The Evolution of the Brain

Neurons are quite distinct from other body cells in ways that make them suited to their specialized role of signal processing and communication, but it is not too difficult to see how they could have evolved from less specialized cells. All living cells are surrounded by a cell membrane that separates the special chemical composition of its interior from that of the external world. This difference in chemical composition results in a small electrical potential between the inside and outside of the cell, in much the same way that a voltage exists between the two sides of a battery. When a part of a cell's membrane is disturbed in a certain way, it loses its electrical potential, becoming depolarized at the site of the disturbance. This sudden change in electrical potential can itself be a disturbance, causing additional depolarization along the membrane. In most cells, such depolarization would not spread far, certainly not to neighboring cells. But a few changes in the shape and arrangement of cells (in just the way that neurons are fashioned) permits depolarization to propagate quickly from one neuron to the next, and allows it to travel quickly as an electrochemical signal from one end of an animal to the other.

An example of a simple nervous system is provided by the jellyfish (or *Medusa*). The jellyfish's nervous system forms an undifferentiated network and serves primarily to coordinate the animal's swimming motions. Since the jellyfish's skirt must open and contract in a coordinated manner for the animal to move through the water, its nervous system serves as a simple communications network making it possible for all parts of the skirt to open repeatedly and then contract at the same time.

Worms are the simplest organisms to have a central nervous system, which includes a distinct brain that is connected to groups of neurons organized as nerve cords running along the length of its body. This more complicated nervous system allows worms to exhibit more complex forms of behavior. An anterior brain connected to a nerve cord is the basic design for all organisms with central nervous systems, from the earthworm on the hook to the human on the other end of the fishing rod. But although we can discern a separate brain in worms, it is not the case that the brain is the sole "commander" of the animal that the rest of the nervous system and body obeys. Indeed, even with its brain removed, worms are able to perform many types of behaviors, including locomotion, mating, burrowing, feeding, and even maze learning.

As we move to insects we find increased complexity in all aspects of the brain and nervous system. So-called giant fiber systems (also found to some extent in worms and jellyfish) that allow rapid conduction of nerve impulses connect parts of the brain to specific muscles in legs or wings. Such connections permit the cockroach to dart away as soon as it senses the moving air preceding a quickly descending human foot. The brain itself is typically divided into three specialized segments, the proto-cerebrum, the deuto-cerebrum, and the trito-cerebrum. In addition, insects possess a greater variety of sensory receptors than any other group of organisms, including vertebrates, that are sensitive to the odors, sounds, light patterns, texture, pressure, humidity, temperature, and chemical composition of their surroundings. The concentration of these sensory organs on the insect's head provides for rapid communication with the tiny yet capable brain located within.

Although minuscule by human standards, the range of abilities made possible by insect brains is impressive. These creatures show a remarkable variety of behaviors for locomotion, obtaining food, mating, and aiding the survival of their offspring. They can crawl, hop, swim, fly, burrow, and even walk on water. The female wasp hunts down a caterpillar, paralyzes it with her venom, and then lays its egg on the motionless prey so that her offspring will have a fresh and wholesome meal immediately after hatching. Leafcutter ants harvest leaves and bring them into their nest where they use them to cultivate indoor gardens of edible fungus. Honeybees live in social communities where there is a strict division of labor, and where food gathering worker bees perform a special dance to communicate the location and richness of food sources to their hive mates. It is the evolution of their brains, together with the complementary evolution of their other body parts, that make insects the most abundant multicellular organisms on our planet.

The brain becomes both much larger and still more complex as we move to vertebrates such as fish, amphibians, and reptiles. The spinal cord, now protected within the vertebrae of the backbone, has become primarily a servant of the brain, a busy two-way highway of communication with fibers segregated into descending motor pathways and ascending sensory ones. The brain itself is now composed of a series of swellings of the anterior end of the spinal cord (the brain stem), the three major ones making up the three major parts of the vertebrate brain: the hindbrain, midbrain, and forebrain. From the hindbrain sprouts a distinctive structure, the "cerebellum" (Latin for "little brain").

Among mammals, the brain keeps its three major components, but with two new structures. The neo-cerebellum ("new cerebellum") is added to the cerebellum, looking much like a fungal growth at the base of the brain, and the neo-cortex ("new cortex") grows out of the front of the forebrain. In most mammals, these new additions are not particularly large relative to the brain stem. In primates they are much larger, and in the human they are so large that the original brain stem is almost completely hidden by this large convoluted mass of grey neural matter. In keeping with this remarkable increase of neo-cerebellar and neocortical tissue, humans enjoy the largest ratio of brain weight to body weight of any of earth's creatures.

It is not possible to know exactly why the human brain evolved as it did, but consideration of the structural evolution of the brain and results of comparative research on human and nonhuman brains provides some useful clues. It is now believed that during the long evolution of our brain, nervous systems changed in four principal ways. First, they became increasingly *centralized* in architecture, evolving from a loose network of nerve cells (as in the jellyfish) to a spinal column and complex brain with impressive swellings at the hindbrain and forebrain. This increasingly centralized structure also became increasingly *hierarchical*. It appears that newer additions to the human brain took over control from the previous additions and in effect became their new masters. Accordingly, the initiation of voluntary behavior as well as the ability to plan, engage in conscious thought, and use language depend on neocortical structures. Indeed, the human neo-cortex can actually destroy itself if it wishes, as when a severely depressed individual uses a gun to put a bullet through his or her skull.

Second, there was a trend toward *encephalization*, that is, a concentration of neurons and sense organs at one end of the organism. By concentrating neural and sensory equipment in one general location, transmission time from sense organs to brain was minimized. Third, the size, number, and variety of elements of the brain increased. Finally, there was an increase in *plasticity*, that is, the brain's ability to modify itself as a result of experience to make memory and the learning of new perceptual and motor abilities possible.

One way of understanding the evolution of the human brain is to see it as the addition of higher and higher levels of control. We will see in chapter 8 that the function of animal and human behavior can be understood as the control of perceptions, with perceptions corresponding to important aspects of the environment. For a sexually reproducing organism to survive and leave progeny, it must be able to control many different types of perceptions, that is, sensed aspects of its environment. At a minimum, it must be able to find food, avoid enemies, and mate. But as life evolved, the environment of our ancestors became more complex due to increasing numbers of competing organisms. So it would have been of considerable advantage to be able to perceive and control increasingly complex aspects of this environment. The bacterium *E. coli* can control its sensing of food and toxins only in a primitive way; organisms with more complex brains are able to sense and control much more complex aspects of their surroundings.

This capacity for increased environmental control is nowhere more striking than in our species. Using the advanced perceptual-behavioral capacities of our brain together with our culturally evolved knowledge of science and technology, we can visit ocean floors, scale the highest peaks, and set foot on other worlds. (The role that language is believed to have had in the evolution of the human brain will be considered separately in chapter 11.) But can the most complex human abilities and mental capacities be explained by natural selection? Our brain has certainly not changed appreciably over the last couple of hundred years, and yet we can solve mathematical, scientific, technological, and artistic problems that did not even exist a hundred years ago. So how could natural selection be responsible for the striking abilities of today's scientists, engineers, and artists?

This is actually the same problem that troubled Alfred Russel Wallace, as mentioned in chapter 3. It will be recalled that Wallace, despite being an independent co-discoverer of natural selection, could not, for example, imagine how natural selection could account for Africans' ability to sing and perform European music, since nothing in their native environment could have selected for such an ability. Consequently, for him the brain could only be a creation provided to us by God. We now know that in his embrace of this providential explanation, Wallace failed to realize that natural selection can lead to new abilities unrelated to those that were originally selected.

To use an example from technological evolution, the first personal computers were used to perform financial calculations in the form of electronic spreadsheets. However, these same machines with the proper software could also be used for word processing, telecommunications, computer games, and many other purposes, even though they were not originally designed with these functions in mind. A classic example of this phenomenon of functional shift in biological evolution is the transformation of stubby appendages for thermoregulation in insects and birds into wings for flight. In the same way, selection pressure was undoubtedly exerted on early hominids to become better hunters. The ability to understand the behavior of other animals and organize hunting expeditions must have been very important in the evolution of our species. And the increasingly complex and adapted brain thus selected would have made other skills possible, such as making tools and using language, traits that in turn could become targets for continued natural selection. This transformation of biological structures and behaviors from one use to another was given the unfortunate name of preadaptation by Darwin, unfortunate since it can too easily be misunderstood to imply that somehow evolution "knows" what structures will be useful for future descendants of the current organisms.

American evolutionary paleontologist Stephen Jay Gould provided a better term for this phenomenon--exaptation. He made a major contribution to our understanding of evolution by insisting that we distinguish *adaptation*, the evolutionary process through which adaptedly complex structures and behaviors are progressively fine-tuned by natural selection with no marked change in the structure's or behavior's function, from *exaptation*, through which structures and behaviors originally selected for one function become involved in another, possibly quite unrelated, function. Exaptation makes it difficult if not impossible to understand why our brain evolved as it did. Although the brain allows us to speak, sing, dance, laugh, design computers, and solve differential equations, these and other abilities may well be accidental side effects of its evolution. As Gould and his associate Vrba cautioned:

"…current utility carries no automatic implication about historical origin. Most of what the brain now does to enhance our survival lies in the domain of exaptation--and does not allow us to make hypotheses about the selective paths of human history. How much of the evolutionary literature on human behavior would collapse if we incorporated the principle of exaptation into the core of our evolutionary thinking?"

But although we may never know the actual events and specific selection pressures responsible for our brain power, we have no scientific reason to believe that evolution could not have fashioned our brain through natural selection. The fact that living organisms today have nervous systems and brains ranging from quite simple to amazingly complex is compelling evidence that our brain evolved through forgotten ancestors in progressive stages from simple to complex. And somehow, as a part of this evolutionary process, that most remarkable and mystifying of all natural phenomena came into being--human consciousness.

Resources

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