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From ARMS to Brains - from the Acorn RISC Machine to Spiking Neural Network Architecture

In May 2018, Prof Steve Furber CBE FRS FREng DFBCS FIET CITP CEng spoke to Manchester Branch BCS, the Chartered Institute for IT.

Manchester looms large in the history of computing. Home, for a time, to Alan Turing and where Freddie Williams and Tom Kilburn led the construction of the Manchester Baby (or Small-Scale Experimental Machine) which was the world's first operational stored-program computer in June 1948. Manchester code, published by G. E. Thomas in 1949, went on to become the basis of Ethernet. The Atlas was one of the world's first supercomputers aiming to perform 1 million operations per second, was built at Manchester using discrete transistors, and was the most powerful computer anywhere in 1962.

Following in that tradition, Prof Steve Furber was awarded the Lovelace Medal in 2015 and gave the Lovelace Lecture the same year. Prof Furber started his research career as a PhD student and subsequently Research Fellow in aerodynamics at the University of Cambridge. He was drawn into various small projects at Acorn by Hermann Hauser, when Christopher Curry found out that the BBC was looking to create a small computer to support a series of TV programmes for schools. Prof Furber worked with Sophie Wilson to create a design for the BBC tender proposal. Hauser convinced Furber and Wilson to put together a wire-wrap prototype along with a case design by Alan Boothroyd to show the BBC team. Apparently a working prototype on one side and a case design on the other was enough to convince the BBC to award the contract to Acorn build the BBC Micro.

The BBC Micro took off in a way no one had anticipated. The BBC initially estimated machine sales of around 12,000 but which in fact became sales of over 1.5m machines. As soon as computers came within financial reach, there was huge and unexpected public demand for machines. The BBC Micro was also piggy-backed onto the Government's computer literacy programme, which also contributed to the high demand from schools. It became the de facto standard computer, despite competition from Research Machines Ltd.

Following on from the success of the BBC Micro, designers at Acorn started experimenting with commercially available 16-bit microprocessors for use in successor products. The 6502 8-bit microprocessor used in the BBC Micro had quite good real-time performance (interrupt response time). However, the 16-bit microprocessors had complex instruction sets, aimed at competing with mini-computers available at that time, and as a consequence quite poor interrupt response times. In addition, the 16-bit microprocessors did not make efficient use of memory, which was an expensive component in personal computers. The Acorn team established that the memory was faster than the commercially available 16-bit microprocessors as a result of their complex instruction sets and the number of clock cycles they required to perform operations.

The Acorn team, disappointed with these commercially available 16-bit microprocessors, became interested in some Californian research projects describing a phenomenon called RISC (the reduced instruction set computer). Dave Patterson and Dave Ditzel at University of California, Berkeley with input from John Hennessey at Stanford in particular pioneered this new approach of optimising the processor for a single-chip implementation by using a much simpler instruction set and optimising the architecture through pipelining. Prof Furber recalls "I was sent to Arizona expecting to find a gleaming office building with expensive equipment and a large expert team, instead the Western Design Centre was a bungalow in suburban Phoenix using Apple IIs, and summer placement students from local high schools." A further surprise was learning that a class of graduate students at Berkeley built a very competitive RISC microprocessor in a year. Prof Furber came away from that visit feeling "well, if they could design a microprocessor, then maybe we could too." Sophie Wilson had already been experimenting with RISC ideas, so they formalised the project and 18 months later, they had had the first working Acorn RISC Machine (ARM) chip.

During the 1980s ARM was used by Acorn in the Archimedes product and subsequent variants, shipping about 50,000 units per year, mainly into UK schools. In 1990, Apple expressed an interest in forming a joint venture with Acorn and VLSI Technology to develop ARM for their desktop computer products. The ARM chip was then adopted for Apple's Newton project, an early example of a personal digital assistant, a forerunner of the modern smart phone. Subsequently, there were sales of the ARM chip to mobile phone maker Nokia and other new clients.

Thirty years later, it is now estimated, that 120 Billion ARM chip variants have been manufactured, increasing by over 10 Billion each year. The ARM is by far the biggest volume microprocessor in the world with 75% of everything connected to the internet powered by ARM chips. The simplicity of the ARM design meant it was ideal for system-on-a-chip designs which was one of the most transformative aspects of the chip.

Nowadays, understanding the human brain is one of the great frontiers of science. Prof Furber says "neuroscientists know a lot of detail about the basic components: the neurons, the synapses between the neurons and the 1500 proteins that play a role in synapse function. But we don't have the system-level knowledge." Scanners can see the movement of activity around the brain. But at the information level, we only have computer models, "we can't see that" says Prof Furber.

To contribute to the quest to understand information processing in the brain, Prof Furber has developed the SpiNNaker project. SpiNNaker, a Spiking Neural Network Architecture, is a brain-inspired computer, comprising around 0.5 million processor cores, which has cost over £1M to build using UK research council and EU funding. SpiNNaker has been 20 years in conception and 10 years in construction, "a large chunk of my career has gone into this machine" says Prof Furber.

SpiNNaker is a platform for simulating very large brain-like networks so that neuroscientists can run simulations of abstract neural networks in order to test their hypotheses of brain function. The biggest problem, in building artificial neural networks, is achieving the degree of connectivity in the brain. Prof Furber says "we have just under 100 billion neurons in our head. Each of those neurons has on average many thousands of connections; in some cases quarter of a million connections." These are vast numbers, "of the order of 10^{15} connections" says Prof Furber.

Standard interconnect technologies don't really scale. So, "the major innovation in SpiNNaker is how we do communication" said Prof Furber. Otherwise, SpiNNaker is a conventional massively parallel high performance computer but using little mobile phone processors. A communications fabric is used to multicast any spikes produced by each processor node to other nodes in the computer. Such a spike, a tiny data packet, is "multicast and may go to 10,000 different destinations in the machine, in a small fraction of a millisecond, which is a requirement of real-time brain models" said Prof Furber. SpiNNaker uses packet-switched routing, and tiny 40-bit packets, to achieve this.

Prof Furber said “we are very keen to demonstrate the value to science, now that is beginning to happen. We have recently produced a very detailed model of a square millimetre of brain cortex, with a team from the Jülich Supercomputing Centre, Germany.” This is the first time any neuromorphic platform has been shown to support a biological model of that complexity and scale “over the next year, we plan to scale that up” says Prof Furber. In the spirit of open science, free access to SpiNNaker is available over the internet under the European flagship Human Brain Project.

Following on from the Baby and Atlas, SpiNNaker is another exciting computer innovation to emerge from Manchester.

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