descending inside the crater itself, which would have been “rather risky”, mission manager Makoto Yoshikawa of the Japan Aerospace Exploration Agency (JAXA) Institute of Space and Aeronautical Science in Sagamihara told *Nature*.

“If you’re going into a depression, then you have to worry about things like the solar panels sticking out” and potentially colliding with the surface, says Harold Connolly, a cosmochemist at Rowan University in Glassboro, New Jersey, and a co-investigator on the mission team. He is also working on NASA’s OSIRIS-REx mission, which is exploring a similar body — called Bennu — and plans to collect material from its surface next year. The two missions exchange information and collaborate, in part by sharing staff.

The 1-kilometre-wide Ryugu is what scientists call a rubble-pile asteroid: a collection of rocks and dust held together loosely by gravity. Its low density — only slightly higher than that of liquid water — suggests that it is mostly empty space, and that it has accumulated from debris produced by a collision of other bodies, Connolly says.

Suction does not work in the vacuum of space, and Ryugu has almost no gravity. So the team devised an original technique that allows the spacecraft to pick up material while bouncing on the surface, without actually landing. The method involved loosening material and catching it in a horn (see ‘Asteroid treasure’).

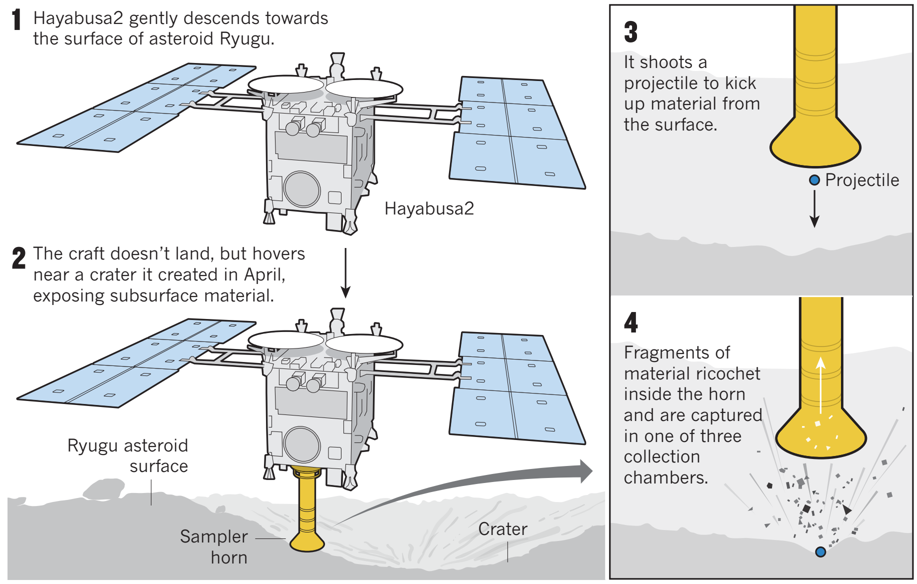
The goal is to bring back a total of around a gram of material. But the team will have to wait until the probe returns to Earth to open the chambers and see what’s inside. While Hayabusa2 is in space, mission control has no way of knowing how much material has been collected in each touchdown operation, Yoshikawa says.

Physicists hope that the materials will help to solve asteroid mysteries — for instance, it’s not clear why Ryugu is so dark. It is among the least reflective bodies in the Solar System, darker than any known meteorite, and the material exposed at the bottom of the freshly dug crater is darker still. Researchers with JAXA are keen to find out whether the April impact itself made the material darker, or whether the crater’s colour is typical of Ryugu’s composition and the surface has been lightened by solar radiation.

Ryugu’s surface is also strewn with an unusual number of boulders — more per unit surface area than any asteroid explored so far, according to a paper the mission scientists published in May (T. Michikami *et al. Icarus* **331**, 179–191; 2019). This makes the approach and touchdown particularly hazardous for Hayabusa2, especially given that the craft has to operate autonomously owing to its large distance from Earth. ■

ASTEROID TREASURE

With its final major manoeuvre, Japan’s spacecraft Hayabusa2 is aiming to become the first probe ever to collect material from beneath the surface of an asteroid.



ARTIFICIAL INTELLIGENCE

AI beats professionals at six-player poker

Triumph in complex variant of game brings bots closer to solving thorny real-world problems.

BY DOUGLAS HEAVEN

Machines have raised the stakes once again. A superhuman poker-playing bot called Pluribus has beaten top human professionals at six-player no-limit Texas hold ’em poker, the most popular variant of the game. It is the first time that an artificial-intelligence (AI) program has beaten elite human players at a game with more than two participants (N. Brown and T. Sandholm *Science* http://doi.org/c766; 2019).

“While going from two to six players might seem incremental, it’s actually a big deal,” says Julian Togelius at New York University in New York City, who studies games and AI. “The multiplayer aspect is something that is not present at all in other games that are currently studied.”

The team behind Pluribus had already built an AI, called Libratus, that had beaten professionals at two-player poker. It built Pluribus by updating Libratus and created a bot that needs much less computing power to play matches. In a 12-day session with more than 10,000 hands, it beat 15 leading human players. “A lot of AI researchers didn’t think it was possible to do this” with our techniques, says Noam Brown at Carnegie Mellon University in Pittsburgh, Pennsylvania, and Facebook AI Research in New York City, who developed Pluribus with his Carnegie colleague Tuomas Sandholm.

Other AIs that have mastered human games — such as Libratus and DeepMind’s Go-playing bots — have shown that they are unbeatable in two-player zero-sum matches. In these scenarios, there is always one winner and one loser, and game theory offers a well-defined best strategy — use it and you can’t lose.

But game theory is less helpful for scenarios involving multiple parties with competing interests and no clear win–lose conditions — which reflect most real-life challenges. By solving multiplayer poker, Pluribus lays the foundation for future AIs to tackle complex problems of this sort, says Brown. He thinks that the success is a step towards applications such as automated negotiations, better fraud detection and self-driving cars.

To tackle six-player poker, Brown ▶

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.