Research

1. Sub question 1

> How does information get stored and exchanged within the human brain according to neurologists?

1.1 How does the brain work?

1.1.1 Anatomy of a human brain

The brain is an immensely complex part of the human body. It consists out of many wires, called synapses, and 'tiny deciding machines', neurons, about 100 billion of them. (Chorost, 2011, p. 75) Neurons are wired in a mesh network trough the use of synapses. Neurons are able to fire and enable or disable connected neurons. "The job of a neuron is to accept spikes of electricity—called action potentials—from its dendrites. Depending on that input, it "decides" whether to send an action potential of its own to other neurons via its axon." (Chorost, 2011, p. 148)

1.1.2 Memory storage

Memories are stored in the brain as spatial and sequential patterns. For example if you would think of a memory containing an earthquake the pattern could be like this: Startling → Disturbing motion → Shaking → On Church and Market (Chorost, 2011, p. 285) Interpret the objects in this hierarchy as neurons firing each other, the lines as synapses.

> Your memory of the alphabet is a sequence of patterns. It isn't something stored or recalled in an instant or in an arbitrary order. (Hawkins, 2004, p. 137)

Memory sequences are retrieved exactly the way they are learned. Try spelling the alphabet backwards, you'll find it very hard, just like learning a new language.

1.1.3 Learning

If you have learned something you have basically made a memory more permanent in your brain; You've strengthened the synapses between the neurons which make the pattern of the memory. The strength of a synapse and thus the strength of a memory is expressed in weights [TODO: source].

If you want to learn something the job is to repeatedly fire the pattern of neurons and strengthen the synapses. This repeating has to be done in order to learn. So instead of what the movie The Matrix states, it's not possible to learn something, for example learning within seconds how to operate a helicopter or how to perform a martial art. Neurons have to fire repeatedly first.

Video: Dexter's Laboratory: The Learning Machine

Another thing is when it comes to learning is: your reference is the limit of what you're able to learn. This sounds weird because learning is all about broadening your reference. But when you think of it, how you're able to learn; you're not able to fire neurons/pattern which aren't there. So if you want to 'download' data into the brain you would have to do it with triggering the existing neurons and make new patterns. ([Hawkins, 2004](#))

[TODO: Gevolgen]

The hippocampus plays a big role in the formation of new memories. The hippocampus exists in both parts of the brain and is directly connected to the neocortex. Imagine it as a buffer before writing into the neocortex, the hard drive. Without the hippocampus it is impossible to store new memories, while it's possible to still remember things before the defect.

1.1.4 Confabulation

> Prediction is not just one of the things your brain does. It is the primary function of the neocortex, and the foundation of intelligence. (Hawkins, 2004, p. 169)

Past memories and realtime experiences are stored the same way in the human brain, although the parts are divided. By retrieving past memories from the neocortex the brain predicts what happens realtime. This is how details can be filled in without having to need to interpret them again. This is called confabulation. "What is actually happening flows up, and what you expect to be happening flows down." (Hawkins, 2004, p. 89)

"Plainly the hippocampus is for encoding, the cortex for storing." (Chorost, 2011, p. 283)

[TODO: Weg halen?]

1.1.5 Neuroplasticity

Brain plasticity, or neuroplasticity, is the ability of the human brain to change over time. (Michelon, 2008) This is an amazing feature which allows the human brain to move certain functions to other parts of the brain.

In one of his articles Michelon ([2008](#)) writes the following:

> A surgeon in his 50s suffers a stroke. His left arm is paralyzed. During his rehabilitation, his good arm and hand are immobilized, and he is set to cleaning tables. The task is at first impossible. Then slowly the bad arm remembers how too move. He learns to write again, to play tennis again: the functions of the brain areas killed in the stroke have transferred themselves to healthy regions!

While this is a vital function of the brain, this also means any future technology like optogenetics -- we'll talk more about that later on in this research -- can't rely on any of the brain's functions being present in one specific area. On the other hand because the brain is so flexible, we have grounds to believe that the human brain will be able to adjust to what ever is being fed to it.

1.1.6 Neurogenesis

Just moving functions from one part of the brain to another part of the brain wouldn't be enough. To help facilitate this, the human brain creates new neurons throughout your whole life, this is called neurogenesis. These newly created neurons usually die away when they're not needed. But while the brain is stimulated or trained, these neurons get a chance to form new connections to other neurons instead of dying away, and thus improve the human brain. (Klemm, 2008)

2. Sub question 2

> What is the current status of communication & information exchange between the human brain and computers / the internet?

In terms of connectivity there's a lot to explore. At the moment we're using mouse, keyboard and touch screens to interact with computers. This is an extra layer which might be removed to have a more direct connection with the human brain. In this subquestion the realms of brain computer interfaces and their accompanying technologies are explored.

2.1 MRI & EEG

These are two vastly interesting techniques which allow us to read information from the human brain. Unfortunately they're unidirectional which means they're only able to read information from the mind, and not write, which we would require.

2.2 Neuroprosthetics

Where MRI and EEG are non-intrusive technologies, there are a lot of interesting advancements being made on the field of neuroprosthetics (or brain implants). One example is a cochlear implant. They stimulate the cochlea (inner most part of the ear) through the use of electric pulses to let it think it's receiving sound.

While part of this implant is in fact a neuroprosthetic, this is no implant in the the human brain. The first true brain implants have already been designed, and they are currently being tested. Take for example the hippocampus, the part of your brain that amongst other tasks takes care of storing and retrieving memories. Currently a brain implant is under development that could mimic part of the hippocampus' abilities and help someone with brain damage to the hippocampus store & retrieve new memories again. (Berger, 2005)

2.3 Optogenetics

This is a fairly new technique and most likely best suited for reading and writing to the brain. By altering the genetics of individual neurons in the brain, scientists are able to see and alter the state of individual neurons with lasers. By inserting a controlled virus into the brain, certain neurons will be genetically modified which will in turn make the neurons light dependent. This allows the neuron to be controlled and read by light. (Boyden, 2011, 05:55)

Devices for Optogenetics are fairly low cost and it’s possible to utilise this technology with with a laser and some cheap electronics like an Arduino. (SNG, 2011)

This is still quite vague, lets give an example of what this technology is capable of. What it does is switch parts of the brain on or off. In a way you can forcefully enable parts of the brain to trigger for example the idea of an earthquake taking place or that you just achieved a goal. Also by disabling part of the brain, you can prevent a fear reaction from taking place. In Ed Boyden's tests, they stopped a pavlovian conditioned mouse from freezing after hearing a tone. This means that optogenetics can possibly cure harsh forms of phobias. (Boyden, 2011)

Wether or not we can actually read from and write to the human brain remains to be seen. But repeatedly activating parts of the human brain and strengthening synapses is exactly what defines learning. (Hawkins, 2011)

> By inserting channelrhodopsin and GFP genes into a neuron, one can make it fire at will and visually confirm that it has fired, simply by shining light of various wavelengths at it through a fiber-optic cable. The fiber-optic cable lets one activate cells and confirm their firing at the same time. In other words, it makes it possible to “write” to an area of the brain and “read” from it at the same time, using the same cable. That is, to invoke two-way information flow. (Chorost, 2011, p. 120)

So, by permanently changing the neurons we can make them sensitive to light. When the light is not active, the human brain functions as normal. But when the light is fired, various wavelengths of light can force parts of the brain on or off. Unfortunately, to be able to read and/or manipulate the state of a function within the human brain we need to know it's exact location. So, we can read the state of a part of the brain, but to read a memory we need to know exactly where it's stored in that human brain. The issue lays within the design of the human brain, because it's plasticity you can't expect anything to be at an exact location. For example "Oh, that memory of you being hit by a bus is stored 2.128mm south east of the center of the neocortex." wil not work. The moment we start to monitor the brain, we can read it's memories from that point in time onwards. But when we have not whitnessed the memory being stored, it's currently not possible for us to discover what pattern of neurons firing resemble what memory.

2.4 Neuromorphic microcontrollers

Neuromorphic microcontrollers are silicon chips which try to mimic the way the human brain works by using memristors & bipolar spin neurons. Current progress in this field is a working chip that's able to play pong like a human does, and which is able to complete digits partially drawn by humans.

The scientists working on the DARPA SyNAPSE program, which is one of the main neuromorphic chip projects, think this technology could break Moore's law. Looking at their planning they expect to go roughly five times as fast as Moore's law. Of course this is a new technology where huge leaps can be made in relatively short amounts of time. But it seems that they're confident that neuromorphic machines can be the solution to breaking free of Moore's law. [(Darpa, 2012)]

2.5 Alternate senses

> The neocortex is amazingly “plastic,” meaning it can change and rewire itself depending on the type of inputs flowing into it. ([Hawkins, 2004, p. 106])

The neuroplasticity of the human brain makes it possible for blind people to "see" with their tongues. The brain doesn't care in which way it gets it's information. It will make sense of whatever stream of data you feed it. ([Hawnkins, 2004, p. 110]) In this case translating visual data to pressure points on the tongue allow blind people to see again. Of course it's not as refined as the human retina, but imagine the possibilities.

Imagine a device that somehow feeds the internet as a sixth sense. Applied properly, your brain could make sense of the patterns being fed to it. The moment you think of a fire-truck, the device would understand that thought, and feed all of the properties of a fire-truck back to you, instantaneously fetched from the internet.

To make a device like the one mentioned before possible we need a better understanding of the streams being fed from the human sense to the brain. We know the human brain itself doesn't see, hear or feel. Rather it makes sense of a non-stop stream of data, and especially the changes in these streams in contrast to it's expectations. ([Hawkins, 2004, p. 111]) We need to know what the streams from different senses look like and how we can mimic them to feed our custom-made "sense" to the human brain.

3. Sub question 3

> What are the differences & similarities between the human brain and the internet when looking at the certain aspects of data storage and retrieval based on our findings?

3.1 Requirements of a intelligent machine

> According to functionalism, being intelligent or having a mind is purely a property of organization and has nothing inherently to do with what you're organized out of. A mind exists in any system whose constituent parts have the right causal relationship with each other, but those parts can just as validly be neurons, silicon chips, or something else. (Hawkins, 2004, p. 75)

In 'On intelligence' Hawkins predicts that computers will never be able to think of themselves, that there's no future in what is called artificial intelligence. His argument is that they can't reprogram their complete own workings except for some small parameters (which are programmed in advance) and thus are not intelligent, like us humans.

Artificial intelligence tries to emulate human behaviour, but according to Hawkins: 'Intelligence is measured by the predictive ability of a hierarchical memory, not by humanlike behavior.' ([Hawkins, 2004, 72%])

Hawking uses the Chinese Room metaphor as an argument why machines will never be intelligent like humans.

> The Chinese room is a thought experiment presented by John Searle. It supposes that there is a program that gives a computer the ability to carry on an intelligent conversation in written Chinese. If the program is given to someone who speaks only English to execute the instructions of the program by hand, then in theory, the English speaker would also be able to carry on a conversation in written Chinese. However, the English speaker would not be able to understand the conversation. Similarly, Searle concludes, a computer executing the program would not understand the conversation either. [Wikipedia, 2013][#Wikipedia:2013]

Because of the brain plasticity, people are able to 'reprogram' themselves. Any input and/or conclusion is changing the internal structure of the brain and making the brain more intelligent. This is also called learning. Computers are not able to learn. There is this thing called machine learning, which is used to make predictions, but it will never be able to stop it's main task and completely rewrite it. Sure you can make really sophisticated machines and behaviour, but it won't be able to quit it's job as a computer and continue on as a butler.

So, a computer will never be as intelligent as a human. It might be better to use the computer/web as an extension of the human brain.

3.2 Capacity

Upper limit, neurogenesis vs modular computers

> Capacity is the first issue. Let’s say the cortex has 32 trillion synapses. If we represented each synapse using only two bits (giving us four possible values per synapse) and each byte has eight bits (so one byte could represent four synapses), then we would need roughly 8 trillion bytes of memory. A hard drive on a personal computer today has 100 billion bytes, so we would need about eighty of today’s hard drives to have the same amount of memory as a human cortex.[(Hawkins, 2004, p. 384)]

Because of the modular design of computers, doubling or quadrupling the memory is no issue at all. Through neurogenesis a brain can increase it's capacity, but it could never double it's capacity in a day. Even doubling it's capacity throughout a lifetime is highly unlikely.

3.3 Centralisation / Decentralisation

As the human brain has no option to replicate itself, or distribute data to a different location it's highly centralised. The data within the human brain can be as much decentralised as we would like, but right now that data is not going to exit the human body through the use of a wire.

Computers are linked together through the internet. Exchanging data and storing information on other computers is rather easy. The internet by nature is decentralised and refers to different locations throughout the internet. A decentralised computer network.

3.4 Computational power

> Neurons are quite slow compared to the transistors in a computer. A neuron collects inputs from its synapses, and combines these inputs together to decide when to output a spike to other neurons. A typical neuron can do this and reset itself in about five milliseconds (5 ms), or around two hundred times per second. This may seem fast, but a modern silicon-based computer can do one billion operations in a second. (Hawkins, 2004, p. 127)

> No matter how many workers you hire, the problem cannot be solved in less time than it takes to walk a million steps. The same is true for parallel computers. (Hawkins, 2004, p. 130)

There's big difference between the computational power of a computer and a human brain.

3.5 Data storage

Data on the internet is served through pages/documents. Often these pages are scripted in html and linked together with hyperlinks. This way you're able to browse from page to page end collect your information. Hyperlinks enable you to browse from one server to an other. So the internet is plainly a bunch of file cabinets, pointing to each other within documents. The DNS protocol allows it to directly access a document through a domain name, but the name is not tied to the content.

The brain doesn't have pages or domain names. The links are different as well. Patterns are the storage, not the nodes (or in the case of the internet the pages). The internet itself doesn't value the storage like the brain does with its weights on synapses. Although you could say that Google's Pagerank tries to emulate this by storing information about the importance of links by looking how often they are linked and accessed. Google's pagerank is used to order its results in it's search engine on importance. But still it doesn't make a hyperlink a synapse.

3.6 Data retrieval speed

How fast are brains able to read from their memories and what is the difference with computers?

3.7 Learning

In the field of learning the human brain and computers differ greatly. Where the human brain can make sense of whatever stream of information is being fed to it, the computer needs everything to be defined in advance. There is a lot of research being done in the field of artificial intelligence, but currently there are no computers that are able to interact with whatever you do if the feature hasn't been implemented. (Hawkins, 2004)

For example if an intelligent robot was built to play a game of football, that same computer would not be able to have a sophisticated conversation with you. Current artificial intelligence is based on fooling the human the machine is smart. It hasn't learnt itself to talk, it didn't learn itself to walk or play a game of football. All of that intelligence has been defined by it's creator.

3.8 Persistence

The human mind works with a two step progress much like computers do. Information gets stored in the short therm memory. And, if important enough, gets stored in the long therm memory later on. When looking at computers you can compare the short and long therm memory with the system memory and the hard disk drive respectively. Anything in memory which is important enough gets stored on the hard disk. The human brain and the computers have much the same weaknesses. Where the human brain forgets information when not used for a long time, the hard disk can get read & write errors resulting in data getting lost.

Luckily, for computers we found a couple of solutions to this problem, two of them being backups and version control systems. The first stores a snapshot of a file or set of files at a different location. The second solution does the same as the first, but keeps a snapshot of the file for each moment in history it changed. This allows you to browse through versions of the information. A very strong feature the human brain is essentially lacking.

3.9 Portability of data

One key problem to the human brain is the fact that it's locked up in your skull. You can't make a copy of it, or pull it out and place it in a different body. At least, not with current technology. The current computer model really shines here, hard disk drives are extremely easy to duplicate or move to a different computer. The moment a hard disk gets faulty, you can replace it. The human brain can adapt to parts of the brain being damaged, but the damaged parts can not be replaced.

3.10 Sharing

Just like the portability of data, sharing is also a problem to the human. The only way for a human to share the information in the brain is in the form of a conversation. We don't have the ability to make connections with other brains like computers can. A conversation can be done over the phone, but the information has to be explained before the receiver can make sense of the data.

With computers you can just send documents, images, sounds or videos to another computer without the need to explain the information. The in advance defined standards of the computer really help here. Because computers expect data to be formatted in a specific way, they can make sense of the raw data. Much like it would be to feed the stream of data coming from your retina (eye) to another human brain.

4. Sub question 4

> What innovations are there in the field of digital communication and storage structures which would fit the needs of the human brain?

4.1 Current technologies

Distributed databases Input methods

4.2 Future technologies

BCI's - Optogenetics

5. Conclusion

We think the furtesth step which you can go in making communication between the brain and the internet less complex is by making a more direct connection. Brain computer interfaces are the future.

5.1 Combination

In what fields can the internet support the brain and vice-versa?

5.2 Proposed vision

Best of both worlds, where the brain has this, the internet has to adopt. Where the internet has that, it can enhance the brain.

6. Sources

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