Excerpts from an article by John Sowa, 12 November 2023

Phaneroscopy depends on mathematics, which includes existential graphs as a formal logic. For logic alone, changing the shape of a graph does not change its meaning. But diagrams can represent logic, geometry, or both. For phaneroscopy, perception and action involve multidimensional moving images. The position of nodes in a graph may represent the position of significant parts of an image. Since diagrams can support both logic and geometry, generalized versions of EGs can serve both purposes. That option can support Peirce's prediction that phaneroscopy "surely will in the future become a strong and beneficient science" (R645, 1909).

2. The Role of Diagrams in Phaneroscopy

Diagrams serve as a bridge between images and languages. Nodes of a diagram describe parts of an image, and links show relations among the parts. For the *Monist* article, *Prolegomena to an Apology for Pragmaticism*, Peirce's title echoes Kant's *Prolegomena*. In it, he addressed Kant's "transcendental questions": How is pure mathematics possible? How is pure natural science possible? How is metaphysics in general possible? Figure 2 shows how Peirce answered those questions. He used diagrams as mathematical structures that relate thought about the world to languages that describe it.

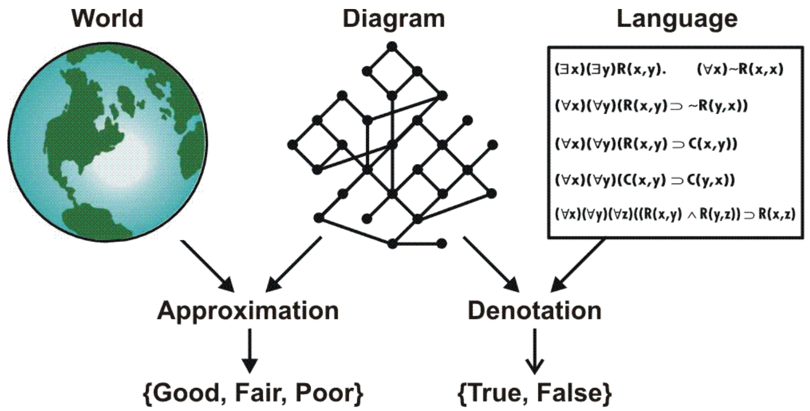


Figure 2: Diagrams relate the world to languages that describe it

The first sentence sets the stage: "Come on, my Reader, and let us construct a diagram to illustrate the general course of thought; I mean a System of diagrammatization by means of which any course of thought can be represented with exactitude" (CP 4:530). Figure 2 shows an important step beyond Tarski's model theory. Instead of a one-step mapping from the world to language, the diagram splits the mapping in two distinct steps.

Phaneroscopy maps images of the world to diagrams, each of which is "an icon of a set of rationally related objects" (NEM 4:316). They serve as Tarski-style models for determining the denotation of languages, formal or informal. But when a continuous world is mapped to a discrete diagram, an enormous amount of detail is lost. Although the right side can be a precise map from a graph to a formal logic, it may be an approximate mapping from an informal diagram to the informal languages that people speak. In his career as a mathematician, logician, philosopher, physicist, chemist, biologist, linguist, lexicographer, and engineer, Peirce understood the complexity of both sides.

[The remaining excerpts begin at the end of Section 5]

Michael Halliday, a lecturer in Chinese at Cambridge from 1954 to 1958, was a cofounder of the Cambridge Logic Research Unit. His study of Chinese, which is radically different from European languages, had a strong influence on the discussions. Since both Chinese and English have a relatively simple grammar in Subject-Verb-Object order, any comparison would emphasize the sharply different semantics and pragmatics. Even though CLRU had not acquired a computer, they began to discuss issues of machine translation (MT). After implementing their theories on a computer, they became prominent in the field and organized the First International Conference on MT in 1961.

Differences between Halliday and Chomsky reflect differences in the languages they studied. Chomsky analyzed languages for which grammar and lexicon could be studied and described independently. Therefore, he claimed that grammar is fundamental to a language and the lexicon is a separable topic. But Halliday maintained that the lexicon cannot be separated from the grammar. Since Chinese does not make a sharp distinction between a word and a phrase, Chinese people who never studied linguistics claim that all words have just one syllable.

For example, the word *che* in Mandarin is a generic term for any kind of vehicle. But many standard Chinese combinations correspond to words in other languages. For example, a che with a motor is a QiChe (energy che), a bus is a GongGongChiChe (public use energy che), a taxi is a ChuZuQiChe (for-hire energy che), and a bicycle is a ZiXingChe (self powered che). But Chinese speakers rarely use those long phrases. If someone says “I parked my che around the corner,” that would mean bicycle for a student or car for a public official. The sentence “I took a che to Beijing,” could mean bus or train (KuoChe, fire che).

For these reasons, Halliday emphasized context: the relevant knowledge of speaker and listener, and the purpose or function of what is said. That led to his *Functional Grammar*, which has a strong resemblance to methods that Peirce developed. Figure 12 shows a classification of experience by Halliday (2014, p. 216). The two circles contain 15 subdivisions, which may be grouped in five trichotomies. With some revisions, a classification of the phaneron based on Figure 12 would be an important step toward Peirce’s goal of phaneroscopy as “a strong and beneficient science.”

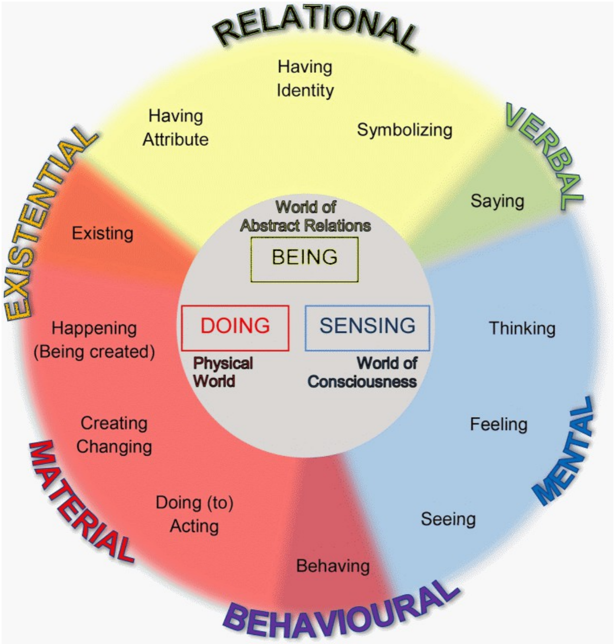


Figure 12: Halliday’s classification of experience

The three nodes in the inner circle of Figure 12 represent the trichotomy [Being, Doing, Sensing], an example of Firstness, Secondness, and Thirdness. Being is a First that may be represented by a monadic relation or predicate. Doing is a Second that relates an actor to an action. Sensing is a mental Third that relates some external First to an internal Second. Peirce would replace *world* with the term *universe of discourse*. He would replace the word *consciousness* with *awareness*, because he assumed a continuum of all living things, including bacteria. Seeds and eggs may be classified as living things, but viruses are non-living signs that are interpreted by living things.

The twelve categories in the outer circle represent four trichotomies, which Peirce could adopt with some modifications. The relational triad has a direct mapping to existential graphs: [Having identity, Having attribute, Symbolizing]. For the material triad [Happening (being created); Creating, changing; Doing (to), acting], Peirce might replace the labels with Greek-based terms. For the mental triad [Feeling, Seeing, Thinking], a generalization to [Proprioception, Perception, Interpretation] would include living things of any kind. Each term of the fourth triad combines aspects of its two adjacent triads: [Existing, Saying, Behaving]. But *Communicating* would be more general than *Saying*.

The five trichotomies in Figure 12 classify the phaneron in 15 types of images, which correspond to Peirce's hypoicons. In Section 3, the conversion rules for generalized existential graphs specify operations for mapping hypoicons from images to diagrams to languages, formal or informal. As an analysis of the phaneron, Halliday's classification has a good match with languages as different as English and Chinese. But the fact that Chinese has standard combinations for *bus*, *taxi*, and *bicycle* is not a coincidence. Those words were deliberately coined, and they're rarely used.

Although their structures are very different, centuries of trade and travel have aligned the vocabularies of Chinese and many other languages with *Standard Average European* (Whorf 1956). An unusual exception is Pirahã, the only surviving member of the Muran languages spoken along the banks of the Amazon river. After 200 years of contact with traders, the Pirahã speakers have learned only the few words of Portuguese they need for the goods they trade. To explain their resistance to change, Everett (2005) went beyond functional grammar in maintaining that culture is fundamental. All aspects of language must be integrated with it: "anthropology and linguistics are more closely aligned than most modern linguists (whether functional or formal) suppose."

To interpret Figure 12 in terms of culture, Peirce would emphasize the role of diagrams that relate experience and language. The first step maps the phaneron to hypoicons, which represent nonverbal or preverbal thinking. As Figures 2 through 11 illustrate, hypoicons can be mapped to diagrams in an open-ended variety of ways by living things of any species. For humans, the mapping to language is only required for speech. For most things they see, hear, touch, and use, all people, including the Pirahã, have no words other than *it* or some *ad hoc* descriptions.

With these observations and the studies by Everett and others, a Peircean interpretation of Figure 12 can explain the unique features of the Pirahã culture and language. For centuries, they lived in a paradise. The climate was always warm, food was abundant in the water and the jungle, and they were surrounded by friendly tribes that spoke related Muran dialects. As a result, they had no need to think, talk, or imagine any mythical or historical times, places, gods, or events. The words and syntax for an eternal present cover everything they wanted to say.

As a result, language for the abstract relations of Figure 12 would be irrelevant. The other categories are sufficient for everything they need or want to say. Yet abstract relations, are important for thinking about possibilities. When searching for food or avoiding danger, the Pirahã must be aware of possible dangers and opportunities. But they don't need words to name them. Studies of the reasoning abilities of the Pirahã people show that their limited vocabulary is not a hindrance, except for specific tasks such as counting. Although they need to consider possibilities, they don't need to count them.

6. Searching for a Language of Thought

Perception and action evolved millions of years before some early hominin began to talk. Monkeys and apes use vocalization primarily for expressing emotions. But the great apes use complex gestures for communication. All four species have learned subsets of human sign language, and they can understand a larger subset of human spoken language than they express with their signs. What is the cognitive foundation for their sign language? Could it be similar to the foundation for human language? Could a moving three-dimensional sign language support diagrammatic reasoning? Could it support Peirce's goal of "thinking in stereoscopic moving pictures?"

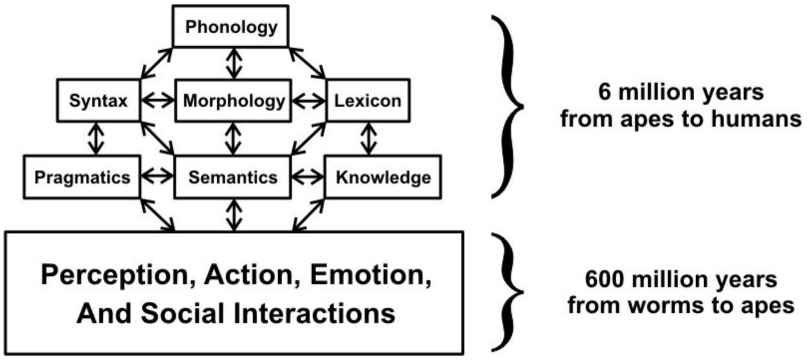


Figure 13: Did human language evolve from the signed languages of the apes?

Spoken language is an addition, not a replacement for the signed languages of the apes. Young chimps and humans, less than a year old, use gestures to communicate. Even when objects of their desires are absent, they can use gestures. When added to speech, gestures increase the precision and expressive power. People gesticulate even while talking on the telephone. Although the listener would not see the gestures, they may help the speaker emphasize key issues by intonation. One observer claimed that he could tell whether a speaker was talking with a man or a woman by watching the gestures.

The signed languages of the deaf are diagrams in motion. They have the expressive power of speech, but with different symbols and emphasis. After years of research, the psycholinguist David McNeill (1992) recognized the role of gestures: relate the content of the discourse to the context and the speaker's intentions.

> Images and speech are equal and simultaneously present in the mind... Gestures look upward, into the discourse structure, as well as downward, into the thought structure. A gesture will occur only if one's current thought contrasts with the background discourse. If there is a contrast, how the thought is related to the discourse determines what kind of gesture it will be, how large it will be, how internally complex it will be, and so forth.

Whether spoken or signed by humans or apes, the purpose of language is to support and enhance social interactions. As a rich system of gestures, the signed languages of the deaf take advantage of multidimensional moving signs to express the classification in Figure 12. The index finger is an indexical that replaces pronouns by pointing. For references to people and things that left the scene, the signer points to where they had been. The signer can also introduce new characters and things, place them in fixed locations in the air, and refer to them by pointing. With moving gestures, the signer can show motion and direction.

The same brain areas that support spoken languages also support signed languages, but areas that support vision and motion are also involved (Campbell et al. 2007). Hearing adults who also learn a signed language become bimodal. Emmorey and MacSweeney (2009) discovered that their brain activation patterns are intermediate between those of deaf signers and hearing non-signers. On tests of mental imagery (generating, rotating, remembering, and matching 3-D shapes), they score higher than non-signers. Those skills, which are important for apes swinging through trees, are the kind that Peirce hoped to represent. The classification of Figure 12 suggests that a person with bimodal training and a system of virtual reality might reach his goal.

In a study of bilingual infants whose parents speak or sign different languages, Petitto (2005) discovered significant similarities and differences. She studied subjects whose parents spoke or signed all six pairs of four languages: English, French, American Sign Language (ASL), and Langue des Signes Québécoise (LSQ). Monolingual and bilingual babies go through the same stages and at the same ages for both spoken and signed languages. Hearing babies born to profoundly deaf parents babble with their hands, but not vocally. Babies bilingual in a spoken and a signed language babble in both modalities, vocally and with their hands. And they express themselves with equal fluency in their spoken and signed language at every stage of development.

To express the semantics of both kinds of language, moving 3-D diagrams are more versatile than a static linear form. The cerebral cortex consists of interacting areas for perception, action, learning, reasoning, emoting, and communicating. As Barsalou (2008) wrote, cognition is "embedded in, distributed across, and inseparable from" those processes. When people view a static object, they anticipate working with it. When people view food, they anticipate its taste when eating it. Musicians identify their own performances by recognizing the fingering. Visual and motor simulations are essential to language understanding. Affect, feelings, rewards, and value judgments are fundamental to all aspects of reasoning and decision making. No single aspect is cognition, but all of them together are cognition. Social interactions facilitate learning by stimulating more aspects.

These observations are consistent with the views of a pioneer in artificial intelligence, Minsky (1965): no single mechanism, by itself, can adequately support the full range of functions required for a human level of intelligence. He coined the term *Society of Mind* (1986) to characterize that insight:

> What magical trick makes us intelligent? The trick is that there is no trick. The power of intelligence stems from our vast diversity, not from any single, perfect principle. Our species has evolved many effective although imperfect methods, and each of us individually develops more on our own. Eventually, very few of our actions and decisions come to depend on any single mechanism. Instead, they emerge from conflicts and negotiations among societies of processes that constantly challenge one another.

Neuroscientists have identified areas of the brain specialized for different aspects of perception, thought, and action. Repeated daily exercises develop smaller more specialized areas. Albert Einstein, for example, had an enlarged area of his brain for the fingers of his left hand because he played the violin daily. A squirrel's hippocampus grows larger in the fall when it must remember where it buried nuts for the winter; that area shrinks in the spring as it retrieves its cache. When London taxi drivers had to memorize the names and locations of every street, they also had an enlarged hippocampus. But when they got the information from satellites, their hippocampus did not grow larger.

Dehaene et al. (2022) "propose that humans possess multiple internal languages of thought, akin to computer languages, which encode and compress structures in various domains (mathematics, music, shape…)." They are processed in specialized areas of the cortex, mostly in the right hemisphere, as opposed to the language areas in the left. but they share similar structural properties: (1) discrete symbols; (2) composition by concatenation, iteration, and recursion; and (3) rules or grammars for generating the structures. The three dots in the quotation above suggest an open-ended variety of activities: games, dances, sports, gymnastics, flying a plane, building a bridge, or riding a horse.

Analyses of brain scans and injuries indicate the regions that control various kinds of thought. Figure 14 shows the lobes of the left hemisphere of the brain and the aspects of cognition they control

(MacNeilage 2008). Peirce's phaneron, the first stage of cognition, is processed in the primary visual cortex at the back of the occipital lobes. But those lobes also process much more than vision. Even people who have been blind since birth can generate moving three-dimensional mental imagery by combining information from other sensory modalities. The occipital place area (OPA), just above the primary visual cortex, seems to be the location for the combined imagery. For transmission to other areas of the brain, mental images may be simplified to mental diagrams or linear languages.

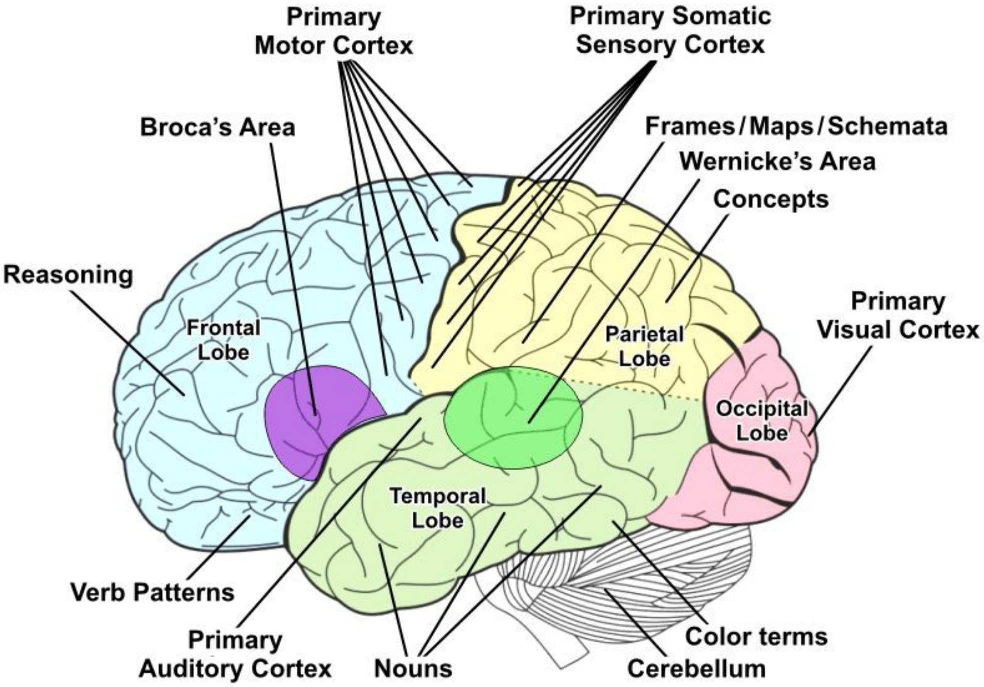


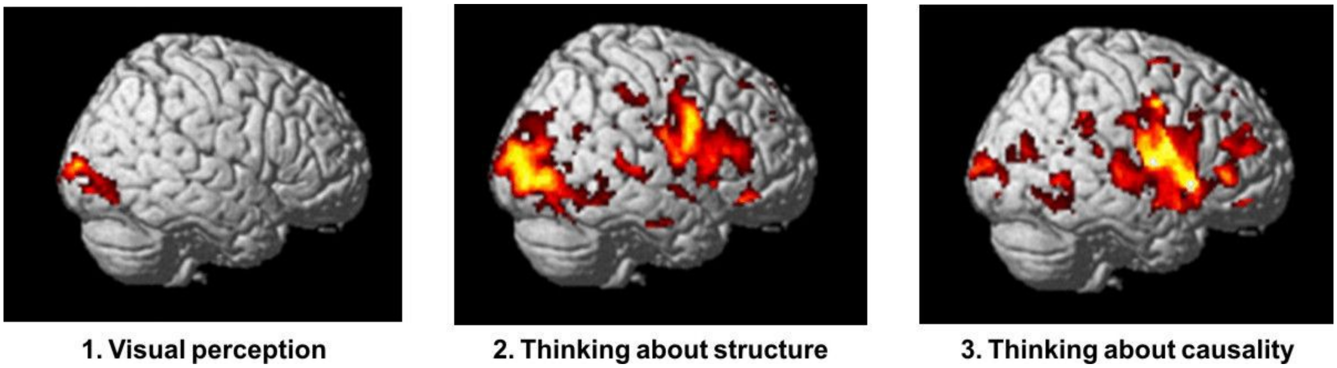
Figure 14: Brain regions of the left hemisphere

Temporal lobes, located behind the ears, process sounds and relate them to imagery in the occipital lobes. They also recognize certain sounds as words, which they relate to Wernicke's area, which is responsible for language interpretation and generation. The parietal lobes generate and process patterns of connections among concepts derived from any source: images from the occipital lobes, sounds and words from the temporal lobes, and feelings from the sensory cortex, which is connected to all parts of the body. These patterns, which correspond to Peirce's diagrams, may also be called maps, frames, schemata, or semantic networks.

The frontal lobes are involved in all intentional or purposive thought and action. The primary motor cortex for controlling action is in the frontal lobes, parallel to the sensory cortex in the parietal lobes. The area for verbs is in the left frontal lobe, but the areas for nouns are in the temporal lobe. Broca's area for generating language, spoken and signed, is connected to Wernicke's area by a thick bundle of nerve fibers called the *arcuate fasciculus*. Both of its ends branch out to areas in the front and rear of the cortex. The prefrontal cortex, which is especially large in humans, is responsible for all complex thought and reasoning. The disastrous operation called a *prefrontal lobotomy*, which was intended to cure mental disorders, left patients with a listless, meaningless life.

The large cerebral cortex has about 16 billion neurons. The much smaller cerebellum, as shown in Figure 14, takes only 10% of the volume of the brain, but it has about 70 billion tightly packed neurons (Herculano-Houzel 2012). For years, scientists thought that its primary role was to control movement, but it also plays a major role in perception, cognition, language, planning, emotion, social interactions, and even mathematical reasoning. The computational power and precision that enables primates to leap through trees also supports the most complex calculations by sedentary mathematicians. Nothing in the cerebellum is conscious, but its computations affect all conscious experience.

To relate brain activity to the kinds of thought, Mason and Just (2015) analyzed the fMRI scans in Figure 15. They found monadic patterns in perception (#1), dyadic patterns in thinking about structure (#2), and triadic patterns in thinking about causality (#3). To avoid the language activity in the left hemisphere, Figure 15 shows only the right hemisphere. For perception, scan #1 shows no noticeable activation outside the visual cortex. For structure, scan #2 shows two bright patterns that relate a large area of the occipital lobe to the the sensory cortex in the parietal lobe. For causality, scan #3 shows that the visual, parietal, and frontal lobes are active; the brightest area includes the sensory and action areas of the parietal and frontal lobes. Areas toward the front are also active for reasoning about the interconnections. Those areas have connections to the cerebellum (lower left in Figure 15).


1. Visual perception

2. Thinking about structure

3. Thinking about causality

Figure 15: Three fMRI scans of the right hemisphere

To minimize preconceptions, only subjects who were not familiar with mechanical devices were selected: college students who did not major in science or engineering. All of them studied four devices and their inner mechanisms: bathroom scale, fire extinguisher, disc brake system, and trumpet. During test sessions, an fMRI scanner recorded patterns of brain activity. An early training session just showed pictures and named the parts: “A bathroom scale consists of a spring, a lever, a ratchet, and a dial.” Later sessions explained structural and causal relations: “The spring pulls a ratchet which rotates a gear attached to a measurement dial.”

The three fMRI scans in Figure 15 show experimental evidence for Peirce’s categories of Firstness, Secondness, and Thirdness. The first scan of visual perception shows monadic patterns in the visual cortex. They are the unprocessed or slightly processed images that Peirce called the *phaneron*. The second scan of thinking about structure shows dyadic patterns that relate activations in the parietal lobes and the occipital lobes. The brightest area is the occipital place area (OPA), which combines information from internal and external sources. That may be the area where mental models or Peirce’s diagrams are constructed. The third scan of thinking about causality shows triadic patterns that relate causal intentions in the frontal lobes to activations in the parietal and occipital lobes.

As an example of musical and linguistic thinking, the composer Vissarion Shebalin had an academic style of composition (Hees & Sligter, 1995). But in the 1950s, he had two strokes, which impaired most of his language abilities. Yet he continued to teach music by gestures and by playing examples on the violin. In 1962, shortly before his death by a third stroke, he completed his fifth symphony, which Shostakovich described as “a brilliant creative work, filled with highest emotions, optimistic and full of life.” But other critics said it was less disciplined and organized than his earlier work. Those criticisms are consistent with the remarks by Shostakovich. The strokes that impaired his language abilities also impaired the academic constraints. The more emotional thinking in the right hemisphere became prominent. Although an increase in the emotional content improved his fifth symphony, it might have been even better if Shebalin had retained more of his former discipline.

These observations show that cognition involves a wide variety of interacting processes in all parts of the brain. Frege's rejection of psychologism and "mental pictures" reinforced the behaviorism of the early 20th century. But recent work in neuroscience uses "folk psychology" and introspection to interpret data from brain scans. In summarizing the issues, the neuroscientist Antonio Damasio (2010) emphasized the importance of imagery:

> The distinctive feature of brains such as the one we own is their uncanny ability to create maps... But when brains make maps, they are also creating images, the main currency of our minds. Ultimately consciousness allows us to experience maps as images, to manipulate those images, and to apply reasoning to them.

The maps and images form mental models of the real world or of the imaginary worlds in our hopes, fears, plans, and desires. They provide a "model theoretic" semantics for thought that uses perception and action for testing models against reality. Like Tarski's models, maps and images determine the criteria for truth, but they are flexible, dynamic, and situated in the daily drama of life. To represent all aspects of thought, they require the features summarized in Section 2 and defined in Section 3.

7. Diagrammatic Reasoning

Everybody thinks in diagrams — from children who draw diagrams of what they see to the most advanced scientists and engineers who draw what they think. Ancient peoples saw diagrams in the sky, and ancient monuments are based on those celestial diagrams. As Figure 2 shows, diagrams serve as a bridge from images to languages. Operations on diagrams can support every kind of reasoning from vague analogies to the most precise deductions. Diagrammatic reasoning is one of Peirce's most brilliant insights:

> We form in the imagination some sort of diagrammatic, that is, iconic, representation of the facts, as skeletonized as possible. The impression of the present writer is that with ordinary persons this is always a visual image, or mixed visual and muscular... This diagram, which has been constructed to represent intuitively or semi-intuitively the same relations which are abstractly expressed in the premisses, is then observed, and a hypothesis suggests itself that there is a certain relation between some of its parts — or perhaps this hypothesis had already been suggested. In order to test this, various experiments are made upon the diagram, which is changed in various ways. (CP 2.778)

His writings on logic, semeiotic, and diagrammatic reasoning, which had been neglected for most of the 20th century, are now at the forefront of research in the 21st. The psychologist Johnson-Laird (2002), who had written extensively about mental models, said that Peirce's graphs and rules are a good candidate for a neural theory of reasoning:

> Peirce's existential graphs are remarkable. They establish the feasibility of a diagrammatic system of reasoning equivalent to the first-order predicate calculus. They anticipate the theory of mental models in many respects, including their iconic and symbolic components, their eschewal of variables, and their fundamental operations of insertion and deletion. Much is known about the psychology of reasoning... But we still lack a comprehensive account of how individuals represent multiply-quantified assertions, and so the graphs may provide a guide to the future development of psychological theories.

For board games like chess, diagrammatic reasoning is the essence of the game. Most chess experts can play a good blindfold game. For them, the board and pieces represent a diagram in Peirce's sense, and their strategies are an example of Pólya's patterns of plausible inference. In describing his way of thinking, Einstein used Peirce's words *visual* and *muscular*:

> The words or the language, as they are written or spoken, do not seem to play any role in my mechanism of thought. The psychical entities which seem to serve as elements in thought are certain signs and more or less clear images which can be voluntarily reproduced and combined... The above-mentioned elements are, in my case, of visual and some of muscular type. Conventional words or other signs have to be sought for laboriously only in a secondary stage, when the mentioned associative play is sufficiently established and can be reproduced at will. (Quoted by Hadamard, 1945)

Over the years, Peirce added further observations about the methods of diagrammatic reasoning:

> All necessary reasoning without exception is diagrammatic. That is, we construct an icon of our hypothetical state of things and proceed to observe it. This observation leads us to suspect that something is true, which we may or may not be able to formulate with precision, and we proceed to inquire whether it is true or not. For this purpose it is necessary to form a plan of investigation, and this is the most difficult part of the whole operation. We not only have to select the features of the diagram which it will be pertinent to pay attention to, but it is also of great importance to return again and again to certain features. (EP 2:212)
>
> The word *diagram* is here used in the peculiar sense of a concrete, but possibly changing, mental image of such a thing as it represents. A drawing or model may be employed to aid the imagination; but the essential thing to be performed is the act of imagining. Mathematical diagrams are of two kinds; 1st, the geometrical, which are composed of lines (for even the image of a body having a curved surface without edges, what is mainly seen by the mind's eye as it is turned about, is its generating lines, such as its varying outline); and 2nd, the algebraical, which are arrays of letters and other characters whose interrelations are represented partly by their arrangement and partly by repetitions. If these change, it is by instantaneous metamorphosis. (NEM 4:219)
>
> Diagrammatic reasoning is the only really fertile reasoning. If logicians would only embrace this method, we should no longer see attempts to base their science on the fragile foundations of metaphysics or a psychology not based on logical theory. (CP 4.571)

With that last quotation, Peirce dismissed Frege's criticism of psychologism. Logic is not based on psychology, but psychology is based on logic. The methods of diagrammatic reasoning apply to every branch of science in Figure 1: from mathematics and phaneroscopy to every branch of philosophy, physical sciences, psychical sciences, practical reasoning, and common sense.

[This is the end of the excerpts.]

The remainder of Section 7 summarizes Peirce's theories of reasoning, formal and informal. It relates the theories summarized in the previous six sections to ongoing research in artificial intelligence, especially the work on generative AI and Large Language Models (LLMs). For machine translation, LLMs are superior to earlier methods. They can also support language-based methods for answering questions, finding analogies, and generating essays. All those methods are supported by the left hemisphere. But much more is required to support complex reasoning methods in either hemisphere or the mathematical computations in the cerebellum.

For AI systems, the elegant grammar and style generated by LLMs create an illusion of competence. But the absence of trustworthy reasoning, computation, and evaluation serves as a counter example. They show that common sense and the most advanced science are more closely related to each other than to the computations with LLMs.