Memcomputing goes commercial

Massimiliano Di Ventra[1,2]

[1] Department of Physics, University of California, San Diego,

[2] CMRR

9500 Gilman Drive, La Jolla, California 92093-0407, USA

Our modern computers have served us well (and continue to serve us well) in solving a wide variety of scientific and industrial problems that we face on a daily basis. In their basic layout, modern computers have been built around the idea that processing of information is done by a unit that is physically distinct from the one where information is stored. It is on this so-called von Neumann architecture that we run our algorithms to tackle any problem. It is then not too difficult to understand that this model leads to an obvious latency in the transfer of information between the processing and memory units, thus creating a bottleneck in the actual execution speed and requiring large amounts of energy to move data.

These limitations are particularly pressing nowadays in view of the necessity to process increasingly large amounts of data, coupled with the physical limitations to scale the fundamental units (the transistors) that make up our modern computers. All this has called into question the validity of this model of computation and has challenged the scientific community to come up with viable alternatives.

One such alternative is quantum computing that has attracted a considerable amount of attention from both the research community and the public at large, even securing its own National Quantum Initiative Act that aims to facilitate and accelerate the development of such paradigm of computation. However, although much heralded as a powerful alternative to our present computers, we need to acknowledge that quantum computers, even if built to scale, would affect only a limited number of computational problems (e.g., encryption or materials design). There is indeed not much evidence that they would be any better than the best algorithms available (running on our standard computers) at solving many hard problems of scientific and industrial interest, such as combinatorial optimization ones.

In addition, quantum computers require a hardware solution to show their full advantage, namely they cannot be simulated efficiently (read with polynomial time and memory) on our traditional computers. This, coupled with the necessity to operate at cryogenic temperatures, makes their deployment to real-life applications not immediately obvious.

Figure 1: Logo of MemComputing, Inc. (http://memcpu.com/).

It is, however, a misconception to think that only quantum phenomena may provide advantages compared to classical ones. In fact, there is a physical property shared by all quantum and non-quantum physical systems that allow us to rethink at once both the fundamental architecture of our modern computers and the nature of what constitutes an algorithm in its traditional sense. This property is *memory* or time non-locality, namely the fact that the state of a given physical system always depends, to some extent, on the history of its dynamics.

In a series of publications, my group and I have then argued that a novel computational paradigm can be conceived if memory is used to both process and store information [1,2]. We have named this novel computing paradigm *memcomputing*, where the prefix "mem" stands precisely for "memory" [1-4]. Memcomputing represents a radical departure from both our traditional computers (and the algorithms that run on them) and quantum computers.

Since time non-locality is also available in non-quantum systems, memcomputing machines can be realized in practice with available electronic technology [5]. In fact, standard CMOS technology is all is needed at the moment to realize this paradigm of computation, of course with an architecture that is not of the von Neumann type.

Importantly, though, since the electronic components of memcomputing machines are non-quantum, the equations of motion describing them can be efficiently simulated on our modern computers (they are standard ordinary differential equations). In fact, we have shown that the *simulations* of memcomputing machines can already deliver solutions of some hard combinatorial optimization problems orders of magnitude faster than traditional algorithms [4,6,7]. The reason for this substantial speed-up is related precisely to the fact that a given problem is first transformed into a dynamical system, whose physical properties drive it towards the solution [4].

The initial research behind this novel approach has been funded primarily by CMRR and has led to the founding of a start-up, MemComputing, Inc. (http://memcpu.com/), located in San Diego. MemComputing, Inc. is already working with industrial partners to solve their most challenging optimization problems. So far, the variety of problems successfully tackled by the software of MemComputing, Inc. has surpassed hundreds of thousands of instances, ranging from maximum satisfiability to quadratic unconstrained binary optimization to linear integer programming. For instance, in the latter class, MemComputing, Inc. has been able to solve in a few minutes a problem that has eluded solution for almost a decade (see http://miplib2010.zib.de/miplib2010/f2000) [8].

In summary, it is clear that non-quantum dynamical systems, in particular those representing memcomputing machines, offer great advantages in solving problems otherwise difficult to tackle with traditional algorithms and even quantum computers. This statement is not hypothetical. By now, it has been corroborated by a wide range of problem instances, whose solutions provide strong evidence that the memcomputing paradigm represents a viable and powerful model of computation.

[1] M. Di Ventra and Y.V. Pershin, *Computing: the Parallel Approach*, Nature Physics **9**, 200 (2013).

[2] M. Di Ventra and Y.V. Pershin, *Just add memory*, Scientific American **312**, 56 (2015).

[3] F. L. Traversa and M. Di Ventra, *Universal Memcomputing Machines*, IEEE Transactions on Neural Networks and Learning Systems **26**, 2702 (2015).

[4] M. Di Ventra and F.L. Traversa, *Memcomputing: leveraging memory and physics to compute efficiently*, J. Appl. Phys**.** **123**, 180901 (2018).

[5] F. L. Traversa and M. Di Ventra, *Polynomial-time solution of prime factorization and NP-complete problems with digital memcomputing machines*, Chaos: An Interdisciplinary Journal of Nonlinear Science **27**, 023107 (2017).

[6] F. L. Traversa, P. Cicotti, F. Sheldon, and M. Di Ventra, *Evidence of an exponential speed-up in the solution of hard optimization problems*, Complexity **2018**, 7982851 (2018).

[7] F. Sheldon, F.L. Traversa, and M. Di Ventra, *Taming a non-convex landscape with dynamical long-range order: memcomputing the Ising spin glass*, arXiv:1810.03712.

[8] F.L. Traversa and M. Di Ventra, *Memcomputing integer linear programming*, arXiv:1808.09999.