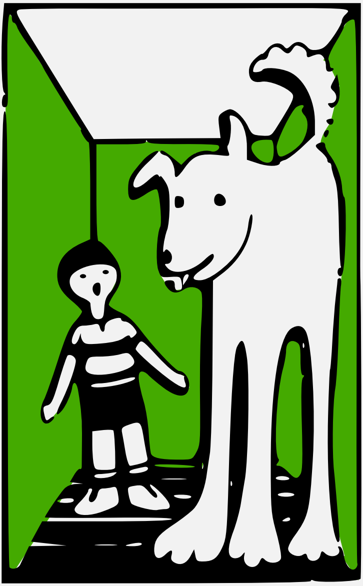
SCIENCE FOR EVERYONE

V. DEMIDOV

HOW WE SEE WHAT WE SEE



MIR

Science
for Everyone

В. Демидов

Как мы видим то, что видим

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How We See What We See

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by Alexander Repyev

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На английском языке

Contents

The author of this book is a journalist and an engineer. The book itself is a result of five years of fruitful cooperation between the author and the investigators of the Vision Physiology Laboratory at the I.P. Pavlov Physiology Institute of the USSR Academy of Sciences at Koltushi, near Leningrad. During this time the author has kept a keen eye on the advances of the Laboratory and covered them in the mass media.

Demidov presents his case drawing on the holographic hypothesis of the workings of the brain, which in recent years has been developed actively by international authors (it is to be noted, however, that this concept is shared not by all the workers). Prominent among these studies are contributions of Soviet scientists, notably at the Pavlov Institute. And since holography is a creation of engineers, it is clear why one of them has been able freely and easily to take bearing using the holographic compass in the sea of evidence, which on the face of it seems to be scrappy, but in fact demonstrates the profound unity of the material foundations of the world before us.

A unified approach to a great variety of problems paid off splendidly. Viewing from the same angle the identification of visual images and "freaks" of fashions, the perception of colour and the structure of individual systems of the visual tract, optical illusions and the shaping of the inner model of the world, Demidov successfully finds explanations for "mysterious" phenomena, and proposes plausible hypotheses. Among such revelations are, for example, the hypothesis of the reasons behind changes in fashions, the explanation of the "mystery" of the Penrose triangle, and of "impossible pictures". The author's view of the essence of abstractions and the notion of beauty is original and curious. Also, Demidov convincingly develops the seemingly paradoxical thesis that optical illusions are the manifestation of the automatic accuracy of the functioning of the visual apparatus, the reflection of the correctness of the model of the world that has formed as a result of man's past experience.

Clarity, readability and scientific rigour are, undoubtedly, the merits of the book. The literature used by the author includes works by foremost authorities on vision, both from the Soviet Union and abroad. Demidov knows personally most of his personages; he visited laboratories and participated in experiments, and that is why he is so successful in conveying the atmosphere of scientific search and adventure in his fascinating and enlightening account.

Written in a lucid and absorbing language, the book introduces us to extremely important frontiers of neurophysiology and psychology, cybernetics and medicine, never lapsing into vulgarization. The author draws liberally on notions from many sciences, gives felicitous, graphic examples, so that from the very first pages the reader will plunge into the absorbing world of discovery. Holography is essentially a mathematical problem, and so it is all the more to the credit of the author that he succeeded in discussing it without formulas, using nontechnical language.

The history of the accumulation of knowledge of visual perception is the history of struggles between science and idealism. The results of modern scientific research have repeatedly supported the materialistic thesis that nature is cognizable in all its aspects, including such complicated ones as vision and thinking. In lieu of the "soul", science suggests electrochemical processes in neuron networks of the brain, remarkable for their perfection. As experimental techniques become ever more sophisticated, we can probe ever deeper into the substance of matter. Man's knowledge of his own self grows, he unravels mysteries before which the mysteries of the ocean and space pale. And at the same time, the language of science becomes more esoteric, science splits into ever narrower disciplines with the result that scientists now barely understand the problems dealt with by their colleagues beyond the walls of their own laboratory. With information snow-balling as it does, scientific popularization, especially one summarizing advances in related domains, becomes indispensable these days. Not infrequently the scientist derives much valuable information from such readable accounts. Demidov's book is one of the most successful attempts to expose the tight interplay of results from a wide variety of fields of learning. Furthermore Demidov relates these findings to problems of vital interest for literally every human being. The book is a brilliant combination of the insight of a scientist and the lively, provoking style of a man of letters.

Academician Oleg Gazenko

I want in everything to touch
The very ground.

B. Pasternak

...Before my eyes, or rather before my right eye, because my left eye has been covered by a black paper patch, through a hole is seen a light rectangle with an ornate network of thin wavy lines. A click, the lines have disappeared, for a fleeting moment a small white square flashes, and again the interwoven lines appear.

"Well, what have you seen?"

"Nothing," I say honestly.

"Right. As expected. And now?"

Another click. This time it seems to me that I see the contour of something with four legs.

"A dog," I say, "Or some other animal. I did not see clearly."

Again, after a click, the tangle of lines is gone. And now I've perceived distinctly: a goat! Or maybe a nanny-goat: as to the udder I was not dead sure....

"A nanny-goat," says Alexandra Nevskaya, "And since you have no training, your time is 150 milliseconds. After all you did not know what sort of pictures I was going to show to you."

"And if I had had some training and had known — what then?"

"Then you would have seen it earlier, within perhaps one hundred or even within 60 milliseconds."

"Why?"

"Because your visual apparatus would have gone over the 'tree of signs' more quickly."

"'Tree of signs'? Just some sort of genealogy...."

"In a way. But at first some history of this problem. In vision, when one sets out to sort things out, literally everything is uncanny and mysterious...."

So began my acquaintance with the Vision Physiology Laboratory headed by Professor Vadim Glezer.

Chapter One

The Boundary of the Preconscious

... Facts not yet accounted for by available theories are of particular value for science, since it is on them that its development primarily depends ...

A. Butlerov

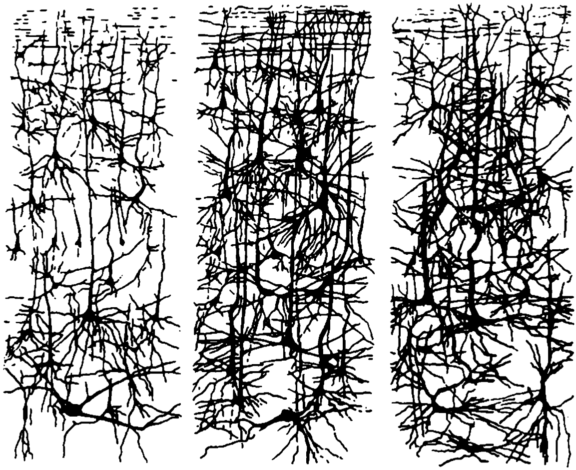
Why are all the conceivable tables in our mind united under the word "table"? Why are all the conceivable trees "trees"? How is man to conceive what he sees?

Three centuries ago, the English philosopher and enlightener John Locke (1632-1704) wrote the book *Assay Concerning Human Understanding,* which embodied 19 years of his experience and thinking. In it he maintained clearly and emphatically that the soul has no inborn ideas. The human brain, he stated, is a sort of clean tablet on which the world, perceived through sense organs, draws its characters.

To identify a subject means to assign it to a particular class. But to which? A child is prompted by his parents, a pupil by his teachers, an illiterate by a literate. These are the first steps on the path of learning.

A second path is that of our own personal impressions. To get acquainted with the world one must not just contemplate it, not just flounder in scholastic speculations, but fearlessly "enter into contact" with it, even making mistakes and suffering setbacks, but recovering and moving on and on. Experience, even gained at a high price, is the best teacher. There is nothing higher than experience and nothing can replace it. So taught John Locke.

Locke was countered by his contemporary, the great German mathematician Gottfried Wilhelm Leibniz



3 months 15 months 24 months

As the living organism develops the organization of its cerebral cortex becomes ever more involved. Notice the shoots—dendrites—becoming ever thicker and more tangled

(1646-1716): yes, true, everything is supplied to reason by our sense organs, everything indeed. Save for ... reason itself!

The foundations of logic and mathematics, those "truths of reason", must, according to Leibniz, reside in the mind primordially. The concept of length, say, must be there long before a man starts measuring something. Therefore, the ability to gauge distances is as innate as are many other human talents.

Experience alone? Or the inborn alone? At the time of Locke and Leibniz experiments were nearly unknown, and problems were mostly solved by way of speculation.

"Just look at the newborn!" the empiricists, Locke's supporters, would call, "Do you think he sees anything? There is nothing in his head, just confusion, a hodgepodge of foggy spots!"

"What spots?" the nativists, who supported the views of Leibniz, Descartes, and Kant, were irate. "The millennia of man's existence must have perfected the human eye so that the newborn sees not a bit worse than the adult! He just cannot speak, otherwise everything would be clear at once...."

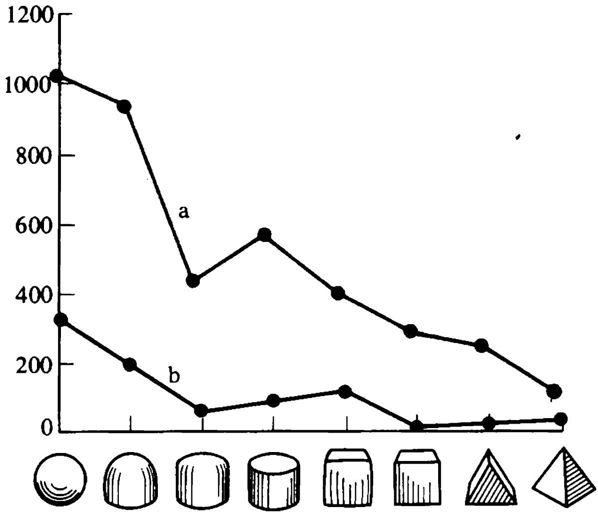
The controversy lingered on for a good two and a half centuries, unsubdued. As science made its advances, the opposing sides marshalled new evidence in support of their assertions, and ignored those that played into the opponents' hands. Only in the recent years has it been found that neither view has the upper hand. Or, if you like, "friendship has won": the truth lies in between, only the happy marriage of experience and inheritance shape a full-blown living thing.

To be sure, experience is undoubtedly of enormous importance for the animal. If a chimpanzee baby is reared in the dark, with weak diffuse light turned on for a short time, its vision does not go wrong, but instead, there are some other, more significant derangements, which concern not so much vision as such, as the brain itself. In such chimpanzee juveniles conditioned reflexes develop much more slowly than in chimpanzees living in a conventional environment. So the light-deficient creatures could not distinguish the keeper who fed them from strangers. Even a bottle of milk evoked no reaction in them.... And the reason is that "in animals devoid of visual sensations the corresponding neurons have not developed biochemically", explains the prominent neurophysiologist José Delgado, known for his remarkably exciting studies on the brain's functions. Under the microscope, the neurons display no departures, but chemical analysis shows that they are poor in proteins and ribonucleic acid, the famous RNA vastly important for life. Furthermore, the brain underfed with information appears to be lighter than it is normally the case.

In 1931, a German physician, Max von Sendem, removed cataracts in several children who were born blind. All the rest of their visual tract was in order. And still it turned out that "in the first days after the operation, the visible world for them made no sense, and they only recognized such familiar things as a stick or their favourite chair by touching". It was only after long training that the children who had recovered their sight learned to see things but their eyesight was later still weaker than is usual for their age. They had difficulties in distinguishing a square from a hexagon. To see the difference, they used to count angles helping themselves with fingers, often failed, and it was apparent that for them this identification was a serious, demanding undertaking. On top of that, they confused things. So the rooster and the horse were the same animals for them because both had a tail. The fish seemed to be very much like the camel, since the fin resembled the hump.

Since his first days, vision helps man to comprehend the world around him. But this unquestionable fact does not answer the question that laid at the foundation of the dispute between the empiricists and nativists: Does the newborn perceive anything in what he sees, or not?

In the case of animals, experiments with newly hatched chicks seem to support the nativists. The ability of distinguishing (at least, their feed) is congenital in birds. One-day-old chicks peck balls ten times more often than small pyramids. They always prefer discs to triangles. And if they are to choose between a ball and a disc, they do not hesitate to concentrate on the volume figure, while ig-



The more an object resembles a grain, the more often it is pecked by chicks, thus showing that the chicks have an inborn ability to distinguish shapes: (a — 10 min after hatching; b — 40 min after hatching)

noring the flat one. In other words, they are more interested in what resembles feed. We refer to the ability to peck just after coming into this world as instinct. But what about the ability to sort out exactly what to peck — is it an instinct as well? Of course. But instinct alone is not enough. It is also necessary that the visual apparatus be able to identify the things resembling feed. Then is it only the idea of feed that is hereditary?

The experimenter passes from chicks to herring gull nestlings. In the nest they are generally fed from their tender mother's bill. And so, in experiments a young gull usually pecks at objects that look like its mother's bill.

It is a hard fact now that the vision of nestlings is so perfect that they can distinguish form. Perhaps we are overly optimistic? What if vision is only "tuned" to some reference forms for each species of birds, leaving them indifferent to other forms?

The question takes care of itself when we bring in the concept of imprinting. This stunning psychological mechanism manifests itself in that, for example, a duckling between his thirteenth and seventeenth hours after hatching "recognizes as mother" any object that moves near it and then always follows this "mother", which may be the incubator keeper, a football, or "a small green box with an alarm-clock ticking in it". Here we undoubtedly have neither instinctive "tuning" to shape, nor instruction: shapes are all too unexpected and the time span between the hatching and the developing of "habit" is all too short. What is more, no imprinting can be produced even several hours after the optimal time. For the duckling, even his real mother will then be a foreign duck. It follows that he sees things distinctly and remembers them hard and fast.

"Well, all of this is no proof," objected, and in a way not without good reason, the empiricists, "The experiments have been performed on animals, not on man.... If only we could ask the baby."

Yes, until fairly recently the newborn has been the most unshakable argument. Really, how can you possibly speak with a creature who cannot talk?

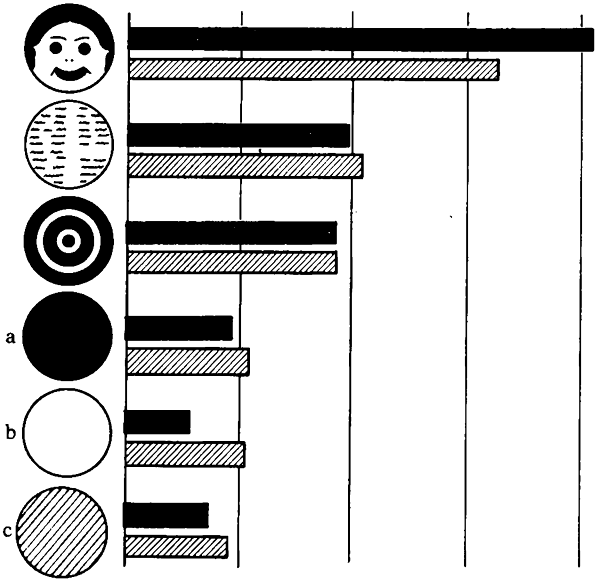
Strange as it may be, being tantalized by this problem, physiologists for some reason have forgotten the classic experiments by the Russian physiologist Ivan Pavlov (1849-1936). Meanwhile, the Pavlovian method of conditioned reflexes can with equal measure be applied both to the speechless dog and to the newborn who has not yet learned to talk. And so, when scientists figured out how an experiment can be staged that would not tire and harm the baby, this last stronghold of empirism fell.

A Swiss doctor, F. Schtirnimann, showed coloured cards to babies from one day to fourteen days old. If the card had a picture on it, it invariably attracted a great deal more attention than a smooth "flat" colour. Other researchers have established that two-week-olds prefer to gaze at things whose form and colouring (or rather diversity of colours) are more involved, and two-month-olds prefer pictures with concentric rings to those with parallel lines. What "confusion" and what "hodge-podge"?

Babies under a month old at a distance of a quarter of a metre make out 3-mm thick lines, half-year-olds 0.4-mm lines. True, the last result is still five times worse than the eyesight of an adult, but it is far better than what had been thought by physicians and psychologists.

An even larger sensation was produced by experiments in which newborns were shown ovals: in one a smiling human face, in another a smiling mouth, nose, and eyes and brows all in disarray, in yet another nothing, just a brightly coloured surface. Babies in the age group from four days to six months liked the first oval, thus demonstrating to the experimenters their inborn faculties to perceive organized structures, such as the human face. If now we suppose that the baby's brain has imbedded in it some reference for recognizing faces (later in the book we shall see that this is not that unlikely) the visual apparatus must be at such a stage of development that the reference standard could be used; and on the evidence available, vision makes a good job of it. It is a hint for producers of toys for infants.

The eye thus supplies man with important information literally from the first day of his life. But how does a baby recognize what he sees? His eye may be caught by some silly designs. So an eight-week-old, for example,



Newborns are more attracted by intricate pictures than by simple coloured pieces (a, b, c are red, white and blue discs). They are especially fascinated by a human face. Blue bars—babies from 2 to 3 months old and the shaded ones—over 3 months old

may be attracted by a circle with a patch of newspaper text glued to it three or four times more often than by a smooth coloured disc, but hardly anybody will dare to infer that the baby is interested in letters.

But interest is still there—vision sends some signals to the eye muscles. On the other hand, as Friedrich Engels put it, "our eye is helped not only by our other senses, but also by the activities of our thinking." In effect, modern science does not separate the eyes from the brain, as it once did. It no longer considers that the role of vision is confined to "transporting" information, just as the postman does, and it no longer asserts that the role of the brain comes down just to "perception", like the reading of a letter. The physiology of the second part of the 20th century says clearly: "The eye is part and parcel of the brain, just deployed at the front."

"Part of the brain".... But where does the visual apparatus end and where the brain proper—the receptacle of reason—start?

Hermann von Helmholtz (German, 1821-1894), "that greatest physiologist" of the 19th century in the words of M. Sechenov, called our perceptions "unconscious conclusions". Really, when watching an aquarium with goldfish, we never construct the syllogisms: "Creatures possessing gills and living in water are fish; these creatures have gills and the liquid in the reservoir seems to be water, hence these are fish." What we do instead is that we just assign "by the aggregate of signs" these dimly blinking things to the class of fish, never giving a thought to it, as we go through the procedure.

Absolutely different is the answer to the question, "What class does the unknown creature brought by nets from the deep of the ocean belong to?" Here we bring to bear all our knowledge and logical powers to achieve a precise classification. We will reason, although the problem here seems to be the same: whether or not the caught coelacanth (a lobe-finned sea creature) is to be classed with fish. The ground was shaky here. Helmholtz was right in saying that there is undoubtedly some similarity between the results arrived at using conscious and unconscious inferences.

It is this similarity that explains the fact that people can virtually never describe how they see what they see. They invent, they attempt to reconstruct the act of vision as they understand it and to render in words what occurs in their visual apparatus.

You may be shown several thousand pictures of sceneries, and then several hundred more, very similar to the earlier ones, but which you have not seen before. At any rate, in eight cases out of ten, and generally even with higher confidence, people distinguish a fresh picture from the old ones: "I've got a feeling I haven't seen it." Whence this feeling? It is only rarely that the man manages some sort of explanation. But it takes much groping in your memory and fishing for leading questions, in other words, much time and effort, generally without hope. But to reject the picture took just a passing glance.

In his article on landscape recognition, the American physiologist Haber writes that pictures are retained in the memory not as words. What is more, not infrequently people try, on the contrary, to remember words in the form of visual images. A Soviet psychologist, A.R. Luria, in his *A Small Book about a Large Memory* provides the results of his many years of observations of a professional mnemonist N who possessed a really prodigious memory. "It made no difference to him whether he was given meaningful words or senseless syllables, numbers or sounds, if they were given orally or in writing; he only required that the elements of the series being suggested be separated from one another by a 2-3 second pause, and the subsequent reproduction of the series was a piece of cake for him. The experimentalist appeared to be helpless in a problem that it seemed, was so simple for a psychologist — the measurement of memory capacity."

Even many years later N was able to reproduce those series faultlessly. How did he memorize them? He "photographed" the tables shown to him by his sight so that they were fixed fast in his brain. And if series were dictated to him, the memorizing procedure was different: he arranged the words-images along a street. Generally he envisioned Gorky Street in Moscow, from Mayakovsky

Square to the centre. Digits, for example, were pictured as figures of people: a seven appeared as "a man with a moustache", an eight as "a stout woman", and so the number 87 was visualized as "a stout woman with a man with moustache". The word "horseman" was pictured either as a cavalryman, or (when N became a professional mnemonist and switched to an "economical" system of memorizing) in the form of an army spurred boot.

After the images had been placed adequately, it was plain sailing (to be sure, only for N) to remember them by taking a stroll along the street either way, starting from any point. If a "word-image" happened to get into an unfavourable position, say in a shadow of a gateway, N might overlook it. Thus he accounted for those extremely rare occasions when he was caught in a slip of memory: "I placed the pencil near the fence — you know that fence in the street — and so the pencil melted into the fence, and I passed it by."

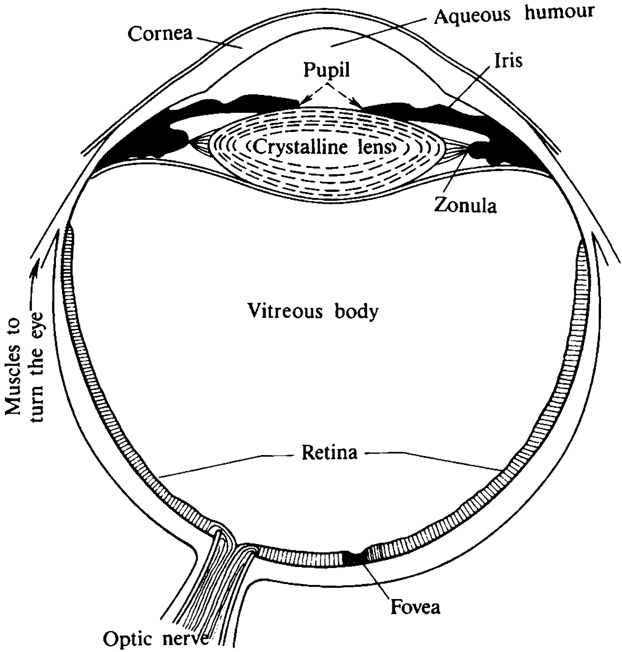
Einstein is widely known to have said about his pondering technique: "It is quite obvious that words of a language in their written or oral form are of no significance in the mechanism of thinking. Psychological entities, which seem to be elements of thought, are some signs and more or less clear images that can be 'arbitrarily' reproduced and combined.... Common words and other signs had only tantalizingly to be sought at the second stage where the above interplay of associations has sufficiently established itself and can be reproduced if desired."

A similar attitude, although expressed in some other terms, is to be found in the book by the prominent Russian statesman Mikhail Speransky entitled *The Rules of High Eloquence* published in 1795: "Our thoughts run far faster than our language, whose slow, ponderous course that is not always subdued by rules infinitely impedes our powers of expression.... The linkage of concepts in the mind is sometimes so subtle, so tender that even the slightest attempt at exposing this connection by words disrupts it and destroys it...."

The Russian poet Fyodor Tyutchev put it in a nutshell: "Pronounced thought is lie!" And we want to find out how the human brain perceives what man sees, why all the tables are "table" for him? Perhaps we should give it up as a bad job? No!

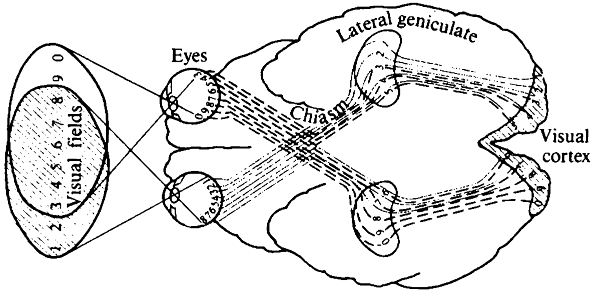
Modern science possesses a beautiful clue to the essence of mysterious mechanisms of every description — the "black box" method. Scientific workers so call things the inner structure of which is unknown. It is dark inside and therefore the observer is free to hypothize. The hypotheses are generally checked after the fashion of the fictitious Russian humorist: "Give a mare a flick on the nose and it will swing its tail." And so the experimenter "flicks" the black box (how? — that depends on his ability to ask nature questions), and then records the response. Question — answer, question — answer.... The more diverse and sophisticated the "question", the richer the information derived.

What next? Next experimenter has to analyze the list of questions and answers, to put hypotheses as to the inner structure of the black box and recheck them by asking new, more prying questions. The dialogue between man and a black box is the richest material stimulating further search. Sooner or later, however, a moment comes when some conclusions must be drawn as to the workings of the box. But the interpretation of experimental findings is a tricky business. For example, a chess-playing puppet may be driven either by an intricate mechanism or by a chessplayer hidden inside. The puppet's response to our movements allows both possibilities to be supposed. What is to be done? Just remove the cover of the automaton and peep inside.



The human eye

Physiologists would also like to peep inside: from "behaviourist" experiments on animals and people, scientists move on to studies of individual neurons and neuron networks, and view the functioning of the visual apparatus from a wide variety of angles. We will cover with them all the paths and will eventually see that the most plausible model of visual perception, memory, and recognition of what man sees (and not only man), which is the richest in consequences and "side paths", is the holographic model. Many investigators in many countries speculated on this possibility drawing on fairly convincing



The visual pathways all the way to the visual cortex. The visual fields of the left and right eyes overlap partly. Owing to the chiasm, the central, most important part of the visual field is represented in both hemispheres by signals coming from both eyes

circumstantial evidence. The workers of the Laboratory under Professor Glezer at Koltushi were the first to come up with hard evidence derived at the level of neurons of the visual cortex. In addition, they have revealed many important details of the workings of the visual mechanism.

And now it would be in order to answer the question of where the visual apparatus terminates and the brain proper begins. The eye's retina contains 125 million light-sensitive cells, called photoreceptors. From these to the brain lead 800 thousand nerve fibres. That makes one fibre per 150 cells, so suggesting that even at the level of the retina there is some effective information processing. Along the nerve, signals arrive at various parts of the brain including lateral geniculate body, and further to the visual cerebral cortex. At each step the most substantial piece of information is extracted from the visual signal so that at a higher level the information is more convenient to handle, including subjecting it to all logical transformations.

The researchers of the Laboratory therefore believe that the visual apparatus terminates where concrete (visual) thinking is replaced by logical (abstract) thinking. The mechanisms of this "preconscious", prelogical system are studied here, using all the means available to modern physiology.

To be sure, here at Koltushi they are unable to embrace all the problems. The visual apparatus is studied at hundreds of laboratories throughout the world, including dozens in the Soviet Union. The issues of vision are of interest to specialists in television and computer designers, machine tool designers and transport experts, the perception of outlines and colour concerns the traffic police and architects, artistic designers working with machines and even children's toys. Each research worker approaches the perception and processing of visual information from a different angle, he utilizes a slightly different methodology, and compares and distills the results obtained by scientists from related fields. Vision provides the brain with nine tenths of the information coming from all the senses, and so it is no wonder that there are enough mysteries to go around. Research at the Laboratory is conducted in close cooperation with hundreds of scientists around the world. It is impossible to reach an acme without the support provided for by a wide and solid foundation, without having one's results checked and rechecked by others, without drawing on these results. We will therefore pay our tribute to the findings made at major international laboratories.

So, let's come to grips with the present thinking on the subject. Or perhaps it would pay to cast our sight into the past. The Russian poet Alexander Pushkin said, "Respect for the past is what distinguishes enlightment from savagery." Let us therefore take several steps back to get some idea of the edifice we are about to enter.

Chapter Two
Galen's Foresight

And he who will give satisfactory Explanations for these phenomena must really be an Inventor and man very knowledgeable in the Control and Workings of such Anatomical Machines.

G. Power, *Experimental Philosophy,* 1664

"Why does the eye see? Why does the memory retain as alive the pictures from the past? Where does the memory reside?" — man started to ask these and similar "children's" questions perhaps since he conceived himself as man.

Some obscure theorizing about the soul watching the world through the pupils of the eyes, just like through an open door, even in ancient times could only satisfy the curiosity of those who did not bother to think. Critical minds sought for real, substantial evidence. Titus Lucretius Carus ironized:

... if our eyes are as doors,
Then the mind, it is clear,
Ought to discern things better if the eyes
Were taken out and removed, door-posts and all.

The philosophical treatise from which these lines are quoted is the elegant poem *On the Nature of Things.* Thus, in the first century B.C., Lucretius summed up the scientific achievements of the ancient world. Just like Empedocles, who lived four centuries earlier than Lucretius, the philosophical poet maintained that

... likenesses of things and their shapes are given off by things
From the outermost body of things, which may be called,
As it were, films or even rind, because the image bears
An appearance and form like to that, whatever it be,
From whose body it appears to be shed, ere it wanders abroad.

To make his idea more convincing, he turned to analogies. After all, haven't you seen the light smoke of a fire and sensed its invisible warmth, marvelled at the discarded skin of a snake, which to the minutest detail duplicates the shape of its body? The "signs" are also like this: they are light, invisible, and duplicate the shape of objects.

> ... you may know that from the outermost body there flow off
> Unceasingly thin webs and thin shapes of things,

concluded the poet.

The hypothesis of "signs", "images of things" was required by the philosophers of ancient Greece to explain the mechanism of vision. Empedocles, for example, taught that in the eye images join with the "internal light" radiating from the pupils (thus, it turns out that "radiant eyes" are of a venerable age!). The contact produces the impression — the man sees objects. So that the soul, peeping out through the pupils, is just unnecessary: the work of vision, to use modern parlance, is a physical process.

"Images", too, were quite physical, material for the ancient Greeks. Democritus (c. 460-c. 370 B.C.), for whom there was nothing in the world but atoms, stated that "images" are the finest atomic layers that flew away from the surfaces of bodies into space. And so, they find their way into the eye through the pupil. But the eye is also composed of atoms and it is bound to contain ones that are congenial to those that have entered it. The similar ones join together, and thus the "sensual imprint" emerges that sets the atoms of the soul in motion, and the soul lives in the brain. It is the reasonable, sensuous soul, unlike the bestial one, that dwells in the heart, and the vegetable one that resides in the stomach ...

But one thing caused confusion. If the brain is the "sensuous soul", it should feel. On the other hand, medical evidence testified that the brain does not even feel pain. And so Aristotle, who did not share the Democritus concepts, at the end of the 4th century B.C. came to the following conclusion: "There is no good reason whatsoever to believe that reason is associated with the body." Hence, there are no good reasons to refer to the brain as the receptacle of reason. According to Aristotle; the soul is united with the body, it is "the cause and the beginning of the living body", and it is to be found in the heart (now we have unearthed the wellsprings of the "fondness of the heart", and so on and so forth!). As to the brain, its role according to the philosopher, was to be a sort of refrigerator, soothing the hotness of the heart. Anatomical ideas of the time could not boast especial accuracy, and nobody dared to defy the opinion of the celebrity. And then... then Aristotle's authority, with all his fallacies, remained unshakable for a good one and a half millennium.

During these fifteen centuries the philosophical teachings of Aristotle were attacked, and finally successfully. It was done by Claudius Galen (A.D. 129-199), the second greatest giant (after Hippocrates) of ancient medicine.

Greek by nationality, Galen was born in Pergamum, the capital of the Pergamum Kingdom, in c. 129 A.D. His father was a prosperous architect, who managed to give his son a splendid education. At the Pergamum library, which had about 200 thousand books and was nearly as rich as the book depository of Alexandria, he got acquainted with the works of Plato and Aristotle, the treatises of the stoics and their irreconcilable opponents, the epicureans. Galen studied medicine with the best physicians of Pergamum, and then travelled for four years, visiting towns famous for their scientific schools. So he had visited Smirna, Corinph, and of course Alexandria, where the local doctors were considered to be the guardians of the ancient Hellenic art of curing. As early as the 3rd century B.C., the physicians Herophilus and Erasistratus conducted autopsies on corpses and performed the first primitive experiments on animals.

Back from his travels, Galen found employment as a doctor at a gladiator school. That he was offered this post betokened his talents. Fighters were expensive, and their proprietors were interested in having them back in the arena after they had been severely wounded by wild beasts or their fellow-gladiators, and thus there was no place for a poor doctor at the school.

By that time, Pergamum had lost its position as capital and had become the seat of the governor of one of the many provinces of the powerful Roman Empire. Splendid, pompous Rome, the heaven for artists, philosophers and scientists, attracted talents. Galen, too, set out for Rome. He quickly came into prominence there and enjoyed "resounding popularity", to use the words of historians, both as a practitioner and as a theoretician of medicine. His lectures invariably attracted many people. He became a celebrity, and when he tried to return to Pergamum, emperor Markus Aurelius recalled him back and promoted him to the post of his private physician. At the time Galen was about 40.

The emperor-philosopher Markus Aurelius, (the last major stoic whose book *Alone with Oneself* left a far more profound mark on history than all of his wars and statutory acts), appreciated highly the gift of his physician. Galen was never interfered with while doing his research. He became the first experimentalist in physiology ever, he made the first trepanations of the skull of animals, exposed the brain, and removed parts of it or dissected it, seeking insight into the interplay between the parts of the brain and the senses. He severed nerves to look into their function. And how many discoveries Galen made while dissecting animals! He was the first to give a description of the seven pairs of nerves coming from the brain to the ears, nose and other organs, he discovered in the brain the optic thalamus, and in the eye the retina connected to the thalamus by a special nerve.

Vision, Galen believed, was possible because of the "light pneuma" located between the crystalline lens and the iris. It keeps coming here from the brain via the optic nerve and perceives light rays. The sensation, a product of such merging, passes over to the "central visual organ", as Galen called the thalamus.

He wrote: "For the sensation to occur, each feeling must undergo a change, which then will be accepted by the brain. No feeling can undergo a change when exposed to light save for vision, because this feeling has a clear and bright feeling organ — the crystalline liquid. But the change would be of no use, if it were not brought to the attention of a controlling initiator, that is to the location of imagination, memory and reason. That is why the brain sends out a piece of itself to the crystalline liquid, in order to recognize the impression it receives. If the brain were not a location from which originated and to which returned all the changes in each of the senses, the animal would be devoid of sensations. In the eyes, colour impressions quickly come to the part of the brain contained in it, the retina."

What a remarkably shrewd conclusion! Let us leave aside the Aristotelian pneuma allegedly sent by the brain to the eyes (by the way, according to some of the modern physiologists, the central nervous system sends to the retina signals that control the sensitivity of cells). We will here overlook the fact that the role of the light-sensitive element was given to the crystalline lens, not to the retina (all the pre-Galenian and most of the later philosophers and physicians fell into the same fallacy). Let us not expect the scientist to answer all the questions at once. We'd better marvel at how convincingly the brain was restored in its right, which ever since has never been questioned, if only by some hopeless scholasticists — Aristotelians who idolized their father of their school of thought. We may only give our due to the audacity of the idea that the eye is an integral part of the brain.

Galen was distinguished for the courage inherent in all true men of science. He was ready to support the most shocking (from the viewpoint of "common sense") hypotheses to account for the working of a living organ without invoking some mysterious and uncognizable forces. One such hypothesis was suggested by him to solve the enigma that greatly troubled all those who dealt with vision: how do the "images" that come to the eye from objects manage to get into the tiny pupil and still retain the "life-size" dimensions of the objects? When the soul was looking out of the eye, there was no question: it was the soul that saw them. But what was to be done with "images" without the soul? And so, Galen discards them together with the soul. His manuscript contains the first drawing in history illustrating the workings of the eye as imagined by the scientist: the organ of vision is a sort of present-day radar.

Yes, Galen said, Empedocles and Plato were right: the eye does emanate rays. But they are needed not to merge with the "images" coming from objects. The rays just feel the objects, as if they were thin invisible spokes. Let a tower or a mountain be arbitrarily huge — the small pupil will be able to take in its configuration with its "ray". Naive tale, you would think? But this is exactly the principle of the radar.

In less than a quarter of a millennium after Galen's death, the Western Roman Empire fell. Ancient science remained forgotten in Europe for nearly ten centuries. Fortunately, unlike Europeans, the Persians and their subjects the Syrians, and especially the Arabs who conquered the Persian Empire in the 7th century, held the learning of antiquity in high esteem. As early as the 5th century, some of Aristotle's works, and later Pliny's, were translated into the Syrian language. In that language Galen's treatises appeared as well.

Centuries passed by ponderously, rulers changed, cities and philosophical schools flourished and declined. In the 9th century the centre of oriental science was Bagdad, the fabulous city. There worked the remarkable thinker, physicist, mathematician, and physician Abu Ali Ibn-al-Haytham, known in medieval Europe as Alhazen. Of especial fame was his work *Optics*.

Alhazen stated that the eye emanated no rays. On the contrary, objects themselves send out rays to the eye from their each and every bit. And each ray excites in the eye a corresponding point on the crystalline lens (here, alas, Alhazen agreed with Galen and thought of the crystalline lens as the "sensuous organ").

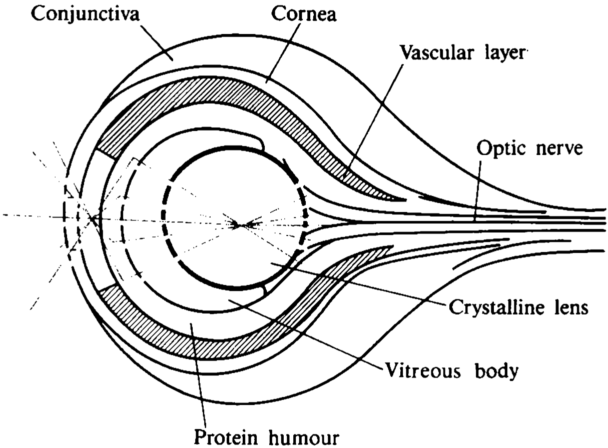
A sea of rays and just one pupil.... Would not they get mixed up, tangled? Alhazen staged an experiment: he lit several candles before a small hole made in a box. And what was the result? On the wall opposite the hole appeared the images of each of the candles. Without any distortions, without any confusion. The scientist concluded: any ray moves through the hole independently, without interfering with others, and this principle is "to be accepted for all transparent bodies, including the transparent bodies of the eye."

Alhazen has thus invented the camera obscura. But as is often in science, he did not put much stock in his observation. Suffice it to direct the hole not at the candles but outdoors and... but Alhazen stopped short of it, and the fame of the discoverer of the eye's model slipped out of his hands.

He was unsuccessful with his model for the additional reason that the picture on the back wall of the box turned out to be inverted. This puzzled him a lot: the world is seen by the eye "upside-down"? Impossible — we perceive it right-side-up. Alhazen was acquainted with Euclid's *Optics* and had a good understanding of the refraction of light. Perhaps the "transparent bodies" of the eyeball change the path of light rays so that the image in the eye returns to "normal"? It is to this predetermined answer that the scientist fitted the drawing of the path of rays. And, as we all know, such a fitting is no good even at a high school level. Alhazen did not believe in the result of his experiment, and so he made no discovery. Even more so, the model he suggested became a burden holding back other researchers.

The authority of Alhazen even had its effect on that genius of the engineering arts, Leonardo da Vinci, a man who was centuries ahead of his time with his engineering ideas. Leonardo approached the contradiction between the inverted image and "direct" perception in the "Arabic" manner: he constructed a diagram of the path of rays in the eye so that the picture on the back wall of the crystalline lens would be "upside up"....

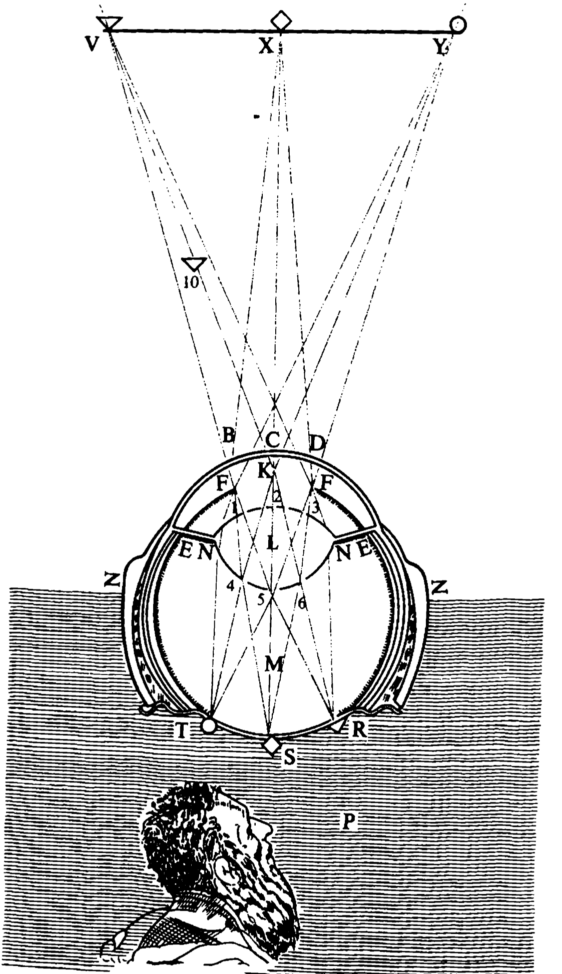
Here we will skip quite a number of years and meet Giambattista della Porta, a rich Italian aristocrat, man of distinction and many contradictions. (The German historian of physics F. Rosenberger characterized him thus: "half-diletante, half-ignoramus, and to a large degree, imposter"; but others do not agree with that harsh estimation and consider it excessive.) His curiosity was beyond belief, he was indefatigable in his search for fresh



Leonardo da Vinci's representation of the path of rays within the eye. He, like others, thought that the crystalline lens perceives light

scientific evidence, and excelled in various experiments, some of which gave him the fascinating and dangerous reputation of a magician. He also constructed cameras obscura, which were well known at that time and as he fooled with them he made one remarkable discovery. He wrote in 1570: "I want to unvail a mystery, about which I had had good reasons to keep silent. If you insert a convex lens into a hole, you will see objects much clearer, in fact, so clear that you will recognize the faces of strollers in the street as if they were in front of you."

Then the inventor went on to compare the new camera obscura to the eye, and absolutely correctly pointed out that the crystalline lens is necessary, just as the lens in the camera, to project an image onto the back wall of the eyeball. But now, unfortunately, his diletantism made



The first physically perfect construction of the path of light rays was made by Kepler itself felt: contrary to all logic, della Porta maintained that the sensitive element of the eye was still the crystalline lens, not the retina.

But for the mind able to reason and better acquainted with the anatomy of the eye than della Porta, everything became clear. Thirteen years after the new camera obscura had been reported (time was sluggish in those centuries) the physician and anatomist Felix Plater, whom Johannes Kepler called famous, learned about the camera. Plater had no doubts: the camera was a splendid and very accurate analogue of the eye. And he resurrected Galen's idea that the retina was the sensitive "outcrop" of the brain located in the eyeball. True, Plater did not succeed in drawing the path of rays through the crystalline lens. His mathematical grounding turned out to be inadequate for this sort of work. The last stroke to the picture was given by Kepler (by the way, he constructed a large camera obscura at Linz to watch the solar eclipse of 1600) in that he merged the ideas of Porta and Plater.

One might as well ask, what has an astronomer to do with physiology? But in those days each scientist of note was a philosopher, and so was interested in science in a wider context without confining himself to narrow professional interests. And so, four years after the construction of his camera Kepler published a new treatise entitled *Supplement to Witelo, Concerning Optical Astronomy* in the fourth and fifth chapters of which he expounds his view of the workings of the eye, the view of a mathematician. His geometrical constructions leave no doubt that "the right side of an object is represented on the left side of the retina, the left one on the right, the top at the bottom, and the bottom at the top".

Unlike his predecessors, Kepler was not put off by the result obtained. For the astronomer, the world is as it is, and not as we would like it to be. Kepler did not set out to think of some artificial way of bringing the image back to "normal" inside the eye. What purpose would this serve? After all, the picture obtained on the back wall of the eyeball "does not terminate the act of vision until the image perceived by the retina has been sent to the brain".

Science again returned to Galen's ideas in order to be able to advance.

But then, early in the 17th century, nobody admired the clarity of vision of the great physician. Not a single progressive scholar of the time would dare to refer to Galen, since it would have amounted to a union with the darkest forces of reaction. This was because medieval scholasticists made Galen's works, with all their fallacies (which unfortunately were numerous!), into a bible, and vehemently attacked anyone who dared to revise or correct any piece of his writing. Galen's books had been the "heavy artillery" of obscurantism, and so for the sake of progress of medicine they had to be rejected in toto, even without sifting the wheat from the chaff.

And only many, many years later, when scholasticism was totally defeated and was only remembered as a sad chapter in medieval history, could science free the works of the great thinker from all that was extraneous, from that which had attracted the theologists to it. For, as the 19th century English naturalist Huxley said: "Those who have read Galen's works are struck by the diversity of his knowledge and his clear understanding of the paths to be followed in physiology."

Chapter Three

Traps for Details of the Image

To perceive is to sort out, and to comprehend the world is to understand the rules to be followed in the selection during perception.

A. Moles, *Théorie de l'information et perception esthétique*

"I've been rereading Pavel Antokolsky recently," said Vadim Glezer, " and remembered the lines:

What is memory?... A larder. A vault.
Life is stored there all anyhow.
Sleeping at their moorings are dead ships,
Motionless, fixed to the ground."

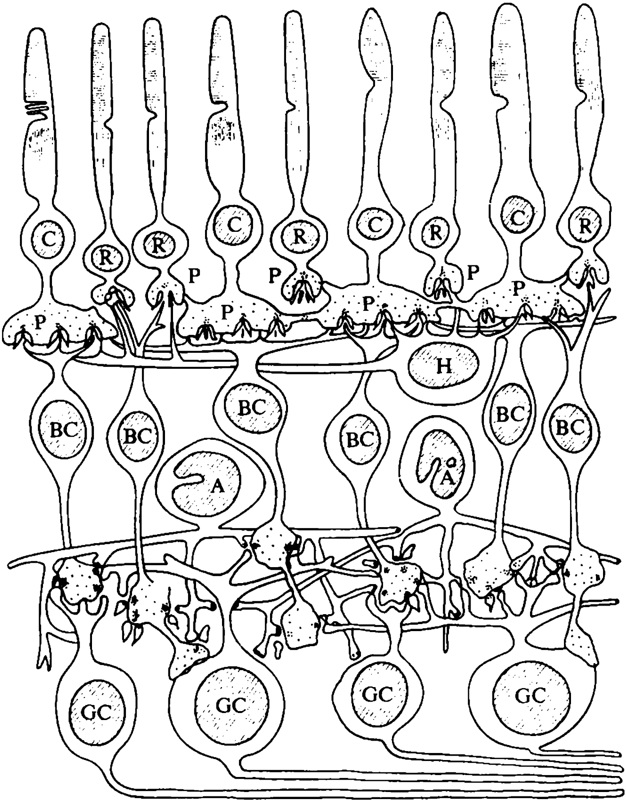
A beautiful picture. Quite impressive. In poetry, of course anything is possible, that's poetry for you. But in everyday life.... Many think even now that memory is something like a store-room in a picture gallery: thousands of canvases lean against a wall — need to remember, pull one out and look....

But who is to look? The ancients answered: the soul. But we know that there is no soul living separately from the body. Also there is no small "man" in the brain who watches with his eyes a sort of TV to take notice of images stored in the memory. In our brain there are 10 billion nerve cells, electric pulses of different frequency and amplitude travel from one to another, various chemical transformations occur in the cells and otherwise there is nothing, absolutely nothing. But we see, our memory works, and we remember events long past. What then goes from the eye to the brain?

In the Middle Ages it was believed that these are ideas. They travel via optic nerves and accumulate in the reservoir of the memory, which was thought to lie somewhere near the back of the head. But again, the word "ideas" explained nothing. With the advent of printing, they began to think that the brain somehow produces impressions of images. Even in the 1950s some scientists preached nearly the same view: visual sensations are a sort of photographic pictures of what our sight catches.

But in the 19th century, physiologists more or less understood the structure of the retina, and the opinion was widespread that from each light-sensitive receptor one nerve fibre comes to the brain. No "ideas" any more. Now came the "excitation relief": it was considered that the cells of the cortex respond to an operation of photoreceptors and so emerges an electric picture of what is seen. For a long time this hypothesis appeared the only one possible, it was supported by the greatest authorities, Sechenov in particular. But still, it had to be discarded, despite its attractive simplicity and clarity, when it became known that the retina has about 150 times as many sensitive elements as fibres.

Really, if images were transferred from the eye to the brain by the principle "from a point to a point", the slightest disruption of the function of the optic nerve or visual parts of the cerebral cortex would markedly distort the picture, so making recognition impossible. But in experiments on cats, nearly three quarters of the fibres of the optic nerves were severed, thus nearly destroying the entire system. Nay, the animals could still recognize simple figures, just as before. In rats, almost 90 per cent of the visual cortex was removed without any effect on the mechanism of recognition, at least in the experiments carried out directly after the operation. Such severe disturbances would have hopelessly destroyed the entire "projection system", if the latter existed in reality. Just try to cut



The retina: C—cone; R—rod; P—pedicel; BC—bipolar cell; A—amacrine cell; GC—ganglion cell

not three quarters but only a tenth of the connection wires in a computer.... This strongly suggests that the visual apparatus functions in some other manner. Again we are confronted with the question of how.

And again they turned to engineering for tell-tale analogies. Yes, engineering: it is simpler than living nature, and easier to understand, and as models engineering analogies are useful at a certain stage. The entire history of science shows that whatever technical means were available during the lifetime of a physiologist they were applied to get an insight into the functioning of the organism. And as for opposite contributions, from biology to engineering, these are extremely few and far between.

Just look: mechanics had made its strides and everything in the organism began to be considered functioning according to its laws. The camera obscura came in, and you have an explanation for the working of the eye. Then photography was brought into the picture, even plates covered with a light-sensitive layer — the red rhodopsin in the rods of the retina, a substance that becomes lighter when exposed to light. With the advent of the telegraph and telephone the brain was likened by some authors to a telephone exchange, and the nerves to electric wires. Eventually came the turn of television: the eye was said to be a sort of transmitting TV camera. Each photoreceptor is a point on the transmitting screen, in the brain we have the cells of the "receptor", and our memory is the recording of this "telesignal" on something like the magnetic carpets of a computer memory. A graphic and simple representation.

But the analogy with television brought things to a deadlock. If in the eye the picture is "broken down" into electric pulses, just as in television, then for 60 years of a human life each of 10 billion neurons of the brain would have to remember six million bits of information, as was shown by Dean Wooldridge of the Californian Institute of Technology in his book *Mechanisms of the Brain*. There is no reason to doubt the correctness of his result. But for a neuron to carry six million bits is extremely doubtful. Extremely. And so the television hypothesis, too, passed away peacefully.

Broadcast television is in general a bad way of transferring information. Enormous powers of TV transmitters are, in essence, wasted. For example, a person appears against the background of a colourful carpet. It goes without saying that the face of the person in this scene is far more important than the objects. But the TV camera with equal thoroughness records both the face, and the background, and also with equal thoroughness transmits both of them into the air. Just think about it: 50 times a second the aerial beams out a signal that carries information about the design of the carpet, a design that can in no way change. If only we could transmit it just once and concentrate on the actor. But modern television is not yet up to the task. And so it continues to use this communication channel in a highly uneconomical manner.

The visual system is different. Above all, it frees the picture of all extraneous information. The first hints came in 1932 from the American physiologist Haldan Hartline, later a Nobel Prize winner. He studied the retina of the frog and much to his surprise he found that each fibre in its optic nerve is a sort of telegraph line along which signals are transmitted not from one photoreceptor but from many at once. Even this alone was unclear: why does nature need such a mess? Some "communication lines" transmitted signals when light was directed on the receptors connected to them, others, on the contrary, only "telegraphed" when there was no illumination. Hartline referred to the first association of receptors as ON, the second as OFF, and this terminology stuck.

The signals from nerve cells, when passed through an amplifier, resemble the rolling of a drum. This way you can hear them in any laboratory dealing with the functioning of neurons where the signals are tape recorded. The cells communicate in the most noise-proof way, by impulses, which are also good in that they are equally suitable for transmitting information from any receptors: light-sensitive, smell-sensitive, sound-sensitive, and so on.

Nature took its time in developing the most suitable way of intercellular communication. In mollusks and other lower animals, information is handled rather primitively, by amplitude modulation of electric signals. Understandably, any noise, by adding to or subtracting from a useful signal, can distort it, and so you can hardly expect the fail-proof operation of the "executive mechanisms". In higher animals, nerves transmit packets of impulses. The amplitude of impulses within a packet is constant, unlike their number. It depends, say, on the degree of excitation of a given receptor cell. In other words, the receptor converts external effects to numbers.

Now that we have numbers, we can do with them whatever we like. Cells are able not only to transform effects to numbers, but also to take logarithms of them: the number of impulses in a packet is proportional, for example, to the logarithm of luminance. After such an algebraic operation, cells can (at any rate, in principle) multiply, divide, raise to powers and extract roots with inputs, and with logarithms, the task is just plain sailing. So, the parallel between the brain and the computer is not ungrounded, although it should not be pursued too far.

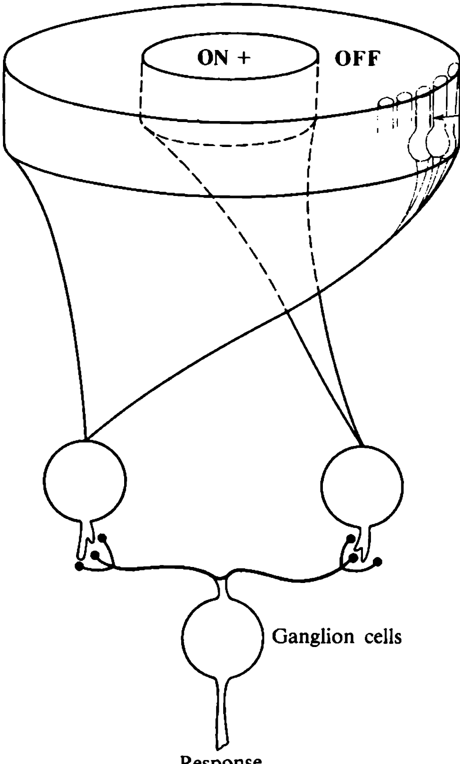
How do neurons, to which signals come from receptors, do their calculating? For this purpose each cell, just like any active element of a computer, has its inlets (where signals arrive) and one output whence pulses go to other neurons. There are generally many inlets, or dendrites, whereas there is only one outlet, or axon. And so, for a signal to be transmitted to several cells, the latter branches out. A neuron's dendrites play different roles. Some of them make for excitation, as if flinging a weight on the pan of a balance, others hamper the activity of the cell. Scientists call the contribution of each dendrite to excitation exactly thus, a "weight".

So long as the algebraic sum of the signals at all the inlets is below a predetermined level, at the outlet there are no pulses (strictly speaking, this is not exactly so: many neurons have a "background activity", that is, without any input excitation they periodically send out output pulses over the axon either to check the line for malfunctions or "to keep the recipient cells awake", but we will neglect this feature here for the sake of simplicity). And once the total action of the input signals has surpassed a certain threshold, the neuron "shoots" a packet of pulses or discontinues its background activity. Should inputs arrive continuously, our neuron will continuously either "telegraph" or keep silent, as appropriate.

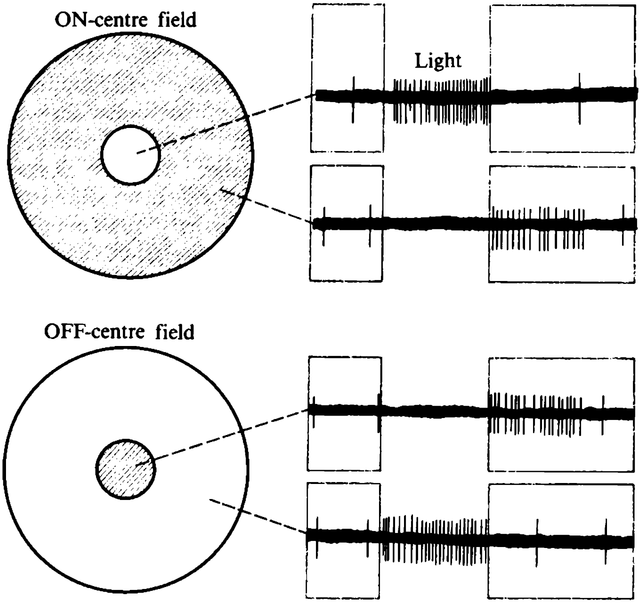
ON and OFF associations, or fields, as they are generally called, are formed because the photoreceptors, via the intermediate retina layers, are connected to the ganglion cells, to each cell several tens or even hundreds of receptors. From the ganglion cell the fibre of the optic nerve runs to the brain. As for the intermediate layers, their task is to perform fairly complex mathematical processing of signals that come from the light-sensitive cells, so that the brain directly receives the result, or rather many results.

In 1959, the American physiologists J.Y. Lettvin, H.R. Maturana, W.S. McCulloch and W.H. Pitts found in the retina of the frog several types of absolutely unknown cells — detectors. These cells are activated when it is necessary to perceive various specific properties of an image. Some respond to the boundary between dark and light areas, that is, to the edge of an object. Others are excited when this boundary is in motion, but do not care when it is motionless. Yet others signal when within the field of sight of a frog's eye something small, dark and moving appears — a pray, obviously, a fly. And once "something" comes closer — the ranging, it seems, is also one of the functions of the special detector — the frog immediately attacks it. By the way, the same fly lying lifeless on the ground is completely ignored by the frog. It will starve to death surrounded by quite eatable, but motionless, flies. The frog's eye is thus such a highly specialized and not very clever apparatus. It transmits to the brain information about some properties of objects and thereby predetermines the actions of the animal according to the principle "small — hunt", "large — take refuge", and so forth.

The eye of more highly organized animals, and of course the human eye, unlike the frog's, gives no such instructions. It reports to the brain everything about a picture which can be transmitted (within the physiological powers of the visual apparatus, to be sure). It is a beautiful communication line, but no commander. That is why the frog's eye raised more questions than gave answers. It was impossible to gap the bridge from it to the visual system of mammals. Indeed, the earliest experiments on cats have indicated that the eye of that predator, who has a splendid feeling of space, is arranged absolutely in a different way. Above all, its fields connected with the ganglion cells look absolutely different: not solid associations of one sign, but "two-step" ones. Nature designed each field as a circle with an ON or OFF centre and an external field of opposite function. Such fields are able to bring out the contours of an image, to enhance the contrast between areas of the picture that differ but insignificantly in brightness. A very graphic demonstration of it was provided in 1959 by the same Hartline. After his experiments, it became clear why "Mach's bands" come into being,



In the retina photoreceptors form associations—fields—owing to neurons that lie between them and ganglion cells. One such a field is shown schematically here: light stimulates the internal part (ON-area) to produce a signal, whereas the external part (OFF-area) is unaffected. A reverse interaction of the areas is possible. The ganglion cell integrates the effect and relays the signal to the lateral geniculate body



Responses of the cells that integrate the signals from the ON- and OFF-areas

which are dark edges at the boundaries between areas of different brightness in the picture: the edges are produced by the visual apparatus for no apparent reason, just because it is built like this.

It is very important that the retina can distinguish contours, because the contour contains the most important information about an object, and we are able to restore by our "inner sight" even the volume of pictures, especially of familiar ones. Designers of TV systems have long been using this property of the human eye to transmit signals with lower energy consumption, to make them less susceptible to noise. Soviet TV engineers have also invented many methods of enhancing contours, Yu. Braude-Zolotarev in 1957 patented the method in which one of two transmitting TV cameras is tuned to contrast, whereas the other is slightly defocussed. Further, from the image in focus is subtracted the image out of focus with the result that contours come out sharply as if drawn by a pen. In recent years, with the advent of digital computers, sharp differences in brightness — contour is exactly this difference — have been found using a wide variety of mathematical techniques of image processing. For example, the American spaceship that landed on Mars used mathematical processing techniques: first of all, it singled out contours of what its TV-eye saw. Robots, too, view the world with their "eyes", invariably distinguishing contours.

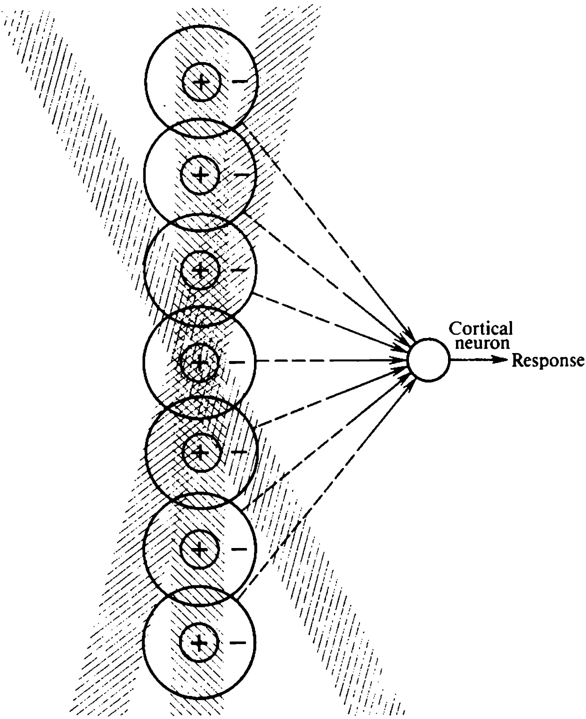
But the television systems discussed above only seek to imitate the work of the retina, which is only the starting element of the living visual system. To get an insight into how the eye operates requires an understanding of the brain. In effect, the most interesting things started when in 1959-1961 the American physiologists D.H. Hubel and T.N. Wiesel implanted into the visual areas of the feline brain a microelectrode, an isolated wire with a naked tip about one ten thousandth of a millimetre in diameter. The microelectrode penetrates a neuron and the experimentalist records the signals coming from the cell on a magnetic tape. By chance, neurons were found in the cortex to which information came not from several hundreds of photoreceptors, like to ganglion cells of the retina, but from many thousands at once. This outstanding discovery does credit to the new experimental apparatus.

Earlier, to find a field associated with a ganglion cell, a simple signal was required, just a sharp beam of light. A bright spot on the screen — that is what excites ON and OFF fields. Passing to the cells of the cortex, we must present to the animal some more involved stimulating images, for example straight lines and rectangles. But not just any stimulus will make the cell respond. Hubel wrote that it took him hours of search to hit upon the lobe of the retina connected with a given cortical cell and to select optimal stimuli for this cell. The reference to stimuli for each cell should by no means be taken literally, though. What is meant here is that the receptors of the retina are connected to the cell in a higher part of the brain through a multitude of intermediate neurons. Owing to such a connection, the cell responds to one pattern element or another to single it out. Scientists agreed to refer to visual fields by the name of those parts of the visual tract where experimental microelectrodes are implanted to study these fields. We have already discussed the fields of ganglion cells of the retina, now we will turn to the fields of the cortex, and later in the book we will acquaint ourselves with the fields of the cells of the lateral geniculate body.

Hubel and Wiesel found in the cortex simple, complex, and supercomplex fields.

The simple ones are "tuned" to single out straight thin lines. If such a line gets in the region of the retina where the field is located, the neurons of the cerebral cortex start "shrieking": "I see, I see." Once the line is removed from the screen, the cell is quiet, just like an indicating lamp.

The complex fields take care of the differences in brightness of the type "straight edge", "angle", "arc", and so on. They also respond when the eye catches a moving object, thereby resembling the frog's detectors. But only resemble. The signalling cells reside in the cortex, not in the retina, and this is indicative of the much higher complexity and flexibility of the visual apparatus of the cat.



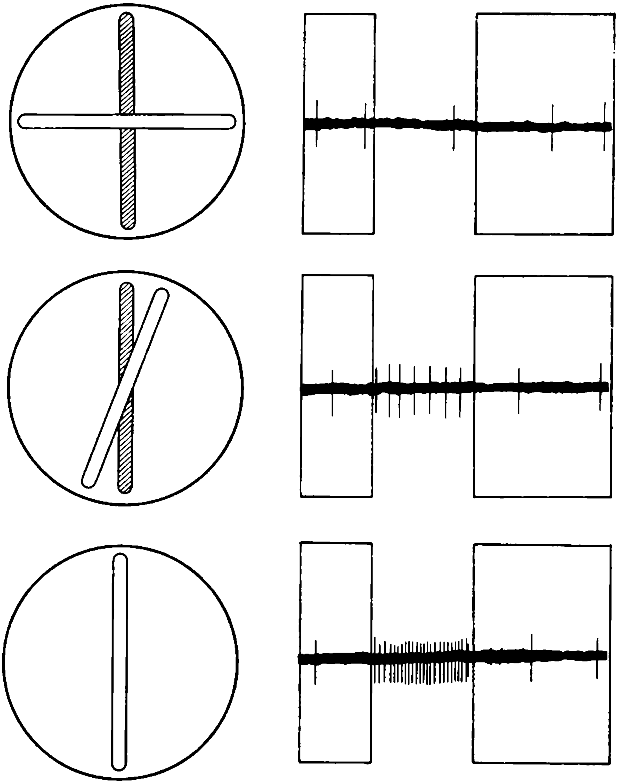
The cortical field combines the signals from the ganglion retinal cells to single out the straight line

Fields have been found that feel the slope of lines approximately in six degree increments throughout the entire 360° range of angles. Fields also exist that only see, say, a horizontal line that moves from above downwards, while a vertical line that wanders to and fro is ignored. (By the way, in the year when Hubel and Wiesel published their results, the Soviet scientist V.M. Glushkov looked at the principle of an electronic system that recognizes simple geometrical figures no matter how they are turned relative to the coordinate axes. He was led to conclude that to be able to do so, the "electronic eye" must above all single out straight lines and arcs.)

The most fascinating, supercomplex fields single out not just lines, but line segments of a certain length. Minute deviations of the size are sufficient for a neuron's response to be nil, the "lamp" does not turn on. A microelectrode may hit a supercomplex cell whose task is to react only to the information coming directly from both eyes and to keep silent if one of them does not see a stimulus on the screen. A shift of the microelectrode a tiny bit deeper or sidewards reveals a neuron that primarily responds to the signals from the right eye, and a neuron next to it that primarily responds to the left eye; these neurons are the lamps that signal that an object is not directly in front but to the side.

Penetrating with their microelectrodes to the cortex, Hubel and Wiesel noticed one more interesting feature. It turned out that fields that respond to lines and brightness differences of the type "straight edge" are arranged in the cortex as "rods" of cells. To each rod, signals come from the fields that lie in about the same place in the retina and are oriented in the same manner: say, they respond to vertical lines and edges only. Their neighbour is a rod that receives signals from the fields of some other slope, and so forth.

The fields in the cortex run into thousands, hundreds of thousands, and millions. By overlapping one another, they enable the visual apparatus, using the same receptors, to assess and detect the motion of an object and elements of its contour and brightness and colour, over the entire field of vision simultaneously. In the region of the clearest



The field has not yet "seen" the line to which it is set, the cortical neuron only produces rare pulses of "background activity". A powerful pulse train comes to other cells all the time while the stimulus acts on the field visibility — the fovea of the retina — the fields of form are concentrated; closer to the edges — the fields of brightness and motion, so that even by side vision we can notice a speeding car or a flash of light. These specific fields have been found in all the mammals on which experiments have been conducted.

Fields are inborn structures. Their cells — "lamps" have been found in the cortex of still blind kittens. The research workers, however, faced a principally important problem: how are these fields organized? Are they the result of the work of the retinal layers or else are sections of the visual apparatus intermediate between the retina and the cortex involved here? Have the fields anything to do with pattern recognition? Many scientists, for example P. Lindsey and D. Norman, the authors of an absorbing book *Human Information Processing*, are of the opinion that this is exactly the case: the picture is analyzed in succession by simple, complex and supercomplex fields, whereupon the brain reaches a conclusion as to what object is before the eyes. They do not provide supporting evidence for this scheme, however, and so the problem remains open.

In the Laboratory, results have been obtained that enable a fairly consistent and promising theory to be constructed for the woıkings of the visual system. Yes, fields are necessary, but not only those just discussed. Other fields are needed as well, that are yet more important and concerned with more interesting and sophisticated image processing. Later in the book we will be looking at them.

Chapter Four

The Tree of Recognition of Good and Evil

I saw in Louisiana a live-oak growing
All alone stood it and the moss hung down
From the branches.

Walt Whitman

In the room where Alexandra Nevskaya works, a subject is sitting peering into the eyepiece of an apparatus. He says, "A goat." A tick is entered into the experiment report. The slide is changed. Another click. "A hand," answers he. A tick, a slide change, a click, and an answer. A tick, a slide, a click.... The fifth, seventh, twelfth subject.... Day in day out, week in week out. From the reports the ticks are transferred to graph "sheets" where they are arranged in chains of points with average lines passing amidst them.

Some subjects are not told which pictures they will see, others are given them to examine beforehand. And again the gate clicks and again people try to make out a contour in the light square that flashes for a fleeting moment — a sheet, a triangle, a bag, a hand, an iron, pincers, a window, a face, a goat....

A moment.... To produce and show for a moment a picture is very simple — presto! This, however, would be a game, not an experiment. But in a serious experiment this "presto" is not that simple.

Our eye is a system of prodigous sensitivity. In his book *The Eye and the Sun*, Academician Sergei Vavilov writes that the excitation threshold for rods involved in night vision is equivalent to the luminous intensity of a conventional candle viewed from a distance of 200 kilometres.

Then the section of retina, which contains about 400 rods, receives only from six to ten quanta, minimal lumps of energy of light and of electromagnetic oscillations in general. That is, for a photoreceptor to respond, just one quantum is sufficient, because it is highly unlikely that not only all but even two "particles" of light would hit the same receptor.

For a long time this result, adequately supported by experiments in which the eye in fact felt the quantum nature of light, seemed to border on miracle: just how did nature contrive to design such a mechanism? The clue came from the latest research. A photon hitting a light-sensitive cell is like a finger pulling a trigger.

The fact is that the wall of the outer member of the photoreceptor — a membrane — is a miniature power station, a d.c. generator. As long as no quantum hits the photoreceptor, the membrane passes nearly equally well sodium and potassium ions: sodium from the cell, potassium to the cell. Each ion is an electric charge carrier, and so the generator produces low voltage. The "firing of a pistol" changes the picture. In the membrane a sort of valve opens, which sharply increases the flow of sodium ions, and hence the voltage as well. As a result, the inner structures of the photoreceptor amplify the initial signal — the photon energy — by about two million times. And the experimentalist sees on the oscilloscope some impulses — the response of the light-sensitive cell to the arrival of a photon.

The description takes much longer than the actual process. After the "trigger is pulled", the signal from the photoreceptor is fed to the neuronal chains of the retina within three thousandths of a second. The most amazing thing here is that nature remains faithful to this arrangement in visual organs of all living creatures, from mollusks to man.

In consequence, the eye is capable of noticing even an extremely short flash, provided it is powerful enough for a sufficient number of photons to reach the retina. In the 1930s, the Soviet worker B. Kompaneisky proved this by illuminating objects with an electric spark in a dark room. At times a flash of one ten millionth of a second was enough for the subject to perceive an object and even to assess its relief.

Admittedly, our conscience cannot handle the situation in such a short time. Even to amplify the received signal, as we have just seen, takes three thousandths of a second. But then, some time is also taken by the nerve cells in retinal layers, the optic nerve, and the many neurons in various parts of the brain. In the middle of the last century, Helmholtz found that the velocity with which excitation is transmitted over the nerves is only 30 metres per second, and the latest research has only expanded the range of possible values: from half a metre to one hundred metres per second. So that the flash of a ten millionth of a second is again just a "finger on the trigger", and the "shot" is made by the entire visual apparatus, which possesses the important property of a short-term memory.

This memory retains the image perceived by the eye for about a quarter of a second. It is because of this that the stills of a cinema film merge into a continuous picture. (Strictly speaking, this explanation of the effect of motion of people and everything that is on the screen is not correct. The picture is perceived not only due to the short-term memory but also due to the higher parts of the brain: they construct intermediate positions of an object between stills.)

It was believed earlier that an image is retained on the retina. The French physiologist Cunet wrote in the end of the 19th century: "The retina behaves as a whole photostudio, where the photographer continuously renews plates, adding to them new layers of light-sensitive material and erasing at the same time the old images."

Experiments, however, showed that there exists a connection between the short-term memory and the brain, not the retina. In order that the vision (not the eye) may be shown a pattern during a time shorter than a quarter of a second, it is necessary to switch off the short-term memory, or rather to limit the time of its action. But where do we find the switch?

Cinema takes care of it. Let our film be the simplest one, consisting of only three frames: a network of wavy lines, a picture, and again a network. Each successive image erases the previous one from the short-term memory, an established fact. And when a man peers into the eyepiece of the apparatus of Nevskaya, the frames with a network sort of open and close in the short-term memory, the "gate of time". The experimenter is now absolutely sure that the man examines the picture during exactly so many split seconds as it is presented to him from control console. By the way, the best eraser is a network consisting of all the objects shown in an experiment superimposed on one another.

It has been shown experimentally that the reliability of recognition of a picture is dependent not only on the duration of exposure, but also on whether or not the subject knows the set of pictures he is going to be shown. I did not know and so I took one hundred and fifty milliseconds, a normal time for participants without any experience.

And if the subject is familiar with the pictures, his performance is better. How much better depends on the number of picture he expects to see. To distinguish one picture out of two possible ones takes fifteen milliseconds, one tenth of what is to be expected from an untrained subject. Now we increase the number to four, and the recognition time is doubled, with eight pictures it is tripled with sixteen, quadrupled, and so on. What is behind these figures?

It turns out that the dependence is given by the relation $X = 15 \log_2 Y$, where X is the recognition time in milliseconds, and Y is the number of pictures that the subject knows may be presented to him.

A logarithmic function is a good sign. A living organism "prefers" exactly logarithmic and related dependencies to any other dependencies. What is the physical meaning of the above formula? Are there perhaps in engineering devices that function according to this dependency? An expert in information theory comes up with a stunning answer: "Your formula is nothing but a description of the tree-type search system." This idea was first published in the book by V. Glezer and I. Zukkerman entitled *Information and Vision*.

A tree .... Suppose you are standing before a huge pile of hats, caps, jockey caps, fezes, silk hats, and so on. You do not know what to look at first — so many sizes, fashions, colours. You hold in your hands a yellow checkered hat with a plume, and you need another one just like it. What is the simplest way of conducting your search?

To be sure, you can take from the pile piece by piece, to examine and to compare. It may well be that your first try will be a success and you will hit upon what you want. The opposite is equally likely: the desired thing will turn up last. It will take a lot of time, and so the exhaustion method is exceedingly uneconomical.

It would be more advisable to make use of "key signs" of the thing you are looking for. You know then already: "yellow", "hat", "with a plume".

Let us do the sorting out based on these features, while ignoring all the other ones. Just look how quickly the amount of work shrinks after each of these steps, how fast we advance toward the goal! Schematically, this "dichotomous" division, that is, division according to the principle "sign — no sign", resembles a branch of a tree, and so the method has been named so. It is higly effective. There is a joke about catching lions in Africa using fences: the continent is divided in two, then the part where a lion is found is divided in two again, and so forth. To confine the predator in a cage 5 × 5 metres, 40 divisions would do, although the continent's surface area is nearly 30 million square kilometres.

But back to our visual apparatus. Does it really achieve recognition at the preconscious level (no logic is yet involved — the time is too short) by travelling over the branches of a tree? We can check this. Let us start increasing the number of pictures. If the hypothesis is true, the recognition time obtained in the experiment will coincide with the predicted one.

But the snag is, at what stage are we entitled to say "Enough!"? How do we know that after some increase in the number of pictures the dependence does not change? Experiment will then, of course, disagree with theory, but when is "then"? In general, there are hosts of various objects in the world, and we physically cannot provide that many pictures, so that our experiment is in danger of going on an infinitum.

Here help comes from the least expected quarter, linguistics. Linguists say that there are only one thousand words that can be depicted in the form of common objects of the type "bird", "tea-pot", "house", "spectacles" and the like.

Nevskaya says: "Therefore, if I do not describe the set of pictures to be shown, the subject may expect any of the thousand. He would hardly give this number, but his brain, drawing on everyday experience, is already set for this order of magnitude. An inexperienced subject seems to be prepared as well. Only the set of images is much larger than with those who know for sure: today they will show me these eight well-known pictures. Substituting one thousand for *Y* in the formula gives us the time of reliable recognition to be about 150 milliseconds, in accordance with experiment. You are going to see it for yourself."

"And how about 15 milliseconds?"

"This is the time required to divide the "alphabet of signs" into two, normally unequal, parts and to select the one that contains the object of interest to us. The time required for one step in the "tree of signs". If we have four objects, we need two steps; eight objects, three steps, that is, 45 milliseconds, and so on."

"And for selection out of one thousand?"

"Ten steps, ten divisions into two parts."

"It is still unclear how the brain performs these divisions, how it is guided in its activity. It is clear about the hats — colour, shape.... We are guided by these signs when recognizing, right?"

"No. The main thing here is the generalized image of an object. Remember the eye of frog? It brings out only the simple signs of objects, such as the edge, the motion, the size. The visual apparatus of higher animals and of man is capable of extracting generalized signs of pictures, which merge into some generalized image. What do these signs look like? Answering this question is exactly the main objective of our laboratory, and in recent years we have been working at it. It is clear already that when generalized signs get into the short-term memory, they dwell there for about a quarter of a second, and during this time the long-term, or main, memory calls the short-term one, and compares its contents with what is available in the long-term stores. It is this process that resembles travel over the tree."

"Consequently, if you present a picture for a time shorter than a quarter of a second, you, as it were, disconnect the comparison apparatus?"

"Exactly. And then, the journey not yet finished, the subject starts conjecturing and makes decisions using an incomplete alphabet of signs and ... makes a mistake. An umbrella, for example, may be mistaken for a pencil, just because they are both elongated."

"But how, then, does vision manage to recognize accurately in a time much shorter than a quarter of a second?"

"Oh, this is wholly the merit of the brain, an example of its uncanny flexibility. Presenting for some problem makes it retune so as to achieve the comparison as quickly as possible. McCulloch, for example, believes that to make recognition easier, the brain construct a hypothetical generalized image of an object before the image appears on the retina. It is quite obvious that this is the case. Take for example, successful mushroom pickers who state that in the forest they try to visualize those mushrooms which they are after. Another evidence favouring the "preliminary operations" of the brain was provided by I. Toidze of Tbilisi. She established that if we are preset to receive some information, the reception threshold becomes lower."

"Why, then, do signs not interfere when I see several things? I now have in my sight this sophisticated piece of equipment, a chair, a table, and other furniture."

"But you see them not all at once but in succession. Simultaneous perception is just an illusion. The eye is, as it were, a "single-pattern" system. It is only able to recognize one image at a time, and then goes over to another one. It would not, of course, be appropriate to reduce the word "pattern" to mean a picture of some object. A "pattern" may be a scene. At first we identify its contents, and only then its elements. I shall show you five objects for a very short period of time and you will see only one. Later, as the exposure time becomes longer, a second, a third, and so on, will appear. By the way, in that case for the perceiver, the relation between the objects is more important than the objects themselves. We have here a picture: a fox catches a butterfly with a net and a kid goat stands nearby. At a 40-millisecond exposure a man sees nothing, at an 80-millisecond exposure he says that "somebody raised something at somebody", and at 150 milliseconds he sees the butterfly-net and some animal, and only at 320 does he identify the fox."

"How do you explain this?"

"Well, if only from the viewpoint of the evolution of the visual system. To survive, our ancient forefathers had first of all to see that "somebody is bullying somebody", and only then to find out the details: a tiger or a leopard. Only those who could respond quickly to danger survived, those who could not sooner or later met with misfortune."

Chapter Five

When We Cannot Say A, We Say B

It is important that a traffic sign's meaning be understood at first glance.

D. Samoilov and V. Yudin
Management and Safety of City Traffic

The building of the Laboratory are a bit off the road. From a bus stop one has to walk through a village and then past the many premises of other laboratories of the Physiology Institute. From time to time one hears a dog barking. To the right of the road, in open air cages mongrel dogs are roaming. As far as intelligence is concerned, mongrels are way ahead of the proud canine possessors of exhibition medals, and as experimental animals for brain studies they are at a premium.

The dogs are not generally fed before an experiment. Experiments require some work to earn an appetizing morsel of meat. And living in enclosures has already developed some habits. If at a predetermined time a dog is not given a bowl with feed, the pangs of hunger will become intolerable, and the animal will be consumed with expectations.

When the dog runs into the ring, it will see several doors with white cardboard signs on each of them. One marked, say, by a cross, triangle, or any other simple figure, or just a straight line. And beyond the door lies feed — a piece of meat, to swallow it just to whet the appetite further. When the dog enters the ring next time, the picture will hang on another door, and so it will have to find it again. Shortly, the dog responds to the picture unfailingly, it hurries directly to it, pushes the door aside with its nose and earns another piece.

It is now that the experiment starts. The horizontal line signalling "meat is here" is now in the company of other lines, differently inclined to the horizontal line, and the dog has to make its choice. But the dog does not waste time, with the same confidence it runs to "its" door. Whatever the arrangement of the pictures, whatever the neighbourhood of the "meat" line, the time taken by the dog will be the same. In other words, we will not witness any "travel over the tree". There exists an inborn reference identification power, for which both the dog and ourselves must be grateful to nature. After all, man too recognizes the line of an adequate incline not using a "tree", but immediately, in a minimal time possible, which is always constant. For this we should give credit to the neuronal fields in the cortex.

At another stage of the experiment, the dog learns to identify unfailingly a simple figure. There is no reference here and the dog will have to select the picture among others. At first everything occurs according to the "tree", as expected. The visual apparatus goes through the signs and the more images the longer the time (according to the above logarithmic dependence) required for the selection. Well, after several experiments the experimenter will notice that a reference will have developed for the figure as well. Yes, for the figure, although no fields in the visual system for this are provided for. How does the experimenter find this out? Quite simply: all the pictures, besides the learned one, are replaced by new ones, and the time taken by the dog to reach the desired door remains the same (should there be no reference, the time would be longer). This finding by the workers of the Laboratory explains many things that appeared unusual before. The ability to perceive a training-reference, which is acquired during training (consciously or unconsciously), is one of the most valuable acquisitions of the visual apparatus in higher vertebrates during their endless path of evolution.

With such a way of identification a decision can be taken during a very short time, nearly in a reflectoral way. Accordingly, those who possessed such a power were more successful in evading the claws and teeth of predators, and in finding their feed. The training-reference supports the opinion of Academician Kolmogorov that a shorter programme provides that more valuable information is derived, since the brain has a staggering ability to adapt so that the most important information may be derived from a picture in a minimum of time.

In man too a training-reference can be developed. Remember how easily a skilled driver takes his bearing among traffic signs and how much pain they give a beginner. For the former it comes about automatically, by reflex, for the latter it is much like a crossword. But if you allow half a year, a year, we will find that both are equal, because the beginner will have developed a reference. Using references, a professional will in general recognize hundreds of objects, which for an uninitiated merge into something shapeless, that requires reasoning at a logical level and perhaps even the use of a measuring instrument. A man not used to dealing with bolts will beyond doubt confuse M5 and M6: they differ in diameter only by 20 per cent. But an assembly line hand will take the necessary part nearly by feel, even if there are a dozen different types of parts in a box.

Why did they develop a reference for a figure in a dog?

A researcher of the Laboratory, Nina Prazdnikova, answered: "We wanted to ascertain whether or not there is any difference in the mechanisms of reference recognition of figures and reference recognition of lines. After all, it may well be that lines, too, a dog accepts after some training, and we just fail to notice it. We know approximately where the cerebral area that is responsible for the reference of the lines with various slopes lies. We performed an operation on the dog to remove this part of the cortex. After the dog recovered and entered the ring, we at first understood nothing. It seemed that there had been no operation at all! Our Polly, that remarkably clever dog, did not fail to select the familiar horizontal line. And if we had not taken into account the time of recognition, we would have remained sure that the operation was all for nothing. But timing showed that the identification turned from one of reference to a "travel over the tree". The line reference had been destroyed by the operation and never appeared any more. Accordingly, it was actually innate and so perfect that nature had not provided for a substitute of the same kind (that is, for reference recognition).

"But the training-reference worked out before the operation remained. When another operation in the parietal lobe had destroyed the mechanism responsible for that reference, the dog chose both familiar lines and familiar figures only using "the tree of signs".

"There are, thus, three different recognition mechanisms?" I asked, "The innate reference, the training-reference, and the "tree"?"

"Yes, and these differ not only in the manner in which they operate, but also in their location in the cerebral cortex. Each stands by in case one of the others fails."

"What developed earlier throughout the evolution?"

"Not the training-reference, by all means. Successive sorting out of all the forms possible and the economical selection by the innate reference are, undoubtedly, much older. In fishes, for example, and they are older than mammals, there is no cortex, and they can neither develop a training-reference nor make use of the "tree of signs". The only thing they have is the successive sorting out and innate references — the fields of ganglion retinal cells. Anna Karas of Moscow University has found that fishes easily distinguish horizontal and vertical lines, for which purpose they have receptive fields in the retina. But a fish almost ignores lines at angles of 45° and 135° whose fields are but weakly pronounced. One-month-old puppies, as we have established, also make use of sorting out as the main mechanism of identification. At two months, they develop line references. Why? Because in dogs, like in cats, it is not the fields of ganglion retinal cells that are tuned to lines, but the fields of cells in the cortex. In a puppy who is only a month old, the cortex has not yet formed, and so he has no reference identification."

"What are the practical implications of this discovery? I mean the redundancy of recognition mechanisms."

"Now we have, for example, given much more thought to experimental procedures. In studies of development and decay of conditioned reflexes, the main instrument is a stop watch. It tells us how quickly a dog learns, after how many training sessions it runs directly to the required figure. Up till now, the tasks we posed for animals were divided into simple and difficult ones. Say, to recognize a triangle is simple, but to recognize an irregular polyhedron is difficult. Now we see that once a training-reference has been worked out, the most difficult problem is no longer difficult, it turns into an exceedingly simple one."

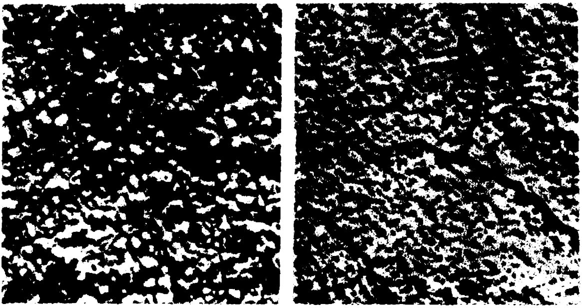
While I listened, it occurred to me: is the training-reference related somehow to the generalized image? Might a reference be developed by presenting fairly complex images that defy words, say photographs of a landscape? Nina Prazdnikova was not at all surprised when she heard about my conjectures: "Why not? Of course, not for any pictures but for some of them a reference may be established. Such experiments have already been staged." And she went on to tell me about experiments on recognition of the so-called "statistics".

These are sorts of figures, something like a multicellular chess design, but the black and white cells are arranged in a mixed-up way. The chaos is, by the way, not random. It obeys some strict, mathematical, statistical pattern. Depending on what formula or synthesizing statistics we slip into the computer, we will get a "chess board" with a definite order of image patterns, a "surname", as it were.

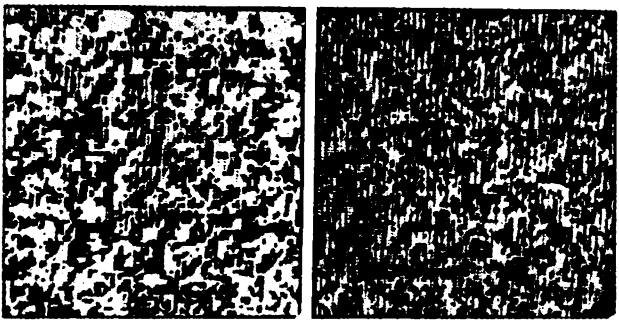
And depending on the ratio of black to white cells, a statistic (any one, regardless of its order) also acquires a "first name", a class. For example, class "75 × 25" means that 75 per cent of the cells are white, and 25 are black. If we deal with first- or second-order statistics, we can easily distinguish classes "75 × 25" and "85 × 15" or "65 × 35". Should the difference be smaller not by 10 per cent either side, but, say, by seven, we will get confused.

The 10 per cent threshold is a "magic number" for fishes, dogs, and humans. This means, above all, that the cortex does not contribute to the recognition of statistics, since fishes have no cortex. What is more, the task of distinguishing statistics is even up to bees! This must be a very ancient problem, if creatures that are so far away from us in evolutionary terms are equally good at it.

Interestingly, although statistics are produced by computers, the latter learn to distinguish "chess boards", much slower than man and highly organized animals in general. It is sufficient to show a statistic to a dog only once to dispel any confusion forever: the dog will unfailingly find the desired statistic among other particoloured pictures. But a computer will need at least 20 shows to achieve the same level of efficiency. This goes to illustrate that sometimes a living thing is higher than a computer. Where do the centres responsible for the recognition of "statistic pictures" reside in the brain? In the lateral geniculate body. This was discovered in the Laboratory. A Moscow scientist, O. Levashov, of the Institute of Con-



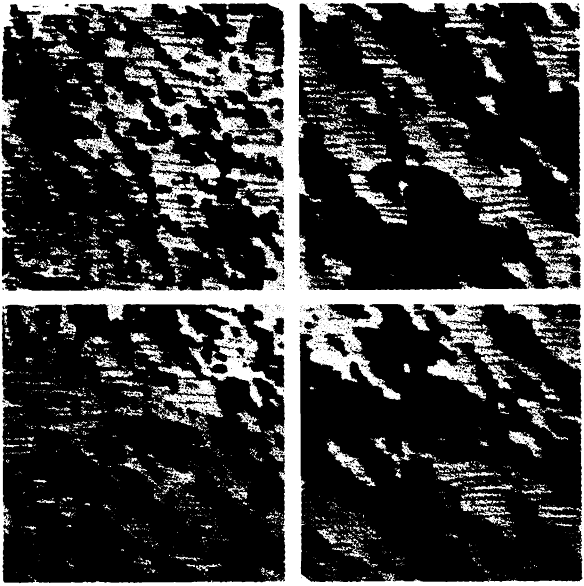
Soils differ in their statistical characteristics, and even insects recognize them



These computer-synthesized second-order statistics are distinguished even by bees

trol of the USSR Academy of Sciences, experimented with electronic models and totally confirmed the role of the receptive fields of the lateral geniculate body's cells in statistic recognition.

What everyday problem summoned such an acute need of the discrimination of "chess boards"? Most obviously,



Fifth-order (left) and eighth-order (right) statistics slightly differ, but the top and bottom pictures seem to be the same, although the percentage of black and white in them is different. The visual apparatus is unable to grasp the difference in higher-than-second-order statistics

the problem is a background. Our prehistoric ancestors had to distinguish shingle from sand, grass from shrubs, even at a distance when individual elements of the picture are difficult to make out and the eye only sees a pattern of light and dark spots, first- or second-order statistics. Why am I so sure that there are only these two? Because higher order statistics are indistinguishable to man and animals. At this level the differences are so unclear, no subtle distinguishing of classes, "names", is possible, and even statistics with different "surnames" are mixed up. At the same time, experiments indicate that the brain is able to take into account the statistical nature of pictures, and itself seems to be constructed following some similar patterns.

The capability of animals to distinguish statistics poses the question of whether or not there is some relation between this ability and strange, although fascinating, habits of some birds? A picturesque description of those habits was given by Karl von Frisch, who received a Nobel Prize for deciphering the "language" of the bees. Males of one of the species of weavers, birds of the sparrow family, construct their nests by artfully weaving a sort of net out of grass blades. But, writes von Frisch, "the female is very particular. If she finds the architectural proficiency of her husband inadequate, she rejects his passes, makes him unweave the nest and start everything all over again." According to the scientist, "the male operates not only by instincts, but he also learns from the experience of his failures." Yet more amazing are the habits of other representatives of the sparrow family, bowerbirds. They decorate their nests with "garlands of bright flowers, berries, parrot feathers, bottle caps, glass fragments and other bright things the male happens to collect near human dwellings. As a final touch, the male may even paint the nest inside with bilberry juice, crushing berries with his bill. The work finished, he steps backwards, just like a painter casting a last critical glance at his creation, and without any hesitation rearranges flowers or corrects the colouring."

What is one to make of it? Is it the beginning of esthetic feeling? Why not? Why should not a sense of the beautiful be associated with some statistical patterns? Speaking about beautiful products of art, we call them "proportionate", "harmonious" — you notice the hint at some units of measurements we use subconsciously? An important thing here is that for statistical identification we do not need, like Salieri, to dissect music (or any other art, for that matter) "as a corpse". We know that only in wholeness, in richness of detail, is beauty able to manifest itself in perception, but the essence of this wholeness is unclear: beauty is elusive, it slips out of one's hands each time it seems that the clue to it is found.

"Formulas of beauty", conceived after the fashion of definitions of the square or triangle, not infrequently are tautologies of the type "the sense of the beautiful reflects the beautiful in real life". No wonder the authors of the entry "Beautiful" in the Great Soviet Encyclopaedia provide no categorical description and instead try to describe the feeling that we experience when exposed to something beautiful. They maintain that "the perception and the emotional experience of the beautiful evoke disinterested love, a feeling of joy and a sensation of freedom." They go on to say: "the emotional experience of the beautiful is disinterested exactly because in it merge personal and social interests, man feels that he personally belongs to the social value of the beautiful."

Now, if it is difficult, perhaps even hopeless, to give an exact definition of the beautiful in words, why could it not be supposed that it may be formulated in the language of mathematics? Niels Bohr noted once that mathematics "looks like a variety of conventional languages adapted to express relationships that are either impossible or difficult to express in words." We have already noted that for all "tables" there exists the generalized image of the table. Perhaps also for "beautiful" for all kinds! — there exists a generalized image provoking the same emotions to which the Encyclopaedia refers? There are many hints of such a possibility. We know that all our senses communicate in the same language — the language of impulses transmitted along nerve networks. Could not it be that the similarity of codes lies behind the fact that critics sometimes try to express their appreciation of a piece of art using the terminology of another art and even the language of emotions that have nothing to do with the arts in general? We thus have "full-blooded painting", "loud colours", "dull sound", "carefree melody", and so on and so forth. We all understand (or rather perceive, everyone in one's own fashion) what exactly the art critic wants to say by his metaphors. But does it mean that he managed to express the gist of the matter? That he has found the formula of the beautiful? But the generalized image of the beautiful piece of art (much like the generalized image of a photograph that we cannot describe in words but easily distinguish from others) is exactly perceived by a member of the audience or a reader, and by the authors of works of art, who are generally unable to give a satisfactory explanation of why precisely this word, precisely that touch of a brush should be used in a given place. "It is better this way," they normally say.

This of course does not mean to suggest that the generalized image is something mystical, that exists beyond time and reality of man, beyond his work and contacts with other people. Nay, it evolves exactly in the labour, in social intercourse, in everything that is called by the all-embracing word "life". You cannot otherwise explain why the beautiful appeals to hundreds, thousands, or even millions of people, who sometimes are separated not only by thousands of kilometres but also by thousands of years. Unquestionable are the definitions given by the Russian literary critic Chernyshevsky: "the beautiful is life" and "beautiful is that creature in which we see life such as it should be according to our notions".

Well and good, but who can give a definition of the notion of life? These difficulties can be overcome using the idea of the generalized image. What does its mathematical description look like? How and where can it emerge in the brain? This is what we are going to discuss later in the book. But, for the time being, we will pose the question of whether or not the generalized image and the training-reference (to be sure, not in the primitive form as is demonstrated on dogs) shed some light on the age-old issue of dress fashions and style in general.

Chapter Six
Cycles in Dress

Fashion, the proud goddess,
On the knees before thou sink
Servant-girls and duchesses.
Even today's monks,
Fighting you in word only
Sport their novel cassocks.

S. Gnevkovsky (1770-1847)

"This spring will be the logical continuation of the fashions of last year. Sporting style and dress outfits will be in vogue. The most characteristic silhouettes are fitting snugly, and straight. The length of suits and dresses for all occasions is below the knee...."

Such reports appear in the mass media at least as many times as there are seasons in the year. And each time modellers with the same vehemence assure us that the new "dashing fashion, our tyrant" (in the words of the Russian poet Alexander Pushkin) brings out the "most winning" aspects of our figure and personality. The garment experts go overboard trying to rationalize the narrower or wider trousers, the shorter or longer skirts, and to find some functional reason in this unending renovation of the suit (not only the suit, for that matter, but also hairstyles, furniture, and the bodies of passenger cars). Some even go as far as to say that fashion—yes, fashion, not style!—"harbours in it the social signs of a given society". Here we can only throw up our hands: the height of the heel or the length of the skirt must be socially significant signs? And what if the members of different social strata wear the same kinds of skirt?

Seriously, now, let us not confuse the large-scale changes that make epochs with vogue, which is only light ripples on the surface of the ocean of style. Indeed, when sharp changes are to be seen in the style of the dwelling interior, the style of dress, the style of human relations, the style of industrial design — these are sure signs of some social processes, shattering countries, continents, and the very globe.

We have no difficulties in distinguishing the style of Ancient Greece from that of Ancient Rome, the Gothic dress of the 15th century from the modernism of the late 19th and the early 20th centuries, the baroque of French absolutism at its height from the ascetic costumes of Cromwell's puritans. We know well what put an end to the style of rococo: the French Revolution with its austere dress of the Jacobians, who preached equality and proclaimed the motto "Peace to the huts, war to the palaces!". The cumbersome frocks of Russian boyars became, at the time of Peter the Great, symbols of backwardness and reaction — we can hardly be surprised at the passion with which the young Russian tsar eradicated them and introduced the European style in dress, manners and everyday life. Style changed completely in Russia after the Great October Revolution with the black leather coats of commissars and red kerchiefs of Communist women being just some of the distinctive marks of the new era of humanity.

Admittedly, it would be a vulgar sociologism to see in changes of style only the influence of social upheavals. Historians attribute quite a few shifts in style to the coming of new methods of weaving and production in general, especially of new machinery and materials. In the 14th and 15th centuries in Western Europe all the kinds of clothing cuts, existing even today, had already been invented. In the 20th century, a new stage in the history of the dress was initiated by technical progress and clothing industries, which produce clothes in mass quantities.

As the tempo of life and information exchange gained speed, so did the change in styles. If in the 15th and 16th centuries it generally took nearly 50 years for a new style to come in, in the 18th and 19th centuries the cycle was reduced to 25-30 years, and in the 20th century to 10 years. In cars and household appliances, the following styles dominated successively: the "constructivist" style of the 1920-30s; the "streamlined" style of the 1930-40s; the ornate "animalist" style of the 1940-50s; the austere "classical" style of the 1950-60s; and lastly, the "space" style of the 1960-70s. And within each major style period, fashion plays with its nuances according to the ever-changing needs of people.

What needs? To be sure, not utilitarian. Clothes are still used to cover nudity, the car to ride, the radio receiver to listen in (here we ignore changes associated with purely engineering innovations, for example, the advent of transistors to replace vacuum tubes. In that case, the novel appearance serves as an excellent illustration of the harmony of form and content).

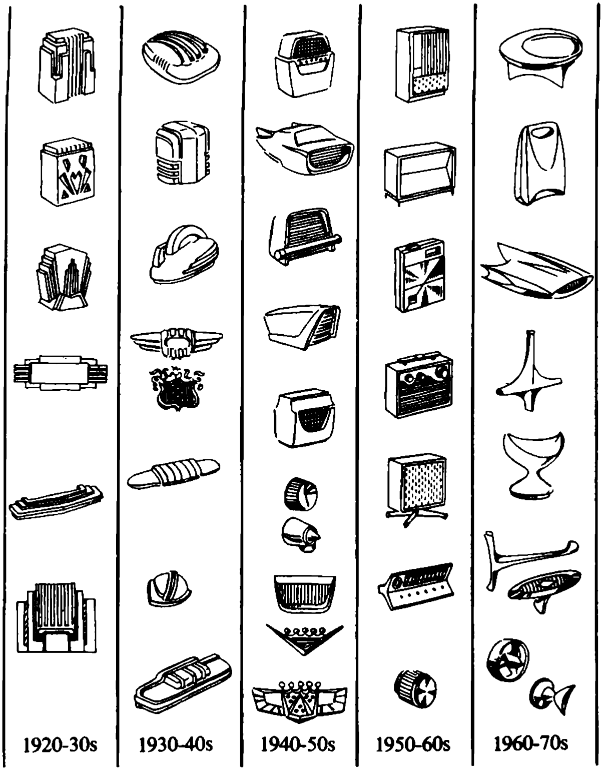
Also, the dynamism of fashion reflects something more than the desire of the producer for higher sales of the product (sometimes this motivation, without any good reason, is presented as the only driving force of change in vogue). There is no denying, of course, that at times a designer is simply asked to "make it good", to appeal to the tastes of the consumers, and more frequently, of the boss. Thus, styling made its appearance. But as ever more gifted designers appear on the scene, the products they work out begin to affect the consumer to a greater degree. And without noticing it, the consumer falls under the influence of the esthetic merits of a product. These merits evoke in man new desires. The preface to a book named *Problems of Design* says: "Imperceptibly industries, and the economy become dependent on esthetic needs, the rational system of production becomes supplemented by the irrational, intuitive, personal, cultural, nonfunctional; and so it is revealed that the economic system and industry

European costume: 1—first half of XVI century; 2—first third of XVII century; 3—early XVIII century; 4—mid-XVIII century; 5—late XIX century; 6—1920s in the Soviet Union need not only science but also the arts." In short, the inconsistency of fashion answers more to the esthetic, than to practical needs. "To be modern" belongs to the category of esthetics and morals.

"The form appears as a specific sign," write the designers M. Fedorov and Yu. Somov in their book *Evaluation of Esthetic Properties of Commodities.* Really, man perceives the shape of an object, somehow or other responds to it, and this reflex is based on intricate relations between personality and the world of things, and not things alone. Professor L. Petrov of the Leningrad Institute of Theatre, Music and Cinema maintains that "fashion is a special way of communication between people." The simplest example is the military uniform: in warfare it tells at a distance who is approaching, a friend or an enemy. Any other uniform, be it stewardess, waiter, railwayman, or policeman, is a sign that illustrates the entire variety of relations of a uniformed man with us and society, a sign that is very clear, exact, and hence economical in the sense that it condenses a vast volume of information in it. And the youth (and people of any age group in general) by their clothes, hairstyles, and behaviour even at a distance, as it were, give a signal to other "birds of a feather".

According to Fedorov and Somov, in the human brain are worked out standards of beautiful and ugly things, criteria that are derivatives of man's individual and social experience. On the basis of these criteria, we generally subconsciously estimate the esthetic merits of what we see. This, of course, does not exclude the possibility of revising our preliminary attitude at a later date, when we proceed to a logical analysis. But at the moment we are interested in the standards, not the revision.

Standards — that is an attraction of the hypothesis of the two experts on esthetics. How close is this to what we



Each decade the dominant style in design changes (parts of radios and cars)

have just discussed with the workers of the Laboratory? Admittedly, the standards there were called generalized images and training-references, and their objective was assumed to be not esthetic, but strictly practical (just recognition). An interesting parallel stands out: could it be that the changes in fashion are a response to the emergence in man's conscience of a training-reference, tuned to a given, frequently occurring form?

Really, earlier, when there were no references, we travelled over the "tree of signs" to identify a new silhouette. We did it perfectly subconsciously, but still did it. And could it be that the discontinuation of the "work of selection" produces those disagreeable sensations — discomfort, boredom, emotional dissatisfaction? And it may well be that the first to grasp such hints are the modellers, artists, designers, that is, those who, by virtue of the very organization of their mentality, are able to feel uneasiness sooner than others? To feel and to do everything in their power....

Perhaps then, love at first sight is just another reaction to that standard, but now positive?

Much comes to mind in association with fashions, beauty, and standards. So the director of the Institute of Social Psychology of Strasbourg University A. Moles holds that the charm or unpleasantness of a man is "related to insignificant deviations of each element of his body from the common scheme". Recall the Spartans, who passed a law prohibiting men to wear clothes of "colour unbecoming to men". Or Pavel I, that denizen of parades, who was out to level out everything:

The size for hats — an inch with a half,
Henceforth do not wear as you please ...

But, to summarize: it is high time to have pity on fighters against the vogues, who fight against the most natural sensation of man, against "tiredness" of esthetic feelings, tiredness of monotonous, familiar information. Of course one should not allow the pendulum to swing too far. True, it is difficult to determine what is "too far".

Some of us remember times when females were not allowed to enter restaurants in trousers. I cannot forgo the pleasure of quoting from a book on fashions issued in 1959: "Sometimes we encounter in the streets girls and young women in trousers. But to appear in trousers in the street, at a meeting, or at college is bad manners — it is considered improper. A girl or a woman may have on trousers only at home, when practicing sports or at work, if this is necessary." Then mini-skirts came under attack, then maxis, requiring, ironically, as a minimum a pant suit. "The female wardrobe relies heavily on trousers", melancholically exhorts the author of the earlier quotation in his new book on fashions published in 1974. What is going to be taboo at restaurants in five years is hard to say. I only know that we are going to have more of those puritanistic outcries. C'est la vie, as the French say.

Incidentally, speaking about the French ... the above-mentioned author, Petrov, in his book *Fashion as a Social Phenomenon* tells an instructive story. Luis XIV, who by the way is said to have pronounced "The state is me," for some reason hated high female hairdos. But he could do nothing about them, no matter how he tried. When the English envoy Lord Sandwich came to Paris with his pretty wife, who had her hair done low, all the ladies at once followed suit. The king was irate. "Frankly, I am insulted by the fact that when I, bringing to bear all my power, came out against those high hairstyles, nobody showed any desire to please me by changing them. But now comes some unknown Englishwoman, and suddenly all the ladies, even princesses, rush from one extreme to the other!"

"All you wrote," Vyacheslav Zaitsev, the foremost Soviet dress designer told me, "is a fairly correct statement of what occurs in the world of fashions. I would only like to comment on its role in the continuation of the human race. If you love and are loved, you want to impress the object of your love. If, unfortunately, you are turned down, you want to impress all the more. And the role of fashions here is colossal. What is more, man is a child of nature. In surrounding nature, things change from season to season, and in man as well. "Fashions of the season" are no freak, but the external manifestation of the desire to note the changes occurring in nature and in the human organism, a desire to be in accord with seasons, a desire to feel friendly glances on you. We are extremely sensitive to how we are looked at, and women in this respect are the most subtle pressure gauges. Friendly glances stimulate us, bring forth the desire to live happily, finely, a desire to work efficiently — this goes without saying. The idea that one of the stimuli for the change in fashions is the tiredness of perception seems to me to be absolutely unquestionable. You know, when you work on a new set of costumes, and this takes about half a year, many clothes do not seem as interesting near the end as they appeared in the beginning. However, if this were not so, I would be horrified: do I really stop in my development?"

Here the author wanted to leave the subject of fashions. But his wife said, "And how about bad fashions? Why not a word about them? Or, maybe there is no such thing?"

Alas. But the problem of what is good and what is bad in the world of fashions is more confused than elsewhere. One French poet said, "the truth is on one side of the Pyrenees while lies are on the opposite side." One thing is certain: if the vogue is used to stress one's alleged superiority over other people, if it is a result of the desire to show off, this vogue is undoubtedly a bad vogue. This is because here esthetics ends and something absolutely different begins: shop window, vanity, and so on.

And talk about fashions is bound to lead us to talk about the personality. To seem or to be? One of the prominent designers of our days, George Nelson, noted that the vogue is no vitamin and no miracle medicine, and so it is unable to turn a boring, dull and miserable life into a meaningful and bright one. This is only up to the man himself. To seem or to be? On our answer to ourselves depends how people will accept the fashions we have chosen. In the final analysis, after all, for the people around us our fashion is our words about ourselves.

Chapter Seven

The World Is Made Up of Details

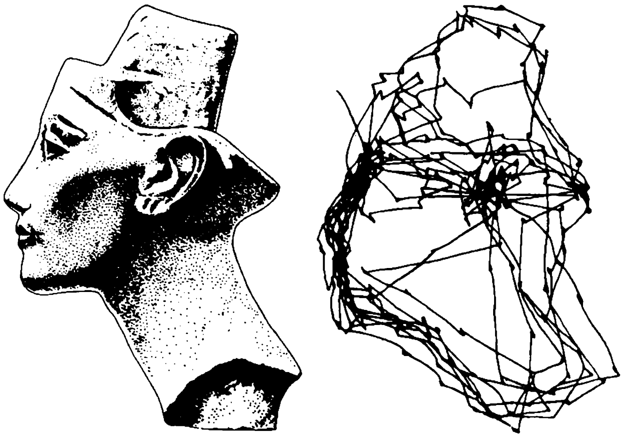
Mix butter into flour with fork until small clums form. Stirring constantly, add cold water to the mixture until one large ball forms. Refrigerate one hour. Roll out dough.

Old American
cooking recipe

Early in the 1960s Alfred Yarbus performed experiments that have now become classic for those who somehow or other are concerned with the studies of perception of form and space. The experiments initiated a large series of various studies, which added much to our understanding of what it means "to look at the world".

On the eye of a subject a small mirror was fixed and a light beam traced on photographic paper the eye's motion while the subject was examining the picture. The tracery obtained indicated that the eye does not follow the outline of an object (alas, even now in some books we read sometimes that "the eyeball moves in accordance with the contour"), but makes strange, seemingly chaotic jumps. As the recordings are superimposed on one another, some curious patterns come to light.

The first of them is that maxima of attention lie at the most important centres in the picture. Specifically, a man or animal is always going to be such a centre in the picture, even if the picture is devoted to something absolutely different, say nature or machinery. Faces of people are more meaningful for us than figures, and figures have more significance than details of the environment. When viewing a portrait, a spectator rests his glance primarily on the eyes, lips, and nose. The same elements — eyes,



This is the way we watch Nefertiti

nose, and muzzle — are the most interesting for the beholder when the head of an animal is depicted.

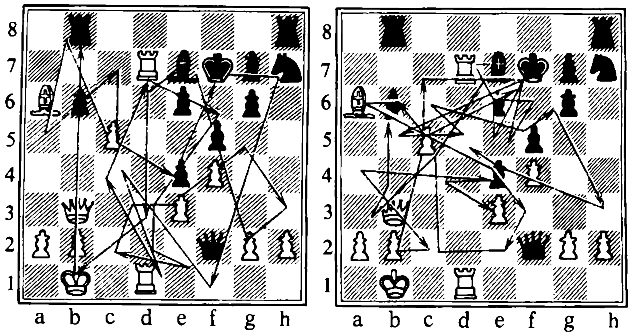
Such a "hierarchy of values" is generally quite understandable. Yarbus wrote: "The eyes and lips are telltale signs of the spirit of a man and his attitude to the beholder, of the steps he may undertake at the next moment, and so on." The "shifting eyes" of a person with a guilty conscience, noted even in ancient times, are by no means accidental. The guilty one concentrates his attention not only on the face of his companion, which is always of interest for a party to a conversation, but also on the hands (perhaps their motions will betray something?), pockets (any weapons there?), the faces of people standing nearby (any tricks on their side?), and we immediately take in the strangeness of such "visual intercourse".

Yes, the movements of the eyes reflect our thoughts. In one of his experiments, Yarbus had subjects look at the picture *Unexpected Arrival* by the Russian painter Repin, with different "settings", and asked them to solve various logical tasks. So what? When it was required to assess the material status of the family, more attention was paid to the furniture and layout of the room, which normally was virtually overlooked. When asked to estimate the age of the personages, the subject concentrated exclusively on the faces. Fast shifts of the eyes from the faces of the children to the face of the mother and back to the face of the newcomer, and immediately back, over the same path again — such is the solution of the problem "How long was the one who had not been expected absent?" The disorderly wandering of the eyes is an attempt to remember the arrangement of the people and things in the room.

Unexpected Arrival is a well-known picture in Russia and abroad. And it is all the more interesting that different people examine it in a different way. Patterns on photographic paper testify that although the elements of the scene attract the attention of different people generally in the same way and in clear relation to the "setting", the paths of tracing the elements by the eyes are different for different people.

> Everyone sees the world in a different image,
> And everyone is right — so much meaning in it.

said Göthe. The individual features are extremely stable. When a man looks at the picture now, in three days or in a weak, the mirror tells us that the path of his glance changes but little. "In essence, the Art is a mirror that reflects the one looking into it." These words of Oscar Wilde are sometimes comprehended as a desire to "express oneself in a more showy way". It appears that they are supported by some documentary evidence.



a b

This is the way a chess player analyzes the board when he (a) assesses the situation and (b) looks for a good move

A somewhat different technique — the filming of the eyes — was used by V. Pushkin to get an insight into the "technology" of solving chess problems: the path of the glance is indicative of the way in which the chess player is thinking. And again we see that the route followed by the eyeballs is dependent on the "setting": to find the solution — one pattern, just to evaluate the situation and to tell whose position is stronger — another pattern. When looking for a solution, the eye is mostly attracted by "functionally significant points" of the position, and therefore large areas of the board are completely ignored by the glance. And when estimating the situation, the "fixation points" of the eyes are distributed all over the board.

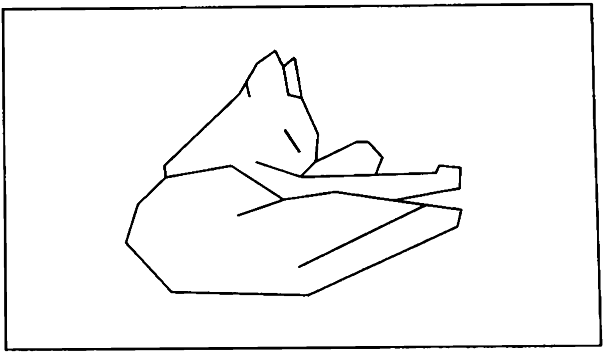
The chess player examines each fragment of the position that attracts his attention for about a quarter of a second. The same period of fixation in reading (prose or verse), was noted by Yarbus and others, so that the chess board for a grand-master is in fact an open book. A quarter of a second, as you remember, is needed for the short-term memory to compare the information with the stores of the long-term memory. We thus get another piece of evidence in favour of the hypothesis of the generalized image. Well, what if this time is too short because the text at hand is difficult or emotionally-laiden, and the reader needs some time to ruminate and call back some associations? Then the glance sticks for a longer time, but again for a period multiple of a quarter of a second.

The volume of information transferred during that fleeting moment to the long-term memory is critically dependent on age. A six-year-old is only able to understand in a minute not more than 70 words, and a 25-year-old student "swallows up" 340. Why? Because the infant, when reading a 100-word text, lets his glance rest upon something 240 times, and 55 times he comes back to what he has just read. But the student stops 3.2 times less frequently and returns 5 times less frequently. According to the Soviet scientists V. Zinchenko, B. Lomov, E. Sokolov, and M. Shekhter, experience enables one to sort out things of secondary importance, to combine several of the simple signs into one complex "sign". In other words, experience changes the very alphabet in terms of which things are identified. That is why, although the time of eye rest is essentially the same in infants and students, the effective rate of information processing in the higher parts of the brain increases drastically. An adult thinks faster than a child, not only due to a higher general development, not only because an adult's memory is richer in knowledge, but also because the inner structure of the brain improves and the ways of representing information perceived by the sense organs become more economical.

Why is the mirror tracery so stable? After Yarbus's experiments the ball was carried on by the American physiologists D. Noton and L. Stark. They were fixing not only the overall pattern of the trace, but also the sequence of the transfers of the eye from point to point. The sequences turned out to be, just like the patterns in the experiments of the Soviet scientist, absolutely individual and extremely stable. In the opinion of the experimentalists, in the first encounter with an object, man, as it were, feels it with his glance, mapping out the paths of the rounds. In the process, the visual memory retains the signs that characterize the object, and the motor memory, the signals from the eye-moving muscles. Thus a "circle of signs" forms, in which the visual and motor information interlace. In the next encounter, the "circle" helps in recognizing the picture.

What formal signs are characteristic of the points of fixation? What exactly does the visual apparatus accept as an important feature in terms of information? Physiologists think that these are the areas of the outline with the strongest curvature, informative fragments. A curious experiment was performed by the American researcher M. Ettniv: he suggested that subjects mark on a picture of a lying cat the points that in their opinion are the most important to comprehend the meaning of the figure. These points turned out, as it might be expected, to be the points of the maximal curvature in a given area of the outline. The scientist singled out about 40 such points and connected them with straight lines: the picture thus bearly suffered, the clarity of recognition did not alter.

It was precisely this feature of the visual apparatus that cubists subconsciously exploited, they sort of "faceted" their images. Many techniques of stylization are based on it: in embroidery with crosses, in carpet making, and so on. Sharp bends in lines do not obliterate the soft curves of the figures of people and animals, which the master craftsman presents.



The Ettniv cat: all the lines are straight, but we recognize it all the same

The maximal curvature points and intersections of contours, those maxima of the function of information content, tell us the fundamental things, such as the arrangement of objects in space. This became especially clear when, because of the industrial requirements, scientists came to grip with robots capable of finding their bearings in space and determining the arrangement of details using their "eyes" — telecameras.

"Does some large object lie beyond the small pyramid?"

"Yes, even three: a large red block, a large green cube, and a blue block."

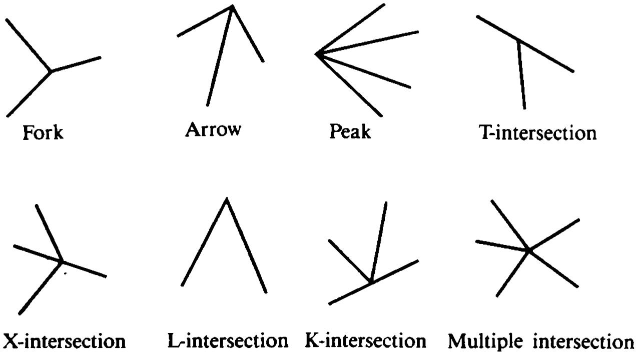
"Now put the smallest block on the green cube on which the pyramid stands."

"OK."

"And now put on the top the smallest pyramid."

"OK."

With whom is the dialogue? Perhaps with a man who poorly distinguishes colours or forms of objects and who is being introduced into spatial and colour relationships of



The eight nodes that exhaust the variety of contour intersections

things? Nothing of the sort. This is a dialogue with a robot, published as early as 1970. You see, a "soulless automaton", as were once called cybernetic devices, distinguishes colours, size, form, and arrangement. How the machine accepts the first two signs can generally be comprehended. We are now well acquainted with colour television, it is also not very difficult to measure the area of the image on the screen. But how about the form and arrangement?

When one thing blots out another — the commonest case — their contours intersect. It would seem that this is bad: well, the eye sees only a part of the object, not all of it. But precisely this gives the vision a body of very useful information.

At intersections, or nodes, may converge two, three, or more lines. It has been established that there are not that many types of nodes, eight in all.

Just look around you and you will see that nodes are some of the most important signs of the depth of space. An *L* type node tells us that the surfaces it separates are likely to belong to different objects. A "bifurcation" indicates a convergence of three surfaces of the same body. But an "arrow", which differs slightly from it, suggests that two surfaces belong to one object, and the third, to another, maybe to the background of the scene.

Recognition rules introduced into the computer memory of a robot, provide for its orientation in space: lines — nodes — zones — surfaces — bodies — overall scene. Such is the deciphering method used by a computer. And how about a human? Apparently nodes are very important for him, too. Making use of them, he turns flat pictures into three-dimensional ones, visualizing (as a rule subconsciously) the arrangement of objects in space and volume forms of bodies.

That this is the case is suggested by the "impossible figures" which normally baffle the uninitiated. One of them is Penrose's triangle. A glimpse at it reveals nothing special. Its three angles (it may be that these produce its generalized image) prepare you for a well-known picture: a volume triangle nailed together out of three bars.

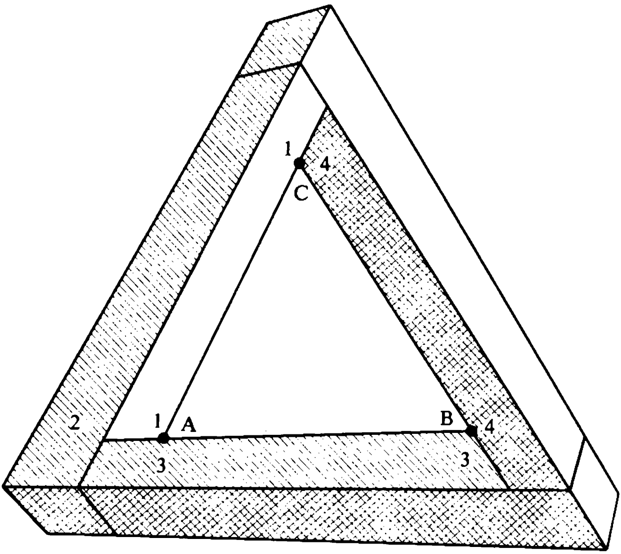
The situation, however, will become more complex, if you set out to reconstruct its three-dimensionality using its flat view. The brain does not accept the reality of this flat figure. The eye wonders over the outline from one apex to the other, going ever faster in a circle, giving no clues as to the solution of the problem. The triangle still remains outlandish, unreal. Why?

As early as three centuries ago Descartes gave the following description of the acceptance of a complex image: "If by way of independent mental operations I found the ratios of *A* and *B*, of *B* and *C*, of *C* and *D*, and lastly of *D* and *E*, this alone does not enable me to understand the relations between *A* and *E*. The truths comprehended earlier will not give me accurate knowledge of this, if I am not able to remember all the truths at once. To help the situation, I will from time to time go over these truths and stimulate my imagination in such a way that, once I have conceived one fact, it will immediately go over to the next one. I will go over the procedure until I learn to shift from the first link to the last one so quickly that none of the stages of the process will be "hidden" in my memory, and so I will be able to take in with my mental sight the entire picture at once." Remember that the brain uses approximately this scheme to control the motion of the eyes, by the very motion that Yarbus first recorded on photographic paper. But in the case of an "impossible figure", this generally impeccable method fails.

Let us see why this is so. The analysis requires some patience, but eventually we will have our rewards: we will be blessed with the mysteries of not only Penrose's triangle but of other "impossible images" as well.

Let the intersecting surfaces *3* and *1* of our triangle form a *T* type node at point *A*. This means that surface *1* lies under surface *3*. Now look at point *B*: another *T* type node formed by planes *3* and *4*. Accordingly, surface *3* lies under surface *4*. We now pass to point *C*: again the same node, which suggests that surface *4* lies under surface *1*. But we have just seen that *4* may not be under *1*, since *4* lies over *3*, and *3* over *1*. Consequently, *4* must be above *1*, but the node suggests the opposite! The eye is thus in conflict with logic. The eye says that all the bars are perpendicular to one another, and logic says, and rightly so, that this is impossible in a triangle. Of course, all of this whirls through the brain very fast, subconsciously, but in general we have just constructed a model of a device that, quite obviously, in reality behaves in some other manner, but essentially leads to the same result.

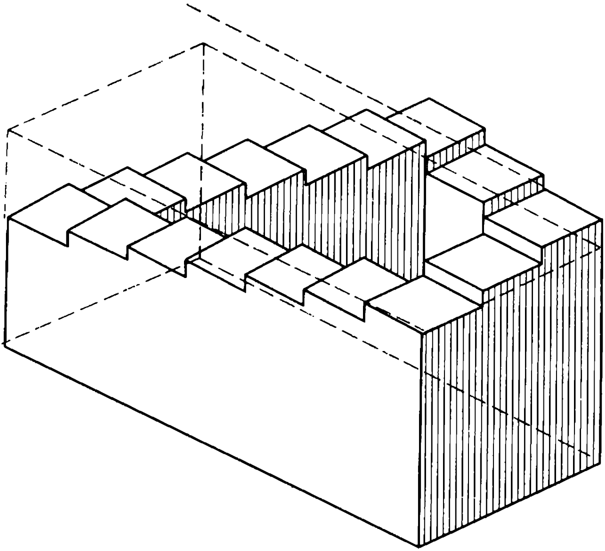
Where do we go from here? It appears that something radical is required, that is, to discard one of the facts (the



Penrose's triangle. What is the secret behind it? We try hard to imagine it as a flat one. But it is a three-dimensional one, and only looks this way because the painter viewed it from a "tricky" angle

unexpected paradox is that superfluous knowledge just hampers). Cover with your finger any of the vertices, preferably the upper one, and you will witness an instant transformation: the sides of the triangle will "spring out" from the plane of the page, making the pseudoplane figure into a three-dimensional one. All three bars will become perpendicular to one another!

Tricks, such as Penrose's triangle, have often been used by the Dutch painter Moris Esher. Not infrequently you may see in his pictures waterfalls "streaming upwards", some mysterious buildings, a ladder going always down in



The ever descending stairs. Here again we tend to regard the structure as a closed figure, although it is apparently not. The trick is due to the angle from which we view the stairs and the perspective convergence

a closed ring. The strangeness of the picture is uncovered using the above technique: you just cover part of the picture, find using a set square and a ruler the points where the perspectives meet and then you see very intricate, sophisticated tricks of the master.

And now we will pose the question of why man perceives the world in fragments? Why do we piece together the whole? We already know that the eye is a single-image system, it perceives objects in succession. On the other hand, the communication theory contains the notion of a frequency band that a line is able to transmit without any distortions. For a telegraph channel the band is 75 herzs wide, the natural reproduction of a voice requires a minimal band of 8,000 herzs, and the TV signal requires several million herzs. By analogy with the frequency band, the throughput of an information channel is measured. The unit used here is not the herz, that is, not the number of oscillations per second, but the number of binary digits of information, called bits, for short, per second.

What are the binary digits? Any number may be represented as two raised to a power: $2^0 = 1$, $2^1 = 2$, and so on. For example, it is believed that the human eye distinguishes from 250 to 300, that is, about 2^8, shades of brightness. The exponent here signals to how many bits of information each gradation corresponds: it equals eight bits. If there were a million gradations, the "price" of each of them would increase nearly to 20 bits.

And further some scientists make the formal calculation: they multiply these information units by the number of light-sensitive elements of the retina, and then by the frequency at which the image perceived by the eye stops flickering. They thus arrive at enormous figures for the throughput of the visual apparatus: from 3 to 200 million bits per second.

But should this arithmetic be reasonable, counter the authors of *Information and Vision*, we could "perceive tens of millions of chaotically distributed black and white points; no doubt, in the course of the evolutional development there was no need for a system with such an enormous throughput". In fact, experiments show that the real figure lies somewhere between 10 and 72 bits per second. By the way, this figure is approximately the same both for the eye and for the ear (for the eye it is somewhat higher). How are such small figures to be interpreted considering that we perceive a TV image, whose information content is one hundred million bits per second? This contradiction is just apparent, however.

The absurd millions of bits of throughput that are allegedly characteristic of the eye come from the formalistic approach to information theory. Meanwhile, one of its principal concepts states that, above all, one should define the alphabet that carries the information and accurately define the number of characters in it. Only then can one take up a slide ruler. And if one goes this path, the question immediately presents itself: what have brightness gradations and the number of photoreceptors to do with it? Is the visual apparatus really concerned with meticulously transmitting to the higher parts of the brain information about brightness differences between individual light-sensitive retinal cells? By no means! The brain receives the generalized image of what has been seen.

We are now left with the following: if we present one character of a 32-character alphabet, try as we might, we will not be able to transmit more than five bits of information ($32 = 2^5$). With our one thousand various generalized images, the informational value of each is not higher than ten binary units ($1024 = 2^{10}$). And since the recognition time for any of these images, or the alphabet of images, is 150 milliseconds, the throughput of the visual system will be only 66.6 bits per second ($10 : 0.150 = 66.6\ldots$). Where are those millions?

It is now clear why our eye only catches several fragments of a picture, those carrying the maximal information. The eye's jumps thus make use of the limited throughput of the visual apparatus to take in the colossal information in the world around us. The transmission rate over the visual channel thus turns out to be constant and not very large at that, it corresponds to the eye's possibilities as an information system (just as communication devices with a variable scanning rate make it possible to produce extremely economical TV transmission systems; the first such system was suggested by the Soviet engineer A. Konstantinov as early as 1933).

But what happens with those image fragments that our sight ignores? Perhaps we do not see them? It looks like that. Everything suggests that the brain just invents them by using those millions of pictures that have passed before the eyes and left their imprint, maybe subconsciously, in the memory. The more capacious the stores of our visual riches, the more complete is our comprehension of whatever new that comes into sight, and the more complete is our power of vision.

> I inhale great draughts of space,
> The east and the west are mine, and the north and the south are mine.
> ....
> I will recruit for myself and you as I go,
> I will scatter myself among men and women as I go,
> I will toss a new gladness and roughness among them
> ....
> Now I see the secret of the making of the best persons,
> It is to grow in the open air and to eat and sleep with the earth

wrote Walt Whitman.

At the same time, this does not mean to imply that our vision makes do with "pieces of images" alone. The first impression is tested by other fragments, outlines and volumes are refined by multiple passes along different paths, and so a complex, rich image emerges. So we can for hours view the great canvases, returning to them many times over and notice amazingly the freshness of the impression of a seemingly familiar scene.

Remember our encounter with Alexandra Nevskaya, who told us about the "single-image" system of perception in accordance with which our visual apparatus works. There this property was uncovered using experiments based on one technique, we have just come to the same conclusion by considering other experiments conducted by different workers. What can be better than confirmations coming from distant laboratories?

The sequential nature of examining an image is also related to learning and prediction: as has been found lately, this technique is the quickest way to the goal. This is due to the fact that a whole visual image containing enormous information is subdivided by the visual system into a number of fragments, subimages, and in these subimages other subimages are uncovered. The Russian humorous writer Koz'ma Prutkov stated with an air of profound wisdom: "There is no great thing, that cannot be surpassed by a greater thing. There is not a thing so small that it cannot hold a smaller thing." By piecing subimages into a whole image, the brain always constructs hypotheses as to what the result will be. That this process proceeds exactly this way is indicated by different experiments. For example, two groups of subjects are shown fairly unclear photographs of geometrical figures, one group is told which figures are the most probable, and the other is not. What then? Although the pictures may be examined indefinitely (in other words, the comparison process does not discontinue abruptly as was the case in the experiments discussed in the previous chapters), those acquainted with the preliminary hypothesis recognize pictures two or three times more efficiently, than those who have not been given the "setting". Clearly, this specific feature of the visual apparatus must always be taken into account when analyzing the functions of an operator. A worker manning a control panel keeps correlating the readings of instruments with his actions. For a recurrent situations he develops stereotyped answers. But in a rare situation, the man may be bewildered — the image of the situation and the response are formulated with difficulty. Therefore, operators, say pilots, are generally trained to behave properly in rare situations. Manuals on piloting an aircraft under complicated conditions not only tell how the plane is to be controlled, but also show the typical readings of the instruments using photographs of pictures of the dashboard. And although you will be dazzled by the sight of dozens of dials in the cockpit of a modern heavy aircraft, the pilot can take in all of them. Our vision, with all its disadvantages, is close to the ideal communication channel, the cherished dream of all communication people who construct their channels out of hardware.

Chapter Eight

All Roads Lead to Rome

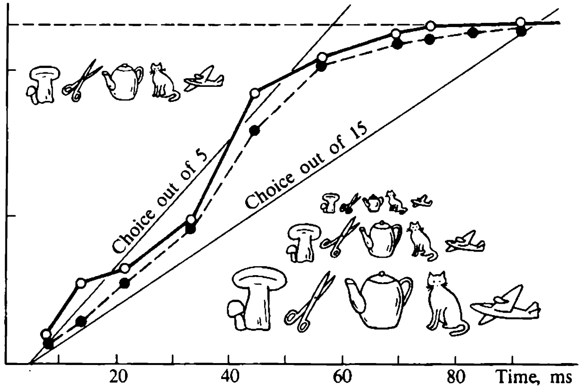
In fact, there is mounting evidence indicating that, in essence, the brain is a group of systems processing information in parallel.

R. Held and U. Richards
Organization of Perception Systems

Has it ever occurred to you to wonder why at three metres, at ten metres, and nearby a dog looks like a dog, a cat a cat? Why does a horse at any angle look like a horse, and a big, medium, or small mushroom all look like mushroom? This property of human (and not only human) vision has long interested scientists. They called this feature invariancy or constancy of perception.

In fact, we accept similar objects as having the same size; although their distances from us may vary, and hence the projections of these objects on the retina will be different. It follows that there exists some mechanism (it seems we just can't avoid these different physiological mechanisms), that refers an object to the same notion and to the same generalized image. Where does it reside, this mechanism? In the visual apparatus or in the higher parts of the brain? Is the accepted image referred to a given image at the preconscious or logical stage of processing? Or, perhaps, some invariant transformations are taken care of by vision, and others by the logic of the higher parts of the brain?

We can answer these questions. After all, we have such an unbiased indicator as time. Just imagine that an observer has been trained to work with five pictures. He recognizes each unfailingly, his visual apparatus "travels over the tree" as is indicated by a clock. And suddenly, instead of a familiar picture, you show another: a picture



Images of different sizes are invariant for the visual apparatus, which still chooses one of the five pictures, not out of 15

of the same object but now at another angle or of another size. If for the visual apparatus this is just the same information, if invariancy starts at the preconscious level, the time of recognition will be the same. Vision will have to choose "over the tree" again from the five pictures. And if the time lengthens, this will imply that the picture is new for the preconscious level of recognition. Accordingly, the picture will become invariant now at a higher, logical level.

Nina Prazdnikova narrates: "I have been working with fishes, apes, and dogs. Then Glezer suggested that I try it with cats. I am not fond of them, because they are difficult to deal with in behavioral experiments: Kipling was right in saying that the cat walks by himself. But in our Laboratory we do some research with them at the cellular level — nothing doing, I had to agree. Why such a wide variety of animals? The main reason is invariancy. On fishes I began my investigations into whether animals are capable of invariant recognition.

"It turned out that just to distinguish, say, a square from a triangle, a fish learns no worse than an ape. It swims quickly to the picture for which it gets its feed and pulls with its mouth at a beed. What is more, recognition capabilities of fish in certain respects are even more pronounced, and more stable each day. But the fishes cannot generalize. They quickly learn to distinguish a black square from a black triangle, but just change the colour to red — and everything will go to the dogs, the lesson begins again. For a fish these are absolutely different figures, hence they possess no invariancy for colour.

"And for a dog all the triangles and all the squares — white or black, large or small, against a light background or against a dark background (alas, dogs do not distinguish colours) — are referred to the classes of "square" and "triangle". A dog trained to go for its feed to one figure of a given class will also go to any other figure, invariant from the point of view of perception. Even a month-old puppy that has just learned to find its food dish, with equal ease learns to recognize images, his invariant powers being by no means worse than that of a full-grown dog."

I asked, "Excuse me, Mrs. Prazdnikova, but still the puppy has seen the surrounding world for some time, may be he has learned all this there?"

"No. We deprived the puppies of the opportunities to learn. We reared them in dark rooms while they could not do without their mother. And then, when they became more or less independent and they could be weaned, we put them in white boxes with diffuse light. The white box, a white bowl with rounded edges, white porridge in it — a puppy had not seen a single black object of the same class and could not "learn", could not "surmise" that this is the same object. And only when it got into the ring and took part in the experiment was he shown various black figures.

"What happened then? Just imagine, such puppies in no way differed from controls as far as their behaviour was concerned. Their invariant capabilities were just as well developed. They were even more active than those who had lived under normal conditions. And perhaps one more detail is of interest: there were no cowards among them, whereas among the controls there were. And our "special" puppies were doing well, just fine. It was a treat to deal with them. Although they were troublesome at times: fourteen puppies, fourteen experimental runs each day, but they kept growing and so we had to do everything very quickly.

"Their visual system grasps differences at once. Say, we have taught a puppy to come up to a black triangle and the next day, quite unexpectedly, we give it a skeleton triangle. It would stop, wait a little — something new! — and then with confidence make its way to the new triangle. It appears that it does see the difference, but the triangular configuration turns out to be a stronger incentive. The same thing happens when sizes or contrasts are changed. For a puppy invariancy, at any rate in the form we managed to discover, is an innate thing."

"But in man, is invariancy a gift of nature?"

"It depends. There is an innate one, an acquired one, and a lost one, so to speak."

"Lost?"

"Exactly."

And so I found out why Alice in The Looking-Glass House — in defiance of Lewis Carroll — had no difficulties in reading there the books printed backwards in a way befitting "that" country.

The fact is that our vision responds differently to an image turn. Nevskaya has found out that we recognize a horse from the left and right in the same time — a total invariancy of the generalized image. But just try and incline the picture so that the horse is going up or down hill, and you will have new, noninvariant images, that is, taking different times to recognize.

However, things are not as simple as that here at the Laboratory. A postgraduate, Nadezhda Stefanova of Bulgaria, has established: slight rockings, when the slope is not steeper than 15°, are perceived by the visual apparatus as invariants, and at larger angles logical processes take over, that is, the recognizing of the new, sort of a search over the "tree of signs". Sort of.... Here there is one substantial difference: it seems that the visual apparatus mentally turns the picture to the usual horizontal position, and only then does recognition starts.

The Americans Shepard and Metzler, who have performed similar experiments, consider that the speed of this turn is about 60° per second. In other words, it takes at least three seconds to recognize the upside down picture that appears before your eyes.

And now we can travel through The Looking-Glass House. Can you readily read the newspaper you see there? It takes some effort, does it not, and the reading speed drops markedly? So, it is exactly this feature which is not inborn in us, but comes with experience. We have lost, for good and ill, what we possessed in early years. It makes absolutely no difference to infants whether letters are normal or backwards in the mirror. When children learn how to write, some write the letters one way, others another way, it makes no difference to them. Alice would have no difficulty in The Looking-Glass House reading the rhyme about Jabberwocky, because at her age, children have not yet lost the invariancy to mirror transformations. Or rather, they have not yet acquired the noninvariancy.

We distinguish symmetrical and mirror images because the brain can turn images, thanks to the cortex of the cerebral hemispheres! And should there be some disarrangement of it, if the invariancy should be lost and such pictures become indistinguishable, that would be real tragedy. Well and good, an affected person will with equal ease read a direct and mirror-image text, but he will confuse 69 and 96, 91 and 61, XI and IX, the letters will not arrange themselves in a line as appropriate, and although he can write, you would not be able to read what he has written.

The inherited invariancy is the invariancy to size. As has been established by Stefanova, large, medium, and small houses are all the same for the vision: the identification time is constant, although all the images on the retina differ in size. In other words, invariancy here is provided at the level of preconscious, prelogical perception.

But as to acquired invariancy, it is an approximation to the logical level, if only a preverbal one. Take such pairs of pictures: a "palm" and a "fist", a "sitting dog" and a "running dog", a "tea-pot" and a "tea-kettle". They are generalized in our conscience as "hand", "dog" and "tea-kettle", and in that sense are invariant. But for the visual apparatus, the palm and fist are different pictures. The recognition time grows at once, if in the set of pictures we suddenly replace one such picture by the other, since the alphabet of visual images is by far inadequate to the set of word-notions.

Science has dealt with invariants for a long time. And for a very long time it was considered that the visual system can accept invariants only because it learns. The innate invariancy to size, for example, was explained as follows. Depending on the distance to an object, its size on the retina is different, and also different will be the "stimulation pattern" in the brain. An animal or man correlate the pattern with the distance, and now we have a new, generalized pattern formed, that is independent of the distance (and hence of the size of the image on the retina). Bishop Berkeley, who initiated Berkeleianism, could not see another path. He maintained that only by touching with its hands could a baby relate the size of a picture on the retina with the object's distance.

And in the 1960s it was proved that touch is not the teacher of our vision, but rather on the contrary. In the experiments performed by the American physiologist T.G.R. Bower, two-month-old babies were involved, who clearly could not correlate visual and tactile signals. The work followed the classic scheme of conditioned reflexes. And when it was necessary to stimulate a baby, he was not fed, like a puppy or a kitten, instead he was played with "ku-ku". Suddenly from under the table, a pretty girl appeared, smiled and said merrily "ku-ku", and so for such spiritual food the baby kept participating in the experiment without going to sleep.

What did Bower do? He arranged different-sized blocks in such a way that their images on the retina be similar in size. And vice versa, blocks of equal size were positioned in such a way that on the retina they would be projected as different-sized objects. All the tricks proved in vain. The baby never mistook his "own" control block for its imitation.

The baby could not be deceived because he viewed the world with both eyes. We perceive the depth of space, as it is now believed, because the right and left eyes see pictures in a somewhat different manner: not just the façade, but the sides also. This has been known for about 200 years ago. True, there are advocates of the view that the depth, and hence the distance, are the result of signals coming from the muscles bringing in line the optical axes of both eyes (otherwise a double image would be seen).

This opinion, however, is unlikely to be true. Take, for example, the stereoscope: the eyes are not brought in line, the optical axes are parallel, but the depth effect is there. By the same token: to judge distances from muscle sensation, a unique relation between the signals of muscles and the distance is required. As early as 1959, however, Glezer proved that we estimate distances from 30 to 50 times more accurately than muscle sensation allows us. Finally, how could we possibly perceive the depth of space in a flash of lightning, should everything be explained by the signals from the muscles? The flash being so short, the muscles would have no time to adapt.

No, the explanation is much simpler. A generalized image, transmitted by the visual apparatus to the higher parts of the brain, is invariant in very many parameters. The "life experience" of a living thing consists exactly in that it learns correctly to estimate variants and distinguish when a mushroom is small because it is really small in size, and when it seems small because it is far away. For the second estimation there exists an innate mechanism of ranging (clearly, not in metres, but from the relations between objects, and as a result of a change in the "face" of a thing).

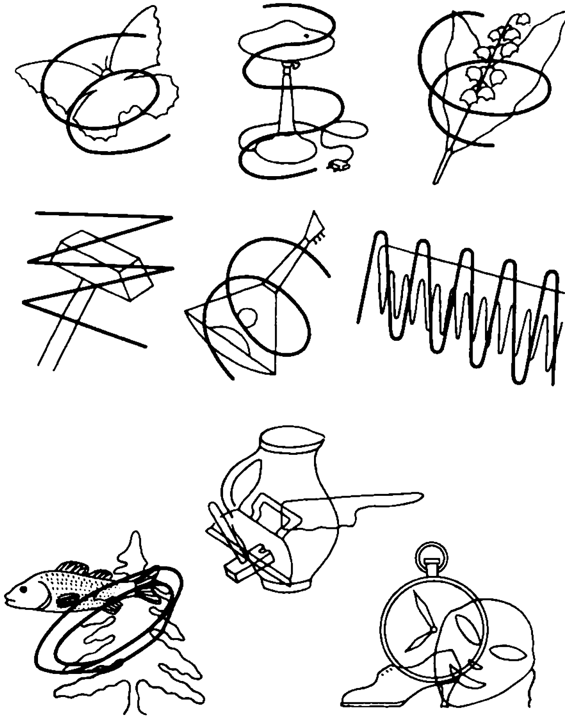
In the brain there are also other innate devices to determine spatial relations, say, to define the sector of the visual field in which an object resides. This follows from a variety of experiments. For example, in the Laboratory L. Leushina showed subjects shapes for such a short time that it was impossible to identify the pictures. But all of them unfailingly determined whether "something" appeared from above or below, from right or left. That is, to estimate the location it is by no means necessary to know what the object is.

Yarbus has discovered one more interesting feature of the functioning of the visual system. He has established that when something moving appears at the edge of the visual field, where one is yet unable to perceive the form, one shifts sight to the object in 150-170 milliseconds. And does so exceptionally accurately: a pause, then a quick shift of the sight, and the fovea on the retina looks directly at the "object". And further, the eye traces the motion flawlessly. What does it mean? Only that the information about the object's movements—speed, direction, acceleration—has been received before the beginning of clear vision. Motion detectors have been found in the retina of the eye of the frog and the dove. In cats, those highly organized creatures, appropriate neurons are located in the cortex. This leads us to conclude that such cells, obviously, are present in man too. Nature, without a doubt, has not deprived man of such an important mechanism of identification.

Consequently, in the visual system, several channels function simultaneously. One of them transmits generalized images, a sort of information invariant to size, brightness, colour, and so on. And other channels transmit information dependent on the object, inherent in it, such as size, colour, and so on. And only further, in the higher parts of the brain do these data merge to give a comprehensive picture of what opens up before our sight. This hypothesis Glezer put forward in 1966, and today the multichannel nature of visual perception has taken on aspects of a theory. The visual apparatus, acting on the multichannel principle, is very compact and rational. After all, size, brightness, colour, and other properties can be equally inherent in a tree, a camel, and an airplane. Channels bringing information about these features to the brain may be constructed relatively simply, because the very properties (save for colour) are simple. Then all the joint forces can take care of the main channel, that of form identification. It seems that, on all the evidence available, nature constructed our vision in exactly this fashion.

The division of roles occurs not only at the level of subsystems of the visual apparatus. The cerebral hemispheres also mind their own business, each solving its specific problem. This was hit upon by studying agnosias, "mental blindness". With such mental derangements the higher nerve functions fall out, the work of the visual mechanism, speech, and hearing are disrupted. But these diseases are unusual. Take, for example, visual agnosias, these are related neither to retinal disorders nor to optic nerve troubles. The afflicted persons experience neither excessive far-sightedness nor excessive near-sightedness, not infrequently they have a normal field of vision—everything seems to be in order. At the same time the patient does not recognize his acquaintances, in especially acute cases he would not be able to say whose face is looking directly at him from a mirror. In other respects, he is an absolutely normal man with seemingly no deviations from the norm.

Sometimes the man sees objects but does not recognize them, so he may call a bench a sofa, a pear a flower, a telephone a clock. But he sets the arms of the clock correctly, exactly on the time that the doctor indicates. Or sometimes he may be unable to name an object without touching it. Or else, can say nothing about colour and shape, but gauges size correctly. Or again, he may see letters, but takes them simply as pictures, although he immediately remembers their names once he has traced their outline with his finger, like a child. Or he cannot read, does not recognize letters but manipulates with digits with obvious ease. Or.... Perhaps that's enough examples. These are too many, and each is a piece of evidence in favour of a fairly complex construction of the visual apparatus and the entire perception mechanism.



With some agnosia forms, patients are unable to make out a figure against the background of interfering lines and other figures: generalized images stored in their memories are inseparable

Physicians noticed agnosias long, very long, ago. Their main forms were described back in the past century. More sophisticated experimental techniques that have come in recent decades have substantially expanded the list of agnosias. After all, it is exceptionally difficult to uncover such specific disorders. When the retina is damaged, the man immediately notices that his "window into the world" has become narrower and distorted. And an agnosia case may not even notice his disease. He often complains, not always however, that he for some reason has begun to see poorly. It even happens that when an examination reveals agnosia beyond any doubt, the affected person does not want to believe it.

From victims of agnosias and results of operations (sometimes these disorders are consequences of haemorrhages) physicians can get an idea of which cortical areas take care of which functions. Drawing on the results of such works and on personal observations, the Soviet physiologist Elena Kok in one of her last books writes that "concrete and abstract perceptions, to a certain degree, are separated and are provided for primarily by different hemispheres. In each of them there exist anatomically separated systems providing for the perception of colour, shape, size, etc., and in the left, more abstract hemisphere these systems are more distinctly pronounced."

And still, however convincing the observations of the cases, physiologists had their doubts. But what if the interhemisphere relations distort the true picture? The fact is that experiments on animals have yielded evidence illustrating both the enormous role of such relationships and the potentialities of absolutely independent activity of each hemisphere. We refer here to the famous "California cats", so called because the experiments were performed at the California Institute of Technology. In the late 1950s the American physiologist R. Sperry severed in several cats the corpus callosum, a "bridge" of tens of millions of nerve fibres connecting both hemispheres. After the operation, there were many expectations, but not that each half would function independently, as if the animal had two brains, which is, in fact, what happened.

How was this discovered? By providing connection of each eye only with one hemisphere. Normally, the retinas of both eyes are connected to each hemisphere: the right halves of the retinas are connected to the right hemisphere, the left ones to the left hemisphere. If the chiasm, the crossing of optic nerves, is severed, information will come from each eye to the hemisphere on the same side, true, only from one half of the visual field, but there is nothing to be done here. Incidentally, for a perfect experiment this is not a large hindrance.

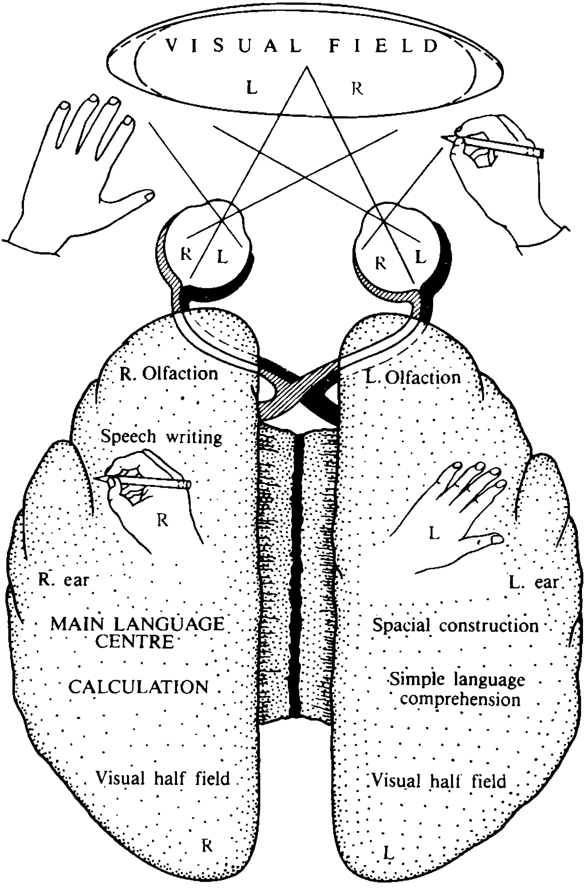
Thus, Sperry transected the corpus callosum and chiasm, with the result that two complexes, "eye-hemisphere" were formed, each of which could be taught to respond to its "own" stimulus. The left complex, for example, knew that food lay beyond the door with a circle, and the right one was in the same way absolutely confident that it was hidden behind the door marked by a square (to be sure, during the learning and control experiments the "superfluous" eye was covered with a patch).

But what will happen if the corpus callosum is severed in man? How will the hemispheres behave? The answer to this question came in the early 1960s, after the American physiologist M. Gazzaniga and the above-mentioned R. Sperry placed under observation a patient on whom such an operation had been performed (neurosurgeons thought that in such a way it would be possible to save him from a severe mental disorder).

No similarity with the cat was observed. The human brain proved once more that it is a unique formation. Of course, anatomical features common for all the vertebrates could not be disregarded: the right side of the visual field is accepted by the left hemisphere, and the left side by the right one. But in everything that concerns mentality, the hemispheres exhibit their distinct individuality.

Take, for example, an apple that appears in the right half of the field of vision. A man with severed corpus callosum will with confidence call it apple, and will readily write the word, since the left hemisphere is responsible for speech and writing. But just transfer the apple to the left side of the visual field that is, make it so that the information will only come to the right hemisphere, and you will hear nothing and have nothing written on a sheet of paper. Why? Because, as Gazzaniga and Sperry have observed once more, the right hemisphere has no "capability" for the verbal expression of information. This does not mean to suggest, of course, that the right hemisphere is "stupid", it is just different. The right hemisphere is dumb, but quite reasonable: having read in the left field of vision the word "pencil" the patient will find this object by feel, and conversely, having felt in the left hand a pencil, he will find a card with the required word written on it. And everything in complete silence, although sometimes words are spoken, but unfortunately without any connection to the situation. Gazzaniga wrote: "The patient may call a pencil put into the left hand (beyond the visual field) a can opener or lighter. Verbal hunches seem to have come not from the right hemisphere, but from the left one, which does not accept the object, but tries to identify it from its indirect signs."

In the Soviet Union it is prohibited by law to transect the corpus callosum intentionally. Soviet scientists believe that the cost paid for the cure of a mental disorder is too high in this case. Too devastating is the damage to the human being. But the case may be that in an attempt to save the patient's life (removing a haemorrhage or a malignant tumour), the surgeon's knife may penetrate those forbidden areas. After such an operation, patients are subjected to an especially thorough examination. The world appears before them in a fairly changed manner,



Functions of the hemispheres

and so they will have to be taught to act correctly in their new space. In addition, neurophysiologists obtain valuable evidence that sheds light on the structure and functions of the brain. In the USSR these studies were initiated by A. Luria in the Neuropsychology Laboratory of the Burdenko Experimental Neurosurgery Institute.

The investigators of the laboratory always begin narrating their observations and concepts with a small historical outline. Well, what was thought before the studies of the split brain? It was thought that from agnosia studies it would be possible to construct an absolutely accurate scheme of the arrangement of the identifying systems in the visual cortex. For example, here is colour, here shape, here size, here recognition of faces, and so on. But the "split" brain has shown that the connections between the hemispheres play an extremely important part here and obliterate the actual volume of problems solved by each hemisphere.

The identification of visual images, which had been traditionally assigned to the left hemisphere alone, appeared to be inherent in the right hemisphere as well. The visual information coming to both hemispheres does not vanish completely in the right one, it is there processed in a different manner than in the left hemisphere. Different processing techniques bring about differences in the end "product", that is, the information that the visual cortex supplies to the higher parts of the brain. These differences are not absolute, however. The right hemisphere, which is not responsible for speech and writing, is able, as we know already, to understand what has been written.

The role of the right hemisphere in identification seems to be a legacy from all those living creatures that has crawled up the evolution ladder to put man on the top. In many respects, it has retained its "beastly" habits. What is most important for an animal? To sort out the properties of an object: danger — no danger, edible — inedible, warm — cold, and so on. And it is exactly these capabilities that are inherent in the right hemisphere in man.

... Clad in white overalls I am sitting in one of the rooms of a laboratory at the Burdenko Institute. To the patient, I am a doctor, and my presence does not embarrass him.

"What is it?" The doctor puts on the table in front of the patient a picture: an ostrich is running through an African desert.

"Don't know.... Something is running.... Here ... sand or water.... Maybe sky?"

"Don't let us make conjectures," the doctor calms down the patient, "you'd better tell me whatever occurs to you. What do you think, is it a living thing or not?"

"Living."

"Right, very well. But cold or warm?"

"Warm.... So smooth, like feathers...."

"Excellent. Has it legs and a tail?"

"Oh, I always have difficulties with tails.... As to legs — here, I see, it has...."

"Is it large or small?"

"Large, larger than a man."

"What is it then?"

"A bear? Well, no... A bear.... It is something round, fluffy. A goose, maybe: you see, the neck is so long."

This man suffers from a severe derangement of the left hemisphere, but using his good right hemisphere, he determines the qualities of things, divides images, supplied to him by his vision, into classes having opposite properties. Divides even without recognizing them. That is, he divides in a way that very much resembles the "travel over the tree of signs". But using those basic antonyms, the man is not able to divide the entire "alphabet of images" to the end and to get to the bottom of things, he is unable to name an object. Why? Perhaps because exact identification is associated with the work of the left, damaged hemisphere?

This assumption is supported by the examinations of other agnosias. It turns out that for the left hemisphere it is important that the picture contained more details and looked as realistic as possible. A skeleton picture for him is an unsurmountable obstacle, an utterly incomprehensible thing. Whereas for the right hemisphere, it is much easier if the information is more schematic. It fails to make out a sparrow drawn with all its feathers, but immediately takes in a sparrow given in a symbolic, especially "children's" manner.

The multichannel nature accounts for many aspects of visual perception. The idea turned out to be of value for identifying devices, one of which was invented in 1973 by the Soviet scientists V. Kharichev, A. Shmidt, and V. Yakubovich. In this device, the information coming from an artificial retina is broken down into two flows. Then these "halves" are processed in a different manner, deriving two kinds of information. The first kind of the information tells us about the configuration of an object, that is, if it is a house, a wolf, or a man, but tells nothing about the size or spacial arrangement. On the other hand, the second kind of information, although telling us nothing about shape, will give us all the information about size, brightness, arrangement, and so forth. Put another way, the system derives from the "contents" of the image such properties that, from the point of view of grammar could be called nouns (table, tree, cat, etc.), adjectives, and adverbs (large, small, from above, from the side, etc.). Remarkably enough, if a computer is taught these notions during its language learning session, it will then identify even such objects it has never been shown.

For example, having mastered the notions "big house", "small cat", and "table", the computer readily identifies the picture "small table".

So much for the multichannel nature of the visual apparatus. As for the generalized image, so important for the identification of an object or an image, completely stripped of all its specific features, it seems to be what enables the brain to refer to all the tables as tables.

It is an abstraction of the table.

The very abstraction that defies all words.

Chapter Nine

Library or Telebrary?

... A clear mind is nothing but the ability to bring thoughts together, to tie already known ideas with less known ideas and to express them in exact and clear words.

Helvétius

Around the end of the first year of life, a baby for the first time pronounces the word "mother" — the tiny human creature makes his or her first step toward comprehending abstractions, to which words belong. But so far the degree of abstraction, the gap between reality and sign (word) used to denote it, is negligible. For the baby "mother" is just his own, unique mother, while all other mothers are not. Each doll has its own name and there is no "doll in general".

Another year passes and the word "doll" comes to mean the doll that the kid takes to bed, the one with which other children play, and the one displayed in the shop-window. The word comes to embrace all similar objects, its abstraction being raised to a higher level.

Another year or so, and our kid masters the word "toy", which includes dolls, and building blocks, and a plastic airplane, and an electric railway. The "power" of the abstraction of the word has grown drastically, the word now denotes things that differ markedly in appearance and function, and the relationship between the tangible image of a thing perceived by vision or touch and the word that denotes the thing becomes ever more elusive.

Finally, by five years of age the child achieves a degree of abstraction that places him or her at the level of an adult. So, the word "thing" denotes now not only objects but also abstractions of lesser rank — "toy", "furniture", "clothes", and so on. The relationship to a concrete image becomes negligible.

This is how the psychologist M. Koltsova describes the development of speech in a child.

But neurophysiologists maintain that by four or five years of age the brain of a child grows to resemble the brain of an adult in a very significant detail of its structure. This detail is the asymmetry of the higher functions of the right and left hemispheres. Until the "critical" age has been reached, both hemispheres can properly perceive speech and control it (the child's brain is very flexible, so if the left hemisphere is damaged by some disease, the right hemisphere takes care of speech). But once the development of the child has crossed a certain threshold, the flexibility is gone, and so the right hemisphere becomes "dumb" for ever. To be sure, this occurs not abruptly but step by step, but the result is exactly like that.

One may well ask, is the growth of the "power" of abstraction of the word and the restructuring of the functions of a hemisphere a coincidence or something more profound? The workers of the Laboratory have answered this question in quite a definite way: it is not a coincidence, by no means. This means that.... But let us digress a bit and consider some historical facts that will put what follows in the proper perspective.

When about a century ago the French anthropologist Paul Broca (1824-1880) came to the conclusion that it is the left hemisphere that takes care of speech, and discovered there a region, the destruction of which disturbed the speech function, the "speaking" hemisphere, from respect for such an important thing as speech, was called the dominant hemisphere, and the "silent" one the subdominant (subordinate) hemisphere. (To a certain degree the terminology is responsible for the fact that researchers concentrated on the dominant hemisphere, and it has not been until fairly recently that they have found out that the subdominant hemisphere is well worth studying as well.) By the way, in a right-hander the dominant hemisphere is the left one with a probability of 95:5; and in a left-hander the ratio is only 35:65, that is, dominant is mostly the right hemisphere. For some unknown reasons, there is a premium on being a left-hander in some sports that do not require much endurance and prolonged physical exertion but rather place heavy demands on reaction, for example, in fencing. But since left-handers are a minority, in what follows we will for simplicity refer to the left hemisphere as the 'speaking' one without, of course, forgetting the real state of affairs.

Long before the experiments by Gazzaniga and Sperry, which made the front pages in the 1930s, electrotherapy emerged—a treatment of mental disorders consisting in passing a weak electrical current through both hemispheres. So, this treatment cured hallucinations and removed the fixed idea of suicide. But late in the 1960s L. Balonov and V. Deglin of Leningrad, USSR, noted that a current fed to one hemisphere switches it off, leaving the other hemisphere totally or nearly totally unaffected. During the treatment the patient remains conscious and can even talk with the doctor, that is, take part in the experiments, which are all the more valuable since the brain separated in such a way has not been damaged surgically. Their experimental findings Balonov and Deglin described in their book *Hearing and Speech of the Dominant and Subdominant Hemispheres.*

Amazing things have been revealed. Above all, the hemispheres very closely interact. But the interaction is not activating or "helping" in nature as might be expected, it is inhibitory: when one hemisphere is disabled, all the functions of the opposite one become much keener. (Strictly speaking, a measure of mutual assistance does exist, but we shall dwell on this a bit later.)

If the right hemisphere is suppressed by current, the burden on the left "speaking" one becomes larger: a man becomes very convivial and talkative, he interferes into other people's conversations, addresses everybody with requests and advice, comments loudly on the behaviour of all those around him. He behaves very much like a tipsy man — by the way, alcohol in the first stage of intoxication stronger affects precisely the right hemisphere.

But this is not the whole story. With the right hemisphere disabled the voice becomes unrecognizable — in some toneless, husky, hoarse, in others snuffling, in yet others the words come out intermittently, they sort of choke on them, and still others lisp or bark. The habitual cadence and melody of speech are gone, there are no logical and emotional pauses, ups and downs in tone, stresses appear in most unexpected places.

And when the left hemisphere is affected, the subject is silent for a time, because the "speech centre" has been suppressed, but in several minutes, after the shock is over and speech is restored, he starts quickly, clearly and expressively (the right hemisphere responsible for the melody is functioning!) to utter incoherent, broken phrases: "... passed me, let me in quickly, how I recognize myself ... ask me, I'll take everything myself...." And the subject becomes very cross that the doctor understands nothing — the anger expressed by vehement gesticulation and grimaces. It turns out that the "speech centre" not only controls the speech apparatus, but also determines the relations of words to what a man wants to say (that is, it seems, to those wordless images that emerge in the brain and come before pronounced words).

And how does the subject react to phrases addressed to him? Balonov and Deglin's findings were beyond expectation.

It was found that the right hemisphere, which was traditionally believed to have nothing to do with word recognition, does play an exceptionally important role in the process. Should it be rendered inoperative, any, even the slightest, interferences confuse the left hemisphere, with the result that it becomes unable to perceive speech. But even if there are no interferences, the subject cannot feel the intonation. While understanding perfectly what is said to him, he is indifferent as to how it is said. Not only emotional perception is gone. The patient decidedly refuses to repeat after the doctor the suggested intonation, just because he simply cannot do this, try as he may.

But when the left hemisphere is suppressed, without understanding the words addressed to him the man reproduces the melody of speech much more exactly than when both hemispheres are operational.

The right hemisphere is also responsible for the understanding of "objective noises", such as the shattering of broken glass, the gurgling of water, the banging of a door, sneezing, snoring, and so forth, including sounds that accompany all sorts of natural phenomena, human actions, and operation of machines. These complex sounds, which cannot be described by words (and the right hemisphere is dumb! — interesting relation, isn't it?), enable us to visualize whole pictures. It is on this ability that all the radio dramas are based — we literally see from sounds as the personage climbs stairs, produces keys from his pocket, unlocks the door, and enters his flat. If the right hemisphere is out, the man can imagine nothing. He just hears a meaningless jumble of words, which invoke neither pictures nor concepts.

With the right hemisphere switched off, it is impossible to recognize even a familiar melody. When asked to sing something, the patient normally refuses and if he concedes, he will sing out of tune, confusing and distorting the melody. But the words of the songs (even if they have nothing to do with the melodies) are just bursting out of him, again suggesting the picture of alcohol intoxication.

When the left hemisphere is suppressed (and hence the right one is activized) any tunes are perceived clearly and reproduced correctly, the patient can even reproduce the rhythm, but he can neither name the song nor remember the words.

The left hemisphere is words, the right is melody and tunes. Everything seems to agree with the scheme of "thinking" and "artistic" characters, to use the words of I. Pavlov: "... Artists grasp life as a single whole, totally, completely, a living reality, without any fractionating, without any separating; others — thinkers—just fractionate it, thereby sort of killing it, and making of it some tentative skeleton, and only then they, as it were, reassemble its parts and attempts to revive it somehow, an endeavour in which they fail completely."

It is now widely believed that the left hemisphere is responsible for abstract thinking, and the right one for concrete, figural. But to recognize this means, sad as it is, to return to the starting point, as the recognition suggests no approaches to the analysis of the mechanism of such a separation of perceptions. But the workers of the Laboratory have been engaged precisely in the search for such a mechanism.

They showed pictures to subjects for a short time, such that the halves of the brain *a fortiori* had no time to exchange the information, and they directed images alternatively to the hemispheres. To this end, as we know already, it is sufficient to present images in one or the other half of the field of vision outside of the overlapping region (look at the figure showing the brain and its "right-left" functions).

The subjects were asked to identify either shape (to say "goat" or "leaf", "dog" or "window"), or shape and size at the same time, or shape and location of a picture in the visual field — higher, lower, to the right or to the left. Why shape was always required is clear, because it is the most important feature of any object.

Similar experiments — but only similar — have been carried out before by many researchers. So, other scientists were only interested in which types of pictures or which signs of images are better identified by the right hemisphere, and which by the left one, how the identification relates to speech, and so forth. But now it was decided to identify mistakes made by a man when recognizing images now by the left and now by the right hemisphere, and also the systematics, frequency and patterns of these mistakes.

A picture is exposed for quite a short time, at times a man seems to have seen nothing, but the experimenter insists, "Answer even if it seems to you that you have seen nothing!" There is no escaping. But it seems from thousands of answers that some mistakes are more frequent than others. And so, some mistakes are systematic and others are random. Most interestingly, with most subjects the mistakes of the left hemisphere are identical, and the mistakes of the right hemisphere are different with different people.

The left hemisphere errs, as it were, in a symmetric way: a figure A is always confused with G, and G may be confused with A. In exactly the same way B and V appear similar. But this hemisphere will never confuse a figure from one pair with a figure from the other, so that A will never be mistaken for B, nor V for G. Never!

But with the right hemisphere we have terrific chaos. Picture A is mistaken for G, B also for G, and G now, for some strange reason, is confused with V and not A.

Confusion may be different with different people but still the right hemisphere does not display the "pairedness" inherent in the left one.

One more important detail: the right hemisphere identifies the shape the more accurately, the more accurately it perceives a second, companion sign, for example, size or location. A mistake in companion sign nearly always results in a mistake in shape. On the other hand, the accuracy of perception of companion signs is immaterial for the left hemisphere. It picks up shape with equal efficiency, whatever the mistakes in arrangement and size. What is more, attempts to identify shape and a companion sign simultaneously normally failed, the shape mistakes being more frequent.

What does all of this mean? First of all it means that the right and left hemispheres perceive the same picture differently. It would seem that this is absurdity — after all, the appearance of objects does not change when we look a bit to the right or to the left. But "absurdity" is an illusion akin to many other illusions. Owing to continuous jumps of the eyes, a picture alternately gets into one or the other hemisphere, the overlapping zone, too, makes its contribution, and furthermore the hemispheres exchange information.

What is more important is that if we accept the concept of a "multichannel" visual apparatus which is currently being worked on in the Laboratory, the difference in perceptions will be quite rationally explained in a way that agrees with the data of neurophysiology.

The left hemisphere, when it identifies shape, only distinguishes what enables it to tell one figure from another, that is, it singles out generalized signs. But, as is easily seen, these signs in different figures may show one or another measure of likeness (for example, at a quick glance you may well confuse a domestic goose with a swan, but never an airplane with a cow). The reason for which mistakes are "paired" is as follows. Images A and G have some signs of their own that make it possible for a hemisphere to consider them congenial, in exactly the same way B and V have signs that make these figures very much alike in perception. On the other hand, the "pairedness" suggests that the signs for each pair differ markedly, that is why we do not have a "leap", that is, erroneous perception of a picture from one pair as a picture from the other pair. This all goes to prove the assumption that the mechanism of "travelling over the tree" is located exactly in the left hemisphere. When an identifying mechanism reaches a "fork", where on one side are the signs of A and on the other side of G, it has to decide on its further direction. And since it works under pressure, decisions are taken without adequate justification: instead of A shown to him, the man "sees" (it seems to him that he really sees!) G. And he says so. And when G is shown, the same mechanism of error will operate with the result that it will seem to the man that he sees A. But figures B and V (or rather their signs stored in the memory) are located on absolutely different "branches" of our "travel over the tree", and therefore under no circumstances these figures can be confused with A or G.

In the right hemisphere visual identification is organized in quite a different way. Here the visual apparatus describes an image in intricate detail, not just some of its signs, as a whole and not fragmented. Therefore, instead of "travel over the tree" we have something here resembling going over cards in a card catalogue. In that case, figure A can only be confused with G if it comes before G, but G can never be confused with A, since there is no way back and the search is in one, rigidly specified, direction. Figure G, in turn, may be confused with V, which is located somewhat further. True, there is no saying why we have exactly that succession, not another one.

As to errors when attempting to identify simultaneously the shape of a figure and its size or location, or all three signs at once, an analysis of errors allowed us to make a conclusion no less important than previous ones. In the left hemisphere each sign — shape, size, and location — is analyzed by a separate identification channel (we have already discussed this without any reference to the hemispheres). And so, in the right hemisphere all the signs are tangled to form a tight knot, and there are no independent channels, but instead there is a whole image, which alone is analyzed.

This implies that the left hemisphere, identifies using separate channels, and along each of them receives a fairly sketchy image of the whole, the most important signs being sifted from secondary ones. That is, the left hemisphere identifies in a very generalized, abstract way, a hard and fast fact now, not just an assumption. And the right hemisphere identifies wholly, using all the richness of signs, extremely concretely.

But is it conceivable to achieve abstraction without a preliminary acquaintance with reality? Abstractions of the type "large-small", "far-near" and the like, seem to be inherent in the organism from birth, being transmitted genetically. After all, such abstractions are even inherent in the visual apparatus of such a primitive creature as the frog. But abstraction of the type "table" or "car" undoubtedly come into being as a result of our contacts with the surrounding world. For them to emerge, first we have to see a car or a table.

A question poses itself: could it be that the development of those abstractions comes easier to the left hemisphere because it is already adequately equipped for the task? For example, it has an inborn mechanism responsible for the invariance of perception: having perceived the image of the same table, but at different distances (that is, on different scales), the left hemisphere signals that this is the same table. But the right hemisphere will have to learn this, and it is only capable of performing that task only in case of need, and only up to a certain age, before the specialization has been completed. Such was the hypothesis that explained the separation of functions between the hemispheres, which has been put forward by the workers of the Laboratory.

Hopefully it is now clear why nature has endowed us with two hemispheres: the right one comprehends the concrete world in the richness of detail, and the left one generalizes the information gleaned to cognize the world at the level of abstractions, including verbal ones. The right hemisphere is a sort of store of images, without any significant connections between the images. The left one, although it is in no position to perceive an image in such detail, takes care of connections between things and perceives the meaning of events. The human brain contains, as it were, two reseach centres: the right one exploring *terra incognita* (abstractions are of no use with the unknown), and the left one examining the simplified version, stripped of "superfluous" detail, of what has been comprehended by the right part, that is, perceived concretely.

Such an approach explains a wealth of facts that have earlier baffled the researchers. It is common knowledge, for example, that the right hemisphere recognizes faces, an ability absent in the left hemisphere. Now in an experiment, the left hemisphere of a subject was shown photographs of well-known statesmen and movie stars. Surprisingly, that hemisphere recognized them better than the right one! If viewed from the traditional understanding the workings of the brain, the result is shocking. But now an explanation is available. The left hemisphere is also involved in recognizing faces, but familiar faces are recorded in it better, in a more condensed way, using some clear highly specific features, that is, in a more abstract way than in the right one.

It is worth noting, however, that speaking about abstractions we tacitly implied the familiar generalization on the verbal level, which is a sign level (a sign viewed not as a picture, but as a carrier of some meaning couched in words). These abstractions are largely the concern of the left hemisphere, whereas the right one is able to abstract in another way. For example, it can find among rather intricate and diverse figures similar ones. Remember Polonius who after Hamlet found a cloud resembling now a camel, now a swallow, and now a whale....

What is likeness? Mathematicians say that hidden in this notion is some projective transformation (we will not, however, plunge too deeply into that definition), and so the right hemisphere seems to perform that operation. It can find a circle of a suitable diameter from a piece of circumference, and it can mentally piece together a figure cut into fragments, to compress it, shift, expand, bend and to work out the result, again mentally. This is all beyond the capabilities of the left hemisphere.

The right hemisphere seems to be of special use for design engineers, who sit at their drawing boards for days on end, for architects and for builders — all those dealing with spatial transformations. And this being so, the abstractions with which the right hemisphere is concerned are hardly less complex and profound than those of the left one. Simply they, those abstractions of the right hemisphere, are different and, alas, inexpressible in words, therefore we know very little about them, just as about the functioning of the right hemisphere, far less than about the left hemisphere.

Anyway, let us try and venture beyond the confines of visual images and perceptions, let us ponder the fact that the right hemisphere's speciality is concrete comprehension, and the left hemisphere's, abstract generalizations (we will remember from the very beginning that we are fully aware of the limitations of this model and of the need to clarify the range of problems handled by each hemisphere and their role in this joint effort).

Observations of patients with severed corpus callosum have shown, in the words of Gazzaniga, that "separation of hemispheres produces two independent spheres of consciousness within one skull, or rather in one organism." Clearly, those spheres also exist in the brain not severed by an operation. And the fact that the left hemisphere is capable of speaking and understanding speech, and the right one is not, leads us to the conclusion that the thinking processes in the left hemispheres can be represented in terms of words directly (it should be stressed again that we fully understand how arbitrary our "directly" is here), and the result of the processes in the right hemisphere will only be "heard" after some transformation, that is, after it has been passed on to the left hemisphere to be shaped as a piece of speech. Einstein believed that once a problem has been solved in the evocative, wordless inner language the tantalizing task of groping for the right words to get the solution across to other people's minds then comes. Words are means of input and output of information, and in the central processor some processes occur that cannot be put into words. This suggests some far-reaching analogy with the computer: before the printing device has yielded the results, the outside observer remains absolutely ignorant of the transformations proceeding within the bowels of the "electronic brain".

This leads one to make another conclusion (which has of late been discussed by the members of the psychology community). It is now known that the right hemisphere controls our senses together with the left one, and if an emotional stimulus comes from the right hemisphere, a man with his corpus callosum severed is unable to explain why, say, he enjoys something. Now it may well be asked whether or not some of our "unexplainable" deeds and feelings are due to the right, silent hemisphere, when the result has not been transferred to the left hemisphere or for some reason has not been deciphered, and hence in either case it cannot be couched in words? Or perhaps "subconsciousness", the catchword not only of mystics but also of artists, poets and writers (all members of creative arts), is just a product of the activities of the right hemisphere, which is known to be more prone to comprehend the world in concrete terms than in logical terms?

Considering that verbal abstractions (that is, those at a very high level) are beyond the capabilities of the right hemisphere, is one to infer that man can only realize himself as a social creature as a result of the activities of the left, speaking hemisphere? Self-consciousness and the notion of socium, community of people, are abstractions of extremely high rank. To conceive them requires much serious thinking. It is worth stressing here that after having received those abstractions the left hemisphere sort of shares them with its companion. So patients with their corpus callosum severed are able to make use of the right hemisphere to perceive the meaning of a historic picture, to identify a national flag and also to evaluate it with a gesture as "good" or "bad" according to their respective social and political attitudes. But for the brain to be equal to those high abstractions it has to be trained to abstract at a verbal level. No wonder that children reared by wolves lose their power of speaking, because speaking calls for contacts with other humans. Studying mathematics, logics, and foreign languages is good training for the abstraction ability.

The differences in the roles of the right and left hemispheres in comprehending the world make it clear why an unbridled passion for television at the expense of reading is so harmful to the development and formation of a child. By its enormous flow of visual information, television mostly affects the right hemisphere (electroencephalographic records made in the USA indicate that the right hemisphere is three times as active during watching a TV programme than the left one). The quick change of images, and the impossibility of replaying insufficiently clear pieces are negative aspects of any dynamic art, and they especially come out in TV, which works the livelong day. Even in cinema or theatre the spectator receives a definite, strictly dosed volume of information, and on his way home he can ponder what he has seen. But television keeps driving on and on, and one has to have a strong will or dislike the programme to switch off the set.

Comprehension (the transfer of information from the right hemisphere to the left one and the recording of it in words) takes both time and skill. Skill! — which is lacking in a baby, as we know that only by five years he develops complete abstracting power at the level of elementary concepts, so that television does not stimulate but on the contrary inhibits the formation of that important ability, the ability of thinking. Reports the American magazine *Readers Digest*: "The workers of the University of South California placed 250 gifted primary-school pupils before television screens for three weeks. Tests revealed a clear decline in all of their creative powers."

Conversely, reading actively shapes the abstracting power of the left hemisphere, and besides develops the power of visualization, that is, the power to record abstract words belonging to specific images. The last process is totally absent when viewing pictures on the screen.

As a result, a reader develops a more intellectual personality than the one who lives at the mercy of visual perceptions without taking the trouble of couching them in words, that is, at the level of abstractions.

In recent years computer teaching has become fashionable, which in essence is a form of TV, only a more boring one. It has its origin with comics-type pictures, so plentiful in instruction manuals and directions for use. Undoubtedly, such "comics" are indispensable for operational manuals, since they expedite the teaching process and reduce the probability of errors drastically. But in teaching at schools and universities .... Perhaps computer teaching deprives the student of something very important, namely of those rich associations that emerge when reading a text and that are related precisely to the abstraction, that is, to the essential ambiguity of the word. Perhaps the concrete character of computer images, their rigid specificity, kills the ability to think and to generate those unclear, although so valuable, inner images referred to by Einstein? Moreover, the right hemisphere "looks" into the past, and the left one into the future. All of this calls for thinking, and — nothing can be done about it — thinking in words.

Now then, what shall we collect for our children: libraries or telebraries?

Chapter Ten

The Flat Three-Dimensional World

The painter
Has painted his daughter,
But she,
Like a moonlit night,
Has drifted away from the canvas.

Leonid Martynov

Apes are fond of drawing. Normally they paint on paper some meaningless stripes and figures. But once, a young female chimpanzee named Moya drew something like a fish or an airplane. When asked, she answered "This is a bird."

Yes, answered. Moya, just like the other young apes Pili, Tatus, Koko and Washoe, has been taught a special language of signs so it can construct simple, grammarless, but still understandable phrases. In the absence of grammar and small vocabulary (about one hundred signals) the "ape language" resembles the speech of an eighteen-month-old baby. And just like the kid comprehending the surrounding world, Washoe may examine her face in a mirror for a long time and then point with his hand at the image and tell the shocked experimentalist "This is me."

And so, Moya has drawn a bird. Later in the presence of a whole committee of experts she has drawn it once more, and also a cat and a strawberry. Understandably the drawings were far from masterpieces of fine art, "but she is only three and a half years old," says Beatrice Gardner, who together with her husband Robert conducts those interesting investigations, "at that age even a human kid would hardly produce something better."

To be sure, those feats do not signal the beginning of an "ape painting" boom in the world, nor that the primate art has finally found recognition. Recent years have seen so much new in the understanding of our "lesser brothers" that it becomes increasingly harder to draw a demarcation line between the abilities of animals and man.

For example, it has always been thought that man alone can use implements and tools that he himself has produced for his use, and animals, including apes, only occasionally utilize a stick or a stone as an auxiliary means. The following piece of behaviour of an ape has been filmed: the ape takes or wrenches out not just any stick that comes its way, but only one that is suitable as a tool. These sensational results came from the primates laboratory of the Pavlov Physiology Institute. Firsov, MD, and co-workers let a team of apes free on the small island on Lake Yazno in the Pskov Region in Russia, and shot a stunning film that has been repeatedly televised.

The female chimpanzee Silva is trying to get a sweet from a deep hole, but cannot reach the sweet with her hand. She begins by wrenching out and debranching one stick, then after she has seen that the stick is too short, she gets another one, a bit longer, then a third one, still longer, and a fourth go gives her exactly what she needs, Her cousin Taras used a stick as a prop to keep the door of a box with a tidbit from closing. Says Firsov: "A stick in the hands of a chimpanzee becomes a universal thing. But after all, the ability to use a forked stick, or a twig as an object suitable for each specific case enables one to view this object as a tool, because it has acquired some generalized characteristic. Such behaviour in apes is similar to the activities of primitive man. Accordingly, the issue of "tool activity", one of the things which separates us, people, from animals, suddenly becomes more involved."

The journalist who interviewed the scientist asked: "If we are to believe that the primates are capable of making generalizations, doesn't this approach abstract thinking?"

"One and the same thing could be called a generalization by a physiologist, and an abstraction by a psychologist," came the reply. It turned out that apes taught to choose the larger single object completely ignore changes in the experimental conditions if they are required to choose between a large and a small set of signs on cards. *Accordingly, apes are even able to make some generalizations.* And generalization borders on conceptualization.... True, it has been held so far that the concept is inseparable from the word. This inseparability, however, is only inherent in man. But in animals, according to modern thinking, concepts are simply different, namely they are less sophisticated than verbal human ones. Scientists are led to conclude that the commonly accepted ideas about the functioning of the animal brain are in serious need of refinements. The nonspeech (the first one according to I. Pavlov) signal system "provides acceptance not only at the level of concepts, the level of images, as is currently believed. In the nerve mechanisms of the chimpanzee brain and, maybe in the brains of other anthropoids, some subsystem is traceable that provides for the perception at the conceptual, though preverbal, level."

Preverbal! How close this all turns out to be to the work of the visual mechanism, doesn't it? Even in man everything occurs precisely like this — "preconsciously", not in words, that is, rather similar to what occurs in animals. Why not assume that Moya's drawings are an attempt to express in images some concepts of her own, to expose to herself her own internal world?

Here we will leave the amazing apes and ask ourselves the question: what are pictures? Why now, when the industrial and scientific revolution made a photographic camera available to anybody, a device that in general gives a true representation of the brightness and colour of images, we still have painters who apply paints to their canvases using exactly such brushes as were used two and a half millenia ago by the painters of Ancient Greece? Why do pictures have prices that sometimes run into six-digit numbers, and some of them cannot be priced at all, whereas good copies, let alone reproductions, cost next to nothing as compared with the originals?

Perhaps it is all a question of how well a painter can please his customer? In fact, according to the Ancient Roman writer Elian the law in Fivas decreed that "painters and sculptors shall impart to what they represent features more exalted than in reality." And any debasing of the original subject was heavily fined. But now the techniques of retouching and photomontage have reached such heights that it is child's play for a good master to remove some unflattering details in a photographic portrait.

Or perhaps this is explained by the fact that the eye in general, and hence the painter's eye as well, discerns millions of shades of colour, and grasp even minute variations in brightness, whereas the best photographic plate is unable to convey even a small percentage of the colour richness of the world? Well and good, but there is also the palette. And it, just like the photographic plate, is limited in its technical powers as to colour, and especially as to brightness.

By selecting paints and artfully mixing them, a painter may produce the illusion of strikingly true ("just like a picture") relations of colours and brightnesses. On the other hand, measurements performed using even fairly rough instruments indicate that even approximate correspondence is lacking here, everything is "distorted". Perhaps then, a picture attracts us by its ability to pro-

Any piece of this drawing by Rembrandt appears as a disorderly tangle of lines. Viewed from a distance, the drawing shows a woman and a child

duce an illusion? But you know that any trick soon becomes boring. Remember the kaleidoscope, how many minutes would you be able to watch it without break? But a picture may at times captivate you for hours. And the most interesting thing, also confirmed by art critics, is that a beholder is equally capable of admiring both exceedingly true and fairly arbitrary representations of colours and outlines.

Things are even more confused by the very paradox of the picture. For one thing, it is just canvas or paper, for the other, it goes far beyond the framework of "simply" canvas or paper. Stated another way, the material nature of a picture is added to by the spiritual elements of whoever looks at it. Without the beholder and his perception no three-dimensionality emerges, there are no "true" dimensions.

Who will then give us an answer as to what is a picture? Let us try and look at canvases through the eye of an art critic who has a subtle feeling for painting. It may well be that this will bring us closer to our goal. What pictures should we take for our analysis? Perhaps the most suitable for our task are the postimpressionists, whose creative output, according to the Great Soviet Encyclopaedia, "by their problematics lay the foundation of the history of fine arts in the 20th century." The postimpressionists, who in their pictures reflected the "painstaking and contradictory search by painters of stable ideological and moral values." And by the way, we will try to find out what makes painters different from one another in general, besides that they paint in a different style, as is generally said.

"Everything in those canvases was permeated by sun; present here were trees, which no botanist could identify; animals, about whose existence the very Cuviet had not suspected ... a sea that as if it were poured out from the crater of a volcano; heavens in which no god could reside. Also present were cumbersome sharp-shouldered natives, and their children's naive eyes suggested the mysteriousness of infinity; and phantasy embodied in flame-red, mauve and sparklingly red shades; and purely decorative compositions in which flora and fauna eluded solar heat and luminescence."

This is Gauguin.

"The picture showed the Grande-Jatte Island. Here, like columns of a Gothic temple, towered some uncanny human creatures, which rather resembled some architectural structures and which were composed of spots infinitely varying in colour. Grass, river, boats, trees — all was as if in a fog, all seemed an abstract cluster of colour spots.

"The picture was painted in very light tones, even Monet and Degas, even Gauguin himself, would not dare to use such a light and such bright paints. It led the beholder into the realm of nearly unthinkable, abstract harmony. If this was life, it was a special unearthly life. The air flickered and glowed, but hardly a puff was to be felt in it. It was a sort of still life of the living, quivering nature, from which all motion had been completely driven out."

This is Seurat.

"With the help of red and green colours, he tried to express wild human passions. He painted the interior of a cafe in blood-red and dark-yellow tones with a green billiard table in the middle. Four lemon-yellow lamps were surrounded by an orange and green glow. The most contrastive, dissonating shades of red and green struggled and collided in the small figures of sleeping tramps. He wanted to show that a cafe is a place where a man may commit suicide, go crazy or commit a crime."

This is Van Gogh.

"At first in the foreground we see bright, nonharmonized coloured spots: tall stems of pines as if glued to the canvas, and compressed space, as if a folded paper sheet. Our glance slides up and down along the stems, next it wanders to the right part of the picture, to the clear outlines of the yellow stripe of an aqueduct. The aqueduct guides our glance away into the left part of the picture, and owing to the contraction in the linear perspective, it creates the illusion of some depth. Our glance traces the background, goes over to the mountain, and comes back to the forefront. Next comes a second round of the examination: the glance now goes the the aqueduct, to the mountain, trying to find its way in the mass of blue spots, and grasp the outline and volume of the mountain. Several orange and red dash brush dabs on the right part of the mountain and light-yellow strokes covered with a thin layer of the blue on the top produce the illusion of volume. And then the valley near the mountain acquires a measure of spatial length and the picture develops some depth. Slowly the space of the foreground comes out. Disorderly spots combine in the mutual arrangement and they begin to be accepted as ground and grass, shadows and light. Longer than anything else the spot in the right lower corner remains as a separate blue spot in the plane of the canvas. But then it joins the hill of clayey ground and appears as a long blue shadow on the ground."

This is Cezanne.

The first three quotations are from the book *Lust for Life* by Irving Stone, the last one from the collection of works by the workers of the Pushkin Museum of Fine Arts in Moscow entitled *Western European Arts of the Second Half of the 19th Century,* the contents of which I am going to draw on extensively in the rest of the chapter.

Four painters, four personalities, four different worlds on the canvas. Four worlds? Or maybe one, but transformed in accordance with the perceptions of the artist?

Critics are unanimous in their opinion. These and other postimpressionists are great not in their technique, although it is of significance and interest, but in that they were telling the world something totally new. They foresaw the upheavels of the 20th century. The Soviet art critic Levitin states: "Our century, with its grandiose wars,

The Dance in Moulen Rouge by Toulouse-Lautrec, 1890

social revolutions, millions of deaths, shattering of all the foundations of the world outlook started not according to the calendar and not with the First World War, but spiritually it started with the ecstatic turmoil of postimpressionism."

In order to express their sensations, the postimpressionists intentionally "distorted nature". In the picture *The Dance in Moulen Rouge* Toulouse-Lautrec exaggerates exactly those things that he wanted to bring out, draw attention to. In the centre are a pair of dancers, Valentin Le Desosse, named "the snake-man" and his partner La Gulue. Does anyone have such wavy legs as Valentin's? Have you ever seen knees where the audacious Toulouse-Lautrec has painted them? And when has a dancer, even the most dashing one, ever been able to twist so, as La Gulue does in the picture?

And also, have you ever seen such a wildly dancing pair? Have you ever happened to witness a picture, static in its texture, turn into a sort of cinemascreen? Just look, he shifts his legs, that Valentin Le Desosse!

Yes, the turn of the century was the time of search for artistic expression, and not only in France. Russian painters also made a significant contribution. The problem of the representation of motion was successfully solved by the Russian painter Surikov. His *Boyarynia Morozova* is precisely an example of that sort of mastery. The painter reminisced: "Do you know that for my *Boyarynia Morozova* I repeatedly added more canvas. My horse would not go, and in motion there are living points and there are dead ones. This is sheer mathematics. The sitting figures in the sledge hold it in place. I had to find the distance from the frame to the sledge to set the sledge in motion. Just a little bit of the distance the sledge will remain stationary. But Leo Tolstoy when he and his wife came to have a look at *Morozova* said, "At the bottom, it is necessary to cut some off, the bottom is not required, it interferes! But nothing can be removed from there — the sledge will not go."

And in that picture not everything is "like in real life". The critics of the time competed with one another searching for "irregularities": not enough place for the carter, the boyarynia's hand is too long and twisted in an anatomically impossible way, and snow in the street is not trodden down so that the sledge rides as if in the field.... The best answer came from Surikov himself: "Without mistakes the picture is so nasty that it is nauseating to look at. In a historical picture after all, it should not be exactly as it was, but there should be some similarity. The essence of the historical picture is guessing. As long as the very spirit of time is there, one is free to make any deviation in detail. And when everything is exactly like it should be — it is repugnant."

It thus turns out that distortions of this sort by no means indicate lack of proficiency in painting nor the desire to try to be original, a sin about which Toulouse-Lautrec and those who shared his views had to hear much. Those "distortions" are a means to reach the goal without fail.

What did Van Gogh try to achieve with his huge dabs, his sharp coloured contouring, his glaring colours, in short by all those procedures that emphasize the "unrealness" in his pictures? That is how he explained it in his letters to his brother Theo:

"I want to paint a portrait of my friend, a painter of great dreams, who works in the same way a nightingale sings, in this is his nature. The man will be a fair-haired. I would like to convey in my painting all the surprise and all the love I feel for him. So, at first I will paint him as accurately as I can. After that, however, the picture is not yet ready. To finish it I will become an arbitrary colourist. I exaggerate the fairness of his hair. I bring it to orange tones, to chrome, to light-lemon colour. Behind the head, in lieu of a conventional wall in a conventional room, I paint infinity. I make the background the richest blue, the strongest I can manage to get. In such a way, the fair, glowing head against the background of the richest blue colour will give a mystical impression, like a star in blue azure."

And now concerning another picture, *Lullaby*: this is a "representation of how a sailor, ignorant of painting, visualizes a woman on the shore, while on the high seas."

"I would like to paint so that all who have eyes would see everything clearly" — such is the creative creed of the painter.

And Cezanne's landscapes, as was noticed by art critics, are all based on curvilinearity. With him the classic perspective is distorted (note that Surikov, Vrubel, and many other painters were also accused of this "sin"). But Cezanne's many-grounds are of an absolutely different nature than, say, Poussin's. In works of old masters, a Soviet art critic attracts our attention, the landscape invited us into the depth of the picture forcing our sight to pass gradually from the foreground to the background. In Cezanne, on the contrary, it is almost as if the landscape counteracts the intrusion of the sight, forces it to overcome some resistance, to wander over the space of the picture in a fairly complex manner. The world of Cezanne is perceived in labours, in the active work of perception, because the painter "reconstructs the unified image of the world, logically passing over to the discovery of the emotional and philosophical perception of nature."

When looking at Cezanne's world, it seems that it rotates, rocking about the central axis of the picture. The painter turned out many canvases, trying to master the dynamics of bends in roads. He audaciously violates the canons of painting: his paints do not fade out in going over to backgrounds, as it was considered necessary according to the theory of air perspective (about Surikov's *Boyarynia Morozova* some critic wrote: "There is no air perspective, which could be easily achieved by erasing some of the figures of the background"), lines do not converge as is required by linear perspective. Objects seem to converge in the centre of the picture, the background becomes simultaneously far away and near. Cezanne painted "impossible figures" even when there was no such a term. He drew different sides of objects from different angles and connected them to form a unity, merged into a wholeness; his objects, as it were, turn in space now with one side, now with another, and such an unusual feature "conveys all the plastic expressiveness of the separate parts of the landscape.... The totality of procedures produces on the canvas a new picturesque space."

Exactly so, a space. To a painter space is different than it is to us. It is organized, it is subdued by the logic of artistic creation, it has none of the fortuities which are characteristic of the world we see through a window. Our sight involuntarily seeks some agreement, rhythm, order — such is the construction of the human visual apparatus (why this is so will be discussed later in the book). And the painter does the work of organizing the material for us: take it and use it.

You only need at first to make some effort, to teach oneself, one's brain, to view a piece of painting in a different manner than a car or a pair of shoes, that is, not in such a primitive and practical manner. To understand pictures takes some schooling. Children trace the outline with a finger to distinguish an object in a picture from others — the unskilled identification apparatus is confused by the tangle of lines. Their parents, sometimes with a measure of bravado, proclaim their lack of understanding of some painters: everything there is so different. They are unable to think of a picture as a window to another world! They consider their opinion the only criterion and applaud the critic who once arrogantly stated in a Parisian newspaper: "How can Mr. Corot see nature as he presents it to us. When strolling in the woods we never see trees similar to those depicted by Mr. Corot."

Such people are fond of photographs, especially colour ones. But even the photography of today is not what it used to be decades ago. The world of photographic image produced from a random point is a random glance. It is of absolutely no interest, what an amateur photographer uncovers having developed his first film. What seemed to be so beautiful appears nauseatingly boring: the mood that accompanied him when he admired the landscape is absent. But whence does it come from, that mood? How is it to be squeezed into the frame? "At present a technically skilled image is accepted as a fact, as something that goes without saying. Claims at artistic photography may only be made by works with profound content and perfect form" — having read this the beginner turns to theory. Much to his surprise he will reveal that modern photography seeks expressive means to no lesser degree than painting. A rich variety of objectives, special film processing and printing procedures; suffice it to open an illustrated magazine to see how differently are the approaches of photographers, how they go overboard in their attempts to express the world — exactly to express, not to reflect — with a maximal approximation to what painters do.

The super wide-angle camera ("fish eye") distorts image exceedingly, turning straight lines into arcs — just remember Cezanne. Solarization turns a photographic picture into a skeleton picture painted with a bushy brush — the extremely emphasized figures have been invented by Van Gogh. A coloured landscape made into a cluster of coloured points — Seurat, Signac.

No, I don't want here to act as a prosecutor of photographers, accusing them of plagiarism. Simply, this approach is very interesting, to make a camera into a sort of brush (although involved is not just a camera, but also many other technical means). The artists of photography take ever greater liberties in trying to answer the appeal of the Russian poet Maximilian Voloshin:

To see all, to understand all, to experience all,
All the forms, all the colours to take in by the eye,
To walk over the world with burning feet,
To accept all and again to incarnate.

And their attempts are not that unavailing. The further they advance the more they deviate from just copying space. They create their space on sheets of photographic paper, and comprehend the real world in their own way. They have no mercy removing anything extraneous from the frame, they make positive prints using two or three negatives if the expressiveness of one is insufficient. They see the world like artists, each in his own way.

Let us now recede into the past, two and a half centuries back.

St. Petersburg, 1715. Ten years before the death of Peter I a Marine Academy was opened there. It was ordered that the following subjects would be taught there: (1) arithmetic, (2) geometry, (3) small arms, (4) artillery, (5) navigation, (6) fortification, (7) geography, (8) the structure of a ship's hull and rigging, (9) drawing, (10) fencing.

In 1716 a Surgery School at St. Petersburg military hospital was commissioned. Here, too, drawing was one of the subjects.

What were students drawing? Parts of war ships, cannons? Organs of the human body? Nothing of the kind: landscapes and portraits! Why with the extreme shortage of educated people at the time, when it was necessary to train as many specialists as possible, did they waste time on a seemingly useless thing?

"Drawing takes as much activity of the brain as science," — who said this? A modern lyrical poet? No. These are words of the teacher of Surikov, Repin, Vrubel, Serov, Polenov, Vasnetsov — Pavel Chistyakov. "The teaching of drawing constitutes so important a subject for development in children of the ability to observe and comprehend, that in schools it should be put on equal footing with other subjects," — these words also belong to him. The names of his great students, artists of world reknown, prove with great weight the truth of his thoughts.

Perhaps now we are gradually coming closer to understanding why some paint pictures and others look at those pictures. And it becomes clearer why good pictures are so comprehensive in their expressiveness, why talented pieces of painting are so hard to describe in words. Is it not because behind a picture there is something more than just a desire of the painter to depict something?

To ponder.... To think about the world ... about your place in that infinite Universe and among your neighbours. A naked hunter would trace on a cliff the outline of a dear pierced with a dart and believe that now he would have his quarry. He tried to conceive the laws governing nature and, to affect them. He is not to blame that rationalistic ideas about the interplay of events took millennia in coming. But he, undoubtedly a man of genius, not only accepted the world in a peculiar way but he managed to bring his perception to us. The Soviet theatre producer Meyerhold noted, "We often in general see the world through the spectacles that one great artist or another wore." Such a profound definition of what is generally called "joint experience". The creative stroke of one man becomes a spark from which a mighty fire starts, and thoughts are engendered in another person, in thousands and millions.

A psychologist, Arnheim, now working in the USA, wrote: "A product of fine art is not an illustration of an author's thoughts, but a final manifestation of thinking itself." That is why the great works of masters live so long. It is said that when Michelangelo was reprimanded that the portraits of the Medici dukes did not sufficiently resemble their originals, the great Italian asked, "But who will notice it in one hundred years?" Ideas behind some pictures sometimes overshadow even history. The designer Nelson, mentioned earlier in the book, wrote: "Botticelli was an Italian painter who painted women's faces as they were never painted before or since. Many people remember Botticelli and his pictures, but who can tell you the name of the political boss of Florence at that time? Or who had the biggest importing business in Venice? Or which city was at war with which, and who won?" And in Russian history, who can offhand name the tsars who ruled when Andrey Rublev, Briullov, Kuindji, Repin, and Surikov worked and lived?

Great canvases are immortal because the scale of an artist's thoughts is large (it should not be forgotten that coloristics, too, is a reflection of thinking). A great man never confines himself in a nutshell, never evades topical issues of life, although on the face of it, it might appear so. A poet wrote:

And since they did not recognize him,
He decided to paint himself.
And the picture came forth to light from darkness,
And everybody shouted:
This is we!

Yes, with his works of art, his thoughts, an artist turns to the general masses. "Pravda" reported once: "an exhibition of pictures is always a citizen's forum for the painter, who exposes for public assessment his ideas of life, time, and man. Here, in contact with the beholder, in the company of work of his colleagues he has the possibility to test the health of his artistic attitudes, the depth of his understanding of the spiritual needs of his contemporaries."

Chapter Eleven

Direct Consequences of the Inverted View

Any idea foreign to our way of looking at things and feeling them always seems incongruous to us.

Helvétius
Concerning the Mind

The inverted world has long been a stumbling block for physiologists. It was obtained, if you remember, from the geometrical construction of the path of rays in the eye as drawn by Kepler. But the first to see it was Descartes whose ideas published in *The Treatise on Light* guided the second half of the 17th century and the entire 18th century. Descartes took a bovine eye and removed from its back wall the nontransparent layer, and then fixed that natural camera obscura in a hole cut in a window shutter. And immediately on the translucent sphere of the eye, he saw the view he could observe from the window.

The view was inverted. But like Kepler, Descartes was not put off by this. He was sure that the soul even from such "signs" is able to reconstruct quite a real image of the material world. True, he did not ask himself whether the soul would be able to reverse the image once more if the picture on the retina were "rectified" using lenses. This question was posed by later investigators and a priori they decided in favour of the soul, that is, the brain. Helmholtz, for example, proved this using as an example people who work with microscopes: they quickly adapt to the situation where the right side in the field of vision is the left one in reality, and vice versa. Also astronomers are not disturbed by the inverted image of the Moon in their telescopes, and photographers using cameras with frosted glass (a rarity now) experience no discomfort when looking at the "inverted" view.

These examples, however, do not carry much weight. In the microscope, telescope, and frosted glass of a camera, man deals with images that do not have stereoscopic depth. In his visual field he does not see his own hands and he does not have to coordinate his movements with the arrangement of objects in space. Observations generally are not very long, and this is also to be taken into account. In a nutshell, a decisive experiment was necessary. It was first staged by Professor of Psychology George Stratton of California University in 1896, using himself as the subject.

At first his perceptions were not that agreeable. His sight remained clear, but objects appeared fairly strange. He wrote in his diary: "The impression was that these displaced, false, illusory images reside between myself and the objects as such. Things were seen one way and thought of another way." For the first three days the scientist experienced nausea and other symptoms of sea sickness. On the fourth day his organism started to return to normal, only mistakes in determining right and left remained, and on the fifth day even they were gone. The man adapted to the unusual world. And when the spectacles were removed, the transition to the earlier, uninverted world occurred amazingly quickly, within one or two hours. In other words, the restructuring of the "inverting mechanism" during the experiment left the earlier habits of the brain untouched.

Unfortunately, the value of the experiment was substantially reduced both by its short duration and by the fact that the inverting spectacles were monocular. The "inverted world" was only viewed by one eye. Meanwhile, as we know, of great importance for us is binocular vision, which imparts depth to objects. It might be assumed that by overturning the world in both eyes an experimentalist would experience stronger effects.

This was exactly the case when 40 years after Stratton's experiments, his compatriot Peterson put on binocular inverting spectacles. He wrote: "I saw my foot approaching me over a rug, which was somewhere in front of me. For the first time I experienced such unusual visual impressions as walking toward myself. Plates on the table twisted so that they became small hills, and it was very strange to observe a spoon moving to the top of liquid, remove it — and nothing spilled. When I entered a long passage, I found that the floor looked like a cape, on either side of which walls descended. This was all the more strange since I could touch the walls with my hands. The wall at the end of the passage looked as if it advanced toward me, and the side-walls as if they receded from it, although I touched them with my hands."

Just like in Stratton's experiment, such disagreeable sensations disappeared in several days. And then the researcher simply took no notice of the inverting lenses until the very end of the experiment. Just as if he were born that way. What is more, when eight months later Peterson put on the spectacles once again, it turned out that his brain during the time elapsed did not forget the habits acquired: The scientist felt absolutely comfortable in the "inverted" world, as if there had been no interruption.

What of it, is everything clear, is everything solved? Scientists would not be scientists if they did not perform their experiments over and over again. New workers always make their own contributions to experimental techniques so as to shed new light on a problem. Exactly this took place when Frederick Sneyder decided to repeat the experiments of his predecessors. He wore the spectacles for a whole month, longer than anybody before him. With time he absolutely forgot about the glasses and thought that his brain had completely returned to the perception of the inverted world. But then somebody asked him; "But still, which objects have you seen: direct or inverted?"

After some thought Sneyder answered: "Before you asked me, they seemed to be standing normally. Now that I remember how they looked before I put on these lenses, I am forced to say that I see them as inverted. But as long as you did not ask me about it, I absolutely did not notice it."

I remember.... I saw.... I see.... What is it? Is it possible that we possess two visions, "visible" and the other "imaginable"?

Psychologists attempted to approach the problem based on the division of perception into "visible worlds" and "visible fields" made by the American scientist James Gibson in 1950 in his book *Perception of the Visual World.*

The Soviet psychologist A.N. Leontiev treats the "visible world" and the "visible field" as two stages of the same process of vision. At one stage works the "sensory tissue", that is, the retina, that brings to the brain, as it were, a flat picture projected by the crystalline lens. At the other stage, the "real contents" is worked out, or rather it is constructed in the brain based on the world of sensory tissue and the past experience of man.

Logvinenko and Stolin of Moscow University turned their attention to the extremely similar descriptions of the "visible field" and of that strange world that people observed through inverting spectacles. And so it was decided to test whether or not we really see the "visible field" through inverting lenses. The subject was a student of the Psychology Department. She first of all learned to view the surrounding world "according to Gibson". And then she put on the inverting spectacles. And when she got used to the inverted world and it became for her as habitual as the normal world, she tried to peer into it again "according to Gibson". As had been expected, the view before her overturned as it did on the first day after she had just put on her spectacles.

What is one to make of it? Only that the image inverted by the crystalline lens is supplied by the retina to the brain as an inverted image. Then this "visible field" is, as it were, overturned by a special neuron mechanism, one of the channels of the multichannel system of visual perception to which we have repeatedly referred. The generalized image is invariant under turns, and so there are no obstacles for seeing objects and identifying them; but whether or not the world is inverted in reality is reported by a special-purpose channel to the visual apparatus. Just recall your perception of the world when you hang upside down: people and houses do not cease for you to be people and houses, and you know that it is not they but you who are upside down, and this information is supplied to the brain by the vestibular apparatus and then the brain makes corrections to the perception. In small babies the inversion mechanism has not yet formed, and for them it is immaterial whether or not pictures shown to them are inverted. This completely removes the age-old problem of whether a baby sees his parents standing on their feet or heads. He just sees their parents and that is all there is to it. The notion of top and bottom comes to him later.

In an adult, however, over years of practice the "top-bottom" channel learns to provide the information required. But what has been taught may be retaught. In other words, we are able to override the signal "the world is upside down" that, due to the presence of inverting lenses, keeps coming to the brain from the visual apparatus. And then there is nothing mysterious in the "inversion", when a man who has long got used to the inverting optics suddenly, by the force of his will again begins to perceive the world "upside down". The trick is simple. A volitional stimulus removes the ban, and the signal "the world is upside down" arrives at the brain. The channel of inversion check operates and reminds the man that the spectacles are still on.

But only the human brain is capable of such complex operations, which goes to prove its especially high development as compared with the brain of any other creatures. So when inverting spectacles are put on an ape, it results in a destructive psychological blow. The ape staggers, makes some irregular movements and collapses. We witness a classical coma picture: reflexes die out, respiration becomes rapid and superficial, blood pressure drops. The animal looks as if it is about to die. The animal remains for days in this extremely acute condition which is indicative of heavy damage to the nervous system. Slowly, step by step, the ape's ability to respond to external stimuli, if only to the strongest ones, returns. For the most part the ape lies motionless, as if it has switched off the surrounding world. All of this "exactly reminds the state of an animal which has gone blind after a disease".

And what about man. He withstands even much more complex impacts on his visual system. In their follow-up programme, Logvinenko and Stolin used lenses that distorted the correlation between the position of an object on the retina and signals from the muscles moving the eyeball. Normally the situation is like this: the closer an object the more intensely the optical axes of the eyes must converge for the image not to double. The spectacles interfered with the direct relation by making it inverse. The vision would order the eyes to converge, but the commands coming from the brain to the muscles would order the opposite, that is, to diverge. At the same time, the muscles controlling the crystalline lens (the image must be kept in contrast) must also be fed with "opposite" commands. The brain, you see, had a hard nut to crack. And although nothing like an ape's reaction was observed, still the brain was totally baffled. All the routine attitudes in the human subject were disrupted, and fresh, unusual images emerged. Shadows, for example, ceased to be shadows. They could "be perceived now as the colour of a surface, now as a transparent area with black emptiness beyond, and now as some peculiar translucent plane, and so on". That is something! "Transparent shadow" constructed by the brain only because it is unable to correlate visual and motor signals.

Yes, all these experiments demonstrate beyond a doubt that the pictures of the world seen by the eye and "reflecting" reality, only reflect it accurately as long as the visual apparatus and all the senses function normally and in cooperation. All the perceptive organs must take part in comprehending reality.

Gibson's "visible field" is, crudely speaking, a photographic picture of objects produced by the retina. A photograph is primitive, flat, and telling us next to nothing about the world of photography. The one, a beginner produces without any idea behind it, so to speak.

But the "visible world" is already a picture, an image. No wonder experienced teachers claim that each of us is a painter, and the only thing that is required is to free oneself of the psychological barrier.

Depreciated and poor, and hence inadequately corresponding to reality, is the world for people deaf to painting, sculpture, music, and the arts in general, because it is the arts that refine our senses by enriching their scope and pushing aside the boundaries of the comprehension of the world. It is about such people the poet said:

They do not see and do not hear,
They live in darkness while in this world,
They never feel the breath of the sun,
Nor know of life in the waves of the sea.

Light has not entered into their souls,
Spring has not flowered in their breasts,
Woods, have not spoken in their presence,
And the starry night is dumb to them.

The thunderstorm whose unearthly speech
Disturbs the rivers and shakes the woods
Has never taken counsel at night
With them in friendly conversation.

(Translated by Jesse Zeldin)

To be sure, all the above by no means belittles the role of science, the role of the logical in the comprehension of the world and the laws of nature governing. But the truth is that the great scientists drew on the arts as a sort of support for their theoretical studies. The French mathematician Poincaré maintains that "useful combinations are precisely elegant combinations, that is, those that to the largest degree are able to satisfy that special esthetic feeling that is known to all mathematicians." And Karl Marx stated it even more definitely: "Whatever disadvantages are in my works, they have the one advantage of representing an artistic whole." Science reveals general, *"above-human" laws. Arts study man, cognize the* "human" in objects and phenomena to which he is related, including in science itself. Science without arts is a cold and hostile phenomenon, together they are a song glorifying man. To penetrate into the essence of things, it is necessary to have in one's imagination an adequate model of the world, of the very "visible world" we have just discussed. And without arts very little can be accomplished here.

The Austrian mathematician Gödel early in the 1930s proved a theorem that became known in cognition theory as the "Gödel theorem". It states that any formalized, logical system in principle cannot be complete. That is, in it there can always be found a statement that can be neither disproved nor proved using the means of that system. To discuss such a statement one must go beyond the system, otherwise nothing but a vicious circle will result. So, many philosophers believe that arts in relation to science is exactly that "other world" which one must enter to satisfy the Gödel theorem in relation to science, that gigantic logical system. Science opens up before us the real image of the world we live in — and still it would be incomplete without arts.

The saying goes: "Each is the maker of his own destiny." Let us add, and of his "visible world". May it be rich and beautiful for each of us!

Chapter Twelve

The Palette

> *... For colour to emerge are necessary lightness and darkness, the light and the dark, or using a more general formula, light and nonlight.*
>
> Goethe

When in 1903 the French chemist Louis Jacque Lumière (the same who together with his brother Auguste invented *cinématographe*) decided to go in for colour photography, he knew nothing about the structure of the retina of the hen. And still in his new invention he nearly literally reproduced an important feature of its scheme.

In the hen, just as in many birds and in some species of turtles, before the completely identical retinal receptors nature placed light filters—fat cells of red, orange, and yellow-greenish colour, in addition to colourless ones. But Lumière took grains of starch, coloured them red, green, and blue, and then sprinkled this three-colour powder onto a photographic plate.

The inventor was guided by the theory of colour vision that is now generally referred to as a three-component one. It dates back to the lecture "A word on the origins of light, which represents a new theory of colours", delivered by Mikhail Lomonosov at a public meeting of the Imperial Academy of Sciences of July 1, 1756.

The great Russian scientist reported: "I once noticed and observed through many years, and later proved by trials with sufficient probability that three species of ether particles show correspondence with three kinds of acting elemental particles that constitute sensory bodies. From a first type of ether comes the red colour, from a second yellow, and from the third blue. Other colours are born by mixing these first three. Nature is all the more amazing in that in its simplicity it is full of tricks, and from a small number of causes it pronounces (*sic*) innumerable images of properties, changes, and phenomena."

That bold thought was not appreciated by the then scientific world. It was not until half a century later that specialists recalled this theory when the three-component hypothesis was supported by the English physicist Thomas Young. He noted that Lomonosov's ideas gave him, to use modern parlance, material for speculations. Young paid attention to the self-evident fact: the retina must inform the brain about the shape and colour of objects. But any part of the image may be coloured in any shade. How does the eye manage to see all the infinite variety of colours? Is it possible that at any given place on the retina there is an infinite number of elements whose task is to respond to one special colour? This is unlikely, for the arrangement would be too complicated. It would then be logical to suppose that colour-sensitive elements are relatively few, but it is due to their combined effect that the sensation of the infinite richness of shades is produced. The three colour-carrying ethers, mentioned by Lomonosov, are transformed into three colour-sensitive elements of the retina. Young's assumptions were developed by Helmholtz in the years 1859-1866 into the three-component theory.

It is now well established that the retina has colour photoreceptors—cones—of exactly three kinds: some have maximal sensitivity to red, others to green and yet others to blue. Scientists even managed to get with their measuring instrument to the cones of the retina of the ape, which distinguishes colours nearly as well as man. The sensitivity of its cones to electromagnetic radiation with different wavelengths showed a satisfactory agreement with theory.

But nature did not install any light filters in front of the photoreceptors of our retina. It was more ingenious: it produced several various pigments, each of which responds primarily to its own quanta. Should one of the pigments be absent, man does not perceive appropriate tones and becomes partially colour-blind, as was the case with the English physicist John Dalton, after whom that deficiency of vision is now called daltonism. By the way, it has been discovered in Dalton by none other than Young.

Cones, comparatively weakly sensitive and concentrated more near the centre of the retina, are used by day. Whereas rods, which as you remember are about 27 times more numerous and which contain the pigment rhodopsin, we use by night. That is why they possess such a high sensitivity. Unfortunately, there are not three but only one type of rods, and so neither by twilight nor by night can we discern colours. A saying goes: "All cats are grey in the night." The rods are able to respond neither to red, nor to orange, nor to yellow rays, and therefore objects of those colours appear black under poor illumination. On the other hand, the "night" elements of the retina are sensitive to ultraviolet radiation. True, we do not need that ability: the crystalline lens, like a light filter, cuts out UV. But if by operation the crystalline lens is removed and replaced by a plastic lens, transparent to short-wave radiation, patients then read the entire ophthalmological table in the light of a UV lamp. People with normal vision see nothing under such circumstances and think that they are being deceived.

But back to the three-component theory. It provides a satisfactory explanation of how various paints are formed out of spectral colours. It suggests ways to "deceive" the eye and to show to it one colour by mixing pairs of completely different rays. To this end, it is only required to stimulate various cones in the appropriate way. There exist, for example, a multitude of colour combinations that are perceived as white: wavelenghts 486 and 590 nm*—blue and orange; 467 and 572 nm—dark blue and yellow-greenish; 494 and 640 nm—red and green; and so on and so forth. Red plus green may give a beautiful yellow shade, but it can also be obtained from orange and navy blue. Recipes for producing any colour from the middle of the spectrum are legion. Instructions are plentiful in textbooks, but textbooks keep silent about what theory does not explain. And it does not explain quite a lot.

Let us take for example black colour. Generally it is associated with the absolutely black body, that is, a body that absorbs all the radiation incident on it. A good approximation to so ideal an object is a small hole in the wall of a box lined with black velvet inside. Absolutely black bodies are necessary to physicists, they are their reference standards for light measurements. But Goethe was right in saying that "the existing does not divide by reason without a remainder." The functioning of physical instruments is far from equivalent to the functioning of the eye.

The Soviet scientist N. D. Nyuberg liked to have a dig at his postgraduates by posing the innocent question: "What is the colour brown?" And really, a painter will get it readily by mixing orange and black paints, but such a result only confuses us. Black, according to its definition, is a neutral component that equally absorbs all the rays of the spectrum. It would seem it is only able to reduce the brightness of colours. But black paint changes colours by making them such that are not obtainable by the mixing of pure spectral tones. By the way, why is there white light (and white paint), but no black or brown light, although there exist black and brown paints?

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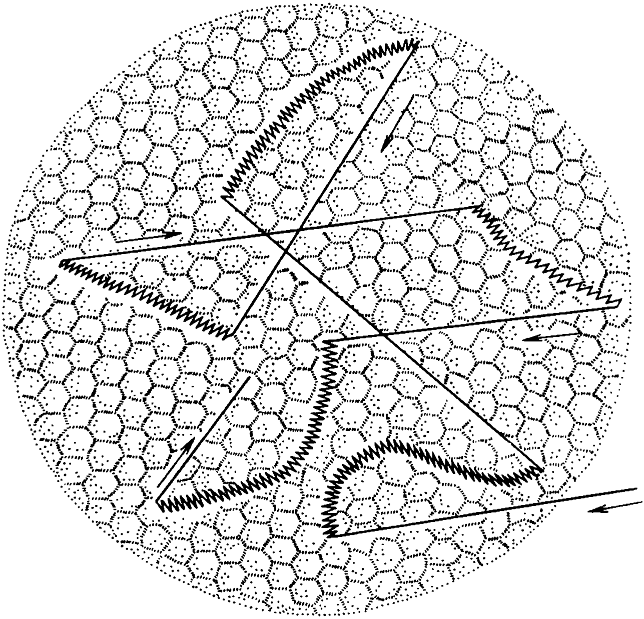
* nm is nanometre, 1 nm = 0.000.001 mm.

It may well be that vision cannot be confined within the existing boundaries of the three-component theory. This fact, however, though not exactly ignored—it is impossible not to notice the obvious!—was evaded.

Attempts have been made to account for the effect, for example by maintaining that "black reduces the brightness of paints and therefore (?) of colour as well". I took that quotation from one fairly respectable book devoted to colour and light. Perhaps the author made no experiments, otherwise he would know that a neutral grey light filter can sharply reduce the brightness of a projector, but the screen still remains flooded by the same colour tone. Furthermore, white colour added to any die "dilutes" it and makes it less saturated, although does not change the colour. Why then do we obtain an absolutely different effect when we add black colour?

Vision has an important amazing feature that until fairly recently has amazed all a lot: it can introduce corrections for illumination. That is, it can perceive colours correctly in general, although the spectral characteristics of light sources vary widely: a gloomy day is rich in blue light, incandescent lamps are yellowish, but still we perceive colours correctly by automatically introducing correction for the light source. What sort of mechanism is this?

At one time it was thought that the eye seeks something white in any picture (that it is really white is known from past experience) and from it it makes correction for the altered spectral composition of the source; say, an excess of red or dark-blue rays. And if there is no white, a light spot will do, since it always seems to be white. Sceptics objected: if you line a room with green velvet to kill all the light spots, the fabric, nevertheless, will still be green. Why? But here the experts would only raise their hands and answer: This is just so. And physiologists would start



Eye micromovements: high-frequency tremor, smooth drift and saccadic jumps. We see only because our eyes are never at rest

anew to seek the mysterious reference point used by the eye in making corrections for illumination. To clarify the results of those searches, we for the moment will leave colours and call one of the earlier works by Yarbus devoted to the eye movements.

Human eyes in portraits look pensively, severely, gaily, or slyly. We do not notice that they are fixed, just as we do not notice that our eyes are in constant movement. I do not mean those "rounds" (as referred to above) made by our eyes in viewing a picture. There are other movements as well. They do not obey our will and are uncontrollable. It is also impossible to stop them, however you try to focus your sight on a point.

The eye muscles are unable to hold the eyeball in a state of total rest. Moreover, their task is just the opposite: to ensure those continuous micromovements. First, the tremor at which the eye quivers with a frequency of about 100 hertz. The tremor amplitude is negligible, it is about the diameter of a photoreceptor of the fovea, of which there are about 50,000 on the area of one square millimetre. Second, there exist drifts, that is, slow, gentle shifts of the sight. Third, drift periods alternate with small jumps, microsaccades. Sight "swims" and suddenly, by a jump, it shifts sidewards, where again drift starts. Those microsaccadic movements are also insignificant in amplitude: a point projected onto the fovea of the retina would not go beyond its confines even with the largest microjump. From three to five times a second the eye performs a large saccadic jump that is imperceptible from outside. Why? What will happen if all these movements are stopped?

To stop them.... To this end, Yarbus invented a sucker, a small projector with a pocket to insert pictures, the test-objects. The projector was so tiny that atmospheric pressure "glued" it directly to the eyeball, so that the test-object appeared to be totally motionless relative to the retina. And.... And in a second or so after an image became fixed, it disappeared! Instead of the picture in the eye's field of view we have a fairly light grey shroud. The scientist called its colour zero (it will become clear from what follows). By the way, that "shroud" could also be seen without the sucker. Just enter a totally dark room and close your eyes to be on the safe side. In about 10 minutes your patience will be rewarded: you will notice that before your eyes you have not blackness, as might be expected, but something light.

Well, what about the sucker? Where has the image gone? Just a slight rap at the test-object with the end of a pencil, and it is there again, in your sight. It appears only to disappear again in a split second. Now it is more or less clear: the rap has disturbed the immobility of the picture relative to the retina. It follows that only movement—of either the eye or the picture, it does not matter—which produces a visual image: movement is essentially necessary for vision to work.

Really, suffice it to introduce in front of the test-object something moving for that object to be splendidly discernible against the background of the zero colour. Accordingly, the zero colour and the object are independent.

The inferences from these experiments are shocking: the presence of light alone does not guarantee vision. Both total darkness and total immobility of an illuminated image relative to the retina are both the same for the visual apparatus. In both cases man sees nothing but the zero colour. Furthermore, let the brightness of the test-object stopped by the sucker be arbitrary, so it may jump or grow indefinitely, the eye would not take notice of that. Yarbus wrote: "Even the hot, blindingly glowing filament of an incandescent lamp becomes invisible."

Which element in the visual system switches off? The retina. The other eye, having no sucker, continues to see everything well. It follows that after a chiasm all the structures of the visual apparatus through which signals from both retinas pass in the same way act in a normal manner.

In what do the retinas differ then? Only in that in the eye with the sucker the picture keeps getting on the same areas, so that the photoreceptors receive constant brightness that does not change at all. Wherever light strikes for the first time it keeps striking there, and likewise the dark areas stay dark. But photoreceptors need something different, they need a light incident upon them varying in its brightness at all times. It is taken care of by the muscles that make an image (whose brightness at each point is generally different) "dance" over the bottom of the eyeball. To this end, the eye keeps moving all the time.

Yarbus's experiments mentioned above became classical, just as his experiments on the recording of the eye movements. These results are referred to by all the workers in the fields of psychology and physiology of vision. But those experiments were only the first step on the path to decipher the enigma of colour. So, it appears that the words "different brightness", we have just used, give rise to many questions and surprises.

Everything started with studies that had to answer the question: What will happen if zero colour appears against the background of some visible image? For the experiment Yarbus manufactured a sucker such that its test-object only blotted out a part of the eye's field of vision. A subject who participated in the experiment saw a strange thing: the test-object (just a piece of white paper) turned into some kind of chameleon. Once the gaze was directed at a large green shield, the paper became green, against the background of a red shield red, and against the background of the yellow shield yellow, it took just several seconds for the test-object to change colour and melt with the background. The white paper was replaced by a coloured one, but this (by the way, as was expected) did not affect its colour-changing properties.

A contradiction cropped up. On the one hand, a stationary test-object must produce zero colour on the retinal area where the image is projected. On the other hand, the visual system ignores this and replaces the zero colour with another one, which depends on the background, thus generating colour (strictly speaking, not always: if the background is particoloured and the screen covers several colours simultaneously, the visual apparatus does not want to sort out the hodge-podge, with the result that the subject sees at last a zero-colour spot against a particoloured background).

To get to the truth, Yarbus used a two-colour screen: a grey "bull's-eye" against a white background. How will vision behave now? At first, however, the two-colour screen merged with the background, but then the experimentalist lit it with a blinking light. And, it emerged as a unicolour one, white, without any grey "bull's-eye" inside, and so, as it were, a white hole appeared in the coloured background.

This was an amazing development. Why did the screen suddenly appear, and where was the grey "bull's-eye" gone? A much closer look had to be taken at the experiment, or rather at the brightness of the light taken in by the eye from various areas of the image.

How do brightnesses vary at the boundary between the white screen and its grey "bull's-eye" when exposed to a blinking lamp? It is clear that they vary in the same way. Both the screen and the "bull's-eye" become now brighter and now duller. The relative brightness at the boundary experiences a zero change.

But the situation is different at the boundary "screen-background". The constant brightness of the background there, as it were, is compared by the eye with the variable brightness of the screen. Put another way, the relative (for vision) brightness is nonzero here. Its variations make it possible for sight to function and for us to see. If there are no relative variations, then everything that lies within the boundaries takes on the colour of the surrounding background. Such was the result of the experiment.

Nature gave a most interesting answer to a well formulated problem.

But a sceptic might well ask: "What relative variations are? A lamp on the ceiling illuminates a room without blinking. Where do relative variations of brightness come from in a real-life picture?" The answer is simple: the image keeps shifting over the retina during the micromovements with the result that the receptors are illuminated now more brightly and now more dimly.

And now we can also turn to another problem: to discuss why the eye, unlike a photographic film, is able to adapt to varying spectral compositions of illumination. Yarbus suggested an interesting hypothesis to this effect. He posed the question thus: "Why do rods and cones of the retina go farther into the eyeball than direct light that carries the image can reach? And once they are there, what do they see there?"It appears that nothing in nature is done for nothing. The photoreceptors at the retinal edge are nothing but zero-colour generators with which our vision compares all the remaining colours.

Light incident on the pupil not only comes to the retina, but is also slightly dissipated by the transparent structures of the eye. Consequently, diffuse flux, in terms of brightness, is something between all the light and dark spots on the image. The edge of the retina gets light as if it had passed through a good, dense, frosted glass, it is a steady, smooth, unchanging flux, whatever the micromovements of the eye. And we know already that this kind of light is equivalent with darkness, and all the receptors that receive it work out zero-colour signals. Whatever the spectral composition of the diffuse light, how much red, green or dark-blue is in it, it is absolutely immaterial (as is shown by direct experiments). All the same, our vision will always get from the retinal edge the required zero colour.

Now, that looks like a reference point. The visual field is surrounded by a band of zero colour. There is a boundary between its constancy and the changing world at which our ever-moving eyeballs gaze. There is a line where brightness varies at all times. This suggests that now we are already in a position to draw the scheme of colour perception.

Suppose you are looking at a clear blue sky. Just sky, nothing more. It alone is projected on the retina. It does not get to the edge, however—we have zero colour there. Between the blue and the zero colour is a boundary. Photoreceptors on "this" side of it produce signals (these can be called numbers with good reason) perceived as "blue colour". It would seem that the light-sensitive cells within the area confined by the boundary should generate the same numbers. This is not so, though. Our visual system is constructed so economically and perfectly that the signal-numbers coming from the boundary "zero colour-sky" are sufficient to perceive the beautiful blue tone (as is shown by experiment). As regards those numbers (or rather their logarithms), the visual apparatus, as it were, gives a command to an unseen painter: "Now, pal, cover the whole of the visible field with signals 'blue sky' ", and so we see that blue tone worked out in our brain.

Now look: a red spot appears against the background of the sky. Its red colour is again the result of the ratio of the numbers from the boundary "blue-red". From the result obtained, the surface of the spot will also be covered by the colour produced by the brain. It is easily seen that we thus have a chain of numbers "zero colour-blue", "blue-red". Stated another way, the red colour is to a certain degree dependent on the zero colour.

Let us now paint a green branch on the red spot. The perception of green will here be connected with the red spot and the blue sky and the zero colour. Each fresh colour tone lying against the background of another tone looks like the next figure of the fascinating coloured "matreshka" (the Russian wooden nesting doll) with the colouring of each internal doll being dependent on the external one, and all of them together on the zero colour (or rather on its intensity). We now know why background can either "bring out" or "kill" a superimposed colour. This all comes down to the complex interplay of signal numbers arriving at the visual system from the retinal photoreceptors.

Zero colour turned out to have surprising capabilities. A subject is sitting at the apparatus in Yarbus's laboratory. He has a piece of white paper in front of his pupil. An experimenter exposes the retinal edge to a red light with wavelength 680 nm—neither green nor blue light receptors respond to that wavelength (we will omit the technicalities of the experiment, it is only worth noting that it is fairly sophisticated and elegant).

"I see a white paper with a reddish tinge," says the man.

"And now?" the scientist turns something in his apparatus.

"It turned green.... Or rather navy blue.... And now some black was added.... Now again red, only much lighter than at first."

Just listening to the dialogue you might imagine that Yarbus introduces some light filters. But he has simply changed the brightness of the red light incident on the edge of the retina. And contrary to all habitual conceptions, the red light receptors of the eye registered colours that were actually absent!

What has happened? Zero colour, which is not accepted by the visual apparatus, is able to change colours presented to the vision. Just increase the brightness of the exposure, that is, increase the flux incident on the retinal edge, and all the colours will darken. Decrease it and the colours will become brighter. Supply more red to the edge and all the colours will acquire a navy blue tinge, add more blue and they will turn orange, more green and they will turn purple. One of the principles of his theory Yarbus formulated as follows: apparent colours always change in contradistinction to the action of the exposure light.

This rule is a qualitative representation of the action exerted on the apparent picture by zero colour. And how about quantitative representation?

Up until recently all the texts on coloristics have taught that colour is dependent on the degree of stimulation of red, green, and blue light receptors of the retina: that is, first, on the spectral composition of light; second, on the sensitivity of light receptors to different wavelengths of electromagnetic waves. Yarbus's theory refines this rule: one also has to take into account the degree of stimulation of light receptors at the edge; in other words, to take into account the action on them of the light diffused within the eye. And since the "action of light" is just a signal-number, then the remaining part is just mathematics, and fairly simple at that. A difference of two logarithms—that is what the "action of light" is. One logarithm expresses the stimulation of, say, the red light receptor at a given place of the retina; the other, of the red receptor at the edge. Two other pairs of logarithms define the actions of the green and blue light components.

In each pair the differences may clearly be positive or negative. They are positive when the inner regions of the retina are more excited than the edge, and negative when the photoreceptors at the edge work out stronger signals than those elsewhere in the retina. To positive numbers correspond the light-red, light-green and light-blue colours, principal colours of positive brightness. To negative numbers correspond the black-blue-green, black-purple and black-orange tones of negative brightness. If all three positive numbers are equal, we see the colour white, but if negative numbers are equal we then see the colour black. And all the remaining colours are combinations of positive and negative numbers. So simple and logical....

The theory of Yarbus covers very many visual effects, including the correction for illumination discussed earlier in the chapter. As a matter of fact, if the spectral composition of light changes, the only result is that, both the edge and the central region of the retina respond differently to the light. But the difference of logarithms of numbers expressing the amount of stimulation remains constant or changes slightly, and hence the subjective perception of colours remains the same or nearly the same.

The novel theory of colour vision prompts engineers as to how to design colour analyzers, which would work no worse than the human eye and would just as slightly react to variations in the spectral composition of illumination. We will now be able objectively to control not only the colours produced by the mixing of pure tones of the spectrum but also all the nonstandard colours defined by such loose terms as mustard, chocolate-brown, etc., shades that invite so many disputes that special-purpose atlases containing samples are published.

Any colour we perceive, as we now know, is the product of the work of the brain. No wonder that different people see colours in a different manner and differently feel the harmony or disharmony of their combinations. Even among painters some excell in representation of shape, and others have a keener feel for coloristics. The history of art brings us the names of outstanding colorists: Velásquez, Tiziano, Veronese, Raffael. Russian critics, for example, thus commented on the coloristic mastery of Surikov: "He gave a new, purely Russian gamma of colours, which was used by Repin and Vasnetsov and traces of which are to be found in the palette of Levitan, Korovin and Serov," or he "unravelled the outlandish beauty of the Russian colouring", and "his colours merge into an inexpressible gamma conceived by vision and defying graphic description". The painter himself would say jokingly: "Even a dog can be taught drawing, but it is impossible to teach colouring."

And here I would like to dwell a bit on some venerable delusion, which has been repeatedly disproved, but appears over and over again on the pages of popular science books and magazines. I am referring to the legend that the ancients allegedly did not perceive some colours.

The case is based on the fact that Homer would call the sea near the Island of Crete wine-coloured, that is, green and not azure, as it is in reality. One popularizer of science in his book published in the early 1960s says: "Homer did not notice this, and his contemporaries did not notice it either. Only several centuries later Greek sculptors began to perceive the brightly blue colour and, exceedingly happy with their discovery, began to paint statues blue."

All this is some unfortunate misunderstanding. It is rooted in the middle of the 19th century, when the British Prime Minister Gladston, a great connoisseur of the Ancient Greek language and Homeric poetry, stated in one of his works that the great poet seems to have distinguished far from all the colour shades. Immediately, some philologists came up with the suggestion that the situation with colour names had been unsatisfactory in the Ancient Hebrew language and Ancient Indian (Sanscrit) as well. They even went so far as to determine the order in which man came to perceive colours: at first, it was held, came only some shades of grey, then followed the colour red, then orange, yellow (at the time of Homer), and then light-green, and finally blue and violet.

The excitement quickly cooled down once ethnographers had established that the most primitive tribes in no way differed from Europeans in their powers of perceiving and distinguishing colours. Later on, linguists, who had been more rigorous in their studies, found that direct or indirect references to white, yellowish-white, yellow, yellow-greenish, green, blue, red, and brown colours are to be found, for example, in ancient Hebrew texts. So that late in the 19th century the *Encyclopaedic Dictionary by Brockhaus and Efron* stated distinctly and categorically: "The totality of all historical and philological evidence does not support the idea that in historical times colour perception had been evolving. The hypothesis of the physiological evolution of those perceptions is also not supported by any evidence in its favour from the realm of natural sciences."

And in the early 1930s a very interesting observation was made by A. Luria. He was participating in an expedition in the then backward regions of Uzbekistan. The expedition's findings were summarized by him in his book *On the Historical Development of Cognizant Processes*. He reported in particular that in those years many Uzbek males and especially females preferred to use the names of colours as derived from common things. And so the notebooks of the members of the team had such entries as the colours of "peas", "peach", "rose", "calf dung", "pig dung", "lake", "cotton in bloom", "pistachio-nut", "tobacco", "liver", "wine", and what not. Could one, based on that evidence, draw the conclusion that Uzbek females, those skilled carpet makers, Uzbek males, those master craftsmen of coloured ceramics, did not distinguish colours? No, of course. It would be more reasonable to suppose that they either did not need or did not know our terms for them.

After all, the seven rainbow colours are a conditional thing. There might as well be four or fourteen. Seven colours were needed by the great Newton only because he wanted, by all means, to tie them to the seven tones of the chromatic range of colours. But Leonardo da Vinci considered that there are only five principal colours. And so, Luria was led to conclude: the name of colours is a historical category. How a term develops, if at all, depends on a variety of things, and primarily on the economic activities of people, on the need to assign a thing to some category or other. The eyes distinguish an infinite variety of shades, but a dictionary carries no more than two or three dozen names. Why? Because a term is always an abstraction, and "the processes of abstraction and generalization do not exist unchanged at all stages; they are themselves a product of social, economic, and cultural development".

In recent decades engineers have shown keen interest in colour. According to some authorities, about 50 per cent industrial accidents occur because machinery and shops are painted ignoring the properties of human vision. The influences of colour are as numerous as are the names for colours and their shades. Blood pressure, appetite, alertness, emotions, and hearing keenness—are just a few of the human "parameters" effected by colour. So black colour is associated with heaviness, white and blue with something light, festive; a room lit by reddish light seems to be warmer, but just replace it by blue light and people will shiver as if there were a chill in the air. Sensations stimulated by colours argue with the scales and thermometer. Once, psychologists illuminated an appetizingly laid table with a light that had passed through special-purpose filters so that the colours of the dishes changed drastically. So meat now appeared grey, salad violet, peas turned into "black" caviar, milk became violet-red, and egg yolk became brownish-red. The guests, their mouths watering in anticipation of the meal, could not so much as make themselves taste the uncannily coloured food. And those who nevertheless attempted to have a bite of something became sick. The effect of colours is stronger than rebukes and prohibitions. For example, if you place a dust bin in the centre of a white circle or square, everybody will try to drop his cigarette butt as accurately as possible so that it does not fall on the white; yellow walls of classrooms and corridors less provoke schoolchildren to soil them. An operator reads the istruments on his console more accurately when the console is painted a colour of some warm tone. And so on and so forth. These paradoxical results tell us: the brain is not only the "creator" of colours but also their subordinate.

Chapter Thirteen

A Sieve for Images

Any system capable of achieving correlation (or tangle) of a pair of traceries is also capable of imitating the work of the Fourier holograph. Such system—a two-dimensional (spatial) grating could be set up in any school physics laboratory.

P. J. van Heerden
Models of the Brain

Students are watching an oscilloscope. On the screen they see a straight line with a sharp surge on it, just like a mountain peak in a field. Everybody sees it, save for the student being tested, the "author" of the peak. The physiologist in charge of the experiment has connected current-conducting electrodes to the muscles of the subject's eye, just by gluing thin wires to the skin where necessary. Each contraction of the muscle fibres responsible for the saccadic motion produces an electric signal. Such is one of the properties of any muscle. The wires catch the signal and feed it to an amplifier, and so a peak appears on the screen. And the man who caused it does not notice it. And it is absolutely impossible to persuade him that it exists. He is angry: "Stop pulling my leg!"

Is this to suggest that at the very moment of a saccadic movement we are blind? A fresh puzzle. Why should a man, or any living creature for that matter, go blind several times a second?

In the Laboratory they found an answer.

Everything started with the mysterious lateral geniculate body, which is located in the way of visual signals between retina and cerebral cortex. It was not clear—and the literature contained no hints—as to its function. Visual signals pass in and out of it apparently without any change. Why no change? There should be something behind this: as it has proved many times nature just cannot be that "stupid".

It was thought that the lateral geniculate body is a sort of amplifying station, like those that "invigorate" signals in transoceanic cable lines. This is quite probable, on the face of it. Only why other nerve circuits have no such stations?

Then another hypothesis came into being: the lateral geniculate body does not amplify but only regulates the intensity of signals: a convenient explanation of why the eye is able to work when brightness changes one hundred million-fold. But this assumption, too, has not been supported by evidence. The colossal range of the eye's sensitivity is explained, specifically, by the fact that the signal worked out by the retinal receptors is proportional to the luminance logarithm, which, by the way, confirms Yarbus's theory. The logarithmic curve at first is very steep, levelling out gradually so that a hundred million-fold change in brightness only produces a ninefold change in signal.

Up until recently, the enigma of the lateral geniculate body had no answer. In their book, *Human Information Processing* the American scientists Lindsay and Norman state that the role of the lateral geniculate ordered structures is mysterious. Really, when a microelectrode is implanted into this cerebral area, the experimenter sees here, just at the output of ganglion cells, the same round fields with an ON and OFF centre and counteracting edge—"black and white" and "coloured" fields. They distinguish neither lines, nor angles, nor directions—nothing. What is their role after all?

A worker of the Laboratory, Nikita Podvigin, said, "The experiments have been rather sophisticated, but this is hardly worth mentioning, the main thing is of course the result. And it is as follows: we have proved that a "screen" consisting of round ON-OFF fields, once transmitted via the optic nerve to the lateral geniculate body turns there into a pulsating one. And the pulsations have the frequency of the saccadic flickerings of the eyeball."

This proceeds in the following way. Immediately after a jump the diameter of each field is quite large. Then they start shrinking and in several hundredths of a second they become small dots. At times the area of a field decreases 250 times. The "pin heads" exist another several hundredths of a second and suddenly they sharply increase in diameter. They keep growing until their boundaries become blurred and wide. From that moment our vision supplies nothing to the higher parts of the brain till the next jump.

In the first moment after the saccade has ceased, the "screen" of the lateral geniculate body relays to the visual system some information that only allows crude outline to be identified. And only then, as the fields shrink, in the image details "cut through" and become ever smaller. When a maximum of information has been extracted from the picture, the fields disappear quickly and all perception stops. In the time before the next jump the visual cortex processes the data obtained from the lateral geniculate body. And next comes a fresh round of analysis. The cycles of perception are quite analogous with those in any computer. To receive new information the old information is erased from the short-term memory during the next jump of the eyes, and so, fresh information is not confused with the previous data. Well, one can never stop being amazed at the fabulous "ingenuity" (if the word can be applied to nature) of the principle of the visual apparatus.

An exceedingly important detail is that the degree of shrinking of the "screen" elements of the lateral geniculate body varies with the light intensity. With dim light our vision is in principle unable to discern small details of the picture projected on the retina since the fields are too large. That is why watchmakers and radio mechanics generally use strong lamps, that is why ,in a dark larder you do not see a needle on the floor, which is immediately visible once you open the door. Bright light is known to boost productivity, because the "pulsating fields" shrink more drastically to make our vision clearer.

Owing to field pulsations in the lateral geniculate body the visual cortex receives an image that has, as it were, been passed through a multitude of sieves; one taking care of the larger "stones"—large details of the picture, the next one smaller stones, and so forth, down to the finest "sand".

What is one to make of it? Nothing so far. But we may consider one fascinating situation. On a table we have a hundred photographs of males and females which are to be sorted out. Just two minutes and the problem is solved. The males are placed on the left stack, the females on the right. A piece of cake, isn't it?

One may now ask the question: According to what criterion has the sorting out been performed? Can you come up with a clear definition? No, not now, you may think about it at your leisure.

Frankly, I would not recommend you do this, you might as well give it up now as a bad job. Thousands of first-rate computer experts failed. And understandably so. It is impossible to give a verbal definition of generalized image such as "man", "woman", "table", and others out of the thousand notions, because these images are visual abstractions. But abstractions must be handled with care. Engels caught methaphysicists at their overly carefree manipulations: "At first they create abstractions, stripping them from sensations, and then they wish to comprehend those abstractions using their senses, and wish to see time and smell space. This is precisely like the difficulty, referred to by Hegel, that we can of course eat cherries and plums, but we cannot eat a fruit, because nobody has ever eaten a fruit as such." So when engineers endeavoured to drive verbal definitions of visual abstractions into the electronic brain of the computer, their failure was predestined.

The situation is somewhat better with verbal descriptions of concrete human faces, but only people, not computers, can produce and use such descriptions. As early as the end of the last century, the French criminalist Alphonse Bertillion, chief of criminal identification for the Paris police developed the idea of the "verbal portrait", which has been used ever since.

In one of his stories the writer of crime fiction Lev Sheinin, an ex-investigator, reminisced: "Compiling a verbal portrait of Yanaka, I interviewed a large number of eyewitnesses. I found out all of his distinctive marks and produced a verbal portrait that depicted Yanaka as being of medium height, a bit stout in stature, having an oval face with a low and slanted forehead, arched eyebrows grown together and reddish. His nose was long and drooping with a hump, his mouth was medium-sized with thick lips, the lower lip drooped, and the corners of his mouth drooped. Yanaka had a square, split chin, his slightly prominent large ears were triangular in shape, slightly swelled eyes were greenish, and his hair red." How vividly we visualize the face of the man from these simple, terse professional terms! Admittedly, the "accuracy" of the above description is a far cry from that obtainable using measuring instruments, but if you possess the talents of a painter you can draw Yanaka's portrait. Of course, you cannot mark the sizes of the facial features in millimetres. But everything is relative. A nose that is long for one face will be fairly normal, even short, for another face, which is more elongated.

What is to be done if an eyewitness does not know professional terminology (which is often the case), if he only caught a glimpse of the criminal and was frightened at that, if only the most general impressions have remained? In that case, a "robot-portrait" is generally used. Police files contain hundreds of slides depicting a wide variety of noses, ears, brows, eyes, beards, moustaches, face ovals, and hairstyles. From these a portrait can be "shaped" with the eyewitness prompting the details.

"No, the face seems to be wider. No, much wider. Now it is OK. And the hair, not so long...."

There is no way of being dead sure that the robot will be the identical twin of the criminal the police are after, but it still can give some guidance.

Perhaps, watching the production of such a portrait, would it be possible to uncover the criteria used to recognize faces? An American physiologist Leon D. Harmon conducted a series of experiments. A skilled criminalist-artist drew the portrait of a "criminal" from the descriptions of "eyewitnesses" who knew the "criminal" well. The artist then compared the resultant portrait with the photograph of the "criminal" and took note of the differences: "The lips have to be a bit thicker, the ears closer, and the face more round...." Using the portrait and the verbal corrections, a new artist, who had not taken part in the experiment, made another robot portrait. And then they held a viewing for the "witnesses".

Much to their surprise the "eyewitnesses" suddenly found out that the picture produced from their words was not a good likeness. The overwhelming majority ruled that is was inadequate; thus the tongue proved once more that it is very approximate and incapable of functioning as a measuring instrument.

On the other hand, in defining the deviations speech was much more correct: the second portrait was approved of and pronounced to be close to the original. But still the best portrait, which guaranteed the precision in recognition of better than 90 per cent, was a portrait drawn simply from a photographic picture. It's not for nothing the saying goes: "A picture is worth a hundred words".

Then the experimenter approached the problem from another angle. Why are we unable to work out anything adequately by "directly" describing the pictures? Maybe they are overlaiden with details? And those details, maybe they are too important? Remember your passing by your old chum without recognizing him, simply because he had grown a beard. Maybe a stylized image, a sort of block mosaic, would concentrate the attention of the viewer on the most significant, most informative details? To get to the bottom of it, it was decided to produce a portrait drawn extremely crudely, as if with the brush of a house-painter.

The painter this time was a computer. It covered the portrait with a network of 20 lines and as many columns, and then worked out the average brightness of each square formed. The result was presented on a display: a hodgepodge of dark and light spots. This notwithstanding, nearly half those involved in the experiment recognized the man shown in the "block portrait". In another experiment almost everybody found, from a "block portrait", a photographic picture among the ones spread on the table, although the face was unknown. Should they do that at random, the probability of success would not be higher than four in a million.

In the 1820s Fourier published his work entitled *The Analytical Theory of Heat*. At the time, steam engines were gaining ground in industry and engineers needed a theory of heat transfer, and so it was put forward. Later on it turned out that the mathematical suit tailored by

Fourier also fits electricians, radio engineers, and airplane designers—in short, members of hundreds of professions, including physiologists.

The universal nature of the formulas is by no means coincidental. One specific example of motion in general is thermal motion. Mathematics gives an equally exact description of the string, the car body vibration on the springs, the supertanker rolling on the seas, the silent travels of the Moon among the stars, and the heartbeat.

The swinging of a pendulum will give a smooth curve, a sinusoid, on the graph. The fanciful trembling of an aspen leaf is a sum of simple harmonic motions, a mass of various sinusoids differing in frequencies and amplitudes. Any oscillation, however involved, can be represented by a series of simple ones. Conversely, out of some simple harmonic motions a complex one can be made up. This follows from the formulas of the Fourier series.

These techniques are widely used in science and technology, and not only in these fields. The Soviet physiologist Bernshtein proved that any recurrent motions can be described using the Fourier language. Johanson at Upsala University developed these ideas further by establishing that the Fourier series may also be used to describe dances: the longer the series the richer is the dance in details that make it unique.

Returning to the "block portrait", what can you say about the brightness of the squares of the mosaic? That it seems to be subject to some kind of oscillations. What is the *lowest* "spatial" frequency, that is, the frequency of brightness variation? The answer is clear: zero hertz—no variation. The completely black or white rows and columns look exactly like this. And the *highest* frequency? The answer is not that simple.

First, the ten hertz frequency is present. Why am I so confident about this? Because there are twenty squares in a row and so there may be no more than ten "black-white" pairs. This is the highest frequency of brightness oscillations that carries useful information.

Useful. Because the "block portrait" contains much "noise", that is, high frequencies due to sharp brightness differences between squares. Fourier analysis shows that such differences are combinations of an infinite number of various oscillations whose amplitudes fall off gradually with frequency. Spatial frequencies of the "noise" jam the useful ten-hertz information. This obtains, for example, when a deer hides in thick bush: the high-frequency signal of foliage and branches "absorbs" the lower frequencies of the information about the deer's body. Military camouflage is also based on "noise", disorderly "high-frequency" painting obliterates the contours of structures and equipment.

The block portrait will be improved drastically if the interfering noise signals are "cut off", that is, stopped by a filter. This operation is readily accomplished by a computer, and the result appears to be more pleasing to the eye than the initial image.

But squinting, what does that achieve? By shielding the pupil with the lid we reduce the incident light flux on the retina. Now the fields contract not as tightly as with a completely open pupil and the "sieve" of the lateral geniculate body now only analyzes the picture using relatively crude "cells". Sharp brightness changes are simply not perceived by our vision under these conditions.

Where do the various spatial frequencies take shape after the analysis? Mounting evidence coming from different countries went to prove that this takes place in the brain. And if this is so, the visual apparatus does the work that is performed by the device recommended by

P. J. van Heerden for do-it-yourselfers in school labs. The brain thus imitates the Fourier holograph.

Holography.... Its material basis—the wave process—was conceived as early as the 17th century. The knowledge required to realize it was possessed by Young, Fresnel and Fraunhofer; but still it failed to make its appearance although each of the above-mentioned figures made a notable contribution to science. Later, Kirchhoff, Rayleigh, Abbe and many other physicists of the second half of the 19th century and early 20th century came close to understanding its principles. And when the 1971 Nobel Prize winner Dennis Gabor finally invented it in 1948, he did not put much stock in it and over the years nearly forgot about it. So long and strange was the fate of holography. Only after the laser came in could scientists work out convenient set-ups for producing holographic images. The first to make it in 1962 were the Soviet physicists Yuri Denisyuk and the US radiophysicists Emmett Leith and Juris Upatnicks.

In its general form, holography is photographing without a habitual camera. The laser beam is split using mirrors, lenses and other optical means into two beams, one being directed at a photographic plate, the other at the object. Light waves reflected from the object arrive at the plate and there interact, or interfere, with the "direct" beams. If the crest of one wave coincides with the crest of the other, they will enhance each other. If the crest meets a trough, they cancel each other. Clearly, the photoemulsion on the plate in the first case will blacken and in the second it will remain white. It is now necessary to develop the hologram to see....

But without a laser the hologram is a miserable picture, just some unexciting plate, resembling a bad negative—everything is grey, there is no image. But suffice it to view it through a laser beam, and somewhere inside, in the unfathomable depth, a three dimensional image will spring to life.

In the physics of light there is a rule called "the Huygens principle" that states that any point of an illuminated object is in itself a miniature light source. In a laser beam each blackened spot of the hologram appears just like a mini-source. The light rays coming from these sources interfere in space, just as in the recording of the hologram the reference beam (from the laser) interfered with the reflected beam (from the object). It is due to the interference that the image emerges such that you can literally pass through it—you will simply have to walk through light.

Holography has been discovered while working with light beams. But since light is a wave, we can imagine holograms obtained with the help of other waves such as ultrasound, radiowaves, X-rays, or even gamma rays. Some advances have already been made in those more exotic kinds of holography. For example, holographic radar (sometimes called side vision radar because it is installed on an airplane and its aerial is directed normally to the plane's course) yields pictures comparable with aerial photographs, those "radio photographs" being unique in that they are obtainable at night and also when the ground is covered with clouds. Subsonic waves hold promise for geologists and geophysicists, who hope to use them to peek into the interiors of the Earth. Some progress has already been made in this field and the prospects opened up are phenomenal.

But holographic photography, of course, does not exhaust the potentialities of holography. The hologram of a point is a splendid lens that beautifully focuses laser radiation on, say, a part of a microcircuit to be welded. And a hologram of several points arranged in a suitable manner can split a laser beam into several ones, each welding its respective part of a circuit. According to the American journal *Electronics* this principle is being used by Siemens in laser welding of microcircuit pins. The new technology is by far more productive than the single-beam one.

We have, however, digressed too far from the topic that reminded us of holography. Back to our visual apparatus. Vision and memory are interrelated and seem to be related to holography.

"I would like to indicate the philosophical aspect of such amazing phenomena as ... the relationship between the holographic record and the human memory," noted Gabor.

Really, one hologram can contain hundreds of thousands of images, and one square centimetre of it now can carry up to one hundred million bits of information. What device can match such a capacity? Only the brain.

The hologram of any object is an ideal filter, which singles the object out among thousands of others. Say, a photograph shows a sea of keys with intricate designs—no way of finding a desired one, just like finding a needle in a haystack. And if we illuminated that chaos with a laser beam and viewed it through the hologram of the lost key, we would find a bright spot where it lied. Holographic recognition systems are a million times faster than traditional ones. Such are, for example, the holographic recognizers used to compare finger prints or hand-written letters. This reminds of the workings of the visual system, which enables us in a split second to recognize a familiar face among a sea of others. But the visual apparatus belongs to the brain.

We have earlier discussed the mathematics that will, it seems, give us a clue to the mystery of the generalized image. Could it be that holography and Fourier series are that clue? There are many good reasons to think so.

To single out different spatial frequencies in a picture, opticians take "gratings" consisting of transparent and nontransparent bands. These do not by any means have to be real gratings, also acceptable are "chess-boards" and concentric rings, and many other configurations, the only requirement being the regular alternating of transparent and nontransparent areas. The higher the spatial frequency required the finer must be the elements of the filter.

With such a filter it is relatively easy to find out whether an image contains appropriate spatial frequencies: have a photocell "look" at the picture through the grating. Then all the frequencies, save for the one at which the filter is tuned, will be suppressed by it, and only "our" light flux will pass unattenuated. The current flowing through the photocell will be the "electric representation" of the intensity of the spatial frequency, or of its amplitude.

Now take ten filters, not one, and look at the picture through a dozen photocell eyes. Their readings will be different for different pictures because each of the pictures features its own distribution of spatial frequencies. Generally speaking, this dozen-eye automaton can roughly assess the similarities and differences of simple images. The electronic device will replace a specific image by an "abstract" combination of voltages. Is there really any need to name this combination somehow, to express it in words? No, there is not. Our machine can do splendidly without it. Perhaps the brain also recognizes in the same way, "without words"? After all, dogs also recognize a multitude of objects, although they, as animals, possess no words.

Undoubtedly, a dozen filters is too primitive an analysis. But why not use fifty gratings, not ten? And analyze not the entire image at once but break it down into areas and then combine the results of recognition? Accuracy will improve, although, to be sure, this would not provide a one-hundred percent guarantee against errors anyway, since a Fourier series goes into infinity. The image will always have a minute detail that sets the picture apart from other nearly identical ones. But nothing can be done about this. The problem "similar—dissimilar" will at all times be solved to some reasonable degree of accuracy.

Gratings are able to help not only the photocell but the human eye as well. After a popular-science magazine published a paper about the work of the Laboratory, I received a letter from a geologist from a town in the Far East:

"Dear Publishers:

The 11th issue in 1974 of your magazine contained a paper by V. Demidov entitled "The Eye and the Image". In it Demidov makes particular mention of Fourier filters. It is said that opticians have long been using filter-gratings. This prompted me to utilize gratings in geological aerial photo interpretation. A picture always contains a number of random oscillations of image tone obliterating the interfaces of different areas of ground surface. And Fourier filters make it possible to remove those random oscillations by straightening out homogeneous surfaces and setting apart inhomogeneous areas. I have produced some makeshift filters (a grating in black India ink has been applied to a transparent celluloid plate). Some effect has been achieved. Unclear outlines of structures now come out more distinctly and are more easily identified."

A large paper on the uses of a wide variety of filters (gratings) was included in the book *Remote Sensing* published by the USSR Academy of Sciences before the meeting of the US-Soviet group on natural resources surveying from air- and space-craft. It stresses the desirability of using gratings in picture identification to improve the quality of images.

Fourier filters thus suppress "noise".... But we can also regard as noise not only interference but all manner of variations of the image, for example, changes in hand-written letters. Computers, for example, "dislike" manuscripts, they prefer special-purpose lettering. It was once attempted to put this state of affairs right by increasing the capacity of computer memory and by entering into it fresh variations of configurations of hand-written letters. But it is impossible to cater for the infinite variety of shapes. Human vision grasps the main thing (generalized image!) in a letter, ignoring minute details.

Do you feel now where we are being led by this reasoning? We are somewhere very near the principles on which visual identification can be constructed. What brain structures are able to play the role of Fourier filters or other holographic components? Here is what van Heerden has to say about it:

"If we have a three-dimensional network of neurons, in which each neuron is connected to a few adjacent ones,... then signals will propagate in this network as a wave propagates in an elastic medium. If, moreover, the ability of the neurons to propagate received signals can be permanently enhanced by frequent use, then the network must act as a three-dimensional hologram, with a storage capacity of the order of the number of neurons present in the network.... In information theory, recognizing,... is described by the correlation function of two time functions, or two images. The elaborate computation of the correlation function can be described mathematically as a filtering operation, but the computation of the matched filter required for this filtering operation is of course as involved as the original computation.... Accidentally and fortunately—or maybe it is in the nature of things—a propagating wave field carries out automatically this laborious computation demanded by the theory."

A team of workers headed by Professor Nikano in Japan have manufactured a regular three-dimensional crystal-like composition, an associatron. In its structure it strikingly resembles van Heerden's description of a possible scheme of the brain. The regular network of electronic "neurons" of the associatron is such that it can pass electrical signals: for example, pulses from a "retina" consisting of many photocells. If a "neuron" receives two signals at once, it makes note of that event in its memory. Otherwise, it records nothing. Accordingly, the system records not so much the information as the result of the superposition of two or more information "blocks" of electrical signals. In other words, it records their association. In Nikano's "crystal" associograms are so closely linked that it is impossible to single out any of them. Recurrent information enhances its track in the associatron, whereas rare signals can be completely lost, being chocked by more frequent information signals. How this all resembles the workings of the brain! And no "storehouses of memory" have so far been found in it, although each neuron is able to remember, and in exactly the same manner, stronger impressions drive out of the memory rarer and weaker ones....

However, whatever intricate models are constructed and whatever general concepts concerning the possible structure of the brain are put forward, a sceptic can always counter, "But who saw, and where, that real neurons actually do holography or at least something related to it?"

A detailed discussion of this topic will conclude the book, but now we will look at so-called optical illusions.

Chapter Fourteen

Illusions Produced by Our Search for Truth

How many times has a tree been mistaken for the continuation of a road, and the shadow of a cliff for a bend? Insurance companies are in possession of statistics that prove that an entire abyss separates the visual image from reality....

R. de la Taille

Les illusion d'optique ou l'algebre de l'imposible

Cognizance is a chain of hypotheses that are tested to be rejected as invalid or accepted and used as a guidance. Vision performs the same job. We do not notice this only because it goes on only at the subconscious level. The "reasonable eye" constructs hypotheses about space and arrangements of objects in it.

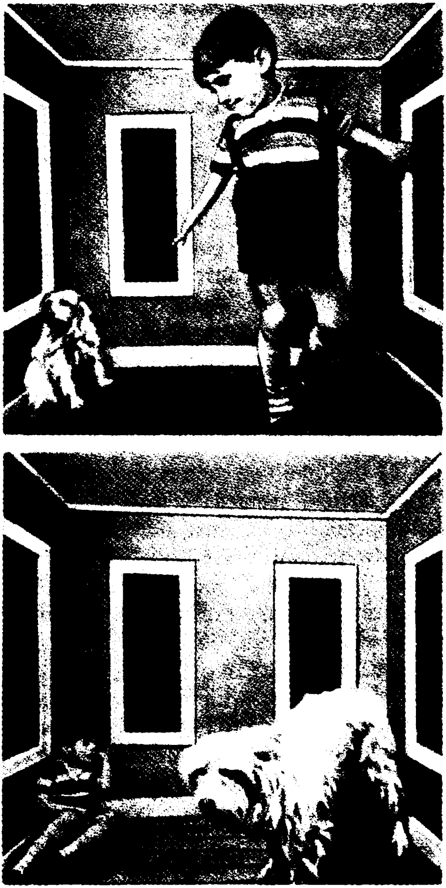
Normally we view the world from eye level. In this world the surfaces of things have definite textures. Grains on a wooden board, the weft and warp of a fabric, the tangle of grass blades, the intricate ornament of tree branches, the striped hide of a zebra, and what not. Texture makes wood different from metals, glass from fabric, sand from water, and so on. Grooves, ripples, and waves provide information of immense importance for the brain. A fleeting glance would be enough to imagine the softness of a fluffy carpet, the chilling touch of a steel sheet. And all these properties can be visualized when looking not only at the real thing, but also at a picture or a photograph of it.

The farther away is an object the closer together are the elements of textures—one of the important signals of distance. The military knows that when buttons on the uniform can be discerned the enemy is 200 metres away, when eyes can be distinguished the enemy is 50 metres away.

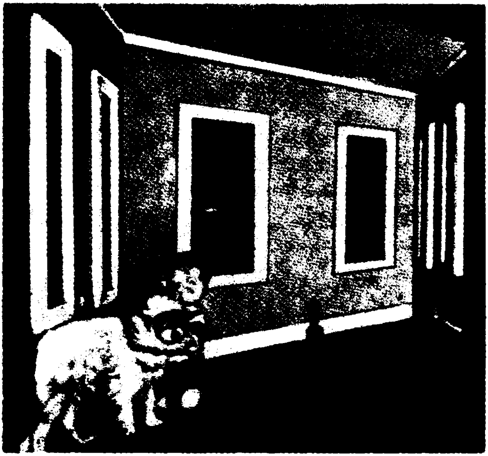
When surveying the terrain, more distant areas are viewed at a more acute angle. Here again the details of textures come closer together, but this tells us something not only about the distance but also about the elevation of the observer. How unusual space becomes when a common point of reference is changed, when some visual axioms have to be replaced by others.

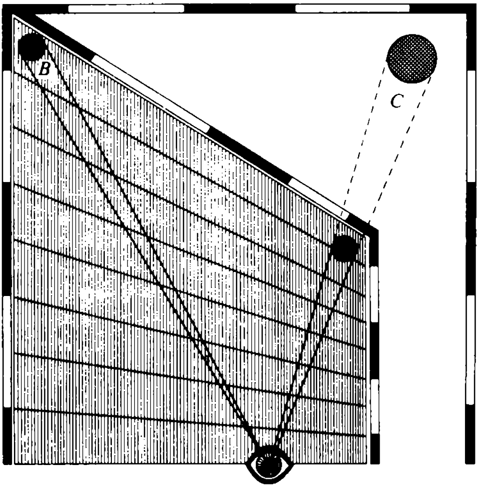
A veteran pilot after many years of flying light aircraft narrates about his first acquaintance with a heavy plane: "I manned the cockpit, took hold of the control wheel, glanced down at the ground and was stunned. My eyes were not at the habitual two metres above the ground but at four! The airfield seemed to have shrunk fourfold. The ground appeared so unusual and distant that I could not imagine how I was to land."

"Could not imagine how I was to land,"—that is what it means suddenly to see textures and the world in a totally different way, from an unconventional angle! Fortunately, our brain is a system possessing colossal adaptive powers. The flier goes on with his story: "I came down from the aircraft dejected. What's to be done—I could not turn down the offer, all the same somebody had to fly and land safely! And so I got into the plane once more. I again pulled the control wheel and began to look at the ground as during a landing. I sort of began to adapt. But suddenly, in the place on the ground where my glance rested, a mechanic appeared. He looked uncannily distant and, as it were, reduced. Again everything became unclear. I came down once more, in several minutes I again sat at the control wheel and started surveying the ground. After having sat so for five minutes I eventually felt that now I can see clearly: a landing is possible. Now I was sure of myself."

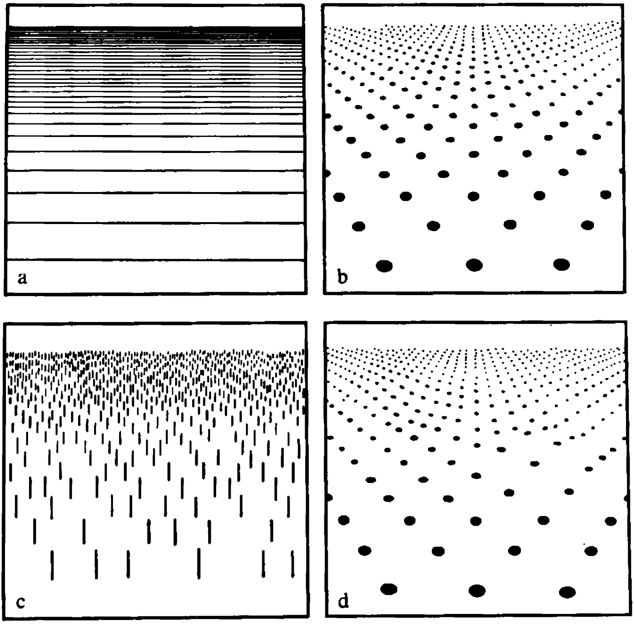


The "magic room", in which people and animals turn into dwarfs or giants, is in fact an ingeneous trick. The curved walls of the room, when viewed from a certain point by one eye, look perfectly normal. Therefore, when gauging the size of the boy, we





automatically compare it with the size of the windows. These elements being visually the same size, the brain concludes that the boy and the dog keep changing their sizes. After all, the "measurements" performed by the visual apparatus are relative



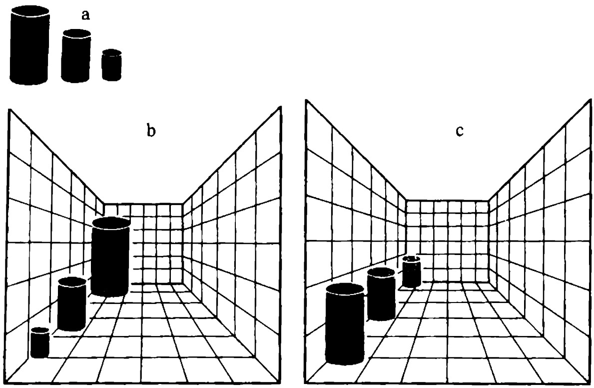
Textures inform us about the distance, nature and form of a surface, the height of observation, and so on and so forth

This adaptation might seem to be too swift. But here is what the above-mentioned Gazzaniga said: "It is to be remembered that we are studying only half of the human brain—a system able to learn readily after the first attempt." Well, if such is the severed brain, it is all the more powerful when the hemispheres exchange information and help each other.

We have, however, digressed a bit. Widely known are the illusions of "growth" of identical objects when they are drawn against the background of converging lines or against the background of "contracting" textures (which enhances the effect). Such pictures are generally cited as examples of "optical illusions". But what has illusion to do with it? Is the eye a measuring instrument like a micrometer? Embodied in the brain is a distinct postulate proved by hundreds of thousands of unconscious experiments: as long as two objects cover the same number of elements of the same texture with their outlines, they are equal in size. This behaviour of vision seems to be above all related to the multichannel character of the processing of information coming from the eye. This is because in addition to the channel of the generalized image (where the signal is independent of the distance of the object, whereby the latter at any distance is perceived as the same object) there exist special-purpose channels that independently and without any connection assess the "true" size and "true" distance. This is called the "texture postulate" and, probably enough, it is the material foundation of the functioning of these channels.

But what does the eye see in the specially contrived picture below? In the first case, the cylinders blot out elements of the same background texture which are at different distance from one another; in the second, they cover different numbers of texture elements, and hence the farthermost cylinder is the largest.

No, it would be unfair to blame vision. The picture is perceived in an absolutely true manner owing to the situation modelled by the brain in its internal perceptive space. The brain constructs a picture of the arrangement of objects, if you wish, a hypothesis, without measuring absolute sizes—a clue to a wide variety of illusions. The relations between the object and the texture of the background are indications of relative characteristics of things (more—less, farther—closer, and so on), which ap-



We gauge the size of objects from the number of texture elements they blot out. The small cylinder (a) is three times smaller than the largest one, but in (b) it seems to be, at least, eight times smaller. In (c) all the cylinders seem to be the same size

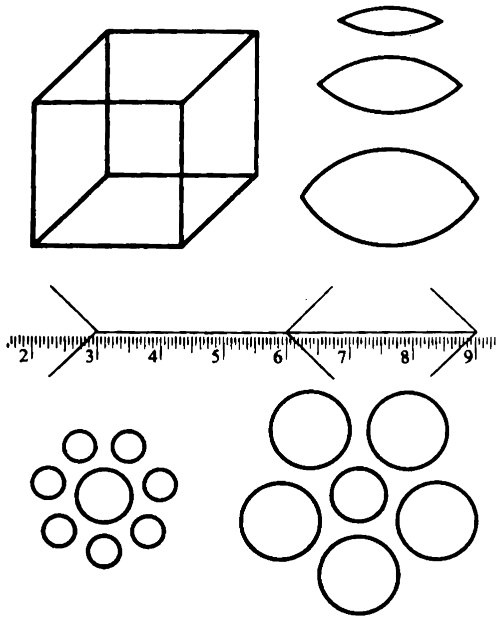
parently can be assessed by the brain with a remarkable accuracy.

But what if there are no textures, if the eye only sees smooth planes and boundaries? Then the consciousness is deprived of one of the most important "key signs" that can be used to adapt to a situation. More than 140 years ago the Swedish naturalist Necker drew a cube that could be turned inside out. One face of it appears now frontal and now back. There being no ripple on the faces, the brain has no grounds for preferring one hypothesis to the other and so it switches from one to the other alternately. In exactly the same manner, at night the eye does not distinguish fine differences in textures with the result that, say, an unlucky driver may mistake a dark cliff for a dark entrance to a tunnel.

One subjected to an illusion does not, as a rule, see its difference from normal clear perception. An illusion is an illusion precisely because the perceived image appears to be as true as any other one. Really, it is exceedingly difficult, nearly impossible, to persuade a victim of illusion to change his or her mind. I remember riding once through the countryside at night. Directly before us—just over there, beyond the trees!—hung the huge yellow disc of the moon. The driver suddenly said: "Now is the time to fly to the Moon!" And went on to explain: "Look, how close it is now, much closer than when it is overhead." Frankly, I was stunned and took some time to answer. But all my explanations in astronomical terms proved to be in vain. The driver only grunted now and then but at heart, I felt it, he stuck to his opinion.

The illusion "the moon near the horizon" has been described even by Ptolemy, who was also the first to give a reasonable explanation for this illusion: the effect is the trick of vision and not the result of the magnifying action of the atmosphere, as it might be expected. We do not make out new details on the lunar disc, which could not be seen when the luminary is at its zenith and the disc looks smaller. What then explains the illusion here?

We are used to having objects diminish in size with distance. The English physicist William Bragg in his book *The Universe of Light* wrote: that if an airplane appeared just over the horizon and it had the same size as when it was overhead, it would be a shocking sight. On approaching the horizon, the moon does not become smaller as the airplane does. Its angular size is constant. But like the plane the moon near the horizon seems to be more distant than overhead. And so the brain draws the unconscious conclusion that the lunar disc had become larger, otherwise it could not have the same angular size as when it is at its zenith. And we see an enormous moon.



Some illusions

When between the eye and a mountain peak there are no textures, vision miscalculates the distance greatly. The passangers of an aircraft flying between cliffs cry out in fright: the wing will now scratch the rocks. But they are a good kilometre away. Even the astronaut James MacDivitt, a man of great skill, became a victim of an illusion: it seemed to him that the final stage of the launcher was only 120 metres away from his spacecraft, whereas instruments indicated 600 metres.

Yes, the world constructed by our consciousness is dependent both on the past and the present. But not only on them. "Perceptive models anticipate the future," wrote the Soviet psychologist Velichkovsky. This anticipation gives a clue to the amazing noise-resistance of communication lines transmitting signals from the senses. Noise is unable to inflict serious damage to the image that has mostly been created beforehand. The picture of the world is formed in the mind out of those fragments that we have amply stocked our mind beforehand, long before the encounter with a given phenomenon. The fragments are cemented by our experience and signals of the sense organs.

The more familiar is a situation, that is, the more it corresponds to the inner perceptive model, the faster and more automatically a man reacts. From scratchy fragments—instrument readings—the operator at a power station visualizes the overall picture of the work of boilers, turbines and generators. And not just visualizes. The main thing in his work is prediction. He must catch the moment when events will require his interference, for which purpose, in the words of one air traffic controller, he "must run ahead of the pilot".

To comply fully with one's post, an operator needs a rich imagination. It will allow him to work with an acute shortage of information, and even—of course for not too long a time—without any new data inputs at all. But what is "imagination" if not a well organized perceptive model? It helps to find the shortest path to a correct solution, and a man with imagination is at all times ready to act. So test pilots always mentally reconstruct their forthcoming flight. They visualize the most likely equipment failures and construct plans of action. In a critical moment they will always have psychologically more time for decisions, because in an anticipated situation, as psychologists note, "the response time tends to zero".

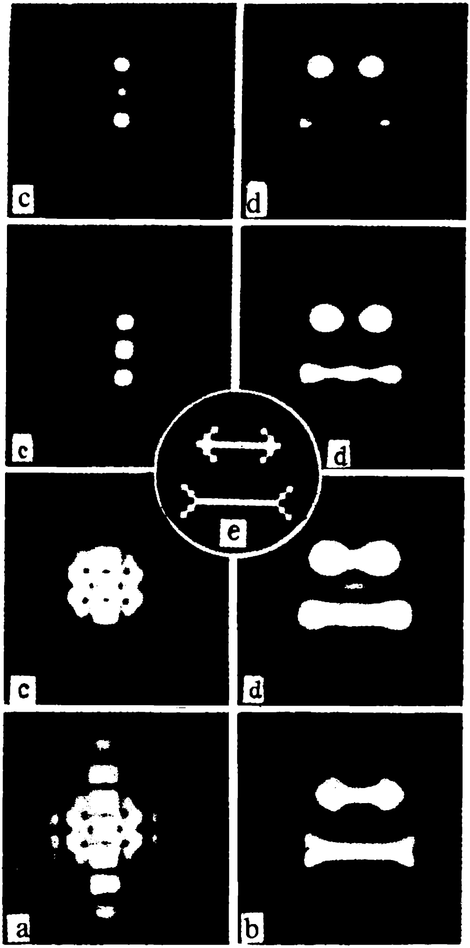
But how dangerous may be the habit to behave following a perceptive model anticipating the reality if a man has weapons in uncontrolled possession. When the Soviet journalist Vasily Peskov on a visit to the USA produced his photo gun, his American colleagues were horrified: "Bury the thing at the bottom of your suitcase and never expose it! Woe betide you if you aim that gadget at somebody: instead of a smile you may get a bullet!" It is only natural that with the US murder statistic as it is one can expect the "first shoot and then ask" behaviour pattern. To be sure, the pressure of such a dismal perceptive model is a consequence of social conditions, and the senses are not to blame here.

Illusions associated with a perceptive model may introduce errors into scientific work by affecting experimental results obtained by the most accurate instruments. The book *Optical Illusions* by S. Tolansky at London University gives many examples of such incorrect perceptions. For example, when assessing by sight the position of a line equal to the halfwidth of a Gaussian curve that describes the probability distribution of a wide variety of events, literally all the experimentalists err by 30 per cent. And even when a marked ruler clearly indicates a mistake, the incorrect drawing still appears correct. Out of three lenses drawn side by side the largest appears the most "paunchy", although all of them have been drawn with the same setting of a pair of compasses, and so their curvature is absolutely the same. According to Tolansky, errors in such situations may be as high as 300 per cent. And nothing can be done about it, since it all comes from "inner models".

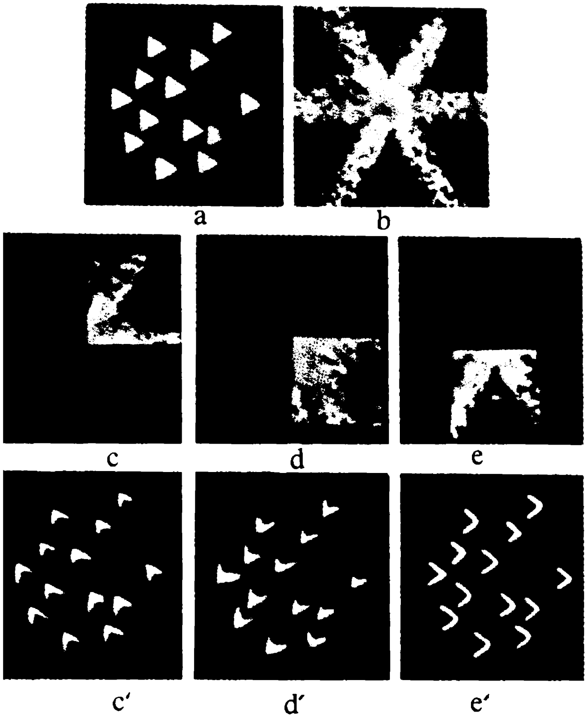
The illusion of lines of equal length ("tailed" lines) that appear to be of unequal length is extremely compelling. It has long been believed that the eye assesses their sizes by jumping from one end to the other. With the tails pointing in the same direction as the motion, the glance, as it were, draws along them, so making the dimension psychologically longer. Conversely, encountering "counteracting" tails, the glance is sort of hampered, and so the line seems to be shorter. But this hypothesis is at odds with the results of Yarbus's experiments. It will be recalled that when an image is fixed using a sucker, it vanishes not at once but in a second or so. And during that time span, when a man is unable to shift his sight along lines, he still sees similar illusory lines as being longer or shorter. It only remains to accept that the illusion is due to the transformations to which the visual image is subjected. As we know, these transformations resemble viewing a picture through a Fourier filter. Fourier analysis appears to be very important, since it accounts for illusions not from psychological (that is obtained by the "black box" method) and not subjective, but objective viewpoints. If we turn the image of lines into Fourier holograms and discard from them high-frequency terms of the series (a computer-assisted exercise), the image recovered from the hologram will be exactly as it appears to us. That is, the illusory longer line will in fact be longer, and even measurements will prove it.

Another illusion is well known: equilateral triangles with the same orientation scattered over the plane of a picture seem to "fly" now in one direction, now in another, and now in yet another. In all probability, that wanton and unpredictable behaviour is explained by the fact that the visual apparatus does not make use of the entire internal Fourier filter in the brain, but only part of it. This effect is beautifully demonstrated by a computer by indicating on the display the "flight of birds" in any direction, for which purpose it only needs to look at the triangles through an appropriate piece of the filter it has synthesized.

Consequently, optical illusions are a product of the brain work. And the latter has a formidable capacity for



When in a hologram the high-frequency signals are removed (d), the restored image (e) of a line with "tails" directed outside is actually larger than that of the line with inward "tails". Here: a—synthesized hologram, b—the image restored from it, c—"truncated" hologram, d—restored image



e triangles (a), like a fly of birds, can be imagined to move in any the three directions. To achieve this, it is sufficient to cut out of synthesized hologram (b) an appropriate piece (c-e) and to tore the image (c′-e′)

:ording past experience. The question thus is: Are illu- ›ns related to experience? Put another way, will they be ·fferent (if only in their intensity) in people with dif- ·ent kinds and amounts of experience? This most interesting issue, among other things was being investigated by the above-mentioned expedition to the out-of-the-way regions of Uzbekistan in the early 1930s. Soviet power was just beginning its transformations there. You could meet there a female student of a medical school and also an "ichkari", a downtrodden woman who never ventured beyond the woman's quarters of a home, and was destined to spend her entire life in an extremely narrow circle of interests and impressions. The members of the team had an unheard opportunity to trace the variation of the workings of the woman's visual perception as the level of education and involvement in social activities increased.

This especially manifests itself in illusions. Specifically, in such a famous illusion as two identical rings one of which is surrounded by rings of larger diameter and the other by rings of smaller diameter: the first one seems to be smaller than the second one. Ichkaris turned out to be illusion-resistant: only a third of them got caught by the illusion. But the more educated the group of subjects were, the higher the share of the illusions's victims was: students, nursery-school teachers—64 per cent, Soviet activists—85 per cent, student school-teachers—92 per cent. This is quite understandable. A man actively involved in social life, and even more so students, often has to make assessments by sight, comparing distances and sizes. Experience shapes the perceptive model of the world, and the latter shapes illusions.

Similar investigations carried out in the late 1960s in African villages gave similar results. Illusions common for town-dwelling Africans were nearly absent in tribesmen living in round huts: the percentages were 64 and 14, respectively.

This again goes to prove the rule that we often see something as we see it not because it is like this in reality, but because we know what it looks like. Our past experience predominates here. For good or ill? In most cases for good. After all, it is our experience that enables us to foresee possible implications to make our decisions with more confidence and speed, and to adapt to the world around us and eventually to live better in it. Commoner events seem to be more true than unusual ones.

In the State Tretyakov Gallery in Moscow there is a St. Petersburg landscape by a famous artist Count F. P. Tolstoy (1783-1873). It is covered with a piece of translucent paper one end of which is dog-eared. And although many know that the paper is drawn they cede to the temptation to lift it. That the paper is a piece of brilliant art is ignored by the perceptive model and so it prompts the most natural solution. Assessment of probabilities thus lies at the heart of the functioning of our perceptions.

Chapter Fifteen

A New Clue to Old Mysteries

Hologram, which was first used as a metaphor or analogy, has become an exact model of normal forms of work of the nervous system.

K. H. Pribram, *Languages of the Brain* (preface to the Russian edition)

A cat was subject to a trepanation of the skull by drilling a hole in it. Normally cats undergo these operations with enviable ease and run about in several hours, but this one lies motionless. Into its vein from time to time are supplied droplets of curare, the once-mysterious poison that South-American warrior Indians used to smear on their arrows and spears. Curare stops the contraction of muscles like a switch. This is remarkably convenient for physiologists: the cat can be handled without tying it to the table, and also it does not move its eyes. They are fixed strictly at one point, at a screen where a "movie" is shown.

A resuscitation apparatus hums quietly. The cat is lying on a warm heating pad and, seems to be blissful. At least, it is not angry and its malice does not ruin the experiment.

And in the screen floats a light stripe—otherwise the fixed eyes would see nothing. Now the stripe is replaced by a "zebra"—two stripes with dark gaps between them, or else three, four or five stripes—as many as the experimenter pleases.

Gratings.... Spatial frequencies, each of which is a signal to the brain.

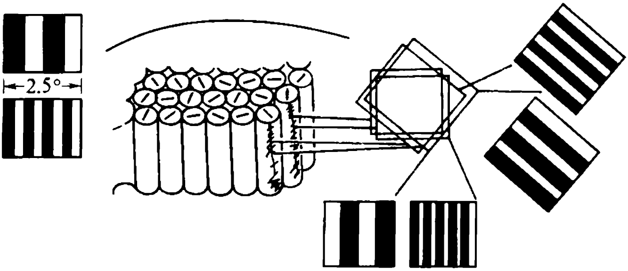
"They revealed to us that the brain really does perform holography," said Glezer. He did not go on to expand, but talked about Hubel and Wiesel and their experiments on cats.

The American physiologists, studying retinal fields, showed the experimental cats various lines, large and small, horizontal, vertical and slanted. For each line in the visual cortex, in its occipital area, a neuron was found that responded to that line alone and not to any other one: a fundamental discovery that made headlines. Curiously enough, they managed to find several cells for a certain definite line. It was necessary to move the microelectrode strictly normal to the cortical surface, and then such cells were encountered one after another, just like stacks of coins. A neighbouring "stack" might be tuned to the same kind of line, only inclined slightly differently.

Why so many cells in a stack? Perhaps science has here an example of redundancy of amazing multiplicity? Could it be that all the neurons of the stack are occupied by the same business? If so, is it this that accounts for the remarkable reliability of the visual apparatus? But this was an issue about which scientists could only conjecture.

At the time, the problem of "the brain and holography" was a matter of a lively debate in the literature on neurophysiology. Do these stacks and these lines have anything to do with the holographic hypothesis?—was the question posed by the workers of the Laboratory at Koltushi. And so they set out to show "movies" to the cats—gratings with different spatial frequencies.

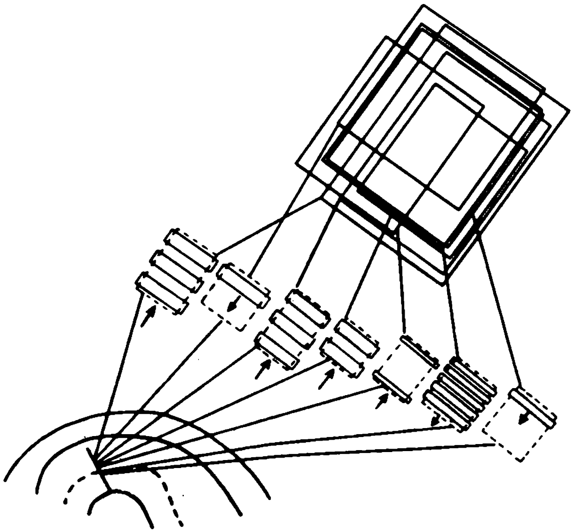
Why just gratings and not anything else? How could Glezer and co-workers be so confident that they would find neurons that respond not only to a single stripe but also to blocks of two, three, etc., lines? The confidence followed from the essence of holography, from Fourier series. The sharp brightness difference is the sum of various spatial frequencies, which extends into infinity.



Fach neuron of the "stack", or column, in the cortex responds to a grating of a given spatial frequency. The solid angle subtracted by the grating is 2.5° in cats and five times smaller in humans. Therefore, our vision is five times keener than the feline vision

Accordingly, if the brain performs holography or something like that, if it can produce Fourier expansions, the visual cortex must have cells tuned to "zebras".

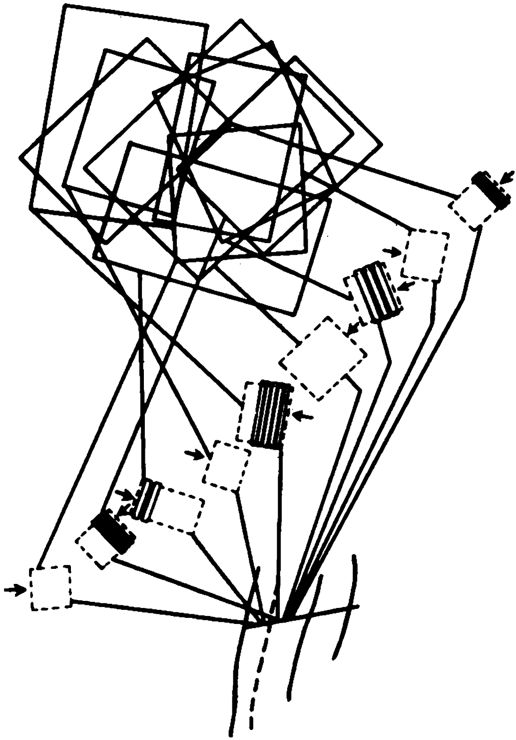
To be sure, the experiments started not from scratch. Back in 1966 the outstanding English neurophysiologist Fergus Campbell suggested that the visual system functions as a multichannel Fourier filter with each channel set to a grating with a certain spatial frequency. He proved it as follows. At first a subject was shown a grating in which the contrast between the bars and gaps was very low, so that the grating was barely perceptible. Next the man shifted his sight to a high contrast grating and watched it for about a minute. And then, when he again tried to discern the low contrast grating, it appeared to be blank. Try as he could he could not make out anything, since the powerful signal from the contrast grating had drastically reduced the sensitivity of his vision. Clearly, in all three cases the images fell on different retinal areas, so that photoreceptor fatigue was out of the question. Accordingly, sensitivity was depressed at some higher levels of



When a microelectrode is implanted strictly perpendicular to the cortex, it encounters neurons that respond to different gratings, but all the fields that distinguish these gratings are inclined at the same angle

transduction of the visual signal, perhaps in the cerebral cortex. If the "weak" and "strong" gratings differed markedly in their spatial frequencies, no depression occurred and in each case different relay channels were operative. But are they really connected to the cortex?

The theoretical reasoning of the workers of the Laboratory step by step transfigured into a long series of trials that ended in remarkable success. Neurons were found that had earlier been predicted theoretically. They didn't respond to single bands, but each cell yielded a full-blooded signal when the cat was shown the grating. Such was the first discovery of the Soviet team.



When the microelectrode is implanted obliquely, the fields overlap and thus arrange at arbitrary angles

A second discovery was that the grating must look like a rectangle of a definite length and width. In the fovea, the sharpest visual area, a neuron of the feline brain will be excited and will recognize the grating as its "own" only if the latter is seen from a solid angle of 2.5°, not more and not less (in man the angle is 0.5°, and so our vision is five times keener than the cat's). In other words, the grating must occupy the entire retinal field associated with a given neuron of the cortex (in what follows we will refer to it as the field of the cell of the cortex).

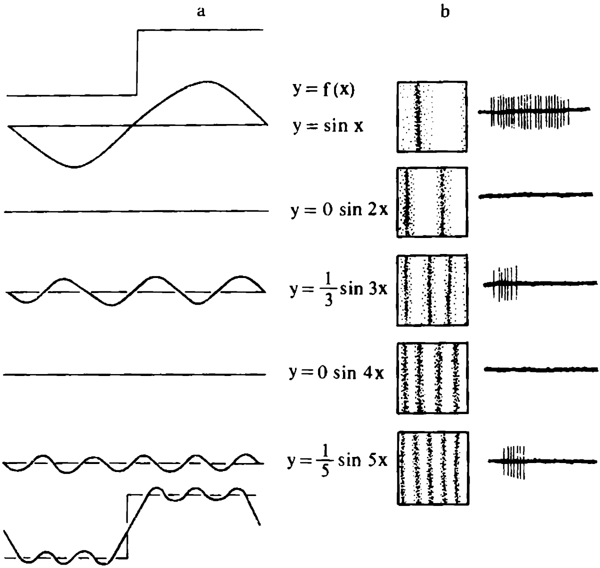
A third discovery turned out to be the most striking: it became clear why there are so many neurons in the stack. They are by no means connected in parallel although they receive gratings projected onto the same retinal area. The neurons in the stack are separated so that each has the task of responding to one grating, ignoring all the others. This means that the stack, if viewed as a whole, will "see" any grating that reaches a given retinal field.

Lastly, all the gratings distinguished by cellular fields of one stack are inclined to the horizon at the same angle. And nearby is another stack tuned to gratings inclined at another angle. And so on, throughout the entire 360°.

What follows from the above arguments? What conclusion can be drawn from the discoveries? In terms of cortex cells, the retina appears as a huge mosaic composed of a multitude of fields, including overlapping ones. A given field is connected with all the neurons of a given stack, and thereby can distinguish all the spatial frequencies to which the neurons of the stack are tuned. And those frequencies have been shown experimentally to obey the laws of the Fourier series. That is, the cortex does nothing but piecewise Fourier transformation of the picture projected on the retina!

The outstanding results obtained at the Laboratory did not pass unnoticed by the international scientific community. They are, in particular, appreciated by the prominent American neuropsychologist Pribram in his concluding remarks to the Russian edition of his book *Languages of the Brain*.

Said Glezer: "Our experiments provided the first evidence in favour of the holographic hypothesis derived at the cellular level. After all, holography is exactly the expansion into a Fourier series of light waves coming



Neurons responding to different gratings bring out sharp changes in brightness: a—sinusoids of different frequencies add up to yield a voltage step, b—corresponding to these sinusoids are gratings of a given spatial frequency

from an object, plus storage of the result of the expansion. And whether the result has been fixed on a photographic plate or in the brain is a detail of the realization principle."

I answered: "Quite so. But one thing is unclear: holography is normally associated with lasers, but there are no lasers in the brain. How, then, does the brain do holography?"

"There are holograms and holograms. As early as 1966 holograms were obtained that had been worked out by a computer and synthesized by a computer. They do not surprise you, eh? But where is a laser in a computer? You should grasp that the principles of holography are mathematics whose material realizations may be different. As you obtain your Fourier transforms so you will have your holography. Or rather quasiholography, if we take its cerebral form. *Holos* is the Greek for "whole". The problem of wholeness of information recording refers not only to vision but also to the physiology of perception in general. The melody of "Carmen" is perceived not just as a succession of sounds but as a particular image, in all its entity, so that later on the music can be accepted and recognized in any key, with any variation down to jazz syncopations—so broad a generalization! But we've digressed a bit. But as for light—yes, to fix it on a photographic plate—a reference laser beam is required. The brain is not a photographic plate, however. To search for a reference beam in it is a hopeless business not because it is difficult but because there are no beams there at all. If a computer can synthesize holograms, why should the cerebral cortex be incapable of it? We should seek the mathematics of the brain, the idea has long been in the air."

"Well let's leave it. But could it be that modern scientists make the same mistake as did thousands of their predecessors concerned with the issue of vision in the past? Could it be that they just substitute another model for the camera obscura that will at some time be recognized as invalid and rejected exactly as the previous one?"

"Why is it a mistake? After all, the camera obscura too within certain limits gives an insight into how an image is projected on the retina, in other words, as a model the chamber is both accurate and inaccurate at the same time, once we stray beyond the confines of the applicability of analogy. The same is true of quasiholography. Furthermore, it is not a mechanical model, like those that have earlier been used to explain the act of vision. This is a mathematical model applicable to the various schematic, constructive realizations of the idea. Mathematics is capable of covering a wide variety of things with one equation. For example, the Russian naval architect Alexander Krylov in his work on the theory of rolling of a ship made use of the equations derived by Lagrange and Laplace to describe planetary motions. The quasiholographic hypothesis by no means tells us how neurons are interconnected and what dendrites relay one signal or another. Its value lies in something else. It prompts us as to where we go from here, what questions are to be put to nature and how. And the most remarkable thing about it is that we find what we have sought to find. So quasiholography passes the "truth" test. It explains, for instance, why the generalized image possesses the property of invariance. From the Fourier picture we can easily obtain a description of the image, invariant to the picture's size, brightness, contrast, and so on. There is thus nothing inherently strange in invariance. Without it the problem would seem far more mysterious."

"I see. Here is something similar to conventional holography, where holograms from close and distant objects are geometrically similar, so that these objects can be identified if a system is available that will respond in a similar manner to both holograms, whatever the difference between them."

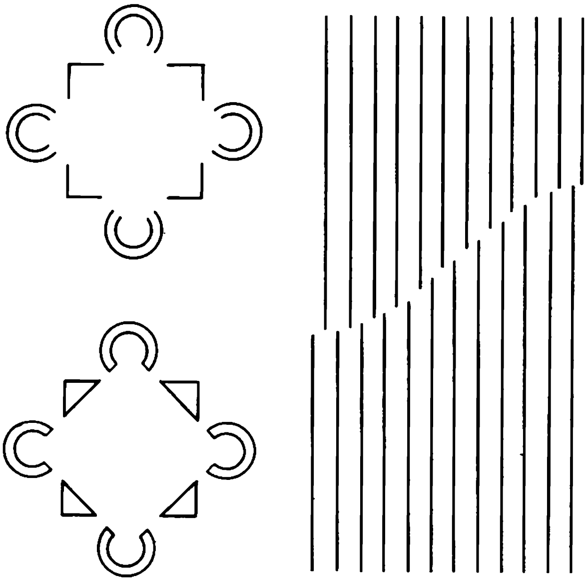
"Yes, but you should not forget that in the brain there are no holograms in the conventional sense of the word."

"Vadim, but does the brain receive information about distances not only because we view the world with two eyes, but also because from identical objects located at different distances come quasiholograms similar in some respects and different in other respects? Then even with one eye man could perceive the depth of space. Take, for example, the test pilot Anokhin who had lost one eye but still remained a pilot. The binocular mechanism of depth perception has been deranged, so suggesting...."

"Don't jump to conclusions. Any idea must be tested and retested by scores of experiments. But let's return to the issue of separation of the outline of an image. Physiologists have so far tacitly reduced it to the simplest case: a clear line is drawn on a white sheet of paper. That is all. Well, in that case identification is only possible using those detectors responsible for lines that have been discovered by Hubel and Wiesel. And in everyday life figures normally appear against a multicoloured background. It masks and absorbs them, destroys the wholeness of the contour. How then do separation and identification occur?

"Colour is important, of course. But if colour differences are insignificant or totally absent, say in twilight when the colour-sensitive apparatus does not function, or when we look at black-and-white photographs, how then is the contour brought out? The main role is here played by textures. Different textures correspond to different spatial frequencies. So a tiger and grass are striped, but in a different manner. The differences lie both in the frequencies with which dark and light areas alternate, and in the slopes of the areas. Where vision feels a sharp change in spatial frequencies, we have boundaries, the contour. And this change is felt with the help of the cortical fields and neurons responding to the "gratings".

Suppose an image is focussed on the retina: to the right a fine texture with vertical lines, and to the left a rough one with slanted lines. We are now viewing the picture from the height of the cells of the visual cortex. This means using appropriate fields that physically exist on the retina in the form of photoreceptors connected with an intricate network of nerve links with neurons of the stacks of the cortex. If one field is on one side of the boundary.



Boundaries that are not drawn but are "felt" stem from the quasiholographic nature of visual perception

and another is on the other side, then appropriate neurons of different stacks will be stimulated. And neurons of other, yet higher levels will conclude: there is a boundary between the textures here.

Look at the hook of a lifting crane, which is painted in slanting black and yellow stripes like a "zebra" because that texture sharply differs from vertical and horizontal lines conventional for a construction site, it just shouts forth its presence and the contrast colours stress its outlandishness still further. Granted, the structure is deliberate, contrived artificially, and that is why it is distinguished so easily. But to make out the boundary of a contour in living things, the brain has to analyze the multitude of spatial frequencies by all the fields of the cortex tuned to differently inclined "gratings".

Mathematically, this implies that cortical neurons perform the operation known as the "taking of the Laplace operator". And how grateful should we be to nature that it mastered such wisdom! This property of vision enables the contour to be continued even where it is broken by other objects. For instance, a book is not halved if a ruler lies across it, and we "see" the lines of the binding where they are covered. Experiments to support the hypothesis of the action of the Laplace operator were first carried out in 1973 in the Laboratory. In a year the English biologist D. M. Mackay conducted similar experiments and arrived at the same conclusions.

Fourier transformations using neurons distinguishing various spatial frequencies are extremely capatious and effective, and when vision starts functioning immediately after birth—in some living creatures better and in others worse—it still functions with amazing perfection. For example, one-day-old chicks unfailingly distinguish a flying duck from a hawk, although they have never seen either. The difference is minute: a duck is a hawk "the other way round" (a long neck and a short tail), while the hawk's neck is short and the tail is long. The main thing is thus which projection is ahead, long or short. And so chicks rush to take refuge once a stuffed hawk is slid on a string over them, but they remain calm if it is sent tail first. How do they manage to discern what is ahead and what is behind?

"In our Laboratory there are some ideas concerning this," noted Glezer. "True, these are just preliminary conjectures, and they still await refinement and clarification, however some scheme is already available. It is supported by observations of cases suffering from visual agnosias, and our experiments on animals. But, I repeat, this is just a first approximation."

And I heard a story that could be seen as a summary of the results of the work conducted at the Laboratory during the past two decades.

There are agnosias in which the visible world falls apart into fragments with no connections between them. A patient is shown a pair of scissors, he sees a straight blade and says: "This is a sword." Next he notices the second blade and says: "No, maybe this is a pitchfork." He looks further, recognizes the rings, but for him these have no apparent relation to the blades, and so he says that they are spectacles.

What conclusion must be drawn here? That in our visual apparatus there are two independent systems. One isolates fragments from a picture or subimages—blades, rings, and so on. The other system out of these subimages compiles the whole image—the scissors. Should the second system fail, the first one would distinguish subimages, but they would not merge into a single image. But should the first system fail as well, identification would become impossible, even with the simplest figures.

What is a subimage? It is a region with a more or less homogeneous structure. Look at a tree growing in a meadow: in the picture there are three distinct textural subimages: the grass, the trunk, and the crown. Their Fourier characteristics are absolutely different. And hence their generalized images are quite unique, not to be confused with the others. Therefore, all the crowns for us are crowns, and all the trunks are trunks.

To be sure, a subimage is not something absolute, which is bound to remain indefinitely as it is. Subimages and images form an hierarchy. For the image "tree", the subimages are "crown" and "trunk", but the crown on its own is the image for the subimages "branch" and "leaf". The world is so great and diverse, and so is the hierarchy of images and subimages.

But does it pay to break an image down into mosaic of subimages, and later to reassemble it? Yes, it does. What is the task of seeing, and in the final analysis of thinking? To establish the spatial arrangement of objects and its variation with time. This is the most general definition of any cognizant activity. Now our task is modest: just to see that near the tree in the meadow strolls a man. How can this be accomplished in the most economical way?

The "point-by-point" transmission, like in TV, is not a good method. We have discussed it in the previous chapters. Also unattractive (we made no mention of that) is generalized quasiholography over the entire field of the image, because then any tiniest change in that huge image entails a restructuring of the entire Fourier expansion. This way of identification is not a bit easier than the "television" method, and therefore nature has chosen another avenue. It has struck a happy mean: it has divided the visual world into images, the images into a sea of subimages, which for the visual apparatus are, as it were, independent and at the same time they merge to produce a single whole.

So the man strolls in the meadow, but the travels of that subimage relative to the others touches neither the subimage of the crown, nor the subimage of the trunk, nor the subimage of the grass. The brain has thus to respond to relatively minor changes in the overall picture, and so information is processed in the most economical way. And to gain victory by small efforts is the primary requirement of life for all living matter: after all, the organism exists not for the sake of information and its processing, but for the sake of living.

How does the visual system manage to isolate subimages that have a texture of their own? This is done by the temporal cells. True, they could do nothing without our old acquaintances—the neurons of the occipital cortex, the neurons that can distinguish textures and boundaries. It does not matter that these neurons cannot trace the entire boundary and have to do with pieces of the boundary because the pertinent fields are all too small. The nerve cells of the temple merge the points of the dotted line traced by the occipital cells to form a solid line, which encompasses an area of texture as if by cutting it out with scissors from the background.

Owing to the extremely complex network of links between the "occiput" and the "temple" the groups of temporal neurons are sort of representatives of a definite subimage. It follows that once a given subimage appears in the visual field, an appropriate group of cells in the temple signals to the higher structures of the visual system "It is here!" Clearly, for such a signal to be given, all the previous links in the visual chain must operate.

The resultant chain of transformations is a curious one. At first the receptors of the retina break down the image into myriads of points. Next the lateral geniculate body transduces the points into pulsating fields. This transformation enables the subsequent structures of the visual tract to analyze the image using the various spatial frequencies and thus to carry out Fourier transformations, the occipital neurons turn the pulsating point image, produced by the lateral geniculate body, into a piecewise holographic one. Now the temple singles out from that mosaic major subimages to make up images. And that most complicated process, more than a match for any engineer, is the most favourable and effective one.

The visual processing program built into the system by nature essentially answers the formula: "In dealing with each specific problem, the program must go over not all the available signs but only a small share of them." Of course, now that we know everything about it the idea appears self-evident. But it did not look like that in the mid-1960s, when the Soviet scientist M. Bongard, who at the time apart from the physiology of vision was concerned with identification systems, put it forward. Bongard's idea was laid at the foundation of many current efforts dealing with a variety of identification problems. His untimely death was a great loss to science, all his acquaintances used to call him a "generator of ideas".

I asked: "Vadim, but your story reduces to the fact that in the temporal cortex there must be cells tuned so that they might take care of any conceivable subimage?"

"No. Not tuned, but self-tunable—a big difference. Before an image for the first time has appeared before the eyes, the temporal neurons are tuned to nothing. And only when textures have been received and pieces of boundaries marked, the temporal cortex comes into play and combines the pieces to form whole boundaries by splitting the image into subimages. We do not know which of the temporal neurons will here take on the role of "combiners". But such neurons are bound to make their appearance—that's the crux of the matter. And the lack of a priori perception is the gist of the idea we are now considering in the Laboratory. Normally, engineers when they design an identification system solve some narrow problem, say, to determine whether certain characters are letters or not. And so, willy-nilly, they attempt a priori to build into it concepts of those images that will be shown to it, and hence concepts of signs that the machine might conveniently use in identification. In man and animals one major advantage of vision is that it need not be preliminarily informed. Undoubtedly, at some point in our lives we have to be informed that this is the crown of a tree, say, so that the responding neurons, responsible for the subimage, would be related in the cerebral structures to the words— in short, we have to learn. It is to be stressed that the visual apparatus requires no training for that learning, it is open to any impressions and any subimages. But what about an image? We may think of it as a result of the merging by some cerebral cells of signals from all the neurons responding to the emergence of constituent subimages."

"Is it conceivable to have so many 'personal' groups of cells?"

"Why not? There are billions of cells in the brain. Billions! Let 'just' a million of them be those 'representatives', then in the longest lifetime you would hardly exhaust the capacity of the system, its memory. After all, subimages, those elements of images, are not that many. So the book, the table, the shelf and what not, consist of the subimage 'rectangle'; thousands of other things, of the subimage 'circle'; others, of combinations of those subimages."

"By the way, concerning the combinations: an image produced that way grows up step by step. Early subimages received just after a saccadic eye movement are still crude. The visual apparatus has just started functioning after an idle period, and the fields of the lateral geniculate body are as yet large in diameter. As they are, they do not enable us to identify the image. The visual system is only able to come forth with a hypothesis "for inside use", which is a result of a comparison between the contents of the memory and an image composed of those rough, nearly shapeless subimages. How the comparison occurs is so far unclear, it is only known that it does exist. It is also clear that this hypothetical image is represented in a quasiholographic form, and it comes from the temporal cortex to the occipital one. This information flow is supported by the scheme of real neuron connections.

In the occiput the hypothesis is compared with the information that has come in by that time from the shrunken field of the lateral geniculate body. If it is not confirmed, that is, does not coincide with the fresh information, the parietal cortex introduces corrections and supplies fresh information from its memory. This, in outline, is the "passage throughout the tree of signs". This process terminates once the hypothesis and the image have coincided completely.

The "occipital-temporal" complex works according to a classical scheme inherent in any stable dynamic system, a feedback system. A living organism is all permeated with feedbacks. They enable it to adapt, to become adequate to the world around it, so wanton and shifting. And when a new mechanism based on feedback is found, you may rest assured that you have found something important.

And now it is high time to focus on one aspect that has been deliberately omitted in the book so far. The generalized image stored in the memory is abstract, "ideal". But any real object is different from an ideal. Returning to the tree, it may be arbitrarily inclined, may have an arbitrary crown, and the trunk may be arranged by nature in relation to the crown in an arbitrary manner. How about identification then?

Glezer's hypothesis takes care of that. In the visual apparatus, it states, there is a system that alters the ideal image given by a set of constituent subimages. The system transforms the "incorporeal ideal" into a "rough reality". Visual realities are necessary for the abstract generalized image to form in the process of learning, and then after the learning is over we at all times transform the remembered abstraction so as to adapt it to the observed reality and thereby to identify it, a remarkably fascinating dialectical process.

The "fitting to the master" is the concern of the parietal cortex. Clearly, the operation is only possible because the transformations in the brain are in the language of mathematics, or rather electrical pulses passing along neuronal circuits. If done in geometric space, in terms of lines and areas, nothing would come out of this, since here there are no abstractions. But the addressee—the parietal cortex—was revealed by observations of the cases of agnosias and experiments on animals.

For us it goes without saying that people distinguish top from bottom, right from left (although it is only in the army that many learn to carry out the order "Right, face!", tip-top). But in a case of parietal hemorrhage orientation in space is disturbed. The patient's eye cannot distinguish between "right" and "left"; the problem, say, "to put the book under the table" becomes insurmountable because the concept of "under", together with many other spatial notions, has fallen out of his mind. But the disease is accompanied not only by visual agnosias. Here, in the parietal lobes lie structures responsible for the grammatical expression of spatial relations, viz. cases and prepositions. The patient, therefore, no longer understands the phrases of the type "the brother of the father", although he knows what the words "brother" and "father" mean, he can even point at them but he is unable to grasp their spatial relationships.

In order to see whether the parietal cortex is responsible for space orientation, Nina Prazdnikova performed in 1977 a series of experiments. She found that when in a dog a part of the parietal cortex is removed, the animal, although able to distinguish a cross from a square, has great difficulties in finding a black point located within a square. But before the operation, the dog would readily handle this extremely simple problem. What happened? The surgery had destroyed the "operators of spatial relations", that is, cells that determine how subimages are arranged. (It is the signals from such neurons that tell chicks whether the front projection of an overhead bird is long or short, and hence whether it is a harmless duck or fierce hawk that slides over them.) And so the dog could no longer get its bearings in space.

But the parietal cortex also has operators capable of giving a command to neuron structures of the temple to shift a subimage sidewards or vertically, or to turn.

Earlier in the book we discussed the experiment by Stefanova who showed her subjects a picture in which a horse alternately climbed up and down a hill. The identification time was the longer the steeper was the slope. The visual apparatus at first, as it were, turned the picture to bring it into the "normal", vertical position, and only then the recognition mechanism came into play. True, the hypothesis of turning has been accepted by some people with restraint. But now it is absolutely necessary. Without it, it is impossible to understand the workings of the visual system, without it there is no explanation for how an abstract, invariant image turns into a concrete horse, the one that is now before your very eyes.

As a matter of fact, now the tree is bent under a gust of wind. Its shape is distorted. The crown has shifted sidewards. A patient with a disturbed parietal cortex does not understand that it is a tree. A healthy brain, however, carries out the operation of displacement and turn. The ideal comes closer to a distorted image and we say: "This is a tree bent by a wind."

The power of the brain to perceive distorted images is beyond belief. I happened to test it on myself, when at an International book fair I leafed through a tome devoted to Picasso, or rather to that period of his life when he had been fond of "decomposing" reality into fragments. He used to deform the faces of his models in a peculiar manner to the extent that they were no longer models in the conventional sense. It had always seemed to me that such deformation, such dislocation of everything, totally destroyed a portrait, and that in it similarity is replaced by unbridled imagination of the great painter. But in the book I held in my hands, those pictures were assembled into a sort of series, each of which was devoted to one of

Picasso's personages. I suddenly found myself thinking that I saw clearly the affinity of the pictures in each series. The brain, that great collector of subimages, brought together the noses, mouths and ears spread over the pages and imparted to them such a tangible portrait quality that it even seemed to me: should the personage of one of the pictures then pass by me, I would recognize him. Yes, Picasso wanted to explode the real image, to break it down into tiny pieces, but he could do nothing with the nature of vision. It proved to be stronger. It recovers the most realistic reality out of cubist and other canvases. The only thing the painter achieved is that it takes us more time to identify his images (we will not here concern ourselves with a discussion of esthetical pluses and minuses inherent in that manner of painting), and many people, whose visual faculties are not that developed, are even unable to perceive the peculiar language of the painter.

The visual system is perpetually learning and accumulating a "collection" of subimages and images, whereby man can find his way in the surrounding world. Something totally new, which we have never seen, may be taken for something familiar, or conversely, to bewilder or even to horrify: remember the stories of how people who had never seen a car scattered in fright at the sight of a belching "monster". Our inner model of the world, as we know now, is largely formed due to the work of the visual apparatus, and the richer the stores of images the wider are our conscious contacts with the world, the easier we accept information and the faster we learn.

The picture of the interaction of the occipital, temporal and parietal cortex as suggested by Glezer and co-workers in the Laboratory, is being clarified. At the same time, this is a clue to the understanding of the structure and workings of the visual apparatus, of its remarkable perfection. And the main thing is that this also paves the way for both the design of electronic identification systems and studies of the architecture of the brain at the highest levels.

If the neurons of the temporal cortex are really "end stations" of a long series of transformations undergone by the visual image as perceived by the retina, this explains the experiments performed in the late 1950s by the American physiologists W. Penfield and L. Roberts. They stimulated the temporal cortex with a weak electric current and the subjects suddenly regained the capability of seeing, literally first-hand, the events that took place many years ago. One female patient (for whom electric current removed her fits of epilepsy) saw herself in a prenatal ward, remembering the finest detail of the setting. In another experiment a young man found himself in the home of his parents in South Africa in the company of his cousins who were laughing and talking, the presence effect was strikingly vivid. Penfield wrote that the reproduction of each episode could sometimes be repeated by interrupting the electrical stimulation and repeating it soon at the same or close point. In that case the episode at all times would begin with the same point. Once the electrode was removed, everything terminated as abruptly as it started. The images were not abstract, but very concrete images as perceived by the visual apparatus—this seems to suggest that the current stimulated the "collector" neurons.

Curiously enough, besides visual images the consciousness of the subjects also produced sound perceptions. One patient heard the voice of her small son who was playing in the yard, hoots of cars, barking of dogs, shouts of boys. Another patient heard an orchestra performing a melody that she could neither sing nor play. Yet another heard a Christmas carole in her church back in her native Holland. Perhaps this also suggests that the temporal neurons also take care of the perception of sound information, and the mechanism used by the brain for this purpose is identical, or at least similar, to the visual mechanism. Could it be that some totally unexpected holographic concept would help scientists dealing with the mechanism of understanding speech?

It is quite obvious that there exists a relationship between seeing, the inner model of the world, a specific situation, and understanding speech. The relation seems to be especially noticeable in the English language, which is so rich in words having many meanings. Speakers can understand one another only if they know what is meant by a word in that particular case. The knowledge comes from their earlier experience, or the context of the conversation. But the prior experience is mostly visual. It is with good reason that some believe that language is a way of relaying to the memory of another person information in the memory of the speaker.

In the chapter on painting we discussed the "speech" of apes. That they can use signs is beyond question. However, they have no language as such. They communicate with humans using holophrases—separate sounds or signs similar to those sounds and signs generally used by babies to express their desires and signal their state. Holophrases, of course, contain some meaning but that meaning is a simple statement of fact. Phrases of human languages are different. They reflect opinions that an event is true or false, that is, that for the speaker in a given situation an event appears so or otherwise.

At the same time, speech is related to visual signs and symbols. According to Pribram, in his book *Languages of the Brain* signs are symbols reflecting constant properties of the perceived world. And symbols are "constructions that take meaning from the history of their use and the current state of the organism using them". Both signs and symbols create the inner model of the world, they accumulate as a living creature acts. "Sign and symbol come together in man as a corollary of his demonstrated increased capabilities for action", that is, for labour. The role of labour in the development of man thus obtain another, now neuropsychological, confirmation.

Pribram wrote: "If indeed it is only through action, an effect on environment (in this case other brains), that the significant and symbolic processes of language are brought together, an explanation is at hand for both the multiplicity of the forms of languages and for the fact that an infant in isolation does not give form to any language. Only by action on other like brains can the human potential be realized. Communicative action thus considered becomes the root rather than the fruit of language."

Put another way, speech is a product of vision and action stimulated by another human brain. It is not coincidental that so many famous writers and painters were involved in activities having nothing to do with the world of arts and letters. To be sure, many opposite examples might be provided, but here we are bound to find some major event or a chain of events that brought that person into the most intimate contact with the everyday world so that his stores of impressions and perceptions would predetermine his or her destiny.

Quasiholographic generalized images allow us also to approach the problem of thinking from a new angle. Some scientists suggest that "thinking is the search for reduction in uncertainty with the help of the distributed holographic memory". Holographic images on a photographic plate make it possible to carry out an associative search for information, which only coincides with an image in general while differing in detail. Handling a problem, a man attempts to evoke some visual structures to simplify the solution markedly. Using that "language of images" which has been developed adequately by modern human engineering, and, strange as it might seem, by advertisement, literally anything can be shown: outward appearance, structure, organization, motion, process, system links, trends and amount, division and many other features of things. No wonder that the "visualization of thinking", is a trick widely used by people with a creative bent.

We have already mentioned that vision provides man with 90 per cent of his information about the world. The models of the Universe and microcosm are, in essence, visual models. That a perceptive model of the world emerges in the blind or even blind-deaf-and-dumb should in the final analysis be put down to the credit of those with eyes, a fascinating problem whose discussion may be a subject of a separate book. Vision exerts its active influence on speech and understanding of speech and on thinking. And so an understanding of the structure of the brain and its workings should come through studies of how people speak, hear and see: how they see what they see. "The things with which we concern ourselves in science appear in myriad forms, and with a multitude of attributes.... Curiosity demands that we ask questions, that we try to put things together and try to understand this multitude of aspects as perhaps resulting from the action of a relatively small number of elemental things and forces acting in an infinite variety of combinations."

These words of the famous American physicist Richard Feynman in the best way possible convey the meaning of scientific research. It is with these words that I would like to conclude my story—necessarily incomplete—about the physiology of vision, whose prestige among other disciplines is ever growing reminding one of the situations with nuclear physics in the 1940-50s.

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SCIENCE FOR EVERYONE

V. DEMIDOV

HOW WE SEE WHAT WE SEE

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[illegible]

SCIENCE FOR EVERYONE

Pattern recognition and freaks of fashions, the perception of color and the structure of the visual tract, optical illusions and shaping of the mental model of the world are some of the topics discussed in this fascinating and enlightening account of the extremely important frontiers of neurophysiology, and psychology, cybernectics and medicine. The author (a journalist and an engineer) visited many laboratories even participated in many experiments – that is why he is so successful in conveying the atmosphere of scientific search and adventure. The book will appeal to the general reader and non-specialist researcher.