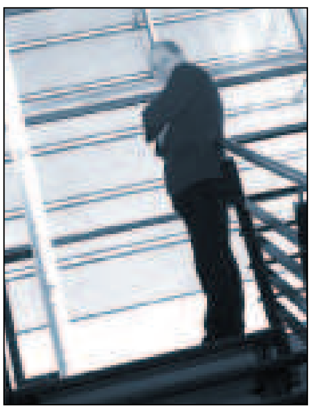
Replication revolutionary

Which came first; the chicken or the egg? How self replicating machines are becoming reality. By **David Boothroyd**.



A decade or so ago, the concept of the home office was revolutionary, but the web and broadband have made it a perfectly ordinary lifestyle. But what about a home factory: a production line in your sitting room capable of manufacturing lots of different products, virtually for free? Surely that is a pipedream?

Not if Adrian Bowyer's plans come to fruition. The senior lecturer in mechanical engineering at Bath University's Centre for Biomimetics is leading a project called RepRap – the Replicating Rapid Prototyper.

The extraordinary idea underlying RepRap is self replication. A rapid prototyper can build many different objects. So why not make one that can build a copy of itself? If you can do that once, you can do it again and again. Result: the cost falls to virtually nothing – just the raw materials – and RepRap machines become available to millions.

If it works, it will be the best application yet of one of the most beguiling ideas in the whole of technology: self replicating machines.

The idea of a machine that can copy itself goes back way before the days of electronic computing, at least to the 1870s, when it featured in Samuel Butler's novel *Erewhon*.

One of the first practical steps towards self replicating machines took place in the 1950s, with an extraordinary project initiated by scientist Lionel Penrose and his son Roger – then a schoolboy, latterly, one of the UK's most brilliant scientists. They built a system of wooden cut outs, in several shapes, which could fit together into compound parts. Placed in a tray and shaken, they would assemble into specific patterns, which would also repeat over 'generations'. Effectively, they had built a mechanical self reproducing system.

But the man regarded as the most brilliant figure in the entire field of self reproducing machines – and, arguably, in the whole of computing – is John von Neumann. Whilst he did most of his research in 1940s, it wasn't published until after his death in 1966 in his book '*Theory of Self Reproducing Automata*'.

In it, he describes a Universal Constructor; a self replicating machine in a cellular automaton environment (like that in John Conway's game of Life). Essentially, von Neumann demonstrated the fundamental logical required for self reproduction. His constructor has 29 possible states, allowing signals to be sent and logical operations to be carried out. A 'tape' of cells encodes the sequence of actions to be performed by the machine. Using a writing head, the machine can generate (by printing) a new pattern of cells, allowing it to make a complete copy of itself – and the tape.

Von Neumann knew simpler forms of self reproduction were possible, such as crystals copying themselves. But he was looking for a deeper form of self reproduction that might be closer to true biology – or 'open ended' evolution – which could enable biological levels of complexity to emerge. His genius was to realise that open ended evolution needed both a constructor and, distinct from it, its own description, which must be copied separately. This was remarkable, because it came before Crick and Watson's discovery of how nature does it using DNA. Open ended evolution emerges because errors in copying the description – mutations – generate variations which can then evolve via natural selection.

After von Neumann, much of the research into self reproducing machines was done in cellular automata – software based models in which self reproduction took place and Conway's Life is the most famous of these.

"These bypass many of the problems of physical reality because you're dealing with what is basically a mathematical model inside a computer," Bowyer says.

More recently, researchers like Matt Moses at the University of New Mexico and Hod Lipson from Cornell University, have made progress towards real, physical self replicating machines. Moses' system consisted of Lego like bricks made of polyurethane resin which were used to make a three axis manipulator. This was subsequently shown to be capable of assembling a duplicate of itself. However, the machine cannot fabricate its own plastic components and must be controlled by an external entity. To be fully self replicating, admits Moses, the device would have to control its own actions autonomously and possess the instructions necessary for carrying out its duplication.

Lipson, meanwhile, made a tower of cubes attached to each other by magnets, which can be energised or not. Called 'molecubes', they can rotate and manipulate other cubes in their surroundings, and by doing that produce a copy of the original tower. The results have been intriguing.

Bowyer calls this kind of work 'pure self reproducing machines', because the aim is to create systems that can make exact copies of themselves with no human intervention, apart from initial provision of raw materials. He is not so interested in that approach because it fails to distinguish between the inherent abilities and drawbacks of human beings and machines.

People, he says, find it very difficult to carve a block of plastic to an accuracy of 0.1mm, which is easy for a computer. Putting carved pieces together – particularly if they can only fit one way – is easy for us, much harder for a machine.

"I want to produce machines that do what they're good at, whilst we help by doing what we're good at. What that means is making a machine that can make all its parts. Then a person can put them together."

Clearly, making machines that do nothing but copy themselves would be pointless. So the aim is to create machines with a self reproducing capacity, but which can also make all sorts of other devices, from coat hooks to cat flaps – almost anything is possible within the size limitations of the systems under development, currently a 300mm cube.

The other key element of his strategy is to give away the RepRap for free – the whole system's electronic design, software, everything needed to build it, will be available from the web. The logic of this is that if you create a system that can copy itself and anyone can have one, you have the potential for an exponential increase in the numbers of such systems being produced and a similar fall in cost, of both the self reproducing machines and the objects they can make.

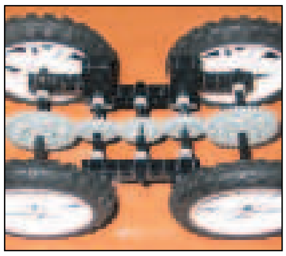
It may sound absurdly generous, but the economics are driven by logic – once a system can copy itself (with a bit of help) it costs very little, other than the raw materials to produce unlimited numbers of it, which makes its monetary value approach zero.

"It is potentially extremely wealth creating but

Courtesy of Bath University

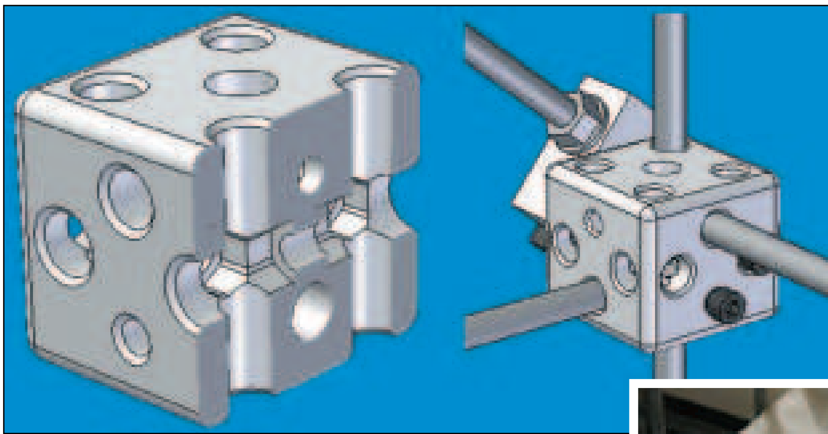
Donald Maclellan

Main picture: Adrian Bowyer: "I want to produce machines that do what they're good at, whilst we help by doing what we're good at. What that means is making a machine that can make all its parts. Then a person can put them together."



Courtesy of Bath University

Above: Future developments could include using the RepRap to make moulds and, from them, produce anything that is mouldable, with materials like epoxy, concrete, plaster of Paris or ceramics.



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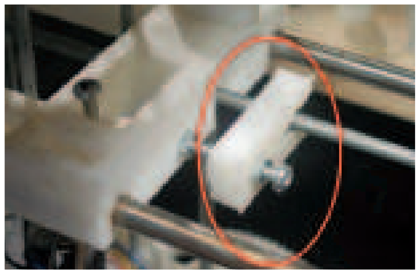
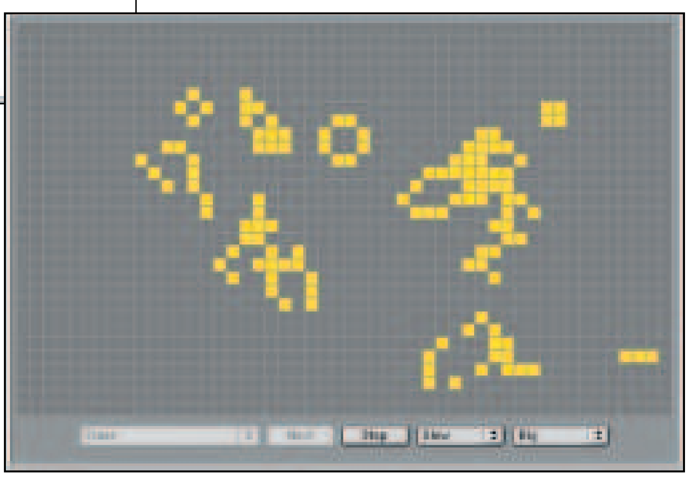


Above: Although aimed initially at plastic parts, second generation machines will be able to produce electrical circuitry. And future machines may be able to reproduce semiconductors.
Right: In September, a RepRap machine, developed in Vienna by Vik Olliver, succeeded in producing the first part for itself (circled in red).

Below: John Conway's Game of Life is one of the most famous examples of cellular automata – software based models that support self reproduction.



itself is worth nothing," Bowyer says. However, there is also a moral dimension, in that he did not want such a system to be under the control of any individual, company, or government. "If you have a powerful technology, a good way to make bad things happen is for only some people to have access to it."

One requirement being asked of anyone building a RepRap is that they make two machines for other people.

The team has set itself a deadline for distributing the first machines by 2008, but Bowyer is quietly confident they can beat this. He is not in complete control of the project – different teams of people are working on prototypes worldwide, some of whom he has never met. Most recently, in September, a RepRap machine developed in Vienna by Vik Olliver, succeeded in producing the first part for itself (see **http://staff.bath.ac.uk/ensab/replicator/**).

First generation machines will produce only plastic products, but the team is already planning a second generation device that will handle low melting point alloys, enabling RepRap systems to deal with electrical conductors and hence produce a combined electrical and mechanical object.

"These second stage machines will have a deposition head in them that works directly on the alloy, so you will be able to produce electrical circuitry. And people are already working to develop inkjet printers that can print semiconductors on plastic sheets. Once RepRap machines are established, there is nothing to stop them creating a semiconductor print head."

But even with plastic only output, Bowyer believes the potential is huge. "I cite plastic coat hooks as an example of what could be produced. It sounds completely trivial, but an economist has told me the worldwide market for them is much larger than for massive objects like gas turbines."

Clearly, it will require a change in mind set for us to think about making our own small plastic objects. But if it takes off and RepRap machines cost almost nothing – and the crucial requirement for that is their capacity for self reproducing – it could happen. People will then simply download designs for objects from the web or create new ones themselves using free 3d modelling software, 'print' them out and the home factory is born.

The self replication concept can apply not only to the RepRap machines, but also to the raw materials. In future, Bowyer is hoping to be able to use a polymer called polylactic acid, which can be made by fermentation from starch using potatoes or maize.

"If you have a few tens of square metres of ground, you can have a supply of raw material that copies itself. And of course, the RepRap can also make a fermenter. Also the plastic is fully biodegradable, so it can go on a compost heap, and the result is you have immediately a local recycling route. That makes it extremely benign ecologically."

Further developments could include using the RepRap to make moulds, and from them produce anything that is mouldable, with materials like epoxy, concrete, plaster of Paris or ceramics.

For some observers, there are two Holy Grails of future technology and they both involve self replication: physical machines of some kind that can copy themselves; and software programs that can learn and create better versions of themselves. Why are these so significant? Because once you reach these points, there will be an exponential increase in what is achieved – and we can sit back and watch.