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The Metaphorical Brain

The Human Brain is perhaps the most complex system known. Scientists have grappled with its complexity in various eras by choosing powerful and well-developed metaphors to guide their investigations. Let us take a look at some of these metaphors.

THE human brain is the only system in the human body that is impressed by its own functioning. Smitten by its capabilities, it has actively engaged in finding out how it evolved and how it is able to accomplish a multitude of impressive feats.

We were able to identify the brain as the seat of all our conscious and cognitive actions only in the 2nd century B.C. Before that we believed that we were governed by spirits living outside our body. The importance of the discovery of the brain as a thinking organ can be assessed by the fact that even now neuroscientists are surprised that the activity of the neurons is correlated with cognitive functions. Nevertheless, once the task of 'thinking' was assigned to the brain, we have been investing serious efforts to isolate the key principles that govern its functioning.

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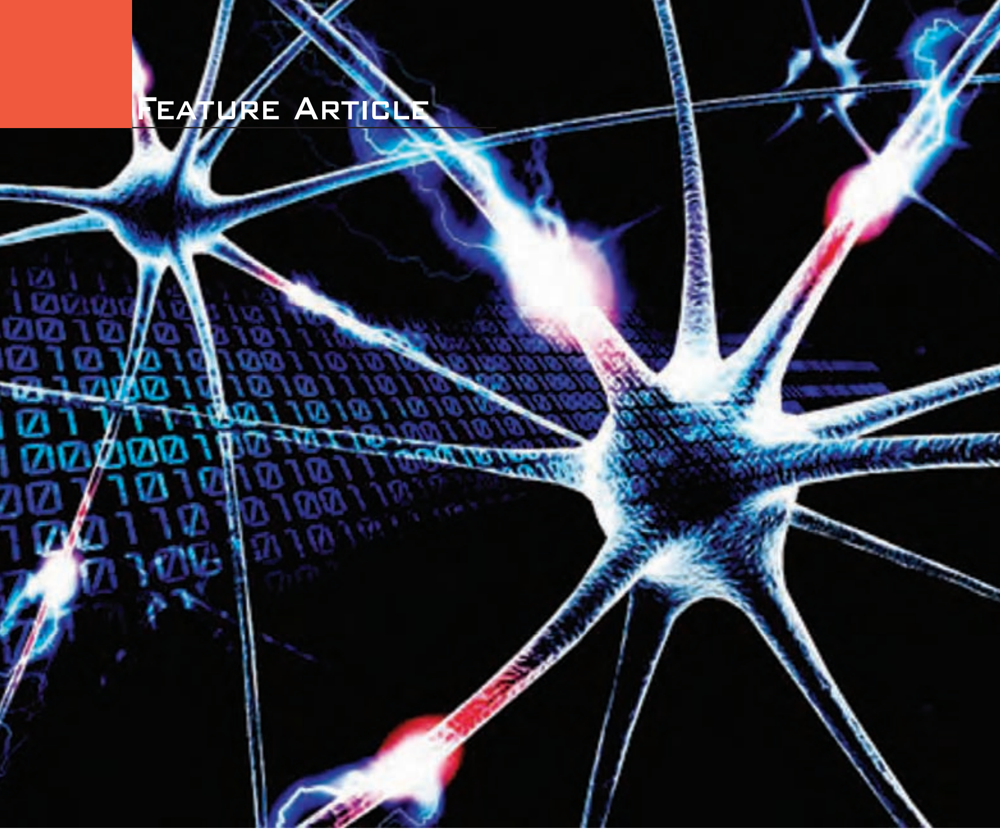
A key aspect of brain function, we have learned, is that it has an inherent tendency to seek correlations and find parallels between seemingly different phenomena. That is, the brain uses analogies and metaphors to understand a phenomenon. Indeed, individuals who can create new metaphors like poets and authors are celebrated by society. Metaphors are deeply rooted in our common conversation as well as in philosophical and scientific thinking.

Similarly, scientists have also used different types of metaphors to get a grasp on the functioning of the brain. These metaphors are often man-made systems that were built during that era and on some occasions, a well understood natural phenomenon. Significantly, the choice of metaphor also guided the future investigations of the brain, including conceptualization of the scientific problem and instrumentation used for its investigation.

Pre-industrial Metaphors

The earliest example of a technology providing a metaphor can be traced to the ancient Egyptians. Man had just learned to extract metals from their ores and was able to transform it into useful objects. So, for the ancient Egyptians the brain with its peculiar wrinkled surface was similar to the 'rather useless' slag. In fact, they thought that the brain was not so important. They considered the outer covering of the brain – called the meninges – more important as it was deformed in subjects with head injury and mental deficiency.

As technology advanced, the metaphors evolved. The Greeks mastered the hydraulic systems and the School of Hippocrates thought of the mind as a hydraulic system in which four different types of fluids are mixed. A change in proportion of these fluids was thought to cause mental illness. For example, increase in phlegm created apathy and increased black bile was the cause of melancholy. In a hydraulic system pressure of the fluids plays a crucial role. So, in ancient Greece drilling of a hole in the skull was recommended as a cure for certain brain disorders including epilepsy. The Roman physician Galen in the second century A.D., refined these metaphors and concluded that there was a highly pure fluid in the nerves, which was used for the transmission of sensory and motor signals.



The hydraulic metaphors of the ancient Greeks persisted until the industrial revolution in Europe, probably because not much happened on the technology front. Rapid advances in technology in the seventeenth century led to new metaphors for the brain; with mechanical movements and clockwork being the dominant ones. It was thought that minute mechanical motions and vibration of particles underlie the thought process. Coherence among different vibrations defined associations, which led to the development of ideas.

Perhaps the most fascinating idea of that era was that human brain and body is 'a machine that winds its own springs', or a living exemplar of a perpetual motion machine. It is worth noting that these ideas are still popular among neuroscientists, except that now we talk about oscillations and coherence of electrical activity. Echoes of metaphors based on our progress in understanding of mechanical systems could be heard even in the twentieth century when the neurophysiologist and Nobel Laureate Charles Sherrington, who coined the term 'synapse', compared the functioning of a brain to looms:

"Swiftly the head mass becomes an enchanted loom where millions of flashing shuttles weave a dissolving pattern, always a meaningful pattern though never an abiding one; a shifting harmony of subpatterns" (Sherington 1948).

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Twentieth Century Metaphors

Emergence of the new field of Cybernetics and development of electronic computing devices in the early 20th century combined with new knowledge of brain anatomy led to new derived metaphors, which matured into at least four new paradigms. Each paradigm unlike their predecessor made more specific assumptions about the brain and suggested specific experiments.

Brain as a Computer

By the middle of 20th century we had learned the following interesting facts about the brain:

1. The brain is a dense network of nerve cells,

2. Nerve cells are connected via synapses,

3. Information is exchanged between two neurons via junctions called synapses only when the sender nerve cell generates an action potential,

4. Nerve cell responses are highly noisy and variable and

5. Synapses are unreliable.

Inspired by the dense connectivity and the switch like behaviour of the neuron (i.e. ability to produce action potentials) computer scientists and mathematicians started to draw parallels between an electronic computer and a brain. The German philosopher and mathematician Leibniz once imagined that all the truths of reason could be reduced to some kind of calculations. Now the computers could perform arithmetic and logical calculations.

Moreover, there was a great deal of apparent functional similarity between computer hardware (vacuum tubes or transistors) and neural elements (neurons and synapses), and both used electrical signal for their operation. So, quite naturally it led us to think of brain as a computing device.

Within this "brain as a computing device" paradigm we try to understand the brain using the language of computers. The brain is assumed to be a Turing machine and the emphasis is on identifying algorithms that it may be using to solve problems related to cognitive and sensorimotor transformation. As part of this paradigm, there is an active interest in implementing currently popular machine learning and artificial intelligence

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algorithms and concepts to understand how the neural hardware produces thought.

Brain as a Dynamical System

Parallel to the computer-based metaphors, cybernetics – especially the control systems theory – inspired brain research extensively. The mathematical tools developed for control systems theory provided a theoretical framework to understand the causal links between stimulus and response, and also among our thoughts.

So in this paradigm we consider the brain as a dynamic system that can be studied using the concepts and tools from classical thermodynamics, Newtonian mechanics and control systems theory. Special interest lies in identifying the dynamic state of the neural networks, and it is implicitly assumed that the neural implementation of cognitive and sensorimotor functions is a transition of the dynamics from one stable state to another.

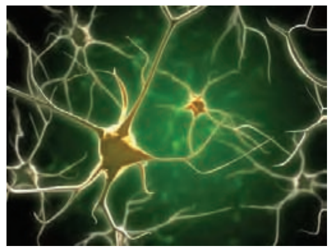
Brain as a Stochastic System

Experiments conducted as part of the above two paradigms led to the development of a new metaphor. Essentially, every component of the neural hardware such as neuron membranes, spiking mechanisms, synapses etc. are noisy or prone to variability in response. Therefore, it was deemed suitable to use methods from probability theory and modeling of point processes to describe the activity state of neural networks and their response to stimuli. These methods were successful in machine learning and artificial intelligence.

Therefore, in this paradigm we view cognitive and sensory motor functions of the brain as probabilistic (Bayesian) inference problem; the brain collects enough information about the stimuli, compares it with its prior ongoing activity and generates a posterior distribution that is the desired activity. Learning is merely updating of the prior state either by changing the ongoing activity or the distribution of the synaptic strengths or neuron firing rates or correlations. Thus, the emphasis is on developing statistical methods to characterize the brain function.

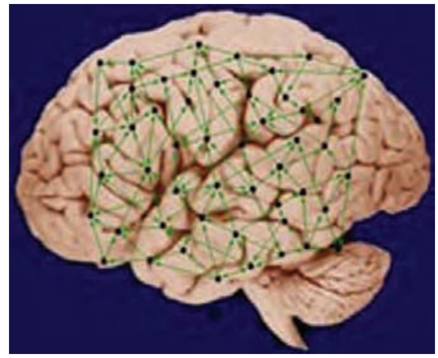
The Brain as a Network

Ramon y Cajal was the first to elucidate the structure of the different brain tissues



and made the first drawing of the neural tissue available in the first decade of the 20th century. It became clear that the brain is a system of inter-connected nerve cells, i.e. it is a network. In the mid twentieth century, the technology of telegraphic networks was available which could have become a strong metaphor for the brain. But the amazing success and progress of computers continued to enthrall human beings. But network as a metaphor for the brain had to wait for the dawn of the twenty first century.

The computing brain paradigm was so powerful that not much attention was paid to the network structure of the brain. Even the dynamical system metaphor of the brain did not demand the knowledge



of specific connectivity of the brain. Therefore, in the last decade there has been a growing interest in understanding the brain in terms of network properties, i.e. in the specific manner in which neurons are connected. It is interesting to note that the development of this paradigm coincides with the popularity of networks as a theoretical framework in virtually every field of knowledge, from quantum mechanics to economics to the spreading of diseases and rumors in society.

Once again technological success of the Internet acted as a driving force for this metaphor. The emphasis in this paradigm is on developing methods by which network structures can be connected to the network activity dynamics and vice versa. In this regard, this paradigm is closely related to the dynamical systems approach to understand the brain. However, new ideas from the field of graph theory and communication engineering are being introduced to neuroscience in order to understand the spread of neural activity, which is considered to be a primitive form of neural computation.

Perhaps the most fascinating idea of that era was that human brain and body is 'a machine that winds its own springs', or a living exemplar of a perpetual motion machine.

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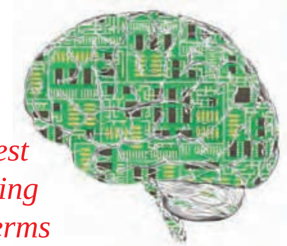

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Holography & Quantum Mechanics

Besides these four successful paradigms, our success in physics led to two more metaphors. Development of the ideas of holography led to the notion that in some aspects brain could be a hologram. The neuroscientist Pribram was particularly excited by the amazing capacity of the holograms to store memory and their robustness to damage, so he pushed for the holographic metaphor to explain the memory capacity and perception abilities of the brain. This was not the first time that

the brain was considered to be an optical system.

Perhaps the most important achievement of mankind in the last century was the development of quantum mechanics. Naturally, quantum mechanics also inspired our thinking about the brain. When we think of the brain function as a sequence of cause and effect, it turns out that the notion of 'freewill' is impossible. Philosophers worried quite a bit about this implication. The inherent uncertainty in quantum mechanics seemed to provide a new metaphor that could reinstate free will in the brain function. So, instead of just coherence, quantum coherence was thought to be the fundamental mechanism for brain function.

Neural Darwinsim: Survival of the Fittest Neural Circuit

By the 20th century, the Darwin-Wallace theory of natural selection was applied to multiple biological systems. This inspired Edelman to propose neural Darwinism, which argued that neural circuits compete largely in the same ways as species do. The idea sounded quite appealing but slowly this idea was absorbed in the other contemporary paradigms.

Evidently, these various paradigms and metaphors are not as segregated as they appear. As a matter of fact, with the development of network as a theoretical framework in neuroscience, the connection among these various paradigms has started to become more obvious.

However, recent interest in cloud computing implies that soon the network metaphor for the brain will be left behind . The brain will be thought of as a cloud computer where no single brain area is sufficient to perform anything of interest and thus, it will become futile to locate functions in the different brain regions. Scientists will perhaps ask questions about how sensory information can be rapidly and efficiently distributed to different areas and how efficiently it can be retrieved. Needless to say, this paradigm shift will start a new kind of exploration and experiments.

Future of the Metaphorical Brain

Going by the history, network and cloud metaphors will also make way for the metaphors derived from newer technology. However, it is also obvious that in the process we will learn more about the brain.

While it took us some time to establish that brain is the organ responsible for thought, since then every new technology has provided yet another metaphor to fill the vacuum of ignorance about the brain function. Arguably metaphors define the life of a scientific paradigm and change in the metaphor is an early sign of change in the scientific paradigm.

Needless to say, the choice of metaphor is detrimental to what we can understand about the phenomenon as they highlight only a partial aspect of the phenomenon. The Brain is a complex system and different types of metaphors can explain parts of its function.

While metaphors are limited in what they can tell us and sometimes can even misguide us, their real merit is in extending the discussion and driving new experiments. At best a metaphor is like the crutches of an injured man. Sooner or later ,we have to give up the crutches and start to walk on our own.

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