2019

Spring 2019
Issue 48

CMRR REPORT

Center for Memory and Recording Research

IN THIS ISSUE

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LETTER FROM THE DIRECTOR

As you can see in both the presentations and discussions with students and faculty, the Center for Memory and Recording Research continues to strengthen its contributions to the study of magnetic recording systems as well as expanding its research into non-volatile memories. The research on non-volatile memory is also highlighted by the 10th anniversary of our annual Non-Volatile Memories Workshop (NVMW), which was held on March 10-12, 2019 and was organized by Paul H. Siegel, Steve Swanson, Jishen Zhao, Eitan Yaakobi, and Hung-wei Tseng. This workshop provides a unique showcase for outstanding research on solid state and non-volatile memories.

We also continue to build our partnership between CMRR, NYU, the University of Lorraine, the University of Paris-Sud, and the Thales Laboratory in France. The collaboration is part of the new International Associated Laboratories (LIA), which is a "laboratory without walls", focused on Nanoelectronics and sponsored by the Centre National de la Recherche Scientifique (CNRS) in France. This association will enhance the exchange of faculty, postdocs, and students between labs, and provide new opportunities for collaborative research.

NVMW 2019

More than 200 researchers from industry and academia recently gathered here at UCSD to share their latest ideas about the future of computer memory technology and data storage systems, as UCSD hosted its 10th anniversary annual Non-Volatile Memories Workshop March 10-12, 2019.

Like its predecessors, NVMW 2019 provided researchers and practitioners the opportunity to gain a broader understanding of what is needed to accelerate the development and adoption of new non-volatile storage paradigms, and to establish professional relationships that will provide the basis for further technological advances.

RESEARCH HIGHLIGHT

Memcomputing Goes Commercial

Massimiliano Di Ventra

UC San Diego, Dept. of Physics

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

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.

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].

RESEARCH HIGHLIGHT

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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.

AWARDS

Dr. Frank Talke was elected an Honorary Member of ASME for his contributions to information storage technology, color ink jet printing and medical device technology. Dr. Talke received his award at the Honors Assembly during the ASME Mechanical Engineering Congress & Exposition in Pittsburgh, Pennsylvania last November.

Congratulations to **Dr. Oscar Vazquez Mena** for being honored by UC San Diego as an individual who upholds the legacy of César E. Chávez by serving the community and advocating for the rights of the voiceless and underserved! Dr. Vazquez Mena is a Faculty Award Recipient in appreciation for his commitment to carry on the César E. Chávez legacy. Before joining UCSD, Dr. Vazquez founded the Indigenous Pipeline to UC Berkeley, promoting the access of first-generation children of indigenous nahuatl and mayan communities to higher education in the Bay Area. Currently at UC San Diego, he is on the committee and a speaker for “Comienza con un Sueño”.

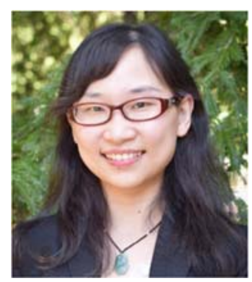
NEW AFFILIATES

Dr. Chunhui Du is a new Assistant Professor in the department of Physics. Dr. Du received her Ph.D. at The Ohio State University in 2015. Her research group focuses on developing quantum sensing and imaging technique to study various properties (spin, charge, and heat, etc.) of quantum materials in the nanometer scale.

Dr. Hailong Wang is a new Assistant Research Scientist at CMRR. Dr. Wang received his Ph.D. in Physics at The Ohio State University in 2015. His previous research mainly focused on the spintronics in various magnetic textures. His research activities at CMRR will involve the spin transport and dynamics of novel magnetic systems including antiferromagnetic insulators, frustrated spin liquids, 2D magnets etc.

Dr. Kenji Nomura is an Assistant Professor in ECE. He received his Ph.D. degree in Material Science Engineering from the Tokyo Institute of Technology, Japan, in 2004. Afterwards, Dr. Nomura became a postdoctoral researcher in Materials Science Laboratory, Tokyo Tech. He became an Associate Professor in the Frontier Research Center at Tokyo Tech in 201-. He developed a key semiconductor material and invented high-performance oxide-TFTs. He worked at Qualcomm, Inc. as a principal engineer from 2012-2017. In 2018 he joined JSOE here at UCSD as a faculty member in ECE.

Dr. Jishen Zhao is an Assistant Professor in Computer Science and Engineering Department. She received her Ph.D. in 2014 at the Pennsylvania State University. Her research spans and stretches the boundary between computer architecture and system software, with an emphasis on memory and storage systems and domain-specific acceleration.



NEW POSTDOCS

Dr. Alex Phan, a former Ph.D. student in Frank Talke's group, is now continuing on as a postdoctoral researcher with Dr. Talke. Dr. Phan received his Ph.D. in Summer 2018 and is currently working on research in the areas of ophthalmic instrumentation and medical devices. Since graduating he has begun a new research project to investigate how traditional ophthalmic instruments can be miniaturized and made portable to connect to smartphone devices. With this project, he and the Talke research group hope to help make ophthalmic care more accessible and utilize internet enabled devices to facilitate the screening process for patient care.

Dr. Igor Vaskivskyi is a postdoctoral researcher with Dr. Fullerton. Dr. Vaskivskyi received his Ph.D. in Mathematics and Physics at the University of Ljubljana, Slovenia in 2015. Dr. Vaskivskyi's research activities involve time-resolved resonant soft X-ray diffraction at XFELS, magnetic X-ray correlation spectroscopy, magnetic X-ray correlation imaging and time-resolved spatial imaging via phase retrieval.