Signs and Reality

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Abstract. Signs and reality are the two fundamental topics of ontology. Reality is whatever exists independently of how we think about it. Signs are those aspects of reality that living things use to interpret, act upon, and communicate about reality. Every signal in a neuron, every thought in a brain, every bit in a computer, and every symbol in any language, natural or artificial, is a sign. Since signs are also part of reality, signs of signs are the part of reality that includes every every branch of science including ontology itself. For applied ontology, that distinction is embodied in digital computers: everything in a computer is a sign, either of the outside world or of other signs inside. Aristotle introduced a theory of signs, which he related to language and logic, the medieval Scholastics extended it, and Peirce developed it as the foundation for ontology. His semiotic addresses important issues that have been neglected by the mainstream of 20th century analytic philosophy.

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1. One, Two, Three

After thousands of years of debate, philosophers have inherited a large body of terminology from competing schools of thought with divergent ways of thinking and talking about what exists. They have all those terms at their fingertips when they write about ontology. To explain them, David Armstrong (1989) wrote an "opinionated introduction" that begins with the distinction between *universals* and *particulars*. His book is short (148 pages) and highly regarded by professional philosophers and Amazon reviewers, who gave it four or five stars. On page 1, Armstrong began with a cautionary note about the "Problem of Universals":

> So let me begin by saying what the problem is. It may turn out that it is really a pseudo-problem. That was the opinion of Wittgenstein and his followers, for instance. Quine is not far from thinking the same. But whether it is a real problem or not should not be decided in advance.

The index of that book is a warning of the terminology to come:

> abstract particulars; argument from almost indiscernible cycles; blob theories; bundle theories; identity of indiscernibles; indiscernibility of identicals; particulars (bare, perfect, thick, thin); tropes (a posteriori, bundles, causality, co-extensive, higher-order, independent existence of, natural classes of, nontransferable, sparse); universalia (ante res, in res, inter res).

Armstrong's final chapter summarizes the issues:

> Metaphysicians should not expect any certainties in their inquiries... Of all the results that have been argued for here, the most secure, I believe, is the real existence of properties and relations. Whether they be universals or particulars is a more delicate matter, and just what properties and relations are required is obscure, and in any case not for the philosopher to determine.

To illustrate the issues, Armstrong cited a "distinction that practically all contemporary philosophers accept... It is the distinction between *token* and *type*" by Charles Sanders Peirce. As an example, he noted that the phrase *the same* in the sentence *Two ladies wore the same dress* means the same type of dress, not the same token. In general, tokens are particulars, and types are universals. But Armstrong cited many more examples that show the complexities and ambiguities in any attempt to define precise identity conditions.

In discussing tokens and types, Armstrong did not mention and probably did not know that those terms are two-thirds of Peirce's three-way distinction or *triad* of which the first term is *mark*:

1. A mark is anything perceptible at the earliest stage of sensation before it has been recognized, interpreted, or classified.
2. A token is a mark that has been classified as an instance of some type. But the same mark, in different contexts for different reasons, may be classified as a token of an open-ended variety of types.
3. A type is a general category or principle for classifying marks as types. Most of the ambiguities and complexities that Armstrong discussed are caused by the fact that no discrete set of types can precisely classify a continuous range of marks.

As an example, Peirce (CP 4.537) cited the word *the*. English has a single type, spelled T-H-E, of which this article has several hundred marks that are classified as tokens of that type. Different marks might be printed in different fonts, written in different handwriting, or spoken in different voices, but each one is a token of the word type *the*.

Peirce did not propose his trichotomies as categories of existence, but as *phenomenological* distinctions for analyzing, classifying, and relating observable marks. In any classification, an ontological category must answer one or more of three fundamental questions: What is something in itself? How is it related to something else? How does it relate other things to each other? Any answer to the first question may be represented as a one-place predicate or *monad* that classifies something by its observable quality or structure; to the second, as a two-place predicate or *dyad* that classifies something by its relation to something else; to the third, as a three-place predicate or *triad* by the way it mediates or relates other things to each other.

As an example, the words *dog*, *pet*, and *gift* might refer to the same individual. Both Peirce and Aristotle would say that the category Dog answers the question *What is it?* Peirce would add that the category Pet answers two questions, *What is it?* and *How is it related to some person?* He would add that calling the dog a gift classifies it by the mediating intention of a giver toward a recipient. If the giver hands the dog to the recipient, that is dyadic transfer. To be a gift, the triad requires a sign of intention, such as saying "happy birthday."

Some philosophers would say that a dog is a member of a *natural kind* whose *essence* makes it a dog. But essences are problematical. The dog species, Canis familiaris, has recently been reclassified as a subspecies, Canis lupus familiaris, of Canis lupus, the gray wolf. The genome or DNA sequence is the most precise way of defining the essence of a species. But fertile hybrids of dogs with other members of the genus Canis are possible. Those hybrids would generate DNA sequences that do not exist in nature. Modern methods of genetic engineering provide even more options. Someone might insert a gene from an underwater creature to create a glow-in-the-dark dog. To call such an animal a member of a natural kind is problematical, but it's just as problematical to call it an artifact. Peirce's categories are determined by phenomena that are observed or inferred from observations, not on debatable essences, substances, or natures.

The category Pet is a *role* that classifies an animal by its relationship to someone who plays the complementary role of *pet owner*. But the variety of pet relationships is open ended. Koko the gorilla, for example, had a pet cat that she named All Ball, using a version of American Sign Language. The role of pet can vary on a continuum from friend to livestock. Some people say that they adopted a pet and call themselves pet parents. Nearly every word that refers to a role has a similar continuum: employee, teacher, cook, tool, foundation, or dwelling. The Canadian census classifies tepees and igloos as dwellings. When the census takers found a man who lived in a sewer, they had to get an official ruling to allow a sewer to be called a dwelling. Like the monadic quality, the dyadic role is determined by phenomena that indicate the kind of relation.

The mediating intention of a triad also depends on an observable sign, such as a promise, a handshake, a signature, or a habitual pattern of behavior. But not all triadic relations involve a mediating intention. The relation Between(*x*,*y*,*z*), for example, is equivalent to a conjunction of two dyads, such as Before(*x*,*y*) and Before(*y*,*z*). Any number of such dyads could be linked together to form a chain, but each one is independent of the others. In an act of giving, a mediating intention binds the giver, gift, and recipient. Removing any one of the participants destroys the act of giving. But a chain of items linked by dyadic relations can be broken at any link without affecting the other relations in the chain. Peirce called a triad defined by a pair of independent dyads a *degenerate triad*.

Yet the triadic relation Give(*x*,*y*,*z*) may be defined in terms of a nominalized verb Giving(*w*) and three dyads that link *w* to each of the participants: Agent(*w*,*x*), Theme(*w*,*y*), and Recipient(*w*,*z*). But those dyads are not independent. The three variables linked to the variable *w* form a triadic connection, which requires the dyads Agent, Theme, and Recipient as *obligatory* links. For a genuine triad, such as Give or Giving, the nominalization of the verb is a purely syntactic transformation that does not affect the semantics.

This transformation raises serious questions about Quine's claim "To be is to be the value of a quantified variable." The syntactic transformations may increase the number of variables without changing the semantics: any triad may be translated from a three-variable predicate to a four variable expression without affecting the truth value. But the four-variable expression increases the flexibility because it allows more relations to be linked to the fourth variable *w*. If new relations are linked to *w*, it's no longer possible to translate the four-variable version back to three variables without discarding some of the information.

As these examples show, Peirce's phenomenological categories distinguish reality from theories about what exists. Although reality is independent of what we may think, we can talk about the same phenomena at different levels of detail from different perspectives with different choices of types and different numbers of existential quantifiers. There is no limit to the variety of perspectives, purposes, questions, answers, decisions, actions, social interactions, and metaphysical explanations.

2. The Theory of Signs

Plato's dialogs show that puzzles about signs, language, and logic were a common topic of debate in the Academy. Aristotle began the systematic study of signs in the first paragraph of his book *On Interpretation* (16a1). He related the basic principles of signs to language, but he made no assumptions about the psyche other than its existence as a repository for signs:

> First we must determine what are noun and verb and after that, what are negation, assertion, proposition, and sentence. Those in speech are symbols (*symbola*) of affections in the psyche, and those written are symbols of those in speech. As letters, so are speech sounds not the same for everyone. But they are signs (*sêmeia*) primarily of the affections in the

> psyche, which are the same for everyone, and so are the objects of which they are likenesses. On these matters we speak in the treatise on the psyche, for it is a different subject.

By using two different words for sign, Aristotle recognized two distinct ways of signifying: *sêmeion* for a natural sign and *symbolon* for a conventional sign. The word *sêmeion*, which was used for symptoms of a disease, implies that a speech sound is primarily a natural sign of a mental affection or concept and secondarily a symbol of the object it refers to. That triad of sign, concept, and object is the *meaning triangle*, for which Ogden and Richards (1923) contributed the name and the diagrams.

From the 12th to the 16th centuries, the Scholastics developed semiotics in great depth and subtlety. They called the concept at the top of the meaning triangle the signification (*significatio*) and the intended object on the right the supposition (*suppositio*). They recognized that the supposition of a sign might not exist: it may be a hypothesis, a mythical beast, or something expected in the future. With his theory of terms, Ockham (1323 T) developed one of the most detailed versions, which generalized Aristotle's option of allowing signs to refer to other signs. In Figure 1, a sign whose supposition is a physical entity is called a first intention (*intentio*), and a sign whose supposition is another sign is a second intention.

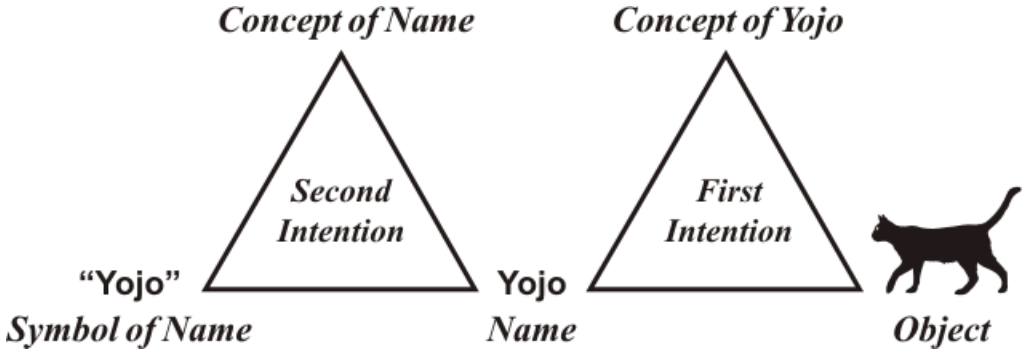

Figure 1. Ockham's meaning triangles

For the signification at the top of a triangle, the usual Latin term was *conceptio* (concept). The sign at the lower left could be a word, an image, or a concept of a concept. The supposition at the lower right could be something physical, something imagined, or another sign. For his theory of propositions, Ockham (1323 P) developed the syntax and semantics for a significant subset of Latin: Aristotle's four sentence types for simple sentences and arbitrary Boolean combinations for complex sentences. For that subset, Ockham's semantics is consistent with the symbolic version by Tarski (1933). In fact, there may have been some influence, since Tarski's colleague, Jan Łukasiewicz, had published several articles on the history of the logic (Simons 2014).

Many theories of signs are limited to first-intentional triangles. Frege, for example, used the terms *Zeichen*, *Sinn*, and *Bedeutung* (usually translated sign, sense, and reference), but he did not let the reference of one sign signify another sign. Franz Brentano (1874), who had studied Scholastic logic, adopted the word *intentio* as the basis for his theory of *intentionality*, which he defined as the directedness (*Gerichtetheit*) of thought toward some object, real or imagined.

Peirce had studied Scholastic logic and lectured on Ockham and Duns Scotus at Harvard. For his theory of signs, Peirce elaborated the option of signs of signs. His term for the concept at the top of the meaning triangle is *interpretant*. Following is one of his most often quoted definitions:

> 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)

A pattern of green and yellow in the lawn, for example, is a mark, and the interpretant is some type, such as Plant, Weed, Flower, SaladGreen, or Dandelion. The guiding idea that determines the interpretant depends on the context and the goals and interests of the observer. The interpretant determines how the observer thinks or talks about the object of the sign.

As Peirce noted, a listener who is an expert in the subject matter can often derive a richer interpretant than the speaker. In effect, an expert can "read between the lines." That variability is essential for flexibility and creativity in language, but many philosophers deplore the lack of precision. Mohanty (1982) remarked "Not unlike Frege, Husserl would rather eliminate such fluctuations from scientific discourse, but both are forced to recognize their recalcitrant character for their theories and indispensability for natural languages." Creative scientists like Einstein and Bohr could often derive more meaning from scientific language than the original authors had intended.

Like objects, events can also be classified by what aspect they describe: a directly observable event (monad); a causally related effect (dyad); or a mediating intention (triad). The next three sentences describe the same event in each of those ways:

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

An act of stabbing can be recognized at the instant it happens. It can be classified by immediate observation of the event. But an act of stabbing cannot be called killing unless a second event of dying occurs. Murder involves a triad because the stabbing (1) is related to the dying (2) by the intention (3). Determining whether an act of stabbing that resulted in killing should be considered a murder depends on subtle clues, whose interpretation may require a judge, a jury, and a lengthy trial.

	1. Quality	**2. Indexicality**	**3. Mediation**
1. Material	**Mark** ***A quality which is a sign.***	**Token** ***An actual existent thing or event which is a sign.***	**Type** ***A principle, habit, or law which is a sign.***
2. Relational	**Icon** ***Refers by virtue of some similarity to object.***	**Index** ***Refers by virtue of being affected by object.***	**Symbol** ***Refers by virtue of some law or association.***
3. Formal	**Predicate** ***A sign of qualitative possibility.***	**Assertion** ***A sign of actual existence.***	**Argument** ***A sign of law.***

Figure 2. Peirce's triple trichotomy

Peirce developed a rich combinatorial system for classifying signs, of which the most widely used subset is summarized in Figure 2. The labels at the top indicate how a sign directs attention to the object: quality is some aspect of the mark itself, indexicality is some causal or pointing relationship, and mediation involves some law, habit, or convention.

1. The signs of the *material triad* (mark, token and type) signify by the nature of the sign itself.
2. The signs of the *relational triad* (icon, index, and symbol) signify by some relation: an icon refers by some similarity to the object; an index refers by a physical effect, which includes causality or a method such as pointing by hand or voice; and a symbol refers by a habit or conventional association.
3. The signs of the *formal triad* (predicate, assertion, and argument) signify by a formal rule that associates sign and object: before a predicate is applied to anything, it represents a possibility; an assertion combines a predicate with signs that indicate what the predicate is asserted about; an argument is a sequence of assertions that support a claim or prove a theorem.

Over the years, Peirce had introduced synonyms for some of his more technical terms. The choice of terms in Figure 2 is based on a letter by Peirce (EP 2:488) to Lady Welby. In other writings, he used the words *qualisign*, *sinsign*, and *legisign* for the top line. He had also used the word *tone* for mark, but that word is too closely tied to auditory sensations. The word *mark* can be used as a more general term. For the bottom line, he also used *rheme* for *predicate* and *dicent sign* for *assertion*. In 1908, Peirce (EP 2:483) extended his framework to ten trichotomies, but the nine terms in Figure 2 are sufficient for most purposes. The following examples, adapted from (Sowa 2010), illustrate each of the nine kinds of signs:

1. **Mark**. A ringing sensation before it is recognized as a token of any type.
2. **Token**. A ringing sound that is recognized as a sign of a telephone call.
3. **Type**. The principle that a ringing telephone means someone is trying to call.
4. **Icon**. An image that resembles a telephone.
5. **Index**. A finger pointing toward a telephone.
6. **Symbol**. An icon of an old-fashioned telephone that is generalized to any kind of telephone.
7. **Predicate**. A logical predicate or a word such as *telephone*, which may represent any telephone, real or imagined.
8. **Assertion**. A sentence that asserts the existence of a phone call: "Your mother's calling."
9. **Argument**. A sequence of assertions that expresses a lawlike connection: "It may be an emergency. You should answer the phone."

Peirce coined the term *indexical* for a word like *this* or *that*, which has the effect of a pointing finger. Instead of being troublesome exceptions, as they were for Frege and Russell, indexicals are an integral part of a systematic framework.

The three triads in Figure 2 make finer distinctions than most definitions of signs, and they cover a broader range of phenomena. Anything that exists may be a sign of itself (token or sinsign). Shortly after the Big Bang, there were no living things that could interpret the marks of any event. But as soon as some living thing invented instruments that could detect ancient light, they became tokens of types.

> A sign, then, is anything whatsoever — whether an Actual or a May-be or a Would-be — which affects a mind, its Interpreter, and draws that interpreter's attention to some Object (whether Actual, May-be, or Would-be) which *has already* come within the sphere of his experience. (Peirce 1911)

In other writings, Peirce used the term *quasi-mind* to emphasize the generality. A dog, like its owner, could experience a ringing sound as a mark and recognize it as a token of a familiar type. An intelligent dog might discover that a ringing phone is an index of its owner's habit of answering it. A language of

some kind is a prerequisite for signs at the formal level of predicates, assertions, and arguments. Apes that have learned a human sign language have some of that ability. Whether the signs they use among themselves are comparable is still an open question.

As an example, Figure 3 illustrates the concept of representation with two meaning triangles. The first-intentional triangle at the bottom shows that the name Yojo refers to a cat illustrated by an image at the bottom right. The peak of that triangle is a concept illustrated by the same image enclosed in a balloon. The second-intentional triangle at the top, shows that the symbol [Cat: Yojo] refers to the same concept that is shared with the peak of the first-intentional triangle. The uppermost balloon illustrates a concept of representation that relates the symbol [Cat: Yojo] to a concept of the same cat.

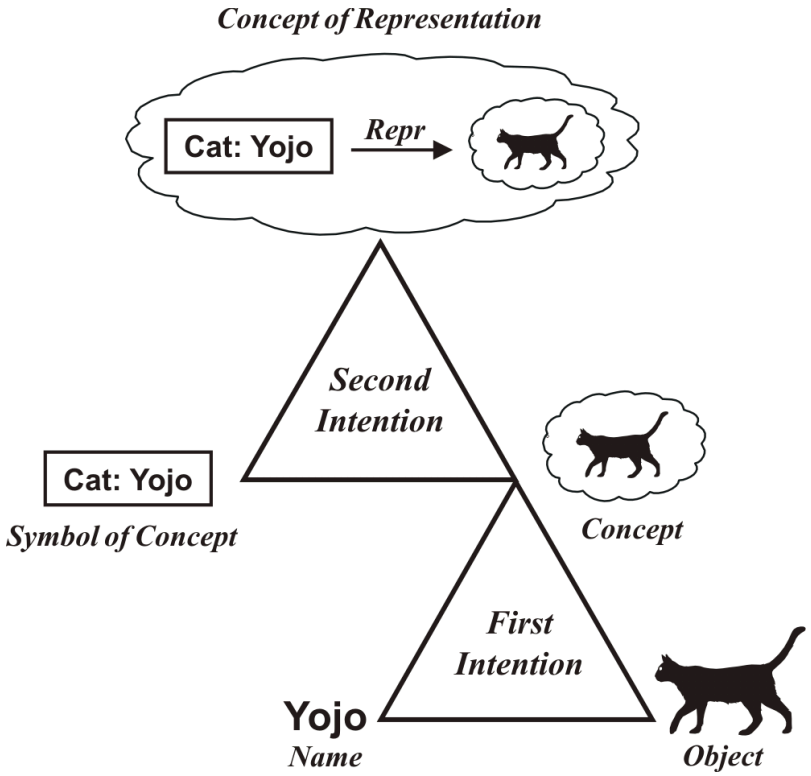

Figure 3. Meaning triangles for the concept of representation

Of the five signs shown in Figure 3, three have physical marks and two are mental concepts, which are enclosed in balloons. Although mental concepts are not directly observable, no introspection is needed to infer their existence. The triangles are based on semiotic principles, which, as Peirce said, would hold for any living thing. The simplest kinds, such as bacteria, would respond according to the first triad: they would move away from acid and move toward sugar. Those responses are determined by their genes, but the genes themselves are very complex signs.

As these examples show, the Scholastic theory of signs and Peirce's further developments are far richer than just the first-intentional triangle by Ogden and Richards. The most important aspect of Peirce's theory is its dynamic nature: any node can spawn another triangle to show more relationships to the entity represented by that node. In Figure 3, for example, the concept of the cat Yojo is the top node of a first-intentional triangle and the rightmost node of a second-intentional triangle. For more quotations by Peirce and an analysis of their implications, see Peirce's theory of signs by Zeman (1977).

By avoiding any assumptions about the psyche, Peirce avoided psychologism. As he said, "Thought is not necessarily connected with a brain" (CP 4.551). Although every thought depends on some mind or quasi-mind, he emphasized that the quasi-mind need not be human:

> I define a sign as something, A, which brings something, B, its interpretant, into the same sort of correspondence with something, C, its object, as that in which it itself stands to C. In this definition I make no more reference to anything like the human mind than I do when I define a line as the place within which a particle lies during a lapse of time. (1902)

3. A Semiotic Foundation for Ontology

Armstrong admitted that nearly all the philosophical terminology in his book is controversial. But he made two exceptions: Peirce's "distinction between *token* and *type*" (page 1) and "the real existence of properties and relations" (page 135). With his "logic of relatives", Peirce(1870) developed a notation for representing both monadic properties and N-adic relations. Frege (1879) adapted it to his version of first-order logic. Peirce (1885) adapted it to his algebraic notation for first-order and higher-order logic. Those aspects of Peirce's logic and semiotic would be the least controversial part of any foundation for ontology.

As another argument for Peirce's semiotic, two classics of formal ontology failed to define more than a small subset of the categories required for applied ontology: *The Logical Construction of the World* by Carnap (1928) and *The Structure of Appearance* by Goodman (1951). The only formal specification in Carnap's book is the 16-page Chapter IV A on *autopsychological objects*. Those are prerequisites that any self (*autos*) would require. To define them, Carnap assumed the logic of the *Principia* and the development of mathematics by Whitehead and Russell (1910). Then he attempted to define everything in terms of single relation: similarity of elementary experiences (*Elementarerlebnisse*). To combine them, he used logic plus a version of mereology. But he ended Chapter A with an admission that these definitions are "examples" of what should be elaborated into a complete system. Chapter B on *physical objects* is an "outline" with no formal notation of any kind. It ends with a vague discussion of biological objects, which include something called "my body." Chapter C on *heteropsychological objects* is an even vaguer discussion of social relations of one body to another (*heteros*).

Chapter C shows that Carnap had started at the wrong end. In Chapters A and B, he tried to construct everything from elementary experiences. But experiences are signs, and in Chapter C he admitted "The construction of [the sign] relation is more difficult than any of the others which we have hitherto undertaken." As Aristotle, the Scholastics, and Peirce had shown, signs can be defined by a short specification that assumes a mind but makes no assumptions about its nature. The only requirement is that a mind can relate one sign to another and store some signs for future reference. Carnap mentioned the word *mind*, but defined it only as an unobservable part of a body. That definition would have been sufficient for him to adopt Peirce's definition of sign. With Peirce's semiotic, Carnap could have stated more precise and detailed definitions of experience, similarity, language, communication, and social relations.

Carnap (1967) noted that Goodman started with an assumption that physical objects exist. That approach enabled him to define a larger subset of relations for representing a visual scene. But neither Carnap nor Goodman defined an ontology that was adequate to specify movement and causality in physics, let alone chemistry, biology, languages, and social relations. Without those relations, it's impossible to specify an ontology for business, finance, engineering, medicine, law, or life.

Philosophical Investigations by Husserl (1900) is another classic that has had a strong influence on formal ontology. Husserl covered a wider range of issues than Carnap or Goodman, including issues about language and intentionality that were influenced by Brentano. Husserl's discussions of language have had a strong influence, but many philosophers have rejected his treatment of intentionality as "anthropomorphic." There are three responses to that objection:

1. Intentionality can be defined by a triadic relation in Peirce's semiotic, which requires a mind or quasi-mind, but makes no assumption about the nature of the quasi-mind. A computer program could simulate or reason about his definition of intentionality.
2. Intentionality is not anthropomorphic, but biomorphic. The biologist Lynn Margulis (1995) observed that a bacterium swimming upstream in a glucose gradient exhibits intentionality: "The growth, reproduction, and communication of these moving, alliance-forming bacteria" lie on a continuum "with our thought, with our happiness, our sensitivities and stimulations."
3. People, their behavior, and their social organizations are essential topics for applied ontology. Any specification of people and their interests must be anthropomorphic.

As these examples show, Peirce's semiotic or something equivalent is necessary for any ontology that can support language, communication, and social relations. To show that it is sufficient to define all the terms that any philosopher might adopt is beyond the scope of this article. But a few examples can show how the nine terms in Figure 2 can clarify and replace the large number of controversial terms that Armstrong discussed:

- **Universal** and **Particular**. Since there is no universally accepted definition of these terms, no exact replacement is possible. For most purposes, however, universals may be represented as sign types, and particulars may be represented by tokens of a type. In logic, every type may be represented by a monadic predicate, and every token is an instance of the predicate for the type.
- **Abstraction**. Every abstraction may be represented by an expression in logic. In Table 2, that expression may be a predicate (formal quality), or it may be the same kind of expression used to represent anything in column 3 (type, symbol, or argument).
- **Abstract particular**. Although a pure abstraction, such as a circle, has no physical mark, any thought about an abstract particular is a physical mark in the brain. Therefore, an ontology could treat abstract particulars as signs whose marks are not observable by publicly accessible means.
- **Trope**. Many philosophers are reluctant to admit that *particularized properties*, such as a patch of redness, are first-class entities. Therefore, they call them *tropes*. In a theory of signs, they are marks, which may be interpreted as tokens of types. For any system of reasoning, the type may be represented by a monadic predicate, and the token may be represented by a quantified variable.

Since the traditional terms have been used in conflicting ways by many different philosophers, no formal definitions are possible. Peirce's nine words are not sufficient to express all the details of an ontology, but it is better to represent the details by two kinds of terms: the terminology of whatever logic is used and the terminology of the subject matter that is being represented.

4. Ontology as Science or Engineering

As a branch of philosophy, ontology is the study of existence. But an applied ontology is an engineering specification of what exists or may exist in some domain. The domain may be as narrow as a particular application, or it may be the entire universe for all time. Traditional philosophical terms are important for relating new developments to the long history of the subject. But the index of Armstrong's book has over a hundred terms that are unfamiliar to most programmers and systems analysts.

Peirce had studied philosophy ranging from the ancient Greeks and the medieval Scholastics to the early writings by Whitehead, Russell, and Husserl, nearly always in the original languages. But he was also a scientist who had published research in astronomy, chemistry, logic, mathematics, physics, and psychology. He had also been employed as an associate editor of the *Century Dictionary*, for which he wrote, revised, or reviewed over 16,000 definitions (Sowa 2006). He had also published an article on logical machines (Peirce 1887) in the *American Journal of Psychology*, and Minsky (1963) included it in his bibliography of artificial intelligence.

With that background, Peirce chose the nine terms in Figure 2 as a precise, neutral framework for analyzing any word that might occur in an unabridged dictionary. It has the simplicity and generality for specifying a scientific ontology or an engineering ontology for any particular domain:

- A *scientific ontology* is about some domain that exists independently of the ontologist: it may consist of natural phenomena; it may consist of artifacts that an archaeologist is trying to analyze; it may consist of some mixture of nature and artifacts; and it may include human societies. In any case, a scientific ontology is judged by the same criteria as any theory of science: it must make testable predictions about the domain. A failure of a prediction would require a revision or rejection of all or part of the theory. A scientific theory, such as Newtonian mechanics for example,, may fail some tests, but still be useful for domains in which its predictions are known to be as accurate as more fundamental theories.
- A *design ontology* specifies products or methods that do not yet exist. The designer controls the specifications of the intended results. But the designer must work within the constraints of ontologies for any resources used in the development and for any environment in which the results may be used. The criteria for a good design are pragmatic: How useful are the results?
- An *engineering ontology* is a combination of science and design. A scientific ontology is descriptive, a design ontology is prescriptive, and an engineering ontology may have both descriptive and prescriptive aspects.

For every ontology, some guidelines are necessary for choosing the domain, the methods for analyzing it, and the ways of representing the specifications. They must address issues of logic, metaphysics, and terminology:

- **Logic**. An informal ontology may be stated in a natural language. A formal ontology is stated in some version of logic, but even the most formal ontologies have comments and explanations in ordinary language. Aristotle's syllogisms were the first formal logic used to state an ontology, and those syllogisms are still the most widely used subset of the modern description logics. But Aristotle himself stated many principles that could not be expressed in syllogisms. They require first-order, higher-order, metalevel, and multivalued logics. When computer systems with different ontologies communicate with humans or among themselves, the inevitable inconsistencies must be resolved by nonmonotonic, statistical, or fuzzy reasoning.
- **Metaphysics**. Any theory must include some axioms that are assumed without proof. Metaphysics, sometimes called *first philosophy*, analyzes the implicit assumptions of any field. No formal proof of a metaphysical principle is possible because the choice of which logic to use is itself a metaphysical issue. In classical first-order logic, no predicate P can be both true and false about the same instance x. But in a multivalued or fuzzy logic, P(x) may be unknown, almost certainly true, likely, or unlikely. Some logical distinctions, such as *predicate* and *instance*, are related to metaphysical distinctions, such as *universal* and *particular*. Are the distinctions exactly equivalent? If so, why use different words for them? If not, how do they differ? The criteria for evaluating metaphysical principles are indirect: How fruitful are they

for producing successful theories in the fields to which they are applied?

- **Terminology**. A well-defined collection of terms for any domain is essential for communication and collaboration among the people who work in that domain. They are a valuable starting point for an ontology of the domain. As the definitions and assumptions become more complete and precise, the terminology may evolve into an ontology. WordNet, for example, is an organized collection of a large subset of English vocabulary, and its terms (or *synsets*) are often aligned to formal ontologies. Some people call WordNet an ontology, but it is closer to a general-purpose terminology.

An ontology for a narrow domain, such as a program specification, may be able to specify everything in that domain precisely. But an ontology that includes anything outside the control of the designer must be an approximation. No ontology that claims to represent everything can be completed until every branch of science, including the social sciences, has answered every possible research question. Since no perfect universal ontology is possible, different kinds of ontologies for different purposes will require different approximations. Whatever may happen, one principle is certain: every ontology will consist of signs of signs, and every applied ontology must relate signs about the subject matter to the signs inside a computer system.

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