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Mechanical engineering

Walk this way

EXCEPT perhaps after parties, most grown-up humans take the ability to walk on two legs for granted. Yet with bipedal walking, evolution has pulled off an impressive feat of engineering, one that human engineers have not been able to reproduce in a robot. This may be because engineers have been looking in the wrong place.

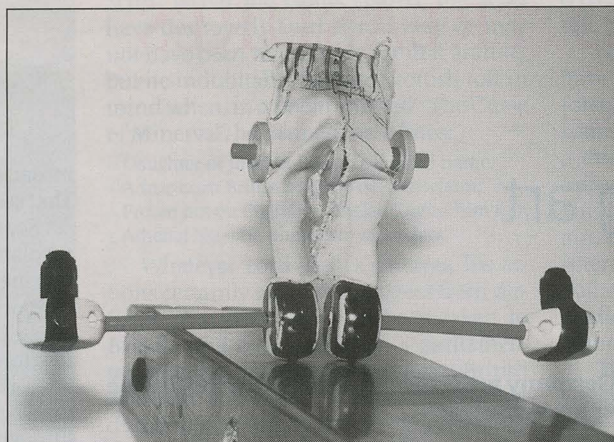
How humans walk has been pondered in great detail. A better understanding of the process could lead not just to more nimble robots but also to better prosthetic limbs and new treatments of muscular diseases that impair walking. But most research in the field has focused on the complicated interactions between the nervous system and the muscles. However, this may only be part of the story.

In the late 1980s, Tad McGeer, a mechanical engineer, built a pair of leg-like objects with no control mechanism, and showed that they were capable of marching down shallow slopes all by themselves, powered only by gravity. This suggested that the design of the body might matter as much as the signals the legs receive from the brain.

Since then, more people have become interested in the mechanics of walking. With his colleagues, Andy Ruina, an engineer at Cornell University in Ithaca, New York, has been building a range of legs that can walk by themselves. The simplest model has two straight rods, joined at a "hip", with two semi-circular "feet" attached to the ends of the rods. These can walk down slopes without signals from any brain and without falling over.

But making toys that can walk is only part of what the group does to understand walking. A lot of the walking is "virtual". Mariano Garcia and Michael Coleman, graduate students in the group, have written a number of computer simulations to see if a model of walking fits what legs do in practice. The equations that describe the motion of the walker take into account the mass of the feet and hips, the angle of the slope and the force of gravity. Cranking through the calculations, the computer looks for motions that will be stable.

The results show that even a simple pair of legs is capable of a diverse array of gaits. There is the standard one leg in front of the other motion, called "period one" motion because it repeats itself after each step. Change the angle of the incline, and you get "period two" motion, which looks like limping: the same motion is repeated only after two steps. Make the slope even steeper, and the period of the motion keeps doubling—after limping comes staggering, and finally chaotic walking, where the legs take short and long steps at random, never settling down into a pattern but not falling down either. On the steepest slopes the legs finally succumb, and simply fall over.



Mr FancyPants takes a stroll

The latest toy from Dr Ruina's laboratory, however, is a walker with more complex behaviour. Named Mr Fancy-Pants (owing to the pair of trousers it sports), it has no knees, but is stabilised with weights around its ankles. Mr Fancy-Pants has the distinction of being the first walker that can walk, but cannot stand still.

This is important, because Mr Fancy-Pants does not have a big, wide base, which is what makes most things stable. Rather, some aspect of the motion keeps it from falling over. In many ways, Mr FancyPants moves like a person who has stumbled, but instinctively knows where to put his leg to avoid taking a spill. Remarkably, Mr FancyPants seems to put its legs in exactly the right place to stop falling, just because of the way it is constructed, not because of any complicated signals from a control mechanism like a brain.

The computer model that attempts to describe Mr FancyPants's motion shows that it walks in an unstable way. Unstable walking is only possible under the most ideal conditions—even the slightest change will cause the walker to topple over. But Mr FancyPants walks in the real world, where conditions are never ideal. How it does so while remaining stable is something of a mystery.

For a system to be stable, small disturbances must not affect it. For instance, friction acts to stabilise the motion of a pendulum through the air. But stability can also arise from what are known as "non-holonomic constraints". An ice-skater is non-holonomically constrained, for example, because he can move back and forth, but not from side to side. So the skater is constrained in a way that a person on ice without skates, who can slip and slide where he pleases, is not. What Dr Ruina and Mr Coleman are proposing in a forthcoming paper in *Physical Review Letters* is that Mr FancyPants may be constrained in a similarly non-holonomic way: Mr FancyPants cannot move by slipping and sliding, only by lifting its leg and making contact with the ground as it steps.

A complete model of how two-legged creatures walk will eventually have to include the muscular system, nerves, brain and skeleton. But Dr Ruina and his colleagues have shown that two legs can walk a long way alone, without the guidance of an active brain. Be glad of that after the party. ■