state of minimum energy. In the case of X-ray and neutron crystallography, the iterative 'shake-and-bake' algorithm[1] has been revolutionary. This method involves the random perturbation of the positions of atoms in a crystal until the lowest-energy state is found, and it has reduced the time required for determining crystal structures from months to just hours.

Juhás and colleagues call their approach[2] for inverting PDF data the 'Liga algorithm', because the method is modelled on the rules of promotion and relegation that determine the position of participating teams in most of the world's soccer leagues. Teams correspond to trial clusters of atoms; 'winning' clusters (those with the smallest errors between the model and the experiment) are iteratively promoted, whereas losing ones (those with the largest errors) are relegated, so that an optimal global structure is more quickly found. The authors show that their algorithm can determine a number of nanoscale structures, such as that of the 'buckyball' C_{60} molecule, with a perfect success rate. Genetic algorithms, in contrast, take considerably longer and have far lower rates of success.

So what are the limits of this approach, and can it be extended to other global-optimization problems? The limits are typically reached when there are more parameters in the theoretical model than can be represented by data, so that the inverse problem becomes 'ill-conditioned' — that is, it has unstable solutions. Optimization strategies must therefore include some way of stabilizing the solutions. Some of these approaches, such as choosing model parameters by guesswork, can involve more than a whiff of the black art, and potentially produce results that vary widely from one investigator to the next.

Alternative methods using powerful statistical methods such as bayesian analysis have been developed, which can avoid the arbitrariness of choosing model parameters[5]. They achieve stability by taking into account a priori information in order to constrain the overall probability distribution for a particular structure. Strategies such as the Liga algorithm could be extended significantly by including known structural information based on a system's physical and chemical properties or knowledge derived from theory and computational materials science. It may well then be possible to resolve heterogeneous nanostructures containing many hundreds of atoms. ■

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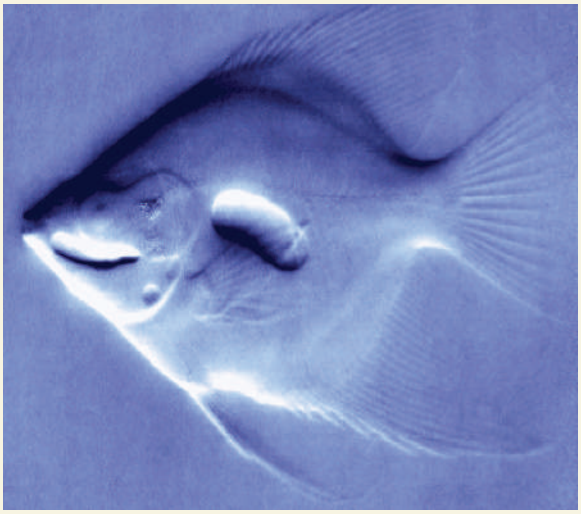
X-RAY IMAGING

Soft focus



From Wilhelm Conrad Röntgen's first snapshot of his wife's hand in 1895, to the security scanner that blows Arnold Schwarzenegger's cover in *Total Recall*, the use of X-rays to image dense objects has been part of common lore. Franz Pfeiffer and colleagues (*Nature Phys.* doi:10.1038/nphys265; 2006) now realign the popular view. They use X-rays to generate high-contrast images not only of bone, but also of the soft tissues that surround them. The approach could readily be used to improve the diagnostic power of existing medical-imaging equipment.

Conventional medical X-ray imaging uses the fact that the harder and denser the body tissues are, the more radiation they absorb, and the more contrast they produce on X-ray films. This makes it easy to distinguish bones and other dense bodies, such as tumours, from surrounding tissues. But discerning details of softer tissues from only the contrast in absorption is difficult.

When an X-ray passes through tissue, however, it is not just absorbed: its phase is changed too. And this phase shift is more sensitive to variations in the composition of soft-tissue structures than is absorption. But until now, extracting information about phase has required interferometric reconstruction techniques and bathing the target object in the ultra-high-intensity radiation of a synchrotron particle accelerator.

Pfeiffer *et al.* use a sequence of phase-contrast gratings to manipulate the relative phases of the X-rays that illuminate and subsequently emerge from an object. They can thus generate phase-contrast images — for example this 50-mm × 50-mm picture of an angelfish — using commercial X-ray sources at much lower intensity, and cost, than has previously been possible. The authors note that, as well as improving the detail in X-ray images, their approach could be adapted for use with other low-intensity radiation sources, such as neutrons and ions.

Ed Gerstner

COGNITIVE SCIENCE

Brain development and IQ

Richard Passingham

If intelligence is partly determined by our genes, how does brain development relate to IQ? An attempt to answer this question measures the size of the outer layer of the brain, the cortex, with surprising results.

Shaw and colleagues (page 676 of this issue)[1] have investigated whether there is a relationship between intelligence and physical dimensions of the brain. Specifically, they measure the thickness of the cortex; the complex computations carried out by the brain depend on the firing of the cortical cells. The authors' results indicate that intelligence can be related to how the cortex changes during development.

Rather than making structural measurements in post-mortem brains, Shaw and colleagues used magnetic resonance imaging (MRI) in living subjects. This allowed the authors to obtain images from people whose IQ could also be tested so as to look for correlations between the two measures. Moreover, detecting anatomical features associated with an individual's intelligence requires a large pool of subjects, because any effects may be small and could be missed if the sample size is inadequate. The use of imaging, rather than post-mortem measurements, allows data to be gathered from a sufficient number of individuals.

The authors scanned 307 children from the age of six years and followed them through adolescence with further scans. For each child, the authors estimated intelligence using subtests of the Wechsler Intelligence Scales — the most commonly used IQ tests. An alternative approach would have been to look at a cross-sectional sample of children and adolescents of different ages, scanned only once each. But, as the authors note, such methods are open to many objections: for example, teaching practices may change over time, which would affect the IQ scores.

Shaw and colleagues find no significant correlation between cortical thickness and intelligence in their data from young children. Yet they cite a study of adults by McDaniel[2] that reports a modest correlation of 0.3 between intelligence and the total volume of the brain. The reason for the different results could be that the relevant factor is the total area of the cortex rather than its thickness, but it turns out that this is probably not the case. As the children were followed up, the nature of the relationship changed. In young children, the correlation tended to be negative, but in late childhood, around the age of ten, it was positive.

The authors illustrate this point by plotting continuous curves of cortical thickness for subjects from the ages of seven to nineteen, dividing the sample into three groups on the basis of their scores in the IQ tests: those of 'superior', 'high' and 'average' intelligence. IQ measures are normalized to the age group, and should in theory remain the same as the children age. Figure 2 on page 677 shows the curves for cortical thickness in brain areas that show different developmental patterns according to intelligence. Children in the group with superior intelligence have a thinner cortex in these areas in early childhood, but cortical thickness increases sharply until age eleven compared with the other groups, before decreasing through adolescence. The authors note that those of superior intelligence show a prolonged period of prefrontal cortical gain and the most rapid rate of change.

These differential changes do not occur in all cortical areas. The most notable positive correlations with IQ in late childhood occur in the prefrontal cortex. This region lies at the top of the information-processing hierarchy, receiving highly processed information from all five senses[3]. The brain areas showing the biggest difference in the shape of the growth curve between those with superior intelligence and the other groups lie in the lateral and medial frontal gyri. But are these the areas that are most active when subjects perform IQ tests? This aspect can be assessed by functional MRI, which provides an indirect measure of the increase in arterial blood flow to areas in which cellular activity is increased. Previously, subjects have been scanned while taking non-verbal tests that measure IQ, and increased activity has been found in the lateral and medial prefrontal cortex — regions that are among those highlighted by Shaw and colleagues' developmental measures[4,5]. Furthermore, individual differences in IQ are correlated with the amplitude of the functional MRI signal in the lateral prefrontal cortex[6].

We know that variations in general intelligence, or *g*, among people depend to a great extent on genetic differences[7]. So, if *g* is highly heritable and the increase in the thickness of the prefrontal cortex is related to *g*, it is tempting to assume that this developmental change in brain structure is determined by a person's genes. But one should be very wary of such a conclusion. The body's development is intimately linked to interactions with its environment. For example, in a classic experiment, Rosenzweig and Bennett[8] showed that the thickness of the cortex in adult rats is affected by the degree to which the animals' early environment is enriched in terms of activities. Even in human adults, structural changes can be seen in the cortical grey matter as a result of practice[9]. Thus, it could be that people with superior intelligence also live in a richer social and linguistic environment, and that it is this that accounts for the sharp increase in the thickness of their prefrontal cortex in late childhood. However, Thompson and colleagues[10] previously looked for genetic influences on brain structure by comparing the cortical thickness of pairs of identical and non-identical twins. They found that some regions, including the frontal cortex, are, to use their words, under "tight genetic control".

Shaw and colleagues speculate that differences in the shape of the growth curves of cortical thickness could be influenced by various factors. These include the number of neurons that collect in the subplate under the cortex during late fetal development, the development of the myelin sheath that insulates the fibres of the neurons, and the selective elimination at puberty of neuronal connections that are not useful. Testing these hypotheses will require animal experiments that measure cellular development. Studies in animals have the advantage that the relative influence of genetics and experience can be disentangled, and so should provide a clearer picture of how intellectual ability is affected by the factors that underpin cortical development.

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ENVIRONMENTAL CHEMISTRY

Boiling up an acid plume

There is more than just a sizzle when red-hot lava meets the sea. The plumes seen in this picture consist not only of steam produced by the evaporation of water, but also of aerosols and gases that stem from the reaction between the lava and salt water.

M. Edmonds and T. M. Gerlach have investigated the composition of such plumes produced by lava from Kilauea Volcano, Hawaii (*Earth Planet. Sci. Lett.* doi: 10.1016/j.epsl.2006.02.005). Their main tool was open-path Fourier transform infrared spectroscopy, which allowed remote sensing of the plumes and estimation of the amounts of various components — water, carbon dioxide, nitrogen dioxide, sulphur dioxide and hydrogen chloride. The most notable of Edmonds and Gerlach's conclusions stem from their analyses of this last species, HCl.

First, from thermodynamic considerations they calculate that the HCl gas is created following the hydrolysis of magnesium chloride salts (and not of sodium chloride, as an alternative explanation has it). Second, given that conclusion, they estimate how much HCl is produced by the lava–seawater interaction. The outcome depends on various assumptions and factors, including the type, extent and duration of the lava flow.

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Edmonds and Gerlach estimate that a lava flow of 1 m^3 s^{-1} could in principle produce 3.7 kg s^{-1} of HCl, or 300 tonnes daily. For various reasons that they discuss, this number is likely to be much lower (3–30 tonnes). Figures of this latter order of magnitude produce only localized high concentrations of HCl gas and acid rain. But the authors point out that in the past the story must have had a more serious edge. Eruptions of Hawaiian volcanoes in 1840, 1919 and 1950 produced massive lava flows, with sustained lava fluxes entering the sea. The result was an estimated HCl output of 200–2,200 tonnes per day over several weeks, a much more serious environmental hazard.

Tim Lincoln