Spying on God

For **Valentin Braitenberg**, the brain was the most interesting research subject in the world, apart from the world itself. A former Director at the **Max Planck Institute for Biological Cybernetics** in Tübingen, he spent thousands of hours poring over a microscope to get to the bottom of this most complex of organs. His purpose was to examine the fiber pathways in various areas of the brain and to search for their functions.

TEXT **ELKE MAIER**

Rome, 1948. In the anatomical laboratory of a psychiatric clinic, where neurologists work at the dissecting table to find the causes of language impairment, locomotor disorders and mental derangement, an ambitious medical student is looking through a microscope at a piece of brain tissue. What he sees stays with him forever: “A structure made up of fine threads, so many and so fine that even the strongest magnification of the microscope was hardly sufficient to allow all of them to be seen clearly. Some of the threads ran together in bundles and in layers in specific directions; others lay seemingly randomly distributed every which way through the tissue. Embedded in this felted mass of fibers, it was possible to discern spherical structures, the nuclei of the nerve cells […].”

The name of the student was Valentin Braitenberg, and this experience in the laboratory was to define his career. At the time of his death last September, at the age of 85, he was one of the foremost neuroscientists in the world. It was during his time in the laboratory in Rome that he set his heart on studying the network in the brain. He was convinced that this tangle held the key to understanding how “the mental functions originate in our heads.”

Braitenberg’s professors were less optimistic. In their view, it was impossible to understand these processes simply because their complexity went beyond the analytical abilities of humans. They thought the interwoven fibers were an impenetrable jumble, and advised their student not to waste too much time thinking about the brain functions hidden within it.

But it was not so easy to dissuade Valentin Braitenberg from pursuing his ideas, particularly when a goatee-sporting, cigar-smoking mathematics professor from Massachusetts added fuel to the fire: Norbert Wiener, a former child prodigy and one of the first researchers in the new area of cybernetics, had published a book that same year entitled *Cybernetics or Control and Communication in the Animal and the Machine*. It conveyed some of the euphoria generated by the new electronic computing machines that heralded a new era for some scientists. Braitenberg was deeply impressed by the book. Were these computers not also so complex that it was impossible to understand them from the outside? And were they not nevertheless constructed by someone who must have thought them through completely?

After studying in Innsbruck and Rome, Valentin Braitenberg, who was born in Bolzano on June 18, 1926, became a specialist in neurology and psychiatry and obtained a German postdoctoral lecturing qualification in information theory and cybernetics, the science concerned with the control processes in living organisms and machines. As a professor of cybernetics at the University of Naples and, from 1968, a Director at the Max Planck Institute for Biological Cybernetics in Tübingen, he concentrated on the body’s crucial control centers.

His approach was that of a neuroanatomist: his goal was to describe the typical structure of a certain part of the brain in order to deduce its function. He liked to describe this work as “spying on God,” for which, he said, he spent at least 10,000 hours sitting at his microscope, “looking at thin sections of brain from top to bottom and every which way under 100x to 100,000x magnification.” He had, he said, enjoyed this as much as other people enjoy spending the same amount of time traveling the world.

In 1968, he was appointed a Director at the Max Planck Institute for Biologi-

The tree of knowledge: The cerebellum is arranged in strict geometric form. Valentin Braitenberg drew conclusions regarding the function of certain areas of the brain from the pathways of nerve cell fibers.

Photos from: *Tentacles of the Mind. Encounters with Valentin Braitenberg*, Edition Raetia (2011) – Almut Schüz cal Cybernetics in Tübingen, where he and his colleagues Werner Reichardt, Karl Georg Götz and Kuno Kirschfeld spent many pleasant hours. The four researchers studied the common house fly, *Musca domestica*, with the aim of understanding its visual system. As the laboratory animal of choice for neuroscientists, the fly has the advantage that its eyes and brain are arranged neatly and that it always responds to certain stimuli in the same way. This makes it easier for researchers to investigate the underlying mechanisms.

As is normally the case with insects, flies see the world through compound eyes – spherical structures made up of hundreds or thousands of separate, rod-shaped eyes which abut each other on the surface to appear like honeycomb. Each of these "ommatidia" is equipped with its own lens and registers a small section of the environment. The brain then composes a meaningful mosaic of the many individual images. But how must the individual eyes be wired to avoid gaps and overlaps of the mosaic tiles?

The researchers investigated this question with wafer-thin sections of tissue, which they dyed and studied under the microscope in order to reconstruct the fiber pathways. This meticulous exercise resulted in the first detailed circuit diagrams of the eye of a fly. Above all, the scientists were astonished by how accurately the 3,000 ommatidia in each eye are wired up. Six neighboring single eyes conduct their signals through the same cable to a shared nerve cell, which bundles the information and passes it on. The brain can thus filter out interference before it computes an overall picture from the individual images.

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» No one could present knowledge about the intelligence hidden in nature more convincingly than Valentino Braitenberg: long after his retirement, his 14 machines, which he simply called 'vehicles,' achieved quasi-cult status in robotics.«

The spatial resolution that the fly achieves with this arrangement is not as good as that of a human, but the temporal resolution is much better. Were *Musca domestica* to watch a movie at the cinema, it would not see continuous action on the screen, but a series of separate stills. However, in rapid flight, or when avoiding the fly swatter, high temporal resolution is beneficial.

As Valentin Braitenberg and his fellow scientists observed the different types of nerve tissue in flies, frogs, mice and humans, they encountered some that were laid out in a strictly geometric arrangement while others were characterized by an apparent confusion. It was only after they had counted the links and analyzed them statistically that they began to understand the structural principles. The first type is characteristic of the cerebellum, and the second is typical of the cerebral cortex. The scientists in Tübingen had found an explanation for both forms.

Pioneer of network analysis: Valentin Braitenberg.

The rigid arrangement of the cerebellum with its parallel fibers running in two distinct directions is needed for the accurate coordination of sequences in time, such as the very precise movements needed to play the violin, at which Valentin Braitenberg was a virtuoso. The more relaxed structure of the cerebral cortex, on the other hand, with its seemingly random distribution of nerve cells, is flexible enough to create new connections for learning and filling gaps with new knowledge. This is what allows the cerebral cortex to perform the function of an associative memory. The idea that conclusions about their function could be drawn from the tangled fibers was thus not at all a flight of fancy on the part of a youthful researcher.

This is how Valentin Braitenberg approached the interpretation of the fine structures: "I pretend that a very clever, anonymous engineer has used all the information available to him about the animal's environment to design for the nerve cells within the brain a circuit that is as efficient as possible."

He then assumed the role of the engineer – with a thought experiment that made him a name among roboticists and that has since been implemented in practice many times. In his book *Vehicles: Experiments in Synthetic Psychology*, he designed 14 increasingly complex machines and showed that complex behavior can be created with astonishingly simple mechanisms.

The first of these imaginary beings is a simple little motorized cart with a temperature sensor. Its responses are easy to comprehend: it travels faster in a warm environment than in a cold one. On the other hand, vehicle number 14, the most sophisticated, gives the impression of having free will and being able to make independent decisions. Nevertheless, it is a comprehensible construction of wires, switches, threshold devices and detectors – and bears no comparison with the human brain with its hundred billion nerve cells and a million kilometer-long fibers that, if laid end to end, would reach from the earth to the far side of the moon and back again.

"Imagine the inside of St. Peter's in Rome filled with a huge quantity of fibers around a millimeter in diameter that crisscross the building in every direction creating a firm mat – then you have an idea of what the brain looks like when magnified a thousand times," writes Braitenberg.

It is hardly surprising, then, that where many questions about the brain are concerned, we are still clueless about what is going on in our own heads. However, a glance at the past reveals how much more we do know, thanks to scientists like Valentin Braitenberg: for many hundreds of years, scholars thought that the soft mass inside the skull was merely "slime for cooling the heart."