news and views

those of minor mutations; small changes in the inputs used to trigger patterning mimic the natural variation in development seen from embryo to embryo. On both of these counts, the network is satisfactorily robust. Most small changes in parameter values have little effect — only at rare thresholds does the behaviour of the model switch from one stable state to another.

Initial conditions can also be varied more widely, to explore how this gene network might behave in different developmental contexts. For example, the model was designed with a precise periodic input to trigger activity of the segment-polarity genes throughout the whole length of the body. This mimics what happens in Drosophila (Box 1). In many other insects, however, segmentation spreads through a field of cells from head to tail (much as it does during early patterning in vertebrate embryos). In these cases, the segment-polarity system seems to be conserved, but the upstream triggers may not be.

Von Dassow et al. are quite happy with this: their model will generate the same segment pattern with a variety of different inputs, and the inputs can be much less precise than those known from Drosophila.

Our understanding of gene networks is at an early stage. We perceive their complexity only after it has been filtered by the limitations of the techniques used to study them. Genome databases and DNA-chip technologies are now widely used in industry, in hospitals and in many devices that we have at home. A compact disc player, for instance, makes use of a miniature laser diode only a few millimetres big. In two papers in Applied Physics Letters and Physical Review Letters, Cao et al. describe a laser that is a thousand times smaller still: their laser is a small grain, 1.7 micrometres in diameter — about one-tenth of the diameter of a human hair.

The microlaser created by Cao et al. is not the smallest ever laser source, but it is a special type of microlaser. It uses a highly disordered structure to obtain laser action. The behaviour of light waves in disordered structures is highly complex, yet disordered materials are familiar to us all. Every substance that looks white falls into this category, including paper, white paint, fog, marble and a glass of milk. The study of the behaviour of light in such disordered materials is an active field of research.

A light wave that passes through a white object like a glass of milk will undergo a process called multiple scattering. Milk is a suspension of many small fat droplets, each with a strong tendency to scatter light: when a light wave hits a fat droplet its direction of travel will be changed in an arbitrary way. A light wave passing through a glass of milk will be scattered thousands of times by watts of fat droplets. This is what gives milk and all other disordered substances their opaque white appearance.

It is this mechanism of multiple scattering that Cao et al. use to make a tiny random laser. However, multiple scattering alone is not enough to make a laser. A laser requires two ingredients: a material that amplifies light, and some feedback mechanism that (temporarily) traps the light in order for the amplification to be efficient. In normal lasers the trapping element is a cavity — two mirrors facing each other with the amplifying material in between. The light passes back and forth between the mirrors, thereby passing several times through the amplifier, until it leaves through one of the mirrors that is partially transmitting (Fig. 1a).

In the case of a random laser the cavity is replaced by multiple scattering. In 1967, Letokhov predicted that the combination of multiple scattering and light amplification would lead to a form of laser action. Nonetheless, it was 25 years before random laser action was observed experimentally.

It became clear that the multiple scattering of light that takes place in a disordered material does not really provide a feedback mechanism, but it makes the light stay inside the material long enough for the amplification to become efficient. Instead of bouncing from one mirror to another, the light waves bounce from one particle to another thousands of times before they leave the disordered material (Fig. 1b). Because the multiple scattering is completely random, the term ‘random laser’ is used. The emission charac-

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How small can you make a light source? A common light bulb is a few centimetres in diameter. You can make light bulbs several millimetres across, but for a light-emitting device much smaller than this, we should turn to lasers. Lasers are nowadays widely used in industry, in hospitals and in many devices that we have at home. A compact disc player, for instance, makes use of a miniature laser diode only a few millimetres big. In two papers in Applied Physics Letters and Physical Review Letters, Cao et al. describe a laser that is a thousand times smaller still: their laser is a small grain, 1.7 micrometres in diameter — about one-tenth of the diameter of a human hair.

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Laser physics

The smallest random laser

Diederik Wiersma

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Figure 1 Comparison between a regular laser and a ‘random laser’. a. In a regular laser the light bounces back and forth between two mirrors that form a cavity. After several passes through the amplifying material in the cavity, the gain amplification can be large enough to produce laser light. b. In a random laser the cavity is absent but multiple scattering between particles in the disordered material keeps the light trapped long enough for the amplification to become efficient, and for laser light to emerge in random directions.
teristics of a random laser are similar to those of a normal laser: the emission spectrum can be extremely narrow, which means that the colour of the emission is well defined, and the output can be pulsed. But unlike a regular laser, a random laser will emit randomly in all directions, just like the emission from a common light bulb.

The tiny random laser built by Cao et al., which consists of disordered clusters of zinc oxide (ZnO) nanocrystals. After excitation by an external light source, these ZnO nanocrystals provide both the amplification and the random scattering needed for random laser action. They are also easy to make and extremely cheap: one ZnO cluster costs much less than 1 cent. In addition, the laser characteristics can be easily tuned by varying the geometry of the clusters. Each cluster will operate at its own specific wavelength, depending on its shape and size.

One might question how laser action occurs in a disordered material, given that it lacks a real cavity (Fig. 2). The answer is simple. The condition for lasing comes from a careful balance between gain and loss. The gain depends on how much time the light spends inside the amplifying material; the loss depends on how easily the light can escape. Lasing simply occurs when the gain becomes larger than the loss. For example, within a sphere of disordered amplifying material of radius a, the gain is proportional to its volume (4πa3/3) and the loss is proportional to its surface area (4πa2). This means that, upon increasing the volume, it is possible to reach a situation where the gain becomes larger than loss and the system starts to lase. The threshold volume does not necessarily have to be very big: in the case of ZnO clusters it is only a few cubic micrometres.

Although random laser action in ZnO clusters can be explained by multiple scattering, the details are still vague. Apart from the trapping of light by multiple scattering, other processes can play a role. If the scattering is very strong, light waves can start to bounce randomly in closed loops and get trapped. This is the mechanism behind localization of light in a disordered medium, a peculiar phenomenon in which light transport comes to a complete stop. But the conditions for obtaining localization are very strict, and not likely to exist in ZnO clusters. More common is additional feedback from the surface of the sample. The outer surface of a cluster will reflect light back inside, which enhances the entrapment. Especially for micro-size systems, such as small clusters or films, feedback from the boundaries is expected to be an important factor. More theoretical and experimental work is needed to understand these random microlasers in detail.

Reducing the size of a laser source to a few micrometres opens up many possibilities. It