and Sandholm radically overhauled Libratus's search algorithm. Most game-playing AIs search forwards through decision trees for the best move to make in a given situation. Libratus searched to the end of a game before choosing an action.

But the complexity introduced by extra players makes this tactic impractical. Poker requires reasoning with hidden information — players must work out a strategy by considering what cards their opponents might have and what opponents might guess about their hand on the basis of previous betting. But more players makes choosing an action more difficult, because it involves assessing a larger number of possibilities.

The key breakthrough was developing a method that allowed Pluribus to make good choices after looking ahead only a few moves, rather than to the end of the game.

Pluribus teaches itself from scratch using a form of reinforcement learning similar to that used by DeepMind's Go AI, AlphaZero. It starts off playing poker randomly and improves as it works out which actions win more money. After each hand, it looks back at how it played and checks whether it would have made more money with different actions, such as raising rather than sticking to a bet. If the alternatives lead to better outcomes, it will be more likely to choose them in future.

By playing trillions of hands of poker against itself, Pluribus creates a basic strategy that it draws on in matches. At each decision point, it compares the state of the game with its blueprint and searches a few moves ahead to see how the action played out. It then decides whether it can improve on that action.

AI PLAYPEN

Pluribus's success is largely down to its efficiency. When playing, it runs on just two central processing units (CPUs). By contrast, when it first beat leading professionals, DeepMind's original Go bot used nearly 2,000 CPUs; Libratus used 100. When playing against itself, Pluribus plays a hand in around 20 seconds — roughly twice as fast as human professionals.

Games have proved a great way to measure progress in AI because scores can be compared with those of top humans — and bots can objectively be hailed as superhuman if they triumph. But Brown thinks that AIs are outgrowing their playpen. "This was the last remaining challenge in poker," he says.

Togelius thinks there is mileage yet for AI researchers and games. "There's a lot of unexplored territory," he says. Few AIs have mastered more than one game, which requires general ability rather than a niche skill. And there's more than simply playing games, says Togelius. "There's also designing them. A great AI challenge if there ever was one." ■

KOHEI TANAKA/UNIV. TSUKUBA

A bright red rock layer rests above a pocket of orange rock containing fossil egg fragments.

PALAEONTOLOGY

Dinosaurs nested in groups

A site in southeast Mongolia suggests that some dinosaurs guarded their eggs, much like certain modern birds.

BY JONATHAN LAMBERT

An exquisitely preserved dinosaur nesting site discovered in the Gobi Desert shows that some of these prehistoric animals nested in groups and, like birds, protected their eggs.

"Dinosaurs are often portrayed as solitary creatures that nested on their own, buried their eggs and then just went away," says François Therrien, a palaeontologist at the Royal Tyrrell Museum of Palaeontology near Calgary, Canada. He co-authored a study (K. Tanaka *et al. Geology* http://doi.org/c8cc; 2019) published this month in *Geology* describing the find. "But here we show that some dinosaurs were much more gregarious. They came together and established a colony that they likely protected," Therrien says.

The find includes the fossils of 15 nests and more than 50 eggs that are roughly 80 million years old. It provides the clearest evidence yet that group nesting evolved before modern birds split off from the dinosaurs 66 million years ago.

Certain modern birds and crocodiles build nests and lay eggs in a communal area during their breeding seasons. Many palaeontologists think that this 'colonial nesting' first arose in dinosaurs as a way to counter nest predators. But the evidence for this hasn't been solid, says Amy Balanoff, a palaeontologist at Johns Hopkins University in Baltimore, Maryland.

Since the 1980s, palaeontologists have unearthed fossilized eggs or nests that are clustered together. But the surrounding rock often represents several thousand years or more, making it difficult for researchers to tell whether the eggs were laid at the same time, or just in the same place years apart, says Darla Zelenitsky, a palaeontologist at Calgary University in Canada and a study co-author.

The recently described nest site is different. Located in southeast Mongolia, the 286-square-metre formation contains vivid layers of orange and grey rock. Between these bands runs a thin streak of bright red rock that connects 15 clutches of relatively undisturbed eggs. Some of the spherical eggs, about 10–15 centimetres in diameter, had hatched and were partially filled with the red rock.

Flooding from a nearby river blanketed the nesting site under a coating of sediment and probably created the red line, says Therrien.

"Because everything is relatively undisturbed, it likely wasn't a massive flood," he says.

But the streak connects all of the eggs, suggesting that the dinosaurs laid them in a single breeding season. "Geologically, I don't think we could've asked for a better site," says Zelenitsky.

"It's a compelling story," says Balanoff, adding that the researchers back it up with a strong analysis.

The team was also able to identify the type of dinosaur that was probably responsible. The eggs' exterior and interior textures, as well as shell thickness, point to a kind of non-avian theropod, a large group that includes dinosaurs such as velociraptors and *Tyrannosaurus*.

The researchers also estimated that just over half of the nests had at least one successful hatch owing to the number of fragmented eggs. This relatively high rate mirrors the hatching success of modern birds and crocodiles that guard their nests, as opposed to those that abandon or only occasionally check them.

Daniel Barta, a palaeontologist at California State University, Los Angeles, agrees that such a high rate suggests that some dinosaurs tended their nests. But he cautions that eggs that have hatched and those that predators have cracked open can often look similar. ■

ENVIRONMENT

China feels the heat over rogue CFC emissions

The government says it will build a monitoring network to understand what is going on.

BY DAVID CYRANOSKI

When atmospheric models traced a mysterious spike of an ozone-destroying gas to two provinces in China earlier this year, scientists waited to see how the Chinese government, and other nations, would respond to this possible violation of international law.

Now the government is under pressure to act — and has presented a plan to help it track and reduce emissions of the chemical, known as trichlorofluoromethane or CFC-11. Measures include establishing a national monitoring network to track ozone-depleting chemicals, along with heftier penalties for companies caught illegally producing the chemical.

Details of the plan emerged in notes released last month from a May meeting of the Multilateral Fund for the Implementation of the Montreal Protocol in Montreal, Canada.

The document "sets the stage for real progress on this important issue", says David Fahey, director of the Chemical Sciences Division at the US National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory in Boulder, Colorado.

The Chinese environment ministry disputes that there is enough evidence to pin the recently discovered spike in emissions on China, but agrees that more data are needed to understand the problem.

CFC-11 was once a popular refrigerant, and widely used to produce polyurethane foam insulation. But the legally-binding 1987 Montreal Protocol called for its production and trade to be phased out by 2010.

The treaty worked, and global CFC-11 production dropped until 2013, when a surprising slowdown in that decline suggested that there was a new source of emissions.

In a study published in *Nature* in May 2018, researchers traced the spike to east Asia (S. A. Montzka *et al. Nature* **557**, 413–417; 2018). In another published in May 2019, they traced it more precisely, to the provinces of Hebei and Shandong in northeastern China, using data from monitoring stations in Japan and South Korea (M. Rigby *et al. Nature* **569**, 546–550; 2019). Scientists suspect that factories in those provinces might have resumed production of a CFC-11-based foam insulator. Because China has ratified the Montreal Protocol, it is obliged to address any illegal CFC-11 production.

In May, China's environment ministry questioned the conclusions of the most recent study, noting "great uncertainty" in the reported amount and location of emissions. But the statement also said that the study "makes us realize the importance of atmosphere monitoring".

China has released few details about its plan for a national monitoring network. But the documents from the Montreal meeting say routine monitoring will begin within three years in several key cities. If the network uses stations close to Hebei and Shandong, it could pinpoint the source of the mysterious CFC-11 spike, says scientists. That in turn would aid efforts to eliminate the spike, says Stephen Montzka, an atmospheric chemist at the NOAA Earth System Research Laboratory who was part of the team that identified ▶

JG/ALAMY

A source of ozone-destroying gas has been tracked to China, and foam manufacturers are in the firing line.