Stepping Stones to a deeper understanding of the human brain

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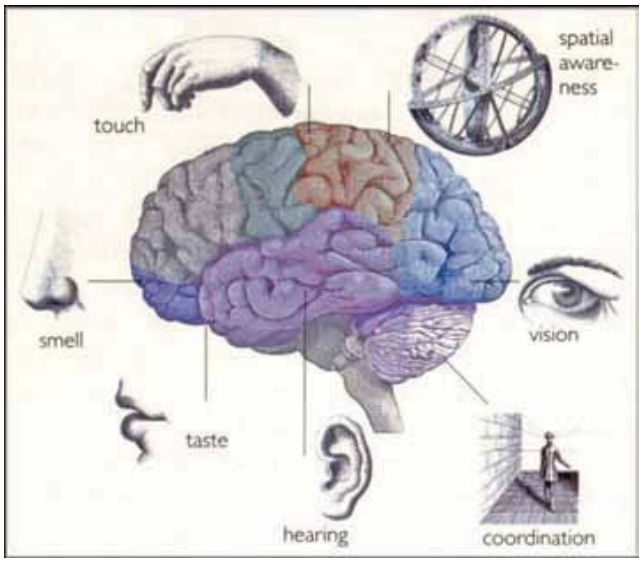
The human brain is a fascinating and amazing organ. Our understanding of the brain functions and the models we use impact strongly on our picture of the human being as a whole and the ideas we have about the relation between body and mind, the generation of consciousness, learning and memory formation. In 2010 I studied Neuroscience (Learning) and attended lectures by Professor Gerard O'Brian at Flinders University, S.Australia for topic NEUR 8003. As my assignment I submitted an essay called "Constructivism and the Neural Network Model of Cognition". I found the neural network model exciting and in the article below, I want to show that the most recent model of brain function, the neural network model of cognition, opens new perspectives which correlate to some extent with Rudolf Steiner's (1921) findings and descriptions of the process of perception, concept and memory formation.

In the course of the past four centuries the research methods for the brain have gone through huge developments –

- Scientific investigation of the brain started around the 17th century when **autopsies** allowed for the first time to relate processes in the body to specific conditions in the brain. The examination after death was for a long time the most important source of knowledge of the brain and is still important today.
- Later, **lesions to a certain part of the brain** were identified to impact on distinct abilities and behaviours. They allowed the first understandings of structure-function relationships.
- A **hierarchical sequence of tasks** was found which matched certain steps in evolution. So the brain stem and cerebellum was considered as reptilian brain responsible for the regulation of deeply unconscious processes, the limbic system in midbrain as the mammal brain which is mainly connected to the emotional life, and the cortex as specifically human brain where more conscious processes concerned with thinking take place.
- **Systems** were discovered which serve certain distinct functions, like the auditory, visual or motor centres of the brain. This led to an identification of the **topographic organisation** of the brain, which means, for example, that certain body parts are represented in a map of the cortical area.



From Gerard O'Brian, PowerPoint presentation slide 6, 12 August 2009, adapted from Carter P. (2010) Mapping the Mind

This stream of research is now aided by the new imaging techniques (PET = **positron emission tomography** and fMRI = **functional magnetic resonance imaging**) which detect changes in metabolism or blood flow to indicate regions of activation in the brain while a person is engaged in specific isolated tasks. These methods do not measure neural events but the metabolic changes correlated with these activities. As the brain is a metabolically demanding organ we get a good impression of the areas involved in

certain processes, even though this method is too imprecise to be used for individual diagnoses.

The cellular and molecular level

While the mentioned investigations lead from the whole into the parts, on the other side research on the cellular and molecular level revealed more and more of the functional properties of nerve tissue. The electric activities of neurons allowed the observation of single nerve cells and their reaction to specific stimuli. During the 20th century the knowledge of the chemical nature of the brain increased. The role of neurotransmitters was discovered as being the messenger substances in the gap between the nerve cells.

The generation of consciousness

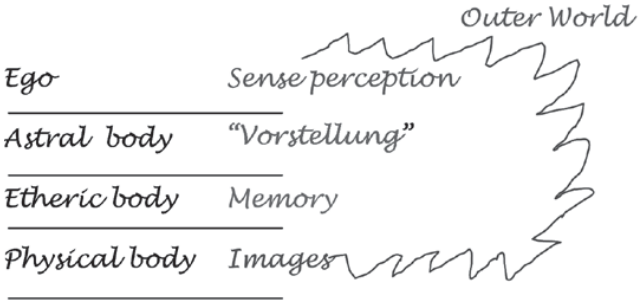
At the same time, there always was the desire to understand how we actually generate consciousness. Each new step in scientific knowledge about the brain together with an increasing amount of behavioural studies produced another model of how the soul lives and works in the human being. This developed from the idea of a dualism of spirit and body to the clearly materialistic view of the physical brain as being the only place where human behaviour (i.e. all our thoughts, intentions, desires, emotions – all of which are classified as behaviour) is generated. A very interesting question arises out of this latter view: Where in the brain does **learning** happen, how does it manifest in the physical substance of the brain and where do we find **memory**?

Classical Cognitive Science started with the **digital computer model** of the brain exactly in the years digital computers dominated computer science (Clark 2001). While originally the digital computer was developed to imitate features of human thinking, this fascinating technical device quickly became a model used to explain our cognitive functioning. Because the processes in neurons are known to be similar to electric processes, we talk about being wired in a specific way, and memory equals information, stored somewhere in our brain like in a computer file with a limited capacity.

This has led to the idea that learning means l**earning to process information**, and has inspired the constructivist teaching approach with a strong emphasis on **problem solving**. The focus point of learning is the construction of your own subjective knowledge, while the storage of information seems to be a minor problem, because the vast amount of knowledge that already exists can now easily be looked up on the internet and does not need to be stored in our (limited) memory. Learning is considered to be the **alteration of the way you think**.

Perception, concept, memory – Rudolf Steiner's description

Let us now look at some indications of Rudolf Steiner about perception, understanding and memory. In a sequence of lectures held in July and August 1921 in Dornach (*Menschenwerden, Weltenseele und Weltengeist,* GA 206), which I want to follow closely here, he talks about the formation of memory in the fourfold human organism, consisting of physical body, etheric and astral body and ego. A closer consideration can show us that in our normal life we have a perception of our own ego only when we are awake. Steiner talks here only of the awareness of our ego, not about the working of our ego organisation in the body, which we mostly are unaware of. Being awake is closely connected to our sense perceptions, and from this perspective **ego awareness is present when and only when there is sense perception** of any kind (p118).



After Rudolf Steiner GA 206, 21. Lecture, Dornach 13. August 1921, (untranslated lecture of the cycle "Man as a being of Sense and Perception").

The next step towards generation of memory happens, when we form what Steiner calls "Vorstellungen" – there is no clear translation

for this word, I would like to call them specific concepts or representations here - on the basis of our perceptions. We give things a name or have a more or less precise picture of them in our mind that can **represent** the actual thing in our thinking without the need of the object to be there. With this step we enter deeper into our soul life, the **concepts or representations are formed in our astral body**. We leave the ego and the very individual sense perceptions behind and enter into the astral body, but at the same time we get something more general, the concepts, which can be shared with others!

How do these concepts then enter into memory? Rudolf Steiner stresses **concepts do not linger somewhere** in the unconscious part of our mind and reappear in the act of remembering (the storage model). He says that in fact **by forming a concept we acquire a certain capability, which later on leads to the fact that we can recall the same concept**. He also describes that the formation of concepts is only temporary and that a certain amount of energy is needed to form these concepts again, not on the basis of sense perceptions but from memory. This energy is related to our life energy and thus to the forces of growth, nutrition, development and reproduction. Memory is formed in the etheric body – the body in which growth, development and regeneration occurs.

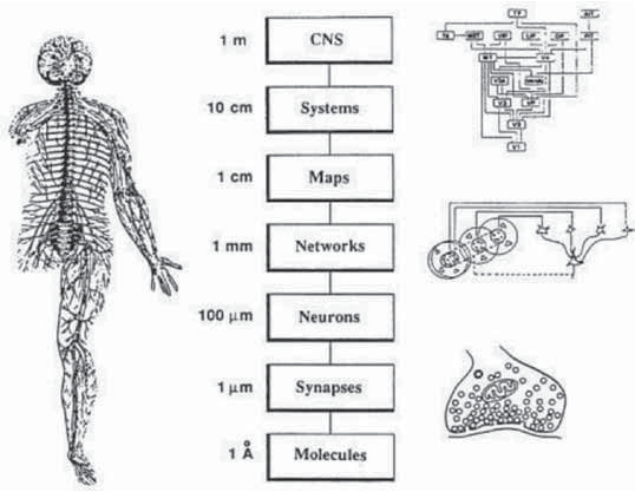
What is the role of the physical body? Each time a memory is formed in the etheric body, it is still in flow, part of a life process. When it enters into the physical body it **becomes an image**, but a deeply unconscious picture, which is not a real picture of the object in the outside world, but has a more systematic resemblance relation to it like the picture in a distorting mirror. If we know the laws this mirror obeys, we can reconstruct the original picture (p126).

In the act of bringing up a memory, the ego works from this image in the physical body to stimulate the memory in the etheric body, which then becomes concept in the astral body (p. 137). This double ego process is shown in the drawing by the zigzag line.

The neural network model of cognition

I would now like to show how the neural network model of cognition has features that seem to fit these descriptions and that lead closer to a real understanding of the human being than does the digital computer model. It is still a model and it can depict only the simplest processes the human mind is capable of, so there is a lot of room for new discoveries and improvement.

I am following mainly the **connectionist model** (as described in Bechtel, 1989, or Rumelhart, 1990). Looking for the level of function in the brain that is most likely to offer the physical basis of consciousness, forming of concepts or memory, connectionists came to the conviction that the level of molecules or cells on the one hand or the level of systems and maps on the other hand don't seem to offer as much potential for depicting these processes as the **level of neural networks**.



From Gerard O'Brian, PowerPoint presentation slide 5, 12 August 2010. Adapted from Churchland, P. S. (1992), Neurophysiology.

This approach claims that outside stimuli (sense perceptions) are represented in the brain by patterns of activation over an ensemble of units (groups of neurons). These ensembles respond to specific stimuli and are in contact with other ensembles, thus creating the neural networks.

We have roughly 100 billion or 100,000,000,000 neurons. Each neuron has up to 10,000 neighbours. You can imagine how many possible patterns of connections that offers.

Each connection again has several different possibilities for the **strength** of communication:

As I mentioned before, the synapses are not simple connections like contacts in an electric system, but they are places where the electric signal that travels along the axons initiates the release of chemical substances, the neurotransmitters. These chemicals cross the gap between the terminal of an axon and the dendrites of the neighbour cell, thus causing the receiving cells to create their own signal. The amount of neurotransmitter released is dependent on the strength of the signal, and the chemicals can either have an inhibitory or an excitatory effect on the postsynaptic cell.

All of these possibilities make the number of electrochemical configurations enormous. We can start to imagine that each thought, each picture, each experience will create a **different activation pattern** in the brain.

The question of ego presence in the brain

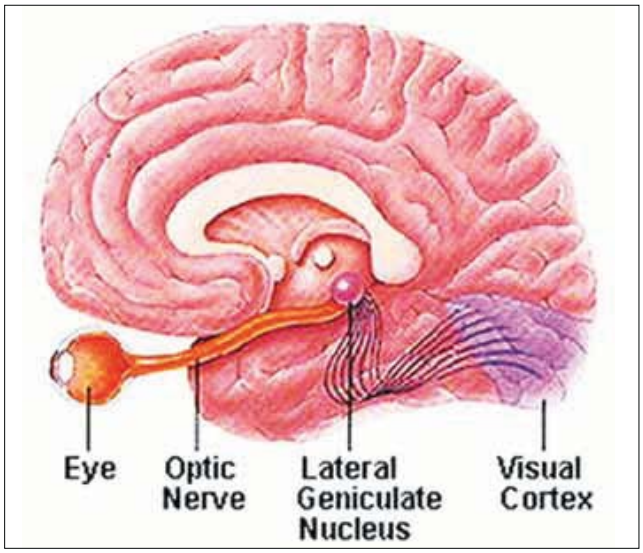
But even though the sheer number of patterns or pictures representing the outside world is very impressive, the question remains: **who reads** these representations? Who generates the conscious mind we experience in us? The confessed materialist Churchland says: "The answer is straight forward: no one. There is no distinct "self" in there beyond the brain as a whole." (Churchland 1995).

This sounds strange, but it coincides beautifully with a remark Rudolf Steiner made in the cycle "Man as a Being of Sense and Perception (GA 206, lecture 3, 24 July, 1921). He said that the brain is actually a very good material picture of the astral, the etheric and the physical body, but the ego can't be found there. It works in a free relationship to the head. If we think of the brain as a mirror organ which provides in its biological processes pictures, albeit distorted pictures, it is the ego that reads the pictures from outside the body.

Thinking within the neural network model, however, we use the specific language which is attached to it: the cells do their work because of their physical nature.

Perception, learning and memory in a neural network

But what exactly is thought to happen in a neural network during perception and memory formation? As an example, we can look at the processing of visual stimuli. The neurons in the retina receive visual stimulation and transfer it along their axons (the optical nerve) to a group of neurons called the lateral geniculate nucleus (LGN). Via synapses they give their information to the LGN neurons. Here the two different pictures coming from the eyes are modified, parts are suppressed, others reinforced, and then this new information is conveyed to the visual cortex in the back of the head, where we become conscious of the actual picture.



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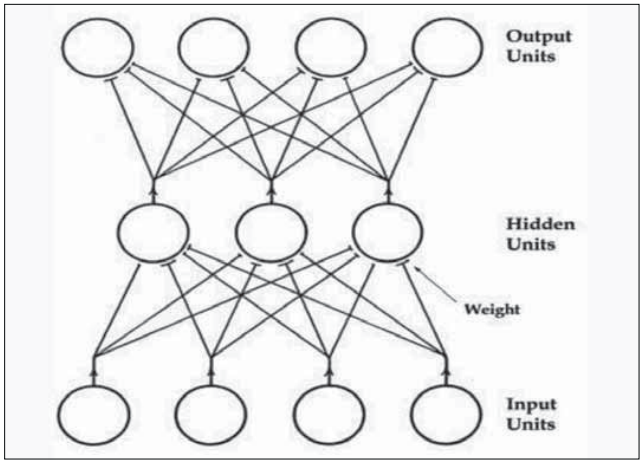


From Gerard O'Brian, PowerPoint presentation slide 13, 12 August 2010

In the simple schematic model of a feed forward network shown above, **the input layer of units** represents the neurons which receive input from an external source (in our example visual stimuli) but any other types of sensory stimuli could be represented by the same model. All of these input units are connected to each unit in the next layer (in our example the LGN), which are called **hidden units**, and these again are connected to the **output units** in the third layer (in our example the neurons in the visual cortex). The units of the third layer create output which we would expect to be the actual conscious perception of the picture which was seen. In the language of the model however, as no one is present to perceive, the output is said to be signals that impact on other systems, for example to create a motor response or a certain emotion or behaviour. Let us assume that these signals have a clear configuration which is in a regular, clearly systematic relation to the outside stimulus.

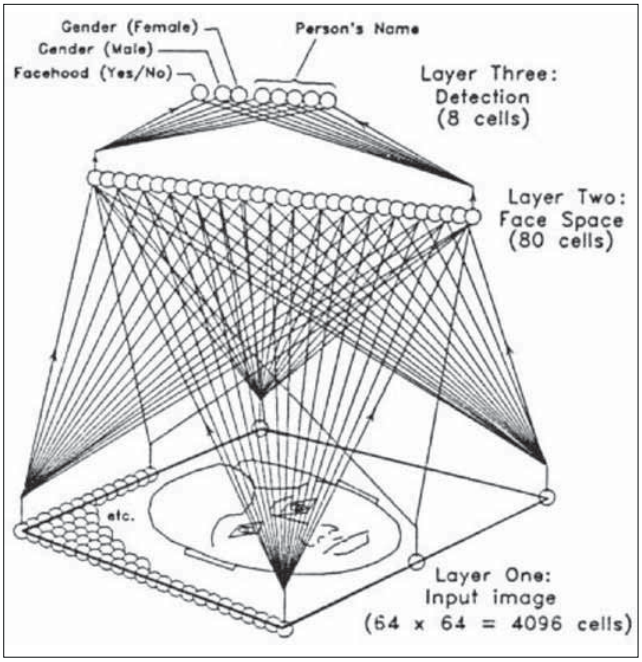
But we have to take it one step further. Neurons are always active. Little electrical signals are traveling along the nerve all the time. It is crucial for the understanding of the network idea that their functioning is not a simple on-off quality that can be imitated by an electrical switch. Even when the neuron is not stimulated, it has a resting rate, and incoming stimuli only change the rate with which a neuron is firing, which means the speed and intensity of the electrical impulses traveling along the nerve. This measurable physical quantity is shown in a range between 0 and 1, for example; zero meaning no firing, 1 meaning the highest possible rate. Each input unit thus has a specific **activation value** which is modelling this firing rate of a neuron. The **firing rate** of a neuron determines how much neurotransmitter is released at the synapses, and thus how strong the excitatory or the inhibitory effect on the post synaptic neuron will be.

The pattern of different activation values across a layer of units is called the **activation pattern**. As all input units are connected with each single unit of the hidden layer, this activation pattern is passed on to **each** of the hidden layer units. The hidden units create their own activation value from the incoming signals. The interesting parts in this process are the connections between the units. They represent dendrites with synapses, neurotransmitters and receptors in the brain. As in nature, the connections in the model have different strengths, called **connection weights**. The connection weight has two dimensions: the amount of released neurotransmitter is represented by a number, which is positive when the transmitter has an excitatory effect and negative when it has an inhibitory effect.

The neurons or units in the hidden layer sum up all incoming signals – the activation pattern of the input layer, modified by the connection weights – by generating their own activation value (changing their firing rate). The newly developed activation pattern of the hidden layer is then passed on to the units of the output layer and is again modified by the connection weights.

The importance of the connection weights

Network models like the described feed forward network can be simulated on digital computers and are used for pattern recognition which is not the strength of digital computers.



A very simple model of an artificial neural network for recognising real faces (from Churchland P. M. (1995), The engine of reason the seat of the soul, Chapter 3 p. 40). The output layer is trained to produce a code that identifies if the object is a face, the gender, and the persons name.

These network simulations need to be "trained" to perform their tasks. Starting with randomly set connection weights and a defined pattern at the output level, these are slowly adjusted by minimising the resulting fault until they settle into a configuration that allows the network not only to perform well on the training tasks, but also on similar, new tasks (e.g. face recognition or matching letters or groups of letters (graphemes) with speech sounds (phonemes) in a speech generating device). By constantly adapting the connection weights until the desired output is reached, the network is learning, it acquires certain skills and that means it is creating memory.

Which process in nature is depicted in the learning of the model?

The most interesting and biologically realistic process happens in the hidden layer, and that is the process of adapting the connection weights. In nature, we are in fact born with a more or less set number of neurons and only a few connections between them. Most of the connections are not genetically programmed and even twins seem to have different ones.

- Each *sense perception* in every moment of our life generates a new activation pattern which is unique: nobody else can have exactly the same perceptions at this moment. This is the level of the ego meeting the outside world.
- These activation patterns reach the hidden units and are conveyed to the neurons of this layer modified by our individual experiences, associations, habits etc. represented in the connection weights. The activation pattern of this layer of neurons forms a representation or concept – *Vorstellung* - on the level of the astral body. This formation of concepts is volatile and is influenced by new information coming in from sensory perceptions, from other networks or from memory.
- Repetitions and experiences shape and change the connection weights. New dendrites actively grow towards other neurons along well used pathways and more synapses are formed. This is the place where learning occurs and **memory is formed**: On the level of the etheric body where physical and chemical changes occur and growth processes take place (Sousa 2006).
- Finally each perception, together with the impact of the already present memory brings the brain in a very short period of stability, where the actual **image** of the physical condition can be read by the ego. Consciousness arises from moment to moment when the networks settle into a stable pattern, which I imagine like the picture in the mirror which is read by the ego, to give way to the next constellation immediately afterwards. It is a distorted picture as we know; it consists of an electrical and chemical constellation in time. Nevertheless, this emerging momentary pattern stands in a systematic relationship to the outside object like the picture in a distorting mirror to the real object.

This is what Rudolf Steiner said 1921:

"No objection can be taken from the fact that, naturally, because the world is big and formed differently than the inside of the human being, there can't be an image of the world inside the human being. The image is there, the image is the last of the stages the outer world experience goes through inside the human being. The other stages, concept or representation ("Vorstellung") and memory, are transition stages. …Our astral body changes the sense perception, transforms it into a pale concept; our etheric body takes all the content out of the perception and contains only the possibility of retrieval. But the experience actually causes something in us; something becomes imprinted as an image in us." (Translation KA)

Concluding reflections

I hope that you could get an impression of the exciting similarities between the neural network model of cognition and Rudolf Steiner's description of 90 years ago. The new perspective the model allows is also that memory, knowledge lies in the physical constellation of the networks, in the way the neurons connect to each other. Memory is not stored at a separate place; it is present in exactly the same region where the original sense impression is processed. That means that memory is involved in every single cognitive process, because the connection

weights determine the travelling of the signals and shape the patterns in which the system settles (Bechtel 1990). This explains why Kirschner, Sweller and Clark (2006) claim that, "long term memory is viewed as the central, dominant structure of human cognition" (p 76).

The neural network model can be seen as an example of how the physical world, especially in the realm of our organs, actually depicts the spiritual structure of the human being (Steiner, Man as a Being of Sense and Perception GA 206, Lecture on 24 July 1921).

With the modern cognitive neuroscience an interesting dialogue between biology, chemistry, psychology, computer science, philosophy and other scientific realms has started which does not avoid epistemological discussions. Even if the conversations are still far away from accepting the existence of a spiritual world, the research results can help us use Rudolf Steiner's indications to develop a deeper understanding of the human nature. ◆

Kerstin Andersson moved with her family to South Australia in 2007. She trained in Germany as a Waldorf teacher and curative educator, and works now as a Learning Support Coordinator and Extra Lesson Teacher at Mt Barker Waldorf School. 2010 she had the opportunity to complete a graduate certificate in Neuroscience (Learning), and is currently studying Special Education at Flinders University. One of her main interests is to gain a deeper understanding of Rudolf Steiner's indications in relation to current scientific research.

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