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Dichotomy makes us think

⇒ The article illustrates a systematic for the appropriate interconnection between levels of information processing in the brain. A closer look at vision and neural processes underpins a recurring pattern of dichotomy of input and output signals.

1 Hypothesis on dichotomy as a principle

Many things, such as our eyes, developed from a systematic based on symmetry. The resulting variety and functional efficiency is remarkable. The central nervous system with the brain has played a role since the Cambrian explosion in biodiversity around 540 million years ago and the emergence of higher forms of life. Simultaneously with this development, the bilaterally symmetrical physique appeared. And with that a first basic dichotomy – left and right.

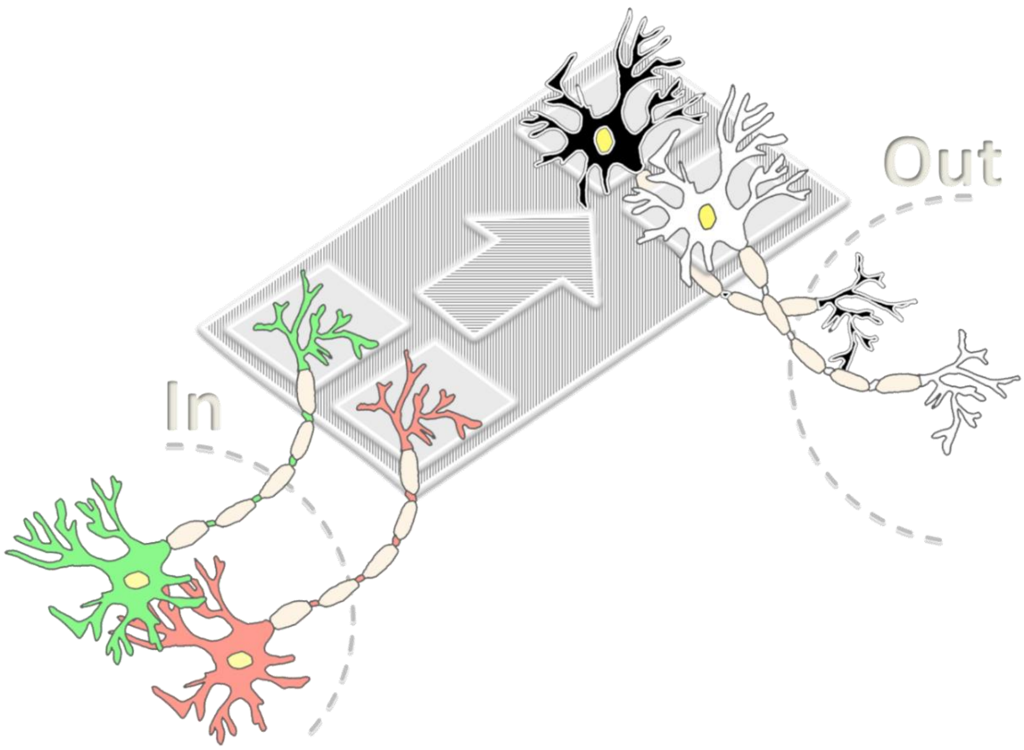
This leads to the question of which principles are behind the neuronal developments. The search is aimed at functional concepts that could give fundamental answers to an approach to information processing in general. One starting point is the exchange of information via nerve fibers between separate areas in the brain. How do nerve fibers or axons find their way from their starting point to the next level of information processing? How does order come about, where neurons retain the order of an upstream processing stage? Neighboring neurons in the somatosensory cortex, like the correspondingly neighboring neurons in the intervening thalamus, react to stimuli from neighboring parts of the body – they are structured somatotopically. The situation is similar with neighboring locations on the retina. These are wired image-accurately across successive stages across retinotopically arranged neurons. A hypothesis on possible growth and pathfinding of axons should help. The crucial point will then be how much the hypothesis formulated as follows is reflected in the neuronal processes.

It shall be assumed: >> Axons, which connect information processing levels with one another, essentially depend on being accompanied by axons from neighboring start neurons, whose respective activations are mutually exclusive as far as possible. <<

Neurons are often found in a 50:50 dichotomous division. Some stand for information content, others for the opposite. The exact opposite of an information content in the brain cannot be determined perfectly. The fields with neurons or receptors from which neurons acting in opposite directions obtain their input always have overlaps with the neighborhood. This blur is counteracted by an automatic selection of more suitable information content. Thus, visual image processing has led to a selection of sensitivity to strong contrasts. Neighboring ganglion cells of the retina can only react to the same contrast at transitions or along lines. It is its nature the contrast arises from the fact that the neighborhood looks different. If a neuron reacts to a visual image contrast, it can be assumed that neurons in the vicinity are rather quiet. At the same time, it is even more certain that an antagonistic neighboring neuron, which represents the opposite of the information, definitely does not react. A quiet neighborhood along with one's own activity is transferred to the next level of information processing if the corresponding neuron arrangements are retained. Somatotopicity, retinotopicity, and other forms of alignment retention correspond fairly well with the hypothesis.

2 Partnership against neuronal cell death

Apoptosis is a mechanism that causes damaged or dysfunctional neurons to die. This fate is also experienced by superfluous neurons that fail to permanently connect their axons to receiving sites at a target location. So the question is not just how nerve fibers find their way from their starting point to the next level of information processing. There must be a mechanism that allows a growth phase and protects against cell death while an axon is still on the way to its target. If two partner axons secured each other's continued existence in their growth and pathfinding phase, then that would be an answer and would also go quite well with the above-mentioned hypothesis. Partner axons would alternately take on the function of destination during their migration. At the same time, it would be easier for both of them to find their way to neighboring neurons in the input area of the subsequent information processing stage.

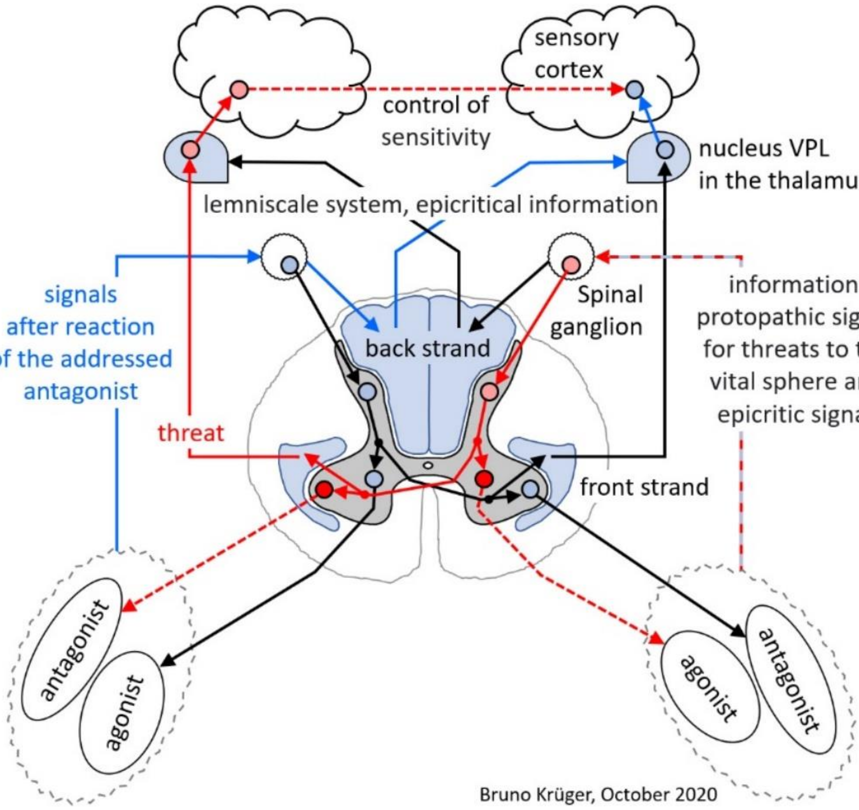


Depiction: Content-wise opposite input neurons lead to differently opposite outputs.

The chosen line of thought becomes really exciting when the principle of contrariness is transferred from one level of information processing to the next and theoretically continues as often as desired. What changes from level to level is the information content. The principle would remain the same. However, opposite input signals would be processed into *differently opposite* output signals.

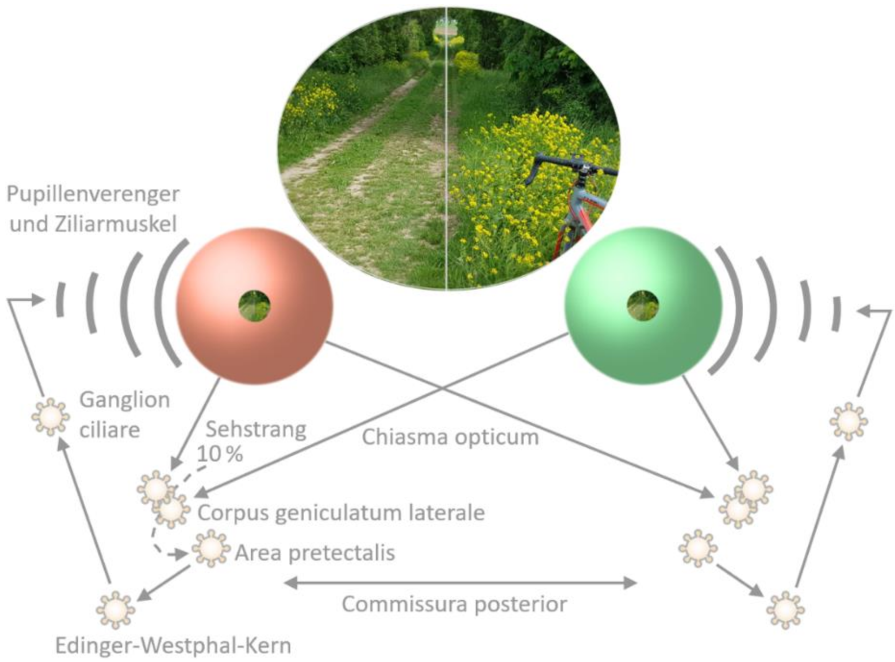
3 Bilaterally symmetrical physique and vision

Without a bilaterally symmetrical body, there is no central brain. Both are related. The task of the brain is to perceive environmental stimuli and react with muscle movements. Sensitive nerve signals and motor commands are brought into a context. How the points to which the somatosensory system refers are classified in a body knowledge and overall picture is subject of a separate article. Among other things, it treats Pathfinder qualities of the axons and their growth towards the opposite side of the body.
→ https://www.kruegerGold.de/Texte/2021-Wer-Wie-Was-Evolution.pdf ... Illustration from it:



Depiction: Cross-body nervous system circuitry in mammals

Relevant observations of the functions of the nerve cells involved in vision, the course of the nerve tracts and the tasks of processing centers are considered in another article with the symmetrical appearance of pairs of eyes. Without symmetry there is no seeing.
→ https://www.kruegerGold.de/Texte/2021-Symmetrie-und-Sehen.pdf

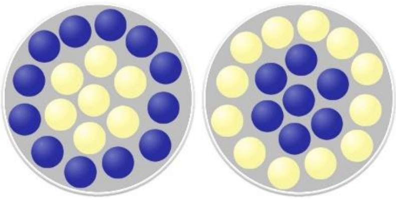


Depiction: System for controlling the eyeball muscles via the parasympathetic system

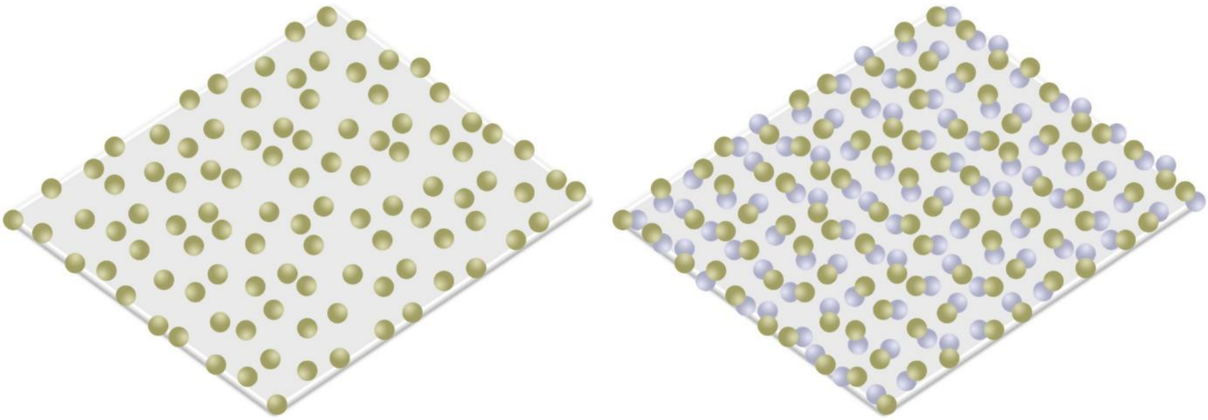
4 Sight and visual processing

Brain areas involved in visual processing are best researched in neurology. One of many sources: https://www.kurt-paulus.de/pdf/Visuelle_Verarbeitung_im_Gehirn_com.pdf … The wealth of existing knowledge is used to classify the principle of contraryness and dichotomy as a success factor behind the complex processes. Contrasts and symmetries are more than just observations. They are the drivers of evolution and brains.

On- and off-center ganglion cells on the retina are approximately 50:50 evenly distributed. The same applies to the further connecting nerve cells in the lateral geniculate body of the thalamus and to the receiving cells of the input layer IV-C of the visual cortex. Up to this stage of visual processing, the nerve cells involved react to pixels in the on/off center logic. That changes from here.

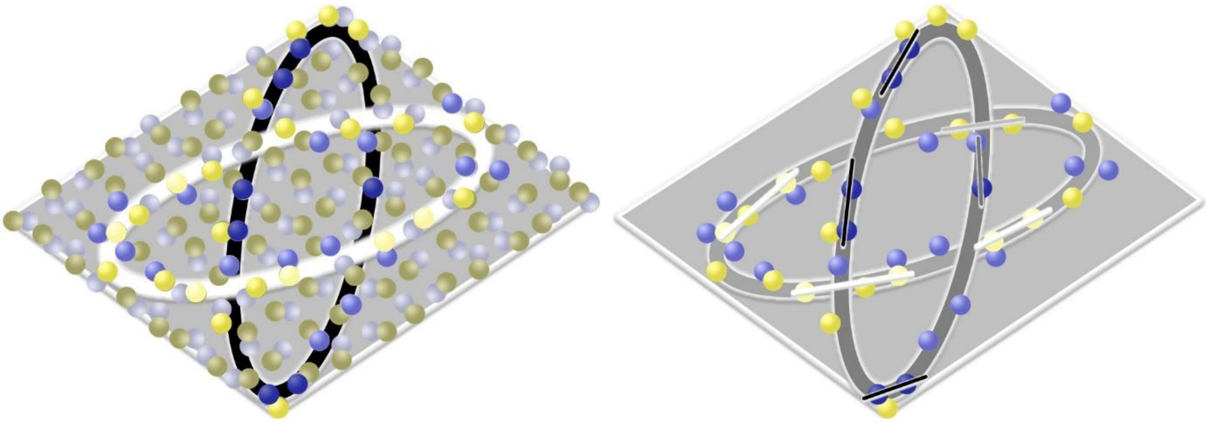


Depiction: On- and off-center cells react in opposite ways to their receptive field.

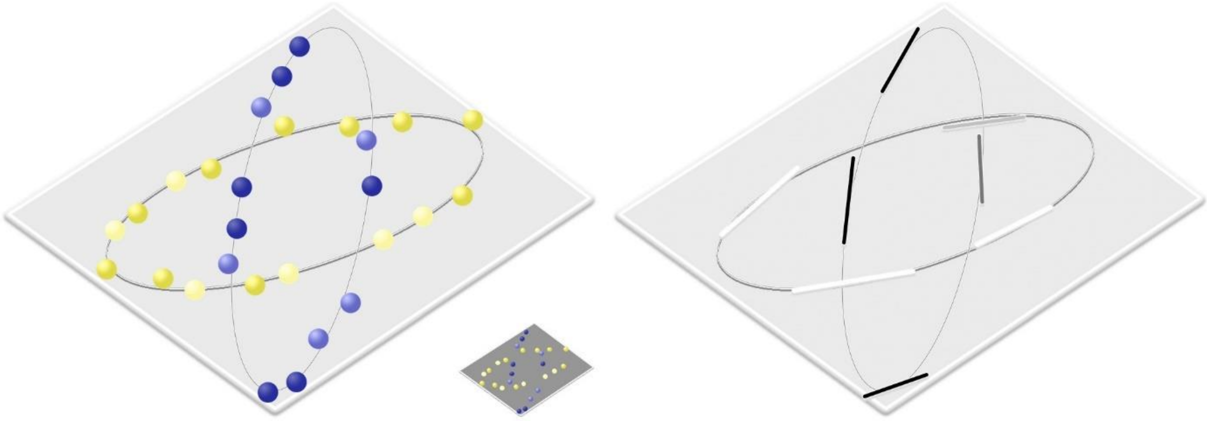


Depiction: There are as many off-center cells in layer IV-C as there are on-center cells.

In layer IV-C of the primary visual cortex (V1), nerve fibers arrive from the lateral geniculate body (CGL) of the thalamus. In this layer, a distinction is made between *simple* and *complex* cortical cells as well as "end inhibited" cells. The *simple* cells are most responsive to lines at a specific location and orientation between 0˚ and 180˚ to the horizontal - to within ±10˚.

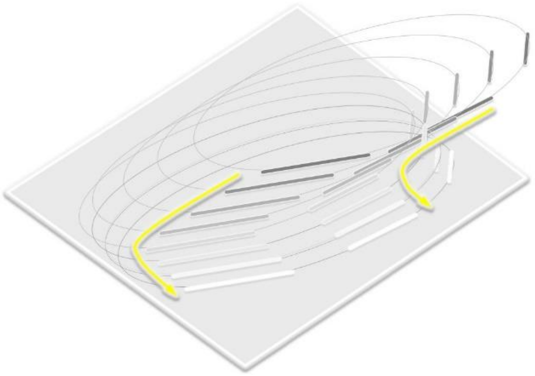


Depiction: On-center-sensitive cells (here: yellow) and off-center cells (blue) react to contrasts.



Depiction: Environment – captured as a system of lines with orientation directions assigned

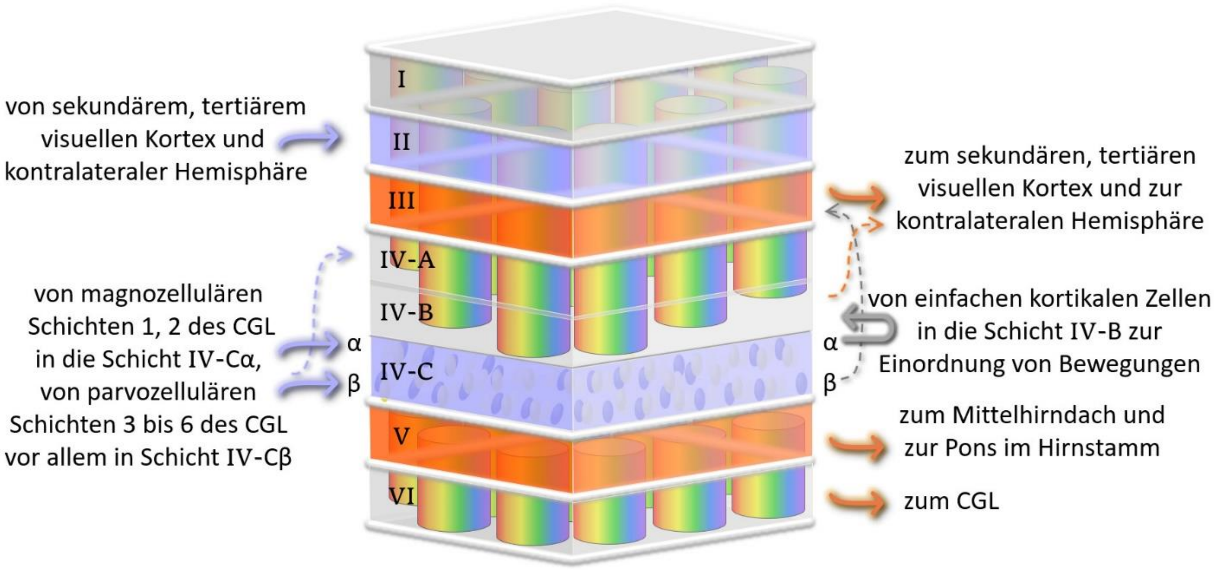
The *complex* cells receive input signals from several simple cells and form a second level of information processing within layer IV-C. They respond to a specific direction of movement in which the lines move. To do this, they use several simple cells if their signals are separated in time. The end-inhibited cells are even more complexly wired with signals from simple and complex cells. They react to both the direction of movement and the length of the lines. The thing to note is the division of labor between *simple* and *complex* cells when recognizing lines. In one case lines are classified according to the angle of their orientation and in the other according to the angle of their direction of movement.



In layer IV-B of the primary visual cortex, directions of movement are assigned to previously detected lines. In the picture, lines change their direction of movement:

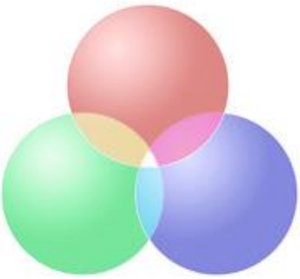
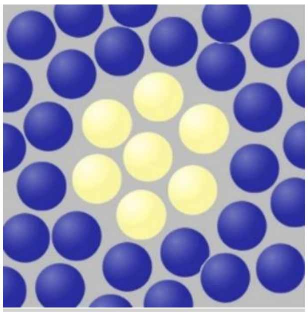
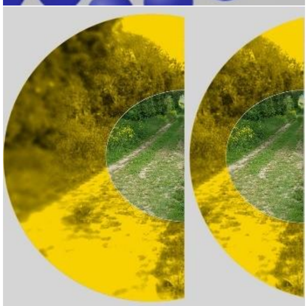
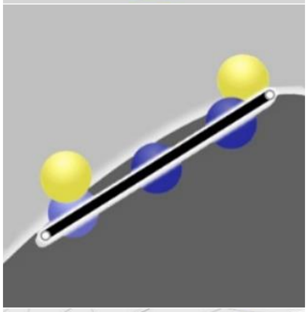
1. from top right to bottom left and
2. from top left to bottom right.

Depiction: A second level of information processing assigns directions of movement to lines.



Depiction: Major input (blue) and output (red) layers in the primary visual cortex (V1)

The dichotomy principle determines the inputs and outputs of the information processing levels in the brain. At the entrance, the principle ensures a guaranteed inactive partner neuron in the vicinity of each activatable neuron. It creates separation. At the output, the principle ensures that attributes are distributed among entire groups of neurons, each of which contributes more or less to the information content. This makes the principle of the dichotomy robust against unavoidable imprecision on the way to the subsequent information processing stages.

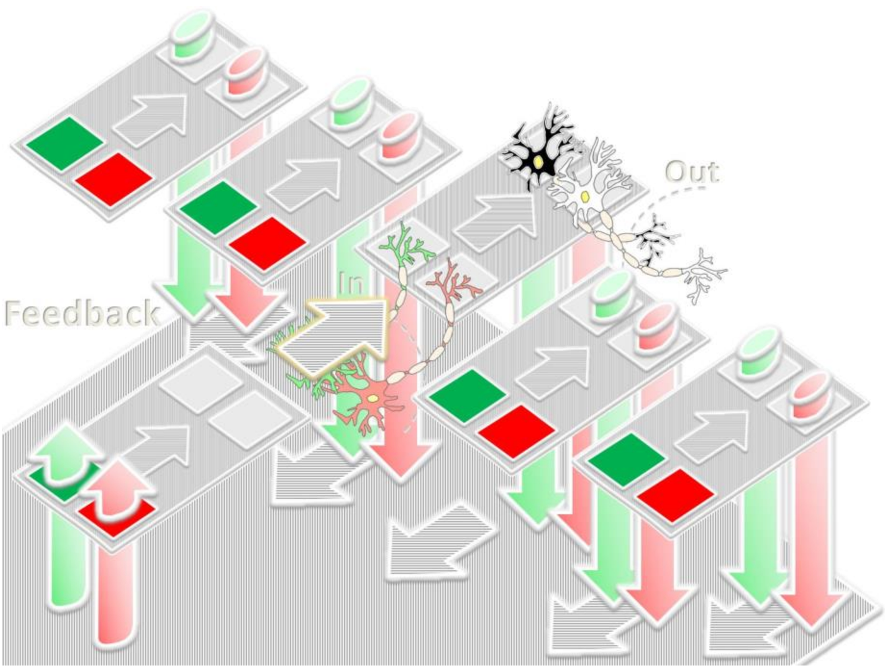
	Type of specialization in opposites	*Representation*
	**Color** is sensed in the retina using cone cells as color receptors. Of these, there are three types specializing in different primary colors. In humans, the ganglion cells of the subsequent circuitry specialize in a red-green, a blue-yellow and a black-white countercolor mechanism.	Cone cells
	**Contrast** is sensed in the retina with the circuitry of two types of ganglion cells, on-center and off-center-sensitive ganglion cells. The receptors of the retina, which are located in a receptive field of the visual field, provide the input for a circuit. On-center cells respond to bright spots in a darker area, and off-center cells to a light area with a dark center.	On-center and off-center ganglion cells
	**Perspective from the left or right** is created by seeing with two eyes. Ganglion cells of the retina of the left and right eyes, which are associated with the left visual field, reach the lateral geniculate body (CGL) of the thalamus of the right hemisphere via the optic nerve. Signals from the perspective of the left eye are displayed in the right thalamus in layers 1, 4, 6 of the CGL. Right eye projected to layers 2, 3, 5.	Layers 1, 4, 6 versus 2, 3, 5 of the CGL, and on the next level: eye dominance columns in V1
	**Lines and edges** are detected in layer IV-C of the primary visual cortex (V1) with wiring to simple cells. The lines are differentiated according to their direction of orientation. Locations in the visual field are mapped retinotopically onto circular fields on neurons. Neurons in these fields are arranged according to orientation direction. The arrangement runs column-like through layers of the visual cortex.	circular Arrangement of neuron fields in V1
	**Directions of movement** are detected in layer IV-B of V1 with interconnection of *simple cells* to *complex cells*. Locations in the field of vision remain retinotopic on circular fields - and complex cells are arranged according to the orientation directions of the lines. Movements are switched on from V1 via the parietal "*where path"* to cortex areas specialized in movement. Separated from this, the temporal "*what pathway*" leads to areas of pattern recognition.	*simple* and *complex* cells in the V1, and on the next level: "*where pathway*" and "*what pathway*"

5 Systematics of feedback

Up to this point, dichotomy and differentation in information processing has been discussed. We initially saw successive processing stages as completely decoupled from one another in the opposite direction. To understand growth, we used a hypothesis: axons are said to be accompanied by axons whose respective activations are mutually exclusive. This hypothesis would be compatible with the challenge that axons can grow to distant target areas faster than they are stopped by cell death. To this end, partner axons should communicate with one another and thereby secure their existence with changing transmitter and receiver roles.

In the event, that subsequent processing stages feed back signals to preceding stages, dichotomy and selectivity are further stabilized. Feedback can be found in almost all information flows in the brain. However, they are significantly less pronounced in terms of the number of axons and amount of information. Feedback sustains triggered activations longer. Important information remains available for further processing for a short time. The effect of feedback is not limited to an undifferentiated amplification of entire brain areas.

A dichotomous arrangement of oppositely active axons would also be compatible with the hypothesis discussed for the signaling pathway of feedback. Last but not least, the necessary total number of axons could be reduced in this way. The idea behind this is that entire groups of similar information processing elements work towards a feedback aspect and are interconnected accordingly. The feedback on an aspect could be reduced to a pair of axons and routed to the feedback signaling pathway.

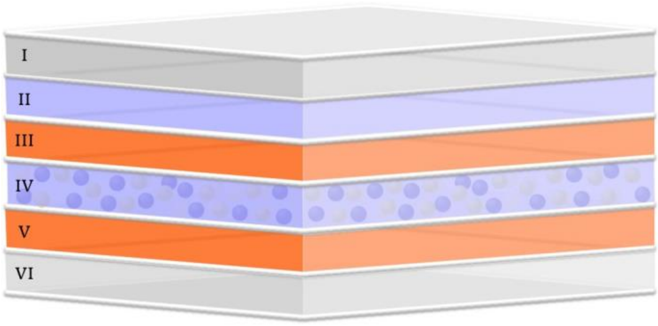


Depiction: Similar information processing elements provide feedback via subsequent processing.

The picture shows a dichotomous contrast with the colors red and green. When cooperating information processing stages indicate a common attribute with a greater or lesser degree of their signal strength, the feedback acts like a group amplifier on a mixer. Both upstream and downstream information processing levels only have to agree that red and green are mutually exclusive. Axons within and between brain areas experience an increase in their transmission abilities depending on their frequent use. Unused axons atrophy. Feedback is therefore the engine of neuronal plasticity … the adaptation to a signal processing, which is relevant.

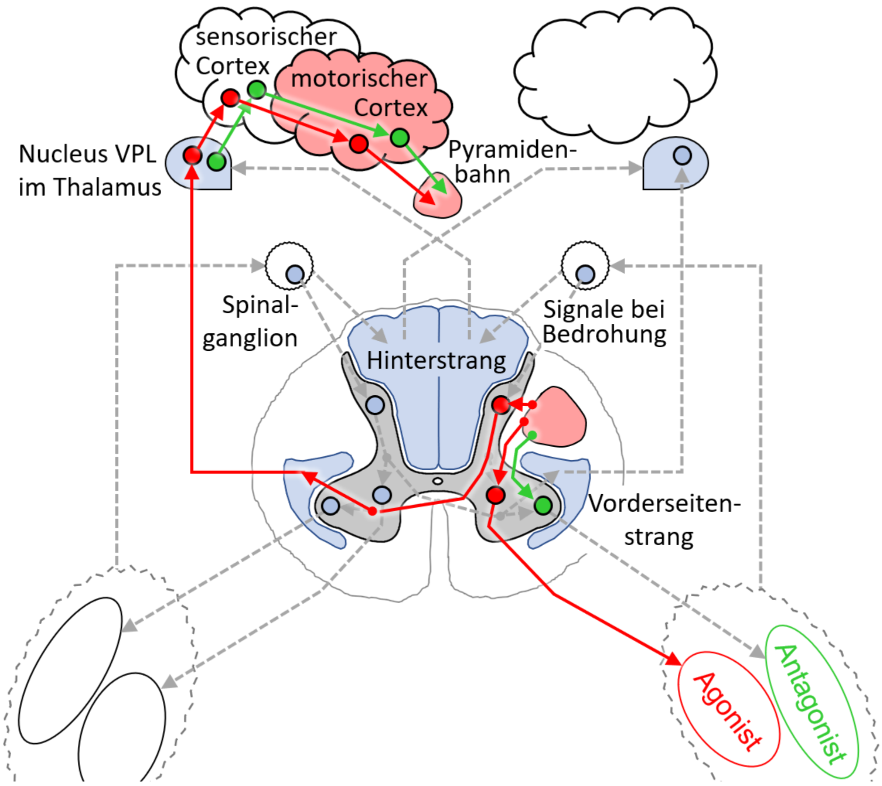
6 Motor skills

The brain, vision and perception have a common goal … the optimal reacting of a bilaterally symmetrical living being to its environment. We're talking about motor skills. All areas of the brain require feedback to function. And they also need a separation of input and output. For this purpose, neuronal cells are already differentiated in the spinal cord with different properties. One type of neuron specializes in receiving from upstream stages. In the cerebrum, the granule cells fulfill this task, especially in layers II and IV. Another species specializes in sending downstream – pyramidal cells primarily in layers III and V. Interestingly, layers IV and V interface primarily to the spinal cord and thalamus and to archaic parts of the brain. Correspondingly the cortex layers IV, V arise before II and III in embryogenesis. Layers II and III primarily form the interface to other areas of the cerebrum and to the contralateral hemisphere.



Depiction: Six layers of the cerebral cortex support the separation of sending and receiving.

Separation of input and output characterizes all areas of the brain and is particularly important for motor skills. In the final stages of information processing, there should be no superfluous signal loops. Paths for stabilizing feedback should bridge distances as distant as possible.



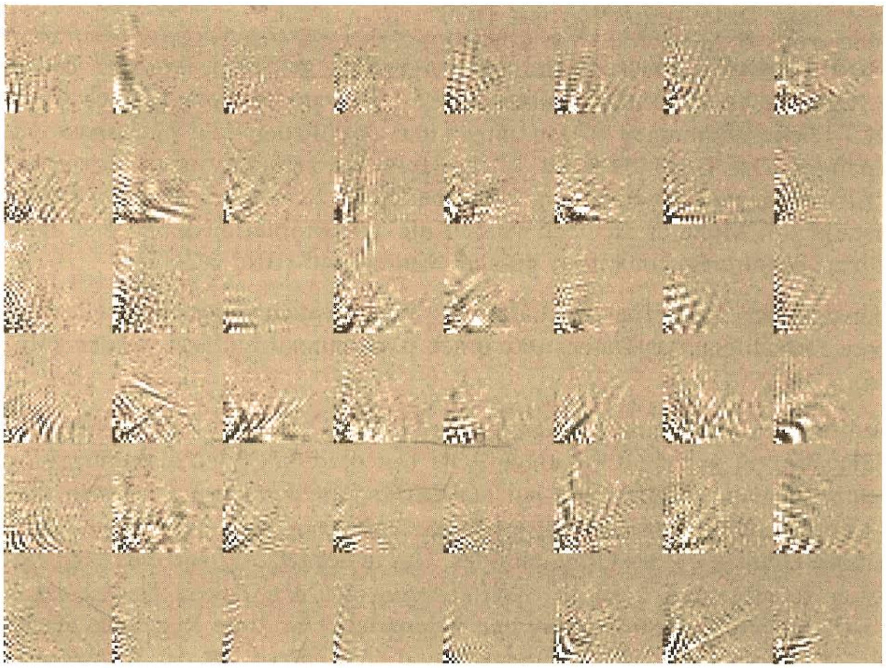
Depiction: Feedback for motor control via the spinal cord

The two-stage motor function serves this purpose. The first level of command is in the brain. This activates the second stage in the spinal cord. In this systematic, the spinal cord is the most distant place from which optimally separated feedback can be realized. In the mammalian cerebrum, signals from the spinal cord reach the somatosensory cortex. In particular, sensitive, protopathic signals that report a threat to the body interact with motor neurons for reflexes. As a second part of their task, they form a differentiated signal return path from the second level of motor activity back to the brain. The motor cortex is adjacent to but separate from the somatosensory cortex. This ensures that connections between the areas are limited to what is necessary and are nevertheless possible without hindrance.

Similar information processing elements in terms of motor function are individual muscles that can be grouped together. This reduces the required feedback axons to what is necessary. The dichotomy that is absolutely necessary results from the division of all muscles that can be controlled by the brain into *player muscles* and *opponent muscles*. Or: *agonists* and *antagonists*.

The article „Role of Intrinsic Properties in Drosophila Motoneuron Recruitment During Fictive Crawling“ by Jennifer E. Schaefer, Jason W. Worrel, Richard B. Levine from September 2010 (Source: https://journals.physiology.org/doi/full/10.1152/jn.00298.2010) gives an idea of how reflexes on the one hand and central control on the other hand interact. “Motor neurons in Drosophila larvae can be divided into easily responsive and difficult to responsive types. Type 1b (b = big) neurons have larger synaptic input areas and control only a single muscle. Type 1s (s = small) neurons have smaller input areas and control entire muscle groups. The easily responsive 1b neurons specialize in precise movements and to be addressed earlier than the 1s neurons, which in turn specialize in powerful movements.” Finally, it becomes clear how groups of similar information processing elements develop even in primitive organisms and can form a two-level hierarchy.

7 Innovative intermediate step in image processing

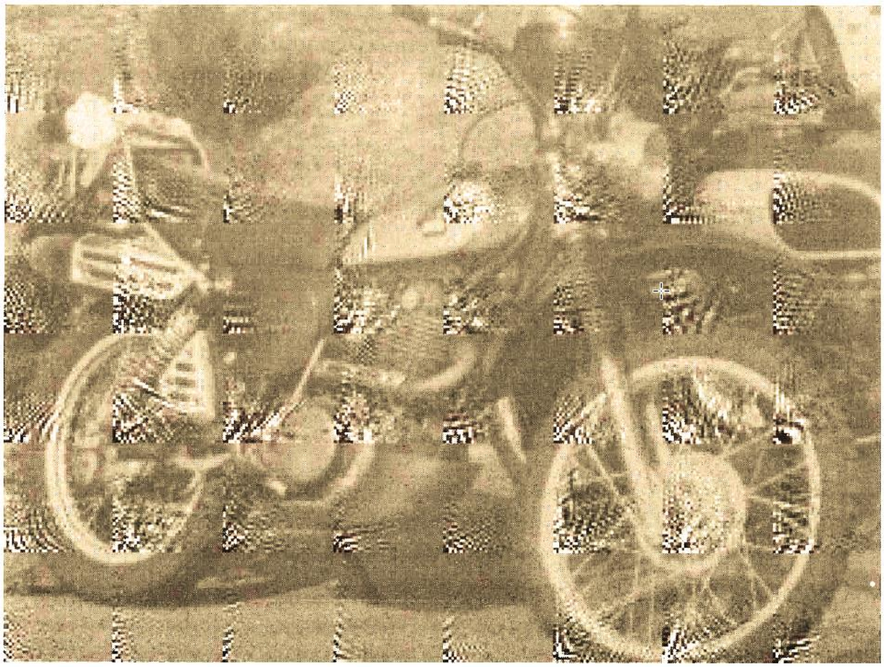


Depiction: 40x40 pixel blocks are transformed here into the frequency range.

Digital image and video processing has been using a mathematics for over 30 years, which also helps us to better understand our vision. As with the eye, technical image recording assigns the measurable magnitude of brightness to a number of pixels. Their grid is designed for the desired detail resolution. Digital image processing then makes use of the fact that there are two absolutely equal mathematical forms of representation for image information. In addition to the point-by-point, true-to-image representation of the brightness measured in each case, the alternative form of representation transforms the original image data into a frequency range. This is familiar to mathematicians, they know the so-called Fourier transformation for one, two, three, n-dimensional functions.

Theoretically, an image does not have to be structured in 40x40 or even 8x8 image blocks. This is done with regard to an economically sensible calculation effort for the transformation. Of course, we can also transform images as a whole. The picture above shows a so-called Discrete Cosine Transform with 40x40 blocks. The transformed blocks are modified with high contrast for display reasons. In the frequency domain visualization, they show the average gray value of the original image block on the bottom left. Values for increasingly horizontal spatial frequencies are shown towards the right, values for increasingly vertical frequencies are shown towards the top. The benefit lies in the data reduction to a single-digit percentage range of the original image data. The traded information losses are less relevant for our vision when the resolution of the brightness values is reduced towards higher spatial frequencies. Digital image and video processing has found an intermediate step in image calculation that optimizes the existing image information for a new dimension of signal differentiation. Information technology differentiates according to the relevance of the data.

Unlike modern video technology, our sense of vision had an additional challenge to overcome. In evolutionary development, one innovation after another has to be found and integrated into our brain using existing strengths. The absolute strength of the brain lies in its automatic adaptation to dichotomy of content. This is followed in particular by the dichotomous division into on- and off-centre ganglion cells of the retina.



Depiction: With the means of mathematics, the original image can be recovered.

One of the most outstanding innovations of evolution was the emergence of mammals. These are characterized both by anticipatory behavior and neurologically by their cerebrum. And that is exactly what, with more than 30 visual areas, uses about 60% of its cerebral cortex for perceiving, interpreting and reacting to visual stimuli. And as research into the primary visual cortex has shown, here too, as with digital videos, information processing starts with an intermediate step of image display.

The first level of information processing in the cerebrum transforms the grid of pixels received by the eyes into lines and differentiates them according to orientation directions. As with digital image and video processing, this creates the basis for a new dimension of differentiation. Movement! The difference to the motion recognition of primitive living beings lies in the properties of edges and lines, which are optimal for dichotomous further processing. From the point of view of static pattern recognition, lines in a two-dimensional image grid are either more or less pronounced. Or from the point of view of motion detection they are either more or less quickly disappearing. Lines that have been recognized in their direction of orientation are dichotomously divided onto two types of neurons for the attribute >>*contrast*<< and secondly for its >>*differentiation value according to time*<< – the *simple* and the *complex* cells. The usefulness of the cerebrum lies in its superior perception of space and time. To do this, it captures the environment as a system of lines.

8 Evolution boost with feedback mechanism

In retrospect, it is not easy to distinguish crucial steps in brain development from each other. The evolution of living beings and their brains is based on mutations, i.e. small steps that are sometimes more, sometimes less successful. It is thus difficult to identify the crucial step that led to the centralization of brains. The facilities for this, such as the electrical transport of stimuli via nerve fibers, already existed in more primitive creatures. The bilaterally symmetrical Bilateria and the Cambrian explosion of biodiversity then led to centralization. As it seems, it is the concept of symmetry as such that leads to the ongoing selection of appropriate neuronal interconnections. It is possible that the impetus for this development can be found in mutations that could make a decisive contribution to the assumed hypothesis: >> *Axons, which connect information processing levels with one another, essentially depend on being accompanied by axons from neighboring start neurons, whose respective activations are mutually exclusive as far as possible.* <<

The innovative power of this seemingly tiny step is revolutionary from the point of view of news theory. This would specifically select axons that occur in pairs and can only be active in opposition to each other and never at the same time. This produces nothing less than 0 and 1 as information carriers. At the same time, the axons implement the required communications transmission paths. In electrical engineering, a distinction is made between combinatorial circuits and finite automatons. Combinatorial circuits work without feedback mechanisms. They translate signals and stimuli at their input with always the same behavior and the same reactions at the output. Automatons, on the other hand, work with feedback. Previous signals and stimuli at their input cause cached states of the circuit that connect to new inputs. This bridges any challenge in complexity and enables seamless evolutionary steps from primitive to more advanced brains. Communications feedback is only possible with the invention of 0 and 1. This is the only way to differentiate what is fed back from anything else, which might be nonsense. *Basically, this marks the step from stimulus driven to real information processing. And a central brain is suitable for this.*

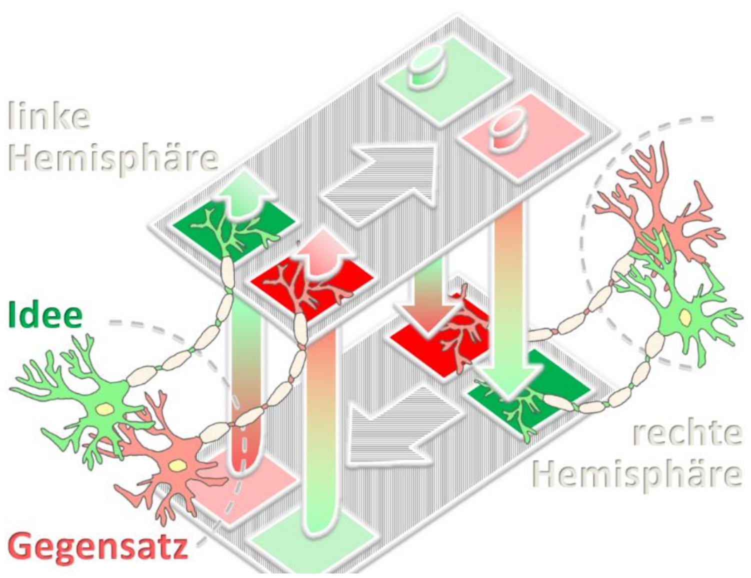
What is still realized in the modern brain more like a combinatorial circuit without feedback was brought about correspondingly early in evolution. This often affects vital tasks and robustly functioning processes. In addition, the evolution uses any freedom of design for automatons. As soon as the input and output of information processing in the brain stand out from the completely primitive, one speaks of sensory and motor functions. Sensory system accepts stimuli from the environment and motor system implements reactions. These are the opposing sides of neural information processing. The pure sensor technology should truthfully recognize the environment.

Here, feedback is used to amplify and store the signals classified as correct and important for a short period of time. Pure motor activity is intended to trigger reactions to the environment. Feedback is used here to ensure that the required target muscle is also reached. Most of the thinking – perceiving and classifying information, planning and carrying out learned courses of action – lies in between. To do this, we imagine a transition over many stages of information processing from the sensor system to the motor system.

The senses of sight and hearing as the drivers of the brain seem plausible. This article has focused on the particularly well-researched sense of sight. With these senses, the environment is recorded more precisely than ever before. Their development promises superior abilities that, with the centralization of a control center, lead to holistic motor functions. The mammalian cerebrum goes one step further and systematizes an even more differentiated perception. The wealth of neurological knowledge leads us to a comprehensive understanding of the interconnection between the levels of information processing in the brain. In part, it is the knowledge gained from research into higher mammals that shows us the basic connections. Even if these were already relevant for earthworms.

9 Thinking and Welfare

A muscle stimulus can be good at the right moment and bad at the wrong moment. An idea "dog" can be good in the version friend of man, in the version biting it can also be evil. All ideas up to and including muscle commands must be able to alternate between two opposing evaluations. In evolution there are continuous advances and not big leaps. The evaluation task for right and wrong, go and no-go must always emerge from a primitive preliminary development. Forerunners of holistic control are the reflexes that respond to threats. See sensory protopathic spinal cord signals. Fleeing or fighting reflexes are further present in mobile creatures. This already creates a basis and allows welfare-oriented thinking. What is still missing is a mechanism for how the processing of dichotomous signals can result in actual interventions in behavior. A first division of the evaluation task with the means of the nervous system is the ramping up of readiness for activity via the sympathetic nervous system and the antagonistic ramping down via the parasympathetic nervous system. This can and must work without complex thinking and time-consuming feedback.



Depiction: Calling up ideas or their opposites through the interaction of both hemispheres

Thinking begins with each further level of differentiation and information processing. The sympathetic and parasympathetic nervous systems start this systematic approach as they alternate attitudes that work deep in the brain. In this way, the motor function, which in turn is decoupled from somatosensory reflexes, receives a first holistic corrective. The automaton brain develops a state storage by means of sympathetic and parasympathetic. A first differentiation that classifies in brain existing knowledge and skills according to the standard of welfare.

This leads to the ideal idea from a communications science point of view. Their activation should be realized with a feedback between both hemispheres for an ideal wholeness. For an equally ideal delimitation against fuzziness, the core of the idea should not be influenced by feedback within one hemisphere. Opposite areas representing the ideal idea should, when at rest, represent both the idea and its opposite. It is then only a matter of the current state of thinking whether the activated idea leads to a differentiation in content or a differentiation in the evaluation that accelerates subsequent processing steps. *Bad dog* in the sympathetic state of alert would then be such an evaluative classification. In the brooding state of the parasympathetic nervous system, the content-related idea of *dog = non-cat* can arise.

The point is that both hemispheres appear in the example of the ideal "idea" with a dual role allocation. One side slips into the role of the decision-maker looking for advice, the other into the role of the advising observer. The difference is that the decider starts the process. At the end of the process, the distribution of roles expires and can be realigned at any time. For special skills, the impulse-giving decision-making role can also be specialized in one hemisphere. But that doesn't mean that the other side is inactive. So we know the specialization of the cerebral hemispheres. The left side has its strengths, for example, in language and orientation of our attention in space. We know the right side as a creative side with strengths in catching a complete picture and overall impression. The artist sees the finished image in his mind's eye.