Brains and machines

Thought experiments

Brain-computer interfaces sound like the stuff of science fiction. Andrew Palmer sorts the reality from the hype

In the gleaming facilities of the Wyss Centre for Bio and Neuroengineering in Geneva, a lab technician takes a well plate out of an incubator. Each well contains a tiny piece of brain tissue derived from human stem cells and sitting on top of an array of electrodes. A screen displays what the electrodes are picking up: the characteristic peak-and-trough wave forms of firing neurons.

To see these signals emanating from disembodied tissue is weird. The firing of a neuron is the basic building block of intelligence. Aggregated and combined, such “action potentials” retrieve every memory, guide every movement and marshal every thought. As you read this sentence, neurons are firing all over your brain: to make sense of the shapes of the letters on the page; to turn those shapes into phonemes and those phonemes into words; and to confer meaning on those words.

This symphony of signals is bewilderingly complex. There are as many as 85bn neurons in an adult human brain, and a typical neuron has 10,000 connections to other such cells. The job of mapping these connections is still in its early stages. But as the brain gives up its secrets, remarkable possibilities have opened up: of decoding neural activity and using that code to control external devices.

A channel of communication of this sort requires a brain-computer interface (BCI). Such things are already in use. Since 2004, 13 paralysed people have been implanted with a system called BrainGate, first developed at Brown University (a handful of others have been given a similar device). An array of small electrodes, called a Utah array, is implanted into the motor cortex, a strip of the brain that governs movement. These electrodes detect the neurons that fire when someone intends to move his hands and arms. These signals are sent through wires that poke out of the person’s skull to a decoder, where they are translated into a variety of outputs, from moving a cursor to controlling a limb.

The system has allowed a woman paralysed by a stroke to use a robotic arm to take her first sip of coffee without help from a caregiver. It has also been used by a paralysed person to type at a rate of eight words a minute. It has even reanimated useless human limbs. In a study led by Bob Kirsch of Case Western Reserve University, published in the Lancet this year, BrainGate was deployed artificially to stimulate muscles in the arms of William Kochevar, who was paralysed in a cycling accident. As a result, he was able to feed himself for the first time in eight years.

Brain scans, Eberhard Fetz
Looking for serendipity, Grey matter, red tape
cells in the visual cortex of macaque monkeys encoded 50 different aspects of a person's face, from skin colour to eye spacing. That enabled them to predict the appearance of faces that monkeys were shown from the brain signals they detected, with a spooky degree of accuracy. But conducting scientific research on human brains is harder, for regulatory reasons and because they are larger and more complex.

Even when BCIs breakthroughs are made on humans in the lab, they are difficult to translate into clinical practice. Wired magazine first reported breathlessly on an then new BrainGate system back in 2005. An early attempt to commercialise the technology, by a company called Cyberkinetics, foundered. It took NeuroPace 20 years to develop its technologies and negotiate regulatory approval, and it expects that only 500 people will have its electrodes implanted this year.

Current BCIs often require experts to operate them. “It is not much use if you have to have someone with a master’s in neural engineering standing next to the patient,” says Leigh Hochberg, a neurologist and professor at Brown University, who is one of the key figures behind BrainGate. Whenever wires pass through the skull and scalp, there is an infection risk. Implants also tend to move slightly within the brain, which can harm the cells it is recording from; and the brain’s immune response to foreign bodies can create scarring around electrodes, making them less effective.

Moreover, existing implants record only a tiny selection of the brain’s signals. The Utah arrays used by the BrainGate consortium, for example, might pick up the firing of just a couple of hundred neurons out of that 85bn total. In a paper published in 2011, Ian Stevenson and Konrad Kording of Northwestern University showed that the number of simultaneously recorded neurons had doubled every seven years since the 1950s (see chart). This falls far short of Moore’s law, which has seen computing power double every...
Indeed, the Wyss Centre in Geneva exists because it is so hard to get neurotechnology out of the lab and into clinical practice. John Donoghue, who heads the centre, is another of the pioneers of the BrainGate system. He says it is designed to help promising ideas cross several “valleys of death”. One is financial: the combination of lengthy payback periods and deep technology scares off most investors. Another is the need for multidisciplinary expertise to get better interfaces built and management skills to keep complex projects on track. Yet another is the state of neuroscience itself. “At its core, this is based on understanding how the brain works, and we just don’t,” says Dr Donoghue.

Me, myself and AI

This odd mixture of extraordinary achievement and halting progress now has a new ingredient: Silicon Valley. In October 2016 Bryan Johnson, an entrepreneur who had made a fortune by selling his payments company, Braintree, announced an investment of $100m in Kernel, a firm he has founded to “read and write neural code”. Mr Johnson reckons that the rise of artificial intelligence (AI) will demand a concomitant upgrade in human capabilities. “I find it hard to imagine a world by 2050 where we have not intervened to improve ourselves,” he says, picturing an ability to acquire new skills at will or to communicate telepathically with others. Last February Kernel snapped up Kendall Research Systems, a spinoff from the Massachusetts Institute of Technology (MIT) that works on neural interfaces.

Kernel is not alone in seeing BCIs as a way for humans to co-exist with AI rather than be subjugated to it. In 2016 Elon Musk, the boss of SpaceX and Tesla, founded a new company called Neuralink, which is also working to create new forms of implants. He has gathered together an impressive group of co-founders and set a goal of developing a BCI for clinical use in people with disabilities by 2021. Devices for people without such disabilities are about eight to ten years away, by Mr Musk’s reckoning.

Neuralink is not saying what exactly it is doing, but Mr Musk’s thinking is outlined in a lengthy post on Wait But Why, a website. In it, he describes the need for humans to communicate far more quickly with each other, and with computers, if they are not to be left in the dust by AI. The post raises some extraordinary possibilities: being able to access and absorb knowledge instantly from the cloud or to pump images from one person’s retina straight into the visual cortex of another; creating entirely new sensory abilities, from infrared eyesight to high-frequency hearing; and ultimately, melding together human and artificial intelligence.

In April it was Facebook’s turn to boggle minds as it revealed plans to create a “silent speech” interface that would allow people to type at 100 words a minute straight from their brain. A group of more than 60 researchers, some inside Facebook and some outside, are working on the project. A separate startup, Openwater, is also working on a non-invasive neural-imaging system; its founder, Mary Lou Jepsen, says that her technology will eventually allow minds to be read.

Many BCI experts react to the arrival of the Valley visionaries by rolling their eyes. Neuroscience is a work in progress, they say. An effective BCI requires the involvement of many disciplines: materials science, neuroscience, machine learning, engineering, design and others. There are no shortcuts to clinical trials and regulatory approval.

In all this, the sceptics are right. Many of the ambitions being aired look fantastical. Still, this is a critical moment for BCIs. Vast amounts of money are pouring into the field. Researchers are trying multiple approaches. Mr Musk in particular has a track record of combining grandiose aspirations (colonising Mars) and practical success (recovering and relaunching rockets via SpaceX).

To be clear, “The Matrix” is not imminent. But BCIs may be about to take a big leap forward. For that to happen, the most important thing is to find a better way of connecting with the brain.