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Mind maths: The sum of consciousness

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The brain is constantly drawing links between every bit of information that hits our senses – is this what allows us to be aware of what we see?

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An experience's colours, smells and tastes are impossible to isolate from one another *(Image: Jasper White/Getty)*

Getting to grips with consciousness may seem like a step into the unknown, or even the unknowable, but Giulio Tononi at the University of Wisconsin-Madison was not daunted.

The first challenge was to find a good definition of consciousness by boiling it down to its most essential elements. He reasoned that each moment of awareness is a fusion of information from all of our senses. An experience's colours, smells and sounds are impossible to isolate from one another, except through deliberate actions such as closing your eyes. At the same time, each conscious experience is a unique, never-to-be-repeated event. In computational terms, this means that a seat of consciousness in the brain does two things: it makes sense of potentially vast amounts of information and, just as importantly, it internally binds this information into a single, coherent picture that differs from everything we have ever - or will ever - experience.

Perhaps the best way to understand this is to consider the difference between the brain and a digital camera. Although the screen seems to show a complete image to our eyes, the camera just treats the image as a collection of separate pixels, which work completely independently from one another; it never combines the information to find links or patterns. For this reason, it has very low "integration", and so according to Tononi's theory, it isn't conscious. The brain, on the other hand, is constantly drawing links between every bit of information that hits our senses, which allows us to be aware of what we see.

Physicists haven't paid much attention to measuring how much information a physical system can hold on to and integrate, so Tononi worked out the equations himself. The result is a quantity known as "phi". "Now I could go back to neurobiology with this tentative theory: any seat of consciousness must have a high level of phi, and other systems must not," says Tononi.

Some accepted anatomical findings gel with this tentative theory. For instance, we know that the cerebral cortex is crucial for conscious experience - any damage to the brain here will have an effect on your mental life. Conversely, the cerebellum is not necessary for conscious awareness, which was something of a puzzle given that it contains more than twice as many neurons as the cerebral cortex.

When Tononi analysed the two regions using his theory, it all made sense: the cerebral cortex may have fewer neurons, but the cells are very well connected to one another. They can hold large amounts of information and also integrate it to generate a single coherent picture - the level of phi is very high. The cerebellum is more like the digital camera: it may contain more neurons than the cerebral cortex, but there are fewer interconnections and so no coherent picture - the level of phi is low, in other words.

"I've been studying consciousness for 25 years, and Giulio's theory is the most promising," says

Christof Koch at the California Institute of Technology in Pasadena. "It's unlikely to be the final word but it goes in the right direction - it makes predictions. It moves consciousness away from the realm of speculative metaphysics."

Lights out

Tononi's theory can also explain what happens when we fall asleep or are given an anaesthetic - through experiments he has shown that the level of phi in the cerebral cortex drops as our consciousness fades away.

This makes sense when we consider all of the ideas emerging from the field of computational neuroscience. The cerebral cortex is home to many of the highly interconnected "rich club" hubs, which may explain why it is so good at integrating incoming information. Neural signals zip freely through these interconnections to generate conscious experiences. Fall asleep, though, and the neural signals within the cerebral cortex slip further away from the critical point vital for neural communication. The physical interconnections remain, but traffic no longer flows through them. The Bayesian brain loses its ability to make sense of the world around it - all of the thoughts engaged in the brain's winnerless competitions fade to black.

The various strands of the computational neuroscience story come together powerfully. Are they the final word in our understanding of the brain? "They're undoubtedly flawed in some way - no one is being naive," says Beggs. Nevertheless, he and others think neuroscience is poised to become a numbers game. "We'll find out in a few years," he says. "In the meantime, it's certainly a fun journey."

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