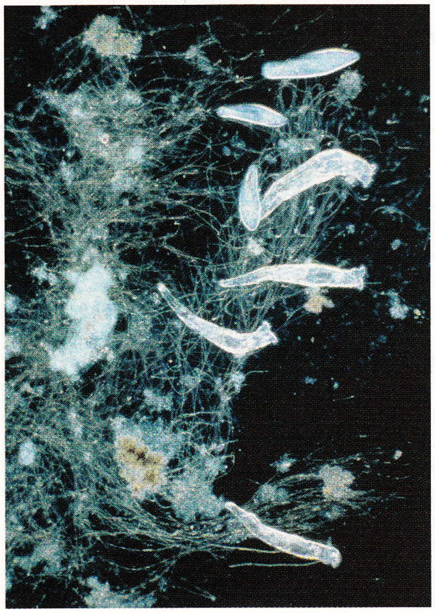

Evolution

Darwin's rotifers

An obscure group of invertebrates casts light on how new species form

WHEN Charles Darwin opened his first notebook on the subject of how organisms change over time, the field was not even referred to as "evolution". It was, rather, "the species problem"—in other words, how did life's variety arise? Darwin showed in detail how life changes over the course of time by the process of natural selection, but failed to explain how those changes can take different courses, dividing a species in two and thus multiplying the number of species.

The two main schools of thought about speciation that emerged in the 20th century to fill this intellectual vacuum can be summed up as "breeding defined" and "niche defined". The former argues that the reason members of a species resemble one another is that they are constantly swapping genes. The latter says it is that they are all adapted to live in the same ecological niche. The two explanations are not mutually exclusive. But it is only by looking at an asexual group that the second can be tested independently of the first.

Few creatures—even bacteria—do without sex entirely, but bdelloid rotifers are among that minority. As far as anyone can tell, these microscopic freshwater animals have not exchanged genes, one with another, for 100m years. This asexuality seems to have arisen only once, yet biology recognises about 380 species of bdelloid. If these species are not defined by interfertility, which obviously they are not, are they real, or just the convenient conventions of taxonomists? If they are real, it provides one clear answer to the species problem. Which is why Tim Barraclough and his colleagues at Imperial College, London, spent three years collecting bdelloids from ponds and streams in Britain and Italy. The results of this international small-game hunt have just been published in *Public Library of Science Biology*.

Dr Barraclough and his team classified their trophies in three ways. One relied on the DNA sequence of a gene called cytochrome oxidase. The second applied the same method to another gene called 28S ribosomal DNA. The third used an anatomical technique—the dimensions of the mouthparts—that is also applied to the finches of the Galapagos Islands which, tradition has it, set Darwin thinking about the species problem in the first place.

One advantage of these three ways of classifying things is that the results of each can be quantified and processed statistically using a technique called cluster analysis. Doing so showed Dr Barraclough three things. The first was that the three variables clustered similarly, suggesting that they were accurate markers of ancestry. The second was that they clustered in a way that more or less agreed with the traditional taxonomy of the bdelloids. The third, and most significant, was that they clustered in a particular way. The clusters had what are known in the argot of the trade as deep roots. In other words, individuals within a cluster were very much more similar to each other than they were to those of other clusters. That, in turn, suggests something is acting to keep them that way, by eliminating intermediate forms.

Specific information

The only plausible candidate for that something is natural selection to fit particular niches. Different niches, having different requirements, result in different genes and different shaped mouthparts. Indeed, the team has one excellent example of this. Just as three sorts of body lice, specialised to be able to grasp different sorts of hair, live on humans, so water lice are host to two sorts of bdelloid. One sort live on the creature's legs, the other on its body. Dr Barraclough's classification shows that these two apparent species are, indeed, real and evolutionarily distinct, even though they share a host.

The niche model of speciation thus looks proved. That does not rule out a gradual drift to infertility as an additional explanation, but makes it possible that infertility is a consequence, rather than a cause of speciation. In that case, there is probably active selection against hybridisation, since hybrids will be neither one thing nor the other, and thus not fit for the niche. But that, best beloved, is a subject for a whole different research project. ■

Philosophy and neuroscience

Posing the right question

The neurology of morality is being explored

IT IS the hoariest dilemma in undergraduate moral-philosophy classes: how do you pick the lesser of two evils? Often the problem is posed as the runaway-railway-wagon paradox. Given a choice between deliberately pushing someone in front of the wagon, in order to slow it down sufficiently for five people further down the line to escape, and allowing the five to die that the one may live, what should you do? Conversely, given a choice of throwing a set of points so that the wagon will go down a line where it will kill only one person, as opposed to five down the other line, what should you do?

On the face of things, the outcomes are identical in both situations. Either one person dies or five do. But, whereas most people have no difficulty choosing which is better in the second case (to kill one rather than five), the first usually causes paroxysms of guilt. Moral philosophers have spent years discussing this paradox. It has, however, taken a team of neuroscientists, led by Michael Koenigs of the University of Iowa and Liane Young of Harvard University, to come up with at least part of the real answer.

Basic emotions, such as fear, are regulated in part of the brain called the limbic system. These emotions—along with the limbic system—are shared by all mammals. Social emotions such as compassion, shame and guilt, however, are confined to a small number of species, and are most strongly expressed in man. They are associated with a particular part of the prefrontal cortex, an area of the brain that is much bigger in humans than in other mammal species. Dr Koenigs, Ms Young and their colleagues suspected that the seat of the runaway-railway-wagon paradox lies in that specific part of the prefrontal cortex, known as the ventromedial prefrontal cortex (VMPC).

To test this idea, they looked at six people with damage to the VMPC on both sides of their brains. These people are known from other work to have poor social-emotional responses. The researchers compared the responses of these people to various moral dilemmas with those of a group whose brains were undamaged and a second group with equivalent damage in other parts of the cortex. All three groups were asked questions (including the runaway-railway-wagon paradox) that previous studies have shown fall either side of the divide between the obvious and the ▸▸

squirm-inducing. The researchers' hypothesis was that people with VMPC-damage would come to the utilitarian answer in difficult cases (push the guy in front of the wagon) more often than either of the other two groups. And that, as they describe in this week's *Nature*, was exactly what happened. In cases where the choice involved personally causing harm, even for good ends, destroying the centre of social emotion also destroyed what is regarded by most people as normal moral judgment.

Pinning down the location of this part of morality does not answer the more fundamental question of why it evolved the way it did. It does, however, assist the process of thinking about that question.

In these cases it seems that the decision on how to act is not a single, rational calculation of the sort that moral philosophers have generally assumed is going on, but a conflict between two processes, with one (the emotional) sometimes able to override the other (the utilitarian, the location of which this study does not address).

That fits with one of the tenets of evolutionary psychology—a field which, as its name suggests, seeks to explain, rather than merely describe, mental processes. This is that minds are composed of modules evolved for given purposes. Dr Koenigs and Ms Young have shown that the VMPC may be the site of a "moral-decision" module, linked to the social emotions, that either regulates or is regulated by an as-yet-unlocated utilitarian module.

This does not answer the question of what this module (what philosophers would call "moral sense") is actually for. But it does suggest the question should be addressed functionally, rather than in the abstract. Time, perhaps, for philosophers to put away their copies of Kant and pull a dusty tome of Darwin off the bookshelf. ■

Tricky. I'll have to think about it

Higher mathematics

Truth and Lies

Mapping the most complex known mathematical object

FOR more than a century mathematicians have known about Lie groups. These are families of shapes named after Sophus Lie, a Norwegian mathematician who discovered them. There are four "simple" Lie groups and five—this being mathematics—that are not quite so simple.

The simplest member of the simplest Lie group is the circle, which looks the same however it is rotated. Its higher-dimensional cousin, the sphere, has the same properties, only more so, and is thus the second-simplest of the same family. The five non-simple groups—dubbed "exceptional" in their complexity and symmetry—are harder to envisage and, for almost 120 years, the details of the most intricate of these have lain beyond reach. This week a group of mathematicians led by Jeffrey Adams of the University of Maryland announced that they had completed a map of the largest and most complicated one, a structure known to mathematicians as E_8.

Lie groups have two defining features: surface and symmetry. A sphere has two surface dimensions. In other words, any place on its surface is defined by just two numbers, the longitude and the latitude. But it has three dimensions when it comes to symmetries. A sphere can spin on an axis that runs, say, from north to south, or on each of two axes placed at right angles to this. E_8 is rather more difficult to visualise. Its "surface" has 57 dimensions—that is, it takes 57 co-ordinates to define a point on it, and it has 248 axes of symmetry.

Grappling with such a structure is as tricky as it sounds. But Dr Adams's team decided to have a go. They want to create an atlas of maps of the Lie groups. This involves making a description in the form of a matrix for each structure. (A matrix is a multi-dimensional array of numbers, such as that found in a sudoku puzzle.)

Dr Adams and his colleagues began by writing a computer program that would generate such matrices, a task that took them more than three years. It transpired that they needed 453,060 points to describe E_8 but that they also needed to express the relationship between each of these points. That meant they had to devise a matrix with 453,060 rows and the same number of columns. In total this gives 205 billion entries. To complicate things further, many of these entries were not merely numbers but polynomials—sequences in which a given number is raised to a series of different powers, for example its square and its cube.

Processing such a vast quantity of data was beyond the capacity of even modern supercomputers, so the team were forced to tinker with the problem to make it tractable. This tinkering led them to a piece of ancient maths known as the Chinese remainder theorem.

This theorem is contained in a book written in the late third-century AD by a mathematician called Sun Tzu (not to be confused with the military strategist of the same name). It is used to simplify large calculations by breaking them down into many smaller ones, the results of which can then be recombined to generate the answer to the original question.

One problem addressed in the original book concerns counting soldiers. Sun Tzu's solution was that the soldiers should first split into groups of three, then groups of five, then groups of seven, with the number unable to join a group (in other words, the remainder) being noted each time. The three remainders can then be used to calculate how many soldiers are present. For example, if two were left over from the groups of three, three left over from the groups of five and two left over from the groups of seven, there would have been 23 soldiers in the unit (or possibly 233, but the difference should be obvious to even the stupidest commanding officer).

The researchers worked out how to use the remainder theorem to bring their calculation within the capacity of a supercomputer called Sage, which spent more than three days crunching the numbers to generate the map of E_8. Not content with letting the supercomputer do all the arithmetic, the mathematicians simultaneously jotted down some calculations of their own on the back of an envelope. They worked out that if each entry in the matrix were written on paper that was one inch square, the answer would cover an area the size of Manhattan.

And the point is

Apart from the satisfaction of mapping E_8 at long last, mathematicians are pleased because the structure keeps popping up in another branch of intellectual endeavour: string theory. This purports to be the best explanation of the universe beyond the Standard Model of physics that describes all known particles and forces, but which is generally acknowledged to be incomplete. String theory requires that the universe has many more dimensions than those that are obvious, but that most of these extra dimensions are too small to be discerned with today's equipment. One of the ways in which they can be hidden involves E_8, so having a mathematical map of its structure could be handy. Cheaper, too, than building a particle accelerator the size of the solar system. ■