Sandia National Laboratories

FULL STACK NEUROMORPHIC

Technologies and Capabilities

SANDIA'S INNOVATION MARKETPLACE

JANUARY 2023

WELCOME TO SANDIA NATIONAL LABORATORIES' INNOVATION MARKETPLACE

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Why Work with Sandia?

Leverage World-Class Technology and Research

For 70 years, Sandia has delivered essential science and technology to resolve the nation's most challenging security issues. A strong science, technology, and engineering foundation enables Sandia's mission through a capable research staff working at the forefront of innovation, collaborative research with universities and companies, and discretionary research projects with significant potential impact.

The Best and Brightest

In keeping with our vision to be the nation's premier science and engineering laboratory for national security and technology innovation, we recruit the best and the brightest, equip them with world-class research tools and facilities, and provide opportunities to collaborate with technical experts from many different scientific disciplines. The excitement and importance of our work, an exemplary work environment, partnerships with academia, industry, and government, and our record of historic contributions help us attract exceptional staff. Our employees are recognized by their professional peers for their outstanding contributions.

Exceptional service in the national interest

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To discuss licensing and partnering opportunities, please send inquiries to: ip@sandia.gov

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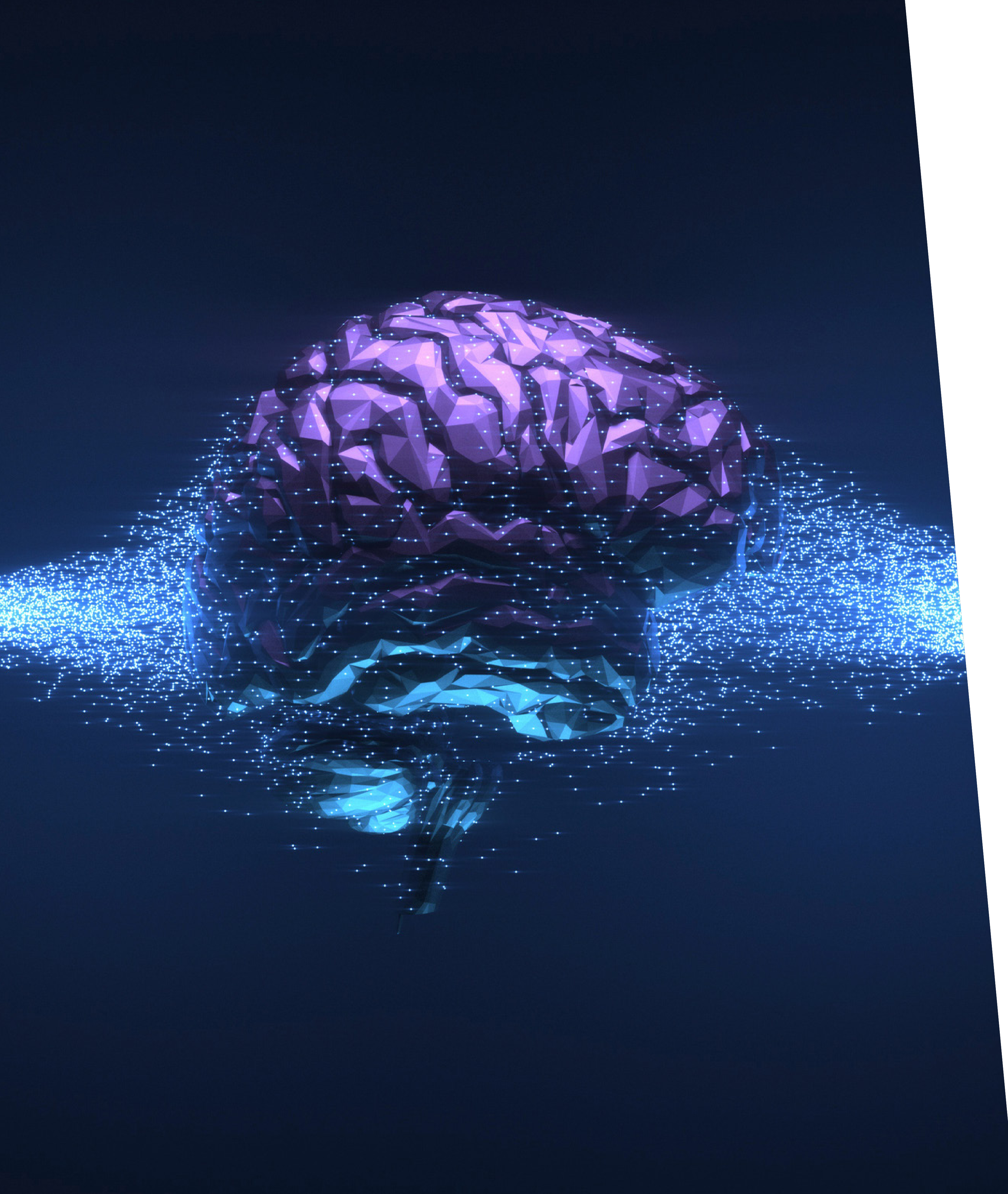

THE REVOLUTIONARY POTENTIAL OF BRAIN-INSPIRED COMPUTING

AI-enabled smart products and services are exceptionally useful for everyday purposes such as wearables, cell phones, and home monitoring and automation systems; they also introduce new capabilities to key national security technologies including satellites, drones, and ground sensors in critical settings.

Currently, AI computation is energy intensive. Edge solutions that compute in the cloud or at offsite data centers are used to meet power demands for the device itself as well as for the computation to process and complete tasks. This approach conserves device battery power but introduces other limiting factors such as data transfer latency and user privacy concerns.

Neuromorphic computing is known for integrating algorithms, architecture, and hardware elements in a manner modeled after the human brain. Increasingly favored by researchers in artificial intelligence (AI) and machine learning (ML), neuromorphic approaches are recognized for their ability to accomplish more with reduced power consumption and a smaller overall footprint. Due to their closely integrated architectures, neuromorphic approaches present a strategy for computing locally within device memory. In-memory computation could enable small, compact, and energy efficient smart devices and sensors equipped for even more adaptive and responsive AI computing in real-time.

Sandia researchers are shaping the future of computing through the co-design and development of novel neuromorphic approaches.

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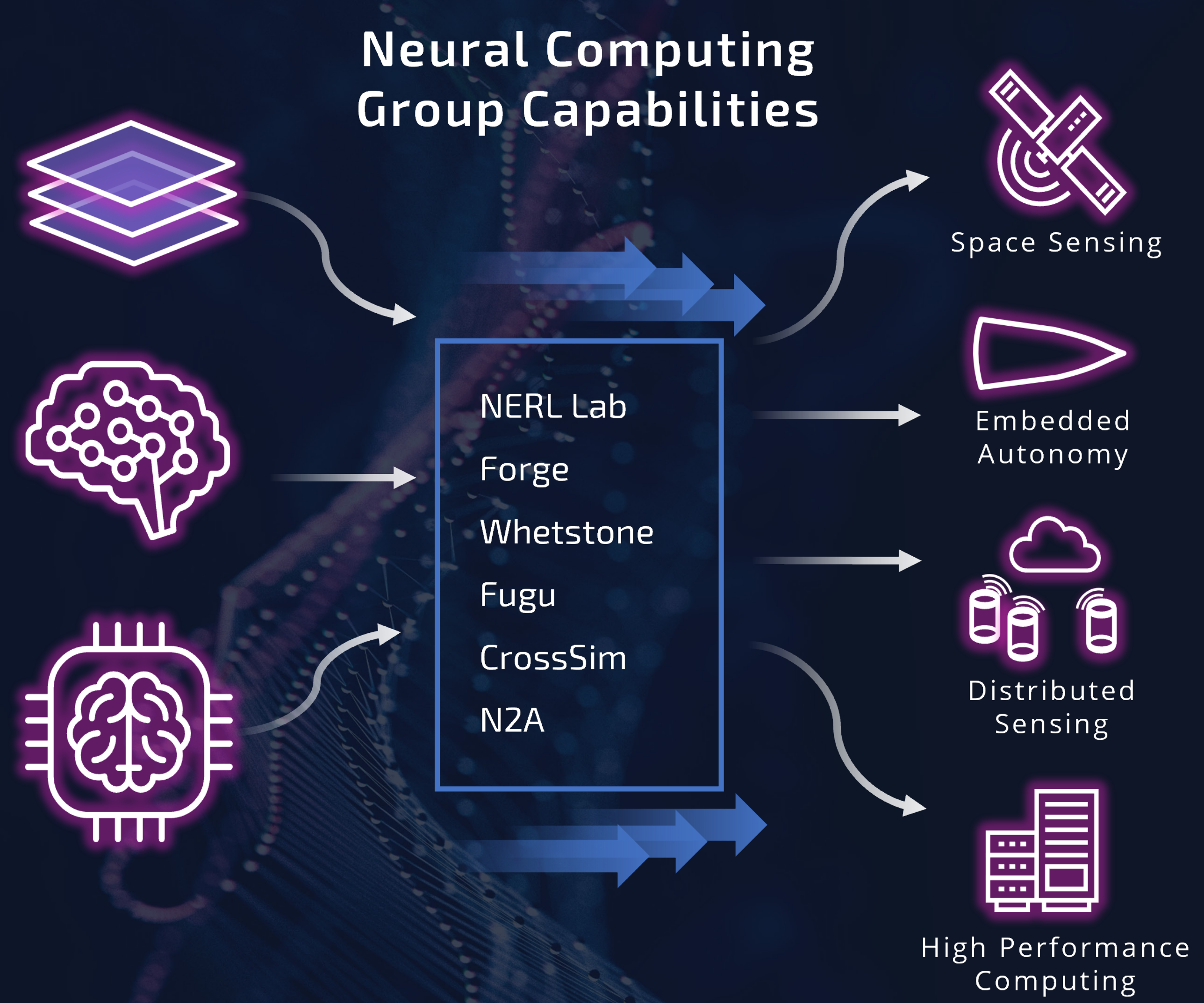
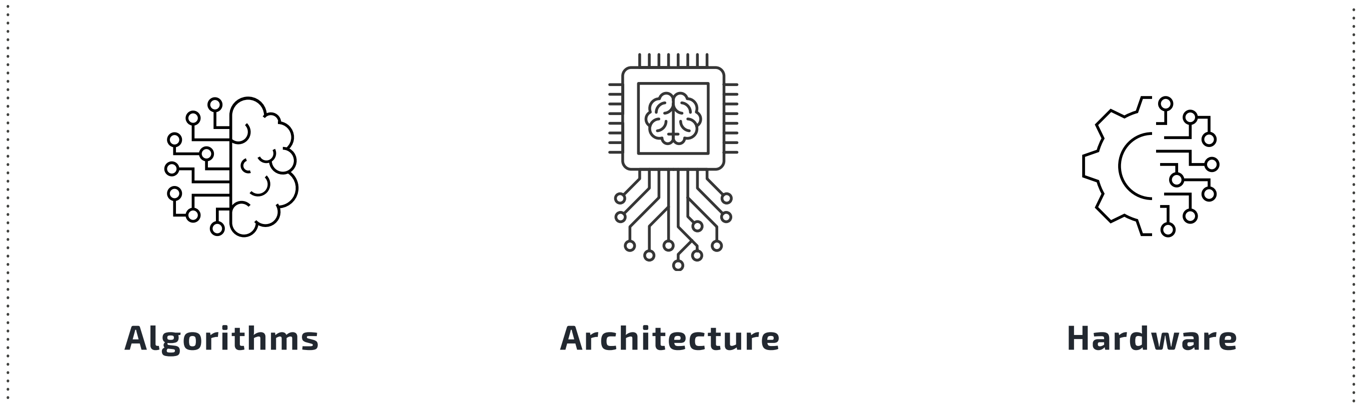
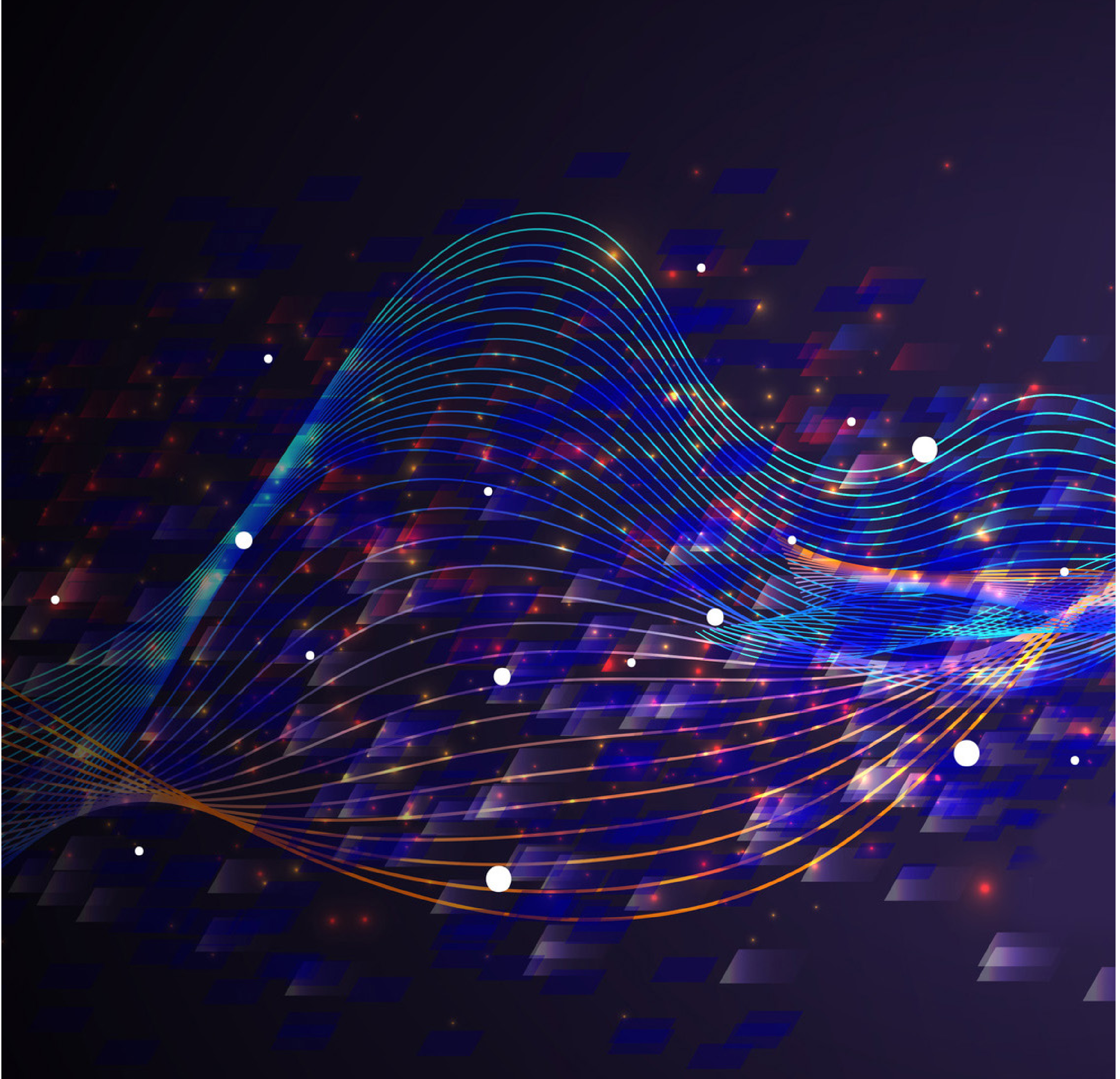


In order to bring brain-inspired neuromorphic hardware, algorithms, and AI closer to realization for diverse applications, Sandia National Laboratories' Neural Computing group is working at multiple scales to build a suite of cross-cutting capabilities.

Sandia's interdisciplinary team of experts in mathematics, cognitive science, algorithm development, electrical engineering, and device physics have developed neuromorphic computing algorithms, architecture, and hardware to address U.S. national security mission areas and beyond.



Sandia's unique capabilities, deep technical expertise, intellectual property (IP), and facilities can provide value to partners seeking to further their neuromorphic computing efforts.



ALGORITHMS

Capitalizing on the improved functionality provided by neuromorphic architectures and hardware requires new and altogether different approaches for programming and algorithm development.

A major advantage of neuromorphic systems and approaches are their lower energy consumption compared to traditional computing; however, deep neural networks come with a computational cost that presents barriers for broad deployment.

Sandia's Neural Mini-Apps

Sandia researchers have developed novel strategies for advancing neural algorithms to address near and long-term computing needs and objectives. Drawing on decades of experience developing mini-apps for HPC advancement, Sandia has developed a suite of neural mini-apps to assist researchers in understanding, predicting, and improving neuromorphic computing technologies. Each of these Sandia-developed programs perform different tasks. They also allow researchers to collect data and analyze system effects to build their understanding.

Neuromorphic Random Walks

This mini-app produces diffusion models and neuromorphic simulations by performing the same calculation many times with random inputs.

A recent publication in *Nature Electronics* demonstrated that neuromorphic simulations offer computational advantages for solving complex statistical problems, such as disease spread, information flow, and complex market dynamics. These results indicate the potential for flexible neuromorphic systems to complement AI as an application for brain-inspired hardware.

Neural Sparse Coding

Sparse coding is a method for data modeling that breaks and reduces the complexity of computations.

Neural Graph Analysis

This mini-app can identify shortest paths on a neuromorphic computer while allowing researchers to probe how well their system worked.

Fugu: Sandia's Neural App-Builder

An easy-to-use common software framework for spiking neuromorphic hardware

Fugu provides a common software framework for designing and prototyping algorithms for spiking neuromorphic hardware and compiling them to multiple hardware platforms. Fugu supports the use and development of spiking neural algorithms for arbitrary computations, demonstrating that neuromorphic paradigms can be used in non-neural applications spaces.

Whetstone

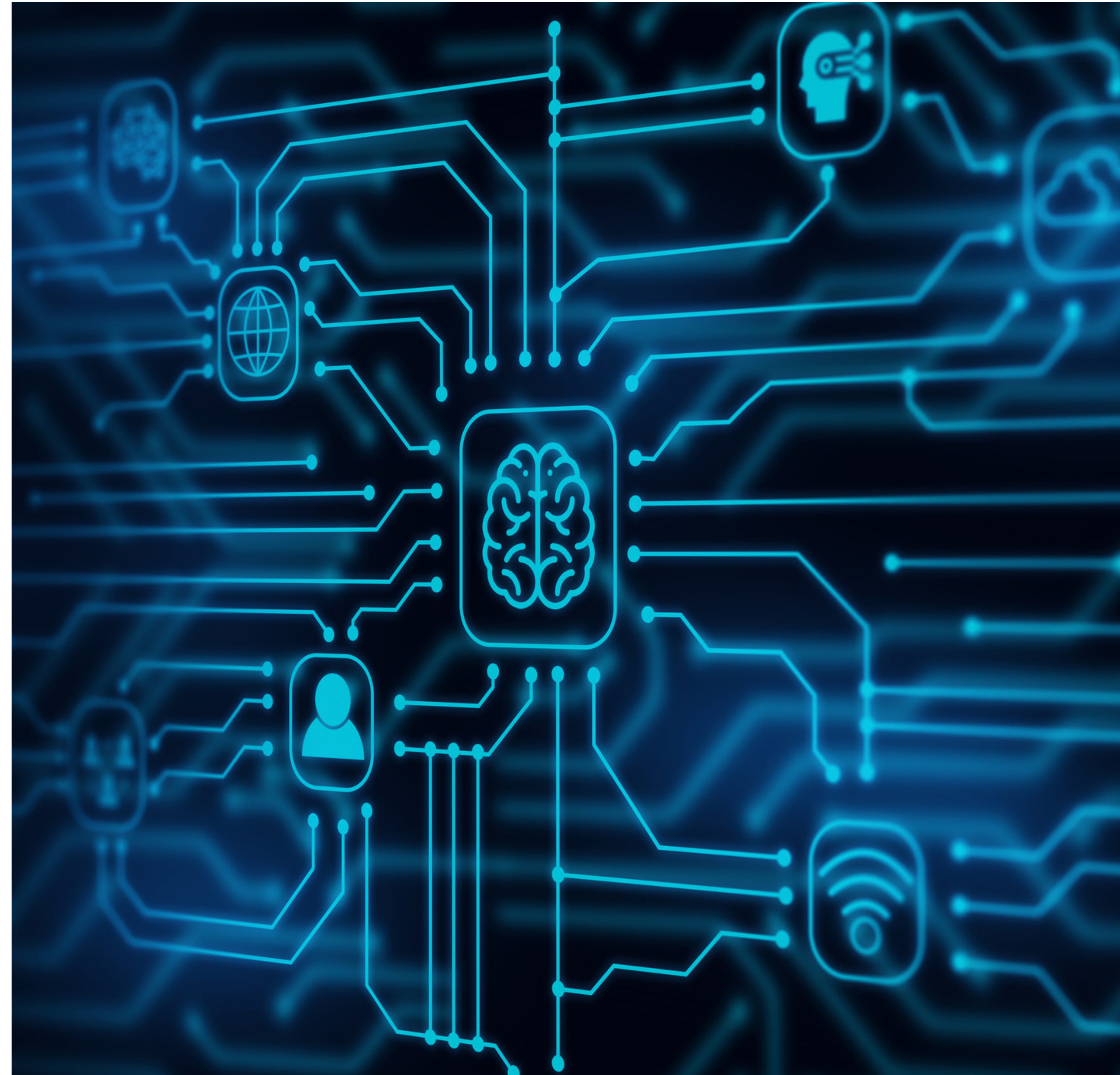
An open-source tool for generating spiking neural networks that can run on low-power hardware

Whetstone-trained networks, when coupled with emerging neuromorphic chips, have the potential to improve the efficiency of neuromorphic hardware by 100x compared to conventional platforms running deep-learning networks, as measured by frames per second per Watt. Whetstone offers performance advantages that can be realized in a range of applications with low-power computing needs. It also provides a bridge between the machine learning and neuromorphic computing communities by reducing barrier-to-entry for neural network application developers who may not have familiarity with spiking algorithms or neuromorphic hardware.

Neurons to Algorithms (N2A) Tool

A framework for expressing neural dynamics across a wide range of scales

N2A is a software tool capable of compositionally building complex neural models from simple parts represented as systems of dynamical equations. Because systems of dynamical equations can represent most physical processes in the brain, this enables the generation of robust, multiscale models that can leverage data and models originated at scales from cellular processes to structural plasticity in neural circuits. In addition to serving as a platform for consolidating neural models from across research efforts, N2A is being developed as a front end "neural compiler" for neuromorphic hardware.



ARCHITECTURE

Neuromorphic approaches are distinct from Von Neumann architectures and require completely new and different approaches to system design.

While neuromorphic systems offer significant potential benefits such as energy efficiency, low size, weight, and power (SWaP), low latency, and real-time processing of cluttered data in AI/ML or edge computing applications, their novel design features are pushing researchers to investigate new architectural strategies.

Sandia Spiking Temporal Processing Unit (STPU)

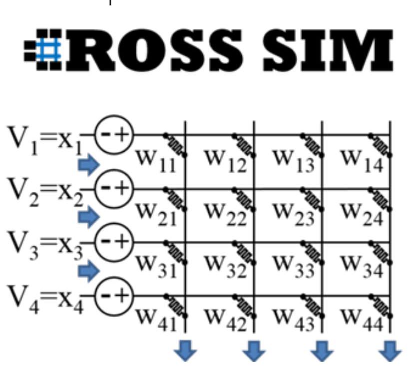
A challenge for neuromorphic computing is to develop architectures that enable complex connectivity like those between neurons with the ability to incorporate spike timing into the architecture. Spiking neural networks (SNNs) are a fundamentally different approach seeking to bridge the gap between neuroscience and machine learning by mimicking the firing of biological neurons.

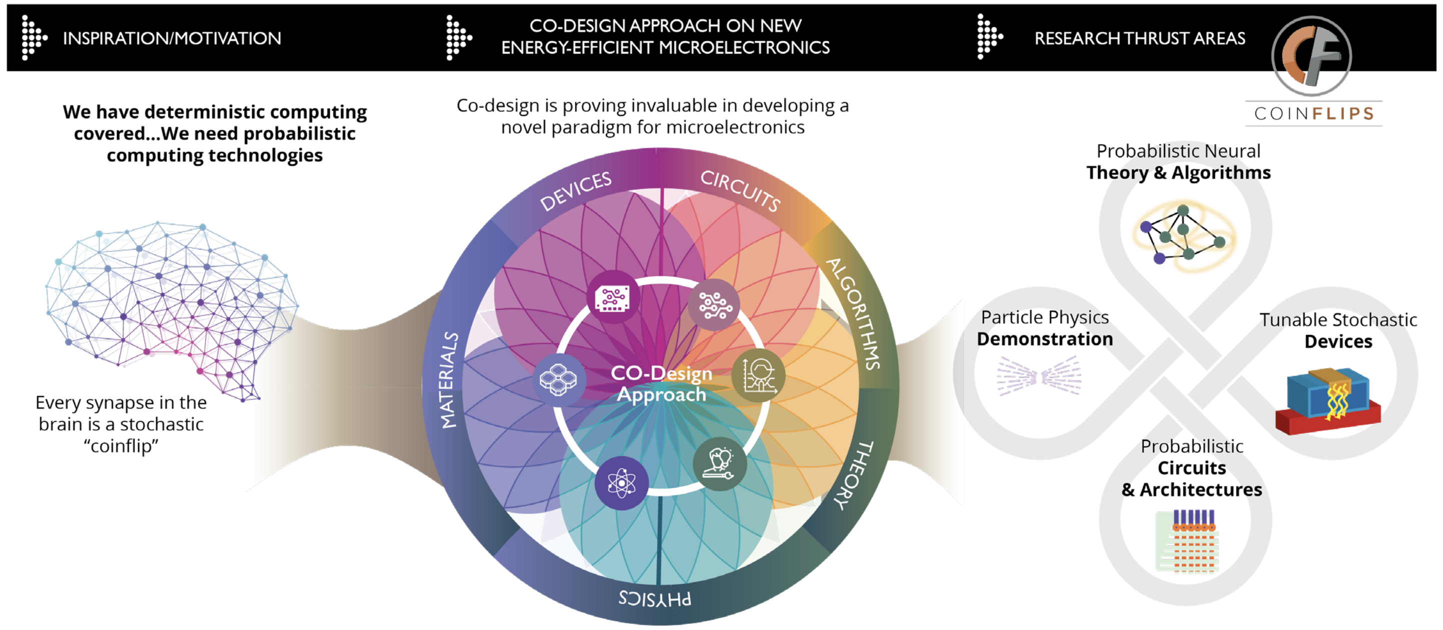
Compared to formal neural networks, SNNs have significantly reduced energy consumption when used with neuromorphic hardware. The Sandia Spiking Temporal Processing Unit (STPU) is designed to directly implement temporal neural processing in hardware. This use of timing has the potential to enable dramatically lower energy consumption during implementation of neural machine learning algorithms for pattern recognition and more directly enable the development of novel neural algorithms that operate in the time domain.

Cross-Sim: Crossbar Simulator

An open-source simulator for modeling neural-inspired ML algorithms on analog hardware

Cross-Sim includes noise models for reading and updating resistances, which can be based on idealized equations or experimental data. It can also introduce noise and finite precision effects when converting values from digital to analog and vice versa. These effects can be turned on or off as an algorithm processes a data set and attempts to learn its salient attributes so that it can be categorized in the machine learning training classification context. CrossSim allows the robustness, accuracy, and energy usage of a machine learning algorithm to be tested on simulated hardware.



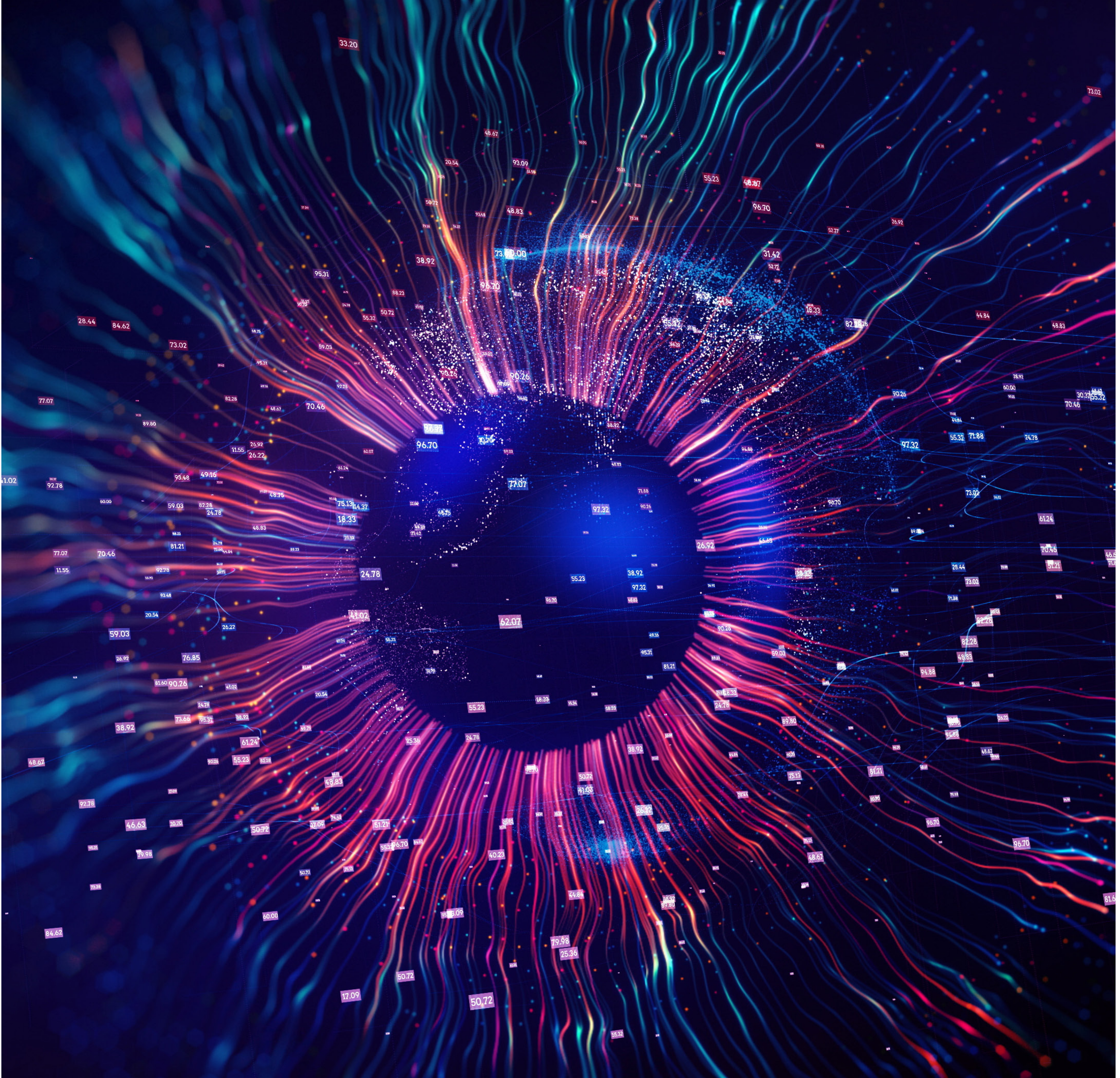


COINFLIPS

CO-Designed Improved Neural Foundations Leveraging Inherent Physics Stochasticity

The human brain embraces and controls stochasticity, or randomness, across space and varied time scales; at the same time, many applications of computing have inherent uncertainty. After decades of emphasis on deterministic problem-solving approaches, the Sandia-developed COINFLIPS seeks to embrace stochasticity to solve uncertainty problems and define the future of high-performance computing.

By combining stochastic devices into neuromorphic architectures, COINFLIPS could improve both the speed and energy efficiency of probabilistic computing applications. AI-enhanced codesign of next-generation microelectronics will enable algorithm and hardware innovations that will accelerate progress toward next-generation high-performance neuromorphic computing systems. Because using stochasticity will require revisiting how neuromorphic hardware is designed, co-design approaches that seek to synchronize efforts across materials, devices, circuits, and algorithms are supporting this work in areas of increasing competitiveness, such as microelectronics.



HARDWARE

By virtue of its low-power, brain-inspired communication structure and highly parallel design, neuromorphic hardware enables greater processing at the sensor — reducing data transmission and post-processing needs.

To enable future generations of energy-efficient computing, a complete reconceptualization of hardware design is needed. The integration of emerging devices, materials, interconnects, and non-linear phenomena must coincide with the needs of scientific computing applications. In order to take advantage of neuromorphic benefits such as flexibility, low energy usage, and asynchrony, Sandia researchers have developed novel hardware compatible with these approaches.

Neuromorphic Object Recognition

and physics-based optical neurmorphic classification

More effective strategies for object recognition could unlock more agile and adaptive smart devices in a multitude of applications. Presently, emerging technologies such as autonomous driving, feature recognition, and imaging must perform critical image and feature recognition tasks primarily through digital image analysis. The conversion and downstream analysis associated with these techniques requires significant power and time, therefore presenting a key constraint for technology implementation.

Diffractive neural networks have shown promise for the classification of optical information at lower energy and higher speeds. Sandia researchers are exploring alternative approaches where passive optical materials act as neural networks and perform neuromorphic inference without relying on computation. All-optical approaches such as this as well as hybrid approaches have potential for significant improvements in speed and energy consumption.

Sandia's work in single-layer and two-layer diffractive neural networks (DDNs) established conditions under which high performance can be acheived and optimized, further demonstrating the how DNNs can be harnessed in physical systems. This work also demonstrates the importance of co-design and co-optimization of materials, architecture, and algorithms for acheiving high performance and reducing system complexity.

From left: Sandia researchers Steve Verzi, William Severa, Brad Aimone and Craig Vineyard (Photo by Randy Montoya)

Meet Sandia's Experts

Brad Aimone, PhD

Dr. Brad Aimone is a Distinguished Member of the Technical Staff focused on leveraging computational neuroscience to advance machine learning and use brain-inspired computing platforms for future scientific computing applications. Dr. Aimone earned his PhD in computational neuroscience from the University of California, San Diego and his bachelors and masters degrees in chemical engineering from Rice University.

William Severa, PhD

William Severa is a mathematician in the Cognitive and Emerging Computing Department at Sandia National Laboratories. Dr. Severa received both his PhD and MS degrees in mathematics from the University of Florida and his bachelors degree from Florida Atlantic University.

Craig Vineyard, PhD

Craig M. Vineyard leads the Neural Exploration and Research Laboratory (NERL) at Sandia where he pursues computing research in machine learning, neural-inspired/neuromorphic computing, and algorithmic game theory. Dr. Vineyard received his bachelors, masters, and PhD degrees in computer engineering from the University of New Mexico.

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Facility Spotlight

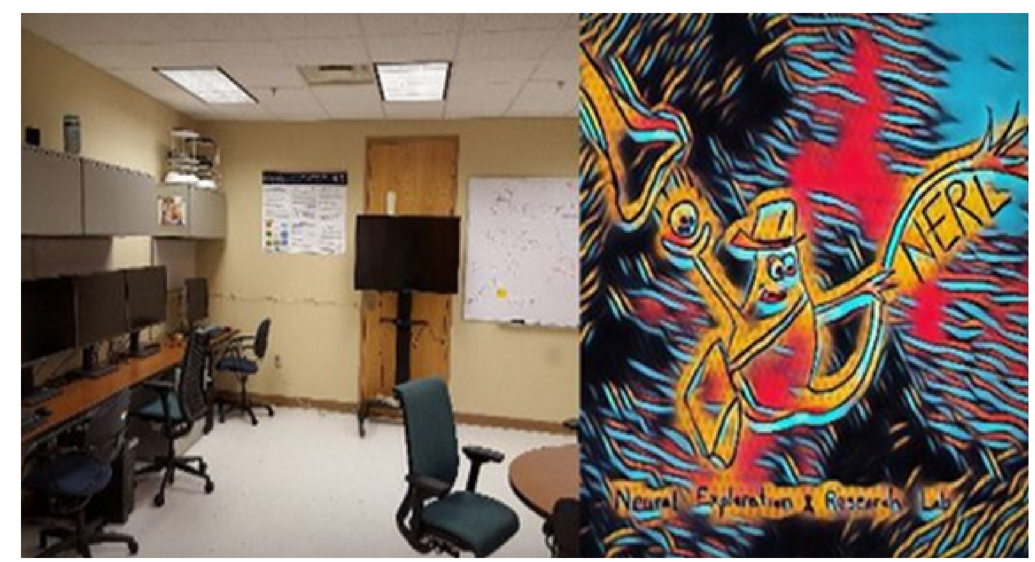
Neural Exploration & Research Laboratory (NERL)

Sandia's Neural Exploration & Research Laboratory (NERL) enables researchers to explore the boundaries of neural computation. The research conducted in the lab evaluates what is possible with neural hardware and software for national security benefit and the advancement of basic research.

Current areas of NERL research include:

- Machine Learning and Deep Learning
- Microelectronics Co-Design
- Neural Computing and Applications to High Performance Computing (HPC)
- Computational and Mathematical Neuroscience
- Reinforcement Learning
- Remote Sensing
- Edge Sensing and Processing

Find Sandia NERL on Github
github.com/SNL-NERL



PARTNER WITH SANDIA

Sandia can offer access to world-class scientific knowledge, advanced technologies, and specialized research facilities through a variety of partnership types.

License Agreements

Sandia can work with industry, government, other national laboratories, and academia to find the right license agreement to fit their needs.

Cooperative Research & Development Agreement

In a Cooperative Research and Development Agreement (CRADA), Sandia and one or more partners outside of the federal government can collaborate and share the results of a jointly conducted research and development project.

Strategic Partnership Projects or Non-Federal Entity Agreements

In a Strategic Partnership Project (SPP) or Non-Federal Entity (NFE) agreement, Sandia can perform work on a reimbursable basis for a non-federal entity from private industry, state/local government, nonprofits, or academia.

New Mexico Small Business Assistance Program

The New Mexico Small Business Agreement (NMSBA) Program allows New Mexico small businesses facing a technical challenge to access the unique expertise and capabilities of Sandia.

Technology Deployment Center (TDC) Agreements

Technology deployment centers are a unique set of scientific research capabilities and resources. The primary function of technology deployment centers is to satisfy DOE programmatic needs, while remaining accessible to outside users.

Full Stack Neuromorphic

Intellectual Property (IP) available for licensing

Algorithms

US Patent 11,436,475	Anomaly detection with spiking neural networks	SD 14754
US Patent 11,409,922	Devices and methods for increasing the speed and efficiency at which a computer can model a plurality of random walkers using a density method	SD 14649
US Patent 11,281,964	Devices and methods for increasing the speed and efficiency at which a computer can model a plurality of random walkers using a density method	SD 14649
US Patent 10,970,630	Neuromorphic computing architecture with dynamically accessible contexts	SD 14181
Patent App. 16/013,810	Devices and methods for increasing the speed or power efficiency of a computer when performing machine learning using spiking neural networks	SD 14662
Patent App. 17/314,751	Neural network robustness via binary activation	SD 15133

Architecture

US Patent 11,501,432	Spiking retina microscope	SD 15156
US Patent 10,891,540	Adaptive neural network management system	SD 13479
US Patent 10,445,065	Constant depth near constant depth, and sub-cubic size threshold circuits for linear algebraic calculations	SD 14103
US Patent 9,412,446	Multilevel resistive information storage and retrieval	SD 12822
Patent App. 16/939,372	Neural mosaic logic unit	SD 14814
Patent App. 17/200,003	Device and method for random walk simulation	SD 15346

Hardware

US Patent 10,392,243	Coupled memristor devices to enable feedback control and sensing of micro/nanoelectromechanical actuator and sensors	SD 13189
US Patent 9,831,427	Ion barrier for memristors/reram and methods thereof	SD 12865
US Patent 9,336,870	Methods for resistive switching of memristors	SD 13146
US Patent 8,872,246	Memristor using a transition metal nitride insulator	SD 12053

CONTACT US!

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