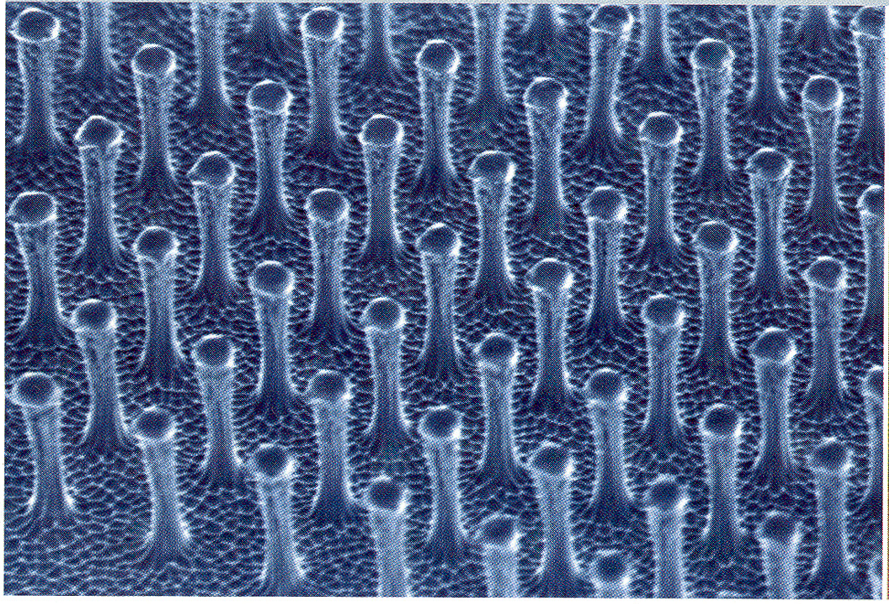
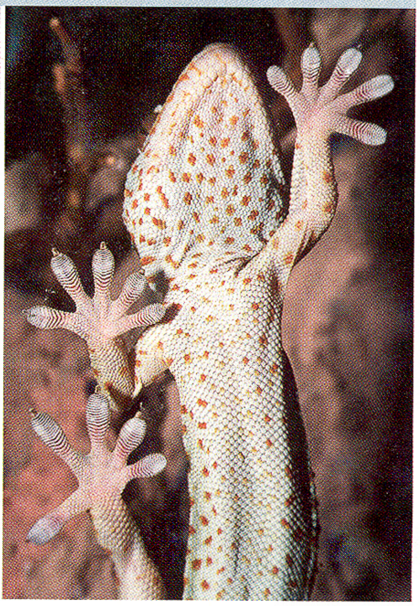




Technology that imitates nature

Biomimetics: Engineers are increasingly taking a leaf out of nature's book when looking for solutions to design problems

AFTER taking his dog for a walk one day in the early 1940s, George de Mestral, a Swiss inventor, became curious about the seeds of the burdock plant that had attached themselves to his clothes and to the dog's fur. Under a microscope, he looked closely at the hook-and-loop system that the seeds have evolved to hitchhike on passing animals and aid pollination, and he realised that the same approach could be used to join other things together. The result was Velcro: a product that was arguably more than three billion years in the making, since that is how long the natural mechanism that inspired it took to evolve.

Velcro is probably the most famous and certainly the most successful example of biological mimicry, or "biomimetics". In fields from robotics to materials science, technologists are increasingly borrowing ideas from nature, and with good reason: nature's designs have, by definition, stood the test of time, so it would be foolish to ignore them. Yet transplanting natural designs into man-made technologies is still a hit-or-miss affair.

Engineers depend on biologists to discover interesting mechanisms for them to exploit, says Julian Vincent, the director of the Centre for Biomimetic and Natural Technologies at the University of Bath in England. So he and his colleagues have been working on a scheme to enable engineers to bypass the biologists and tap into nature's ingenuity directly, via a database of "biological patents". The idea is that this database will let anyone search through a wide range of biological mechanisms and properties to find natural solutions to technological problems.

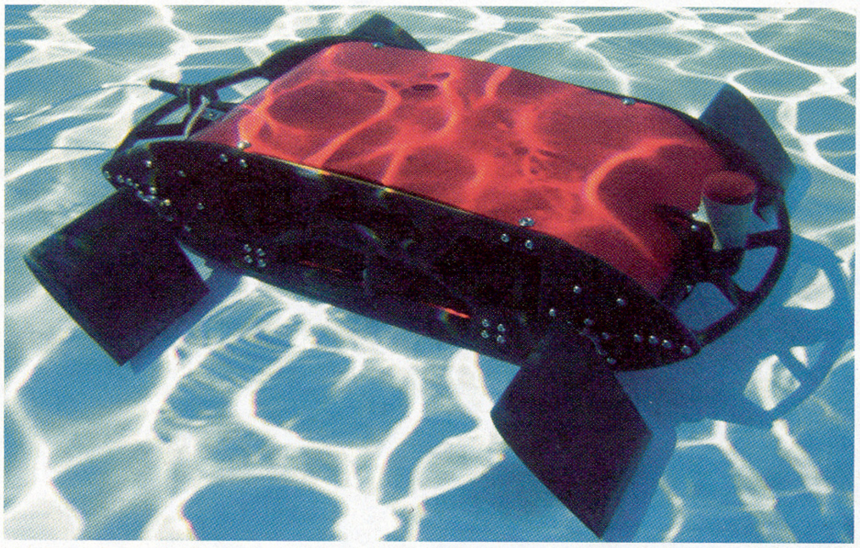
How not to reinvent the wheel

Surely human intellect, and the deliberate application of design knowledge, can devise better mechanisms than the mindless, random process of evolution? Far from it. Over billions of years of trial and error, nature has devised effective solutions to all sorts of complicated real-world problems. Take the slippery task of controlling a submersible vehicle, for example. Using propellers, it is incredibly difficult to make refined movements. But Nekton Research, a company based in Durham, North Carolina, has developed a robot fish called Madeleine that manoeuvres using fins instead.

In some cases, engineers can spend decades inventing and perfecting a new technology, only to discover that nature beat them to it. The Venus flower basket, for example, a kind of deep-sea sponge, has spiny skeletal outgrowths that are remarkably similar, both in appearance and optical properties, to commercial optical fibres, notes Joanna Aizenberg, a researcher at Lucent Technology's Bell Laboratories in New Jersey. And sometimes the systems found in nature can make even the most advanced technologies look primitive by comparison, she says.

The skeletons of brittlestars, which are sea creatures related to starfish and sea urchins, contain thousands of tiny lenses that collectively form a single, distributed eye. This enables brittlestars to escape predators and distinguish between night and day. Besides having unusual optical properties and being very small—each is just one-twentieth of a millimetre in diameter—the lenses have another trick of particular relevance to micro-optical systems. Although the lenses are fixed in shape, they are connected via a network of fluid-filled channels, containing a light-absorbing pigment. The creature can vary the contrast of the lenses by controlling this fluid. The same idea can be applied in man-made lenses, says Dr Aizenberg. "These are made from silicon and so cannot change their properties," she says. But by copying the brittlestar's fluidic system, she has been able to make biomimetic lens arrays with the same flexibility.

Another demonstration of the power of biomimetics comes from the gecko. This lizard's ability to walk up walls and along ceilings is of much interest, and not only to fans of Spider-Man. Two groups of researchers, one led by Andre Geim at Manchester University and the other by Ron Fearing at the University of California, Berkeley, have independently developed ways to copy the gecko's ability to cling to walls. The secret of the gecko's ▸▸



Madeleine, a swimming robot modelled on a fish

success lies in the tiny hair-like structures, called setae, that cover its feet. Instead of secreting a sticky substance, as you might expect, they owe their adhesive properties to incredibly weak intermolecular attractive forces. These van der Waals forces, as they are known, which exist between any two adjacent objects, arise between the setae and the wall to which the gecko is clinging. Normally such forces are negligible, but the setae, with their spatula-like tips, maximise the surface area in contact with the wall. The weak forces, multiplied across thousands of setae, are then sufficient to hold the lizard's weight.

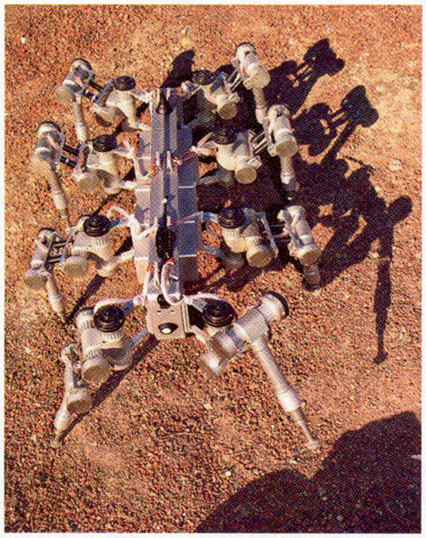
Both the British and American teams have shown that the intricate design of these microscopic setae can be reproduced using synthetic materials. Dr Geim calls the result "gecko tape". The technology is still some years away from commercialisation, says Thomas Kenny of Stanford University, who is a member of Dr Fearing's group. But when it does reach the market, rather than being used to make wall-crawling gloves, it will probably be used as an alternative to Velcro, or in sticking plasters. Indeed, says Dr Kenny, it could be particularly useful in medical applications where chemical adhesives cannot be used.

While it is far from obvious that geckos' feet could inspire a new kind of sticking plaster, there are some fields—such as robotics—in which borrowing designs from nature is self-evidently the sensible thing to do. The next generation of planetary exploration vehicles being designed by America's space agency, NASA, for example, will have legs rather than wheels. That is because legs can get you places that wheels cannot, says Dr Kenny. Wheels work well on flat surfaces, but are much less efficient on uneven terrain. Scientists at NASA's Ames Research Centre in Mountain View, California, are evaluating an eight-legged walking robot modelled on a scorpion, and America's Defence Advanced Research Projects Agency (DARPA) is funding research into four-legged robot dogs, with a view to applying the technology on the battlefield.

Having legs is only half the story—it's how you control them that counts, says Joseph Ayers, a biologist and neurophysiologist at Northeastern University, Massachusetts. He has spent recent years developing a biomimetic robotic lobster that does not just look like a lobster but actually emulates parts of a lobster's nervous system to control its walking behaviour. The control system of the scorpion robot, which is being developed by NASA in conjunction with the University of Bremen in Germany, is also biologically inspired. Meanwhile, a Finnish technology firm, Plustech, has developed a six-legged tractor for use in forestry. Clambering over fallen logs and up steep hills, it can cross terrain that would be impassable in a wheeled vehicle.

Other examples of biomimetics abound: Autotype, a materials firm, has developed a plastic film based on the complex microstructures found in moth eyes, which have evolved to collect as much light as possible without reflection. When applied to the screen of a mobile phone, the film reduces reflections and improves readability, and improves battery life since there is less need to illuminate the screen. Researchers at the University of Florida, meanwhile, have devised a coating inspired by the rough, bristly skin of sharks. It can be applied to the hulls of ships and submarines to pre- ▸▸

The hook-and-loop mechanism (left) of burdock seeds (centre) inspired Velcro (right)



The robot scorpion being evaluated by NASA (above) and a robolobster (right)

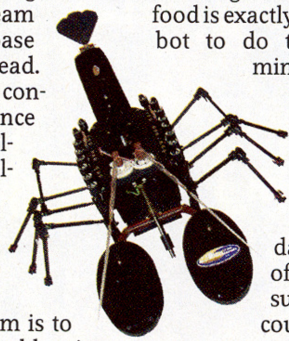
vent algae and barnacles from attaching themselves. At Penn State University, engineers have designed aircraft wings that can change shape in different phases of flight, just as birds' wings do. And Dr Vincent has devised a smart fabric, inspired by the way in which pine cones open and close depending on the humidity, that could be used to make clothing that adjusts to changing body temperatures and keeps the wearer cool.

From hit-and-miss to point-and-click

Yet despite all these successes, biomimetics still depends far too heavily on serendipity, says Dr Vincent. He estimates that there is only a 10% overlap between biological and technological mechanisms used to solve particular problems. In other words, there is still an enormous number of potentially useful mechanisms that have yet to be exploited. The problem is that the engineers looking for solutions depend on biologists having already found them—and the two groups move in different circles and speak very different languages. A natural mechanism or property must first be discovered by biologists, described in technological terms, and then picked up by an engineer who recognises its potential.

This process is entirely the wrong way round, says Dr Vincent. "To be effective, biomimetics should be providing examples of suitable technologies from biology which fulfil the requirements of a particular engineering problem," he explains. That is why he and his colleagues, with funding from Britain's Engineering and Physical Sciences Research Council, have spent the past three years building a database of biological tricks which engineers will be able to access to find natural solutions to their design problems. A search of the database (available on the web at www.bath.ac.uk/~ensab/TRIZ/) with the keyword "propulsion", for example, produces a range of propulsion mechanisms used by jellyfish, frogs and crustaceans.

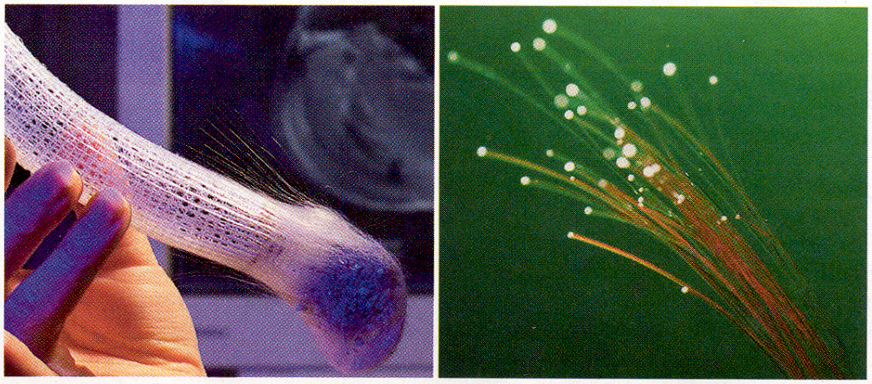
The database can also be queried using a technique developed in Russia, known as the theory of inventive problem solving, or TRIZ. In essence, this is a set of rules that breaks down a problem into smaller parts, and those parts into particular functions that must be performed by components of the solution. Usually these functions are compared against a database of engineering patents, but Dr Vincent's team have substituted their database of "biological patents" instead. These are not patents in the conventional sense, of course, since the information will be available for use by anyone. By calling biomimetic tricks "biological patents", the researchers are just emphasising that nature is, in effect, the patent holder.



One way to use the system is to characterise an engineering problem in the form of a list of desirable features that the solution ought to have, and another list of undesirable features that it ought to avoid. The database is then searched for any biological patents that meet those criteria. So, for example, searching for a means of defying gravity might produce a number of possible solutions taken from different flying creatures but described in engineering terms. "If you want flight, you don't copy a bird, but you do copy the use of wings and aerofoils," says Dr Vincent.

He hopes that the database will store more than just blueprints for biological mechanisms that can be replicated using technology. Biomimetics can help with software, as well as hardware, as the robolobster built by Dr Ayers demonstrates. Its physical design and control systems are both biologically inspired. Most current robots, in contrast, are deterministically programmed. When building a robot, the designers must anticipate every contingency of the robot's environment and tell it how to respond in each case. Animal models, however, provide a plethora of proven solutions to real-world problems that could be useful in all sorts of applications. "The set of behavioural acts that a lobster goes through when searching for food is exactly what one would want a robot to do to search for underwater mines," says Dr Ayers. It took nature millions of years of trial and error to evolve these behaviours, he says, so it would be silly not to take advantage of them.

Although Dr Vincent's database will not be capable of providing such specific results as control algorithms, it could help to identify natural systems and behaviours that might be useful to engineers. But it is still early days. So far the database contains only 2,500 patents. To make it really useful, Dr Vincent wants to collect ten times as many, a task for which he intends to ask the online community for help. Building a repository of nature's cleverest designs, he hopes, will eventually make it easier and quicker for engineers to steal and reuse them. ■



A Venus flower basket has spiny skeletal outgrowths very similar to optical fibres