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Abstract: Depending on context, information embraces many interpretations, from Bateson's "difference that makes a difference," to Shannon's engineering aspects, to C.S. Peirce's emphasis on meaning and the role of signs. Information also has a physical aspect, reflected through its structure. Peirce's three kinds of sign are indispensable in reasoning. The first is the diagrammatic icon, exhibiting similarity or analogy. The second is the index, like a pronoun or relative that forces attention to a particular object. The third is the symbolic name or description that signifies its object by means of an association of ideas or habitual connection. Peirce's pragmatic view is that knowledge is fallible information that we believe sufficiently to act upon. I argue in this book that knowledge representation is a complete triadic sign, with the meaning of the information conveyed by its symbolic representation and context, as understood and acted upon by the interpreting agent.

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INFORMATION, KNOWLEDGE, REPRESENTATION

Practitioners of knowledge representation (KR) should have a shared working understanding of what the concepts of information, knowledge, and knowledge representation mean. That is the main thrust of this chapter.[1] As a symbolic species,[2] we first used symbols as a way to convey the ideas of things. Simple markings, drawings, and ideograms grew into more complicated structures such as alphabets and languages. The languages came to embrace still further structure via sentences, documents, and ways to organize and categorize multiple documents, including ordered alphabets and categorization systems.

Grammar is the rules or structure that govern language. It is composed of syntax, including punctuation, traditionally understood as the sentence structure of languages, and morphology, which is the structural understanding of a language's linguistic units, such as words, affixes, parts of speech, intonation or context. The field of linguistic typology studies and classifies languages according to their structural features. However, grammar is hardly the limit to language structure. In the past, semantics, the meaning of language, was held separate from grammar or structure. Via the advent of the thesaurus, and then linguistic databases such as WordNet and more recently concept graphs or *knowledge graphs* that relate words and terms into connected understandings, we have now come to understand that semantics also has structure. It is the marriage of the computer with language that is illuminating these understandings, enabling us to capture, characterize, codify, share, and analyze. From its roots in symbols, we are now able to extract and understand those very same symbols to derive information and knowledge from our daily discourse. We are doing this by gleaning the structure of language, which in turn enables us to relate it to all other forms of structured information.

WHAT IS INFORMATION?

Many definitions of *information* may be found across the ages, often at variance because of what sense is primary. Some definitions are technical or engineering in nature; others emphasize intention, context or meaning. Gregory Bateson offered one of the more famous definitions of information, claiming it the "difference that makes a difference."[3] Claude Shannon, the founder of information theory, emphasized a different aspect of information, defining it as a message or sequence of messages communicated over a channel; he specifically segregated the meaning of information from this engineering aspect.[4] For Charles S. Peirce, information is equivalent to *meaning*, which is measurable as the breadth times the depth of the object. Despite this difference, I see both Shannon and Peirce talking broadly about the same underlying thing, though from different aspects of the universal categories. Shannon is addressing a Firstness of information, Peirce a Thirdness, as I will explain.[5]

Some Basics of Information

The idea of information has an ethereal quality. It is something conveyed that reflects a 'difference,' to use Bateson's phrase, from some state that preceded it. Indeed, Norbert Wiener, of cybernetics fame, stated in 1961 that "Information is information, not matter nor energy."[6] By coincidence, that was also the same year that Rolf Landauer of IBM posited the physical law that all computing machines have irreversible logic, which implies physical irreversibility that generates heat. This principle sets theoretical limits to the number of computations per joule of energy dissipated. By 1991 Landauer was explicit that information was physical.[8] Physicists confirmed that data erasure is a dissipative heat process in 2012.[8] The emerging consensus is that information processing does indeed generate heat.[9] By these measures, information looks to have a physical aspect.

The motivation of Shannon's 1948 paper on information theory was to understand information losses in communication systems or networks.[4] Much of the impetus for this came about because of issues in wartime communications and early ciphers and cryptography and the emerging advent of digital computers. The insights from Shannon's paper also relate closely to the issues of data patterns and data compression. In a strict sense, Shannon's paper was about the amount of information that could be theoretically and *predictably* communicated between a sender and a receiver in a message. The message communication implies no context or semantics, only the amount of information (for which Shannon introduced the term 'bits'[10]) and what might be subject to losses (or uncertainty in the accurate communication of the message). (Weaver, Shannon's later co-author of a popular version of the original paper, stated explicitly that use of the word "information must not be confused with meaning."[11]) What Shannon called 'information' is perhaps better understood by what we now call 'data.' (Of course, data has its own multiple interpretations. Bob Losee defines data as the product of a process.[12] Jonathan Furner likens data to datasets and then documents.[13])

Shannon labeled his measure of unpredictability, information entropy, as *H*. Shannon called *H entropy* because it resembled the mathematical form for Boltzmann's original definition of 2nd law entropy (as elaborated by Gibbs, denoted as *S*, for Gibb's entropy).[14] The 2nd law of thermodynamics expresses the tendency that, over time, differences in temperature, pressure, or chemical potential equilibrate in a closed (isolated) physical system. Thermodynamic entropy is a measure of this equilibration: for a given physical system, the highest entropy state is one at equilibrium. Fluxes or gradients arise when differences in state potentials occur. (In physical systems, these are *sources* and *sinks*; in information theory, they are *sender* and *receiver*.) Fluxes go from low to high entropy and are non-reversible — the 'arrow of time' — without the addition of external energy. Heat, for example, is a by-product of fluxes in thermal energy. In a closed system (namely, the entire cosmos), one can see this gradient as spanning from order to disorder, with the equilibrium state being the random distribution of all things. This perspective, and much schooling regarding these concepts, tends to present the idea of entropy as a 'disordered' state. Because these fluxes are directional in isolation, we see a perpetual motion machine as impossible.

Shannon's *H* is expressed as the average number of bits needed to store or communicate one symbol in a message. Shannon entropy thus measures the change in uncertainty transmitted and predictably received between the sender and receiver. The actual information that gets transmitted and received was formulated by Shannon as *R*, which he called rate, and expressed as:

$$R = H_{before} - H_{after}$$

R, then, becomes a proxy for the amount of information accurately communicated. *R* can never be zero because all communication systems have losses. H_{before} and H_{after} are both state functions for the message, so this also makes *R* a function of state. While Shannon entropy (unpredictability) exists for any given sending or receiving state, the actual amount of 'information' (that is, data) that is transmitted is a change in state measured by a change in uncertainty between the sender (H_{before}) and the receiver (H_{after}). In the words of Thomas Schneider, who provides a clear discussion of this distinction, "[Shannon] Information is always a measure of the decrease of uncertainty at a receiver."[15]

Shannon's idea of information entropy has come to inform entropy in physics and the 2nd Law of Thermodynamics.[16] According to Koelman, "the entropy of a physical system is the minimum number of bits you need to describe the detailed state of the system fully." Very random (uncertain) states have high entropy, patterned states have low entropy. Work by individuals such as Jaynes suggested a reinterpretation of statistical mechanics to equate the concept of thermodynamic entropy with information entropy.[17] How others interpreted Jayne's work helped add to the confusion that somehow Shannon entropy is related to the 'disorder' of thermodynamic entropy. To unpack this confusion we need to introduce the ideas of scale and open systems with external inputs of energy.

At cosmic scales — that is, a closed system — we see the tendency to dispersal and disorder. However, at our local scale, we see order and life and the development of complex biological systems[18] and self-replication.[19] Erwin Schrödinger, of the cat thought-experiment, in his famous 1943 lectures on "What is Life?",[20] tried to square life with what he knew then about the physical and chemical world. One insight he had was to introduce the idea of genetic material carried in an 'aperiodic crystal' (DNA as eventually discovered). Another assertion was that living matter evades the decay to thermodynamic equilibrium by feeding on what he called 'negative entropy,' a sort of reverse entropy toward order. Brillouin extended the idea to information and shortened the name to 'negentropy.'[21] Prigogine tried to get at the same questions with his minimum entropy dissipative structures.[22] Over time, Schrödinger and others changed from an entropy basis to the related Gibbs free energy basis, which is the maximum work potential of a system at constant pressure and temperature. What researchers have been trying to do is to take a static view of thermodynamics under ideal and closed conditions and relate it to the dynamic notions of life and information. Through the more recent work of Annila,[23] Crooks,[24] England,[25] Karnani,[9] Salthe,[26] and many others, the starting assumptions of static and closed conditions have been re-assessed under local and dynamic ones. We have seen a shift to questions of non-equilibrium thermodynamic conditions, such as life, and how maximum entropy production may be favored to dissipate high influxes of external energy. We now understand that open systems receiving fluxes of outside energy, such as Earth, favor order and structures that dissipate these external fluxes faster. Some, such as Annila and England,[27] relate these forces to evolution.

What appears as fundamental truths relating to information, entropy, dissipation, and structure in dynamic environments underlie these current strains of research. Some have "hinted at a possible deep connection between intelligence and entropy maximization."[28] What we can say so far is that information is physical and perhaps energetic, with strong conceptual and deeper ties to the ideas of thermodynamic entropy. Messages are the ways information is conveyed, and always incur losses. Order and structure seem to play a role here, perhaps in providing faster ways to dissipate energy toward equilibrium in high-energy local conditions. Still, we have yet to discuss meaning, and senses like information having economic value.[29]

The Structure of Information

Structure is something, of tangible or intangible character, that refers to the recognition, observation, nature, or permanence of patterns and relationships of things. The concept may refer to an object, such as a built structure, or an attribute, such as the structure of society, or something abstract, like a data structure or language. Structure may thus be abstract, or it may be concrete. Its realm ranges from the physical to ideas and concepts. As a term, 'structure' is ubiquitous to every domain. We may find structure across every conceivable scale, from the most minute and minuscule to the cosmic. Even realms without any physical aspect at all — such as ideas and beliefs — are perceived by many to have structure. We apply the term to any circumstance in which things are arranged or connected to one another, as a means to describe the organization or relationships of things. We seem to know structure when we see it and to discern structure of very many kinds in contrast to unstructured or random backgrounds.

In this way, structure resembles patterns, perhaps even is a synonym. Bates closely relates information to patterns, as well as providing a broad listing of other information aspects.[30] The structure of Peirce's universal categories implies, I believe, likely patterns in our information. Using thermodynamic insights, Bejan has devoted his career to outlining how the 'constructal law' of flows and related concepts such as order, organization, design or form, contribute to the structures we see in nature.[31] Information in relation to structure raises questions such as, which structures are preferred? Why do some of them perpetuate under the conditions of nature? An aspect of structure, which provides insight into its roles and importance, is we can express it in shortened form as a mathematical statement. One could even be so bold as to say that mathematics is the language of structure.

Forms of Structure

The natural world is replete with structure. Patterns in nature are regularities of visual form found in the natural world. We may model such patterns mathematically. Typical mathematical forms in nature include fractals, spirals, flows, waves, lattices, arrays, Golden ratio, tilings, Fibonacci sequences, and power laws. We can see natural forms in clouds, trees, leaves, river networks, fault lines, mountain ranges, craters, animal spots and stripes, shells, lightning bolts, coastlines, flowers, fruits, skeletons, cracks, growth rings, heartbeats and rates, earthquakes, veining, snowflakes, crystals, blood and pulmonary vessels, ocean waves, turbulence, beehives, dunes, and DNA. The mathematical expression of structures in nature is frequently repeated or recursive in nature, often in a self-organizing manner. The swirls of a snail's shell reflect a Fibonacci sequence, while natural landscapes or lifeforms often have a fractal aspect.[32] Fractals are typically self-similar patterns, generally involving some fractional or ratioed formula that is recursively applied. Another way to define it is a detailed pattern repeating itself.

Even though we can often express these patterns mathematically, and they often repeat themselves, their starting conditions can lead to tremendous variability and a lack of predictability. This lack makes them chaotic, as studied under chaos theory, though their patterns are often discernible. While we certainly see randomness in statistics, quantum physics, and Brownian motion, it is also striking how what gives nature its beauty is structure. As a force separate and apart from the random, there appears something within structure that guides the expression of what is natural and what is so pleasing to behold. Self-similar and repeated structures across a variety of spatial scales are an abiding aspect of nature. Such forms of repeated patterns or structure are also inherent in that unique human capability, language, a topic on which Warner has written extensively.[33]

Some Structures are More Efficient

The continuation of structure from nature to language extends across all aspects of human endeavor. I remember once excitedly describing to a colleague what likely is a pedestrian observation: pattern matching is a common task in many fields. (I had observed that pattern matching in very different forms was standard practice in most areas of industry and commerce.) My 'insight' was that this commonality was not widely understood, which meant that widely divergent pattern matching techniques in one field were not often exploited or seen as transferable to other domains.

In computer science, pattern matching is the act of checking some sequence of tokens for the presence of the constituents of some pattern. It is closely related to the idea of pattern recognition, which is the characterization of some discernible and repeated sequence. These techniques, as noted, are widely applied, with each field tending to have favorite algorithms. Typical applications that one sees for such pattern-based calculations include: communications,[34] encoding and coding theory, file compression, data compression, machine learning, video compression, mathematics (including engineering and signal processing via such techniques as statistics or Fourier transforms), cryptography, NLP,[35] speech recognition, image recognition, OCR, image analysis, search, sound cleaning (that is, error detection, such as Dolby), and gene sequence searching and alignment, among many others.

To better understand what is happening here and the commonalities, let's look at the idea of compression. Data compression is valuable for transmitting any form of content in wired or wireless manners because we can transmit the same (or closely similar) message faster and with less bandwidth.[36] Compression uses both lossless (no loss of information) and lossy methods. Algorithms for lossless data compression usually exploit statistical redundancy — that is, a pattern match — to transmit data more concisely without losing information. Lossless compression is possible because most real-world data has statistical redundancy. In lossy data compression, some loss of information is acceptable by dropping detail from the data to save space. For instance, some frequencies are inaudible to people. A lossy audio recording may drop these frequencies without being noticed.

A close connection relates machine learning and compression. A system that predicts the posterior probabilities of a sequence given its entire history can be used for optimal data compression (by using arithmetic coding on the output distribution), while an optimal compressor can be used for prediction (by finding the symbol that compresses best, given the previous history). In contrast, cryptography seeks to construct messages that pattern matching is too time-consuming to analyze.

Evolution Favors Efficient Structures

An example shows how Shannon entropy relates to patterns or data compression. Let's take a message of entirely random digits. To accurately communicate that message, we would need to transmit all digits (bits) in their original state and form. Absolutely no compression of this message is possible. If, however, patterns reside within the message (which, of course, now ceases to make the message random), we can express them algorithmically in a shortened form so that we only need communicate the algorithm and not the full bits of the original message. If this 'compression' algorithm can then be used to reconstruct the bit stream of the original message, the data compression method is deemed lossless. The algorithm so derived is also the expression of the pattern that enabled us to compress the message in the first place. We can apply this same type of intuition to human language.

In open systems, structures (patterns) are a means to speed the tendency to equilibrate across energy gradients. This observation helps provide insight into structure in natural systems, and why life and human communications tend toward more order (less randomness). Structure will always continue to emerge because it is adaptive to speed the deltas across these gradients; structure provides the fundamental commonality between biological information (life) and human information. Of course, in Shannon's context, what we measure here is data (or bits), not information embodying any semantic meaning or context. However, it does show that 'structure' — that is, the basis for shortening the length of a message while still retaining its accuracy — is information in the Shannon context. This structure arises from order or patterns, often of a hierarchical or fractal or graph nature. Emergent structure that can reduce the energy gradient faster is favored.

These processes are probabilistic and statistical. Uncertainties in state may favor one structure at one time versus another at a different time. The types of chemical compounds favored in the primordial soup were likely greatly influenced by thermal and light cycles and drying and wet conditions. In biological ecosystems, huge differences occur in seed or offspring production or overall species diversity and ecological complexity based on the stability (say, tropics) or instability (say, disturbance) of local environments. These processes are inherently non-deterministic. As we climb up the chain from the primordial ooze to life and then to humans and our many information mechanisms and technology artifacts (which are themselves embodiments of information), we see increasing complexity using different structural mechanisms.

The mechanisms of information transfer in living organisms occur (generally) via DNA in genes, mediated by sex in higher organisms, subject to random mutations, and then kept or lost entirely as their host organisms survive to procreate or not. Those are harsh conditions: the information survives or not (on a population basis) with high concentrations of information in DNA and with a priority placed on remixing for new combinations via sex. Information exchange (generally) only occurs at each generational event. Human cultural information, however, is of an entirely different mediation. We can record our information and share it across individuals or generations, extended with innovations like written language or digital computers.

Common to all of these perspectives — from patterns in nature and on to life and then animal and human communications — we see that structure is information. Human artifacts and technology, though not 'messages' in a conventional sense, embody information within their structures.[37] We also see the interplay of patterns and information in many processes of the natural world.[41] Examples include complexity theory, emergence, autopoiesis, autocatalysis, self-organization, stratification and cellular automata.[38]

We, beings who can symbolically record our perceptions, seem to recognize patterns innately. We see beauty in symmetry. Bilateral symmetry seems deeply ingrained in the perception by humans of the possible health or fitness of other living creatures. We also seem to recognize beauty in the simple. Seemingly complex bit streams reduced to a shorter algorithmic expression are always viewed as more elegant than lengthier, more complex alternatives. The simple laws of motion and Newtonian physics fit this pattern, as does Einstein's $E=mc^2$. This preference for the simple is a preference for the greater adaptiveness of the shorter, more universal pattern of messages, a lesson from Shannon's information theory.

These insights point to the importance of finding and deriving structured representations of information — including *meaning* — that can be simply expressed and efficiently conveyed. Building upon the accretions of structure in human and computer languages, the semantic Web and semantic technologies offer just such a prospect. These insights provide a guidepost for how and where to look for the next structural innovations. We find them in the algorithms of nature and language, and in making connections that provide the basis for still more structure and patterned commonalities.

The Meaning of Information

For Charles S. Peirce, signs convey all information. All signs are a triadic whole of the *object*, how it is perceived or signaled (*representamen*), and how it is understood or interpreted (*interpretant*), including meaning. Signs might be iconic, such as physical road signs or brand logos. Signs might be indexical, such as seeing the weather vane pointing the direction of the wind or hearing the whistle signaling the approaching train. Alternatively, the sign might be one of convention or patterns ('habits' or 'laws' in Peircean terms), as embodied in symbols. Examples of symbols include the stylus impression on clay, the crystalline structures of RNA and DNA,[39] the printed letters and words on the page, or the ordered magnetic charges on a hard drive.

No matter the medium or form, information is a physical sign that indicates some change in state, the 'difference' in Bateson's term. Because information is real, it can be theorized over and investigated empirically. In a letter to Lady Welby in 1902 Peirce says:[40]

> "As for the 'meaning,' logicians have recognized since Abélard's day and earlier that there is one thing which any sign, external or internal, stands for, and another thing which it signifies; its denoted breadth, its 'connoted' depth. They have further generally held, in regard to the most important signs, that the depth, or signification, is intrinsic, the breadth extrinsic."(CP 8.119)

Peirce specifically defined *information* as the *breadth* x *depth* of a concept (1867, CP 2.407-8) or what he also called the *area.* (CP 2.419) He affirmed the same view more than 35 years later. (1903, EP 2:305) The *breadth* refers to all of the external things regarding the concept, spanning its extensions or denotations, the things to which it connects. The *depth* applies to the intensions or comprehension about the concept, what it *is*, including internal properties or qualities. Peirce preferred *extension v comprehension* when referring to these two respective ideas. Peirce uses these terms in their absolute senses. That is, for a given thought or concept at hand, complete information would mean correctly comprehending all of the context and aspects of that given thing. This complete understanding is the 'truth' about the subject, in all of its absolute, dynamic elements. In fact, for signs, Peirce is repeatedly clear about distinguishing what the sign is about, what he calls the *immediate object*, which is what the sign conveys, and the actual *dynamic object*, the real thing that is the (inadequately signified) object of the sign:

> "We must distinguish between the Immediate Object, — i.e. the Object as represented in the sign, -- and the Real (no, because perhaps the Object is altogether fictive, I must choose a different term, therefore), say rather the Dynamical Object, which, from the nature of things, the Sign *cannot* express, which it can only *indicate* and leave the interpreter to find out by *collateral experience*." (1909, CP 8.314).

For example, no matter how cleverly or comprehensively we try to convey the idea of a general type called *diamonds* (the dynamic object), the object we signify to convey this reality (immediate object) can never be complete. There is never enough breadth, depth, perspective, and completeness to capture the dynamic *diamond*, similar to the territory map in Jorge Luis Borges's "On Exactitude of Science." These concepts are no different from the Shannon idea that losses always occur between what is sent and what is received.

If one applies these breadth and depth measures to a domain, we begin to get into massively scaled senses of information. All objects and their connections, no matter how tenuous, and their characteristics, no matter how subtle, constitute the entirety of the possible information space. This expansion is not tractable, which means we must find pragmatic ways to handle the combinatorial challenge, as well as to filter what is useful based on context and relevance.

Information is thus a very lossy concept. We have the real world, and all that it is. We represent what is in this world, imperfectly and incompletely. The messages we convey are subject to loss. We perceive or try to signify what we understand from these messages. Our representations are understood or not, and interpreted via circumstance and context. Higher losses across this circuit lower trust in the information and decrease our ability to act.

We can, however, take Peirce's views on sign-making (*semiosis*) and information and derive a somewhat integrative picture of how all of these piece parts may fit together. *Figure 2-1* is not a standard presentation because, first, I merge Shannon information constructs into the standard Peircean interpretation. Second, also in keeping with Shannon, I show arrows indicating information loss.[*] In *Figure 2-1* we first stipulate a given domain and scope of inquiry (not shown). Real things occupy this space, never, unfortunately, wholly understandable nor transmittable as fully correct messages. The dynamic object represents the total information theoretic potential. It is all that one might say about the real object. The dynamic object may be a singular thing or collections of ideas or things. In representing our dynamic objects, we can only convey them as somewhat incomplete immediate objects, which are in Secondness based on Peirce's universal categories (see *Chapter 6*).

* These arrows should not be confused with diagrams from other authors that depict the flows of understanding or meaning in Peircean semiosis.

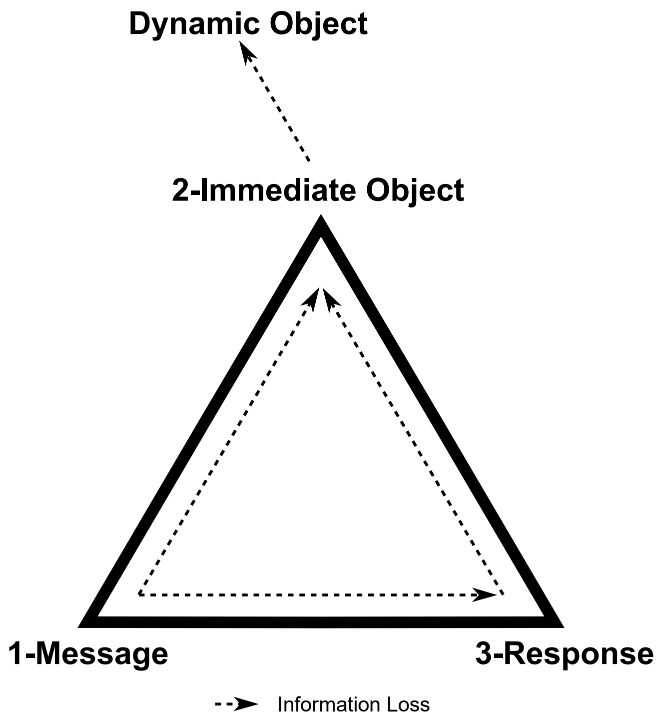

Figure 2-1: Semiotic Information Triad

How these objects are pointed to or signified is also an abstraction. Maybe we convey something iconic like an image, or perhaps we describe it in words. In all cases, our signification is imperfect. In Shannon terms, this is a message, which we can see as an analog of what Peirce called the *representamen.*† This message is a Firstness regarding the universal categories.‡ Structure affects how the message is initially *encoded* for transmittal and then *decoded* at the receiver (that is, the response level).

Then, as *interpretants* — that is, the Response level for those who receive the messages and respond to them — we also understand the object based on our perspectives and contexts. We may grasp and perceive many aspects of the signified object, or we may not. As the representation of the object by the sign, loss also arises from the interpretation of the sign by the responder to the object. Some of that loss, of course, may also be due to a loss of clarity from the sign to the interpretant, or what

† Not all Peirce scholars agree with this view. A key passage is CP 8.332 (1904), one of Peirce's letters to Lady Welby.

‡ Note this is 'message' in the sense of Shannon, not the 'meaning' of the transmission, which is in Thirdness.

the interpretant can perceive and process, all subject to circumstance or context.

Peirce posed three different kinds of interpretants:

> "It is likewise requisite to distinguish the Immediate Interpretant, i.e. the Interpretant represented or signified in the Sign, from the Dynamic Interpretant, or effect actually produced on the mind by the Sign; and both of these from the Normal Interpretant, or effect that would be produced on the mind by the Sign after sufficient development of thought." (1908, CP 8.343)

The *immediate interpretant* is the sense, or quality of the impression, invoked by the sign; Peirce also likened it to a schema. The immediate interpretant is a kind of Firstness. The *dynamic interpretant* is the meaning of the sign for a given concrete instance, an "act of the Mind." (1909, CP 8.315) It is a kind of Secondness. The *normal interpretant*, also called the *final* or *ultimate*, is the full significance of the sign, what it 'means' in all of its various aspects. The normal interpretant is a kind of Thirdness. It is the 'sum of lessons' learned from the sign and is a basis for action. I understand the normal interpretant to embrace all of the *breadth* and *depth* of information knowable to the interpreting agent. Though never expressed as such, I interpret Peirce to liken the immediate interpretant as the sense of something or its impression; the dynamic interpretant as taking note of something, recognizing it as information; and the normal interpretant as something we know and are willing to act upon with all that that means.

I discuss more the transition from information to knowledge in the next section. With Shannon's information theory, we have a technical way to understand and quantify information concerning entropy and its potential. That theory also gives us a robust framework for understanding and evaluating information losses, and how it is that we lose fidelity and truth as we move from the real to the perceived and communicated. As information theory gets better understood from the standpoints of the statistical mechanics of dynamic, non-equilibrium systems — that is, the circumstances of life and humans — I think we will begin to further understand the role of structures and patterns as favored dissipation systems. We are still building awareness that information is a rich environment, one which we may use Peirce's universal categories and semiosis to represent. We are still at the cusp of unpeeling these perspectives into an integrated information whole.

WHAT IS KNOWLEDGE?

As a book about knowledge representation, we have been sneaking up on what this concept of *knowledge* means. We see that it is grounded in information somehow, but it is also different. Significant terms we associate with knowledge and its discovery include *open*, *dynamic*, *belief*, *judgment*, *observation*, *process*, *representation*, *signification*, *interpretation*, *logic*, *coherence*, *context*, *reality*, and *truth*. These were all topics of Peirce's deep inquiry and explicated by him via his triadic worldview. To get at the question, I begin with some of our common sense understandings of 'knowledge.' I then supplement these notions with what Peirce himself had to say about the nature of knowledge. We conclude this section by looking at the critical question of *doubt*, and why that is the basis for stimulating inquiry and our search for new knowledge.

The Nature of Knowledge

Let's take the statement: *the sky is blue*. We can accept this as a factual statement. However, if we know the sky is dark or black, we know it is the night. Alternatively, the sky may be gray if it is cloudy. When we hear the statement that *the sky is blue*, if we believe the source or can see the sky for ourselves, then we can readily infer whether the observation is correct, occurring during daylight, under a clear sky. Our acceptance of an assertion as factual or being true carries with it the implications of its related contexts. On the other hand, were we simply to state *le ciel est bleu*, and if we did not know French, we would not know what to make of the statement, true or false, with context or not, even if all of the assertions were still correct.

This simple example carries with it two profound observations. First, context helps to determine whether we believe or not a given statement, and if we believe it, what the related context implied by the statement might be. Second, we convey this information via symbols — in this case, the English language, but applicable to all human and artificial and formal notations like mathematics as well — which we may or may not be able to interpret correctly. If I am monolingual in English and I see French statements, I do not know what the symbols mean.

Knowledge may reside solely in our minds, and not be part of 'common knowledge.' However, ultimately, even personal beliefs not held by others only become 'knowledge' that we can rely upon in our discourse once others have 'acknowledged' the truth. Forward-looking thinkers like Copernicus or Galileo or Einstein may have understood something in their minds not yet shared by others, but we do not 'acknowledge' those understandings as knowledge until we can share and discuss the insight. (That is, what scientists would call independent verification.) In this manner, knowledge, like language and symbol-creation, is inherently a social phenomena. If I coin a new word, but no one else understands what I am saying, that is not part of knowledge; that is gibberish.

None of this denies that individuals may 'know' things or have insights not shared with others. Perhaps we could call this 'personal knowledge.' My larger point, as it was for Peirce, is to advocate a more elevated understanding of knowledge that has the essences of being shared, valid to some degree, and supported by a community one respects. Indeed, the process of sharing knowledge with communities is to test and reflect on the shared understanding, thereby honing and improving our knowledge of the subject.

Peirce maintained, in part, we have to *believe* information for it to become knowledge. Put another way; we need to believe information to act upon it.[*] As our prior discussion also showed, we also see that the information upon which our judgments may depend may differ at all levels of human experience, perceptions, and language.

* Actions, of course, are not all premised on belief. Actions might be coerced or unconsciously reflexive.

We have a variety of viewpoints on any topic of ordinary human discourse. One criterion we apply when evaluating a viewpoint is whether it is *coherent*. Coherence is a state of logical, consistent connections, a logical framework for intelligently integrating diverse elements. Another criterion for evaluating information is whether it is ambiguous. *Ambiguity* is a frequent source of error, as when we wrongly identify the object, then connections can get drawn that are in glaring error. This potential error is why *disambiguation* is such a big deal in semantic systems. *Context* is thus an essential basis for resolving disambiguities. The same information may be used differently or given different importance depending on circumstance. One immediate implication of these italicized points is that we need to embed our information in a pragmatic semantics that reflects these realities.

Besides semantics, let's also look at some of the other common sense characteristics we associated with knowledge, and how these senses may affect what we need in a knowledge management systems:

- *Knowledge is never complete* — gaining and using knowledge is a process, and is never complete. A completeness assumption around knowledge is by definition inappropriate;
- *Knowledge may reside in multiple forms* — structured databases represent only a portion of structured information (spreadsheets and other non-relational data stores are other structured forms). Further, general estimates are that 80% of information available resides in documents, with growing importance to metadata, Web pages, markup documents and other semi-structured sources. A proper system for knowledge representation should be equally applicable to these various information forms;
- *Knowledge occurs anywhere* — relevant information about customers, products, competitors, the environment or virtually any knowledge-based topic may arise from internal and external information. The emergence of the Internet and the universal availability and access to mountains of public and shared information demands its thoughtful incorporation into knowledge management systems;
- *Knowledge is about connections* — the epistemological nature of knowledge can be argued endlessly, but I submit much of what distinguishes knowledge from information is that knowledge makes the connections — that is, asserts relations — between disparate pieces of relevant information, and it does so truly and believably. As these relationships accrete, the knowledge base grows. We need knowledge systems that enable us to add new connections as discovered without adversely impacting our existing knowledge characterizations;
- *Knowledge structures evolve with the incorporation of more information* — our ability to describe and understand the world or our problems at hand requires inspection, description, and definition. Birdwatchers, botanists, and experts in all domains know well how investigation and study of specific domains lead to more discerning understanding and 'seeing' of that domain. Before learning, everything is just a shade of green or a herb, shrub or tree to the incipient botanist;

eventually, she learns how to discern entire families and individual plant species, all accompanied by a rich domain language. We need to explicitly recognize in our KM systems how increased knowledge leads to more structure and more vocabulary; and

- *Knowledge is about what is agreed upon** — since knowledge is a state of understanding by practitioners and experts in a given domain, it is also vital that those very same users be active in its gathering, organization (structure), use, and consensus of what it is and what it means. The adjudication of knowledge is ultimately a social and community phenomenon. We should build KM systems around and for its users.

Of course, we may ascribe other senses to knowledge. Peirce, for example, notes that all knowledge comes to us via observation. (1897, CP 2.444) He notes that different knowledge may have different economic value. (1902, CP 7.158) He also separates out 'acquaintance' knowledge in his discussion of how to evaluate signs. 'Acquaintance' knowledge comes from 'collateral observation,' which goes beyond mere context to also include the meaning of the background knowledge applied to recognizing and interpreting the sign:

> "Now let us pass to the Interpretant. I am far from having fully explained what the Object of a Sign is; but I have reached the point where further explanation must suppose some understanding of what the Interpretant is. The Sign creates something in the Mind of the Interpreter, which something, in that it has been so created by the sign, has been, in a mediate and *relative* way, also created by the Object of the Sign, although the Object is essentially other than the Sign. And this creature of the sign is called the Interpretant. It is created by the Sign; but not by the Sign quâ member of whichever of the Universes it belongs to; but it has been created by the Sign in its capacity of bearing the determination by the Object. It is created in a Mind (how far this mind must be real we shall see). All that part of the understanding of the Sign which the Interpreting Mind has needed collateral observation for is outside the Interpretant. I do not mean by 'collateral observation' acquaintance with the system of signs. What is so gathered is *not* COLLATERAL. It is on the contrary the prerequisite for getting any idea signified by the sign. But by collateral observation, I mean previous acquaintance with what the sign denotes." (1909, CP 8.179)

We communicate shared knowledge via symbols. That means we communicate these assertions as arguments, which require *judgment* as to whether and how to act:

> "That is the first point of this argument; namely, that the *judgment*, which is the sole vehicle in which a concept can be conveyed to a person's cognizance or acquaintance, is not a purely representitious event, but involves an act, an exertion of energy, and is liable to real consequences, or effects." (1908, CP 5.547)

Prior knowledge, or 'collateral observation,' helps inform the judgment. The role of prior knowledge suggests that local context, broadly defined as the locality in a *knowledge graph*, needs to play a role in the characterization of knowledge.

* Per the more expansive definition used above, which reduces the role of 'personal knowledge.'

In another vein, Joel Mokyr, whom we will have a chance to discuss in *Chapter 3*, proposes a useful split between propositional knowledge (descriptive knowledge) from the know-how of procedural language.[41] A search will turn up many other assertions in the literature across disciplines about the nature and classification of knowledge.

Knowledge as Belief

Information is a proposition or assertion conveyed to us via signs, most often symbols, about objects in our domain (or world). The breakpoint from information to knowledge, based on our evaluation so far, occurs when we believe the information, and are willing to act upon it. We observe and evaluate the sign; if our response is action or a willingness to act, we can consider the sign as knowledge. I suspect under this interpretation that the act of merely recording the assertion, storing it for later use or inspection, does not qualify as an act of belief. This interpretation seems to conform with Peirce's idea of the dynamic interpretant.

The centrality of the idea of belief to knowledge goes back to at least Plato and then the Enlightenment in a formulation known as 'justified, true belief (JTB).'[42] The proposition must be believed as true with justification to qualify as knowledge. Peirce essentially endorsed this notion (though with some caveats and expansions as I suggest below):

> "Plato is quite right in saying that a true belief is not necessarily knowledge. A man may be willing to stake his life upon the truth of a doctrine which was instilled into his mind before his earliest memories without knowing at all why it is worthy of credence; and while such a faith might just as easily be attached to a gross superstition as to a noble truth, it may, by good luck, happen to be perfectly true. But can he be said to *know* it? By no means: to render the word knowledge applicable to his belief, he must not only believe it, but must know, -- I will not say, with the ancients, the rationale of the real fact, as a reality, -- but must know what justifies the belief, and just WHY and HOW the justification is sufficient. I beg that the reader will turn this over in his mind and satisfy himself as to how far what I am saying is true. For it is not a very simple point but is one that I intend to insist upon. Before knowledge of any subject can be put to any extensive use, it is almost indispensable that it should be made as thorough and complete as possible, until every detail and feature of the matter is spread out as in a German handbook. But if I am asked to what the wonderful success of modern science is due, I shall suggest that to gain the secret of that, it is necessary to consider science as living, and therefore not as knowledge already acquired but as the concrete life of the men who are working to find out the truth. Given a body of men devoting the sum of their energies to refuting their present errors, doing away with their present ignorance, and that not so much for themselves as for future generations, and all other requisites for the ascertainment of truth are insured by that one." (1902, CP 7.49-50)

Peirce describes in this passage the nature of truth, the means of justification, and the role of doubt. Let's first understand more precisely what Peirce means by *belief:*

> "A cerebral habit of the highest kind, which will determine what we do in fancy as well as what we do in action, is called a belief. The representation to ourselves that we have a specified habit of this kind is called a judgment. A belief-habit in its development begins by being vague, special, and meagre; it becomes more precise, general, and full, without limit. The process of this development, so far as it takes place in the imagination, is called thought. A judgment is formed; and under the influence of a belief-habit this gives rise to a new judgment, indicating an addition to belief. Such a process is called an inference; the antecedent judgment is called the premiss; the consequent judgment, the conclusion; the habit of thought, which determined the passage from the one to the other (when formulated as a proposition), the leading principle." (1880, CP 3.160)

Interestingly, though, Peirce closely ties belief to probability:

> "Probability and chance undoubtedly belong primarily to consequences, and are relative to premisses; but we may, nevertheless, speak of the chance of an event absolutely, meaning by that the chance of the combination of all arguments in reference to it which exist for us in the given state of our knowledge. Taken in this sense it is incontestable that the chance of an event has an intimate connection with the degree of our belief in it. Belief is certainly something more than a mere feeling; yet there is a feeling of believing, and this feeling does and ought to vary with the chance of the thing believed, as deduced from all the arguments. Any quantity which varies with the chance might, therefore, it would seem, serve as a thermometer for the proper intensity of belief. Among all such quantities there is one which is peculiarly appropriate. When there is a very great chance, the feeling of belief ought to be very intense. Absolute certainty, or an infinite chance, can never be attained by mortals, and this may be represented appropriately by an infinite belief." (1878, CP 2.676)

These views are one reason why Peirce contributed so much to probability theory over his career. Peirce's views are strongly tied to his belief in fallibilism: while truth exists, it can never be known absolutely, but as an approximation moving toward its limit function through testing and inquiry (namely, the scientific method).

> "... I used for myself to collect my ideas under the designation *fallibilism*; and indeed the first step toward *finding out* is to acknowledge you do not satisfactorily know already; so that no blight can so surely arrest all intellectual growth as the blight of cocksureness; and ninety-nine out of every hundred good heads are reduced to impotence by that malady — of whose inroads they are most strangely unaware!" (1897, CP 1.13)

A core consistency underlying Peirce's views of knowledge is his belief in reality. Reality exists outside of the mind or the individual; it exists whether minds exist to consider it; and it can be unveiled or discovered over time through observation and inquiry. In all of his writings, except when dedicated to the topic, Peirce attempted to look outside of psychology for his premises and logic. Objective truth exists, even if not absolutely knowable at its limits:

> "There are Real things, whose characters are entirely independent of our opinions about them; those Reals affect our senses according to regular laws, and, though our

> sensations are as different as are our relations to the objects, yet, by taking advantage of the laws of perception, we can ascertain by reasoning how things really and truly are; and any man, if he have sufficient experience and he reason enough about it, will be led to the one True conclusion. The new conception here involved is that of Reality." (1903, CP 5.384)

Knowledge is what we know of the past that influences our expectations about the future. It produces judgments and enables us to act, based on our believed probabilities. Unlike standard JTB, though, Peirce's version of knowledge asserts the fallibility of truth, is more rigorous in proposing how to justify and test for it, and includes the role for community adjudication. Thus, while neither truth nor justification may ever be absolute, and may change based on what we discover about objective reality, the weighing of the evidence gives us the belief in knowledge upon which to act.

Doubt as the Impetus of Knowledge

Another difference from JTB that Peirce emphasizes regards the drive or the quest for knowledge. So long as we doubt, we have an impetus to inquiry and knowledge. Upon attaining what Peirce called 'full belief,' once doubt has been removed and its irritation sated, the impetus to acquire knowledge on that topic abates:

> "Doubt is an uneasy and dissatisfied state from which we struggle to free ourselves and pass into the state of belief." (1892, CP 5.372)

> "The irritation of doubt causes a struggle to attain a state of belief. I shall term this struggle *Inquiry*, though it must be admitted that this is sometimes not a very apt designation." (1892, CP 5.374)

The 'irritation of doubt,' how to remove it, and how to make ideas clear were the subjects of a series of papers by Peirce in *Popular Science Monthly* in the late 1870s. One of the papers, "The Fixation of Belief,"[43] critically reviewed what Peirce claimed were the only four methods for obtaining belief and removing doubt. The four methods are the: 1) method of tenacity, wherein one repeats or wills to believe something; 2) the method of authority, wherein governments or external forces insist upon certain beliefs; 3) the *a priori* method, wherein precedent or social consensus determines beliefs; or 4) the method of science, obtained from the scientific method and the application of observation, testing, and logic. Peirce noted logical and other pitfalls for the first three methods. Only the fourth method can fix (and re-fix!) belief in an objective reality based on fallible truth. It is noteworthy given Peirce's lifelong devotion to science and the scientific method that he also makes the explicit point that belief, however, is not the objective of science:

> "We believe the proposition we are ready to act upon. *Full belief* is willingness to act upon the proposition in vital crises, *opinion* is willingness to act upon it in relatively insignificant affairs. But pure science has nothing at all to do with *action*.... There is thus no proposition at all in science which answers to the conception of belief." (1898, CP 1.635)

Through science, we gain probabilities on our information that constitutes conditioned or provisional knowledge. Belief, how Peirce defines it, is not a matter of science, but of action:

> "But in vital matters, it is quite otherwise. We must act in such matters; and the principle upon which we are willing to act is a belief. Thus, pure theoretical knowledge, or science, has nothing directly to say concerning practical matters, and nothing even applicable at all to vital crises. Theory is applicable to minor practical affairs; but matters of vital importance must be left to sentiment, that is, to instinct." (1898, CP 1.636-7)

Peirce perhaps does not say all that he could regarding doubt and the scientist's quest for truth. What we do glean from these perspectives, though, is the importance of the scientific method to inquiry, the driving force of doubt in our seeking more information, and the role that belief plays in elevating information to knowledge.

WHAT IS REPRESENTATION?

'Representation' is the second part of knowledge representation (KR). One dictionary sense is that 'representation' is the act of speaking or acting on behalf of someone else. This sense is the one, say, of a legislative representative (the Thomas Hobbes view, a dominant theme in classical empiricism[44]). Another sense is a statement made to some formal authority communicating an assertion, opinion or protest, such as a notarized document. The sense applicable to KR, however, according to the *Oxford Dictionary of English*, is the one of 're-presenting.' That is, "the description or portrayal of someone or something in a particular way or as being of a certain nature."[45]

Peirce bases his representational view of the world on semiotics, the study and logic of signs. In his seminal writing on this in 1894, "What is in a Sign?",[46] Peirce wrote that "every intellectual operation involves a triad of symbols" and "all reasoning is an interpretation of signs of some kind." Do not confuse Peirce's semiosis with that of Ferdinand de Saussure, which was for many years better known but lacks the perspective of Thirdness (mediation, continuity) in Peirce's version.

After the advent of computers, knowledge representation (and reasoning) was formalized as a sub-discipline of artificial intelligence and received more focused attention. Davis *et al.* wrote an influential piece in 1993 that stipulated five requirements for knowledge representation,[47] all of which are captured in one way or another by the approach recommended in this book. We may study KR through standard texts such as by Brachman and Levesque,[48] or van Harmelan.[6] We may understand KR via the language of thought hypothesis of Jerry Fodor[52] or via set theory (such as from Zhou[49]) or Fred Dretske's representational thesis (which pays particular attention to phenomenology but does not mention Peirce).[54]

Clearly, for the reasons cited throughout this book, Peirce is the polestar I have chosen to guide my thinking on knowledge representation. We have already seen his insights in information and knowledge. His semiosis takes dead aim at the questions of how to represent knowledge, and the role and the unique triadic relationship of signs. Indeed, the sheer consistency and coherence of his logics and philosophical views dovetail directly with the needs of conveying information and knowledge to computers. Except for John Sowa's book,[50] now nearly 30 years old, it is time to bring Peirce back into the knowledge representation fold of AI.

The Shadowy Object

When we see something, or point to something, or describe something in words, or think of something, we are, of course, using proxies in some manner for the actual thing. If the something is a 'toucan' bird, that bird does not reside in our head when we think of it. The 'it' of the toucan is a 're-presentation' of the real, dynamic toucan. The representation of something is never the actual something but is itself another thing that conveys to us the idea of the real something. In our daily thinking we rarely make this distinction, thankfully, otherwise, our flow of thoughts would be wholly jangled. Nonetheless, the difference is real, and we should be conscious of it when inspecting the nature of knowledge representation.

How we 're-present' something is also not uniform or consistent. For the toucan bird, perhaps we make caw-caw bird noises or flap our arms to indicate we are referring to a bird. Perhaps we point at the bird. Alternatively, perhaps we show a picture of a toucan or read or say aloud the word "toucan" or see the word embedded in a sentence or paragraph, as in this one, that also provides additional context. How quickly or accurately we grasp the idea of 'toucan' is partly a function of how closely associated one of these signs may be to the idea of toucan bird. Probably all of us would agree that arm flapping is not nearly as useful as a movie of a toucan in flight or seeing one scolding from a tree branch to convey the 'toucan' concept. There's a reason why we love the game of charades.

The question of what we know and how we know it fascinated Peirce over the course of his intellectual life. He probed this relationship between the real or actual thing, the *object*, with how that thing is represented and understood. This triadic relationship between immediate object, representation, and interpretation forms a *sign* and is the basis for the process of sign-making and understanding that Peirce called *semiosis*.[51]

Even the idea of the *object*, in this case, the toucan bird, is not necessarily so simple. The real thing itself, the toucan bird, has characters and attributes. How do we 'know' this real thing? Bees, like many insects, may perceive different coloration for the toucan and adjacent flowers because they can see in the ultraviolet spectrum, while we do not. On the other hand, most mammals in the rainforest would also not perceive the reds and oranges of the toucan's feathers, which we readily see. Perhaps only fellow toucans could perceive by gestures and actions whether the object toucan is healthy, happy or sad (in the toucan way). Humans, through our ingenuity, may create devices or technologies that expand our standard sensory capabilities to make up for some of these perceptual gaps, but technology will never make our knowledge fully complete. Given limits to perceptions and the information we have on hand, we can never completely capture the nature of the dynamic object, the real toucan bird.

Alternatively, let's take another example more in keeping with the symbolic nature of KR, in this case, the word for 'bank.' We can see this word, and if we speak English, even recognize it, but what does this symbol mean? A financial institution? The shore of a river? Turning an airplane? A kind of pool shot? Tending a fire for the evening? In all of these examples, an actual object is the focus of attention. What we 'know' about this object depends on what we perceive or understand and who or what is doing the perceiving and the understanding. We can never fully 'know' the object because we can never encompass all perspectives and interpretations.

Peirce well recognized these distinctions. As we noted before, he termed the object of the representations as the *immediate object*, while also acknowledging this representation does not fully capture the underlying, real *dynamical object*:

> "Every cognition involves something represented, or that of which we are conscious, and some action or passion of the self whereby it becomes represented. The former shall be termed the objective, the latter the subjective, element of the cognition. The cognition itself is an intuition of its objective element, which may therefore be called, also, the immediate object." (1868, CP 5.238)

> "Namely, we have to distinguish the Immediate Object, which is the Object as the Sign itself represents it, and whose Being is thus dependent upon the Representation of it in the Sign, from the Dynamical Object, which is the Reality which by some means contrives to determine the Sign to its Representation." (1906, CP 4.536)

> "As to the Object, that may mean the Object as cognized in the Sign and therefore an Idea, or it may be the Object as it is regardless of any particular aspect of it, the Object in such relations as unlimited and final study would show it to be. The former I call the *Immediate Object*, the latter the *Dynamical Object*." (1909, CP 8.183)*

One imperative of knowledge representation — within reasonable limits — is to try to ensure that our immediate representation of the objects of our discourse is in close correspondence to the dynamic object. This imperative, of course, does not mean assembling every minute bit of information possible to characterize our knowledge spaces. Instead, we need to seek a balance between what and how we characterize the instances in our domains with the questions we are trying to address, all within limited time and budgets. Peirce's pragmatism, as expressed through his *pragmatic maxim* discussed in *Chapter 14*, helps us reach this balance.

Three Modes of Representation

Representations are signs (CP 8.191), and the means by which we point to, draw or direct attention to, or designate, denote or describe a particular object, entity, event, type or general. In Peirce's mature theory of signs, he characterizes signs according to different typologies, which we cover in this and later sections. One of his

* See further the prior *Figures 1-1* and *2-1*.

better-known typologies is how we may denote the object, which, unlike some of his other typologies, he kept relatively constant throughout his life. Peirce formally splits these denotative representations into three kinds: *icons*, *indexes*, or *symbols* (CP 2.228, CP 2.229 and CP 5.473).

> "... there are three kinds of signs which are all indispensable in all reasoning; the first is the diagrammatic sign or *icon*, which exhibits a similarity or analogy to the subject of discourse; the second is the *index*, which like a pronoun demonstrative or relative, forces the attention to the particular object intended without describing it; the third [or *symbol*] is the general name or description which signifies its object by means of an association of ideas or habitual connection between the name and the character signified." (1885, CP 1.369)

The *icon*, which may also be known as a *likeness* or *semblance*, has a quality shared with the object such that it resembles or imitates it (see *Table 2-1*). Portraits, logos, diagrams, and metaphors all have an iconic denotation. Peirce also views algebraic expressions as icons since he believed (and did much to prove) that mathematical operations can be expressed through diagrammatic means (as is the case with his later existential graphs).

An *index* denotes the object by some form of linkage or connection. An index draws or compels attention to the object by this genuine connection, and does not require any interpretation or assertion about the nature of the object. A finger pointed at an object or a weathervane indicating which direction the wind is blowing are indexes, as are keys in database tables or Web addresses (IRIs or URLs[52]) on the Internet. Pronouns, proper names, and figure legends are also indexes.

An icon	is a sign fit to be used as such because	it possesses the quality signified.
An index		it is in real reaction with the object denoted.
A symbol		it determines the interpretant sign.

Table 2-1: Three Ways to Denote Objects of Signs

Symbols, the third kind of denotation, represent the object by accepted conventions or 'laws' or 'habits' (Peirce's preferred terms). Symbols are an understood interpretation, gained through communication and social consensus. All words are symbols, plus their combinations into sentences and paragraphs. All symbols are generals, though we express them as individual instances or tokens. For example, 'the' is a single symbol (type), but it is expressed many times (tokens) on this page. Knowledge representation, by definition, is based on symbols, which are interpreted by either humans or machines based on the conventions and shared understandings we have given them. When Peirce returned to the investigation of signs later in his career, he attempted many times to help clarify how to best distinguish between these three.

For example:

> "There is an infallible criterion for distinguishing between an index and an icon. Namely, although an index, like any other sign, only functions as a sign when it is interpreted, yet though it never happened to be interpreted, it remains equally fitted to be the very sign that would be if interpreted. A symbol, on the other hand, that should not be interpreted, would either not be a sign at all, or would only be a sign in an utterly different way. An inscription that nobody ever had interpreted or ever would interpret would be but a fanciful scrawl, an index that some being had been there, but not at all conveying or apt to convey its meaning." (1904, NEM 4:256)

Peirce confined the word *representation* to the operation of a sign or its relation to the interpreter for an object. The three possible modes of denotation — that is, icon, index or symbol — Peirce collectively termed the *representamen*:

> "A very broad and important class of triadic characters [consists of] representations. A representation is that character of a thing by virtue of which, for the production of a certain mental effect, it may stand in place of another thing. The thing having this character I term a *representamen*, the mental effect, or thought, its *interpretant*, the thing for which it stands, its *object*." (1897, CP 1.564)

Symbols are in Thirdness, one of the universal categories we discuss at length in *Chapter 6*. As a preview, though, understand these symbols are themselves representations, which build in an ever-growing cascade, to convey deeper and more complicated representations, each with a meaning to its interpretant:

> "The easiest of those [ideas in which Thirdness is predominant] which are of philosophical interest is the idea of a sign, or representation. A sign stands *for* something *to* the idea which it produces, or modifies. Or, it is a vehicle conveying into the mind something from without. That for which it stands is called its *Object*; that which it conveys, its *Meaning*; and the idea to which it gives rise, its *Interpretant*. The object of a representation can be nothing but a representation of which the first representation is the interpretant. But an endless series of representations each representing the one behind it may be conceived to have an absolute object at its limit. The meaning of a representation can be nothing but a representation." (1893, NEM4:309-310; MS 717)

Again, note that representation is the complete triadic sign, while meaning is the understanding conveyed by the symbolic representation, as understood and acted upon by the interpreting agent.

Peirce's Semiosis and Triadomany

In the same early 1867 paper in which Peirce laid out the three modes of denotation of icon, index, and symbol,[70] he also presented his three phenomenological categories for the first time, what I (and others) have come to call his *universal categories* of Firstness, Secondness, and Thirdness.* This seminal paper also provides the con-

* See entire *Chapter 6*, especially *Table 6-2*.

textual embedding of these categories, which is worth repeating in full:

> "The five conceptions thus obtained, for reasons which will be sufficiently obvious, may be termed *categories*. That is,
>
> BEING,
> Quality (reference to a ground),
> Relation (reference to a correlate),
> Representation (reference to an interpretant),
> SUBSTANCE.
>
> The three intermediate conceptions may be termed accidents." (1896, EP 1:6, CP 1.55)

Note the commas, suggesting the order, and the period, in the listing. In his later writings, Peirce ceases to discuss Being and Substance directly, instead focusing on the 'accidental' categories that became the first expression of his universal categories. Being, the starting point, is the absolute, most abstract beginning for Peirce's epistemology.[54] The three 'accidental' categories of Quality, Relation and Representation are one of the first expressions of Peirce's universal categories of Firstness, Secondness, and Thirdness, as applied to Substance. "Thus substance and being are the beginning and end of all conception. Substance is inapplicable to a predicate, and being is equally so to a subject." (1867, CP 1.548)

These two, early triadic relations — one, the denotations in signs, and, two, the universal categories — are examples of Peirce's lifelong fascination with trichotomies.[55] He used triadic thinking in dozens of areas in his various investigations,* often in a recursive manner (threes of threes). It is not surprising, then, that Peirce also applied this mindset to the general characterization of signs themselves.

Peirce returned to the idea of sign typologies and notations at the time of his Lowell Institute lectures at Harvard in 1903.[56] Peirce expanded upon his first triad of icons, indexes, and symbols with two additional trichotomies.

In one of these additions, the second trichotomy, Peirce proferred three ways to describe the use of signs. These three uses are: *qualisigns* (also called *tones*, *potisigns*, or *marks*), which are signs that consist of a quality of feeling or possibility, and are in Firstness; *sinsigns* (also called *tokens* or *actisigns*), which consist in action/reaction or actual single occurrences or facts, and are in Secondness; or *legisigns* (also called *types* or *famisigns*), which are signs that consist of generals or representational relations, and are in Thirdness. Instances (tokens) of legisigns are replicas and thus are a sinsign. All symbols are legisigns. Synonyms, for example, are replicas of the same legisign, since they mean the same thing, but are different sinsigns.

In the second of these additions, the third trichotomy, Peirce described three ways to interpret signs (*interpretant*) based on possibility, fact, or reason. A *rheme* (also called *sumisign* or *seme*) is in Firstness and is a sign that stands for its object for some purpose, expressed as a character or a mark. Terms are rhemes, but they also may be icons or indexes. Rhemes may be diagrams, proper nouns or common nouns.

* *Table 6-2* lists more than 60 examples.

A proposition expressed with its subject as a blank (unspecified) is also a rheme. A *dicisign* (also called *dicent* or *pheme*) is the second interpretation of a sign. A dicent is in Secondness and is a fact of actual existence. Icons cannot be dicisigns. Dicisigns may be either indexes or symbols and provide indicators or pointers to the object. Standard propositions or assertions are dicisigns. An *argument* (also called *suadisign* or *delome*) is the third way of a reasoning sign, in Thirdness, and stands for the object as a generality, law, or habit. A sign itself is an argument, including major and minor premises and conclusions. Combinations of assertions or statements, such as novels or works of art, are arguments. Context resides in Thirdness.

One might expect these three Peircean sign trichotomies to result in 27 different possibilities (3 x 3 x 3). However, the nature of the monadic, dyadic and triadic relationships embedded in these trichotomies only logically leads to 10 variants (1 + 3 + 6).[57] *Table 2-2* summarizes these ten sign types and provides some examples of how to understand them. The 1 + 3 + 6 variants include Sign I, Signs II to IV, and Signs V to X, respectively, as shown in the table.

	Sign by Use	*Relative to Object*	*Relative to Interpretant*	*Sign Name (redundancies)*	*Some Examples*
I	Qualisign	Icon	Rheme	(Rhematic Iconic) Qualisign	A feeling of 'red'
II	Sinsign	Icon	Rheme	(Rhematic) Iconic Sinsign	An individual diagram
III		Index	Rheme	Rhematic Indexical Sinsign	A spontaneous cry
IV			Dicisign	Dicent (Indexical) Sinsign	A weathercock or photograph
V	Legisign	Icon	Rheme	(Rhematic) Iconic Legisign	A diagram, apart from its factual individuality
VI		Index	Rheme	Rhematic Indexical Legisign	A demonstrative pronoun
VII			Dicisign	Dicent Indexical Legisign	A street cry (identifying the individual by tone, theme)
VIII		Symbol	Rheme	Rhematic Symbol (Legisign)	A common noun
IX			Dicisign	Dicent Symbol (Legisign)	A proposition (in the conventional sense)
X			Argument	Argument (Symbolic Legisign)	A syllogism

Table 2-2: Ten Classifications of Signs[58]

The schema in *Table 2-2* is the last one fully developed by Peirce. We will next return to this schema in *Chapter 16* (specifically *Table 16-3*) when we turn to the topic of semantic parsing of natural language. However, also realize, in Peirce's last years, he also developed 28-class and 66-class sign typologies, though incomplete in important ways and details. These expansions reflected sign elaborations for various sub-classes of Peirce's more mature trichotomies, such as for the immediate and dynamic objects previously discussed (*c.f.*, 1904, CP 8.342-379).

A symmetrical and recursive beauty exists in these incomplete efforts, with sufficient methodology suggested to enable informed speculations as to where Peirce may have been heading.[59] [60] [61] [62] Twenty-five years ago Nathan Houser opined that "… a sound and detailed extension of Peirce's analysis of signs to his full set of ten divisions and sixty-six classes is perhaps the most pressing problem for Peircean semioticians."[63] I somewhat agree, but applying the *pragmatic maxim* suggests it is not the next priority. True, with much digging the archeology of Peirce's intent at the time may be discerned to some degree. However, Peirce himself would likely have re-considered and revised his views, as he was wont to do over time, especially in light of massive changes in knowledge over the past century. Such is the nature of knowledge, and how we dynamically respond to it.

A significant portion of the Peircean community believes that signs and semiosis are the central aspects underlying Peirce's philosophy. Passages in Peirce's writings support this interpretation. However, I agree that Peirce's 'theory of categories,' to use Siosifa Ika's phrase, is the better key to understanding Peirce's metaphysical and epistemological realism.[64] Besides Ika's well-reasoned thesis, I argue three additional reasons to see the universal categories as the more fundamental driver. First, Peirce, as we noted, conducted his thought in threes and tried to reason in threes. Second, similar and compelling passages in Peirce (see throughout and in *Appendix A*) support the primacy of the universal categories in contradistinction to signs. Third, the categories prescind* both signs and logic, indicating their superordinate position.

Thus, in this book, we take a different path. Rather than engaging in the archeology of Peirce's intended sign schemas, I have chosen to try to fathom and plumb Peirce's mindset. His explication of the centrality and power of signs, his fierce belief in logic and reality, and his commitment to discovering the fundamental roots of *epistêmê*, guide how to think about knowledge representation attuned to today. I believe Peirce's triadomany,[55] especially as expressed through the universal categories, provides the illuminating light to this guidance.

Chapter Notes

1. Some material in this chapter was drawn from the author's prior articles at the *AI3:::Adaptive Information* blog: "The Open World Assumption: Elephant in the Room" (Dec 2009); "Give Me a Sign: What Do Things Mean on the Semantic Web?" (Jan 2012); "The Trouble with Memes" (Apr 2012); "What is Structure?" (May 2012); "The Irreducible Truth of Threes" (Sep 2016); "The Importance of Being Peirce" (Sep 2016); "Being Informed by Peirce" (Feb 2017).
2. Deacon, T. W., *The Symbolic Species: The Co-Evolution of Language and the Brain*, New York: W.W. Norton, 1997.
3. Bateson, G., *Steps to an Ecology of Mind: Collected Essays in Anthropology, Psychiatry, Evolution, and Epistemology*, University of Chicago Press, 1972.

* See the section on *Hierarchies* in *Chapter 7*.

4. Shannon, C. E., “A Mathematical Theory of Communication,” *Bell System Technical Journal*, vol. 27, Jul. 1948, pp. 379–423.
5. One might try to avoid the term “information” because it has multiple meanings or differing interpretations, substituting instead narrower definitions for each meanng. Moreover, multiple meanings do not have crisp boundaries, so that there is always a probability of misunderstanding or misassignment. However, when a term is commonly used, we need to accept the reality of its use. Thus, Peirce tried mightily, a practice to which I adhere, to define terms as understood and put forward. This consideration applies to any term or definition.
6. Landauer, R., “Irreversibility and Heat Generation in the Computing Process,” *IBM Journal of Research and Development*, vol. 5, 1961, pp. 183–191.
7. Landauer, R., “Information Is Physical,” *Physics Today*, vol. 25, 1991.
8. Bérut, A., Arakelyan, A., Petrosyan, A., Ciliberto, S., Dillenschneider, R., and Lutz, E., “Experimental Verification of Landauer’s Principle Linking Information and Thermodynamics,” *Nature*, vol. 483, Mar. 2012, pp. 187–189.
9. Karnani, M., Paakkonen, K., and Annila, A., “The Physical Character of Information,” *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, vol. 465, Jul. 2009, pp. 2155–2175.
10. As Shannon acknowledges in his paper, the “bit” term was suggested by J. W. Tukey. Shannon can be more accurately said to have popularized the term via his paper.
11. Shannon, C. E., and Weaver, W., *The Mathematical Theory of Communication*, Urbana, Illinois: University of Illinois Press, 1998.
12. Losee, R. M., *Information from Processes: About the Nature of Information Creation, Use, and Representation*, Springer Science & Business Media, 2012.
13. Furner, J., “‘Data’: The Data,” *Information Cultures in the Digital Age*, M. Kelly and J. Bielby, eds., Springer, 2016, pp. 287–306.
14. According to Wikipedia, the equation was originally formulated by Ludwig Boltzmann between 1872 and 1875, but later put into its current form by Max Planck in about 1900. To quote Planck, “the logarithmic connection between entropy and probability was first stated by L. Boltzmann in his kinetic theory of gases.”
15. Schneider, T. D., “Information is Not Entropy, Information is Not Uncertainty!,” *Molecular Information Theory and the Theory of Molecular Machines* Available: https://schneider.ncifcrf.gov/information.is.not.uncertainty.html.
16. Koelman, J., “What Is Entropy?,” *Science 2.0* Available: http://www.science20.com/hammock_physicist/what_entropy-89730.
17. Jaynes, E. T., “Information Theory and Statistical Mechanics,” *Physical Review*, vol. 106, 1957, pp. 620–630.
18. Zimmer, B., “The Surprising Origins of Life’s Complexity,” *Quanta Magazine* Available: https://www.quantamagazine.org/the-surprising-origins-of-lifes-complexity-20130716/.
19. Sarkar, S., and England, J. L., “Sufficient Physical Conditions for Self-Replication,” *arXiv:1709.09191 [cond-mat, physics:physics]*, Sep. 2017.
20. Schrödinger, E., *What Is Life?: The Physical Aspect of the Living Cell*, Trinity College, Dublin: University Press, 1944.
21. Brillouin, L., “The Negentropy Principle of Information,” *Journal of Applied Physics*, vol. 24, 1953, pp. 1152–1163.
22. Prigogine, I., and Nicolis, G., “Biological Order, Structure and Instabilities,” *Quarterly Reviews of Biophysics*, vol. 2,3 and 4, 1971, pp. 107–148.
23. Annila, A., and Salthe, S., “Physical Foundations of Evolutionary Theory,” *Journal of Non-Equilibrium Thermodynamics*, vol. 35, 2010, pp. 301–321.
24. Crooks, G. E., “The Entropy Production Fluctuation Theorem and the Nonequilibrium Work Relation for Free Energy Differences,” *Physical Review E*, vol. 60, Sep. 1999, pp. 2721–2726.
25. England, J. L., “Dissipative Adaptation in Driven Self-Assembly,” *Nature Nanotechnology*, vol. 10, Nov. 2015,

pp. 919–923.

26. Salthe, S. N., “Naturalizing Information,” *Information*, vol. 2, Jul. 2011, pp. 417–425.
27. England, J. L., “Statistical Physics of Self-Replication,” *The Journal of Chemical Physics*, vol. 139, Sep. 2013, p. 121923.
28. Wissner-Gross, A. D., and Freer, C. E., “Causal Entropic Forces,” *Physical Review Letters*, vol. 110, 2013, p. 168702.
29. Eaton, J. J., and Bawden, D., “What Kind of Resource Is Information?,” *International Journal of Information Management*, vol. 11, 1991, pp. 156–165.
30. Bates, M. J., “Information and Knowledge: An Evolutionary Framework for Information Science,” *Information Research: An International Electronic Journal*, vol. 10, 2005, p. n4.
31. Bejan, A., and Lorente, S., “The Constructal Law and the Evolution of Design in Nature,” *Physics of Life Reviews*, vol. 8, Oct. 2011, pp. 209–240.
32. There are dynamic illustrations of many of these patterned phenomena, but it is also the case that animated images on the Web tend to have a short shelf life. There are some examples related to this section that may be found on Wikipedia, which likely means that similar images may be found by searching exact and related topics in that source, even should the exact links provided here prove dated. Examples of patterned examples include fractals such as http://upload.wikimedia.org/wikipedia/commons/f/f4/Animation_of_the_growth_of_the_Mandelbrot_set_as_you_iterate_towards_infinity.gif, http://upload.wikimedia.org/wikipedia/commons/f/fd/Von_Koch_curve.gif, and http://upload.wikimedia.org/wikipedia/commons/7/76/Feigenbaumzoom.gif, cellular automata such as http://upload.wikimedia.org/wikipedia/commons/8/86/Oscillator.gif, with recursion and repeated patterns (such as in the whorls of flowers) providing examples of how simple stratagems may also result in rather complex behaviors.
33. Warner, J., *Human Information Retrieval*, MIT Press Cambridge, MA, 2010.
34. Communications is a particularly rich domain with techniques such as the Viterbi algorithm, which has found universal application in decoding the convolutional codes used in both CDMA and GSM digital cellular, dial-up modems, satellite, deep-space communications, and 802.11 wireless LANs.
35. Notable areas in natural language processing (NLP) that rely on pattern-based algorithms include classification, clustering, summarization, disambiguation, information extraction and machine translation.
36. There is a massive list of “codecs” (compression/decompression) techniques available (http://en.wikipedia.org/wiki/List_of_codecs); fractal compression is one.
37. Kelley, K., *What Technology Wants*, Viking/Penguin, 2010.
38. Wolfram, S., *A New Kind of Science*, Champaign, IL: Wolfram Media, 2002.
39. Michael Buckland, among many others, question treating physical characteristics as messages (pers. comm.). However, at a certain level of Thirdness, inanimate patterns like crystalline structures do represent the “best” mediating organization at time of formation to maximize entropy production. At the level of symbology, of course, human language is much more derived. It is the idea of mediation and Thirdness that brings crystals and language together, not the nature of the symbols used.
40. Peirce, C. S., and Welby, L. V., *Semiotic and Significs: The Correspondence Between Charles S. Peirce and Lady Victoria Welby*, Indiana University Press, 1977.
41. Mokyr, J., *The Gifts of Athena: Historical Origins of the Knowledge Economy*, 2002.
42. “Justified true belief” (JTB) fell out of favor with Gettier’s criticisms of justification (see Gettier, E. L., “Is Justified True Belief Knowledge?,”*Analysis*, vol. 23, 1963, pp. 121–123). Peirce had a different, nuanced view as well; see the main text.
43. Peirce, C. S., “The Fixation of Belief,” *Popular Science Monthly*, vol. 12, Nov. 1877, pp. 1–15.
44. Hobbes, T., *Elements of Law, Natural and Political*, Routledge, 2013.
45. See https://en.oxforddictionaries.com/definition/representation.
46. Peirce, C. S., “What is in a Sign?,” 1894.
47. Davis, R., Shrobe, H., and Szolovits, P., “What Is a Knowledge Representation?,” *AI Magazine*, vol. 14, 1993, p.

17.

48. Brachman, R. J., and Levesque, H. J., *Knowledge Representation and Reasoning*, Morgan Kaufmann, 2004.

49. Zhou, Y., “A Set Theoretic Approach for Knowledge Representation: the Representation Part,” *arXiv*, vol. 1603, Mar. 2016.

50. Sowa, J. F., *Knowledge Representation: Logical, Philosophical, and Computational Foundations*, Brooks/Cole Pacific Grove, 2000.

51. Peirce actually spelled it “*semeiosis*.” While it is true that other philosophers such as Ferdinand de Saussure also employed the shorter term “semiosis.” I also use this more common term due to greater familiarity.

52. The URI “sign” is best seen as an *index*: the URI is a pointer to a representation of some form, be it electronic or otherwise. This representation bears a relation to the actual thing that this referent represents, as is true for all triadic sign relationships. However, in some contexts, again in keeping with additional signs interpreting signs in other roles, the URI “sign” may also play the role of a symbolic “name” or even as a signal that the resource can be downloaded or accessed in electronic form. In other words, by virtue of the conventions that we choose to assign to our signs, we can supply additional information that augments our understanding of what the URI is, what it means, and how it is accessed.

53. Among all of his writings, Peirce said: “The truth is that my paper of 1867 was perhaps the least unsatisfactory, from a logical point of view, that I ever succeeded in producing; and for a long time most of the modifications I attempted of it only led me further wrong.” (1895, CP 2.340).

54. The polymath Buckminster Fuller also maintained that the triad was the most stable structure in the universe; see https://bookofthrees.com/buckminster-fuller-building-blocks/.

55. See CP 1.568, wherein Peirce provides “The author’s response to the anticipated suspicion that he attaches a superstitious or fanciful importance to the number three, and forces divisions to a Procrustean bed of trichotomy.”

56. Peirce, C. S., and The Peirce Edition Project, “Nomenclature and Divisions of Triadic Relations, as Far as They Are Determined,” *The Essential Peirce: Selected Philosophical Writings, Volume 2 (1893-1913)*, Bloomington, Indiana: Indiana University Press, 1998, pp. 289–299.

57. Understand each trichotomy is comprised of three elements, A, B and C. The monadic relations are a singleton, A, which can only match with itself and A variants. The dyadic relations can only be between A and B and derivatives. And the triadic relations are between all variants and derivatives. Thus, the ten logical combinations for the three trichotomies are: A-A’-A”; B-A’-A”; B-B’-A”; B-B’-B”; C-A’-A”; C-B’-A”; C-B’-B”; C-C’-A”; C-C’-B”; and C-C’-C”, for a total of ten options.

58. From CP 2.254-263, EP 2:294-296, and MS 540 of 1903.

59. Borges, P., “A Visual Model of Peirce’s 66 Classes of Signs Unravels His Late Proposal of Enlarging Semiotic Theory,” 2010, pp. 221–237.

60. Burch, R. W., “Peirce’s 10, 28, and 66 Sign-Types: The Simplest Mathematics,” *Semiotica*, vol. 2011, Jan. 2011.

61. Farias, P., and Queiroz, J., “On Diagrams for Peirce’s 10, 28, and 66 Classes of Signs,” *Semiotica*, vol. 147, 2003, pp. 165–184.

62. Jappy, T., *Peirce’s Twenty-Eight Classes of Signs and the Philosophy of Representation: Rhetoric, Interpretation and Hexadic Semiosis*, Bloomsbury Academic, 2017.

63. Peirce, C. S., *The Essential Peirce: Selected Philosophical Writings, Vol 1 (1867-1893)*, Bloomington: Indiana University Press, 1992.

64. Ika, S., “A Critical Examination of the Philosophy of Charles S. Peirce: A Defence of the Claim that his Pragmatism is Founded on his Theory of Categories,” Ph.D., University of Notre Dame Australia, 2002.