NEURONICS26

From memory devices to physical computation

Scientific directions and ideas to watch at the Neuronics Conference 2026

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A programme-wide editorial preview

The field represented at NEURONICS26 is changing its central question. The early challenge was whether emerging memories could reproduce synaptic weights. The programme now asks something more demanding: which physical properties of matter can become useful computational operations, and how can those operations survive the transition from an individual device to an integrated system?

Across the abstracts, five recurring resources stand out: ionic motion, stochastic switching, nonlinear dynamics, material heterogeneity and three-dimensional integration. The most interesting contributions do not merely report another memory window or classification accuracy. They connect a physical mechanism to a computational function, or expose the conditions under which that connection succeeds or fails.

1

Dynamics becomes the operation

Spiking, probability and reservoir response arise from device evolution in time.

2

Variability is being reassigned

Some work suppresses fluctuations; other work deliberately converts them into entropy or search.

3

The system is the real test

Arrays, algorithms, compact models and integration decide whether device physics becomes useful hardware.

1. When dynamics becomes the computing primitive

A strong message of NEURONICS26 is that useful computation need not be imposed on a material as a sequence of externally controlled memory updates. It can emerge from the natural trajectory of a device: oscillation, adaptation, threshold crossing, stochastic switching or fading memory. This moves the field from imitating abstract neural components toward designing with dynamical systems.

Beyond multiply-and-accumulate

Cheol Seong Hwang's keynote, "What else can we do with memristors?", provides an appropriate conceptual opening. Rather than treating memristors only as analogue weights for multiply-and-accumulate arrays, the abstract examines reservoir kernels, forward-forward learning, hardware approaches to difficult optimization problems and probabilistic bits. Its importance lies in questioning whether the dominant mapping of memristors onto conventional artificial neural networks is unnecessarily restrictive. The talk also keeps the discussion grounded by insisting that accuracy, power and time-to-solution must include peripheral circuitry.

Spikes and probabilities produced by the device itself

Gwangmin Kim's invited contribution uses NbOx selector-only Mott memory cells to combine non-volatile synaptic resistance and volatile neuronal dynamics. Resistance is converted directly into digital information through spike counting, avoiding repeated analogue-to-digital conversion. The same spiking Hopfield platform is configured for a physical unclonable function and simulated annealing, making it a particularly clear example of one physical substrate supporting distinct computational regimes.

Jiyong Woo approaches probabilistic computing through Ti/SiOx/Ti threshold-switching oscillators. By modifying oxygen-vacancy supply, oscillation becomes probabilistic and generates a sigmoidal p-bit response. The abstract connects physical analysis of charging and discharging to a vehicle-routing demonstration. The broader question is whether device-level probability can accelerate useful optimization after the full hardware overhead is counted.

Roberto Fenollosa Esteve's contributed talk challenges a different assumption: that repetitive neuronal firing requires an explicit reset or an autonomous oscillatory instability. In the reported circuit, continuous memristive dynamics and periodic excitation create spikes through a mismatch between voltage evolution and adaptation of the internal memory state. This is scientifically provocative because it shifts the design criterion from static current-voltage characteristics to the interaction between kinetics and stimulation.

> ***Question for Seoul: When should a dynamical feature be treated as device variability, and when does it become the computation itself?***

2. Ion motion: from instability to controllable state variable

Ionic motion appears throughout the programme in perovskites, electrochemical memories, ion-gated reservoirs and magneto-ionic devices. What changes from one contribution to another is not the presence of ions but the degree of control over their pathways, timescales and coupling to electronic or magnetic states.

The same ion dynamics, two opposite computational goals

Jung Ho Yoon's invited talk makes the contrast explicit. In one regime, Ru-ion motion in a SiO2 nanorod matrix is engineered for electroforming-free, low-power and linear conductance modulation. In another, porous oxides and controlled Ag-ion supply generate rapid stochastic outputs. Scanning thermal microscopy and electrothermal simulations are used to investigate the multi-filament origin of the randomness. The contribution is notable because deterministic memory and physical entropy are presented not as unrelated device classes, but as controllability regimes of ion motion.

Multiple timescales as information-processing capacity

Takashi Tsuchiya's ion-gating reservoirs exploit coupled ion-electron dynamics rather than suppressing them. The reported platforms span responses from megahertz to tens of hertz, and the edge-of-chaos regime provides strong computational capacity. Their integration with mechanical and gas sensors shows why reservoir computing is attractive at the sensor boundary: the material can extract temporal features before raw data are transferred to a conventional processor.

So-Yeon Kim's contributed work on halide-perovskite memristors focuses on making mobile ions controllable internal state variables. Interfacial engineering is used to suppress stochastic filamentary pathways, while compositional engineering in lead-free perovskites enables low-voltage switching and extraction of physical parameters from time-dependent responses. The emphasis on mechanism and interpretation is important: improved performance is connected to a more explicit model of hysteresis rather than reported as an isolated device metric.

Liza Herrera Diez extends ionic control into magnetism. Magneto-ionic gating tunes magnetic anisotropy and the linearity of synaptic updates; a second configuration separates long-term binary magnetic storage from volatile update eligibility. That separation resembles a hardware distinction between stored information and temporary permission to learn, offering an intriguing route toward reward-modulated plasticity.

> ***Question for Seoul: Can ionic devices be classified by controllability and timescale, rather than by material family alone?***

3. From an attractive device to a credible computing system

The programme repeatedly exposes the gap between a device demonstration and a useful computing architecture. Variability, conductance relaxation, asymmetric updates, conversion overhead, wiring and model fidelity all become decisive when devices are assembled into arrays or connected to learning algorithms.

Co-design rather than ideal-device thinking

Sangbum Kim proposes a memory hierarchy for analogue compute-in-memory in which different technologies are optimized for training and inference. This relaxes the demand that one synaptic device satisfy every requirement. The contribution frames device-algorithm co-optimization in three ways:

selecting algorithms tolerant to imperfections, adapting established algorithms to the hardware, and creating algorithms aligned with device physics.

Hyunjeong Kwak follows the ECRAM path from tungsten-oxide transport measurements to nonideality-aware training and a circuit-integrated 64 × 64 cross-point array. The breadth matters: variable-temperature Hall measurements address the switching mechanism, while relaxation and update imbalance are carried into hardware-aware training. It is the type of material-to-system chain that allows claims of energy-efficient analogue training to be evaluated coherently.

Jiwoo Eun's student contribution pushes this logic into pretrained language models. Measured ECRAM potentiation and depression curves are incorporated into analogue fine-tuning of Pythia-70M, together with knowledge distillation, clipping and quantization studies. The reported results are an early step rather than a claim of large-model competitiveness, but they address an important methodological point: device curves must enter the training loop before the scalability of analogue fine-tuning can be judged.

Integration and modeling define the ceiling

Jeehwan Kim's keynote argues for deterministic weight representations and monolithic three-dimensional integration as an alternative to fragile analogue state control. Vertically coupling sensing, memory and computing layers attacks data movement directly, while strain-engineered devices point toward extremely low switching energies. The central proposition is that materials and integration—not an isolated device metric—set the ultimate performance limit.

Luca Fehlings addresses the complementary need for interpretable compact models. The Heracles framework connects polarization switching and charge trapping in HfO2 ferroelectrics to retention, imprint, circuit design and reliability. Such models are essential if technologists and circuit designers are to exchange quantitative constraints rather than idealized device curves.

> ***Question for Seoul: Which nonidealities should be eliminated, which should be compensated algorithmically, and which should be used as computational resources?***

4. Heterogeneity and defects as design variables

A final direction running through NEURONICS26 is a change in attitude toward imperfect materials. Defects, filament pathways and nonlinear heterogeneity are not automatically desirable, but several contributions show how they can be measured, confined, trained or converted into reproducible functionality.

Learning functions, not only weights

Marco Fanciulli's invited talk presents physical Kolmogorov-Arnold networks implemented with silicon-on-insulator synaptic nonlinear elements. Instead of treating hardware nonlinearities as fixed defects surrounding trainable linear weights, the nonlinear current-voltage functions themselves become learnable edge operations. Floating-back-gate charge trapping may store the learned function shape, while negative differential resistance and multistability increase expressivity. This is a substantial conceptual departure from conventional crossbar thinking.

Controlling pathways from the atomic scale to the array

Jimin Lee's invited contribution follows Ag-filament formation in MoS_2 across lateral and vertical geometries, operando transmission electron microscopy, physics-based modeling, wafer-scale growth and CMOS back-end integration. The work illustrates how van der Waals gaps can guide ion migration and reduce variability rather than simply introducing another switching material.

Jaehyeong Lee's student talk uses in-situ atomic layer reduction to tune oxygen vacancies in vertically stacked TiO_{2-x} ECRAM channels. Electrochemical impedance spectroscopy connects the ion-migration barrier to pulse-update nonlinearity, and the optimized material is carried into a two-level vertical device. The scientific value lies in establishing a measurable chain from defect chemistry to learning-relevant behavior.

Dmitry Ichyotkin's student contribution combines electrochemical metallization and valence-change mechanisms in sputtered amorphous-silicon/yttria-stabilized-zirconia structures. The abstract reports multilevel switching, controlled current limiting and device-to-device dispersion below 16% across three fabrication batches. Its broad relevance comes from the attempt to reconcile filamentary ion transport with reproducibility and a path toward transistor-controlled arrays. It should be watched as a materials-to-integration study, while the proposed megabit-scale direction remains future work.

> ***Question for Seoul: Can heterogeneity become a trainable and reproducible hardware resource without losing manufacturability?***

Questions to carry into NEURONICS26

- What is the most useful level of abstraction for comparing oscillators, memristors, ECRAM, magneto-ionic devices and physical nonlinear networks?
- When a device exploits stochasticity, what benchmark demonstrates an advantage after peripheral circuits and sampling time are included?
- Can experimentally measured dynamics become a standard input to algorithm development, rather than a late-stage correction?
- Which material variables remain controllable after scaling to dense arrays and three-dimensional integration?
- How should the community compare deterministic accuracy, adaptive capability, energy, latency and robustness without reducing all systems to a single metric?

A programme defined by productive tensions

The most valuable feature of NEURONICS26 may be the coexistence of apparently opposing strategies. Some researchers seek deterministic states; others cultivate randomness. Some reduce device variability; others train nonlinear heterogeneity. Some move computation into memory arrays; others argue that dynamics near sensors or within oscillators offer a more native computational language. These are not contradictions to be resolved by choosing one winning platform. They are the scientific tensions through which the field is learning what physical computation can become.

The conference will be most productive if discussions move beyond isolated performance records and ask which mechanisms are controllable, transferable and scalable. The abstracts already suggest that the next stage will depend less on discovering one ideal device than on learning how materials, dynamics, circuits and algorithms constrain—and enable—one another.

Editorial note

These highlights are an AI-assisted editorial selection based on the scientific content of the submitted abstracts, their connections across the programme, and their potential to stimulate discussion. They are not a ranking of speakers or presentations. Contributions whose abstracts were incomplete or marked TBC were not interpreted substantively in this preview.

Complete official programme: https://www.nanoge.org/Neuronics26/program