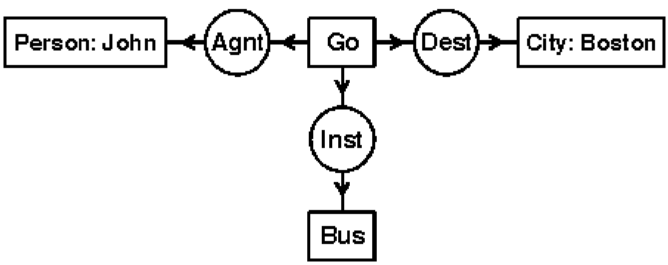

Fig. 1. Conceptual graph for *John is going to Boston by bus*

For his Begriffsschrift, Frege (1979) adopted a tree notation for first-order logic with only four operators: assertion (the "turnstile" operator), negation (a short vertical line), implication (a hook), and the universal quantifier (a cup containing the bound variable). Figure 2 shows the Begriffsschrift equivalent of Figure 1, and following is its translation to predicate calculus:

$$\sim(\forall x)(\forall y)(\mathrm{Go}(x) \supset (\mathrm{Person(John)} \supset (\mathrm{City(Boston)} \supset (\mathrm{Bus}(y) \supset (\mathrm{Agnt}(x,\mathrm{John}) \supset (\mathrm{Dest}(x,\mathrm{Boston}) \supset \sim\mathrm{Inst}(x,y)))))))$$

Frege's choice of operators simplified his rules of inference, but they led to awkward paraphrases: *It is false that for every x and y, if x is an instance of going then if John is a person then if Boston is a city then if y is a bus then if the agent of x is John then if the destination of x is Boston then the instrument of x is not y.*

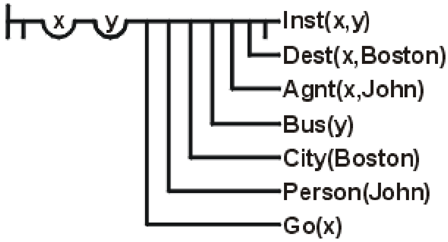

Fig. 2. Frege's Begriffsschrift for *John is going to Boston by bus*

Peirce began to experiment with *relational graphs* for representing logic as early as 1882, but he couldn't find a convenient representation for all the operators of his algebraic notation. Figure 3 shows a relational graph that expresses the same sentence as Figures 1 and 2. In that graph, an existential quantifier is represented by *a line of identity*, and conjunction is the default Boolean operator. Since Peirce's graphs did not distinguish proper names, the monadic predicates isJohn and isBoston may be used to represent names. Following is the algebraic notation for Figure 3:

$$\Sigma_x \Sigma_y \Sigma_z \Sigma_w\ (\mathrm{Go}(x) \bullet \mathrm{Person}(y) \bullet \mathrm{isJohn}(y) \bullet \mathrm{City}(z) \bullet \mathrm{isBoston}(z) \bullet \mathrm{Bus}(w) \bullet \mathrm{Agnt}(x,y) \bullet \mathrm{Dest}(x,z) \bullet \mathrm{Inst}(x,w))$$

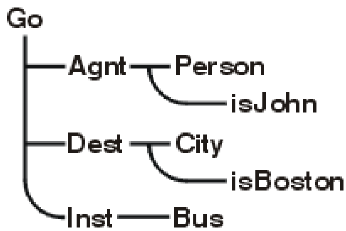

Fig. 3. Peirce's relational graph for *John is going to Boston by bus*

In 1896, Peirce discovered a simple convention that enabled him to represent full FOL: an oval enclosure that negated the entire graph or subgraph inside. He first applied that technique to his *entiative graphs* whose other operators were disjunction and the universal quantifier. In 1897, however, he switched to the dual form, the *existential graphs*, which consisted of the oval enclosure added to his earlier relational graphs. Peirce (1898) observed that metalevel relations could be attached to the oval to make further statements about the enclosed graphs. The most important innovation of the graphs was not the notation itself, but the rules of inference, which were an elegant and powerful generalization of *natural deduction* by Gentzen (1935).

Hilbert and Ackermann (1928) gave equal credit to Peirce and Frege, but later publications almost completely ignored Peirce. Frege was certainly a brilliant logician who deserves credit for the first publication of full FOL and for his high standards of rigor. Yet he had little influence on the technical development of logic, and mathematicians in the late 19th century were developing higher standards without any assistance from logicians. The historical footnotes have been amply documented by Putnam (1982), Quine (1995), Dipert (1995), and Hintikka (1997), but those studies don't explain why references to Peirce disappeared from the literature during most of the 20th century.

The primary reason for the focus on Frege at the expense of Peirce was not their logic, but their philosophy. Frege addressed narrow questions that could be expressed in logic; instead of broadening the scope of logic, many of his followers dismissed, attacked, or ridiculed attempts to address broader issues. In other areas of cognitive science, a similar emphasis on narrow technical questions led Watson (1913) to throw out the psyche from psychology by renaming the field *behaviorism*, and it led Bloomfield (1933) and Chomsky (1957) to throw out semantics from linguistics. Katz and Fodor (1963) reintroduced a tiny amount of semantics through a negative formula: "Language description minus grammar is semantics".

For linguistics and artificial intelligence, the narrow focus meant that the most important questions couldn't be asked, much less answered. The great linguist Roman Jakobson, whose career spanned most of the 20th century, countered Chomsky with the slogan "Syntax without semantics is meaningless." In AI, Winograd called his first book *Understanding Natural Language* (1972), but he abandoned a projected book on semantics when he realized that no existing semantic theory could explain how anyone, human or computer, could understand language. In a later book, coauthored with the philosopher Fernando Flores, Winograd (1986) abandoned the analytic foundations of his first book in favor of methods inspired by Heidegger's phenomenology. Winograd's disillusionment also affected many other AI researchers, who turned to the useful, but less ambitious problems of text mining, information retrieval, and user-interface design. Those techniques may be practical, but they won't solve the problems of understanding language, meaning, intelligence, or life.

After a century of narrow questions, it is time to examine the broader questions and ask how Peirce's methods might answer them. His first *rule of reason*, "Do not block the way of inquiry" (CP 1.135), implies that no question is illegitimate. Peirce applied that principle in criticizing Ernst Mach, the grandfather of logical positivism:

> Find a scientific man who proposes to get along without any metaphysics — not by any means every man who holds the ordinary reasonings of metaphysicians in scorn — and you have found one whose doctrines are thoroughly vitiated by the crude and uncriticized metaphysics with which they are packed. We must philosophize, said the great naturalist Aristotle — if only to avoid philosophizing. Every man of us has a metaphysics, and has to have one; and it will influence his life greatly. Far better, then, that that metaphysics should be criticized and not be allowed to run loose. (CP 1.129)

Whitehead and Gödel were two distinguished logicians who also considered metaphysics to be the heart of philosophy. The analytic philosophers cited them only for their contributions to logic, never for their philosophy. This article analyzes the origins of the extreme narrowness of analytic philosophy, Peirce's broader scope, and the potential of Peirce's semiotics to serve as the basis for reintroducing topics that the analytic philosophers deliberately rejected.

2 Logical Negativism

In his book *Beyond Analytic Philosophy*, Hao Wang, a former student of Quine and assistant to Gödel, classified philosophers by the terms *nothing else* and *something more*. The leaders of the analytic movement were mostly characterized by what they excluded: they chose a methodology that could address a limited range of topics and declared that nothing else was a legitimate matter of discussion. By applying logic to a narrow range of questions, they often achieved high levels of precision and clarity. But the philosophers who sought something more felt that the unclear questions were often the most significant, and they tried to broaden the inquiry to topics that the nothing-else philosophers rejected. Whitehead and Russell were two pioneers in logic who collaborated successfully on the *Principia Mathematica*, but were diametrically opposed in their attitudes toward philosophy. Whitehead (1929) constructed one of the largest and most ambitious metaphysical systems of the 20th century, but Russell was an outspoken critic of metaphysics. For the second edition of the *Principia*, Russell added a lengthy introduction based on his system of *logical atomism*, but Whitehead wrote a letter to *Mind* saying that he had taken no part in the revisions and he did not wish to be associated with any of the additions or modifications. Whitehead aptly characterized both of their philosophies in his introduction of Russell for the William James lectures at Harvard: "I am pleased to introduce my good friend Bertrand Russell. Bertie thinks that I am muddle-headed, but then, I think that he is simple-minded" (Lucas 1989, p. 111).

To describe the narrow scope, Wang (1986) coined the term *logical negativism* for the critical, but reductionist approach of his former thesis adviser:

> Quine merrily reduces mind to body, physical objects to (some of) the place-times, place-times to sets of sets of numbers, and numbers to sets. Hence, we arrive at a purified ontology which consists of sets only.... I believe I am not alone in feeling uncomfortable about these reductions. What common and garden consequences can we draw from such grand reductions? What hitherto concealed information do we get from them? Rather than being overwhelmed by the result, one is inclined to question the significance of the enterprise itself. (p. 146)

In support of this view, Wang quoted a personal letter from C. I. Lewis, the founder of the modern systems of modal logic, about the state of philosophy in 1960:

> It is so easy... to get impressive 'results' by replacing the vaguer concepts which convey real meaning by virtue of common usage by pseudo precise concepts which are manipulable by 'exact' methods — the trouble being that nobody any longer knows whether anything actual or of practical import is being discussed. (p. 116)

The negativism began with Frege (1879), who 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." His strength lay in the clarity of his distinctions, which Frege (1884) summarized in three fundamental principles:

1. "always to separate sharply the psychological from the logical, the subjective from the objective;"
2. "never to ask for the meaning of a word in isolation, but only in the context of a proposition;"
3. "never to lose sight of the distinction between concept and object."

These distinctions may sound good in isolation, but in practice the borderlines are not clear. Instead of trying to understand the reasons for the lack of clarity, Frege imposed arbitrary restrictions:

> In compliance with the first principle, I have used the word "idea" always in the psychological sense, and have distinguished ideas from concepts and from objects. If the second principle is not observed, one is almost forced to take as the meanings of words mental pictures or acts of the individual mind, and so to offend against the first principle as well.

With this interpretation, Frege made it impossible to formalize metalanguage as language about language because there are no physical objects that can serve as the referents of metalevel terms. In the *Tractatus*, Wittgenstein (1921) observed Frege's restrictions and defined all meaningful language in terms of references to physical objects and their relationships. Everything else, including his own analysis of language, had no legitimate reference: "My propositions are elucidatory in this way: he who understands me finally recognizes them as senseless" (6.54).

While reviewing Quine's *Word and Object*, Rescher (1962) was struck by the absence of any discussion of events, processes, actions, and change. He realized that Quine's static views were endemic in the analytic 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'."

Rescher found that the only analytic philosopher who bothered to defend the static view was Strawson (1959), who adopted *identity* and *independence* as the 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 "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:

1. Since people are commonly identified by numbers, such as employee numbers or social-security numbers, Strawson should grant numbers ontological priority over people. 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 the rebuttals, Strawson (1992) published a textbook that he used to inculcate philosophy students with the thing-property doctrine. He mentioned *event semantics* as proposed by Davidson (1967), but 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).

When the nothing-else philosophers turn their criticism on one another, they are left with nothing at all. In developing a semantics for a fragment of English, Montague (1967) stated his goal of reducing ontology to nothing but sets: "It has for fifteen years been possible for at least one philosopher (myself) to maintain that philosophy, at this stage in history, has as its proper theoretical framework set theory with individuals and the possible addition of empirical predicates." To disguise the emptiness of the foundations, Montague called the elements of his sets *possible worlds*, but the logician Peter Geach, who was strongly influenced by Frege, dismissed Montague's worlds as "Hollywood semantics" (Janik & Toulmin 1973). In his famous paper, "Two Dogmas of Empiricism," Quine turned his critical skills on the work of Carnap, his best friend and mentor. In the process, he destroyed the last positive claims of logical positivism. In his mature review of topics he covered during his career, Quine (1981) began with the reduction of ontology to sets, which Wang deplored; he then continued in chapter after chapter to criticize various attempts to add something more, such as modality, belief statements, or ethics. His conclusion was that precise, local, context-dependent statements could be made, but no formalized general-purpose system of logic, ontology, knowledge representation, or natural language semantics is possible. Quine's arguments would seem to justify Winograd in abandoning the quest for artificial intelligence. Yet people somehow manage to learn languages and use them successfully in their daily lives. Other animals are successful even without language. What is the secret of their success?

3 Peirce's Contributions to the Study of Meaning

Although Peirce had never read Quine's arguments, he wouldn't have been troubled by the negative conclusions. In fact, he would probably agree. Like Leibniz, Quine would agree that absolute certainty is possible only in mathematics and that all theories about the physical world are fallible and context dependent. Peirce went one step further: he even extended fallibilism to mathematics itself. A major difference between Peirce and Quine is that Peirce (1906) not only recognized context dependence, he even developed a notation for representing it in his existential graphs:

> The nature of the universe or universes of discourse (for several may be referred to in a single assertion) in the rather unusual cases in which such precision is required, is denoted either by using modifications of the heraldic tinctures, marked in something like the usual manner in pale ink upon the surface, or by scribing the graphs in colored inks.

Peirce's later writings are fragmentary, incomplete, and mostly unpublished, but they are no more fragmentary and incomplete than most modern publications about contexts. In fact, Peirce was more consistent in distinguishing the syntax (oval enclosures), the semantics ("the universe or universes of discourse"), and the pragmatics (the tinctures that "denote" the "nature" of those universes).

What is revolutionary about Peirce's logic is the explicit recognition of multiple universes of discourse, contexts for enclosing statements about them, and meta-language for talking about the contexts, how they relate to one another, and how they relate to the world and all its events, states, and inhabitants. That expressive power, which is essential for characterizing what people say in ordinary language, goes far beyond anything that Kripke or Montague, let alone Frege or Quine, ever proposed. As an example, the modal auxiliary *must* in the following dialog expresses a context-dependent necessity that is determined by the mother:

Mother: You must clean up your room.
Child: Why?
Mother: Because I said so.

The necessity in the first sentence is explained by the mother's reply *I said so*, which is a context-dependent law that governs the situation. To clarify the dependencies, Dunn (1973) demonstrated two important points: first, the semantics of the modal operators can be defined in terms of laws and facts; second, the results are formally equivalent to the semantics defined in terms of possible worlds. For natural language semantics, Dunn's semantics can support methods of discourse analysis that can relate every modal or intentional verb to some proposition that has a law-like effect, to a context that is governed by that law, and to a lawgiver, which may be God, an official legislature, or the child's mother (Sowa 2003). Although Peirce could not have known the work of Kripke or Dunn, he anticipated many of the relationships among modality, laws, and lawgivers, and he recognized levels of authority from the absolute laws of logic or physics to more lenient rules, regulations, social mores, or even a single individual's habits and preferences.

Unlike Frege, Russell, and Carnap, Peirce did not avoid the challenge of characterizing the language people actually use by escaping to a purified realm of formal logic and ontology. He had been an associate editor of the *Century Dictionary*, for which he wrote, revised, or edited over 16,000 definitions. The combined influence of logic and lexicography is apparent in a letter he wrote to B. E. Smith, the editor of that dictionary:

> 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.

In this remark, Peirce equated the lexicon with the set of expressible ideas and declared logic as essential to the analysis of meaning. Yet he considered logic only one of the three major subdivisions of his theory of signs:

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.
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.

Many people talk as if logic is limited to deduction, but Peirce insisted that induction and abduction are just as important, since they are the branches of logic that derive the axioms from which deduction proceeds. Peirce also emphasized the importance of analogy, which is a very general method of reasoning that includes aspects of all three of the other methods of logic. In fact, analogy is essential to induction and abduction, and the method of *unification* used in deduction is a special case of analogy.

One of the pioneers of formal semantics, Barbara Partee (2005), admitted that the formalisms developed by Montague and his followers have not yet come to grips with the "intended meanings" of their abstract symbols and that lexical semantics and lexicography cover material that is very far from being formalized:

> In Montague's formal semantics the simple predicates of the language of intensional logic (IL), like *love*, *like*, *kiss*, *see*, etc., are regarded as symbols (similar to the "labels" of [predicate calculus]) which could have many possible interpretations in many different models, their "real meanings" being regarded as their interpretations in the "intended model". Formal semantics does not

> pretend to give a complete characterization of this "intended model", neither in terms of the model structure representing the "worlds" nor in terms of the assignments of interpretations to the lexical constants. The present formalizations of model-theoretic semantics are undoubtedly still rather primitive compared to what is needed to capture many important semantic properties of natural languages.... There are other approaches to semantics that are concerned with other aspects of natural language, perhaps even cognitively "deeper" in some sense, but which we presently lack the tools to adequately formalize. (Lecture 4)

In Montague's terms, the intension of a sentence is a function from abstract sets (called possible worlds) to truth values, and the intensions of words are other abstract functions that can be combined to derive the function for a sentence. In lexical semantics and lexicography, words are decomposed into patterns of words or word-like signs, and any connection to logic or possible worlds is rarely discussed and often denounced as irrelevant. As Partee said, there are no known mathematical "tools" for mapping all the words and signs of lexical semantics to Montague-style functions. Even if the words could be mapped, an even greater challenge would be to map the relatively loose patterns of lexical semantics to Montague's strictly regimented functions of functions for combining the basic functions.

A more realistic way to bridge the gap between the formal and the informal is to recognize that loose informal patterns of signs are the foundation for perception and analogical reasoning by all mammals, including humans. Children learn language by mapping perceptual and motor patterns to verbal patterns, and for adults, there is a continuity between the informal patterns learned in childhood to the most highly disciplined patterns used in science, mathematics, and logic. The advantage of Peircean semiotics is that it firmly situates language and logic within the broader study of signs of all types. The highly disciplined patterns of mathematics and logic, important as they may be for science, lie on a continuum with the looser patterns of everyday speech and with the perceptual and motor patterns, which are organized on geometrical principles that are very different from the syntactic patterns of language or logic. Transferring the problems to a broader domain does not automatically solve them, but it provides a richer set of tools to address them.

4 Patterns of Symbols in Language and Logic

A semiotic view of language and logic gets to the heart of the philosophical controversies and their practical implications for linguistics, artificial intelligence, and related subjects. The analytic philosophers hoped that they could use logic to express facts with the utmost clarity and precision. Wang (1986) observed that Carnap, in particular, was "willing to exclude an exceptionally large range of things on the grounds that they are 'not clear,' or sometimes that 'everything he says is poetry.'" But the logicians Peirce and Whitehead and the poet Robert Frost recognized that clarity is often an oversimplification. Whitehead (1937) aptly characterized the problem:

> Human knowledge is a process of approximation. 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. The problem is to discriminate exactly what we know vaguely.

And Frost (1963) suggested the solution:

> I've often said that every poem solves something for me in life. I go so far as to say that every poem is a momentary stay against the confusion of the world.... We rise out of disorder into order. And the poems I make are little bits of order.

Contrary to Carnap, poetry and logic are not at opposite extremes. They are complementary approaches to closely related problems: developing patterns of symbols that capture important aspects of life in a memorable form. Logic is limited to expressing factual content, but poetry can express aesthetic and ethical interpretations of the facts. Any particular interpretation of a poem can be asserted in logic, but a good poem can express a volume of possible interpretations in a single phrase.

The greatest strength of natural language is its flexibility in accommodating patterns ranging from poetry and cooking recipes to stock-market reports and scientific treatises. A very flexible syntactic theory, which is also psychologically realistic, is *Radical Construction Grammar* (RCG) by Croft (2001). Unlike theories that draw a sharp boundary between grammatical and ungrammatical sentences, RCG can accept any kind of construction that speakers of a language actually use, including different choices of constructions for different sublanguages:

> Constructions, not categories or relations, are the basic, primitive units of syntactic representation.... the grammatical knowledge of a speaker is knowledge of constructions (as form-meaning pairings), words (also as form-meaning pairings), and the mappings between words and the constructions they fit in. (p. 46)

RCG makes it easy to borrow a word from another language, such as *connoisseur* from French or H_2SO_4 from chemistry, or to borrow an entire construction, such as *sine qua non* from Latin or $x^2+y^2=z^2$ from algebra. In the sublanguage of chemistry, the same meaning that is paired with H_2SO_4 can be paired with *sulfuric acid*, and the constructions of mathematical and chemical notations can be freely intermixed with the more common constructions of English syntax.

The form-meaning pairings of RCG are determined by language-specific or even sublanguage-specific *semantic maps* to a multidimensional *conceptual space*, which "represents conventional pragmatic or discourse-functional or information-structural or even stylistic or social dimensions" (Croft, p. 93). Although Croft has not developed a detailed theory of conceptual structures, there is no shortage of theories, ranging from those that avoid logic (Jackendoff 1990, 2002) to those that emphasize logic (Sowa 1984, 2000). The versions that avoid or emphasize logic represent stages along a continuum, which an individual could traverse from infancy to childhood to adulthood. Each stage adds new functionality to the earlier stages, which always remain available; even the most sophisticated adult can find common ground in a conversation with a three-year-old child. Following are the basic elements of logic, each of which builds on the previous elements:

1. Every natural language has basic constructions for expressing relational patterns with two or three arguments, and additional arguments can be added by constructions with prepositions or postpositions.
2. The three logical operators of conjunction, negation, and existence, which are universally available in all languages, are sufficient to support first-order logic.
3. Proper names, simple pronouns, and other indexicals are universal, but various languages differ in the selection of indexical markers.
4. Metalanguage is supported by every natural language, and it appears even in the speech of children. Metalanguage supports the introduction of new words, new syntax, and the mapping from the new features to older features and to extralinguistic referents.
5. Simple metalanguage can be used even without embedded structures, but the ability to encapsulate any expression as a single unit that can be embedded in other expressions provides enormous power.
6. When combined in all possible ways, the above features support the ability to define modal operators and all the intensional verbs and structures of English.

In addition to supporting any representation for logic, a general theory of intelligence must also support reasoning methods. The most primitive and the most general is analogy, which by itself supports case-based reasoning. Sowa and Majumdar (2003) showed how Peirce's three branches of logic — induction, deduction, and abduction — could be defined as highly disciplined special cases of analogy. Unlike the methods of logic, which are limited to language-like symbols, analogies can relate patterns of signs of any kind: they can support the metaphors described by Lakoff and Johnson (1980), they can link abstract symbols to image-like icons, and they can relate similar patterns of percepts across different sensory modalities.

5 Everything Is a Sign

In focusing their attention on tiny questions that could be answered with utmost clarity in their logic, the analytic philosophers ignored every aspect of life that was inexpressible in their logic. The Continental philosophers did address the unclear questions, but their prose was so opaque that few people could read it. Although Peirce invented the logic that the analytic philosophers adopted, he incorporated logic in a much broader theory of signs that accommodates every possible question, answer, perception, feeling, or intuition — clear, unclear, or even unconscious. With that approach, the border between analytic and Continental philosophy vanishes. In fact, all borders in cognitive science vanish, except for local borders created by differences in methodology.

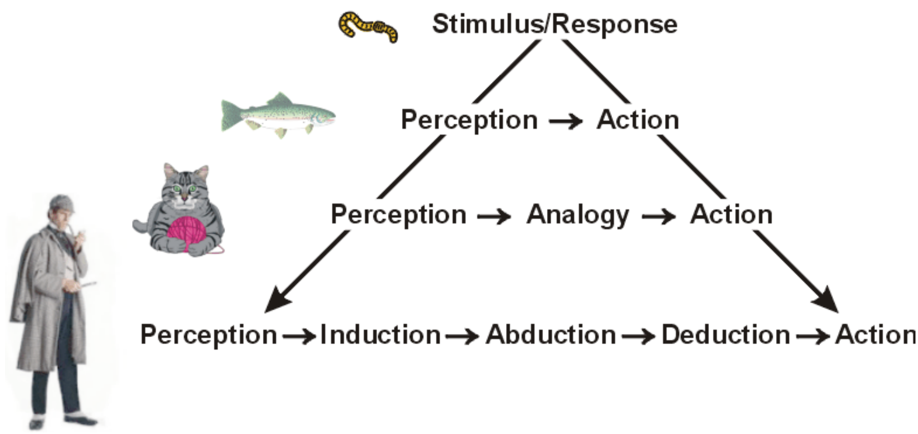

Fig. 4. Evolution of semiosis

To illustrate the generality of semiotics, the following examples show how Peirce's ideas can be applied to a wide range of topics:

- Figure 4 illustrates the evolution of cognitive systems according to the sophistication of their semiotic capabilities. For the worm, a sign that serves as a stimulus triggers a response with only a few intermediate levels of signs passed from neuron to neuron. The fish, however, has highly developed perceptual and motor mechanisms that depend on vastly more complex neural mechanisms. For the cat, the ball of string is a mouse analog, which can be used in exercises that build the cat's repository of learned sign patterns to be invoked when hunting prey. The human inherits all the capabilities of earlier levels and adds the symbol processing that supports language and logic.
- Peirce's fundamental assumption is that anything in the universe that can have a causal influence on anything else is a potential sign, independent of the presence of anything that can interpret signs. The big bang at the beginning of the universe, for example, could not be observed by any cognitive agent at the time, but astronomers today can observe its effects in the background microwave radiation.
- In the classification of signs, three basic categories are Mark, Token, and Type. A mark is an uninterpreted sign of any kind, a type is a pattern for classifying marks, and a token is the result of classifying a mark according to some type. For example, a pattern of green and yellow in the lawn is a mark, which could be interpreted according to the viewer's interests as a token of type Plant, Weed, Flower, SaladGreen, Dandelion, etc.
- A sign may be characterized by the way the mark determines the referent:
    1. **Icon:** according to some similarity of image, pattern, or structure.
    2. **Index:** according to some physical relationship; e.g., immediate presence, pointing to something remote, or causally indicating something not directly perceptible.
    3. **Symbol:** according to some convention; e.g., spoken words, written words, money, flag, uniform...

- Communication, memory, learning, and reasoning depend on signs — but most signs are not symbols. In Figure 4, organisms from the level of bacteria to worms respond to indexes. With larger brains and more complex sensory organs, animals from fish to mammals add icons. The human level of symbol processing supports the open-ended levels of complexity possible with logic and language.
- According to Peirce, the ability to respond to signs is characteristic of all living organisms. Since a virus cannot process signs, it is not alive. Instead, a virus is itself a sign, which a susceptible organism interprets by generating replicas.
- Pietarinen (2004) pointed out that Peirce had anticipated much of the modern work on speech acts, relevance, and conversational implicatures; although he hadn't listed the principles as conveniently as Grice (1975), he discussed and analyzed versions of them in many of his writings. Peirce had also anticipated Davidson's event semantics by insisting that actions and states were entities just as real as their participants, and he anticipated Perry's "Essential Indexical" by pointing out that every statement in logic requires at least one indexical to fix the referents of its variables.
- Although Peirce's graph logic is equivalent to his algebraic notation in expressive power, he developed an elegant set of rules of inference for the graphs, which have attractive computational properties. Ongoing research on graph-theoretic algorithms has demonstrated important improvements in methods for searching and finding relevant graphs during the reasoning processes (Majumdar et al. forthcoming).

The key to Peirce's modernity is his solid foundation in history. Unlike Frege and Russell, who made a sharp break with the Aristotelian and Scholastic work on logic, many of Peirce's innovations were based on insights he had derived from his studies of medieval logic. In fact, Peirce had boasted that he had the largest collection of medieval manuscripts on logic in the Boston area. In general, major breakthroughs are most likely to come from unpopular sources, either because they're so new that few people know them, so old that most people have forgotten them, or so unfashionable that nobody looks at them.

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