

architecture in which connections between layers of simulated neurons are strengthened on the basis of experience. Deep-learning systems can then draw complex information from reams of unstructured data (see *Nature* 505, 146–148; 2014). Google, of Mountain View, California, uses such algorithms to automatically classify photographs and aims to use them for machine translation.

The second is reinforcement learning, a decision-making system inspired by the neurotransmitter dopamine reward system in the animal brain. Using only the screen's pixels and game score as input, the algorithm learned by trial and error which actions — such as go left, go right or fire — to take at any given time to bring the greatest rewards. After spending several hours on each game, it mastered a range of arcade classics, including car racing, boxing and *Space Invaders*.

Companies such as Google have an immediate business interest in improving AI, says Sutton. Applications could include how to best place advertisements online or how to prioritize

stories in news aggregators, he says. Sprague, meanwhile, suggests that the technique could enable robots to solve problems by interacting with their environments.

But a major driver is science itself, says Hasabis, because building smarter systems means gaining a greater understanding of intelligence. Many in computational neuroscience agree. Sprague, who has created his own version of DeepMind's algorithm, explains that whereas AI is largely irrelevant to neuroscience at the level of anatomical connections among neurons, it can bring insight at the higher level of computational principles.

Computer scientist Ilya Kuzovkin at the University of Tartu in Estonia, who is part of a team that has been reverse-engineering DeepMind's code since 2013, says: "The tricks we use for training a system are not biologically realistic. But comparing the two might lead to new ideas

about the brain." A particular boost is likely to come from the DeepMind team's choice to publish its code alongside its research, Kuzovkin says, because his lab and others can now build on top of the result. "It also shows that industry-financed research goes the right way: they share with academia," he adds.

DeepMind was bought by Google in 2014 for a reported £400 million (US\$617 million), and has been poaching leading computer scientists and neuroscientists from academia, growing from 80 to 140 researchers so far.

Its next steps are again likely to be influenced by neuroscience. One project could be building a memory into its algorithm, allowing the system to transfer its learning to new tasks. Unlike humans, when the current system masters one game, it is no better at tackling the next.

Another challenge is to mimic the brain's way of breaking problems down into smaller tasks. Currently, DeepMind's system struggles to link actions with distant consequences — a limitation that, for example, prevented it from mastering maze games such as *Ms. Pac-Man*. ■

"The tricks we use for training a system might lead to new ideas about the brain."

NEUROSCIENCE

Researchers seek definition of head-trauma disorder

Guidelines should assist in diagnosis of brain disease seen in retired American footballers.

BY HELEN SHEN

Dave Duerson suspected that something was wrong with his brain. By 2011, 18 years after the former American football player had retired from the Phoenix Cardinals, he experienced frequent headaches, memory problems and an increasingly short temper. Before he killed himself, he asked that his brain be donated for study.

Researchers who examined it found signs of chronic traumatic encephalopathy (CTE), a degenerative condition linked to repeated head injuries. At least 69 cases have been

reported in the literature since 2000, many in former boxers and American football players (P.H. Montenegro *et al. Alz. Res. Ther.* 6, 68; 2014) — heightening public concern about concussions during contact sports. Yet much about CTE is unknown, from its frequency to its precise risk factors and even whether its pathology is unique.

Researchers now hope to take a major step towards answering those questions. At Boston University in Massachusetts on 25–27 February, neuroscientists will convene to examine the characteristics of CTE in brain tissue from post-mortem examinations. They hope to agree

on a set of diagnostic criteria for the disease, and to assess whether it is distinct from other brain disorders, such as Alzheimer's disease.

The effort is sorely needed, says Walter Koroshetz, acting director of the US National Institute of Neurological Disorders and Stroke in Bethesda, Maryland, which is organizing the meeting. "The definition is the important piece that lets you do the rest of the research," he says. And the stakes are high. CTE is associated with memory loss, irritability, depression and explosive anger, which are thought to appear and worsen years after repeated head trauma. Research by Ann McKee, a neuropathologist


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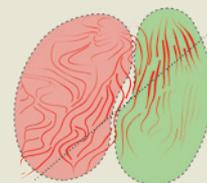


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Repeated head injuries in American football have been linked to a degenerative brain disorder later in life.

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at Boston University, suggests that CTE often occurs alongside Alzheimer's disease and other neurodegenerative disorders. "I think this disease is more common than traditionally recognized," she says.

Such research helped to spur a major lawsuit against the US National Football League (NFL) over its handling of head trauma, involving some 4,500 former players and a potential settlement of more than US\$765 million. The findings have led researchers worldwide to examine the risks of head trauma in other sports, including professional rugby and amateur soccer.

To make CTE studies more systematic, McKee has proposed pathological criteria and disease stages defined by the severity of a person's symptoms (A. C. McKee *et al.* *Brain* <http://doi.org/2dc>; 2012). CTE often involves deterioration of white matter in the brain, as well as abnormal aggregation of a DNA-binding protein called TDP-43 — which is also implicated in amyotrophic lateral sclerosis. But McKee says that CTE's most striking feature is the clumped distribution of an abnormal, hyperphosphorylated form of a protein called tau that normally helps to stabilize the internal structure of cells.

Tau deposits are found in the brains of elderly people and in those with Alzheimer's disease — leading some sceptics to question whether CTE is a distinct disorder. And critics such as Christopher Randolph, a neuropsychologist at Loyola University Medical Center in Maywood, Illinois, worry that CTE research has a basic sampling bias. The brain banks that support many CTE studies largely rely on tissue donated by players or their families, who often suspect that the individual had a severe neurological problem. This tips the balance towards those who may have various brain disorders.

Mistaking other conditions for CTE could have serious consequences, says Randolph, who worked with the Chicago Bears NFL team until 2002. "If you are in the grips of major depression, your actions may be different if you believe

you have a fatal neurodegenerative disease and you're just going to get worse, versus believing that you have a treatable illness," he says.

McKee acknowledges the sampling bias but says that acquiring donated tissue from healthy individuals will take time, because relatively few people request post-mortems in the absence of a visible problem. But she is convinced that many of the athletes' brains that she has received show an unmistakable signature that includes concentrations of hyperphosphorylated tau around blood vessels, especially in the furrows of the cerebral cortex. This is a departure, she says, from the more-uniform tau deposition seen in diseases such as Alzheimer's.

At the meeting, researchers will put these potential CTE signatures to the test. McKee and her team have prepared images of tissue slices from 25 brains from multiple brain banks. The sample, from players and non-players, includes suspected cases of CTE and known cases of Alzheimer's disease and other tau-based disorders. Neuropathologists will evaluate the images without information on the subjects' personal or medical histories, and will present their blinded diagnoses at the event.

If reliable neuropathological criteria can be found for CTE, researchers hope to use them to re-examine medical records from other deceased patients. Currently, many of the psychological symptoms associated with CTE are difficult to distinguish from other disorders, and brain-imaging tests for CTE are still in early development. Universal criteria for detecting CTE in donated brains could help scientists to search for other signatures so that physicians can diagnose the disease in living people. ■

CORRECTION

The News story 'Language origin debate rekindled' (*Nature* **518**, 284–285; 2015) misspelt the name of Paul Heggarty.