NIH National Institutes of Health
The BRAIN Initiative®

Neuromorphic Principles in Biomedicine & Healthcare

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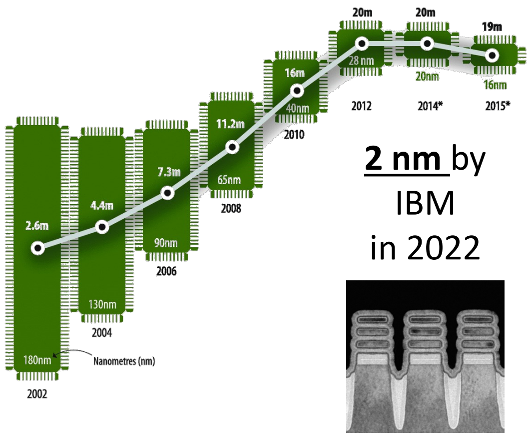
Disclaimers

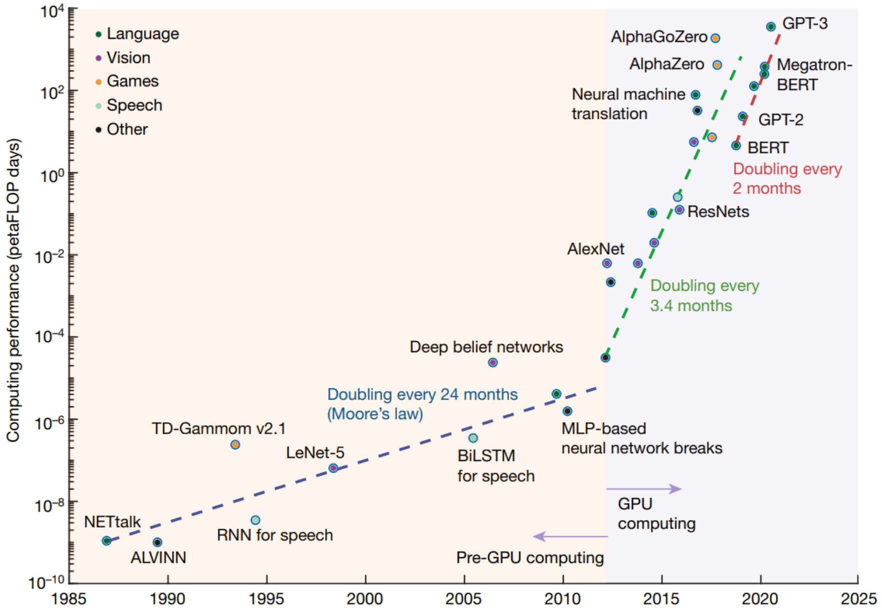
- The opinions expressed in this presentation do not reflect the views of the National Institutes of Health, the Department of Health and Human Services, or the United States Government.
- Financial disclosure: none

Why neuromorphic approaches/technologies?

The Tip-Top of Transistors.

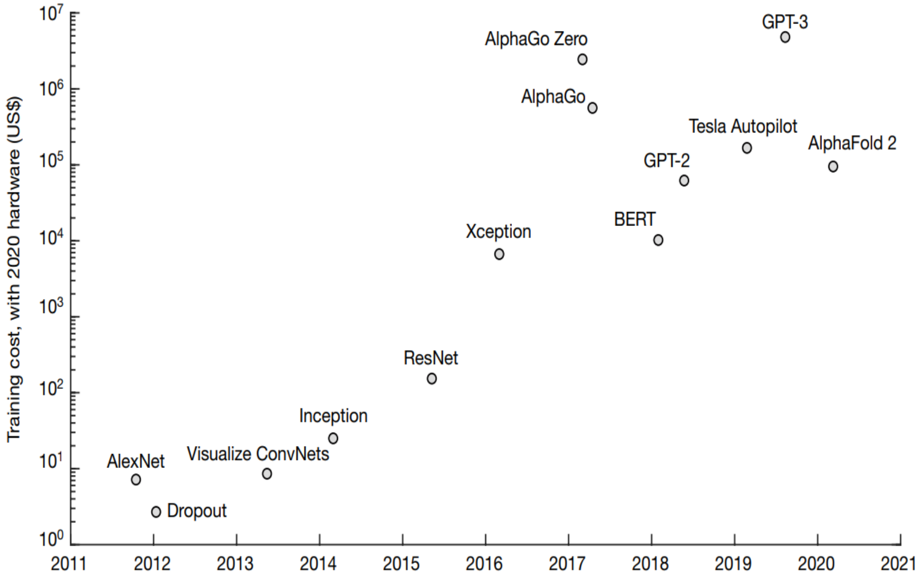


2 nm by
IBM
in 2022



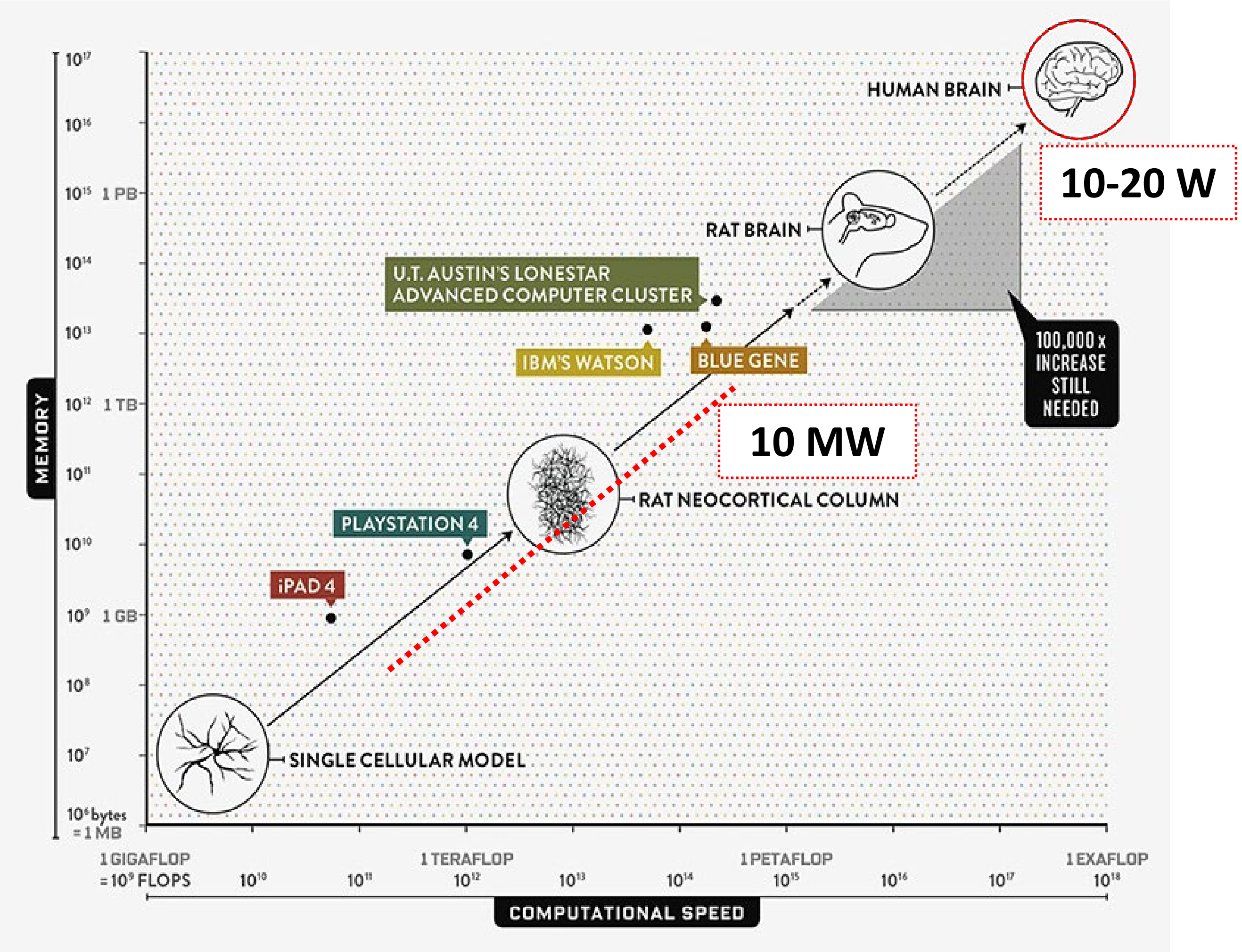
Transistors are reaching their physical limitations

Computing demand escalation



Training cost escalation

Human brain far outpaces current technologies



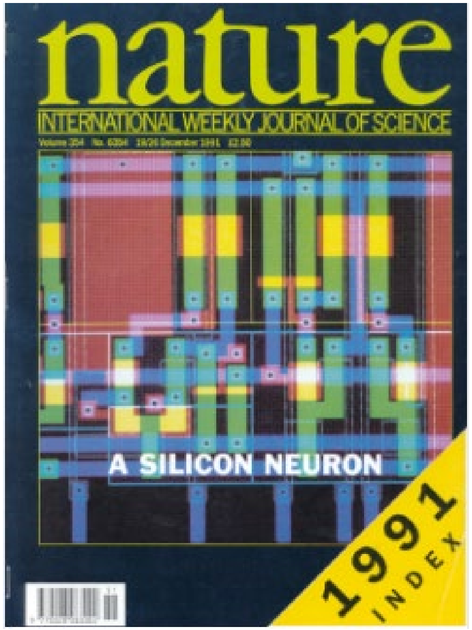
Visualizing the Trillion-Fold Increase in Computing Power (visualcapitalist.com)
Graphics adapted from J. Kulwatno, AAAS ST&P Fellow, NSF

Features of the brain

- Power-efficient
- Data-efficient
- Flexible/adaptive/resilient
- One/zero-shot learning
- Continual learning
- Causal learning
- Lifelong learning

Neuromorphic engineering conceived ~1988

First ‘silicon retina’ demonstrated in 1991 by Misha Mahowald (1963-1996)

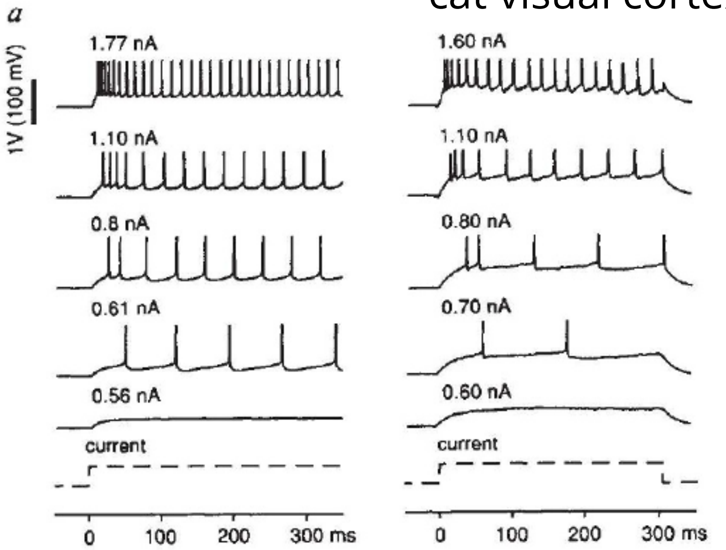


https://www.mahowaldprize.org/misha-mahowald

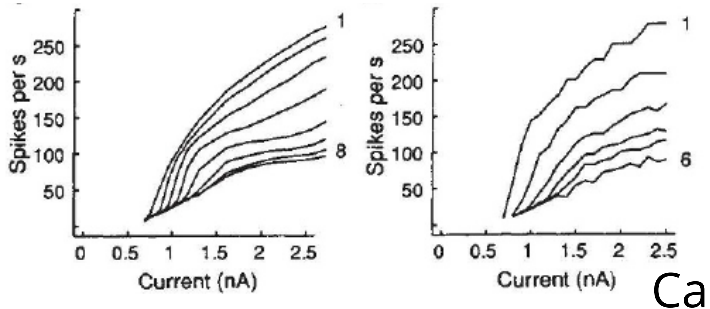
Photo: R. Douglas

Silicon Neuron

In vitro neuron - cat visual cortex



Current-discharge relation of 1st 8 spikes



Power Efficiency

The power dissipation of the whole circuit including instrumentation amplifiers is only 60 μW, which compares favourably with the 500-mW dissipation of a typical operational amplifier.

Adapted from Mahowald M & Douglas R. Nature 354 515-518

Caltech

What is neuromorphic computing

- Von Neumann processors have <u>separate</u> CPUs and memory units
- Compute is synchronous: one master clock.

- Neuromorphic processors are inspired by brains composed of neurons, synapses, dendrites. Glia cells and neuromodulators are in newer designs.
- Compute and memory are collocated.
- Compute is asynchronous

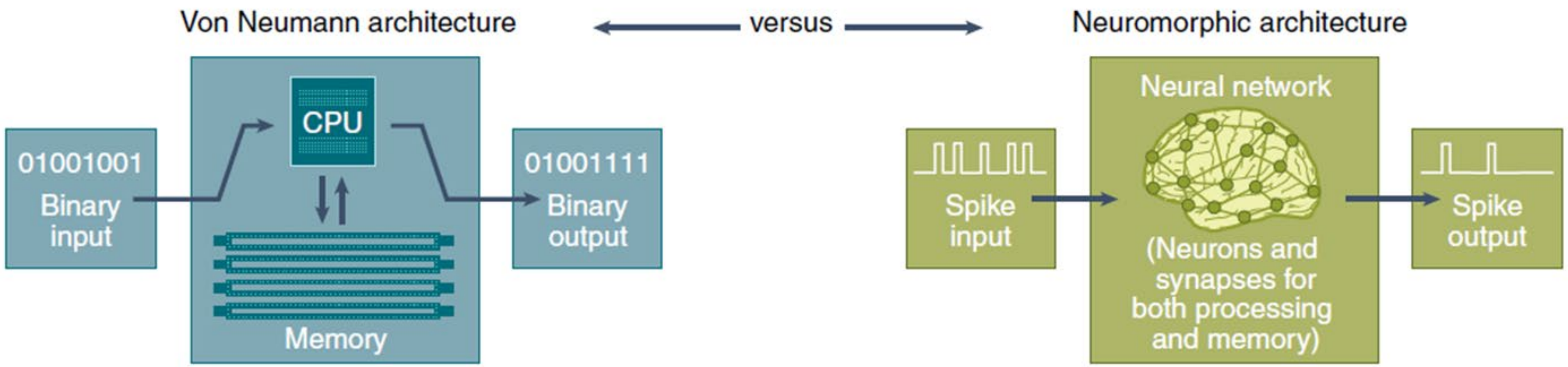
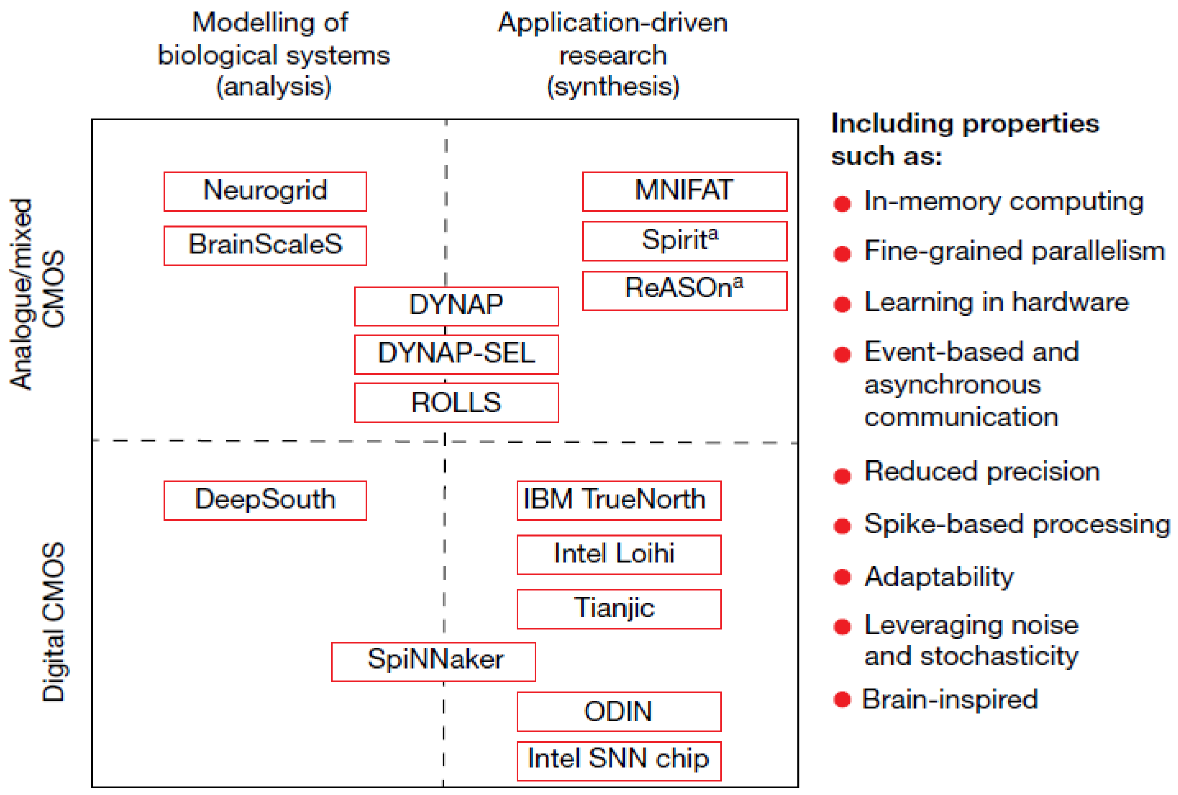


Figure from Schuman 2022 Nature Computational Science

Neuromorphic computers are most well known for their **extreme power efficiency**. This low power is due to both their event driven and massively parallel nature, where only a small portion of the entire system is active at any one time -> sparse like the brain.

Neuromorphic systems today

- Both industry and academia have taken an interest in neuromorphic systems (e.g., IBM's TrueNorth, Northpole, and Intel's Loihi)
- Variety of academic efforts, including DYNAPs, Neurogrid, MNIFAT, and BrainScales ongoing
- Usefulness of neuromorphic hardware such as BrainScales-2 has been demonstrated for spiking neural networks running at a much accelerated (1000x-10,000x) timescales compared to biological timescales
- Most neuromorphic systems are inference only and do not learn in real time



Mehonic 2022 Nature v.604 255-260

Why should NIH care neuromorphic principles and technologies?

- Many neurological or neuropsychiatric conditions could benefit from power-efficient neuromorphic algorithms, architectures, and devices
- Low power footprint can enable
  - ✓ on-chip seizure detection in epilepsy / Responsive neurostimulation (RNS)
  - ✓ on-chip spike sorting to accelerate neuroscience discoveries
  - ✓ Sophisticated algorithms for implantable or wearable devices
    - Deep brain stimulation (DBS)
    - Vagus nerve stimulation (VNS)
    - others
- Neuromorphic architecture operates based on spikes and is intended to **adapt** and learn at time scales commensurate with individual responses – hardware weights can change in response to stimulus
- **Yet the neuromorphic engineering and neural engineering/biomedical communities operate in parallel research tracks; different conferences**
- The upcoming NSF-NIH co-sponsored workshop on Neuromorphic Principles in Biomedicine & Healthcare seeks to convene clinicians, neuromorphic engineers, neural/biomedical engineers and businesses to determine the opportunity landscape

NPBH 2024

2024 Workshop on Neuromorphic Principles in Biomedicine and Healthcare

https://2024.neuro-med.org

ORGANIZING COMMITTEE:

Ralph Etienne-Cummings
Johns Hopkins University

Jennifer Blain Christen
Arizona State University

Duygu Kuzum
University of California

Luke Osborn
Case Western Reserve University

Francisco Valero-Cuevas
University of Southern California

POTENTIAL TECHNICAL COMMITTEE (TO BE INVITED):

Gina Adam
George Washington University

Shantanu Chakrabarty
Washington University St. Louis

Gert Cauwenberghs
University of California San Diego

Robert Stevens
Johns Hopkins University

Sydney Cash
MGH-Harvard University

CALL FOR PARTICIPATION

WORKSHOP OVERVIEW

The goal of the workshop is to bring communities together to create a new generation of biomedical and neuroengineering technologies that operate with extreme energy and data efficiency, adaptability, and performance advantages compared to current approaches.

We plan to congregate biomedical engineers, neural engineers, neuroscientists (computational and physiologists), neuromorphic scientists and engineers, materials scientists, clinicians, and mainstream engineers (e.g., electrical engineers, optical engineers, computer engineers, device engineers) to introduce new brain- and biology-inspired design principles to engineers who are currently investigating non-von Neumann architectures. We expect that these new principles will provide alternative methods to solve relevant problems in the biomedical field, and to do so with significant improvements in the various metrics of the field.

INTELLECTUAL MERIT

The planned interactions will leverage the synergistic interests of the National Institutes of Health (NIH) [including the National Institute of Neurological Disorders and Stroke (NINDS) and the National Institute of Biomedical Imaging and Bioengineering (NIBIB)] and the National Science Foundation (NSF) to improve healthcare technologies, while also discovering fundamental concepts in engineering.

NSF/NIH Workshop on Neuromorphic Principles in Biomedicine & Healthcare: 21-22 October 2024 in Baltimore, MD (Award # 2433739)

https://2024.neuro-med.org

SPEAKERS/PANELISTS (TO BE INVITED):

Terry Sejnowski
Salk Institute

Alfredo Quinones-Hinojosa
Mayo Clinic

Tim Denison
Oxford University

Elizabeth Tyler-Kabara
University of Texas, Austin

R. James Cotton
Northwestern University

Sri Sarma
Johns Hopkins University

Sihong Wang
University of Chicago

Pamela Abshire
University of Maryland, College Park

William Stacey
University of Michigan

Bruno Olshausen
University of California, Berkeley

Kwabena Boahen
Stanford University

Rajesh Rao
University of Washington

Nathan Crone
Johns Hopkins University

Brad Aimone
Sandia National Laboratory

An expected output of the workshop will be a neuromorphic biotechnology roadmap that articulates the benefits of the approach, highlights the challenges and proposes a potential pathway to achieve the benefits. We expect analysis of the needs of the field, presentation of emerging technologies and concepts, and their potential impact on the common interests of the NIH and NSF. The workshop will primarily feature discussion and debates that will lead to a roadmap to clearly identify the near-term and longer-term opportunities and elucidate the potential partners – including the private sector – who should participate in driving these efforts.

BROADER IMPACTS

The two-day workshop program will include 2 keynote addresses, 12 invited presentations, poster sessions for graduate student attendees, moderated discussion sessions and meetings with NIH and NSF program managers. We will also invite the program committee, composed of 5 experts, to serve on discussion panels. A further group of 6 scholars/entrepreneur/innovator will be convened for this workshop. We will encourage all of them to bring their students to participate in the discourse and present posters.

We will stage the workshop to coincide with Biomedical Engineering Society (BMES) conference that will take place in Baltimore in October 2024. We expect both in-person and virtual participants. The invited speakers will be asked to address five questions that will lead to ***Needs, Challenge, Contribution, Impact and Investment Statements*** for the field. The output of the workshop will be a curated document that presents a roadmap for how neuromorphic engineering can contribute to biomedical technologies, enhance current approaches, promote scientific and engineering discoveries and offer entrepreneurial opportunities for the future.

National Institutes of Health | NSF | National Institute of Biomedical Imaging and Bioengineering — Technologies to Shape the Future of Health | National Institute of Neurological Disorders and Stroke

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NPBH 2024

2024 Workshop on Neuromorphic Principles in Biomedicine and Healthcare

Confirmed Agenda

Day 1 – October 21, 2024

Keynote: Timothy Denison, U. Oxford

Topic 1- Epilepsy & cortical disorders (neuromodulation):

- Victor Jirsa – INSERM;
- William Stacey – U. Mich.;
- Sridevi Sarma – JHU

Topic 2 - Human-machine interfaces (prosthetics)

- Elisa Donati – U. Zurich
- R.J Cotton – Northwestern

Day 2 – October 22, 2024

Keynote: Zhenan Bao, Stanford U.

“Learning from Skin: from Materials, Sensing Functions to Neuromorphic Engineering”

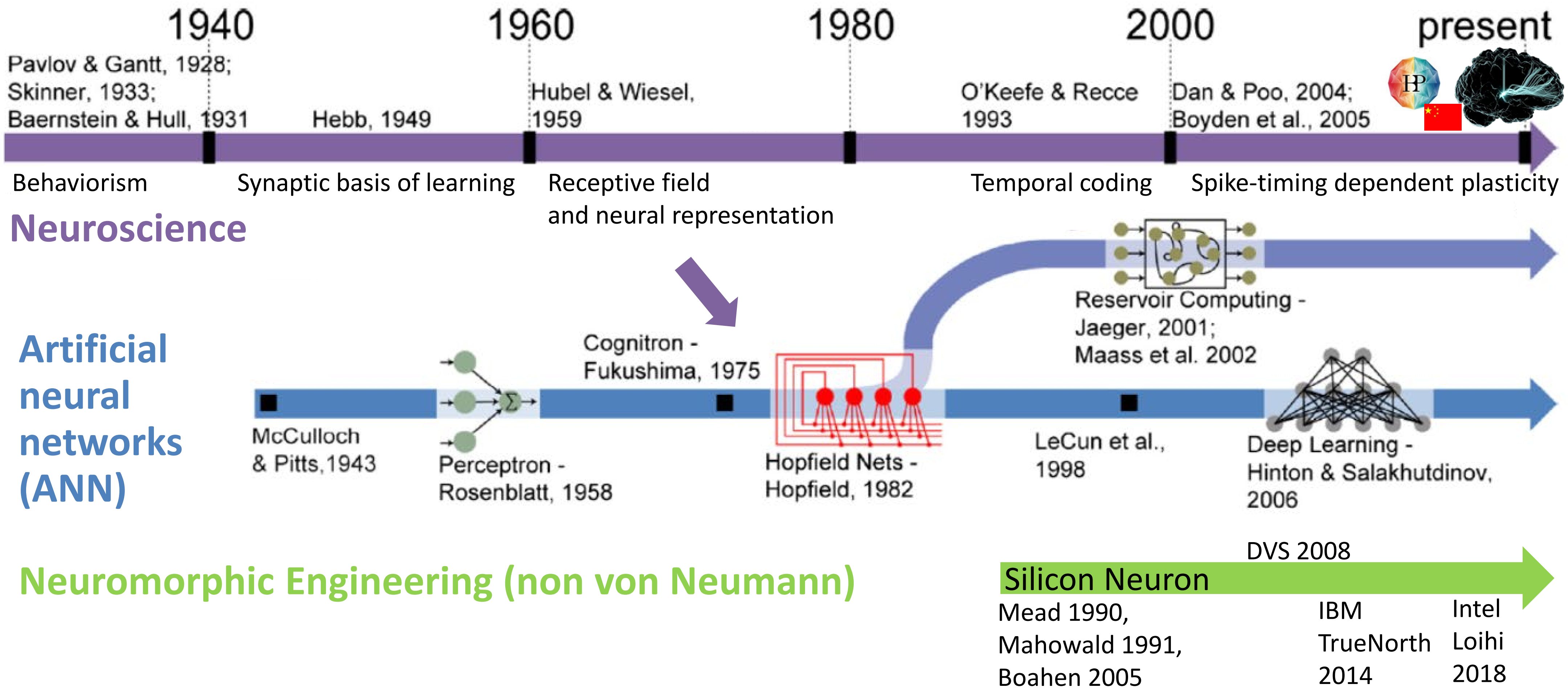
Topic 1 - Materials for neuromorphics (devices & architectures)

- Duygu Kuzum - UCSD

Topic 2 - Medical imaging, wearables and analysis.

For more, visit: https://2024.neuro-med.org (registration will open soon)

Long relationship among neuroscience, AI, and Neuromorphic engineering



- Tremendous advances in neuroscience past ten years
- Deep learning was enabled by accelerators, GPU and TPU (scaling)
- Digital algorithms are slow, power and data hungry: **need new computational basis.**
- **Neuromorphic is an alternative efficient algorithm & architecture**

Figure adapted "A historical survey of algorithms and hardware architectures for neural-inspired and neuromorphic computing applications", C. D. James, et al., *Biologically Inspired Cognitive Architectures* 2017.

Questions

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