NATURE

STICKY BUSINESS

GECKOS CAN RUN ACROSS CEILINGS, CATCH SPIDERS UPSIDE DOWN AND GENERALLY DEFY GRAVITY. HOW ON EARTH DO THEY DO IT? AND COULD HUMANS EVER DO THE SAME? BY DANIEL WEISS

PHOTOS: KELLAR AUTUMN

In the late-1990s, Kellar Autumn went to the US state of Hawaii for a vacation – and found his hotel room overrun with spiders. "I'm kind of arachnophobic," explains Autumn, a professor of biology at Lewis & Clark College in the US state of Oregon. "I couldn't relax in this place because everywhere I went, there would be one of these spiders."

One afternoon, Autumn looked up to see a particularly large spider perched right above his head. Before he could figure out what to do, a gecko darted across the ceiling and began to tussle with the spider. "The gecko was smaller, but it easily won the battle. It just grabbed the spider and flipped it right off the ceiling," Autumn recalls. "I started thinking, 'What is it that lets the gecko stick to surfaces like that? What are the mechanics in its feet?'"

THE BEAST WITH HAIRY TOES

Autumn may not have found relaxation in Hawaii, but he did find his professional calling. When he returned from vacation, he checked the scientific literature and found that despite hundreds of years of interest, details of the gecko's amazing gravity-defying adhesion ability remained a mystery. Only now, after a decade's research by Autumn and his colleagues, has this mystery been solved.

Long before Autumn grew interested in geckos, conventional microscopes had shown that the lizards' toes are covered with tiny hairs called setae – about 6.5 million in all on a single large gecko. Were these setae equipped with miniature hooks or suction cups? Did they secrete some sort of natural glue? No one was sure.

In the 1950s, electron microscopes deepened the mystery by revealing that each of these tiny setae branched off into more than 100 even smaller hairs, called spatulae. "Each one of these hairs has the worst case of split ends you've ever seen, and they branch down to the nanometre scale," explains Autumn. "The question is, what is it at the tips of a billion or so little nano-hairs that allows a gecko to stick?"

To find out, Autumn took some gecko setae and tested their properties using a special positioning system equipped with sensors to measure the forces involved in the hairs' adhesion. For two months, Autumn and his students tried and failed to stick an individual gecko hair to a surface. "In retrospect, this lack of adhesion was telling us something important," says Autumn. "The gecko adhesive is non-sticky by default. When you touch a gecko's toe, it's not sticky."

Autumn's team persevered and eventually their research paid off. The reason the gecko's hair sticks turns out to have nothing to do with glues, hooks, suction cups or any other conventional method of adhesion. It is instead due to van der Waals force. This is a physical attraction between molecules that becomes significant when objects are less than a nanometre apart. In order to activate the van der Waals force, geckos perform a special manoeuvre. They do the shuffle.

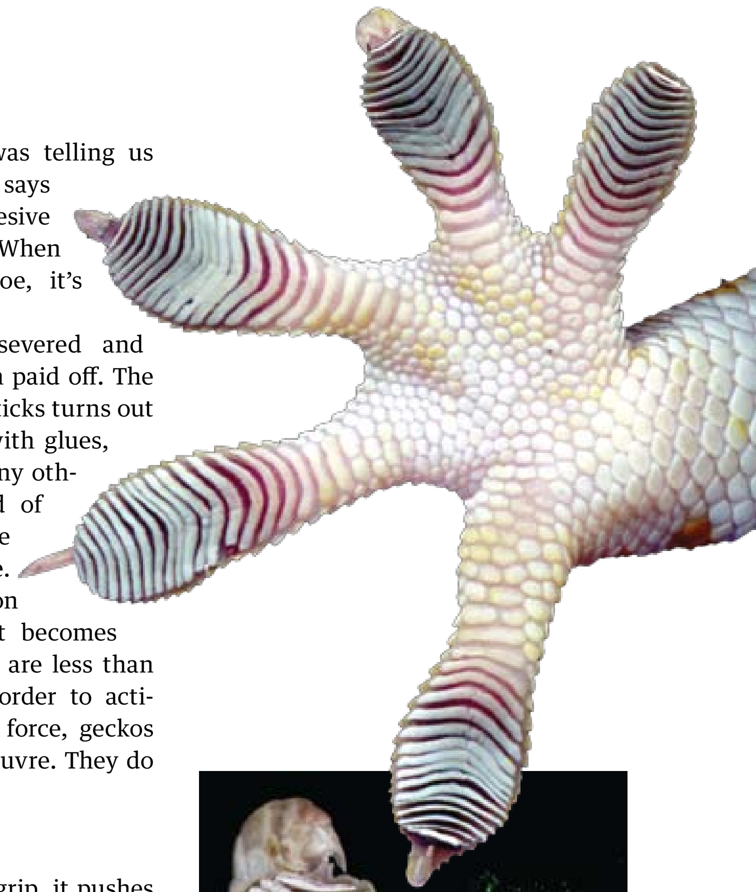
BACKWARD LOGIC

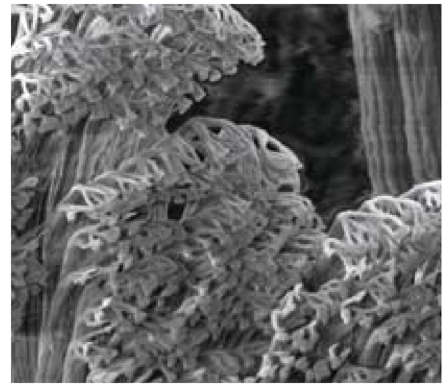
When a gecko wants to grip, it pushes gently against the surface to press the hairs up against it and then drags its toes ever so slightly backwards – about 10 micrometres (millionths of a metre) – so the normally curly hairs uncurl and lie flush with the surface. This drag and uncurl action "causes an increase in the number of those end tips that come into intimate contact with the surface," says Autumn.

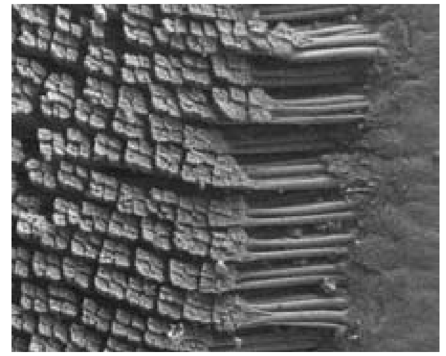
If you press your hand against a table, about one part in 10,000 of its surface area will be within 0.3 nanometres of the table surface and subject to van der Waals; after the push-and-drag motion, almost 50 percent of the surface area of a gecko's hair is this close, according to Autumn's calculations. By mimicking the gecko's push-and-drag motion, Autumn's positioning system finally got the test hair to stick.

The van der Waals attraction of a single hair is relatively small, but the billion or so spatulae on a gecko's toes combined can theoretically support up to 130 kilograms, or 2,500 times the animal's weight, says Autumn. But even better – the stickiness of geckos'

Not only were these feet made for climbing, they're equally adept at sticking too. Look at a gecko's sole under a microscope (opposite page, third and fourth from top) and you'll see the millions of microscopic foot-hairs that each split into hundreds of nano-tips. Move over Super Glue.







There are over 1,000 species of geckos and they live virtually everywhere. The Tokay (top) is the easiest to find and is thus the researchers' favourite, er, pet. Never seen a gecko's toeprint? Well, now you have (second from top).

PHOTOS: KELLAR AUTUMN

Cutkosky (right) admires StickyBot with main designer Sangae Kim. The robot gecko's best features are undoubtedly its feet, each featuring four segmented toes (opposite page, bottom). Could it climb Everest one day?

ARTIFICIAL GECKOS

The relatively soft silicone used to make StickyBot's synthetic hairs helps it scale walls, but the hairs tend to accumulate dirt and thus reduce their ability to adhere. The first self-cleaning GSA has been produced by Dr Ronald Fearing, a professor of electrical engineering at the University of California at Berkeley in the United States, who has collaborated with Autumn. Fearing's synthetic hairs are made from hard polymers such as polyethylene and polypropylene, which are used to make plastic bags and plastic milk jugs. These shed dirt just like real gecko hairs, but can only adhere to extremely smooth surfaces like glass. In the future, Fearing hopes to add hierarchical setae and spatulae structures so the hairs will adhere to rougher surfaces.

feet is controllable. When geckos want their feet to stick, they stick; when they want them to release, they release.

"Geckos need to attach and detach their feet millions of times and do it really fast," says Autumn. "They plant their palm first and roll their toes out." Then, when they want to move on, they detach, peeling the toes away like strips of tape. As a gecko peels its toes away, it actually gets a tiny boost of energy to help it release its feet from the surface. "The gecko's hairs act as springs," says Autumn. "When the gecko loads its foot and begins to climb, it stretches the little springs out in the hair and energy is stored until it removes its foot."

One more key attribute of gecko hairs: they don't get dirty. "If you pick up a gecko anywhere in the world, it will have clean feet," says Autumn. Part of the reason is that gecko hairs are made of a relatively hard substance called keratin, which is also the primary component of scales, shells and beaks. This hardness prevents the hairs from deforming against dirt particles and offering a broad surface for them to stick to. According to Autumn's calculations, the spherical dirt particles tend to stick to a flat surface rather than to the curved gecko spatulae, so the hairs stay clean.

VELCRO? GECK-O!

Now that they understand the incredible adhesive abilities of gecko hairs, scientists are hard at work trying to develop a synthetic version that can stick to surfaces without leaving behind the goopy chemicals that glues and tapes do.

One of the most promising applications for gecko-inspired synthetic adhesives (GSAs) is in climbing robots, such as the StickyBot series developed by Mark Cutkosky, a professor of mechanical engineering at Stanford University in the US state of California, who has collaborated with Autumn.

The latest version, StickyBot III, weighs about a kilogram, is about a metre long including its tail, climbs up walls at about 6 centimetres per second and can maintain its grip on an overhang up to 20 degrees from the vertical. Impressive, though its performance pales in comparison with live geckos, which can dart up walls at a metre per second and hang upside down from the ceiling by a single foot.

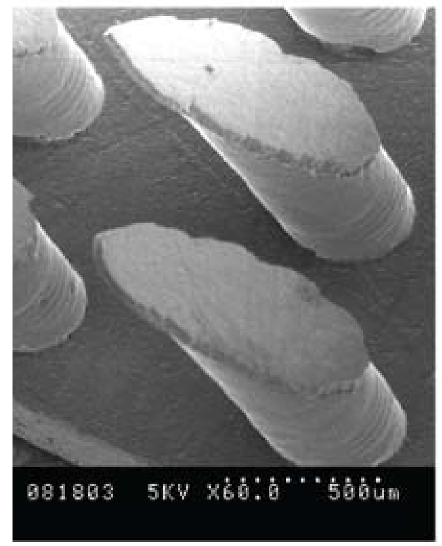
The synthetic hairs produced by Cutkosky's team are made from materials such as silicone: softer than the keratin that makes up real gecko hairs. "If you go into harder materials, you need to branch them into increasingly fine structures at the tip so they'll conform to every detail of the surface," says Cutkosky.

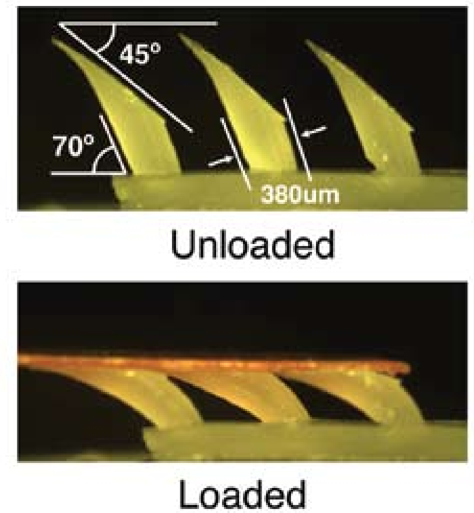
Instead of these fine branches, the ends of StickyBot's hairs are fitted with wedge shapes that taper from 20 micrometres down to a single micrometre. "These wedges bend over very easily when you load them with a little bit of sideward force," says Cutkosky. "As they bend over, the side of the wedge comes into contact with the surface that we're trying to stick to and we get adhesion."

For now, though, GSA-covered gloves and shoes that will allow people to make like geckos and climb walls and across ceilings remain in the future.

Nonetheless, Autumn had enough confidence in Cutkosky's GSA technology to let his nine-year-old daughter, Kaisa, hang from a window, attached only by a 39-square-centimetre swathe of artificial gecko feet. "She hung there for at least 15 minutes," says Autumn. "But I'm pretty confident she could have just hung there indefinitely." You want to walk up walls? Hang in there. ■

When loaded with a little sideward force, the wedges fitted to the ends of StickyBot's hairs can bend over very easily. Talk about bending over backwards in sticky situations.





PHOTOS: MARK CUTKOSKY