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. A s 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)

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 "patterns of plausible inference" (Pólya 1954). 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 normative science, metaphysics, physical sciences, psychical sciences, practical reasoning, and common sense.

Independent of format, linear or diagrammatic, Peirce distinguished three basic kinds of reasoning: *abduction*, *deduction*, and *induction*. He also recognized the issues of vagueness, incompleteness, uncertainty, and likelihood. To support them, he also distinguished two methods that combined aspects of the basic three: *analogy* as an approximate combination of all three and *probability* as a deduction of relative frequency. Following is his summary of the basic three (CP 8.209ff, 1905):

1. The first, which I call *abduction*, consists in examining a mass of facts and in allowing these facts to suggest a theory. In this way we gain new ideas; but there is no force in the reasoning... Abduction furnishes all our ideas concerning real things, beyond what are given in perception, but is mere conjecture, without probative force.
2. The second kind of reasoning is *deduction*, or necessary reasoning. It is applicable only to an ideal state of things, or to a state of things in so far as it may conform to an ideal. It merely gives a new aspect to the premisses. It consists in constructing an image or diagram in accordance with a general precept, in observing in that image certain relations of parts not explicitly laid down in the precept, and in convincing oneself that the same relations will always occur when that precept is followed out... Deduction is certain but relates only to ideal objects.
3. The third way of reasoning is *induction*, or experimental research. Its procedure is this. Abduction having suggested a theory, we employ *de*duction to deduce from that ideal theory a promiscuous variety of consequences to the effect that if we perform certain acts, we shall find ourselves confronted with certain experiences. We then proceed to try these experiments, and if the predictions of the theory are verified, we have a proportionate confidence that the experiments that remain to be tried will confirm the theory... Induction gives us the only approach to certainty concerning the real that we can have.

According to Peirce (1902), "Besides these three types of reasoning there is a fourth, analogy, which combines the characters of the three, yet cannot be adequately represented as composite." Analogy is a more primitive reasoning method because it does not require linguistic symbols, and it may be approximate. It could find patterns of images (phemes) that meet the conditions of the three basic methods: a likely guess for abduction, a convincing argument for deduction, and a useful observation for induction. To insure accuracy, testing and evaluation are necessary.

The cycle of pragmatism in Figure 18 shows Peirce standing in the center of four arrows that represent abduction, deduction, action, and induction — or approximations of them. This cycle may be considered a refinement of Uexküll's cycle in Figure 3. The brain labeled *cognitive memory* would store the results of each cycle. For living things of any species, the steps may be approximated by analogies. In high-speed action, such as a sports competition or an escape from danger, some steps may be processed in milliseconds. For advanced research and development, major steps may require lengthy processes with many subcycles.

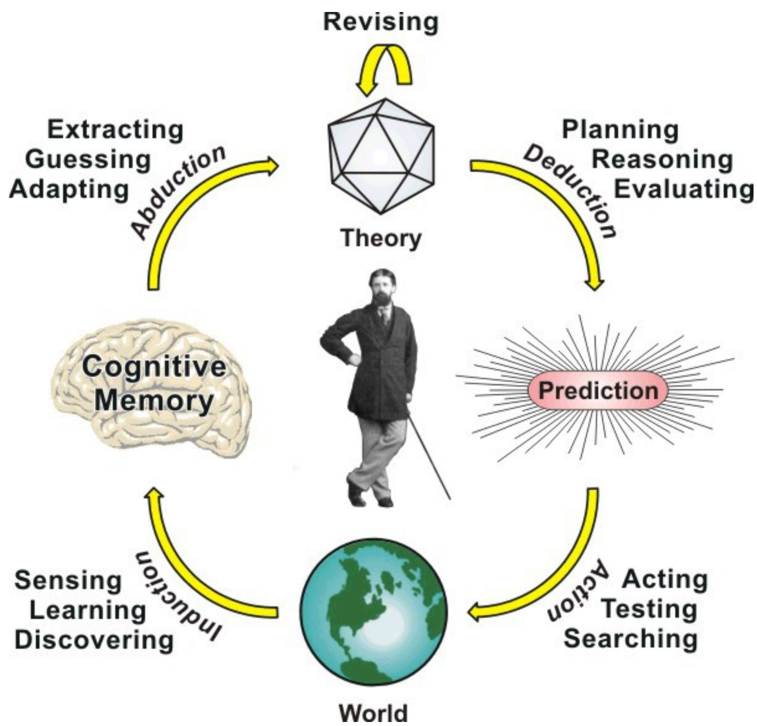

Figure 18: Peirce's cycle of pragmatism

As a first step, abduction examines a mass of facts that suggest a theory. It may be called a scientific hypothesis, a commonsense intuition, or an educated guess. To relate the new theory to others in memory, some revision may be required. When a theory is applied to a situation, deduction may derive an open-ended variety of predictions. An agent who chooses a theory may select predictions that support current goals and requirements. The lower branches of Figure 18 show how actions based on the prediction are performed on the world, and how observations of the results support inductions that update memory.

The cycle of pragmatism and the descriptions by Peirce are consistent with the latest developments in the cognitive sciences. Since the 1950s, the methods of abduction, deduction, and induction have also guided research on reasoning in computer science and artificial intelligence. But a new paradigm called *generative AI*, which is based on *Large Language Models* (LLMs), has dominated recent debates about the future of AI. The LLM algorithms were originally developed by Google for *machine translation*, and they proved to be superior to earlier MT systems. (Jurafsky & Martin 2024)

To encourage research, Google made its patented technology freely available to the OpenAI community, and thousands of volunteers around the world developed a surprisingly powerful range of applications. Some people claim that generative AI is approaching a human level of *artificial general intelligence* (AGI) and that it may attain a level of superintelligence in a few more years. But others maintain that the primary value of LLMs lies in translating languages, natural or artificial. The issues are confused because applications may use combinations of AI methods, old and new. Old methods often do the reasoning, and LLMs support the language interface.

A complete theory of AI must include an agent that takes charge of controlling the system, keeping it healthy, and carrying out its assigned tasks. Figure 19 shows a design for an AI system that uses Peirce's theories as a guide. The arrows of the new cycle are the same as Figure 18. In the center, the photo of Peirce has been replaced by Figure 17, the Baddeley-Hitch diagram of a central executive. On the left, the brain labeled *Cognitive Memory* has been replaced by a cauldron labeled *Knowledge Soup*. The labels in red are names of AI techniques; there is no limit to the number and variety.

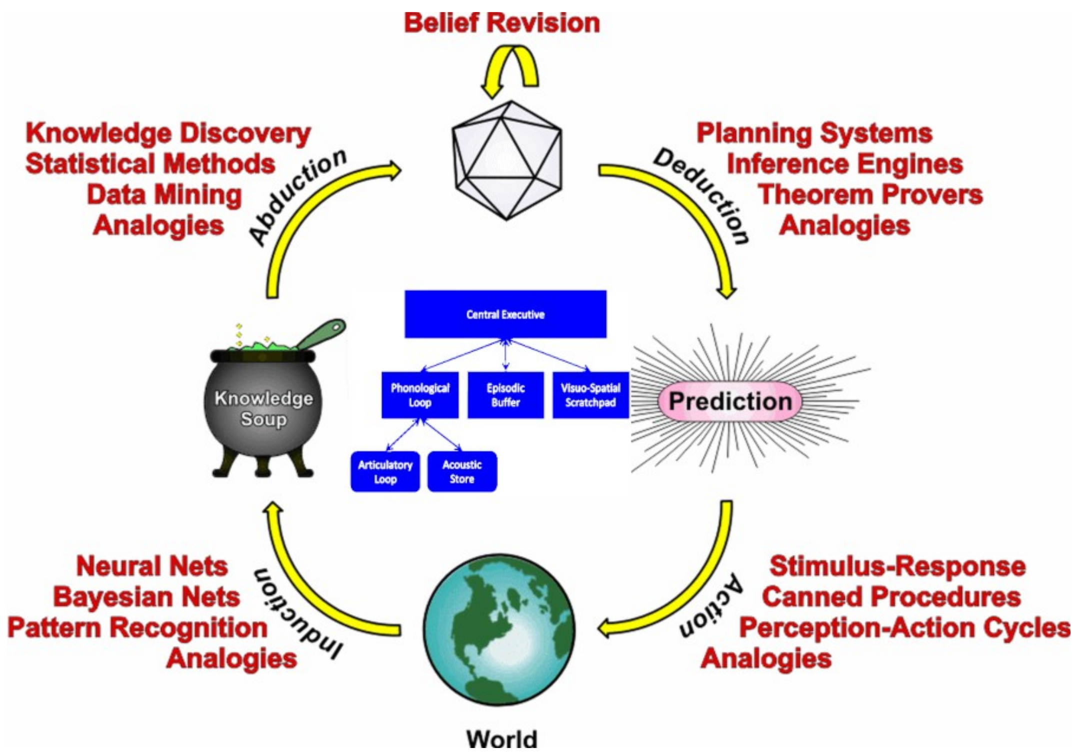

Figure 19: Design for an AI system based on Peirce's theories and cognitive science

The yellow arrows in Figure 19 are fundamental to sound reasoning methods in logic, computer science, and AI systems. The red labels on those arrows suggest some technologies for implementing them, but there is no limit to the number that may be useful The term *knowledge soup* emphasizes the different modules discussed in Section 6, the varied content, and the loose connections among them. The central executive in the center indicates the importance of an agent that can monitor and guide the components of an intelligent system and the actions they perform. All AI systems have some program that controls everything else. That program should be designed as a central executive whose operations are specified by the same AI theory.

The cycles in Figures 18 and 19 are similar to cycles drawn by authors in AI, engineering, and cognitive science. The AI pioneers, McCarthy and Minsky with eight coauthors (2002), drew a complex version with arrows pointing in all directions. Buried in that complexity was a clockwise cycle of four nodes that resemble Figure 19. The article would have been more readable if the authors had started with that basic cycle and shown the details in separate diagrams.

Figure 20 shows a similar four-step cycle drawn by John Boyd (1996): the OODA loop (Observe, Orient, Decide, Act). The observation stage includes the variety of content in the knowledge soup: unfolding circumstances, implicit guidance and control, outside information, and unfolding action with the environment. The orientation stage includes cultural traditions, genetic heritage, analyses and experiments, near information, and previous experience. The decision stage derives a hypothesis that guides the action or test whose results are observed. And the loop continues.

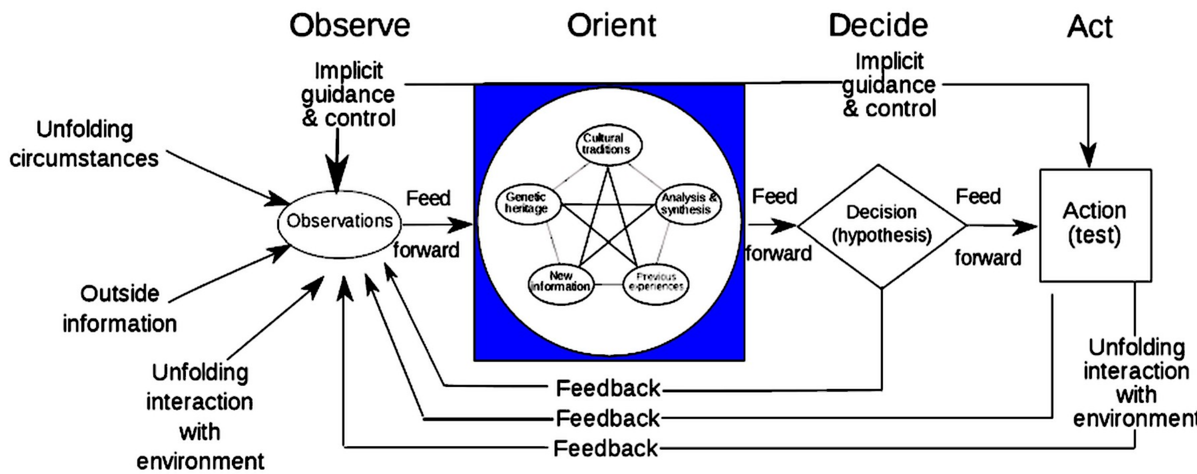

Figure 20: The OODA Loop for guiding thought that leads to action

Boyd originally designed the OODA loop for training pilots in aerial combat, where split-second decisions are essential. He later earned an MS degree in economics and spent years of consulting in industry. That led him to generalize the loop to support decisions in any applications at any speed. Graves and Garret (2014) used OODA loops to analyze and solve “wicked” engineering problems. They defined them as problems that involve “complex interdependences between the systems involved, and incomplete, inconsistent, information about the problem context. Wicked problems are dynamic and span many domains with complex legal, ethical, and societal aspects.”

Loops drawn by Peirce, Uexküll, Boyd, engineers, AI experts, and cognitive scientists have a great deal in common: (1) an intelligent agent — human, animal, or robot — that serves as a central executive; (2) a large repository of loosely organized knowledge in every sensory modality about every imaginable specialization; (3) observations, similar to Peirce’s phaneroscopy, for sensing, acquiring, or imagining new information; (4) orientation, abduction, or guessing for arranging relevant, important, or urgent information; (5) decisions based on logic, habit, training, sudden insight, or a forced guess; (6) actions whose results or inductions are added to the knowledge soup. A clockwise cycle of four boxes and four arrows is typical, but not essential.

Peirce's views were strongly influenced by his father Benjamin, who started teaching him Greek, Latin, and mathematics as soon as he learned to talk. When he was twelve, he found a book on logic, which he devoured in a week. But his years of work in science and engineering taught him the complexity of the world and the impossibility of solving wicked problems with absolute precision:

> Get rid, thoughtful Reader, of the Okhamistic prejudice of political partisanship that in thought, in being, and in development the indefinite is due to a degeneration from a primal state of perfect definiteness. The truth is rather on the side of the Scholastic realists that the unsettled is the primal state, and that definiteness and determinateness, the two poles of settledness, are, in the large, approximations, developmentally, epistemologically, and metaphysically. (CP 6.348)

With that statement, Peirce would disagree with the logicians Frege and Russell, but he would agree with Wittgenstein’s language games. Both of them would agree with Whitehead (1937):

> Human knowledge is a process of approximation. In the focus of experience, there is comparative clarity. But the discrimination of this clarity leads into the penumbral background. There are always questions left over. The problem is to discriminate exactly what we know vaguely.

And all three of them would agree with the poet Robert Frost (1963):

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

In summary, the unsettled is the primal state, there are always questions left over, and the theories we make are little bits of order. But phaneroscopy, semeiotic, and pragmatism have a solid foundation in cognitive science, diagrammatic reasoning, and the methods of research (methodeutic) of every branch of science. Although existential graphs are precise, a linearization that represents significant features may be convenient for computer processing. But when diagrams are as precisely defined as Euclid’s, diagrammatic reasoning with Peirce’s rules can be as precise as any linear notation. The option of including continuous, informal, or even blurred images, enables generalized existential graphs to represent heuristic, statistical, and commonsense methods.

The references contain more detail on all these issues: on ways that Peirce improved on his successors (Haack 2007; Sowa 2006a); on modal logic (Dunn 1973; Hintikka 1973; Sowa 2006b); on language (Whorf 1956; Halliday 2014; Majumdar & Sowa 2009; Sowa 2010).

For background information on related issues:

Peirce’s contributions to the 21st century, https://jfsowa.com/pubs/csp21st.pdf

The Role of Logic and Ontology In Language and Reasoning, https://jfsowa.com/pubs/rolelog.pdf

Natural Logic: Foundation for language and reasoning, https://jfsowa.com/talks/natlog.pdf

Worlds, models, and descriptions, https://jfsowa.com/pubs/worlds.pdf

From existential graphs to conceptual graphs, https://jfsowa.com/pubs/eg2cg.pdf

Reasoning with diagrams and images,
http://www.collegepublications.co.uk/downloads/ifcolog00025.pdf

Two paradigms are better than one, and multiple paradigms are even better,
https://jfsowa.com/pubs/paradigm.pdf

Slides with more examples of issues in AI and neuroscience: https://jfsowa.com/talks/vrmind.pdf