

Get a Grip: Intel Neuromorphic Chip Used to Give Robotics Arm a Sense of Touch

By John Russell

July 15, 2020

Moving neuromorphic technology from the laboratory into practice has proven slow-going. This week, National University of Singapore researchers moved the needle forward demonstrating an event-driven, visual-tactile perception system that uses Intel's Loihi chip to control a robotic arm combining tactile sensing and vision. Noteworthy, they also ran the exercise on a GPU system and reported the Loihi-based system performed slightly better and at much lower power.

NUS researchers presented their results today at the virtual Robotics Science and Systems conference (<https://roboticsconference.org/>) being held this week. The combination of tactile sensing (grip) with vision (location) is expected to significantly enhance Robotic arm precision and delicacy of grip when handling objects. The use of neuromorphic technology also promises progress in efforts to reduce the power consumption required for robotics which is a central goal for neuromorphic technology.

"We're excited by these results. They show that a neuromorphic system is a promising piece of the puzzle for combining multiple sensors to improve robot perception. It's a step toward building power-efficient and trustworthy robots that can respond quickly and appropriately in unexpected situations," said Harold Soh a NUS professor and author on a paper (<http://www.roboticsproceedings.org/rss16/p020.pdf>) describing the work (Event-Driven Visual-Tactile Sensing and Learning for Robots).

Intel has long been at the forefront of efforts to commercialize neuromorphic technology, and its Loihi (<https://www.hpcwire.com/2020/03/18/intels-neuromorphic-chip-scales-up-and-it-smells/>) (chip)/Pohoiki (<https://www.hpcwire.com/2019/07/17/intel-debuts-pohoiki-beach-its-8m-neuron-neuromorphic-development-system/>) (system) is among the most developed platforms. Neuromorphic systems mimic natural systems such as the brain in that they use spiking neural networks (SNN (https://en.wikipedia.org/wiki/Spiking_neural_network)) to process information instead of the artificial neural networks (ANN (https://en.wikipedia.org/wiki/Artificial_neural_network)) more commonly used in machine/deep learning.

Mike Davies, director of Intel's Neuromorphic Computing Lab, said, "This research from National University of Singapore provides a compelling glimpse to the future of robotics where information is both sensed and processed in an event-driven manner combining multiple modalities. The work adds to a growing body of results showing that neuromorphic computing can deliver significant gains in latency and power consumption once the entire system is re-engineered in an event-based paradigm spanning sensors, data formats, algorithms, and hardware architecture." Intel also posted (<https://newsroom.intel.com/news/singapore-researchers-neuromorphic-computing-robots-feel/#gs.av7uff>) an account of the work.

This excerpt from the NUS paper nicely describes the challenge and contribution:



Fig. 5. (Left) Containers used for container classification task: coffee can, plastic soda bottle, soy milk carton, and metal tuna can. (Right) The objects in our expanded dataset (36 object classes with various visual and tactile profiles) collected using the same protocol.

(<https://6lli539m39y3hpkelqsm3c2fg-wpengine.netdna-ssl.com/wp-content/uploads/2020/07/Objects-for-test-.NSU-paper.png>) Many everyday tasks require multiple sensory modalities to perform successfully. For example, consider fetching a carton of soymilk from the fridge humans use vision to locate the carton and can infer from a simple grasp how much liquid the carton contains. They can then use their sense of sight and touch to lift the object without letting it slip. These actions (and inferences) are performed robustly using a power-efficient neural substrate—compared to the multi-modal deep neural networks used in current artificial systems, human brains require far less energy.

"In this work, we take crucial steps towards efficient visual-tactile perception for robotic systems. We gain inspiration from biological systems, which are asynchronous and event-driven. In contrast to resource-hungry deep learning methods, event-driven perception forms an alternative approach that promises power-efficiency and low-latency—features that are ideal for real-time mobile robots. However, event-driven systems remain under-developed relative to standard synchronous perception methods."

The value of multi-modal sensing has long been recognized as an important component for advancing robotics. However, limitations in the use of spiking neural networks have impeded the use of neuromorphic chips in real-time sensing functions.

"Event-based sensors have been successfully used in conjunction with deep learning techniques. The binary events are first converted into real-valued tensors, which are processed downstream by deep ANNs (artificial neural networks). This approach generally yields good models (e.g., for motion segmentation, optical flow estimation, and steering prediction), you're right this is just one of many possible ways. Accept Reject

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(<https://6lli539m39y3hpkelqsm3c2fg-wpengine.netdna-ssl.com/wp-content/uploads/2020/07/Photo-B-Robotic-system-2.jpg>)

This novel robotic system developed by NUS researchers comprises an artificial brain system that mimics biological neural networks, which can be run on a power-efficient neuromorphic processor such as Intel's Loihi chip, and is integrated with artificial skin and vision sensors.

Credit: National University of Singapore

"Neuromorphic learning, specifically Spiking Neural Networks (SNNs), provide a competing approach for learning with event data. Similar to event-based sensors, SNNs work directly with discrete spikes and hence, possess similar characteristics, i.e., low latency, high temporal resolution and low power consumption. Historically, SNNs have been hampered by the lack of a good training procedure. Gradient-based methods such as backpropagation were not available because spikes are non-differentiable. Recent developments in effective SNN training, and the nascent availability of neuromorphic hardware (e.g., IBM TrueNorth and Intel Loihi) have renewed interest in neuromorphic learning for various applications, including robotics. SNNs do not yet consistently outperform their deep ANN cousins on pseudo-event image datasets, and the research community is actively exploring better training methods for real event-data."

(<https://6lli539m39y3hpkelqsm3c2fg-wpengine.netdna-ssl.com/wp-content/uploads/2020/07/NSU.NuTouch.png>) Another obstacle was simply developing adequate tactile sensing devices. "Although there are numerous applications for tactile sensors (e.g., minimal invasive surgery and smart prosthetics), tactile sensing technology lags behind vision. In particular, current tactile sensors remain difficult to scale and integrate with robot platforms. The reasons are twofold: first, many tactile sensors are interfaced via time-divisional multiple access (TDMA), where individual taxels are periodically and sequentially sampled. The serial readout nature of TDMA inherently leads to an increase of readout latency as the number of taxels in the sensor is increased. Second, high spatial localization accuracy is typically achieved by adding more taxels in the sensor; this invariably leads to more wiring, which complicates integration of the skin onto robot end-effectors and surfaces," according to the paper.

The researchers developed their own a novel "neuro-inspired" tactile sensor (NeuTouch): "The structure of NeuTouch is akin to a human fingertip: it comprises "skin", and "bone", and has a physical dimension of $37 \times 21 \times 13$ mm. This design facilitates integration with anthropomorphic end-effectors (for prosthetics or humanoid robots) and standard multi-finger grippers; in our experiments, we use NeuTouch with a Robotiq 2F-140 gripper. We focused on a fingertip design in this paper, but alternative structures can be developed to suit different applications," wrote the researchers.

NeuTouch's tactile sensing is achieved via a layer of electrodes with 39 taxels and a graphene-based piezoresistive thin film. The taxels are elliptically-shaped to resemble the human fingertip's fast-adapting (FA) mechano-receptors, and are radially-arranged with density varied from high to low, from the center to the periphery of the sensor.

"During typical grasps, NeuTouch (with its convex surface) tends to make initial contact with objects at its central region where the taxel density is the highest. Correspondingly, rich tactile data can be captured in the earlier phase of tactile sensing, which may help accelerate inference (e.g., for early classification). The graphene-based pressure transducer forms an effective tactile sensor, due to its high Young's modulus, which helps to reduce the transducer's hysteresis and response time," report the researchers.

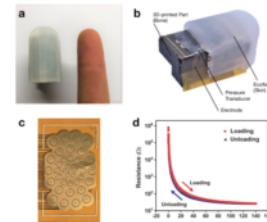
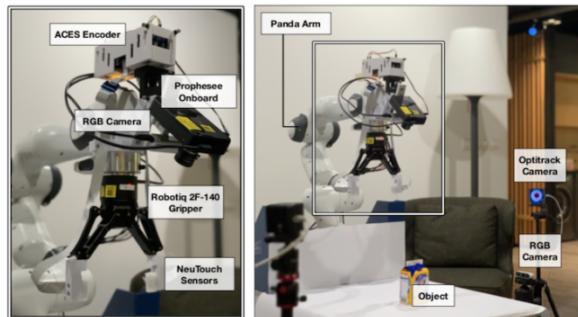


Fig. 1. (a) NeuTouch compared to a human finger. (b) Cross-sectional view of NeuTouch and constituent components. NeuTouch performs tactile sensing using an electrode layer with 39 taxels and a graphene-based piezoresistive thin film that is embedded beneath the protective Epeox "skin". (c) Spatial distribution of the 39 taxels on NeuTouch. (d) Pressure response curve of the graphene-based pressure transducer.



(<https://6lli539m39y3hpkelqsm3c2fg-wpengine.netdna-ssl.com/wp-content/uploads/2020/07/NSU.RoboticArm.png>)

Fig. 3. Robot Experiment Setup. (Left) Close-up of the Franka Emika Panda arm and sensors; a NeuTouch sensor was attached on each Robotiq gripper finger. The Prophesee event and Realsense cameras were mounted on the arm and pointed towards the center of the gripper's grasp area. Our prototype ACES encoder was mounted on top of the arm's control panel. (Right) A view of the object classification experiment showing three OptiTrack cameras (11 were used, and out of scene), the RGB scene camera, and the object (soy milk carton) to be grasped and lifted.

[\(https://6lli539m39y3hpkelqsm3c2fg-wpengine.netdna-ssl.com/wp-content/uploads/2020/07/NSU.RoboticArm.png\)](https://6lli539m39y3hpkelqsm3c2fg-wpengine.netdna-ssl.com/wp-content/uploads/2020/07/NSU.RoboticArm.png)

The primary goal, say the researchers, was to determine if their multi-modal system was effective at detecting differences in objects that were difficult to isolate using a single sensor, and whether the weight spike-count loss resulted in better early classification performance. "Note that our objective was not to derive the best possible classifier; indeed, we did not include proprioceptive data which would likely have improved results, nor conduct an exhaustive (and computationally expensive) search for the best architecture. Rather, we sought to understand the potential benefits of using both visual and tactile spiking data in a reasonable setup."

They used four different containers: a coffee can, Pepsi bottle, cardboard soy milk carton, and metal tuna can. The robot was used to grasp and lift each object 15 times and classify the object and determine its weight. The multi-modal SNN model achieved the highest score (81percent) which was about ten percent better than any of the single mode tests.

(https://6lli539m39y3hpkelqsm3c2fg-wpengine.netdna-ssl.com/wp-content/uploads/2020/07/Neuromorphic-Performance_Lohoi-system.NSU_.png) In terms of comparing the Loihi neuromorphic chip with the GPU (Nvidia GeForce RTX 2080), their overall performance was broadly similar but the Loihi-based system used far less power (see table). The latest work is significant step forward.

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It's best to read the full paper but here is an overview of the experiment taken from the paper.

- **Robot Motion.** The robot would grasp and lift each object class fifteen times, yielding 15 samples per class. Trajectories for each part of the motion was computed using the MoveIt! Cartesian Pose Controller. Briefly, the robot gripper was initialized 10cm above each object's designated grasp point. The end-effector was then moved to the grasp position (2 seconds) and the gripper was closed using the Robotiq grasp controller (4 seconds). The gripper then lifted the object by 5cm (2 seconds) and held it for 0.5 seconds.
- **Data Pre-processing.** For both modalities, we selected data from the grasping, lifting and holding phases (corresponding to the 2.0s to 8.5s window in Figure 4), and set a bin duration of 0.02s (325 bins) and a binning threshold value $S_{min} = 1$. We used stratified K-folds to create 5 splits; each split contained 240 training and 60 test examples with equal class distribution.
- **Classification Models.** We compared the SNNs against conventional deep learning, specifically Multi-layer Perceptrons (MLPs) with Gated Recurrent Units (GRUs) [54] and 3D convolutional neural networks (CNN-3D) [55]. We trained each model using (i) the tactile data only, (ii) the visual data only, and (iii) the combined visual-tactile data. Note that the SNN model on the combined data corresponds to the VT-SNN. When training on a single modality, we use Visual or Tactile SNN as appropriate. We implemented all the models using PyTorch.

TABLE III
INFERENCE SPEED AND POWER UTILIZATION

| | GPU | Loihi |
|----------------------------|--------|--------|
| Num. Inferences per second | 616.63 | 749.23 |
| Average Power (W) | 60.24 | 1.34 |

TABLE I
CONTAINER & WEIGHT CLASSIFICATION (ENTIRE INPUT SEQUENCE):
AVERAGE ACCURACY WITH STANDARD DEVIATION IN BRACKETS

| Model | Tactile | Vision | Combined |
|------------------------------|--------------|--------------|--------------|
| SNN (\mathcal{L}) | 0.71 (0.045) | 0.73 (0.064) | 0.81 (0.039) |
| SNN (\mathcal{L}_ω) | 0.71 (0.023) | 0.72 (0.065) | 0.80 (0.048) |
| ANN (MLP-GRU) | 0.50 (0.059) | 0.43 (0.054) | 0.44 (0.062) |
| ANN (CNN-3D) | 0.75 (0.061) | 0.68 (0.022) | 0.80 (0.041) |

(<https://6lli539m39y3hpkelqsm3c2fg-wpengine.netdna-ssl.com/wp->

content/uploads/2020/07/NSU-results.png).

Link to paper: <http://www.roboticsproceedings.org/rss16/p020.pdf> (<http://www.roboticsproceedings.org/rss16/p020.pdf>).

Link to Intel release: <https://newsroom.intel.com/news/singapore-researchers-neuromorphic-computing-robots-feel/#gs.av7uff>
(<https://newsroom.intel.com/news/singapore-researchers-neuromorphic-computing-robots-feel/#gs.av7uff>).

Link to video: https://www.youtube.com/watch?time_continue=19&v=tmDjoSIYtsY&feature=emb_logo (https://www.youtube.com/watch?time_continue=19&v=tmDjoSIYtsY&feature=emb_logo).

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By Tiffany Trader

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Graphcore Introduces Next-Gen Intelligence Processing Unit for AI Workloads

(<https://www.hpcwire.com/2020/07/15/graphcore-introduces-next-gen-intelligence-processing-unit-for-ai-workloads/>)

British hardware designer Graphcore, which emerged from stealth in 2016 to launch its first-generation Intelligence Processing Unit (IPU), has announced its next-generation IPU.

By Oliver Peckham

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Exascale computing aspires to provide breakthrough solutions addressing today's most critical challenges in scientific discovery, energy assurance, economic competitiveness

By Jack Dongarra and Stanimire Tomov

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There's No Storage Like ATGC: Breakthrough Helps to Store 'The Wizard of Oz' in DNA

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Even as storage density reaches new heights, many researchers have their eyes set on a paradigm shift in high-density information storage: storing data in the four nucleotide: [to-store-the-wizard-of-oz-in-dna/](https://www.hpcwire.com/2020/07/15/theres-no-storage-like-atgc-breakthrough-helps-to-store-the-wizard-of-oz-in-dna/)

By Oliver Peckham

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The America's Cup Dream

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 - Maxar Builds HPC on AWS to Deliver Forecasts 58% Faster Than Weather Supercomputer (https://www.hpcwire.com/solution_content/aws/maxar-builds-hpc-on-aws-to-deliver-forecasts-58-faster-than-weather-supercomputer)

Intel® HPC + AI Pavilion



Supercomputing the Pandemic: Scientific Community Tackles COVID-19 from Multiple Perspectives (<https://www.lcsm.org/covid-19-from-multiple-perspectives/>)

Since their inception, supercomputers have taken on the biggest, most complex, and most data-intensive computing challenges—from confirming Einstein's theories about gravity to fighting the COVID-19 pandemic—[scientific-community-tackles-covid-19-from-multiple-perspectives/](#)

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 - Software First: oneAPI Simplifies Development for Heterogeneous Computing (https://www.hpcwire.com/solution_content/intel/software-first-oneapi-simplifies-development-f)
 - Expanding Resources with Rapid HPC Orchestration in the Cloud (https://www.hpcwire.com/solution_content/intel/expanding-resources-with-rapid-hpc-orchestration-in-the-c)

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What's New in HPC Research: Volcanoes, Mobile Games, Proteins & More

(<https://www.hpcwire.com/2020/07/14/whats-new-in-hpc-research-volcanoes-mobile-games-proteins-more/>)

In this bimonthly feature, HPCwire highlights newly published research in the high-performance computing community and related domains. From parallel programming to exascale games-proteins-more/)

By Oliver Peckham

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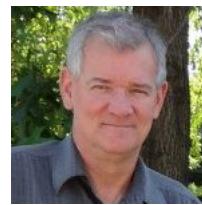
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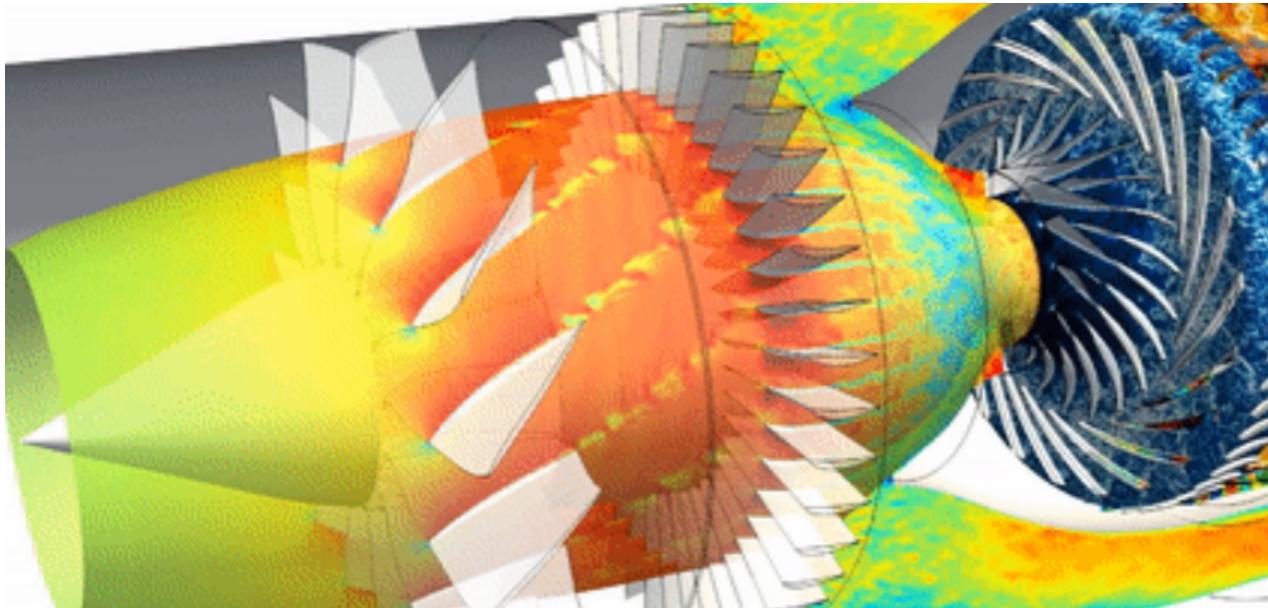
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Joliot-Curie Supercomputer Used to Build First Full, High-Fidelity Aircraft Engine Simulation

(<https://www.hpcwire.com/2020/07/14/joliot-curie-supercomputer-used-to-build-first-full-high-fidelity-aircraft-engine-simulation/>)

When industrial designers plan the design of a new element of a vehicle's propulsion or exterior, they typically use fluid dynamics to optimize airflow and increase the vehicle's [supercomputer-used-to-build-first-full-high-fidelity-aircraft-engine-simulation/](#)

By Oliver Peckham

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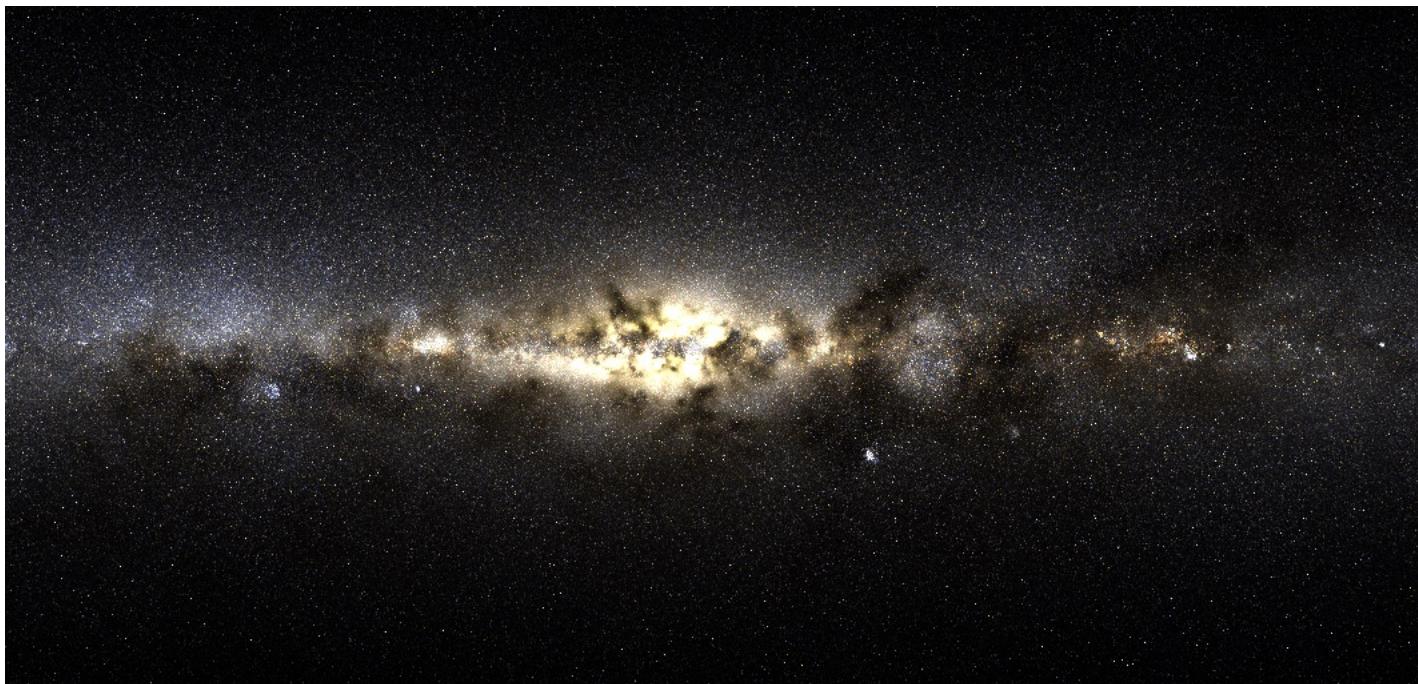
U.S. CTO Michael Kratsios Adds DoD Research & Engineering Title

(<https://www.hpcwire.com/2020/07/13/u-s-cto-michael-kratsios-adds-dod-research-engineering-title/>)

Michael Kratsios, the U.S. Chief Technology Officer, has been appointed acting Undersecretary of Defense for research and engineering. [Read more... \(https://www.hpcwire.co](#)

By John Russell

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Supercomputer Research Reveals Star Cluster Born Outside Our Galaxy

(<https://www.hpcwire.com/2020/07/11/supercomputer-research-reveals-star-cluster-born-outside-our-galaxy/>)

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The Milky Way is our galactic home, containing our solar system and continuing into a giant band of densely packed stars that stretches across clear night skies around the world (<https://www.hpcwire.com/2020/07/11/supercomputer-research-reveals-star-cluster-born-outside-our-galaxy/>).

By Oliver Peckham

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Max Planck Society Begins Installation of Liquid-Cooled Supercomputer from Lenovo

(<https://www.hpcwire.com/2020/07/09/max-planck-society-to-deploy-lenovo-supercomputer/>)

Lenovo announced today that it is supplying a new high performance computer to the Max Planck Society, one of Germany's premier research organizations. [Read more...](#)

By Tiffany Trader

Twitter (<http://twitter.com/intent/tweet?status=Max%20Planck%20Society%20Begins%20Installation%20of%20Liquid-Cooled%20Supercomputer%20from%20Lenovo+https%3A%2F%2Fwww.hpcwire.com%2F2020%2F07%2F09%2Fmax-planck-society-to-deploy-lenovo-supercomputer%2F&title=Max%20Cooled%20Supercomputer%20from%20Lenovo&source=https%3A%2F%2Fwww.hpcwire.com/>) **Facebook** (<http://www.facebook.com/sharer/sharer.php?u=https%3A%2F%2Fwww.hpcwire.com%2F2020%2F07%2F09%2Fmax-planck-society-to-deploy-lenovo-supercomputer%2F&title=Max%20Planck%20Society%20Begins%20Installation%20of%20Liquid-Cooled%20Supercomputer%20from%20Lenovo>)



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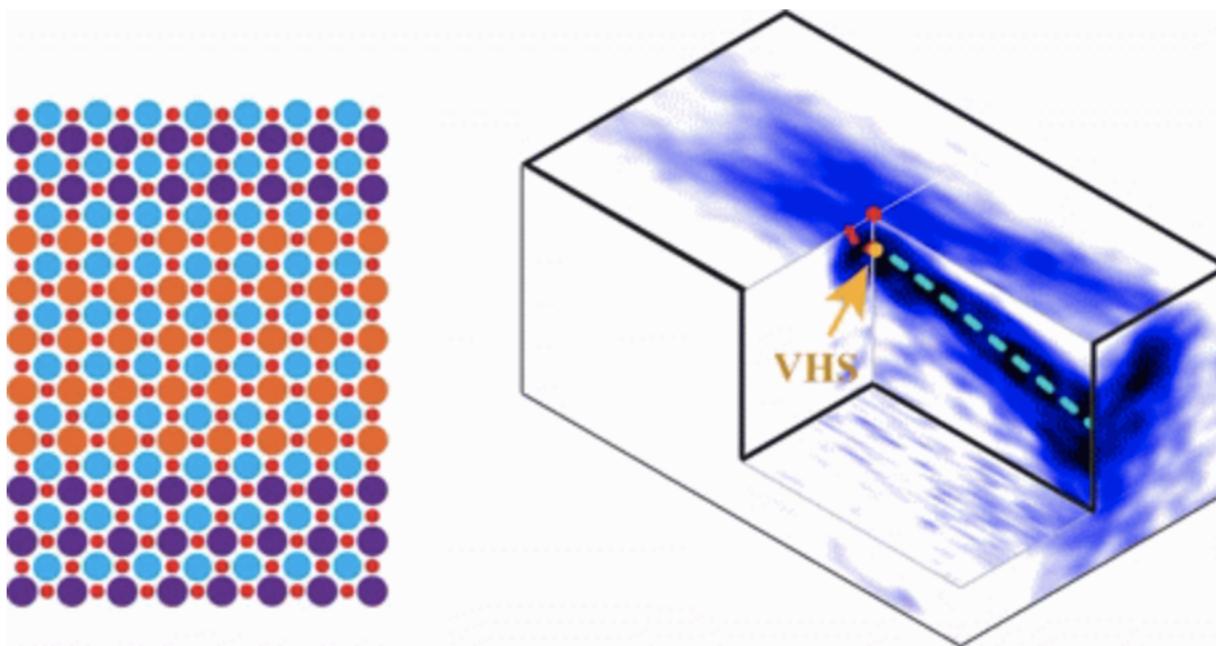
Xilinx Announces First Adaptive Computing Challenge

(<https://www.hpcwire.com/2020/07/09/xilinx-announces-first-adaptive-computing-challenge/>)

A new contest is challenging the computing world. Xilinx has announced the first Xilinx Adaptive Computing Challenge, a competition that will task developers and startups with Challenge in partnership with Hackster.io, a developing community... [Read more... \(<https://www.hpcwire.com/2020/07/09/xilinx-announces-first-adaptive-computing-challenge/>\)](https://www.hpcwire.com/2020/07/09/xilinx-announces-first-adaptive-computing-challenge/)

By Staff report

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Reviving Moore's Law? LBNL Researchers See Promise in Heterostructure Oxides

(<https://www.hpcwire.com/2020/07/09/reviving-moores-law-lbnl-researchers-see-promise-in-heterostructure-oxides/>)

The reality of Moore's law's decline is no longer doubted for good empirical reasons. That said, never say never. [Read more... \(<https://www.hpcwire.com/2020/07/09/reviving-n>\)](https://www.hpcwire.com/2020/07/09/reviving-n)

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President's Council Targets AI, Quantum, STEM; Recommends Spending Growth

(<https://www.hpcwire.com/2020/07/09/presidents-council-targets-ai-quantum-recommends-spending-growth-stem/>)

Last week the President Council of Advisors on Science and Technology (PCAST) met (webinar) to review policy recommendations around three sub-committee reports: [Read recommends-spending-growth-stem/](#).

By John Russell

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Penguin Computing Brings Cascade Lake-AP to OCP Form Factor

(<https://www.hpcwire.com/2020/07/07/penguin-computing-brings-cascade-lake-ap-to-ocp-form-factor/>)

Penguin Computing, a subsidiary of SMART Global Holdings, Inc., announced yesterday (July 6) a new Tundra server, Tundra AP, that is the first to implement the Intel Xeon S Project (OCP) form factor. Read more... (<https://www.hpcwire.com/2020/07/07/penguin-computing-brings-cascade-lake-ap-to-ocp-form-factor/>)

By Tiffany Trader

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Google Cloud Debuts 16-GPU Ampere A100 Instances

(<https://www.hpcwire.com/2020/07/07/google-cloud-debuts-ampere-a2-family/>)

On the heels of the Nvidia's Ampere A100 GPU launch in May, Google Cloud is announcing alpha availability of the A100 "Accelerator Optimized" VM A2 instance family on Google Cloud Platform which combines two HGX A100 8-GPU baseboards using... [Read more... \(<https://www.hpcwire.com/2020/07/07/google-cloud-debuts-ampere-a2-family/>\)](https://www.hpcwire.com/2020/07/07/google-cloud-debuts-ampere-a2-family/)

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Q&A: HLRS's Bastian Koller Tackles HPC and Industry in Germany and Europe

(<https://www.hpcwire.com/2020/07/06/qa-hlrss-bastian-koller-tackles-hpc-and-industry-in-germany-and-europe/>)

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In this exclusive interview for HPCwire – sadly not face to face – Steve Conway, senior advisor for Hyperion Research, talks with Dr.-Ing Bastian Koller about the state of HPC management in Germany and Europe.
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