Relating Language to Perception, Action, and Feelings*

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Abstract. The world is a continuum, but words are discrete. Sensory organs map the continuous world to continuous mental models of sights, sounds, and motions. Muscles and bones move in a continuous range of positions, postures, forces, and speeds. Internal feelings of hunger, thirst, pains, pleasures, fears, and desires have a continuous range of variation. But discrete words and patterns of words cannot faithfully represent the continuum of perceptions, actions, and feelings. Peirce's semiotics and Wittgenstein's language games provide a framework for relating language to the world and to perceptions and actions in the world. Peirce analyzed signs and transformations of signs in networks of discrete symbols and in patterns of continuous images. Wittgenstein showed how language is integrated with every aspect of human activity. To implement their insights, the discrete networks of symbols must be mapped to continuous mathematics. This article is a summary of the methods and applications for mapping natural languages to conceptual graphs and continuous transformations. Those methods have been used to analyze and classify plot twists in narratives and the structure of expository texts.

Keywords: conceptual graphs, natural language processing, semiotics, analogy, mental models, continuity, catastrophe theoretical semantics.

1 Language and Brain

The human brain is built on an ape-like plan with a greatly enlarged cerebral cortex. If the cortex were removed, the human brain stem and cerebellum would be hard to distinguish from those of a chimpanzee or gorilla. After reviewing the fossil evidence, Terrence Deacon [1] concluded that the mainstream of evolution from the apes to Australopithicus, Homo habilis, Homo erectus, and Homo sapiens was driven by "the co-evolution of language and the brain." Gradual changes in the vocal tract indicate an early shift toward more complex vocalization. The earliest language-like vocalizations, perhaps spoken by some Australopithecines, gave their speakers a competitive advantage over other primates. The need for a larger vocabulary and a more precise grammar drove the rapid increase in size and complexity of the brain. Figure 1 shows aspects of language that evolved in the past 6 million years on top of a foundation of 600 million years of evolution from primitive worms.

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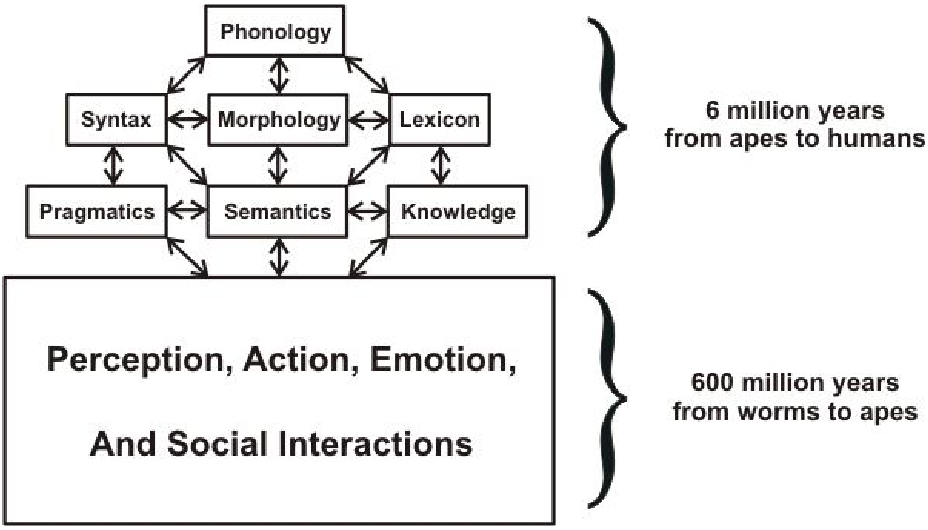

Fig. 1. Human language supported by an ape-like foundation

Yet Figure 1 has some questionable features. The labels on the language boxes correspond to traditional academic fields, but those boxes don't have a one-to-one mapping to modules in the brain. The box labeled *knowledge*, for example, includes information in different areas of the brain: language-independent images; concepts related to language, but independent of any specific language; and knowledge encoded in the patterns of a particular language. The box labeled *pragmatics* involves the use of language in all the activities of life. But knowledge of an activity is directly based on actions and perceptions, only indirectly on the words that express them. As Wittgenstein emphasized, words are always learned and used in the context of some activity: "The word *language-game* (Sprachspiel) is used here to emphasize the fact that the speaking of language is part of an activity, or of a form of life" [2: §23].

Nobody knows exactly how the brain works, but neuroscience has accumulated a great deal of evidence about the areas of the brain associated with various functions. For right-handed people, the left hemisphere of the cerebral cortex (LH) is critical for language. Figure 2 shows areas of LH involved in language processing [3, 4]. Broca's area, which generates the syntax and phonology of speech, is adjacent to the primary motor cortex for the mouth, face, tongue, and vocal tract. Wernicke's area, which relates language to semantics, is adjacent to the primary auditory cortex and close to the sensory areas for vision and touch. It is also directly beneath the parietal lobe, which maintains patterns that are variously called cognitive maps, frames, or schemata. Lamb [5, 6] argued that the primary nodes for concepts are located in the parietal lobe. Nouns, which map to images, are in the temporal lobe, close to both the auditory and visual areas. Verbs are in the frontal lobe, close to the motor areas that control actions.

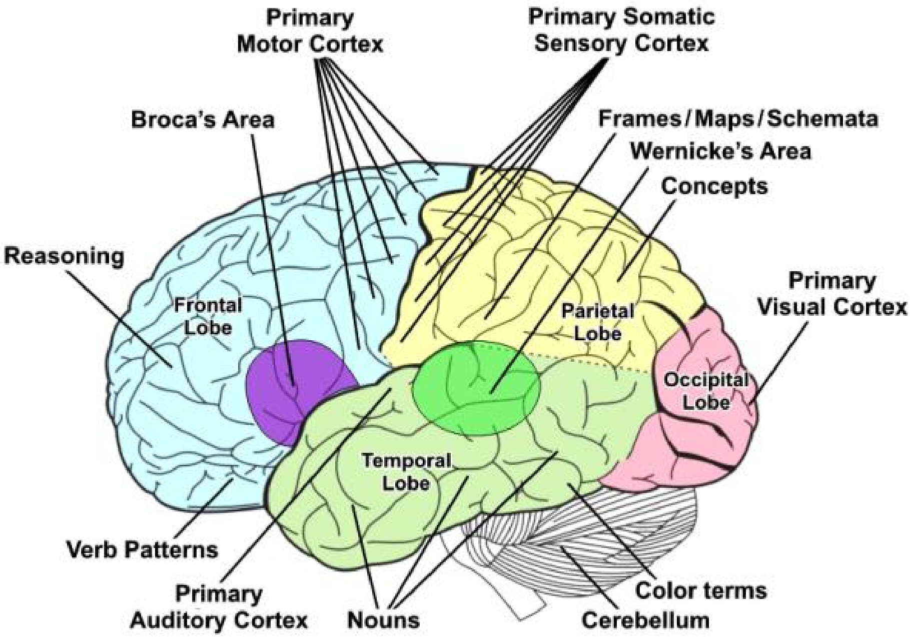

Fig. 2. Language areas of the left hemisphere

The cerebral cortex is essential for language and all complex reasoning. But the brain stem controls the basic functions necessary for maintaining life. It also integrates all inputs and outputs to and from the cerebral cortex. One part, called the *superior colliculus*, integrates vision with eye movements and head position. It also relates vision to the auditory inputs processed by the *inferior colliculus*. The *cerebellum* learns and controls fine tuned, but automatically executed skills. Using just the superior colliculus and the cerebellum, a frog can jump along the lily pads in a pond, track a fly in mid flight, and shoot out its tongue at just the right speed and direction to catch it. Humans use the same neural mechanisms for shooting a basketball, performing gymnastics, or playing the piano. For a person talking on a cell phone, the superior colliculus can bypass the cortex and enable the cerebellum to control walking without thinking.

As Figure 2 shows, language areas are distributed around the cortex. Instead of a dedicated language module, brain areas specialized for perception and action are also used to interpret and generate language. Broca's area, for example, overlaps two regions called Broadman's areas BA44 and BA45. BA44 is active in controlling the mouth for speech and eating. BA45 is active in producing both spoken and signed languages. It is also active in precise motor control for using tools.

The processes carried out by the brain stem and cerebellum are outside conscious awareness and independent of language. But they are essential for producing and maintaining the images in the cortex that are mapped to and from language. The superior colliculus is responsible for controlling eye movements, relating multiple fragmentary glimpses, and enabling the visual cortex to assemble them in a stable, panoramic image of the environment. But the frontal lobes can also provide the stimuli to generate an imaginary model of a planned, hypothetical, or desired environment. As the neuroscientist Antonio Damasio [4] said,

> 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.

Although the details of information processing in the brain are major research problems, brain scans show the active areas, and anatomy shows the pathways that connect them. For language understanding and generation, Wernicke's area and Broca's area are connected by a thick bundle of fibers called the *arcuate fasciculus*. Those fibers transmit information in both directions to coordinate the semantic processing in Wernicke's area with the syntactic processing in Broca's area. But the verb patterns, which are located in BA47 close to Broca's area (BA45), are critical for relating sentence structures to actions, planning, and reasoning. The nouns that participate in those patterns are located in the temporal lobes. The arcuate fasciculus has branches that connect to those areas and to the parietal lobe with its concepts and cognitive maps.

The evidence from neuroscience confirms what linguists, psychologists, philosophers, and language users have known for millennia: nouns are linked to images, verbs are linked to actions, the links depend on background knowledge, and people with different backgrounds often misunderstand each other. For computer processing, it implies that language understanding requires methods that go beyond the discrete words and patterns of words that appear in texts. For any subject that has a continuous range of variation — anything except subjects like chess, Sudoku, or computer programs — the semantics requires continuous mathematics. The discrete patterns of language must be mapped to and from continuous fields and transformations.

2 Discrete and Continuous Processing

The early stages of language processing must analyze the discrete words and patterns of words that occur in speech and texts. For VivoMind software, the results of the analysis are translated to conceptual graphs (CGs) as the semantic representation [7, 8, 9]. But the graphs are still discrete. They must be translated to continuous fields for the next stage of analysis. Key to that translation is an insight by Charles Sanders Peirce, whose existential graphs (EGs) are the foundation for CGs [10].

Peirce was inspired by the graphs used to represent molecules in organic chemistry. He designed his EGs as a notation for representing "the atoms and molecules of logic." The continuous fields are forces like gravity or electromagnetism. In the verb patterns, each verb is a nucleus, and the nouns orbit the nucleus in a continuous force field. The verb *sleep*, for example, has one *actant* or participant; it has valence 1. The verb *hit* has 2, *give* has 3, and *buy* or *sell* has 4.

René Thom [11] was a mathematician who developed catastrophe theory and applied it to a variety of physical phenomena. As he broadened the range of applications, he discovered psychological and linguistic phenomena that displayed related patterns. He used the dependency grammar developed by Lucien Tesnière [12] to represent patterns of events. When he analyzed the dynamic evolution of those events and their consequences, he discovered that they fell into patterns that resembled the chaotic patterns he observed in physics. He showed that those patterns could be used to classify the typical kinds of plot structures found in literature. Thom's ideas were developed further by Petitot [13] and Wildgen [14]. Most linguists ignored those developments because they use mathematical computations that are unrelated to the usual linguistic theories. But Tesnière's dependency structures have a direct mapping to conceptual graphs [7]. That mapping enables the methods of catastrophe theoretical semantics (CTS) to be adapted to CGs.

3 Applications

VivoMind software has mostly been applied to nonfictional documents on subjects such as oil and gas exploration or rare earth magnetic materials [8, 9]. For those purposes, CTS proved to be valuable for classifying document types. It can distinguish documents that serve different purposes, even though they have similar vocabulary and ontology. Examples include chapters from a textbook, research reports, tutorials, and surveys that cover similar material. These methods can even distinguish routine or incremental research from novel papers and highly innovative speculation.

To illustrate the differences between a serious and a humorous text, we used the methods to compare the patterns of betrayal in two anecdotes: the BRUTUS story betrayal model [15] and a joke called "Meeting St. Peter." In both of them, the situation is painful for the victim. But the victim in the serious anecdote is a sympathetic character (a student); in the other, the victim is a stereotypical butt of humor (a salesman). Following are two stories of betrayal analyzed by the CTS methods.

"Betrayal" by BRUTUS

> Dave Striver loved the university. He loved its ivy-covered clocktowers, its ancient and sturdy brick, and its sun-splashed verdant greens and eager youth. He also loved the fact that the university is free of the stark unforgiving trials of the business world — only this isn't a fact: academia has its own tests, and some are as merciless as any in the marketplace. A prime example is the dissertation defense: to earn the PhD, to become a doctor, one must pass an oral examination on one's dissertation. This was a test Professor Edward Hart enjoyed giving.
>
> Dave wanted desperately to be a doctor. But he needed the signatures of three people on the first page of his dissertation, the priceless inscriptions which, together, would certify that he had passed his defense. One of the signatures had

to come from Professor Hart, and Hart had often said-to others and to himself-that he was honored to help Dave secure his well-earned dream.

Well before the defense, Striver gave Hart a penultimate copy of his thesis. Hart read it and told Dave that it was absolutely first-rate, and that he would gladly sign it at the defense. They even shook hands in Hart's book-lined office. Dave noticed that Hart's eyes were bright and trustful, and his bearing paternal.

At the defense, Dave thought that he eloquently summarized chapter three of his dissertation. There were two questions, one from Professor Rodman and one from Dr. Teer; Dave answered both, apparently to everyone's satisfaction. There were no further objections.

Professor Rodman signed. He slid the tome to Teer; she too signed, and then slid it in front of Hart. Hart didn't move.

"Ed?" Rodman said.

Hart still sat motionless. Dave felt slightly dizzy.

"Edward, are you going to sign?"

Later, Hart sat alone in his office, in his big leather chair, saddened by Dave's failure. He tried to think of ways he could help Dave achieve his dream.

The next story is an updated and extended version of a joke that was circulated around the Internet.

Meeting St. Peter

A computer salesman died and went to meet St. Peter at the Pearly Gates.

St. Peter: Welcome to our reception hall. We've made some updates to our traditional procedures in order to speed up the process and make our guests feel more comfortable. Instead of the old book of sins, we now use an iPad.

Computer Salesman: That sounds great. I love the new technology.

Then St. Peter swiped the iPad and projected scenes from the salesman's life on the wall next to the Pearly Gates. The salesman began to squirm when he saw some of the long-forgotten events.

St. P: Relax. We got rid of the old trial because it takes too long. We developed new methods that predict the same results with six-sigma reliability. We just let people choose whether they would prefer to go to Heaven or Hell.

Then he took another swipe at the iPad and showed some scenes from Heaven. People in white robes were sitting on clouds, playing harps, and singing hymns.

C S: That looks boring.

Then St. Peter took another swipe at the iPad and showed scenes from Hell.

A toga party was going on. There was wild music, dancing, drinking, and carousing. Men and women in various stages of undress were engaged in every activity imaginable.

C S: That's fantastic. I choose Hell.

St. P: Done.

St. Peter took another swipe at his iPad, a trap door opened, and the salesman found himself sliding down a steel chute. He was rapidly accelerating down a well-worn path, polished by many previous travelers.

Finally, he flew through an open door into a huge cavern with fire and brimstone stinging his eyes. At once, a dozen little devils with pitchforks started prodding and pushing him toward a fiery pit.

C S: Hey, wait a minute! What happened to the party?

Then the chief devil walked over, stroking his beard.

Chief Devil: Ooooh. You must have seen our demo.

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