Bradley Love.

Minding the gap

Cognitive models may be the way to bridge the gap between brain and behaviour.

Bradley Love (UCL) has an admirably eclectic publication record. At one time or another he has looked into the development of cognitive skills through computer game playing, decision-making by supermarket shoppers, optimism bias in sports fans and how Amazon reviews affect our assessment of consumer products. The common thread uniting these and other studies, he suggests, is the development of cognitive models – a way of providing an explanatory bridge between behaviour and neural mechanisms.

Eclecticism was a hallmark of his early education in the USA. "As an undergraduate, I was interested in topics in cognitive science across computer science, maths, neuroscience and psychology, and fortunately the university I attended was tolerant of that." What drove this diversity was a keen desire to understand deep and ancient philosophical questions, particularly how people build internal representations of objects and concepts from the outside world. "I thought maybe we could start answering them in a scientific way through neuroscience and by adopting techniques in computation."

His first undergraduate project explored how people represent concepts as webs and links, while his first published output outlined an algorithm for web page ranking (actually pre-dating the one developed by Google). "Then I got more interested in how people do things versus machines," he says. "Not like artificial intelligence models, but models that go through the same steps that people go through when we are learning something or making a decision."

At this point, with brain imaging in its infancy, his work was strongly driven by a desire to make sense of behavioural data, extracting key principles to develop and test cognitive models. "But I always felt like the brain should be part of that."

Making sense of data

The emergence of technologies such as fMRI provided a way to bring the brain and neural mechanisms into the dissection of human behaviour. Furthermore, he argues, cognitive models provide a bridge between the different levels of analysis – behavioural, how people learn and make decisions on the one hand, and neuroscientific, the neural mechanisms that underlie these behavioural traits on the other. Each provides constraints on the other – neuroscientific experiments can indicate whether models are biologically plausible, while behavioural studies can reveal whether they accurately capture what people really do.

Indeed, a strong theme running through Professor Love's work is the desire to go beyond description and capture the fundamental principles that underlie how people behave and how the brain works. One of his favourite thought experiments is to imagine that every connection in the brain has been mapped and every molecular interaction between neurons has been tracked. Would we then understand the brain? "The puzzle's not solved by any means," he suggests.

A good illustration of his approach is work he has carried out with Alison Preston in Texas and Mike Mack in Toronto, which used neuroscientific studies to shed light on two plausible cognitive models of object categorisation (that we create abstractions or 'prototype' representations of related objects or hold and compare individual representations). Behavioural studies have struggled to distinguish the two, but functional brain imaging data were more consistent with the idea of individual representations.

Similarly, he, Dr Preston and Dr Mack have explored what happens when conceptual knowledge has to be updated – perhaps when a new type of car is developed, adding to the universe of existing car types. Again, Professor Love had originally proposed possible cognitive mechanisms from behavioural studies: "That was actually a model I developed in my PhD dissertation, purely by looking at behavioural data. I was convinced people were using this kind of mechanism, and I started thinking how is this implemented in the brain?"

By trawling the literature, he recognised that structures such as the hippocampus and medial temporal lobe were likely to play critical roles. Using brain imaging allied to computational modelling, he and his colleagues were able to show that connections between these structures were associated with the updating of conceptual information, suggesting that conceptual representations in the hippocampus are continually being updated and overwritten as new information is collected.

His work has also shone light on another distinctive feature of human decision-making – heuristics. "For decades, people thought of heuristics as these quick mental short cuts," says Professor Love. The prevailing idea is that heuristics are a solution to limited neural processing capacity, enabling us to disregard information and still arrive at reasonably sensible decisions.

Cognitive psychologists have developed models such as tallying and 'take the best' to explain these approaches. Yet Professor Love's analysis suggested that heuristic decision-making is not that dissimilar to other forms of decision-making, when considered within the context of Bayesian probability frameworks. "If you go in with strong prior expectations, you'll end up with this more simple procedure," he suggests. He also argues for the need to go beyond labelling to dig into underlying mechanisms: "If you look at the heuristic and what kind of mental operations are required for doing, say, the tallying heuristic versus the take the best heuristic, they're very different, in terms of attentional demands and sequential processing demands."

An analysis of supermarket shopping patterns has provided insight into human decision making.

"RATHER THAN YOUR CHOICES FOLLOWING YOUR PREFERENCES, IT COULD BE THE OTHER WAY ROUND, YOUR PREFERENCES FOLLOW YOUR CHOICES."

Decision making in the supermarket

One of Professor Love's recent studies has taken advantage of the explosive growth in data available on consumer decision-making. Working with Tesco, he was able to sift through five years of purchasing data from thousands of shoppers, to address the 'exploration/exploitation dilemma' – should people stick with what they know or try something different?

Theory suggests that, faced with uncertainty, people should lean towards exploring. And laboratory studies have confirmed this is how people typically respond. "We started thinking, do people actually do this in the real world, in domains where the choices are not objective rewards," says Professor Love. In the real world, choices are more subjective and multidimensional – between, say, a low-fat strawberry yoghurt and a full-fat toffee sundae. "We had an idea people might explore differently."

The wealth of data on shopping patterns confirmed his theory: "We found the exact opposite of the laboratory studies. Basically, people explore less and less the more they are exploiting." They then may shift suddenly and the process resets. Professor Love describes the behaviour as 'coherency maximisation': "Rather than your choices following your preferences, it could be the other way round, your preferences follow your choices." Professor Love could even test the robustness of the observations through a form of intervention – sending consumers vouchers to encourage them to shift their choices, the responses to which, as predicted, depended on where in the explore/exploit timeline consumers were.

The rise of 'big data' is opening up new opportunities to explore human behaviour. Professor Love is also spending time on secondment at the Turing Institute, the home of UK data science, where he has the chance to interact and discuss methodological innovations with specialists from multiple areas of computer science, mathematics, statistics and data science.

Looking forward, he is excited by the potential of convolutional neural networks, the building blocks of a new generation of machine learning and artificial intelligence tools. Built by computational scientists, they nevertheless drew inspiration from the human brain, particularly image processing by the ventral stream. It is possible, he suggests, that these tools will help us to understand brain function. And, conversely, neuroscientific insights may contribute to the development of tools that are profoundly changing the nature of society: "Even if there is some small way that our field can give back to it, that would be both intellectually interesting and practically important."

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