An excerpt from a forthcoming article by John Sowa, 23 September 2023.

6. Searching for a Language of Thought

Although language is important for human communication, the systems of 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?" (NEM 3:191)

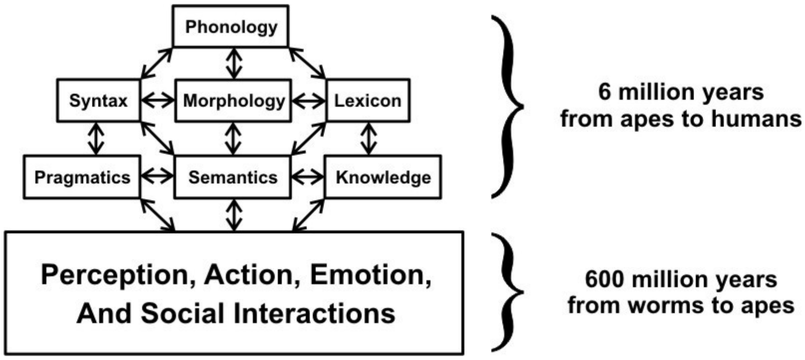


Figure 12: Did human language evolve from the signed languages of the apes?

Spoken languages, which replaced the signed languages of the apes, are usually accompanied by gestures and pointing. When added to speech, they increase its precision and expressive power. The signed languages of the deaf are diagrams in motion. They have the expressive power of speech with gestures and pointing. 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.

As a rich system of gestures, the signed languages of the deaf take advantage of multidimensional moving signs to support expressive power comparable to spoken languages. 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 was hoping to learn. In effect, gestures are moving diagrams that can relate imagery and actions to languages of any kind.

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 combinations 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* to characterize that insight (1986):

> 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.

Figure 13 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 combinations. For transmission to other areas of the brain, mental images may be simplified to mental diagrams, which could be represented by gestures in sign languages or by generalized EGs in a computer.

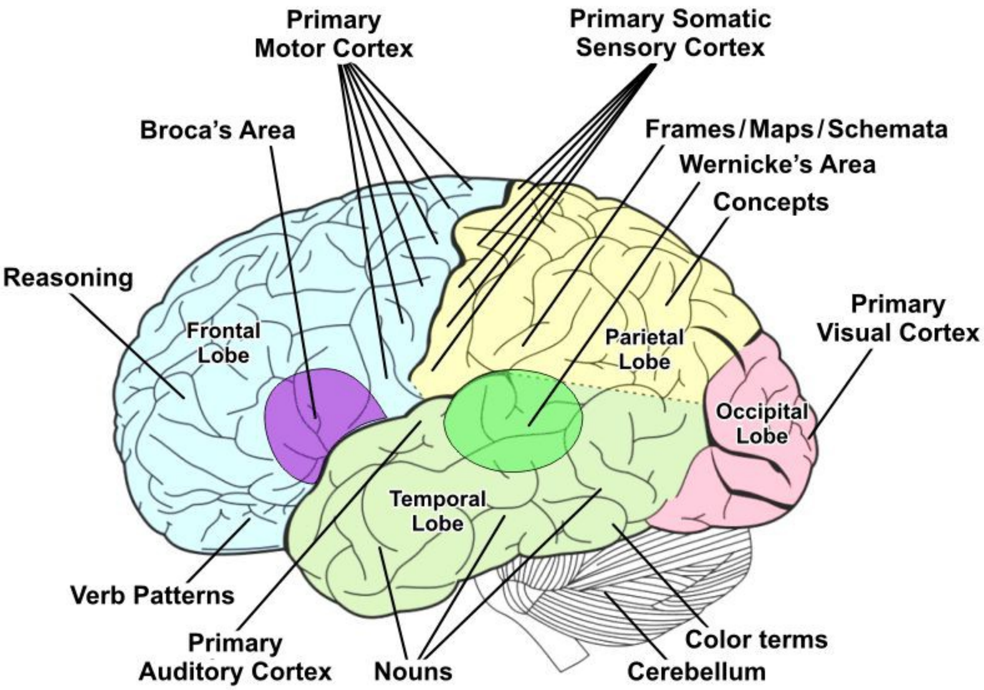


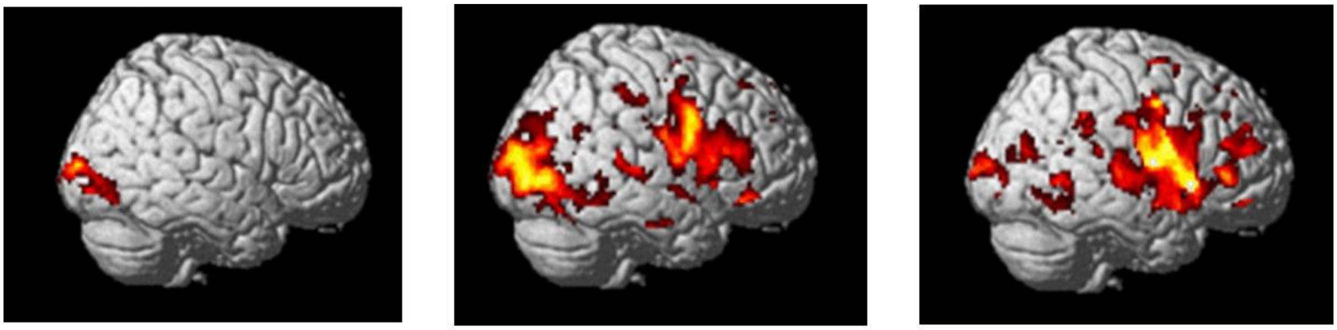
Figure 13: Brain regions of the left hemisphere

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 and 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, purposive, or complex 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 13, 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 plays a major role in perception, cognition, language, planning, emotion, and social interactions. The cerebellum is also active in mathematical reasoning. Apparently, the computational power and precision that evolved for apes leaping through trees can also support the most advanced calculations by sedentary mathematicians.

A remarkable experiment produced three kinds of fMRI scans (Figure 14). They show monadic patterns in perception (scan #1), dyadic patterns in thinking about structure (#2), and triadic patterns in thinking about causality (#3). To avoid showing the language activity in the left hemisphere, Figure 14 shows only the thinking patterns in the right hemisphere. For perception, fMRI 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 14).



1. Visual perception 2. Thinking about structure 3. Thinking about causality

Figure 14: Three fMRI scans of the right hemisphere (Mason & Just, 2015)

For the experiment that produced those scans, Mason and Just selected subjects who were not familiar with mechanical devices: college students that did not major in STEM subjects (science, technology, engineering, or math). 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 14 show experimental evidence for Peirce’s *phenomenological categories* of Firstness, Secondness, and Thirdness. The first scan of visual perception shows monadic patterns in the visual cortex. They may be 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.

These observations indicate that cognition involves a wide variety of interacting processes. The scattered activations in Figure 14 (right hemisphere) show that the thinking processes gather information from all parts of the brain. The linguistic processes in the left hemisphere are not the primary source or destination of information. 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 that imagery is fundamental:

> 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, images determine the criteria for truth, but they are flexible, dynamic, and situated in the daily drama of life. To represent the full semantics, 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. They correspond to the mathematical “patterns of plausible inference” identified by Polya (1954). The role of diagrammatic reasoning is one of Peirce’s most brilliant insights, and the patterns of diagrams support every kind of reasoning from vague analogies to the most precise deductions:

> 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)

Peirce’s 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 existential graphs and rules of inference 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 about science, 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)
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> 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)
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> 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 or should be 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, engineering, and common sense.

By relating logic and imagery, diagrammatic reasoning can bridge the gap between abstract symbols and physical reality. Einstein (1944) criticized the "fear of metaphysics" (Angst vor der Metaphysik) as a "malady (Krankheit) of 20th-century empirical philosophy." In reviewing Quine's *Word and Object*, Rescher (1962) was struck by the absence of any discussion of events, processes, actions, and change. C. I. Lewis (1960), whose logic and epistemology were strongly influenced by Peirce, criticized the sterility of formalisms that lost any connections with observations:

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

Note: This section will conclude with a presentation of diagrammatic reasoning for induction, abduction, deduction, and analogy.

It will also analyze the Large Language Models (LLMs), which have been very useful for machine translation and for natural language interfaces to computer systems. LLMs can also be useful for suggesting hypotheses that must be verified by formal methods, such as diagrammatic reasoning.

For an introduction to Peirce's existetenial graphs and some of the issues in Sections 1 to 5 of this article, see slides 13 to 34 of *Language, ontology, and the Semantic Web*, a lecture at the 2020 European Semantic Web Conference, https://jfsowa.com/talks/eswc.pdf

For more detail about material that is summarized in Section 3 of this article, see Sowa, John F. (2018) Reasoning with diagrams and images, *Journal of Applied Logics* **5:5**, 987-1059. http://www.collegepublications.co.uk/downloads/ifcolog00025.pdf