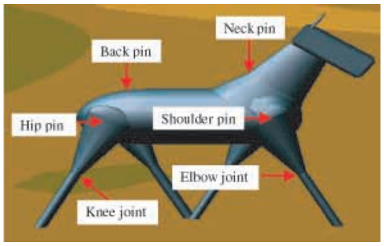
Setting the Pace



Watch a dog trotting or a horse galloping, and it is hard to see how such different gaits could all be explained by a single set of equations. But Hugh Herr's team working at MIT have modelled running animals ranging in size from a chipmunk to a large horse, with a single set of equations, and the results are very convincing (p. 959)!

Herr's 'Leg Lab' is interested in anything to do with movement. Over the years they've built robots that balance, run and even hop. Ultimately, they want to understand how humans and animals walk and run. One way to learn how animals move is by mathematically simulating the physics that keeps them up and about. Greg Huang, a postdoc in the Leg Lab, was intrigued by the effect an animal's size has on the way it moves. So he set out to develop a set of equations that could simulate large and small animals' movements. But first he figured out how to model the movements of a medium sized animal, like a pony.

Instead of simulating every sinew and joint, Huang models a leg as two rigid sections joined by a spring-knee. The knee isn't like the hinged joint we all know, it behaves like a telescope, so the walking leg shortens as it swings forward. Each leg is joined to the cyber-pony's body by a hinge, so the springy leg swings back and forth. Next, Huang gave the simulated animal joints in its neck and back, to model its bobbing movements, and finally he programmed in the forces on the animals hips and shoulder joints that drive the animal forwards. He set the simulations running to see how well his pony trotted through the computer chip.

The results were spectacular. Even though it isn't intuitively obvious that an animal's leg behaves like a spring, the simulation reproduced the physics of the animal's performance extremely well! His cyber-pony used the same energy per stride as its flesh and blood cousin, threw its legs out at the same frequency and pushed off from the earth with the same force as an animal cantering across a field. What's more, the movies his simulations produced were startlingly realistic.

Having got the simulation to work for one animal, Huang wanted to know how unified his theory was. He had to test it on larger and smaller beasts.

Huang modified his simulation to behave like a tiny chipmunk, a goat, two breeds of dog and a large horse. Again the simulations reproduced the physics of the movements well. Just by changing the animal's weight and body plan, a single set of motor controls accurately reproduced all six animal's gaits. The simulations worked so well, that Huang believes 'we've gotten a lot of the biology right!'

One thing the simulation can't do yet is switch from trotting to galloping as the animal gains speed. Huang explains that his simulation of a horse trotting at galloping speeds looks pretty funny. He hopes that in the future he will learn why high speed trotting is unphysical and what throws the gait-switch as an animal steps up the pace.

More Than Spring in the Air

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Life for the leafminer moth is short and sweet. They emerge in early spring, and flutter their life away in a few weeks. Which means that the pressure is on to find a mate! Female moths don't leave that 'all-important encounter' to chance; they release a potent mixture of pheromones to attract suitable suitors. But how do the males home in on their own females, rather than getting distracted by other species that smell similar? Mattias Larsson and his colleagues in Sweden set about getting to the root of the male moth's delicate sense of smell. After close inspection, they discovered that male *Eriocrania semipurpurella* leafminer moths may have as many as five pheromone receptors, but only two are needed to direct them to their mates (p. 989). So what do they use the extra receptors for? Warning them off when they're on the wrong track.

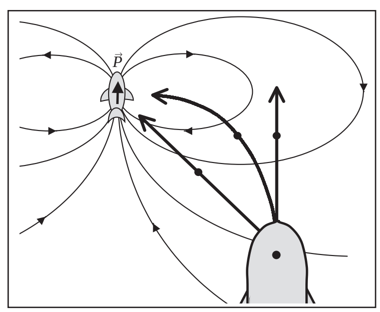
Leafminer moths emerge around the same time that the birch tree buds burst in early spring. This was the signal for Larsson to head out into the field, prepared to trap enough male leafminer moths to test their sensitivity to a variety of pheromones. Back in the lab he looked for pheromone receptors on the moth's antennae and tested their responses to pheromone compounds from leafminers and other closely related species.

In the case of most female moths, their pheromone scent is a blend of volatile organic chemicals. The leafminer moth's organic perfume is a mixture of two enantiomers of a single compound: (R,Z) and (S,Z)-6-nonen-2-ol. Larsson found that *E. semipurpurella* males have one receptor per pheromone enantiomer, which accurately discriminate between the almost identical compounds, and three other receptors that recognise a variety of other scent molecules.

But why does this moth recognise other smelly molecules? Because other moths in the neighbourhood might be using the same basic pheromone mix, which they spice with traces of other compounds. The male leafminer moth doesn't want to waste time being lead astray by ladies of another species, even if they do smell tantalisingly like one of his own. He can tell when he's on the wrong track, because the other receptors act as antagonists! As soon as the male picks up a hint of another pheromone compound, he loses all interest in that female, and begins a new search for the elusive scent that will lead him to his own lady leafminer.

Other insects, like the leafminer's close relative the caddisfly, also rely on pheromones for communication. But for some caddisflies, pheromones send messages of danger rather than romance. The family resemblance between both insects' antennae and pheromone blends makes it likely that the insects inherited the same sense of smell from a common ancestor, but today's leafminers have modified their defence to friendlier uses. For them pheromones register allure rather then alarm.

That Shocking Feeling



Although it's not so hard for us to understand how a bat navigates by echolocation, imagining how a shark 'feels' an electric field is probably beyond most of us: but not Brandon Brown! He has a model that explains how hundreds of electric sense organs buried in the fish's head generate nerve signals that the shark interprets as it homes in on its helpless prey (p. 999).

But how did Brown get interested in sharks when he usually works on the physics of superconductivity? He explains that a colleague put him onto shark's electrosensory perception by telling him about the strange gel that can be extracted from a shark's head. This gel, which packs the shark's electric sense organs, intrigued Brown. From then on, he wanted to know how sharks feel their electric world, so being a physicist, he decided to build a mathematical model to see how these strange sensory organs pick up electric fields around them.

Each electroreceptor is shaped like a deep pore, sometimes 20 cm long, with an electrosensitive bulb at the end, called an ampulla. Some species have several hundred of these pores aligned at various angles through the sharks skin and head. Brown's first challenge was to find out how a single receptor sensed another fish's electric field.

From his calculations, he realised that a single receptor behaves a bit like an antennae, but much slower, so that the sharks sense voltage fluctuations. Brown explains that they don't measure absolute voltages like volt meters because they 'aren't grounded'.

Once he knew how an electric field 'felt' to a single receptor, Brown modelled how the array of receptors in the marine shark's head reacted to an electric field as the shark swam through it, to see if he could explain any aspects of shark hunting behaviour. First he simulated a simple route, where a shark swam through the fish's field at 45° to its target. Then he looked at more complicated approach paths. He modelled the shark's electro-view first as it passed the fish and then as it swam along an arc, spiralling in towards the fish-dipole at the heart of the electric field. Most young sharks swim straight towards their fishy victim, but a few follow a spiral path, similar to the arc he modelled for the last approach. Brown thinks that his results might explain their strange behaviour.

His simulation suggests that the young sharks spiral to maintain the same orientation in the field as they approach their prey. Brown explains that this might be a good way to make sure that an inexperienced hunter always catches the fish. He thinks that the spiral approach could be a learning strategy for inexperienced sharks, which ensures that they don't go hungry when they're on the learning curve.

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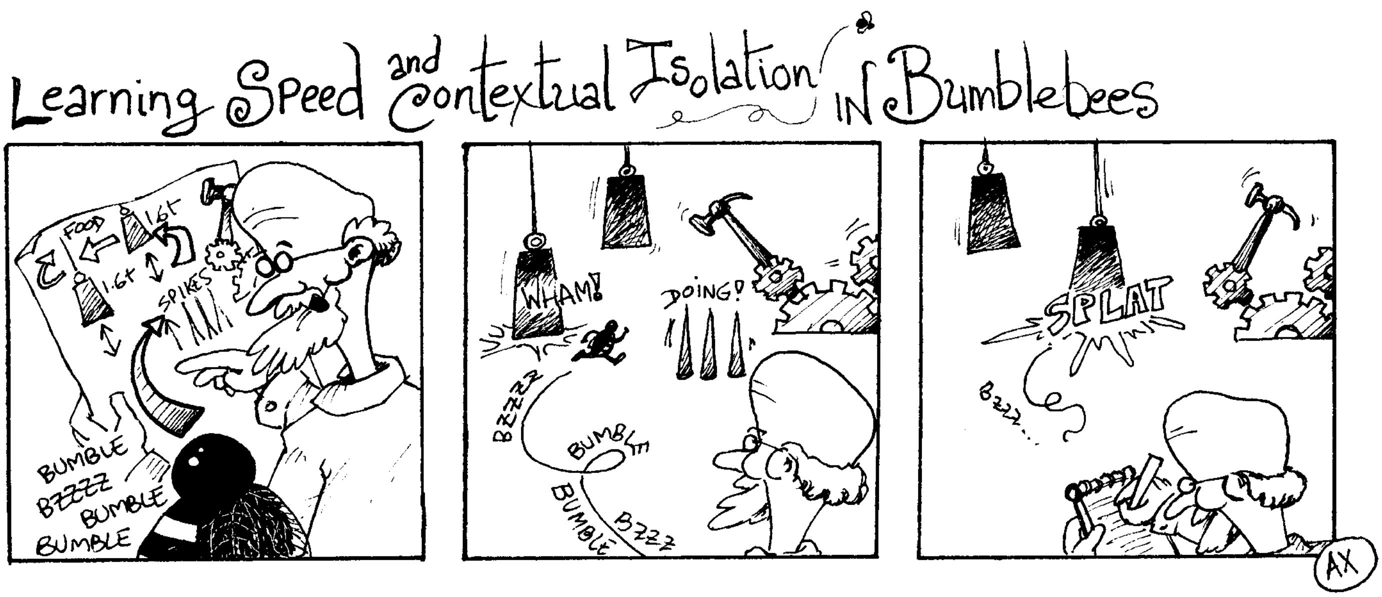
The Journal of Experimental Biology 205 (2002)



Learning in Context

Fauria, K., Dale, K., Colborn, M., and Collett, T. S. (2002). Learning speed and contextual isolation in bumblebees. *J. Exp. Biol.* **205,** 1009–1018.