INTRODUCTION

If we got together to open up your skull, we would encounter an organ that bears more than a passing resemblance to a cauliflower – the brain. Touching the brain reveals that its texture resembles that of a cauliflower as well, and apparently even the flavour is not dissimilar. But as far as cauliflowers go, this one is special, because somehow it is the activity of precisely this organ that determines your thoughts and feelings, wishes and visions. The sizzling of cells in this cauliflower is currently determining whether or not you decide to go on reading this book. It's quite unreal.

Once I ended up telling a taxi driver that I research how consciousness emerges in the brain. Upon hearing this, the taxi driver turned around towards me (thankfully we had already come to a halt!) and roared: „It's IM-POS-SI-BLE!" As far as experiences go, this one was quite refreshing, because it's the first and last time that a taxi driver has ever shouted at me, but I found I could relate to the reasons behind this outburst rather well. The brain is a machine – a complex one, but a machine nevertheless. Our experience of being somebody, of being human, is something that's both subjective and qualitative; it's something spiritual, something that seems to stand apart from anything automatic. Impossible!

I'm a scientist. This means it's my job to study the impossible; to find out whether the impossible is, in fact, impossible or just seems to be, and, with any luck, turn impossible into possible and use it to find out more about the world and about ourselves. When I research these questions, I try to leave personal opinions behind; I run experiments. In the light of scientific research I can tell that the facts we've accumulated up to this day allow us to be rather confident that consciousness – the experience of being human – emerges, somehow, in the brain.

I personally don't find the conclusion that humans' mental processes are located in the brain depressing or frightening in any way. Instead, I find it massively fascinating, because this conclusion leads us to the next question: „So, how exactly does the experience of being somebody arise from neural activity?" How does the impossible become possible?

This book is not loaded with answers. Instead, I focus on the questions, on the mysteries that sometimes drive me to distraction – maybe I'll never find out; perhaps those questions will never be answered. How does consciousness emerge from the functioning of the brain? What exactly makes humans special compared to other animals? Can artificial intelligence mimic or even surpass human intelligence? Why do we sleep? How do we use the brain to get work done and enjoy life? I find these questions compelling and I want to share them with you, because it's simply exciting to stride the line between the known and the unknown and gaze into the vast labyrinth of mysteries.

The book in your hands is written for anyone who might be interested in the brain. The topics discussed in it are directly related to my own research into the human brain, senses and sleep. How does the feeling of being somebody arise from interactions between brain cells? How does the brain create a conscious percept of this *word* here? Why does the consciousness go away when we fall asleep? What's more, why do we even need to spend an entire third of our lives asleep? Why do we dream?

If we aim high and try to solve the big problems of neuroscience, we'll expand the horizons of human knowledge, bit by bit. I promise that this adventure will leave you more knowledgeable than before about the brain and about yourself.

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WHAT MAKES HUMANS HUMAN?

In 2006, my love story with the brain had already begun, but I was still a big football fan. The football World Cup took place that year and France and Italy faced off in the finals. A goal by the living legend Zinedine Zidane gave France the lead; then Italy evened the score. The match was forced into extra time. And then something unexpected happened, something that neither the participants nor the viewers probably still don't fully grasp: dozens of meters away from the ball, Zidane headbutted the Italian player Marco Materazzi's chest. The video shows the blow was forceful and there is no doubt that it was intentional. Zidane was sent off with a straight red card, Italy were crowned world champions following victory in a penalty shoot-out.

What happened? Why did an exceptionally smart and experienced player do something so impulsive? Zidane was one of the best players in the world at the time, and he had previously been voted FIFA World Player of the Year three times. In 2004, he was named the best European footballer of the past 50 years. He was renowned for his flawless technique, but also as a smart playmaker who always knew where to pass the ball. His move left millions of viewers at the stadium and in their homes startled and confused.

Pundits were immediately guessing that Materazzi said something about Zidane's mother or sister and got him mad. I guess that on a purely human level we can all relate to Zidane's behaviour: sometimes when somebody pushes our buttons it's hard to stay in control of our words and actions. But this was no everyday occasion – it was the most important game in football, the FIFA World Cup Final. Zidane must have known that the blow would be followed by a red card, being sent off, and, likely enough, losing the finals. Therefore, two apparently very differently valued options presented themselves: 1) headbutt Materazzi, get sent off, or 2) it's the finals, get back to the game and deal with him later. Upon reflection, it's clear that the second option is the good one. Winning the world cup finals is incomparably more important than speedy payback for an insult. But Zidane's brain chose to go with headbutting his opponent in the chest. Why?

As a rookie brain lover, I was reminded of an incident that happened to another man. That unfortunate soul took a long iron rod completely through his skull, leaving a hole three centimeters across through his frontal lobe. Two very interesting facts came with the accident. First, remarkably, he was conscious after the accident and even capable of reflection about his situation. He is even told to have joked with the doctor who came to his aid: „Doctor, here is business enough for you.“ Just you try driving a metal rod through your computer! Or, actually, don't. The biological brain is amazingly resilient and plastic, whereas a PC would have to be scrapped.

Another and, to us, even more significant development is the way his personality changed after the incident. He became much more impulsive and was no longer a trustworthy employee. Many similar cases of patients with damaged prefrontal lobes show us that they cannot plan their work well, take more risks, make chance decisions and are not in charge of their behaviour. This describes our „mad“ footballer as well. Could we say that at that moment, on the 17th minute of the extra time, Zidane's frontal lobe was struck by an imaginary iron rod? Were certain parts of his frontal lobe temporarily deactivated? Why did it turn out like this? Does similar passing brain damage cause ill-advised behaviour in all people? How to prevent it?

Researching the brain helps us understand who we are and why we are the way we are. In this chapter, we'll first try to understand which brain processes are responsible for the conscious control of one's behaviour and why this control occasionally falters. Why do even clever people sometimes do stupid things? Then we'll look at a newborn's journey of maturation. Are the messes a two-year-old child makes necessary for developing into a full person? Zidane's thumping reminds us that to be human is to be imperfect – in the second half of the chapter we'll enquire whether it's possible to create machines that are smarter than humans.

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INTO THE THOUGHTS OF A TODDLER

Sometimes I see parents berate their small children as if they expected the kid to think the same way as they do. This is not the case. The worldview of a small child is completely different and entirely unfathomable to us adults. Nobody will be particularly surprised if I say a two-year-old child will take the norms and rules at home completely differently than the parents do. But there are other differences, too.

When my firstborn turned two, I found myself astonished – already puberty?! It is true that two-year-old children can be defiant and stubborn; it is not a coincidence that this period is called „terrible twos“. My wife and I often wonder just why kids are so rebellious at this age. It is, however, clear that this is not about a failure to grasp the rules – you may find your two-year-old say „don't yank on the curtain!“ and repeat it all over and over while yanking on the curtain...

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It is worth remembering that kids are very good at learning rules and manners already at the age of one and a half years. So how come the two-year-old flouts them so? Because he knows them already and wants to learn something else – the two-year-old is learning about people. If

you unplug the router, it's not the plug that is interesting: plugged in, plugged out, what's the difference. However, hearing the „Not again... what a child!" from the other room is much more useful for the development of the little brain – daddy always reacts a little bit differently: sometimes he tries to quietly explain: „I've already told you...", sometimes gives you the stink eye without saying a word, sometimes says: „Go to your room, this minute!", or maybe: „No cartoons for you tonight!", or else: „Darling, would you please do something about the kid!"
The faces and behaviour of people are never exactly the same and this diversity helps the brain to develop a better understanding of other people, what they want and what they think, what's going on in their minds. Just look at your two-year-old child when he's up to no good again – he's not focused on the mischief he's making, but rather on your response. He'll check whether you noticed; my son sometimes even says: „Look, daddy, I made mischief!" He's learning about people. He conducts experiments and notes down the results, just like a little scientist. It feels good to know that a two-year-old kid is not actively trying to drive you insane, doesn't it? The little brain needs conflict to learn about other people's minds and reasoning.

Understanding other people's behaviour is hard, because while we only see what people near us do, we'll need to know what they think and what they feel – their state of mind. Such knowledge about other people's states of mind has to be accumulated slowly over a lifetime – this is a long learning process. Toddlers, for instance, have trouble even knowing their own beliefs. Try out an experiment with a friendly three-year-old, for instance – give a three-year-old child a box of sweets that, upon opening, turns out to contain uncooked pasta shapes (or something else the child doesn't care for). You'll see disappointment on her face and she might even voice a protest. But if you now go and ask the kid what she originally expected to find in the box, the answer might surprise you: „I thought it's dry pasta." You just saw her experience disappointment because she expected candy, but now she's saying that she had always thought it would contain pasta.

How does it feel to be the child who doesn't remember her earlier thoughts and wishes? And how is it possible to understand other people's wishes and opinions like this? In a way, it's not. Small children make the same mistake when you ask them: „What would Peter think is in the box?" – „Dry pasta!" But of course. It's hard to know and account for other people's states of mind. In fact, it's so hard that oftentimes even adults are not quite up to the task. It is possible that humans are the only animal species that is capable of it at all. And that is precisely why it takes children a good few years before they get such challenges right. They need time and opportunities to experiment, although I agree that being subjected to those experiments can be bleak work indeed.

But the differences between child and adult consciousness go further. If you ask children how they're feeling, you'll find out that children of five and under do not constantly experience thoughts. While I and probably you as well can be driven to distraction by the unceasing churning of thoughts, then according to small children, their heads are generally quiet – occasionally punctuated by a thought, then empty again. It sounds quite pleasant.

On the other hand it's misleading to think that there's nothing going on in a small child's head. The first time I was taken by surprise, and later excited, when I noticed that my less than two-year-old son picked up a topic after eating that was unrelated both to food and the previous topic. Usually such pronouncements are preceded by a longer period of quietness, which means that the child's utterings are not a direct reaction to the environment or the parents' discussion, but rather indicate actual thinking.

I once heard something quite unexpected from my son as he was eating pizza. With his mouth full, he said: „You know, life is hard." I couldn't believe my ears and asked him to repeat what he just said. „You know, life is hard." It's not quite that hard! At such idle moments, my son has sometimes brought up events that nobody has mentioned for weeks, or said quite surprising things. On Christmas Day morning, when I'd stayed up late the night before, he said over a sausage sandwich: „There's another brain inside the brain!" I had to concur that his theory was about as good as the one that had kept me awake at night. Therefore, domestic observations show that even two-year-old children sometimes come up with thoughts that are unrelated to their immediate environment. Perhaps we can imagine an idle two-year-old's consciousness like this: emptiness, emptiness, random amazing idea, emptiness? Rather, I tend to think that even at the age of two, a child's mind has something going on all the time, coming up with snippets of thought, but their frontal lobe isn't yet fully up to the task of interpreting those neural activity patterns. Noticing one's own thoughts takes skill, too.

By the way, when my two-year-old kept ignoring my instructions, remarks, and suggestions while he was focused on play, I came up with the hypothesis that maybe his brain can focus on playing so thoroughly that he simply *doesn't hear* what I say. That would be neat – a hyperfocusing toddler! Being a scientist, I proceeded with the obvious experiment: instead of the suggestions and admonitions, I kept my voice unchanged and said: „You could eat ice cream while playing", at which point he immediately stopped playing and I found two sets of eyes staring at me – one of them very happy and the other one slightly bothered. The boy was quite happy to eat ice cream while playing, but my wife was slightly disappointed in my educational measures. Not even being told about the scientific experiment about children's selective attention managed to mellow her down. But at least we all had ice cream together.

Finally, it's interesting to note that the prefrontal cortex happens to be one of the slowest developing regions of the brain – the prefrontal lobe and its connections don't develop fully in the teenage years and keep maturing into the 20s. As we saw earlier, the prefrontal lobe is responsible for self-control and conscious reasoning. That explains why small children have difficulty with a task that seems straightforward to us: if you tell a child: „I'll put a piece of candy in front of you. If you can go two minutes without eating it, you'll get five more candies", then a large proportion of the children cannot hold themselves back – they'll eat the tasty candy immediately. It has been shown that children's success in waiting it out (delaying gratification) is related to the development of their prefrontal lobe and predicts future academic success and ability to control their behaviour. It is worth noting that a fair few adults would be bested by this challenge, too.

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SLEEP IS THE PRICE WE PAY FOR NEURAL PLASTICITY

Some romantics out there continue to believe that sleep has a single major function; they believe they know why excessive use of a brain region leads to its sleep. Giulio Tononi and Chiara Cirelli are among the scientists who have researched sleep patterns among some very different species – humans, rats, mice, fruit flies – but who believe that sleep is ultimately necessary for one single fundamental reason. Specifically, they believe that sleep is the price that we pay for neural plasticity.

The human brain is plastic, it undergoes continuous change. Its synapses, or connections between neurons, can vary in size. As I laid out in Chapter 1, there are grounds to believe that the secret of who we are is hidden in the precise architecture of this labyrinth of connections. Our knowledge and personality, our whole mental self-image is written in the pattern of connections between neural cells. And it is this pattern that changes, that is, it is plastic. Fresh knowledge is reflected in changes of the strength of connections between neurons. For example, if you manage to learn anything from this book, then this new knowledge relies on new connections being made between certain neurons and other, existing connections becoming stronger or weaker. The strength of a connection determines how strongly one neuron's activity impacts another's. Biologically speaking, the strength of a synapse depends on the surface area of the presynaptic and postsynaptic membranes that form the synapse – the larger the surface area, the stronger one neuron's impact on the other.

Tononi and Cirelli's romantic idea is based on the fact that in an awake brain, connections become on average – that is, across the total of all connections – stronger. This, in turn, means that synapses become, on average, larger. Larger synapses, however, are not necessarily better – they take up more space, which is in short supply; they consume more energy and slow down future learning. As such, synaptic upscaling is not sustainable.

Therefore, according to Tononi and Cirelli, synapse size needs to be downscaled and this can only happen during sleep. All synapses supposedly decrease in size by the same amount during sleep and therefore what is learned during the day (which is expressed in the relative sizes of the synapses) is retained. Synaptic downscaling cannot happen awake, because the size of all synapses in the brain changes simultaneously and if some synapses were required to deal with the environment or learn new information while this process is taking place, only trouble would ensue.

By now, the increase in the size and number of synapses in an awake brain and their reduction in a sleeping brain has been experimentally proven. For example, it is possible to count the number of synapses in brain cells under the microscope – research has shown that in the brains of both mice and fruit flies, synapses multiply when the creatures are awake and only sleep puts an end to the process.

Naturally, this romantic theory is not without contentious elements, one of which is the following: the little brown bat spends 20 hours a day asleep, but the horse only three or four hours. It hardly seems logical that the synapses in the bat's brain change enough in four hours to merit 20 hours of regulation, while the horse, whose synapse size has been changing for 20 hours, resets them in only four. For a similar length of awake time, the bat needs 25 times more sleeping time, and it is unlikely that a 25-fold difference can be explained solely with synapse size regulation. This doesn't mean that the beautiful theory is wrong, but it appears that the patterns of sleep in various organisms need further principles besides the synapse size change to be fully explained.

The other problem with Tononi and Cirelli's theory is more personal to us. If we observe our, humans', own sleep patterns, it becomes obvious that deep, slow-wave sleep forms only a minor proportion of all sleep, roughly one fourth or one fifth. Therefore, Tononi's theory explains only a small part of the patterns of our sleep. Nor does he attempt to explain the function of REM sleep. And, after all, he doesn't really need to, because not all animals experience REM sleep; but at the same time, it means that Tononi's theory cannot explain our sleep in its entirety.

Therefore, humans' sleep patterns don't reflect the sleep patterns of the entire animal kingdom. But as mentioned above, considering sleep does not end with the question concerning the grand primary function of sleep. Equally relevant is the question why humans' and most mammals' sleep patterns are the way they are: why does sleep consist of cycles where slow-wave sleep is followed by rapid eye movement sleep?

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CONCLUSION

We're done! As easy as that. I'll go through the key ideas once more, just in case.

All mental process take place in the brain. Who you are is directly related to your brain structure, that is, the pattern of connections between your brain cells. I hope that if you ever happen to encounter somebody that insists that consciousness stands apart from the brain somehow, you'll be able to use examples from this book to disprove that statement (for example, even out-of-body experiences can be induced through brain stimulation).

Many otherwise clever people often believe that human beings use just 5%-20% of their brain. We saw in Chapter 4 why this idea is sheer bunk. Share this knowledge. It is always possible to use your brain better and more efficiently. I hope you found some useful tricks.

One simple way to take care of your mental health and stay in good mental shape is sleeping. One of the goals of the book is to show just how important sleep is. The brain needs sleep. Sleep to give your brain time to organise knowledge and tidy up. Sleep to be a more creative and all round nicer person.

The main question the book is concerned with is what makes humans special as compared to other animals and artificial intelligence. Huge investments in artificial intelligence research mean that we will see increasingly smarter machines. Just how close to human minds they can reach is still unclear, for example because we don't know exactly what makes humans so unlike other animals. What makes humans so clever? Can it be imitated? These questions need attention right now. There is no doubt left that artificial intelligence will take a number of jobs from humans over the coming decades. The question we face is how to prepare for it. What kind of work should be found for people whose jobs disappear? How do we modernise the education system to make sure young people will be able to find jobs 20 years down the line? What should we teach our children to make sure they'll have something useful to do in the future world? Just as this book started out with questions, it also ends with questions. It cannot be helped: if the brain was easy to understand, we ourselves would be too simple to understand it. But if you learned something through those questions about yourself and other people, then all is well.