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Small things, big thinking

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Finely tuned for touch and smell, the fly foot has sensors that can detect both chemical and mechanical changes in the environment. The outcome of more than three billion years of evolution, these sensors are far smaller and more sophisticated than man-made chemical sensors which are generally capable of detecting only single types of substances, let alone vibrations and pressure as well. Yet the larvae of the fly manufactures its wonderfully versatile foot originating from just a few cells in its body and using as its raw material something as commonplace as a small piece of fruit found in virtually all compost heaps the world over.

From molecules to jungles, biological systems grow themselves. This natural hierarchical self-assembly process, which operates simultaneously on many scales, fascinates Dr Chris Forman, an Associate Researcher at Cambridge University's Institute for Manufacturing. Having trained as a theoretical physicist and worked in satellite communications, he decided to concentrate his research efforts on sustainability and to look at how academic disciplines could work together to unlock some of the mysteries that lie behind the staggeringly complex processes in biology.

Forman is one of the contributors to a new series of online videos titled Under the Microscope produced by the University of Cambridge. These one-minute videos capture glimpses of the natural and man-made world seen in stunning close-up and convey the excitement of cutting-edge science in areas that range from beetle eyes to killer T-cells, from nano-wires to fish skeletons. Each one is accompanied by an explanatory voiceover from the scientist involved, who talks about his or her research and how it might impact on society. The series will appear twice a week on the Cambridge University website.

In choosing to focus on images of fruit flies and beetle antenna Forman draws attention to the extraordinary structures found in the ordinary organisms – and encourages us to look deep into their structure and function to see how they are fine tuned to tasks that help them to thrive and survive. “I wanted something with a big yuck factor to show the remarkable level of integration that exists in the natural world,” he says. “On a nano-scale the beetle’s eye and the fly’s foot reveal a stunning complexity that simply eludes current manufacturing. And close-up images of bugs grab the attention of children and adults marvellously.”

Forman works mostly at the level of individual molecules – his PhD focused on the prospect of transporting electrons along self-assembled protein fibres, not unlike spider silk – but he also keeps a close eye on the big picture of larger scale structures and processes to guide his work. Perhaps the best example of this interplay between processes at very different length scales concerns the natural levels of carbon dioxide in the atmosphere. The natural balance of CO_2 arises to a large extent from repeating the same chemical reactions trillions upon trillions of times around the planet in living cells, and the precise details of those chemical reactions are determined mostly by the sequence of information in genes.

His vision is that, by understanding molecular self-assembly and mixing this with the ability to perform arbitrary chemistry, we could make radically diverse structures for many purposes from the same restricted set of materials as natural systems. This would make it easier for each local community to be in balance with its immediate environment while achieving its economic goals, and sharing the knowledge of how to do this around the world could allow a global harmony to emerge naturally, one molecule at a time. Such visionary holistic ideas are just one aspect of the fast-developing field known as biomimetics.

While some of Forman's work is based on making connections between existing fields of science, much of it could be described as leaps of the imagination. By thinking a stage beyond what we already know, he is working on ideas that may not see fruition for 20 years – or may indeed evolve into unforeseen directions. "As university researchers we have the freedom to think about such blue sky prospects without some of the restrictions that apply when you are working in the commercial or public sector. In particular, at Cambridge we are also able to move more easily between sectors by virtue of the collegiate system," he says. "The more I study the natural world, the more impressed I am by what it can teach us about molecular organisation. I want to inspire the thinkers and leaders of the future who will take the knowledge discovered in universities and apply it in the commercial and political worlds."

The world's resources are under huge pressure from an expanding human population. Transport is a big user of energy and manufacturing processes rely heavily on transport. As Forman puts it: "Industry depends on large lumps of materials being moved from process to process – often across the planet." He asked himself a simple question: what would happen if we eliminated all methods of transport? "If you can't travel, you have to do everything in one place: raw material extraction, manufacturing, assembly, consumption and recycling. Is there anything that can do this already? Yes – it's called a tree! A tree gets it nutrients, it grows and dies. As it decays it releases its nutrients thereby nurturing the myriad of creatures that use it as an environment. A tree does all this without moving from where it takes root -and it's solar powered. While we can't make everything from trees we can get construction materials, textiles and food which represent the bulk of our basic needs. Perhaps in the future we will be able to extract even more than this from artificial static systems designed to emulate and fit in with the local natural ecology."

All organisms are made from the same basic materials – carbon, hydrogen, oxygen and so on. What drives them to grow, and what makes them so amazingly diverse, is the information stored in their genes and the compartmentalisation that provides a context to that information. "Take a mushroom, a tree and a pig. They appear completely different but they all use DNA, proteins, lipids etc. All have the ability to grow but they grow in markedly different ways, which depends strongly on their local environment. In looking at how these fundamental forces interact at all length scales we are looking both at global environmental factors and the quantum processes in individual molecular interactions that we are only just beginning to grasp. It is a global system with quantum resolution and each of us is part of that system," says Forman.

"A living biological cell is basically a complex network of chemical reactions contained inside a little bag. Can we emulate this process and replicate it? Maybe by compressing our processes into small packages and distributing them all over we can do all our recycling and manufacturing in our houses, rather than in factories with lorries moving large lumps of stuff about? In this way we get more control as individuals over what we want and how it's made. This could be better for both the environment and the economy – as it gives all seven billion of us the same chance to add value to our lives locally, which is considerably more value than currently exists in the world."

Forman believes that science might one day enable us to create products as complex as IPods and computers in our living rooms – designed for our own immediate needs and made from local material. Currently, industrial sectors such as energy, textiles, food and high-tech electronics are all looking at how to copy or exploit nature in many ways. In the energy sector viruses and enzymes are being used to organise batteries or capture solar energy. Sectors such as food and textiles are already biologically-based. In hi-tech electronics people are looking at using organic molecular-based electronics to create next generation flexible displays. “Perhaps these radically different sectors should consider joining forces to learn how they can benefit In terms of optimal use of resources at the molecular scale. Imagine a cake that displayed an edible temporary video screen? Imagine being able to make such a cake in your own kitchen? It’s conceivable that the commercial battles of the future will take place inside artificial cells in the walls of our houses rather than on the shelves of the supermarkets.”

The ultimate goal is to achieve a closed loop economy – a system that is self-sustaining with respect to material, in which the same material loops around and around the economy and is endlessly powered by sunlight alone. On each cycle the precise form and function of the material is determined solely by the individual for whatever purpose they have need of there and then, and the job of industry and regulation is to enable them to do it harmlessly. One way of achieving such a closed loop is to create what is known as an industrial ecology, in which companies trade waste for mutual benefit. The best known example is the city of Kalundborg in Denmark, in which industries as diverse as energy, plaster-board manufacturing, road construction and pig-farming have collaborated to achieve economic and ecological efficiency.

By shrinking a city-wide industrial ecology into a volume the size of a cell, the need to transport raw materials and products over long distances is removed, and the energy required to process the material is reduced to the point where sunlight can be used directly. We know the range of species that can be produced with biological cells; if we are able to harness similar processes we may open up a huge array of possibilities. But how far can we take this idea technologically? Forman is keen to communicate these ideas to the public to acquire their input before it is fully explored scientifically and has devised a talk called “Can iPods grow on trees?” He says: “The idea behind it isn’t as nuts as it sounds.

Every component in an iPod has a biological analogue. To give one example: just as you can upload a tune to play on your IPod, so the lyre bird has learned to reproduce any sound it hears perfectly. Nature is an inspiring teacher."

Provided by University of Cambridge