The Potomac Institute for Policy Studies
VITAL Center Presents

The Future of Computing

Potomac Institute for Policy Studies

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Executive Summary

For over 50 years, Moore's Law has successfully predicted the increase of computing power based on dimensional scaling. Radical technological advances over decades of exponential progress in microelectronics have profoundly altered the way we live. We are reaching the end of Moore's Law, and with that, the end of conventional, scaling-based computing progress. Fundamentally new approaches are needed to push forward the field of computing and ensure the strategic technological advantage of the United States. We must now consider the future of computing that goes beyond conventional complementary metal–oxide–semiconductor (CMOS), von Neumann architecture, or even Boolean logic. Future approaches to computational hardware must provide substantially increased power efficiency and computational ability enabled by development of novel component and architectural designs. At the same time, new software designs will need to accommodate a variety of new and emerging applications and hardware types.

On October 31st, 2019, the Potomac Institute for Policy Studies (PIPS) held a panel discussion entitled "The Future of Computing" to explore future trends in computing and to discuss radically new computational paradigms. Four panelists with expertise spanning government, military, academia, and industry explored emerging developments and future visions of computing. The discussion ranged from bio-inspired computational approaches, to 3D integration, to the new paradigm of thermodynamic computation. A robust Q&A session with the audience followed the panelists' remarks.

Future computational approaches must enable substantial increases in power efficiency and customization while balancing the resulting cost of fabrication. The United States government (USG) often requires lower volume and higher specialization than commercial industry, which results in higher-costs and slower production—factors that intensify the hesitancy of private industry investment. Further, radically new computing methods will require high-risk, high-payout, long-term investments. The USG has greater incentive and ability to drive these riskier investments than industry.

In order to maintain American global leadership in innovation, ensure economic competitiveness, and provide a strategic advantage, the USG must develop and invest in fundamentally new computing paradigms. The USG should foster innovation, encourage collaboration, and invest in alternatives to conventional silicon-based computing methods to usher in the next era of computing. This requires a commitment in both vision and budget resources. It is vital to national security that the USG drive the development and steer the future of computing, as these new systems that have the potential to bring about positive advancements alongside disruptive technological change.

Findings

The panelist discussion brought to light several findings regarding the future of computing post-Moore's Law:

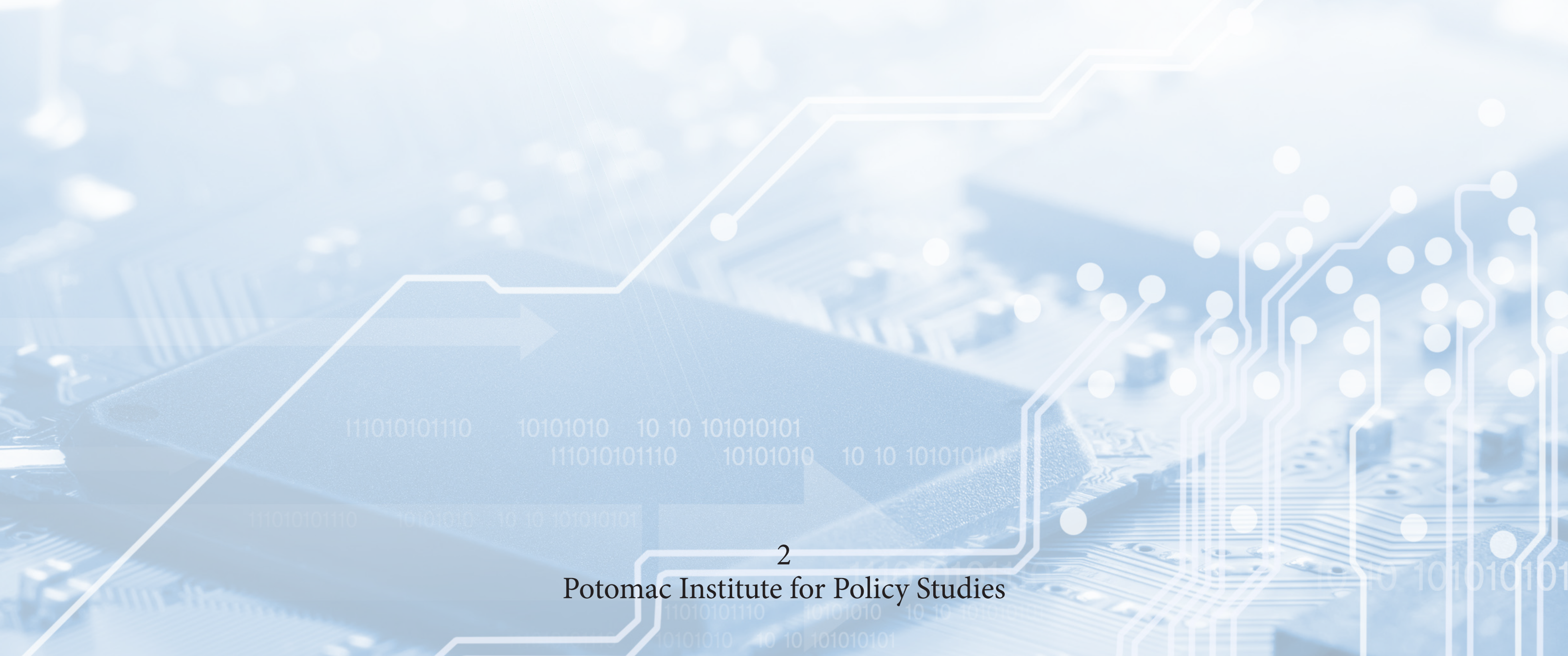
1. **Standard complementary metal–oxide–semiconductor (CMOS) technology has run its course.** Conventional scaling-based computing with traditional CMOS is approaching an end.
2. **China is becoming a prominent player in the development of neuromorphic chips and artificial intelligence.** China has made a concentrated effort to heavily invest in these future computing approaches and develop its domestic microelectronics industry.

3. **Approaches offering substantial increases in power efficiency are the future.** Orders of magnitude in increased power efficiency will be required of future computational hardware.
4. **Customizable hardware offers tailorable design architectures.** Custom hardware offers great improvements in power efficiency over more general-purpose solutions. However, a key challenge towards achieving customizable hardware is cost efficiency.
5. **The promise of artificial intelligence (AI) and machine learning necessitate better computing hardware.** Substantially increased computing capabilities are necessary to handle the ever-increasing computational needs of advanced AI.

Conclusions

Based on the panelists remarks and the robust audience Q&A discussion, we have arrived at several significant conclusions:

1. **Future computing methods will have to look beyond traditional CMOS architectures.** Power dissipation, memory bandwidth, and cost walls have been reached with the end of Moore's Law scaling.
2. **The US risks losing its dominance in microelectronics**. The US microelectronics industry and national security are closely linked. China has invested significant resources into microelectronics and new computing capabilities and has the potential to surpass the US market.
3. **There is more than one future computing paradigm.** Unlike in recent decades where digital, silicone-based computing has dominated, there will be multiple types of computational approaches in the future. Several were discussed during the panel: (a) analog neuromorphic computing with memristors, (b) thermodynamic-based self-evolving computation and (c) customization by advanced packaging paradigms (3D/2.5D).
4. **A return to analog computing paradigms may offer needed improvements in power efficiency.** Analog methods are efficient, low energy, and particularly appropriate for neuromorphic computation needs (i.e. linear algebra problems). They have the potential to increase power efficiency by many orders of magnitude.
5. **Cost-effective customization of hardware can yield substantial power efficiency benefits.** The automated design of "accelerators" will be a major factor in enabling customization in addition to 3D integrated circuit (3DIC) methods. Further, the low-cost, low-to-mid volume fabrication paradigm will also be of increasing importance, especially to the USG which often requires highly-specialized, low-volume fabrication.



Recommendations

The following recommendations aim to provide a forward-looking strategy for the USG to ensure US microelectronics competitiveness and provide a strategic advantage for the US:

1. **The USG must "play offense."** The USG must ensure the US leadership in new, major areas of advanced computing and must drive transformative innovation in the future microelectronics industry. The USG cannot and should not rely exclusively on private industry or foreign nations to develop the future of computing.
2. **The USG needs to prioritize long-term, risk-tolerant investments.** More long-term, higher-risk investments must be made in computing methods to achieve high-reward innovation. The USG has a greater ability to withstand risk on the timescale that research and development (R&D) requires.
3. **The USG must foster the development of future paradigm(s) in computing.** The USG should explore potential avenues by supporting long-term R&D in key post-Moore areas. Centers of Excellence and university/industry consortia should be established to expand this approach.
    a. **Invest in new analog-based approaches to computing.** Analog computing can allow certain operations that are inherently difficult with digital computers and offer approximate computations at higher processing speed using less energy than digital.
    b. **Enable cost-efficient custom hardware solutions for microelectronics.** The USG should explore the low-volume, high-mix fabrication paradigm. This should include the application of artificial intelligence (AI) and machine learning (ML) to facilitate automated design.
    c. **Explore thermodynamic approaches to computing.** The intermediate "mesoscopic" domain should be explored in addition to the classic and quantum regimes. An appropriate study system must be defined to explore this concept.
    d. **Computers that "self-evolve" using deliberate noise as stimulus warrant pursuit.** Traditionally, the USG has funded research in the classical and quantum regimes. Development in the intermediate "mesoscopic" regime, where fluctuations are significant, is necessary.

Event Summary

Computing has radically changed every facet of our lives, allowing computers to become ubiquitous in modern society. Decades of exponential progress in computing systems and architectures have revolutionized the microelectronics industry and our way of life. In line with Moore's Law and Dennard Scaling, computing power has seen steady exponential growth over the past five decades, successfully predicting the doubling of computing power every 18 to 24 months. The fastest supercomputer in the 1980s (e.g. the Cray Y-MP) could house up to eight 32-bit processors for a total of speed of over 2 gigaflops (or 209 flops) using 200 kilowatts of power.[1] Today, the iPhone X's A13 Bionic processor clocks in at more than 100 gigaflops using up to ~6 watts.[2] By current standards, the Cray Y-MP would have a near impossible time running Microsoft 10 operating system, let alone being classified as a supercomputer – a system does not even make the TOP500 list if it isn't hitting at least 1.14 petaflops (11.415 flops).[3]

Since the development of early silicon-based computers, we have made significant increases in power and cost efficiency, computational performance, and memory bandwidth. However, Moore's Law is coming to an end. Consequently, this is ushering in an end to the sustained growth of traditional scaling-based computing progress. Conventional computing with silicon-based computing technology has run its course. These approaches have reached a wall, where traditional regular improvements to power dissipation, memory bandwidth, and cost efficiency have begun to plateau. There is a pressing need to establish the new frontier of computing through development of novel hardware architectures and paradigms as well as innovative software approaches.

As our computing needs change, so too must our computing methods. Radically new computing paradigms are needed to address increasing requirements in new and growing technological fields such as artificial intelligence (AI) or blockchains. The rising computational demands of AI necessitate development of much more powerful computing methods. OpenAI reported that the computing power required for advanced AI processes has been doubling every 3.5 months at the same time progress in computing power has slowed.[4] Soon, the capabilities of current computing hardware will be surpassed. New hardware must be developed to enable the greatly increased computational requirements of these new and emerging technologies.

The USG must ensure the US maintains its strategic and economic advantage in computing. The US must drive transformative innovation in the microelectronics industry and stay competitive in the global market. Significant R&D investments by China in new and emerging computing technologies like quantum computing and neuromorphic computing have been driven by China's ambition to be a global leader in science and technology. According to a Center for a New American Security 2019 report, China aims to develop disruptive, radical innovation in strategic technologies, potentially leapfrogging US technological advances, to establish itself as a science and technology superpower.[5] The USG must

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[1] http://www.0x07bell.net/WWWMASTER/CrayWWWStuff/Cfaqp5.html

[2] https://www.apple.com/iphone-11/specs/; https://gadgetversus.com/processor/apple-a13-bionic-specs/

[3] https://www.top500.org/lists/2019/11/

[4] https://openai.com/blog/ai-and-compute/

[5] Kania EB, Costello JK. Quantum Hegemony? China's Ambitions and the Challenge to U.S. Innovation Leadership. Center for a New American Security. September 12, 2018. https://www.cnas.org/publications/reports/quantum-hegemony

recognize China's S&T goals and leverage the US's ability to innovate and develop technological advances. Although behind current capabilities in the US and China, Russia has started initiatives in quantum computing (investing almost $800 billion in R&D over the next five years) and unconventional computing approaches, such as optical computing.[6] The USG cannot wait for foreign adversaries to develop and maintain exclusive control on new computing systems that have the potential to bring about disruptive technological change.

Novel computational approaches are of vital interest to the USG. The National Strategic Computing Initiative (NSCI) was launched by an executive order in 2015 to foster high-performance computing technologies.[7] A recent NSCI update highlighted three core goals: (1) enable the future of computing, (2) provide a strategic foundation for computing, and (3) ensure coordinated public-private partnerships. [8]Further, in 2017, the Defense Advanced Research Projects Agency (DARPA) launched the Electronics Resurgence Initiative (ERI).[9] The ERI supports the development of post-Moore's law technologies that contribute to US national security interests and ensure continued success of the US microelectronics industry. Programs like these must be fostered and allowed to reach their full potential.

Development of future computing approaches dictates progress in both the hardware and software components. Future computing hardware elements must enable increased power efficiency with increased computational ability through novel component and architectural designs. Likewise, new software designs will need to be appropriate for a variety of applications and varying hardware types.

There are multiple computational paradigms that should be explored from neuromorphic computing to customizable computing architectures to thermodynamic computing. Non-von Neumann technologies such as neuromorphic computing or quantum computing offer radically new computing architectures. Neuromorphic computing (which refers to the broad category of brain-inspired computing) has displayed significant promise in power-efficiency and processing speed compared to conventional computing approaches.[10]

Alternative future computing paradigms might also include computing based on thermodynamics or computers that are able to "self-evolve" using stimulus from background noise. Traditionally, computing approaches have focused on the classic or quantum domains; however, research into the "mesoscopic" regime (the area between classical and quantum) merits exploration. Thermodynamic computing could allow hardware elements to evolve increasingly efficient computing capabilities through system adaptation, coupling energy efficiency, and information processing.[11]

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6 Schiermeier Q. Russia joins race to make quantum dreams a reality. Nature, 2019, 577, 14; https://sputniknews.com/science/201807031065996427-russian-optical-computer/

7 The White House, Office of the Press Secretary. Executive Order -- Creating a National Strategic Computing Initiative. July 29, 2015.

8 United States Office of Science and Technology Policy. National Strategic Computing Initiative Update: Pioneering the Future of Computing. November 2019.

9 https://www.darpa.mil/work-with-us/electronics-resurgence-initiative

10 Schuman CD, et al. A Survey of Neuromorphic Computing and Neural Networks in Hardware. arXiv, 2017. DOI 1705.06963v1

11 Ganesh N. A Thermodynamic Treatment of Intelligent Systems. IEEE International Conference on Rebooting Computing (ICRC), Washington, DC, 2017, 1-4; Perunov N, et al. Statistical physics of adaptation. Physical Review. 2016, X6.2, 021036.

Computing hardware is becoming increasingly application specific, driving the emergence of more specific computing architectures tailored to their targeted tasks. This could lead to substantial increases in performance with minimal power efficiency or capability loses. Just as new computing methods can help advance the field of AI, the reverse is also true. Application of AI and machine learning could help facilitate new and/or better designs of computing components. Further, AI and automation have the potential to drastically speed up production and allow customization – this could help realize the low-cost, low-to-mid volume fabrication paradigm. The USG often requires fewer units with higher specialization than commercial industry, resulting in higher cost and longer production schedules. Realization of a low-cost, low-volume fabrication would help alleviate this challenge. Additionally, advanced packing such as 3D integrated die stacking can allow computational and memory components to be both physically and logically close – increasing efficiency and performance.

USG involvement is vital to provide a strategic infrastructure platform for the future of computing. This should include R&D funding for basic and applied research, encouraging collaboration between government, industry, and academia, and fostering public-private partnerships. Programs such as DARPA's ERI or DARPA's Joint University Microelectronics Program (JUMP) which seeks to fund high-risk, high-payoff research in microelectronic technologies, and incentivize and fund research in fundamentally new computing systems and architectures.[12]

The USG must focus more on long-term, risk-tolerant investments. Private industry R&D is often short-term, while large-scale research projects can take years, if not decades to fully realize. Commercial companies have little business interest in supporting risky investments that only have low volume demand over long periods of time. Further, unique needs of the warfighter are not always addressed by the commercial market, creating gaps in strategic technical areas. The USG has a far greater ability to tolerate riskier investments than private industry on a scale the future of computing requires and should use this to its advantage.[13] If investors are too risk-averse or invest in the wrong areas, innovative technologies that might lead to disruptive advancements in S&T may not be developed. Much like the high-risk, high-payout investments the USG made to develop the Internet or propel Americans to the Moon, so too must the USG make these investments today in the future of computing.

Development of radically new computing paradigms will, however, have implications across the USG, especially acquisitions. Microelectronics are in almost every electronics system used by the warfighter. Defense acquisitions for microelectronics is already exceptionally complicated given complexity and sophistication of parts and the complex supply chain. Implementing radically new advanced computing approaches will have significant impact on current systems that will need to be replaced and/or redesigned to work with these new paradigms. The USG will not have the luxury to wait 10+ years to implement new state-of-the-art technologies. Programs like the Defense Microelectronics Activity (DMEA), which ensures access to a broad array of critical microelectronics needs, are vital to bringing future computing systems into the USG.

Technological advancements in computing architectures and algorithms in a post-Moore's Law world will bring about disruptive breakthroughs in microelectronics and modern society. It is imperative to national security and technological progress that the USG drive these innovations and set the narrative.

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[12] https://www.darpa.mil/program/joint-university-microelectronics-program

[13] Varma R. Changing Research Cultures in U.S. Industry. Science, Technology, & Human Values. 2000, 25, 4; Hourihan M, Parkes D. Federal R&D Budget Trends: A Short Summary. AAAS. January 2019.

Panelists' Remarks

Each panelist spoke for 25 minutes, followed by a short audience Q&A. At the end of the speaker presentations, a panel discussion was facilitated by moderator, Dr. Michael Fritze, Vice President of the Institute. A brief summary of each speaker's talk is presented here. A full broadcast of the panel discussion can be found online.[14]

Dr. R. Stanley Williams: "Brain-Inspired Computing"

Dr. R. Stanley Williams gave the keynote address, "Brain-Inspired Computing." Taking inspiration from the brain, one of the most efficient computational engines we know, Dr. Williams developed the memristor (a portmanteau of memory resistor or programmable resistor). He stressed the need to achieve significantly greater efficiency of future computing systems than continued conventional CMOS scaling can provide. These future computation power dissipation needs will warrant a move towards more analog-based approaches, such as a memristor. "The new era of computation is less about precision, more about probabilities."

Using brain-inspired approaches in his work, Dr. Williams' goal was not to increase the number of elements on a chip, but rather to make them more efficient (imperative for future computation approaches). His goal was not to reproduce the brain, but to build a much better computer that to amplify the capabilities of humans. He also drew a distinction between "deep learning" (using linear algebra computation) and "dynamic Bayesian nets" (using non-linear computation). Dr. Williams commented that, going forward, Bayesian inference logic implemented in non-linear dynamical systems will be the correct type of model.

Dr. Williams discussed computing progress in China, pointing out that China is ahead of the US in certain aspects of neuromorphic computing. For example, the Chinese Tianjic Chip, a 28-nm hybrid chip was recently reported, combining brain-inspired schemes with computer science-based machine-learning algorithms.[15] The revolutionary chip recently demonstrated an unprecedented ability to independently drive an unmanned bicycle, realizing real-time tracking, obstacle avoidance, and balance control without training on certain obstacles – a remarkably difficult task for AI systems.

Dr. Williams acknowledged that future chip improvements may benefit from using memristor elements to accelerate analog vector-matrix multiplication operations in deep learning. for This computational approach could be made reversible by using programmable capacitors instead of resistors. Through using large arrays that utilize cost efficient devices, Dr. Williams predicted that power efficiency and execution time (performance) of computing systems of higher-order (nonlinear) neural networks will see improvements by 10-20 orders of magnitude in the next decade. These improvements, he hypothesized, will allow for a high order of intelligence to be deployed at scale from individual sensors at the edge all the way to large cloud-computing data centers.

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[14] https://potomacinstitute.org/featured/2182-potomac-institute-event-announced-the-future-of-computing

[15] Pei J, et al. Towards artificial general intelligence with hybrid Tianjic chip architecture. Nature. 2019, 572, 106–111. DOI 10.1038/s41586-019-1424-8.

However, to achieve these improvements, Dr. Williams stated a comprehensive research program will be required – one in which the output is a two order of magnitude increase in performance per year compared to the ~2x increase per year during Moore's scaling. Further, progress must be made in not only developing new brain-inspired architectures and computational models, but also new dynamical devices and circuits and new or improved supporting materials.

Dr. Todd Hylton: "Thermodynamic Computing"

Dr. Todd Hylton spoke about his vision of 'Thermodynamic Computing.' This is a paradigm in which computers can "self-evolve" using deliberate noise as a stimulation method. Currently, he stated, power efficiency in computation is about 1000 times above the theoretical 'Landauer Limit'; that is, computing power is significantly inefficient with regards to energy consumption. "We are in the late stages of a mature technology, but we are still a long way from fundamental limits."

Dr. Hylton remarked that today's computers use irreversible logic; they cannot self-organize as they are deliberately "frozen" to eliminate fluctuations and ensure reliability. This means current machines are ill-suited to evolving, complex, real-world problems. However, Dr. Hylton highlighted that dynamical learning and inference-based computation are desirable to counteract these issues – computing should be allowed to "self-evolve." He noted that this approach could have implications for intelligent, adaptive systems such as autonomous vehicles, AI robotics, or smart grids, enabling them to better adapt to their dynamic environment.

A key theme throughout Dr. Hylton's talk was the notion that thermodynamic computing should be the principle of future computing. He stated that thermodynamics is universal, efficient, temporal, and not mechanistic – it drives the evolution of everything. He discussed how electronics and biological life have similar energy scales, driven by fundamental thermodynamics. While challenges in the current computing paradigm are thermodynamic in nature, he remarked that it is notably absent in mainstream computing research. He further stressed that thermodynamic evolution has the potential to be the missing, unifying concept in computing.

Dr. Hylton then broke computing paradigms into three main regimes based on spatial fluctuation (characteristic length) and temporal fluctuation (characteristic time):
1. quantum: coherent, single scale states; e.g. atoms or small molecules
2. thermodynamic: complex, multi-scale, and fluctuation dominated; e.g. nanotechnology or large molecules
3. classical: mechanistic, small fluctuations only, scale separated; e.g. transistors or gases

Currently, most computing approaches lies within the classical regime. However, in Dr. Hylton's view, a larger focus on the intermediate, thermodynamic "mesoscopic" regime is necessary going forward. Further, current theorems need to be extended to include adaptation and allow for self-organizing systems. He stated that thermodynamic computing relies on evolution to through the network minimal loss, making the overall system more efficient.

Dr. Bruce MacLennan: "Unconventional Computing"

Dr. Bruce MacLennan discussed "Unconventional Computing" and his work in this area. He first stressed that the end of Moore's Law is imminent – new approaches to computation are necessary. He highlighted unconventional computing (computation on the scale of real physical processes) as a potentially alternative approach. He remarked that many fewer components are required for such analog processing. Further, Dr. MacLennan highlighted the importance of embodied computation, that is, the importance of using physical effects directly for computation. He remarked that this is an underexplored aspect of computation, due to several challenges such as energy issues, it is less idealized, and there is a lack of commonly accepted, widely applicable models. However, nature provides examples of embodied computation and can inspire its implementation. "Exploit the physics, don't circumvent it."

Dr. MacLennan gave some examples of physical processes that could be leveraged to perform computation:

1. Diffusion: It can be expensive to simulate but is found often in nature or physical systems. Diffusion processes can be used for many computational tasks such as broadcasting information or massively parallel search for optimization, constraint satisfaction, etc.
2. Randomness: Many algorithms already use randomness (e.g. for escape from local optima or symmetry breaking), and it is freely available from noise, uncertainty, and imprecision.
3. Quantum Phenomena: There are several aspects that can be or are already utilized such as continuous variable quantum computing, quantum tunneling, or computations in quantum superposition.
4. Continuous Fields: As physical processes are continuous, it is possible to directly exploit continuous physical processes for analog computing.

One hypothetical question Dr. MacLennan posed was, "How do you wire the brain?" in response to bio-inspired computing – the brain's architecture is still not well understood making brain-inspired computing that much more difficult. He briefly highlighted his work on microrobot swarms and bio-inspired algorithms. The approach uses a form of artificial morphogenesis, which looks to replicate the self-organizing morphogenetic processes in a developing embryo where billions of cells cooperate to create a larger physical form. The microswarms were modeled as one continuous mass, which is able to route connections around obstacles and to demonstrate the ability to assemble complex hierarchical structures (such as an artificial brain).

Dr. Paul Franzon: "Applique Computing"

Dr. Paul Franzon discussed "Applique Computing" – how to enable low-cost customization of computational hardware. Memory and programming dominate computing today. "Centimeters of memory are feeding millimeters of logic in most chips today." Computation is constrained by current memory bandwidth limitations. He postulated that within the next 20-50 years, we will solve the efficiency problems of designing, building, and integrating custom low-mid volume solid-state logic and memory engines. Doing this, he added, will enable (a) high degrees of customization, (b) intimate and high bandwidth 3D integration, and (c) intimate, fast, and low power memory.

Dr. Franzon acknowledged that customization can provide 1000x improvements in performance and power metrics. He identified two key factors that will be necessary for achieving this: (1) the development of automated, low-cost design processes and (2) the performance-to-cost ratio. Dr. Franzon pointed to several examples highlighting the benefits of customization such as a recent publication incorporating a 3D hardware architecture with application-specific processor, a 3D-stacked memory, and sized on-chip memory that achieved a 8.5x increase in processing speed and a 47.5x increase in energy efficiency using almost 3x less silicon area than a standard GPU.[16]

A major means of achieving the post-Moore customization of hardware to function is the 3D integration of chips to make custom computation engines. For example, this could include high bandwidth integration schemes such as 3D CPU's with specialized accelerators stacked with high bandwidth memory. This will require low – mid volume solid state logic and memory engines. He stated that many of today's workloads require more memory bandwidth than is available. Further, low-cost, low-volume chip design processes are required to enable custom accelerators on demand. A possible solution to this, he suggested, was by taking the human out of the loop – we are on the verge of artificial intelligence and machines doing the chip design instead.

Dr. Franzon speculated that in 20 years, even a 3 nm chip would be as easy and cheap to produce as a 180 nm chip through improvements in fabrication. He remarked that the low-cost, low-volume fabrication paradigm could enable cluster tools, new business models, and entirely new technologies.


Image: Shutterstock.com

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[16] Dey S, Franzon PD. An Application Specific Processor Architecture with 3D Integration for Recurrent Neural Networks. Presented at "20th International Symposium on Quality Electronic Design (ISQED)" conference. 2019. DOI 10.1109/ISQED.2019.8697413

Speaker Biographies

Dr. Stanley Williams

Dr. Stanley Williams is Professor in the Department of Electrical and Computer Engineering, holder of the Hewlett Packard Enterprise Chair, and Director of the Center for Computer Architecture Research at Texas A&M University. Prompted by his exploration of the fundamental limits of information and computing, Dr. Williams has done extensive research in nano-electronics, -ionics and -photonics, and how to utilize the nonlinear properties of matter to perform computation efficiently. Before A&M, he was an HP Senior Fellow and Director of Information & Quantum Systems at Hewlett-Packard Labs, where he led a group that developed the first intentional solid state version of Leon Chua's memristor. Prior to this, he worked at Bell Labs before joining the faculty at UCLA, where he served as a chemistry professor for 15 years. Dr. Williams has been awarded more than 230 US patents, published more than 450 peer-reviewed papers, and presented hundreds of invited plenary, keynote, and named lectures at international scientific, technical, and business events.

Dr. Todd Hylton

Dr. Todd Hylton is the Executive Director of the Contextual Robotics Institute and Professor of Practice in the Electrical and Computer Engineering Department at UC San Diego. His research interests include novel computing systems and their application to autonomous vehicle and robotic systems. Prior to his appointment at UC San Diego, he was Executive Vice President of Strategy and Research at Brain Corporation, a San Diego-based robotics startup. From 2007 to 2012, Dr. Hylton served as a Program Manager at DARPA where he started and managed a number of projects including the Nano Air Vehicle program, the SyNAPSE program, and the Physical Intelligence program. Prior to DARPA, he ran a nanotechnology research group at SAIC, co-founded 4Wave, a specialty semiconductor equipment business, and served as CTO of Commonwealth Scientific Corporation. Dr. Hylton received his Ph.D. in Applied Physics from Stanford University in 1991 and his B.S. in Physics from M.I.T. in 1983.

Dr. Bruce MacLennan

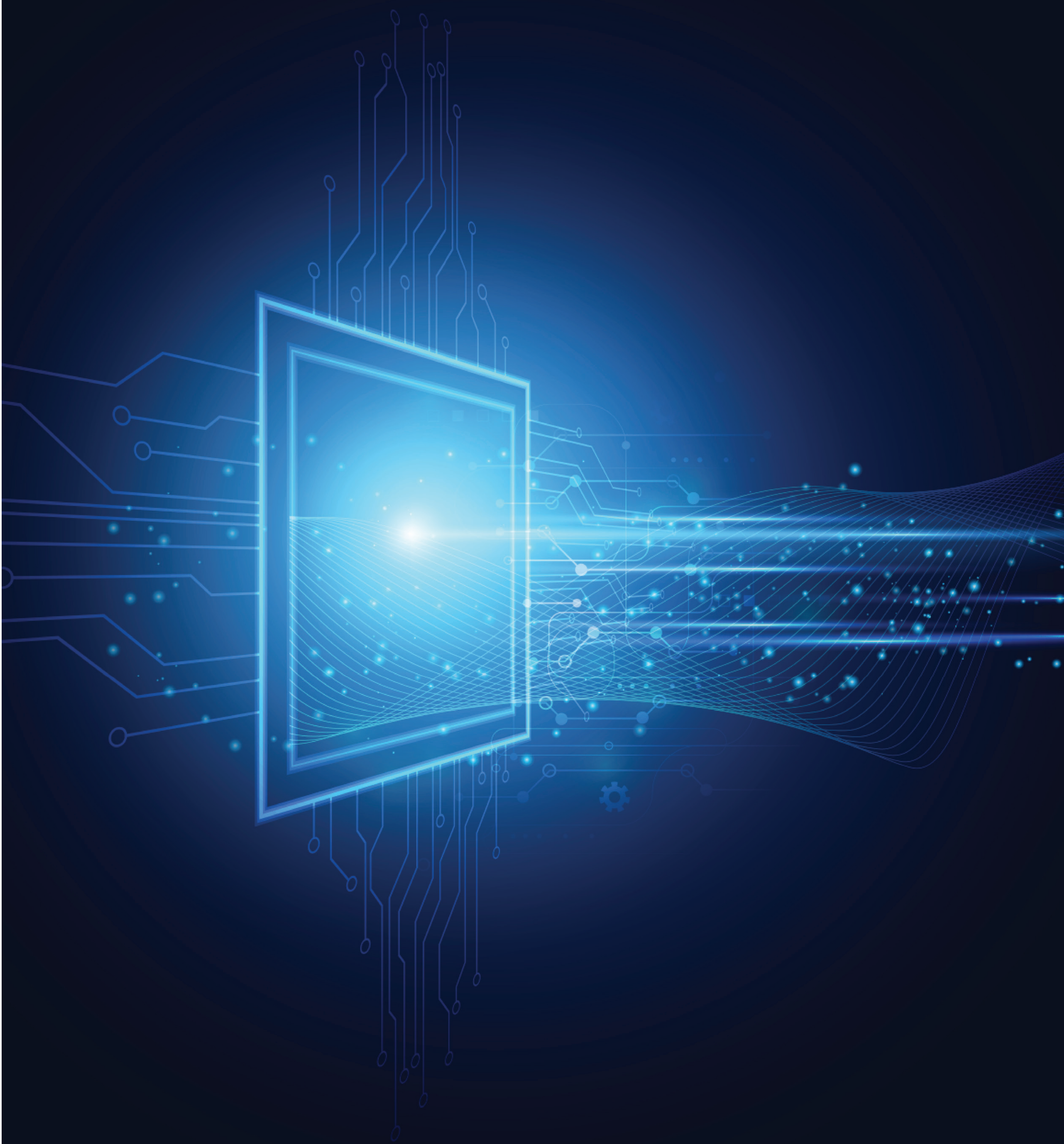
Dr. Bruce MacLennan is an Associate Professor in the Department of Electrical Engineering and Computer Science at the University of Tennessee, Knoxville. His research focuses on bio-inspired computation, self-organizing systems, and the interaction of physical and computation processes (including Post-Moore's Law computing technologies). Prior to UT Knoxville, he was a faculty member at the Naval Postgraduate School where he investigated novel models for massively parallel computing and artificial intelligence. Prior to this, Dr. MacLennan participated in the architectural design of the 8086 and the iAPX-432 microprocessors as a Senior Software Engineer at Intel. In 2008, Dr. MacLennan was invited to become the founding Editor-in-Chief of the "International Journal of Nanotechnology and Molecular Computation."

Dr. Paul Franzon

Dr. Paul Franzon is currently the Cirrus Logic Distinguished Professor and the Director of Graduate programs in the Department of Electrical and Computer Engineering at North Carolina State University. He earned his Ph.D. from the University of Adelaide, Adelaide, Australia. He has also worked at AT&T Bell Laboratories, DSTO Australia, Australia Telecom, Rambus, and four companies he cofounded, Communica, LightSpin Technologies, Polymer Braille Inc. and Indago Technologies. His current interests include applying machine learning to EDA, building AI accelerators, neuromorphic computing, RFID, advanced packaging, 2.5D and 3DICs and secure chip design. He has led several major efforts and published over 300 papers in these areas. In 1993, he received an NSF Young Investigators Award, in 2001 was selected to join the NCSU Academy of Outstanding Teachers, in 2003, selected as a Distinguished Alumni Professor, received the Alcoa Research Award in 2005, and the Board of Governors Teaching Award in 2014. He served with the Australian Army Reserve for 13 years as an Infantry Soldier and Officer. He is a pilot in the Bandit Flight Team, a formation flying unit. He is a Fellow of the IEEE.

Dr. Michael Fritze

Dr. Michael Fritze is a Vice President at the Potomac Institute for Policy Studies responsible for the Microelectronics Policy portfolio. His current interests and activities include USG trusted access strategies, support of needed legacy technologies, DOD innovation policy and outreach to Industry and strengthening the US Microelectronics Industrial Base. He is also the Director of the VITAL Center (Vital Infrastructure Technology And Logistics) at Potomac.



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