

Machine Genes 1

A waterborne logic in living algorithm

Aleutian Islands kayak builder and author of the celebrated *Darwin Among the Machines*, **George Dyson** asks, 'What if Artificial Life isn't?' in this brief prehistory of electronic evolution.

'NATURE (the Art whereby God hath made and governes the World) is by the Art of man, as in many other things, so in this also imitated, that it can make an Artificial Animal,' wrote Thomas Hobbes (1588-1679) on the first page of his *Leviathan*, published in 1651. 'For seeing life is but a motion of Limbs, the beginning whereof is in the principall part within; why may we not say that all Automata (Engines that move themselves by springs and wheelles as doth a watch) have an artificial life?'

Hobbes's views on the nature of living things, foreshadowing the Darwinian revolution in biology, were widely condemned. 'It was a winde, not the holy spirit which in the Creation moved on the waters,' claimed Hobbes, according to Alexander Ross, author of *Leviathan Drawn out with a Hook*. Hobbes questioned prevailing dogma concerning not only the origins of life but also the origins of mind. Arguing that the correspondence between logic and arithmetic implied that thought could emerge from non-thinking things, he anticipated the powers of digital computing and the debate over intelligence among machines.

Five centuries after Hobbes, artificial intelligence continues to be debated by scientists and philosophers, but artificial life (and artificial evolution) is likely to have a greater impact on our future as living things. We should be less interested in the metaphysics of whether machines are developing the ability, individually, to think, and more interested in the details of how they are developing the ability, collectively, to evolve and reproduce.

The great advances in biology of the twentieth century, expanding upon Darwin's insights delivered in the nineteenth, derive from the realisation that at the heart of life as we know it lies a system of information coding and chemical processing mediated by an alphabet of nucleotides joined into strings of DNA and RNA. We may never unravel the exact origins of life, but we do know that once metabolism becomes entwined with

replication, natural selection, as the Darwins showed us, will do the rest. Life does not require replication; statistically approximate reproduction, for simple creatures, is good enough. The difference between replication (producing an exact copy) and reproduction (producing a similar copy) is the basis of a broad generalisation: genes replicate but organisms reproduce. As organisms became more complicated, they discovered how to replicate instructions (genes) that could help them reproduce; as instructions became more complicated, they discovered how to reproduce organisms to help replicate the genes.

It is an uncanny coincidence that the mechanism underlying biological information processing was elucidated in the year 1953, just as the hardware and software underlying the recent revolutions in digital computing and communication were taking form. The breakthrough was made at the Institute for Advanced Study in Princeton, New Jersey, where John Von Neumann, otherwise a theoretician, persuaded the Institute trustees to break their rule of supporting only pure science and allow him to build what became the archetype of the modern digital computer, inoculating its 5,000 bytes of high-speed memory with the order codes and subroutines out of which the rudiments of an operating system and the beginnings of the software industry evolved.

'The heart of the system is a central clock, carrying an enormous load,' the minutes of the first meeting of the Electronic Computer Project reported on 12 November, 1945. The circuitry would be modular, because 'this sort of design is favourable for mass production,' explained the engineers. 'Words coding the orders are handled in the memory just like numbers,' announced Von Neumann who, by breaking the distinction between numbers that mean things and numbers that do things, unleashed the self-modifying instructions that led to the digital universe surrounding us today. 'Von Neumann cleared the cobwebs from our



collage of work by Zoe Kennard and Verity Conneron

minds as nobody else could have done,' says Julian Bigelow, who became the principal architect of the computer that was built at the IAS. 'A tidal wave of computational power was about to break and inundate everything in science and much elsewhere, and things would never be the same.'

It took the next five years to realise Von Neumann's vision – the embodiment, as Von Neumann himself acknowledged, of the Universal Machine invented, as a theoretical construct, by British logician Alan Turing in 1936. Other computers were under construction in other places, but it was Von Neumann's template that would be widely reproduced. The physical design and logical coding of the IAS computer was freely distributed at every stage in its development, leading to some 15 immediate siblings, from Australia to Israel – and a consulting contract between Von Neumann and IBM. Bigelow's prototype – reduced in size, increased in complexity, but unchanged in principle – evolved into the microprocessor, now embedded in our lives to the extent that some 4,000,000 were produced every 24 hours in the year 2001.

Bigelow's team of engineers had to coax a digital computer to life from the non-digital components available in 1946. The machine incorporated 3,474 vacuum tubes, each subject to misbehaviour or failure at any time. The central arithmetic organ processed 40-bit words in parallel at up to 100 kilocycles per second, but could also be 'pedaled', one step at a time, to determine where things were going wrong. The core of the machine was compact, with minimal connection paths

between components achieved by convolutions in the chassis, like the folding of a cerebral cortex into a skull. At its base were 40 'Williams Tubes', each containing 1,024 bits of 24-microsecond, random-access memory, the first of its kind. With twenty cylinders on each side, the computer resembled a turbo-charged V-40 engine, about six feet high, two feet wide, and eight feet long.

Binary digits ('bits') were stored as a 32-by-32 array of spots on the face of a modified cathode-ray-tube display, relying on the faint secondary charge that lingers briefly (attracting dust to the screen of a television) to distinguish between a 0 and a 1. Unlike a modern computer, which displays the contents of a memory stored somewhere else, the spots on the Williams tubes were the memory. Bigelow and his colleagues discovered that as long as the entire pattern was refreshed 100 times a second, they could use the intervening microseconds to write data to and read data from individual addresses in the array. Each of the 40 bits making up a word was assigned the same location in a different tube, analogous to handing out similar room numbers in a 40-floor hotel. Flaws were fatal. RCA allowed the IAS to scan their inventory for unblemished specimens and ship the other 80 percent of them back.

In the spring of 1951, the new machine flickered to life. The first 60 days of uninterrupted operation were devoted to the design of a thermonuclear bomb, verified on 1 November 1952, when a ten-megaton explosion removed the entire island of Elugelab, at Eniwetok Atoll in the South Pacific, from the map. Von Neumann already had other upheavals in mind. 'I am thinking