Essay

Supercomputers, Artificial Intelligence & Brain Power

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Abstract

The title for the fastest supercomputer has been taken by Tianhe-2 benchmarked at 33.86 Petaflops which is about 100,000,000 times faster than the Cray. This begs the question what it can be used for. One such use is artificial intelligence. But, can we simply map the brain and simulate it on a computer?

Key Words: supercomputer, Tianhe-2, artificial intelligence, brain scan, simulation.

Supercomputers

In 1984 when big brother was meant to invade our privacy I was a graduate student in Glasgow working on lattice gauge theories. As part of the research towards my doctorate I spent a week on a special mission to Germany where I was allowed into a secret nuclear base to borrow some computer time on a Cray-XMP. It was the world's fastest supercomputer of the time and there was only one in Europe so I was very privileged to get some time on it even if it was only a few hours of CPU. Such resources would have been hugely expensive if we had to pay for them. I remember how the German's jokingly priced the unseen cost in BMWs. The power of that computer was 400 Megaflops and it had a massive 512 Megabyte ram disk.

The problem I was working on was to look for chiral symmetry breaking in QCD at high temperatures and densities using lattice simulations. In the last few years this has been seen experimentally at the LHC and other heavy ion accelerators but back then it was just theory. To do this I had to look at the linear discretised Dirac equation for quarks on a background of lattice gauge fields. This gave a big hermitian NxN matrix where N is the number of lattice sites times 3 for the QCD colours. On a small lattice of 16^4 sites (working in 4D spacetime) this gave matrices of 196608 square and I had to find its smallest eignevalues. The density of this spectrum says whether or not chiral symmetry is broken. Those are pretty big matrices to calculate the eigenvalues of, but they are sparse matrices with only 12 complex non-zero components in each row or column. My collaborators and I had some good tricks for solving the problem. Our papers are still collecting a trickle of citations.

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Thirty years later big brother has finally succeeded in monitoring what everyone is doing in the privacy of their own homes and my desktop computer has perhaps 100 times the speed and 30 times the memory of the Cray-XMP, which makes me wonder what I should be doing with it. The title for the fastest supercomputer has recently been taken by China's Tianhe-2 which has been benchmarked at 33.86 Petaflops and it has a theoretical peek performance of 53.9 Petaflops so it is about 100,000,000 times faster than the Cray. This beats Moore's law by a factor of 5000 which may be in part due to governments being willing to spend much more money on them. The US who more commonly hold the record wont be beaten for long because the NSA is said to have a secret and very expensive project to build a supercomputer to surpass the Exaflop mark in the next few years. I doubt that any HEP grad students will have a chance to use it.

This begs the question: Why do they need such powerful computers? In the past they may have been used to simulate nuclear explosions or design stealth fighters. Now they may be needed to decrypt and search all our e-mails for signs of dissenting tendencies, or perhaps there is an even more sinister purpose.

Artificial Intelligence

When computer pioneers such as Von Neumann and Turing conceived the possibility of building electronic computers they thought it would be easy to make computers think like humans even though they had no idea how fast computers would become. This turned out to be much harder than expected. Despite some triumphs such as "superhuman" chess programs which can now crush the best grandmasters (seediscussion at World Science Festival) the problem of making computers think like us has seen little progress. One possibility that looked promising back in the 1980s was neural networks. When I left academia some of my colleagues at Edinburgh were switching to neural networks because the theory and the computing problems were very similar to lattice calculations. Today their work has applications in areas such as facial recognition but it has failed to deliver any real AI.
Now a new idea is raising hopes based on the increasing power of computers and scanning technologies. Can we simply map the brain and simulate it on a computer? To get a flavour of

what is involved you can watch this TED talk by neuroscientist Sebastian Seung. His aim is to simulate a small part of a mouse brain, which seems quite unambitious but actually it is a huge challenge. If they can get that working then it may be simply a case of scaling up to simulate a complete human brain. If you want to see a project that anyone can join try OpenWorm which aims to simulate the 7000 neuro-connections of a nemotode worm, the simplest functioning brain in nature (apart from [insert your favourite victim here]).

Brain Scans

An important step will be to scan every relevant detail of the brain which consists of 100 billion neurons connected by a quadrillion synapses. Incredibly the first step towards this has already been taken. As part of the European Human Brain Project funded with a billion Euros scientists have taken the brain of a 65 year old women who died with a healthy brain, and they have sliced into 7404 sections each just 20 microns thick (Obama's Brain Mapping Project which has had a lot of publicity is just a modest scaled down version of the European one). This is nearly good enough detail to get a complete map of the synaptic connections of every neuron in the brain, but that is not clear yet. If it is not quite good enough yet it is at least clear that with an order of magnitude more detail it will be, so it is now only a matter of time before that goal is achieved.
If we can map the brain in such precise detail will we be able to simulate its function? The basic connectivity graph of the neurons forms a sparse matrix much like the ones I used to study chiral symmetry breaking but with about a trillion times as many numbers. An Exaflop supercomputer is about a trillion times more powerful than the one I used back in 1984, so we are nearly there (assuming linear scaling). The repeated firing of neurons in the brain is (to a first approximation) just like multiplying the signal repeatedly by the connection matrix. Stable signals will be represented by eigenvectors of the matrix so it is plausible that our memories are just the eigenvalue spectrum of the synaptic map and the numerical methods we used in lattice gauge theories will be applicable here to.

However, the processes of logical reasoning are more than just recalling memories and will surely depend on non-linear effects in the brain just as the real physics of lattice QCD depends on the highly non-linear interactions of the gauge field. Will they be able to simulate those for a human brain on a computer? I have no idea, but the implications of being able to do so are enormous. People are starting to talk seriously about the moral implications as well as what it may bring in capability. I can understand that some agencies may want any such simulations to be conducted under a veil of secrecy if possible. Is this what is driving governments to push supercomputer power so far?

It would be ironic if the first true artificial intelligence is actually a faithful simulation of a human brain. No doubt billionaires will want to fund the copying of their own brains to giant supercomputers at the end of their lives if this becomes possible. But once we have the capability to simulate a brain we will also start to understand how it works, and then we will be able to build intelligent computers whose power of thought goes far beyond our own. Soon it may no longer be a question of if this is possible, just when.

Reference

1. http://blog.vixra.org/2013/06/28/brain-power/