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The man with the golden brain

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What's the point of a brain? A fundamental question that has led Professor Daniel Wolpert to some remarkable conclusions about how and why the brain controls and predicts movement. In a recent talk for TED, Wolpert explores the research that resulted in him receiving the Golden Brain Award.

The sea squirt, a type of marine filter feeder, swims around looking for somewhere to settle down for the rest of its life. Once parked on a rock in a suitable spot it never moves again. So the first thing it does is eat its own brain. While this may seem a little rash to some, for Professor Daniel Wolpert it makes perfect evolutionary sense.

"To me it's obvious that there's no point in the brain processing or storing anything if it can't have benefits for physical movement, because that's the only way we improve our survival" says Wolpert. "I believe that to understand movement is to understand the whole brain. Memory, cognition, sensory processing – they are there for a reason, and that reason is action."

Wolpert is firmly convinced that movement is the underlying factor and final result behind every functional aspect of a brain. "There can be no evolutionary advantage to laying down memories of childhood, or perceiving the colour of a rose, if it doesn't affect the way you're going to move in later life" he says.

A professor in the Department of Engineering, Wolpert examines computational models and uses simple behavioural experiments to describe and predict how the brain solves problems related to action. Through this combination of theoretical and behavioural work, Wolpert has begun to revolutionise the study of human sensorimotor control, the way in which the brain controls physical movement.

He was recently presented with the prestigious Golden Brain Award, from the California-based Minerva Foundation. The award is given to those producing original and outstanding research into the nature of the brain, regarded by many as the most complex object in the known universe.

So what occurs in the brain when humans produce movement? Science has long struggled with the mysteries of this question. Wolpert uses the example of the game of chess: “We have computers that can generate algorithms of possible chess moves at tremendous speeds, beating the best human chess players. But ask a machine to compete on a dextrous level, such as moving a chess piece from one square to another, and the most advanced robot will fail every time against the average five year old.”

The models employed by Wolpert and his team have yielded startling results, a possible glimpse into the patterns integral to our mental matrix. “It turns out the brain behaves in a very statistical manner, representing information about the world as probabilities and processes, which is possible to predict mathematically” says Wolpert. “We’ve shown that this is a very powerful framework for understanding the brain.”

For action to occur, a command is sent from the brain causing muscles to contract and the body to move. Sensory feedback is then received from vision, skin, muscles and so on, to help gauge success. Sounds simple, but a vast amount of misinformation or ‘noise’ is generated with even the most basic action, due to the imperfections in our senses and the almost incalculable variables of the physical world around us. “We work in a whole sensory/task soup of noise” says Wolpert. “The brain goes to a lot of effort to reduce the negative consequences of this noise and variability.”

The brain’s crystal ball

To combat this noise, our brains have developed a sophisticated predictive ability, so that every action is based on an orchestrated balance between current sensory data and, crucially, past experience. Memory is a key factor in allowing the brain to make the optimal ‘best guess’ for cutting through the noise, producing the most advantageous movement for the task. In this way, our brains are constantly attempting to predict the future.

“An intuitive example of this predictive ability might be returning a serve in tennis. You need to decide where the ball is going to bounce to produce the most effective return. The brain uses the sensory evidence, such as vision and sound, and combines it with experience, prior knowledge of where the ball has bounced in the past. This creates an area of ‘belief’, the brains best guess of where ball will hit court, and the command for action is generated accordingly.”

Movement can take a long time from command to muscles, which can leave us exposed. Like chess, we need to be anticipating several moves ahead, so the brain uses its predictive ability to try and internally replicate the response to an action as or even before it is made, a kind of inbuilt simulator. The brain then subtracts this simulation from our actual experience, so it isn’t adding to the noise of misinformation.

“For behavioural causality, we need to be more attuned to the outside world as opposed to inside our own bodies. When our neural simulator makes a prediction, it is only based on internal movement commands. The brain subtracts that prediction from the overall sensation, so that everything left over is hopefully external."

But this can have intriguing effects on our perceptions of the physical world, and the consequences of our actions. "This is why we can't tickle ourselves, as tickling relies on an inability to predict sensation, and your neural simulator has already subtracted the sensation from the signal" says Wolpert.

"But they hit me harder!"

A further example of this sensory subtraction occurred to Wolpert during a backseat bust-up between his daughters, a familiar experience for most parents during long car journeys. The traditional escalation of hostility was ensuing as each child claimed they got hit harder and so retaliated in kind.

Wolpert explains: "You underestimate a force when you generate it, so as one child hits another, they predict the sensory movement consequences and subtract it off, thinking they've hit the other less hard than they have. Whereas the recipient doesn't make the prediction so feels the full blow. So if they retaliate with the same force, it will appear to the first child to have been escalated."

This led to a simple but effective experiment being conducted called 'tit for tat', in which two adults sit opposite each other with their fingers on either side of a force transducer. They were asked to replicate the force demonstrated by each other when pushing against the others finger. Instead of remaining constant, a 70 percent escalation of force is recorded on each go. It seems that we really don't know our own strength.

Deciding to act

The next challenge for Wolpert is investigating how we make the decision to act, and what happens in the brain if we change our minds after the initial decision. “We think that the fields of both decision making and action share a lot of common features, and our goal is to try and link them together to create a unifying model of how actions affect decisions and vice versa” says Wolpert.

“As we walk around the world, do our decisions depend on how much effort is required, and to what extend does perceived effort influence the decisions we make? Similarly, to what extent does perceived effort relate to the decision to change our minds? These are the questions we want to address.”

To this end, Wolpert is about to begin on a project for the Human Frontiers Science Program on linking decision to action. “We’ve developed robotic interfaces in the lab which allow us to control and create experiences that people won’t have had before.”

“We ask subjects to perform simple tasks using a joystick. Once they are in a rhythm, we generate forces that act proportionally to speed but perturb their arm in unusual ways, such as right angles, and see how they respond. This allows us to build a dataset on novel learning, how people adapt to various forces, and the decisions that they make in the process.”

Wolpert’s ultimate aim is to apply these models of the brain and how it controls movement to a greater understanding of brain disorders. “Five percent of the population suffers from diseases that affect movement. The hope is that we will not only understand what goes wrong in disease, but how to design better mechanisms for rehabilitation.”

Provided by University of Cambridge

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