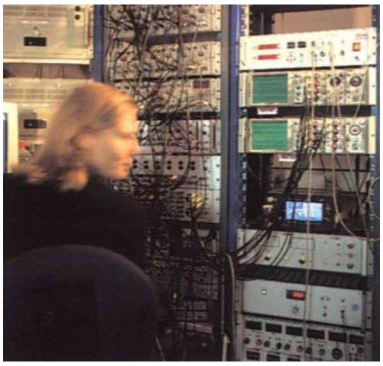
Körber European Science Prize 2000

Perception of Shape in Technology with Insights from Nature

Rodney Douglas, Amiram Grinvald, Randolf Menzel, Wolf Singer, Christoph von der Malsburg

The winners of the Körber European Science Prize 2000 want to discover how the brain processes visual, oral, and olfactory stimuli when recognizing objects, and to make it possible for technical systems to perform similar tasks.



In the laboratories of Wolf Singer, researchers are studying how sensory stimuli are processed, for example, by triggering electrical impulses from individual nerve cells in cat brains and observing how the cells communicate and synchronize themselves. (Photo: Friedrun Reinhold)

Who has not seen the picture of the black and white dalmatian standing in front of a black and white background and whose outline is easier to guess at than it is to recognize. Or the drawing “Heaven and Water” from M. C. Escher, the Dutch artist; it shows, at the top, flying ducks whose shape, going down the picture, gradually changes until the ducks recede to the background and the fish in the background move to the foreground. A third image: plaice lying on the sandy bottom of the sea, their color perfectly adapted to the sand, making them difficult to recognize. All three images are examples of tricky tasks that put our sense of perception to the test but that it passes with flying colors. Every technical system, in contrast, is hopelessly at a loss in such circumstances. How does the human brain do it? And will it be possible some day to teach a computer to respond in the same way?

“Machines still have a hard time recognizing objects, particularly if there aren't any strict rules. Current digital systems can only recognize figures on a white background,” according to Wolf Singer, professor at the Max Planck Institute for Brain Research in Frankfurt. In the present state of development, “even a bee's brain is more advanced than any existing technology, and I think it highly improbable that we will succeed in reproducing the sensory performance of an ordinary house fly in the next 10 to 20 years.”

In an attempt to take a big step forward toward reaching this goal and also toward tackling the puzzle posed by human perception, the Körber European Science Prize was awarded this year to a group of internationally renowned brain researchers. They are the professors: Christoph von der Malsburg (Coordinator), from the Institute for Neuroinformatics at the Ruhr University in Bochum; Rodney Douglas, from the Institute of Neuroinformatics of the ETH Zurich; Amiram Grinvald, from the Dominic Institute of Brain Research, Weizmann Institute for Science in Rehovot, Israel; Randolf Menzel, from the Institute of Biology, Free University of Berlin; and Wolf Singer, from the Max Planck Institute for Brain Research in Frankfurt.

“We want to study nature to identify the principles of information processing that organisms use," says Singer. “And we hope that this knowledge will lead us to discover new forms of therapy and new ways to use technical systems." The study of perception in living beings is a prerequisite for the development of such applications. Decisive issues include: Which neuronal structures does a brain use to recognize an object? How does it distinguish the form of an object from the background? And how can it identify an object whatever the size and from whatever angle? This research forms the starting point of the Körber project. The scientists involved can draw on years of experience.

"Singer and I have been in close contact for a long time," emphasizes Christoph von der Malsburg, project coordinator. "He was interested in the form-background problem, and I suggested in 1981 that the manner in which the individual cells, the elementary symbols, are grouped is of utmost importance for the way in which the brain represents objects."

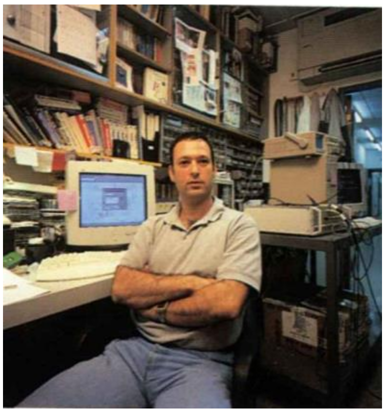
Nerve cells interact, just as atoms do in grouping to form molecules, which in turn, for example, can form grains of sand and these then cement, which can be used to erect a structure such as a bridge or a building. Von der Malsburg's idea is that this grouping can be recognized in the fact that the cells' signals exhibit a temporal correlation. For example, let us say that the eye is supposed to recognize the letter A in red and the letter B in green. Four groups of cells are involved: one group that reacts to the shape of the letter A, another to the shape of B, a third to red, and a fourth to green. If the eye can see the letters long enough, it correctly links the letter A to the color red and the letter B to green. As experiments with probands have shown, if the letters are only shown very briefly, it is impossible for the brain to make the link. As a result, the person confuses the letters' colors.

The research of Christoph von der Malsburg focuses on the questions of how the visual system matures, how the individual cells cooperate, for example in recognizing a face, and how to enable a computer to do the same thing. (Photo: Friedrun Reinhold)

The temporal link even plays a role while the eye is distinguishing a figure from its background. To identify the figure, our perception must separate or, to use the technical term, segment it into its individual parts, such as movement, stereo depth, texture, color, and edges. It was initially thought that the nerve cells that represent the object were active while the cells that imaged the background were inactive, as if the object were illuminated in front of its background. Yet then it turned out that both groups of cells are active at certain intervals. Those responsible for the background trigger simultaneously, just as those responsible for the object do, just not at the same instant as the first group does.

Time acts like a kind of mortar that hardens the elementary symbols, i.e., the different aspects of what is seen, to a whole, making it possible for us to recognize the object. Singer, prompted by von der Malsburg's ideas, has succeeded in identifying 40 Hz oscillations in nerve cells, verifying that the cell group belonging to a figure trigger simultaneously. In carrying out this research, Singer's team made a name for itself by developing methods for conducting electrical impulses from nerve cells in the brain, enabling them to observe the processes of perception.

The studies of another member of the of the Körber project are in a similar vein, both supplementing and making Singer's work easier. Amiram Grinvald developed a revolutionary technology for simultaneously measuring the activity of an immense number of nerve cells. “Until now, it was only possible to observe the activity of individual cells,” Grinvald explains. “By using the new technology, we can record and study how millions of cells work together to achieve higher cognitive functions." Grinvald's trick is that his team has developed fluorescing stains that are injected into the brain and illuminate when the neurons are electrically active. Active nerve cells emit flashes of color that can be traced spatially in the brain and that are recorded in intervals of 50 ms or less. This activity can be videoed and subsequently studied.



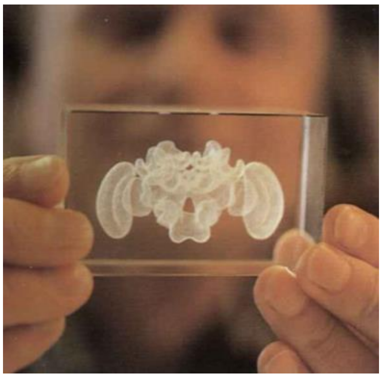
A unique new technique for studying the brain was developed in the laboratory of Amiram Grinvald in Israel. It visualizes the activity of entire areas of the brain by marking cells with a substance that illuminates when electrically stimulated.
(Photo: Friedrun Reinhold)

The fourth participant in the project, Randolf Menzel, also profits from Grinvald's methods. Menzel has long been specialized in the study of the sensory activity of honey bees, an organism whose brain is a simple construct compared with those of humans and other mammals. At the centre of Menzel's interest is insects' sense of smell, not their sense of vision. Nonetheless, there are parallels in the way impressions from both senses are processed in the brain.

“The way in which an object is recognized on a background is a general problem. This is true for our sense of smell just as for our sense of vision,” according to Menzel. “Every scent is made up of many individual components that are perceived as a kind of gestalt and are separated from the background formed by other scents.” A scent of some kind can thus be conceived as a stream of triggers forming a spatially and temporally structured pattern in the brain. Thanks to Grinvald's technique, it has for the first time become possible to achieve the temporal resolution necessary to be able to follow this excitation. Menzel and his team have devised experiments with bees in which the animals have to learn to recognize certain scents as being the signals for a reward. The researchers want to observe what takes place in the brain of these bees. The adjustment and alteration of the sense of perception during learning and remembering is one of the exciting questions that can be studied very well in insects.

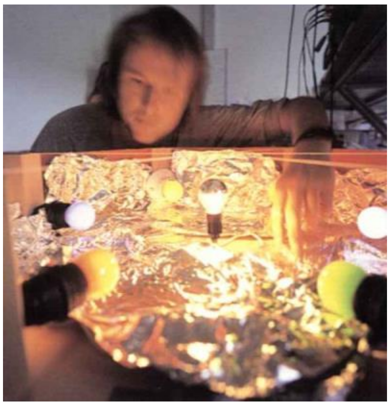
There is another reason for including the honey bees in the Körber project: their brain is relatively simple, giving us the hope that the processes of perception can be understood better in insects than in mammals and the knowledge that we acquire can lead to the faster development of technical applications. Rodney Douglas, who is another of this year's winners of the Körber Prize, is a specialist for such applications. “What we are doing is a mixture of biology and neuronal modeling,” Douglas says about his approach. “We are developing theoretical models that explain how biological systems can segment objects, i.e., separate them into their individual components and recognize them on a background. And we want to use these models to construct chips that can do this, too."

»Was wir machen, ist eine Mixtur aus Biologie und neuronalem Modelling«, erklärt Douglas seinen Forschungsansatz. »Wir entwickeln theoretische Modelle, die erklären wie biologische Systeme Objekte segmentieren, also in Einzelkomponenten zerlegen und vor einem Hintergrund erkennen. Und diese Modelle wollen wir benutzen, um Chips zu konstruieren, die das ebenfalls können.«



Berlin have been studying bees for years, specifically their brain, their ability to learn, and their memory. They have discovered through experiments that the nerve cells of insects process scents and visual stimuli according to similar principles.
(Photo: Friedrun Reinhold)

To make this dream come true, Douglas and his team have developed a new type of “analog" chip. Existing digital systems tick according to an all or nothing principle: signals are transmitted and processed digitally, i.e., in the form of zeroes and ones. There either is an electrical impulse or there isn't. There is no in between. Neurons, the “chips” of the living world, are just the opposite. They are analog, i.e., an excitation can have different values, not triggering a reaction in the nerve cell until a certain threshold is reached. This permits entirely different mechanisms of information processing in which the variable is not just zero or one, but any value between them. In constructing analog chips, Douglas and his team also want to study the links between the biological neurons in order to use the special form of linking that neurons manifest for the project. There are innumerable possible applications of such analog perception chips. Robots could, without any difficulty, recognize parts in factories, keep their bearings outside, or sort garbage. Such machines could safely identify drivers, bank notes, faces, or an individual's voice. “Perception chips” would make it possible to produce new vision aids for the blind or help people who suffer from the “cocktail syndrome,” i.e., people who cannot pick one voice out of several in a crowd of speaking people. Imaginable is even a new kind of data compression for the transmission of videos over the Internet: if a technical system could automatically separate moving objects from a set background, it would be possible to transmit the individual objects with much fewer data.



The neuro-computer scientists in the group led by Rodney Douglas are specialists in the construction of computer chips that function similar to human nerve cells. Robots equipped with such chips learn to recognize objects.
(Photo: Friedrun Reinhold)

A prerequisite for such applications is that we gain a better understanding of perception, both in humans and animals. The prizewinners, however, do not want to wait until the biological processes are completely clarified before creating a technical implementation. The key is the unique opportunity that each party can promote the work of the others. Advances in the study of biological objects will lead to new computer models, that in turn lead to technical applications, but also to posing new questions to those doing experimental work to study and explain this and that effect directly in biological systems. In this way, this Körber project could lead to ongoing interaction that drives development.

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