Aping our ancestors

Roland Ennos argues that the abilities of the great apes to cope in the dangerous mechanical environment of the forest canopy are part of the human species' intellectual inheritance and are intimately connected with our abilities as physicists

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Our capacity to understand and manipulate the world around us, and to fathom our place within it – the marks of a true physicist – have always been thought to be characteristics of human beings alone. However, recent discoveries have shown that we might not be entirely unique. In particular, our nearest relatives, the great apes – by which I mean chimpanzees, bonobos, orang-utans and gorillas – share many of our abilities; they are good toolmakers and architects, and they even have some self-awareness. It is starting to become clear that these abilities, and hence our intellectual inheritance, are linked to the habitat of these creatures – to their need to cope in the dangerous mechanical environment of the forest canopy. Our abilities as physicists are therefore intimately connected to the relationship of the great apes with the commonest material in the forest – wood.

Since the British primatologist Jane Goodall made her first discoveries when observing the chimpanzees of Gombe National Park in Tanzania in the early 1960s, primatologists have found that the great apes, especially chimpanzees, make a wide variety of tools. Some resemble the stone tools of early humans; chimpanzees break open nuts using a hammer-and-anvil arrangement, for example. However, most of the tools that apes use are built from the plants they have around them. They use leaves as sponges to pick up water that they cannot reach with their lips and fine blades of grass to "fish" for termites within their mounds.

Wooden tools are even more common. The savannah chimpanzees of Ugalla, Tanzania, use digging sticks to uproot tubers, just like many hunter-gatherer humans. The savannah chimpanzees of Fongoli, Senegal, even hunt with tools, making spears that they use to harpoon sleeping bushbabies; they break straight branches off trees, strip them of leaves and gnaw the thin ends into points. Forest chimpanzees across central Africa accomplish a yet more impressive feat, producing a whole tool kit to harvest honey from the nests of wild bees. They use a stick chisel to break into the bees' nest, followed by a smaller chisel to widen the gap. Next, they use a pointed stick to puncture the nest, and a final stick to dip into the nest and extract the honey. The use of tools is rarer in other ape species, but all apes do make and use them.

The great apes are good toolmakers and architects, and even have some self-awareness

Experiments on captive apes

It seems, therefore, that the apes – especially chimpanzees – are excellent structural engineers. Maxine Sheets-Johnstone – a philosopher who studies movement and evolutionary biology – has even referred to the knowledge they acquire as a "living kinetic physics", in which the apes exploit their knowledge of weight, ballistics, spatial orientation, effort and force. But the question of whether apes have some conception of the physics of their world, or whether they achieve their feats simply by trial and error, has been, and continues to be, under debate. (For more on whether primates "know" the physics they use, see Robert Crease's article "Primate physics", November 2012, p18.)

To shed light on this question, primatologists have performed a range of ingenious experiments on captive apes. For instance, Héctor Manrique and his colleagues from the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany, have recently investigated the ability of the great apes to understand the concept of rigidity (2010 *J. Exp. Psychol. Anim. Behav. Process.* **36** 409).

In the first task, the researchers presented each ape with a variety of simple stick-like objects with widely contrasting rigidity and a piece of banana hanging on a length of string that was out of reach of the ape due to a dividing mesh screen. The ape's task was to choose a stick and use it to pull the banana reward towards itself. However, only one of the sticks presented to the ape was rigid enough to perform this task. If the apes were able to manipulate the sticks themselves before the experiment – even if only briefly – all four species almost always chose the correct rigid stick. The same was true even if they had only been able to watch an experimentalist manipulate the sticks. In fact, even if they had had no previous experience they still chose rigid sticks more frequently than by chance.

To check that the apes did not just have some innate preference for rigid sticks, the researchers ran another experiment. In this case, the ape had to choose a flexible rope that could be pushed through an angled tube to fish for a reward of yoghurt or apple juice. Once again, the apes almost invariably chose the correct tool, in this case the floppiest one. It therefore seems that the great apes have the ability to think in terms of abstract physical concepts such

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Both images: Adam van Casteren

Ways with wood An example of greenstick fracture (left) and a nest that was built by an orang-utan (right), as observed in Sumatra.

as rigidity. Moreover, recent fieldwork that I have been involved in suggests that the great apes have an understanding of some of the rather more complex aspects of the mechanics of wood.

Nest-building in apes

All of the great apes are capable of building sleeping nests. Every evening they fashion branches and twigs into a cup-like structure, typically taking just a few minutes to produce a nest that is strong, comfortable and deeply enough indented to give them a good, safe night's sleep.

On the face of it, nest-building is not an easy task. For a start, living branch wood has extremely unusual fracture properties. As any cub scout knows, fresh branches do not snap straight across when bent, but instead undergo a form of failure known as greenstick fracture. The branches begin breaking normally halfway across, but because wood is extremely weak along the length of the branch, the fracture is then diverted and the branch splits along its centre. The branch then continues to bend without breaking further. This behaviour makes it extremely difficult to break off branches for firewood, which is why you have to instead saw them off or scavenge for dead wood.

I am a biomechanic – a biologist who is interested in the many ways in which organisms interact with the physical world – and I am also a keen naturalist. Therefore, after our research group at my previous institution, the University of Manchester, UK, had investigated the mechanics of wood fracture and how it was related to the wood anatomy, I started to wonder how apes cope with this unusual mechanical behaviour. Fortunately, my then PhD student Adam van Casteren was about to travel to Sumatra for a project set up to investigate how orang-utans walk, like us, bipedally on branches, so we also equipped him to study nest construction in these animals.

Orang-utans were using the greenstick fracture properties of branches to their advantage

As orang-utans build new nests every evening in a different place, to investigate their bedtime rituals Van Casteren had to find an animal each day and follow it until he saw where it settled and built its nest. He would then return the next morning after it had left and climb up to the nest to dismantle it, investigate the structure and carry out mechanical tests on the wood. What he found after several weeks of following orang-utans and investigating their nests was that they were actually using the greenstick fracture properties of branches to their own advantage (2012 *PNAS* 10.1073/pnas.1200902109).

The orang-utans built their nests in two phases. First, they sat on a bough and drew 10–20 mm thick branches towards themselves, half-breaking them with greenstick fracture, before weaving them together into a well-anchored basket. Sitting in the half-finished nest, they then used two hands to half-break thinner (5–15 mm diameter) branches using greenstick fracture before detaching them completely using a twisting action to make a full break. Together with their brush of leaves, these branches were then stuffed into the nest to produce a soft mattress. It seemed that the orang-utans had a sophisticated knowledge of the mechanics of wood and were using it to perform impressive feats of structural engineering, taking only around three minutes to make their nests. But it had not come instinctively to them. Young orang-utans, like the other great apes, take several years to learn how to build a decent nest, observing their mother and making practice nests until they perfect their craft.

The evolution of self-awareness

Impressive though apes' abilities to make and use tools and build nests are, their skills are not unique; many other animals show abilities that are comparable. The New Caledonian crow, for instance, is adept at making a range of fishing tools from leaves, while many birds build nests that are far more sophisticated than those of the great apes. However, the need that

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Time to tool up
A chimpanzee fishes for termites using a stripped-back twig (left), while another drinks liquid from leaves that have been used as a sponge (right).

apes have to accurately predict the mechanical properties of branches may well also have contributed to the other mental ability of great apes that they share with us almost exclusively: self-awareness.

Chimpanzees and orang-utans are among the few animals (along with dolphins) that can recognize themselves in mirrors and seem to have some concept of themselves as unique individuals separate from the environment or from others. Humans start to develop this ability between approximately 18 and 24 months of age. But what use is self-awareness to great apes and how did they evolve this ability?

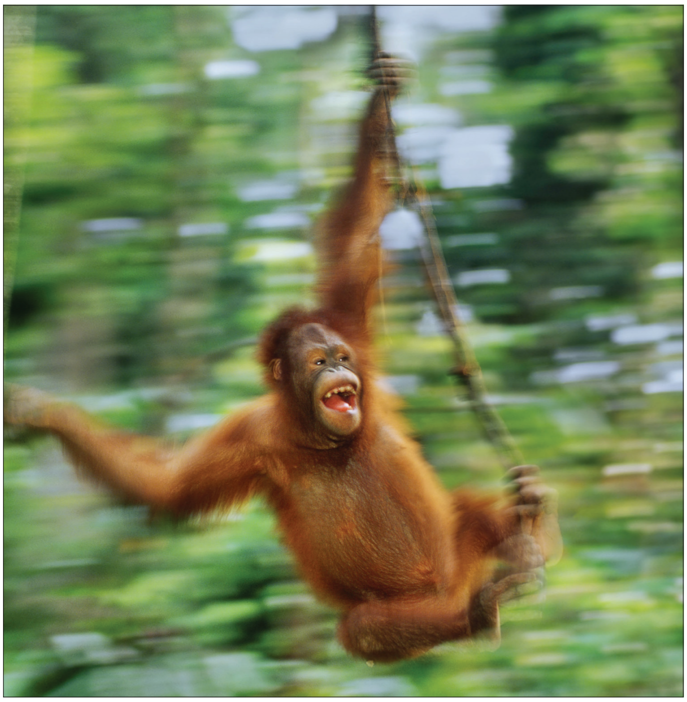
Many primatologists accept the view that self-awareness developed to help great apes live in groups. It would have helped individuals to communicate and co-operate with other members of the group to improve their chances of survival; and particularly wily individuals would be able to manipulate the others and gain an extra advantage. Nowadays, apes certainly have excellent communication skills and are capable of Machiavellian feats of deception, but there are reasons to doubt that the need to communicate within groups was the only or even principal reason for self-awareness. After all, many other animals live in large groups and yet have not evolved it, while orang-utans are notoriously solitary. An alternative theory suggests that the acquisition of self-awareness is down to their mechanical environment.

The unique thing about great apes, in fact, is not that they live in large social groups, but that they are large arboreal mammals. What is extraordinary is that animals weighing upwards of 50 kg can live all their lives in the forest canopy, travelling from tree to tree along the thinnest of twigs and even sleeping aloft, without accidents. As anyone who has climbed trees knows, they are extremely dangerous, and the bigger you are the greater the danger. A small monkey would survive a fall from the treetops, but an orang-utan or a human would be killed. Moreover, the larger you are, the more likely the branches are to break beneath your weight, and the further the branches and twigs will bend. You yourself become a factor that alters your environment.

This realization led two primatologists, Daniel Povinelli at the University of Louisiana and John Cant at the University of Puerto Rico, to suggest that it was the need to move safely in the canopy that drove the evolution of self-awareness. Apes needed to be more intelligent and have a better memory to plan faster, safer routes between trees, but they also needed the concept of self to enable them to predict how well the branches would support them under their weight. Povinelli and Cant predicted that these newly evolved abilities would have enabled the apes to develop a wide range of techniques to safely negotiate their way through the forest. Povinelli has even written a book on this topic called *Folk Physics for Apes: the Chimpanzee's Theory of How the World Works*.

There is good evidence from field studies that self-awareness is indeed extremely important in the locomotion of the great apes, especially the orang-utans, the most arboreal of all the living ape species. Susannah Thorpe, a primatologist from the University of Birmingham, UK, has shown that Sumatran orang-utans use quite different forms of locomotion depending on where they are in the canopy and how thick the branches are. Near the thick bases of branches they use gaits that only rely on that one thick support. They walk quadrupedally – on all fours – on top of the branch, hang from the branch by their arms and swing from it, or even walk bipedally along it. But as they approach the narrow tips of the branches their gait changes; they spread their weight over more than one branch, clambering with a horizontal body or walking upright while holding on to other branches.

Thorpe also documented another aspect of locomotion that demonstrates the physical self-awareness of orang-utans even better. When orang-utans come to gaps in the canopy that are too wide to cross, they resort to another tactic: they climb the tree trunk until it is on the verge of bending under their weight and then "pump" the tree, causing it to sway back and forth until the deflection is large enough for the ape to grab the adjacent canopy. Thorpe even saw a mother and baby acting together as a team to deflect a tree more efficiently. Faced with a difficult gap to cross, the baby climbed higher up the trunk, mak-



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King of the swingers An orang-utan (Malay for "forest person") navigates the forest canopy.

ing the tree more unstable. The mother then swayed the tree to unite the two canopies, the baby climbed down to reunite with its mother and they moved on.

Are apes true physicists?

It is clear that the great apes do have the mental ability to manipulate and understand objects, particularly wooden ones, and they do have enough mechanical insight and manual dexterity to carry out impressive feats of engineering. However, the tool-making ability of apes is limited; they only seem able to manipulate objects that are found together in time and space, such as nearby sticks or stones, and are unable to plan ahead. Experiments on orang-utans and bonobos, for instance, by Emma Tecwyn, then also at the University of Birmingham, showed that they could successfully complete tasks with many stages, but only if at each stage the reward made progress through the apparatus. If they had to arrange the later stages of the apparatus correctly before they manipulated the first stage (like a chef making the batter before cooking the pancake), they were unable to complete the task.

It is also clear that although apes can make tools for an immediate purpose, there is no indication that they are capable of making tools in order to make other tools, as early humans made stone knives to shape spears. Nor are they able to make compound tools from two separate objects, as early humans furnished their spears with stone points. Our ancestors must have made these advances long after we broke off from the African apes around six to seven million years ago. Although great apes are perfectly competent engineers, we must therefore look to the archaeological record and to the field of anthropology before we can understand the evolution of our capacity as humans to become true physicists. ■