A conversation with Dr. Michael Frank, January 22, 2020

Participants

- Dr. Michael Frank - Senior Technical Staff Member, Sandia National Laboratory
- Joseph Carlsmith - Research Analyst, Open Philanthropy

Note: These notes were compiled by Open Philanthropy and give an overview of the major points made by Dr. Frank.

Summary

Open Philanthropy spoke with Dr. Michael Frank as part of its investigation of what we can learn from the brain about the computational power ("compute") sufficient to match human-level task performance. The conversation focused on the applicability of Landauer's principle to the brain's computation.

Reversible computing

Dr. Frank is an expert on reversible computing, a computing paradigm that aims to use logically reversible algorithmic operations, together with extremely non-dissipative (e.g., almost thermodynamically reversible) computing hardware, to achieve very high-levels of energy efficiency.

In particular, by using logically reversible operations to avoid erasing bits, reversible computers aim to bypass limitations imposed by Landauer's principle, according to which erasing a single bit requires at least kT ln 2 energy, where k is Boltzmann's constant, and T is the absolute temperature.

Challenges of reversible computing

A lot of advanced physics and engineering is necessary for figuring out how to do reversible computing well. The goal is to create very fast, very energy-efficient systems. Currently, the closest examples are fairly rudimentary systems like simple oscillators. The transition to reversible computing won't happen overnight, and it may take decades, even once fundamental problems are solved.

Engineering challenges

The biggest challenge is figuring out the fundamental physics involved in improving the trade-offs between energy dissipation and speed in reversible processes. We don't know of any fundamental limits in this respect at the moment, but there may be some, and we need to understand them if so. One question is whether exploiting quantum phenomena can help. Dr. Frank is working on this at the moment.

There are also practical issues involved in improving the degree of reversibility of mechanisms that we know how to design in principle, but which require a lot of advanced, high-precision engineering to get the level of efficiency we want. And there is a lot of engineering and design work to do at the level of circuits, architectures, design tools, and hardware description languages.

Algorithmic overheads

In theoretical models of reversible computing, there are some algorithmic overheads in the computing resources (e.g., memory and number of operations) required to perform a given computation, relative to irreversible methods. However, very little work has been done on the subject.

We know of examples where there is no overhead -- for example, you can simulate a reversible physical system without substantial increases in the memory or number of operations required. In other cases, there are some overheads, and optimal systems will need to find a sweet spot, in which the overhead from the reversibility of the system is outweighed by the energy savings you get from that reversibility. The location of that sweet spot will depend on a lot of factors, and it will likely shift over time as the quality and cost of reversible devices improves.

Lack of resources

Much less money has been spent on reversible computing research than traditional computing research. Dr. Frank estimates tens of millions for reversible computing over several decades, in contrast with the trillions invested in traditional computing paradigms. Much more investment in reversible computing may be required to create a full technology stack, together with supporting infrastructure.

Reversible computing and the brain

It seems reasonable to Dr. Frank to use Landauer's principle to upper-bound the bit-erasures that the brain could be implementing. However, because we have relatively little understanding of which processes in the brain are important to cognition, and because Dr. Frank is not himself a neuroscientist, he is reluctant to speculate about the compute required to replicate the brain's task-performance.

FLOP/s also might not be the right unit of computational work to use in thinking about simulating the brain. Logical gate operations might be preferable.

Possibility of reversible processes in the brain

Dr. Frank thinks that it is possible that there are processes in the brain that are close to thermodynamically reversible, and that play a role in computation. We don't know enough about the brain to answer confidently either way.

Chemical reactions in systems close to equilibrium, involved in maintaining homeostasis in a cell, could be a candidate for such a process. These might not be happening at a high rate, or consuming much energy, but they might be doing something useful that wouldn't be included in a strict Landauer accounting, because they might dissipate less than a kT per relevant operation. Similarly, other gradual processes related to plasticity may be less dissipative, per update, than e.g. neural firings (though the updates themselves might be fairly small). And subtle chemical effects may be involved in altering correlations between brain regions, and/or introducing helpful forms of noise.

We don't have positive evidence that such reversible effects exist and are important to cognition, but we also don't have positive evidence that rules this out.

However, Dr. Frank thinks that it's a reasonable first-order assumption to assume that those effects, if they exist, would only have a small, second-order effect on the amount of computational work required to simulate the system. If these effects are there, they may be fairly subtle and gradual, acting in a long-term way on the brain, in a manner we are not close to understanding.

Dissipation in neural mechanisms

In general, Dr. Frank does not see evidence that biology is attempting to do anything like what human engineers working on reversible computing are trying to do. Reversible computing is an extremely advanced tier of high-precision engineering, which we're still struggling to figure out. Biology, by contrast, seems perfectly happy with what it can do with simple, irreversible mechanisms.

One example difference is that reversible computing engineers can use inertia to propagate signals at the speed of light, with very little energy dissipation. They can also achieve similarly efficient, high-speed results by sending magnetic flux quanta through superconducting circuits. The brain, however, relies on diffusion, which cannot take advantage of such inertia.

In general, most signaling mechanisms in biology are highly dissipative. For example, the biophysical processes involved in neural firing (e.g., vesicle release, action potential propagation, ion channels driving the ion concentrations to new states) dissipate lots of energy. Indeed, most of life seems to be based on strongly driven (e.g., irreversible) processes.

Overall opinion

Overall, Dr. Frank would lean weakly towards the view that you could make a digital model of cognition without including any subtle reversible processes, but because he is not an expert on the neural computation, he would not bet confidently one way or another.

All Open Philanthropy conversations are available at
http://www.openphilanthropy.org/research/conversations