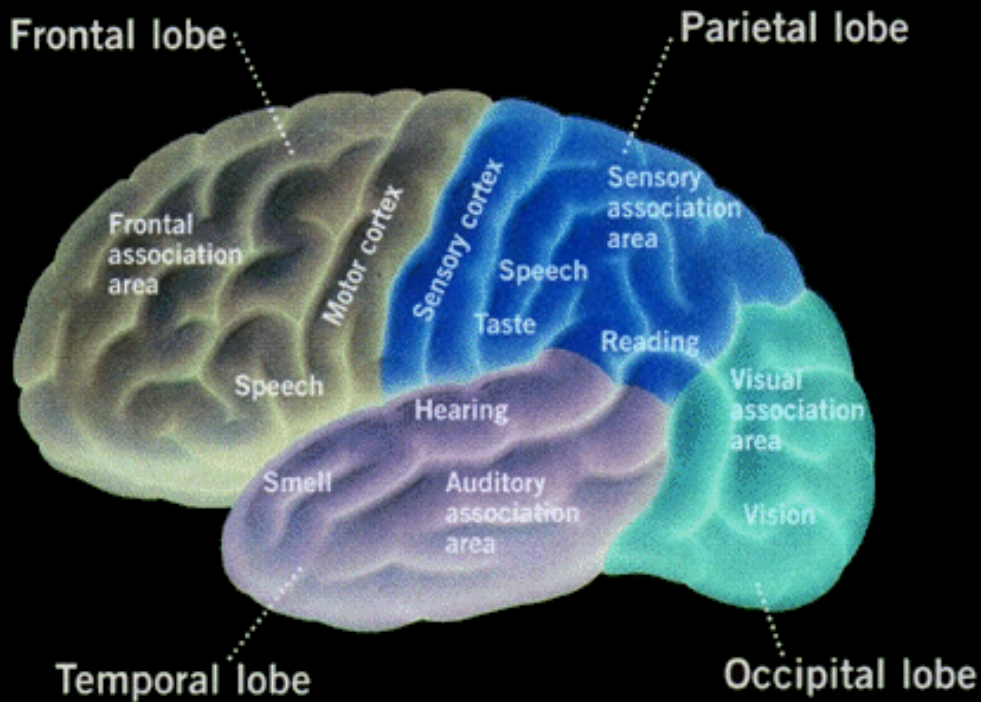


Key Concepts

Neuron, Axon, Dendrite, Vision, Sound, Smell, Brain Pathways,
Rendering Reality, Unique Maps, Mind, Self-aware Mind
Neural Networks, Pattern Recognition

Consciousness is the experience of experiencing.
Tor Norretranders

It is quite remarkable, that the most complex and amazing object in the known Universe is contained within every one of us. Human brain allows us to experience the world. It creates us!



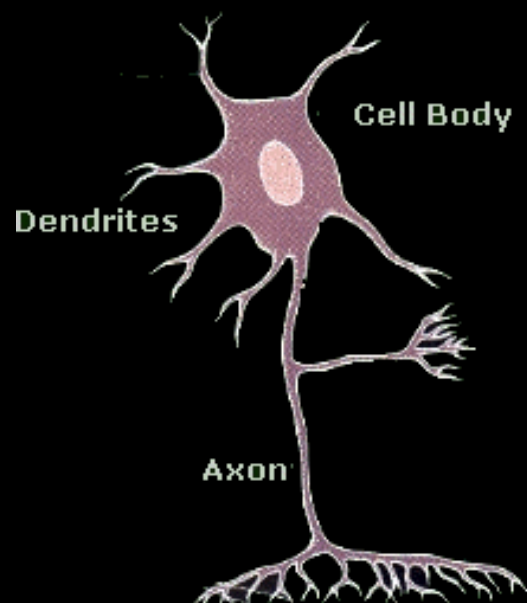
Brain is divided into separate areas, which are collectively or individually responsible for the tasks which make us who we are. These areas are made of intricate network of the brain cells - neurons. Information, in the form of electrical signals, traverses these pathways, it is disseminated, filtered and stored in this giant, always moving network. Our discussion will be primarily based on the human brain, because human brains appear to be more advanced. The general principles that we will talk about (perhaps with exception of one!), apply to the brains of most animals.

How do neurons work?

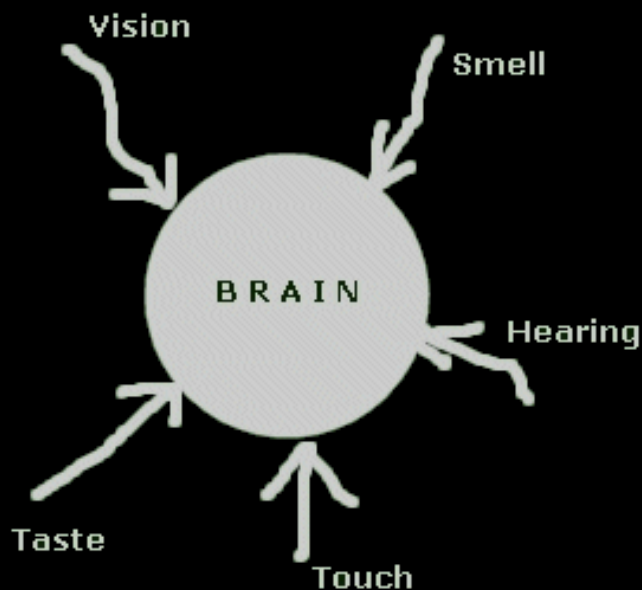
Neurons are transmitters of the signals, the nodes and cables of brain pathways. The signal is not just send through a neuron. Neurons accumulate charges that come to them and propagate them only if certain threshold of accumulated charge is achieved.



Electrical signals arrive into neuron via short input cables called dendrites. The signal leaves neuron via long output cable called axon. Inside, the neuron there is simple threshold based accumulator. The neurons are connected into giant networks by means of synapses. Synapses are essentially the hubs, which allow signals coming from an axon of one neuron to be 'heard' by the dendrite of another.



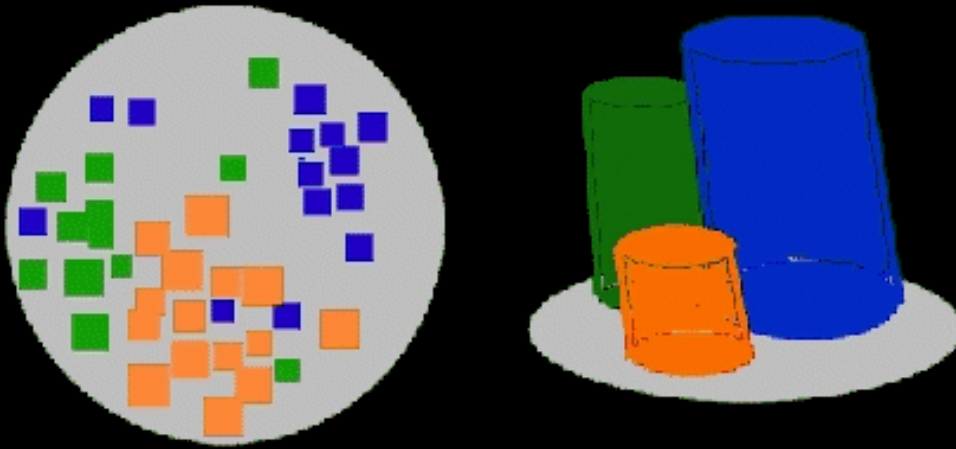
The selfish gene theory translated to the world of neurons says that actually neurons like to exist in the excited state all the time. This idea gives rise to something known as hedonistic brain theory. It says that just like single neuron likes to be in the excited state the entire brain (which would mean us) would like to be in the excited (rather than depressed or tired state).



We shall now ask one of the most often asked philosophical questions - is brain a computer? We will not be able to answer this question fully, until the lecture on Theory of Computation, because there we will define more precisely what is meant by computer. Nevertheless, we will be moving towards this ambitious goal. A lay definition of a computer is a kind of a device capable of accepting an input and producing an output. What are the inputs into the brain? The inputs are sensual signals. We have visual inputs, sound inputs, smell inputs, taste inputs and inputs triggered by a touch. As you realize nothing within human body happens by magic. The inputs do not just end up in the brain somehow. These inputs, after being induced by interactions with the outside environment, traverse intricate neural networks that exists everywhere in our bodies. Failures in this network cause severe damages to human behavior. For example people with damages in spinal cord become paralyzed and can not move.

Vision

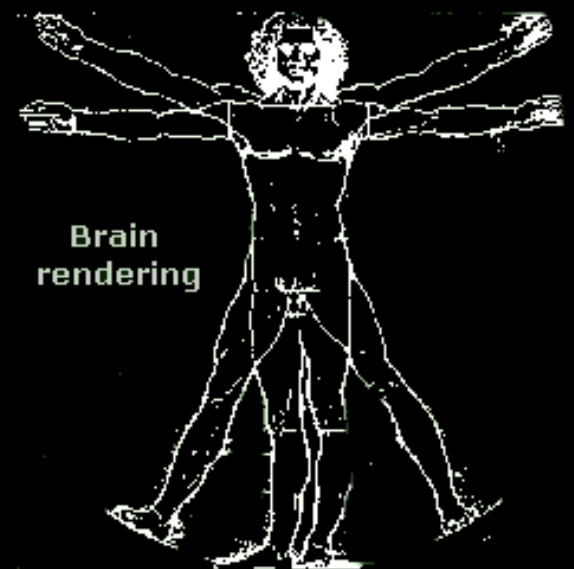
Arguably, the most interesting kind of input into the human brain is visual. Let us try to understand how and what do we see. For this we need a little bit of physics. Light comes in different varieties. Colors that most of us see actually correspond to different wavelength of light. The wavelength of light usually depends of the frequency of oscillation of the originating source. What is an eye? An eye is a very intricate organ, which evolved to recognize different incoming wavelengths of light.



**Incidence of light of different wavelength
per unit of time (say 1 millisecond)**

Imagine that you have a dart board and during the course of one minute you are throwing darts of different color into it. Imagine also that you are very skillful and once you threw blue dart into a spot on the board you will never hit the same spot with the dart of a different color. As you realize, because the time interval is fixed you will hit different spots on the board different number of times. This process resembles very much the process of photons (light particles) hitting our eyes. Every spot is hit different number of times. Different number of times simply corresponds to different colors. Every hit or most hits are sensed by the neuron sensors in our eyes. They rapidly accumulate charges and fire them off. The frequency of firing corresponds essentially to different colors. This information is injected into brain network via optic nerve. It is out of these firing the brain constructs the amazing rendering of the world as we experience it.

he picture that we see when walk around is the coarse approximation to reality shaped by billion years of evolution. We do not see atoms when we look at apples because there is no real evolutionary advantage. There are probably no uniform and smooth objects in nature, what we experience are clever approximations done by our very own brain.

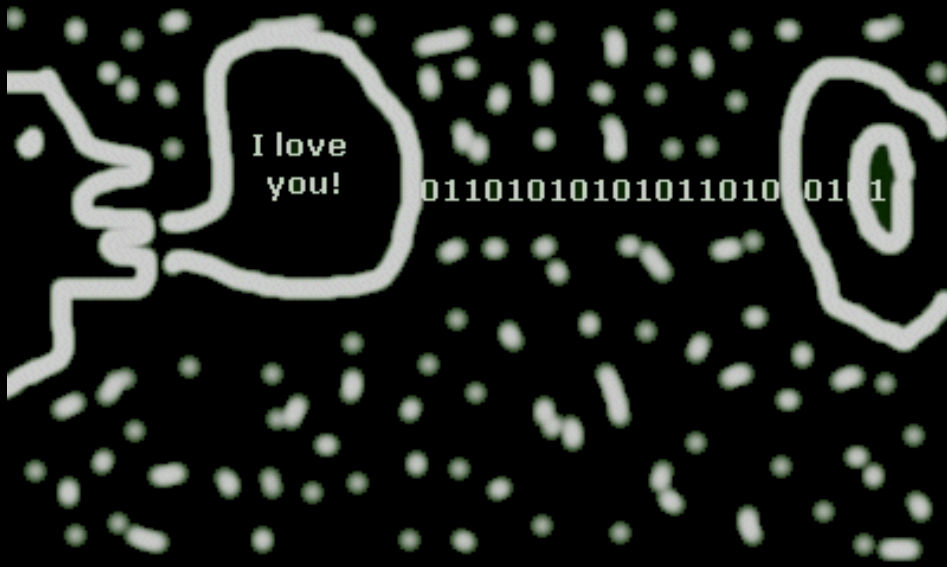


Immanuel Kant, famous German philosopher, observed in his 'Critique of Pure Reason' that it is impossible for us to know our world beyond our senses. This means that we can not really control the rendering levels of our brains (although glasses do come handy for some of us :) It is impossible for us to know if the the 'reality' around us truly exists. Here people can split into two camps - those who believe in physical world and those who don't. In my mind the choice makes no difference. Even if the physical world is just an illusion, we have some fascinating things to understand.

To render continuous picture of reality brain, just like a lot of modern computers, deploys caching and forecasting. It is amazing, but there is a 0.5 seconds delay between your brain processing information and 'you' knowing about it. Who is 'you'? We will clarify this in the section on consciousness and subconsciousness. Nevertheless, the picture that we experience is slightly dated. The brain does an excellent job of fooling us. Before we go deeper into amazing world of neuroscience lets make sure that we enumerate other ways in which information can reach human brain.

Sound

Sound is probably next after vision in 'importance' of inputs. Sound waves propagate through the air and reach our ears. Just like light waves, sound waves have different wavelength, which correspond to different vibrating frequencies of the originating source. For example, all human beings have different voices. A software which can identify you is capable of taking the frequency of your 'Hello' and representing it as a bunch of zeros and ones and then mapping it to a well known entry in a database.



There is a stunning example of usage of sound in nature - bats. These creatures evolve to emit sound waves which get reflected of the surroundings. The ears of bats are equipped with extra sensitive receptors which then receive the signals which come back. Based on these signals bats render a 3D picture in their brains not unlike the one that we experience. Of course the difference is that bats are absolutely blind!

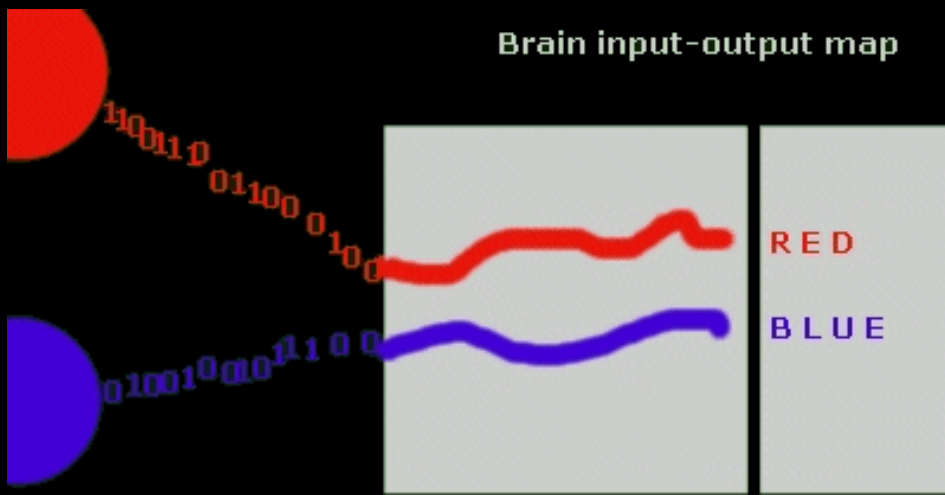
Sound used to play much more important role for our ancestors then it plays now for us. At night, in the forest sound and smell allow animals to spot the pray and run away from a predator.

Smell

Modern people have extended an original intend of all senses. We entertain ourselves with exquisite perfumes, which produce complex patterns of signals in our brains. What exactly causes the smell? You may or may not be surprised. The substances that surround us are not exactly uniform. When you hold a rose in your hand, it appears to have well defined boundaries. As we know this is just an approximation. In reality time atoms of rose float around all around the rose. These tiny particles enter our noses and cause the sensation of smell. Yes the same goes for all other substances not only rose. Smell as you know, is equally used to protect us from eating unfresh food and to select compatible sexual partners.

How do we distinguish it all?

When we look at an apple we understand that it is different from an orange. When we hear voice of a Britney Spears we hear that it is different from Ricky Martin's voice. When we smell Hugo Boss perfume we realize that it is different from Cool Water. How? How is it possible that our brain is capable of discriminating between myriad of different things found around us? Brain is a map. It is a stimuli - response map. It is a Hashtable, if you want to get a crude CS definition. It is a lookup. It is a lookup that occurs via traversal of network of interconnected neurons. Any input signal causes UNIQUE pattern, unique path through the network.



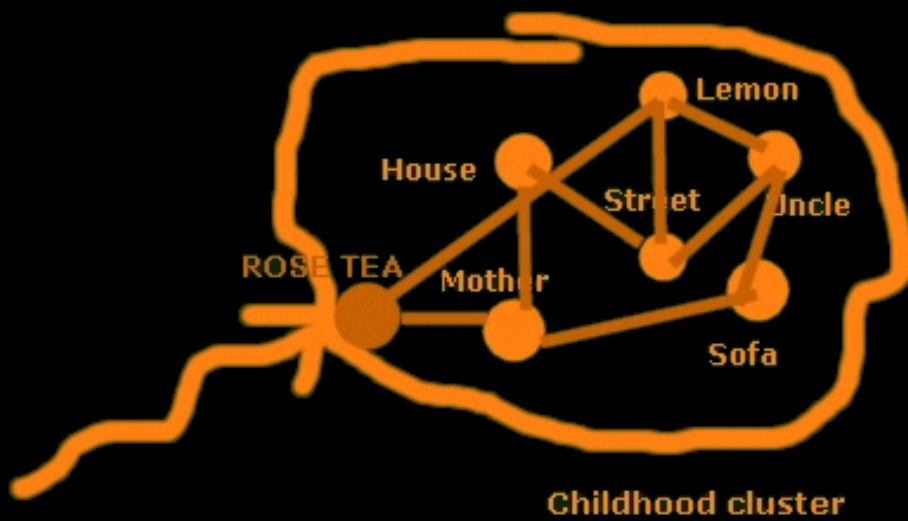
This is one of the major reasons for the size of the human brain. No, it does not contain everything in the known universe, but it is capable of storing a lot. When child is born, the brain is ready to start making its first lookups. Child eagerly memorizes the patterns of the surrounding world. Once we look at it carefully, we will realize that most of human activity is ... automatic! We exists mostly in the subconscious mode! Even sophisticated activities such as speech happen automatically for the most part. Try this: look at any object and try NOT to think of its name. Too late. The lookup already occurred. The situation is quite weird. You can not not think. Seizing inputs is very difficult. And here come three interesting insights.

Headache, Meditation & Crazy Math Professors

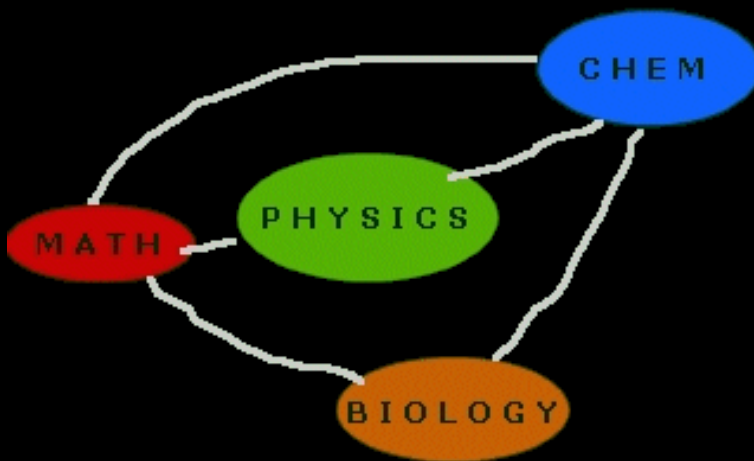
What is headache? What is meditation? And why do crazy math professors stare at the ceiling when you talk to them? If you ever experienced headache, you know that in addition to taking Tylenol you usually close your eyes, perhaps retire to another room. Why? Well your brain processes 11 MB of data per second. 11 MB! Most of the data comes from vision. Closing your eyes substantially reduces the influx of information into your brain. And since common source of headache is a lot of information - headache will go away. Headache means that your brain is overwhelmed with the information, it is thrashing! By retiring to the quite dark place you are giving it a chance to catch up. Right from here lets swing into meditation. Ancient sacred way of communicating with your inner self, hearing the rhythms of your body. Well today's information age is too intense and crazy, that's why people do not even understand what is going on during meditations. Human brain is a very complex object, which is not nearly utilized to its full capacity. During a meditation brain does not operate in the 'usual' way. Thus the experiences is quite different from what you are experiencing every day. I have never meditated and can not give you details on what it feels like. I am however, almost positive that there are other similar experiences, they would be induced by drugs such as LCD or alcohol. With an intake of alcohol, the brain starts ignoring some of the inputs. This is why drunk people are clumsy and can not speak well. The experience of being drunk is quite different from experience of being sober. It resembles brain in a slow motion, almost dreamy. Finally, why do those geeky math professors stare at the ceiling when you ask them why they took 20 points on your final exam? I believe the answer is: 'Because it is blank!' Uniform blank ceiling contains no useful information, it is compressible into a single dot. Since math professors are trying to be very precise when they speak, it is important for their brains to concentrate on speaking. Thus the brain orients eyes in the most plain area of any room - white ceiling!

Associative memory

But you know that brain is not just a dumb map of inputs and outputs! It is much much more. In his famous passage Marcel Proust recalls a substantial portion of his childhood, based on a long-forgotten smell of rose tea. His brain reconstructs pictures from the street and his house, people faces and dialogs. All of this is triggered by a smell of tea. This smell acted as a trigger as a key to enter entire cluster of thoughts.



A cluster consists of a network of neurons and thoughts that are reachable from each other. Often it suffices to enter in any place to start recalling entire cluster. In addition it appears that for the most part, events from the past, which occupy a cluster are not active. Only keys are always ready. As the concepts in a cluster are being recalled (requested) more details usually surface. The clusters exist not only based on spatial and temporal order (space/time), they also exist on the conceptual level. For example, conceptually all silverware should leave in one cluster. This does not mean that the concepts in a cluster are in optimal physical proximity. This is not guaranteed at all, and I am not exactly sure how it works. What I am pretty sure about is that associations exist on the higher level - between clusters of clusters.



What is sleep?

Here is another question that has been haunting philosophers, psychologists and now neuroscientists for quite some time. We have very interesting and peculiar experiences during sleep. Sometimes it seems like we are jumping off the roof sometimes someone evil is chasing us. What is going on? Why sometimes dream make sense and sometimes are absurd? While it is hard to be positive on this controversial topic, several ideas seem to be plausible. First of all let's realize that brain processes enormous amounts of information during the day. What should it retain? How much of the short-term memory should become long term? It is believed that during the day, a lot of (especially new or unusual) inputs are retained. At night there is a walk through the brain which decides which data is useful and incorporates it into the network, while throwing out the useless information. In the harsh CS slang this would be called garbage collection. But what do we see or who sees dreams? We now come to the holy grail of scientific inquires - consciousness or mind.

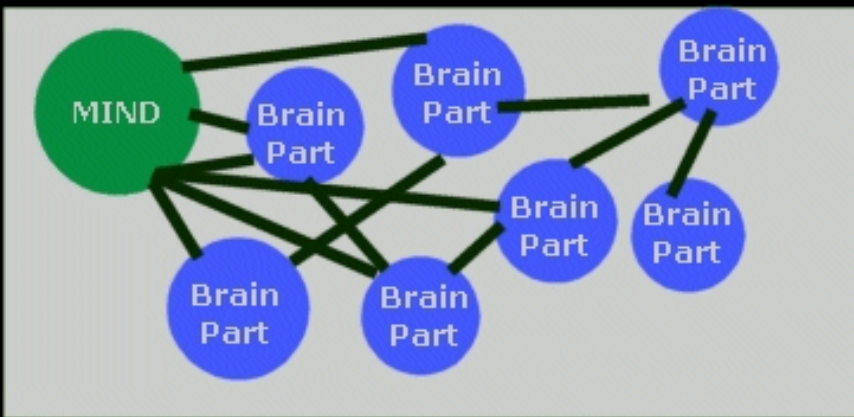
Mind's I

What is mind? This question has been haunting humanity since its earliest days, and became particularly important as we got bold enough to give artificial intelligence (AI) a shot.

Usually, when people think of mind, they think of 'I', 'myself'. We tend to equate mind with ourselves, and more importantly, we tend to think of mind as being necessarily the consciousness.

To understand what is mind, and what kinds of minds are out there, we have to go back to a more fundamental question: 'What are the important differences between humans and animals?' Some people will consider such question too imprecise and will bring up list containing billions of differences. But there is really only one which seems to be profound. Animals are incapable of doing rational forecasting, they can't reason and deduce things logically. For example, a person can choose to go to school and study, knowing that five years from now she will be able to get a better job. Math professors, chess players, police detectives and many others develop if-then-else chains of logical sequences every day. But animals can't do that. They just exist in the instantaneous mode, they are irrational at all times. They have instincts, which allow them to do elementary planning, but this should not be confused with mind. Humans on the other hand, are quite famous for their elementary logical reasoning.

Undoubtedly, the organ which allows us to think and to deduce things is brain. Human brain is a form of complicated neural network. Let us simply model this network, as consisting of several different parts, each of which can communicate and cooperate with others, while dedicated, in principle, to several different tasks. (Incidentally, each part can be visualized just like the entire brain).



So we've got these interconnected and interdependent parts. Now imagine that some (relatively long) time ago, one part of human brain, started to perform elementary logical computations. How can it do that? Just like modern computers do it. Chips in modern computers contain AND and OR gates which allow them to calculate trivial and not so trivial logical expressions. It is not so difficult to model AND and OR gates with neural network; it is quite feasible that part of human brain started doing just that. Let's call this part – MIND.

This MIND sub-part of our brain, turned out to be so useful, from an evolutionary point of view, that it allowed us, in the short period of time, to dominate the macro-world of our planet. As it was from the very beginning, its task is – rationality. Deduce, compute, allow or veto. If A then B else C up and up the spiral of infinite possibilities.

The brain, is rather a friendly community. Brain parts talk to each other, they cooperate and sometimes argue (although you may be in a lot of trouble, if they do). In any case, they offer services to each other, just like roommates who leave together – I do shopping you do laundry, etc. What does the MIND offer? It offers other brain parts to check their strategy against its 'infallible' AND and OR circuitry. Does this behavior make sense in the long run? That's what MIND is trying to rationalize. From here, the next step is to call MIND – brain filter!

M I N D - is the Brain Filter

M I N D - is Brain Police

It does sound funny, but it is a good metaphor. Is this action feasible? Yes or No? The decision comes from the MIND. Recall that when people act irrationally, they may be asked 'Are you out of your mind?!' It is curious how much truth there is in different words and sayings.

So now we got all of these brain parts and one of them is MIND. MIND checks the actions of other brain parts (how often and how effectively we'll see later). Now MIND is just another brain part. When MIND check brain parts, it must check itself as well! Imagine now a system, which overrules itself, which is self-contradictory. Such system must be self-destructive. Or it can be caught in an infinite loop. Therefore, MIND can't really treat itself as a simple brain-part. (Those minds which did are no longer with us). There has to be an exception. What is it? It is the MIND's 'I.'. It is 'I'! When MIND 'sees' itself, it says it is 'I' – do nothing, don't check, otherwise we will be infinitely confused! The mind that calls itself 'I' is self-aware mind and this is what human beings have – a self-aware mind!



MIND, therefore, started to take over control of the long-term behavior of our brain. How? Consider some examples. Suppose that you are sitting in the room with your spouse and he makes seemingly offensive remark. Most likely, you will flip out as well and you spend next ten minutes yelling at each other. Then you will calm down, and continue peaceful coexistence. On the other hand, if you came home and found that your beloved husband left all of his socks on the floor again, but he wasn't home, your anger may cool off before he comes back and the fight will be avoided. What this means is that your MIND, the rational side of you, is not always present! It is there sometimes only. Remember that brain consists of many different sub-parts, one of the sub-pats is MIND. Only some sub-parts (if not one!) can be active at a time. Your MIND gets its share of brain capacity every so often. But there is another important point in the spouse examples. MIND is acting as a logical policeman in our brains. It says: 'Oh, yeah, he did it again, left those socks on the floor, but so what, he is my honey, etc.'. The MIND says that there is no point to yell, because we now in the long term, it has no effect (probably has a negative effect altogether).

Mental disorders & Closemindedness

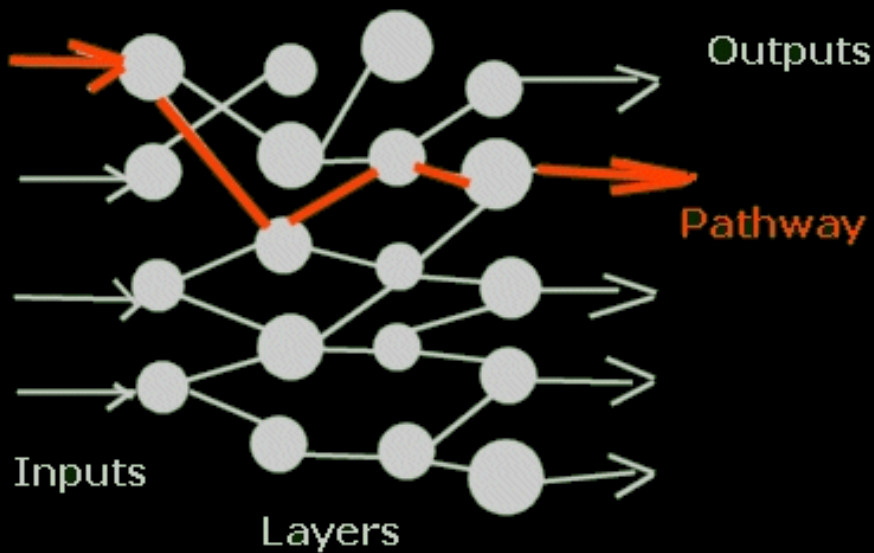
We often hear an expression: 'This guy is crazy or lunatic!' What does it mean? How can we asses the validity of such statement. Leaving in the world were everything is relative it is really impossible to come up with objective judgments. When people call someone crazy they really just mean abnormal, deviating

from average. As you know, the brain is vastly complex structure. We all have different brains. Deviations in the wiring of this network cause different views of the world! People who are 'on the same wavelength' have their brains wired in a similar way at least on one topic. Our experiences shape our brains, but you can not go mad from your life experiences, you can be dumb because of lack of diversity of inputs. People who are born with certain genetical mental disorders have networks that are incapable of processing and storing data in a normal way. On the other hand, perfectly healthy people, who live their lives in one place and have strict rules about rules of conduct end up narrow minded. We will see why is that when we will finish up this lecture with 'artificial brains' - neural networks.

Neural Networks

Mathematician, computer scientists, physicist constantly face array of extremely difficult problems, problems for which they are not able to discover simple solution. It seems unlikely that there exist a simple way to answer a lot of questions that they are asking. The modern science is transitioning from the world of Newtonian Certainty to the world of Heisenberg uncertainty. In such a world, solution techniques which are inspired by the natural phenomenon not only take a role of possible solution, they become the only likely recipes that will work.

Neural networks are inspired by the human brain. They come in variety of flavors, but share the following common properties:



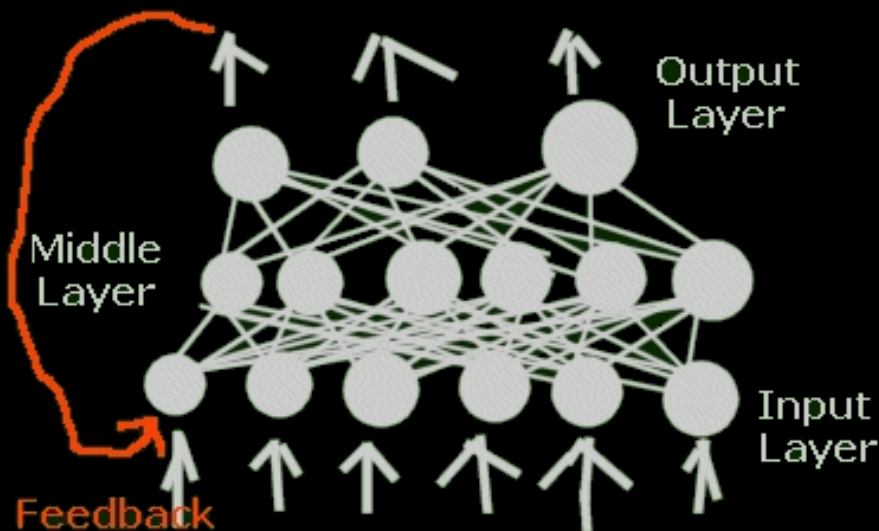
- The network consists of nodes which are connected by edges
- The edges carry certain weight or the nodes carry certain charge
- The node has a bunch of other nodes as its inputs and also may act as an input to the nodes on the next level

The idea is quite simple. The actual connection between nodes are allowed to change as a result of the feedback. Before we clarify what exactly this means let us step a side for a moment and understand what are we trying to achieve here. Suppose that we are researches on Wall Street who are trying to learn the patterns of the Stock Market and eventually write a computer program which will trade automatically based on those patterns. In the ideal (and probably very boring) world, there would exist a function which would given the state of the stock market react in the profitable way:

$$F(x) = Y$$

$$F(\text{Market State}) = \text{Action}$$

But of course there is no such exact, short function. However, there may still be a pretty good correspondence which we may be able to encode into the neural network (NN). NN is a black box. It has a bunch of inputs and spits out bunch of outputs. How can we make it produce right outputs? The answer is - we train it! You will now see some very interesting and intuitive parallels between NN and human brain. A classical NN consists of 3 layers: input layer, middle layer and output layer. All nodes in the input layer are inputs for every node in the middle layer. All nodes in the middle layer are inputs of every node of the output layer.



All the weights of the edges are initialized to a certain number either all the same or not. The network then operates in the following way. The inputs are delivered through the entries in the input level. They float through the pathways according to the weight of an edge. When the outputs are produced, they are compared with desired outputs and then this information in a form of feedback travels back to the input layer, where the weights are re-adjusted. In the NN jargon this is called back propagation. Usually, one set of data is used to train the network and then another one - to test it. Once network stabilizes, you can fix the weights and run it through the second data set, or perhaps let it run for real.

Neural networks are widely used in pattern recognition which is by itself a very interesting, part of computer science. Neural Networks, just like human brain are automatic information classifiers. They restructure in response to the incoming data, they adapt to variety of patterns. So the close-mindedness person is the one who was extensively exposed to the same kind of input. These kind of people tend to classify everything as the

same class, the same set of rules.

Related Bibliography

[User Illusion, by Tor Norretrandes](#)

[Godel, Escher, Bach, by Douglas Hofstadter](#)

[The Mind's Past, by Michael Gazzaniga](#)

[A Natural History of Senses, by Dianne Ackerman](#)

[Society of Mind, by Marvin Minsky](#)

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