Post Von Neumann Computing

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Hasler Stiftung (formerly IBM Research)

HASLERSTIFTUNG

Foundation Purpose

Support information and communication technologies (ICT) to advance Switzerland as a place to work and think.

Mechanisms

1. **Education** Computer Science as compulsory subject in secondary schools
2. **Research** Topical research programs (Smart World, MMI, DICS)
3. **Innovation** Startup funding

Structure

- Foundation board (6 Persons) split into investment and scientific committees
- Offices in Berne

IBM Research

World's largest information technology research organization

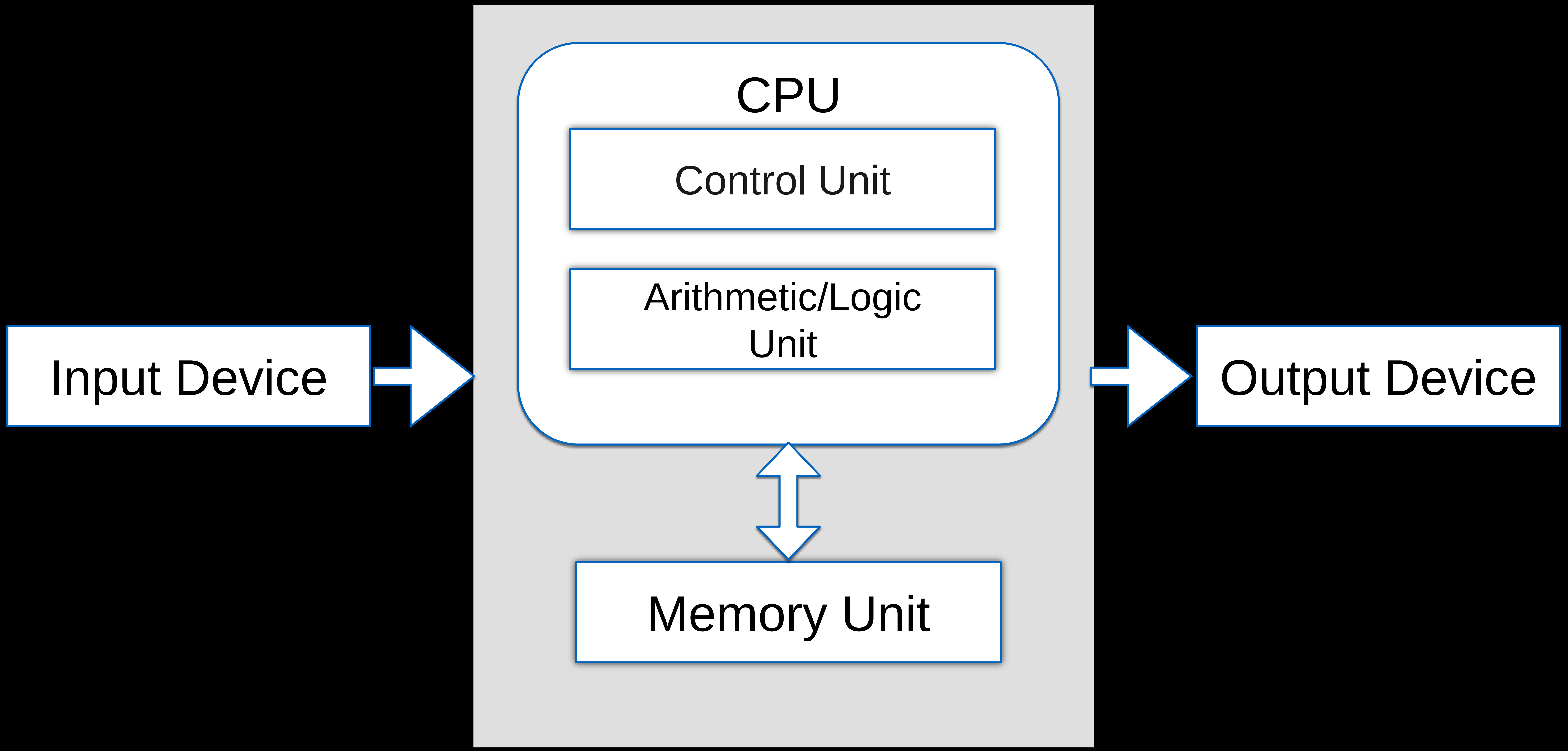
More than 3,000 scientists and engineers

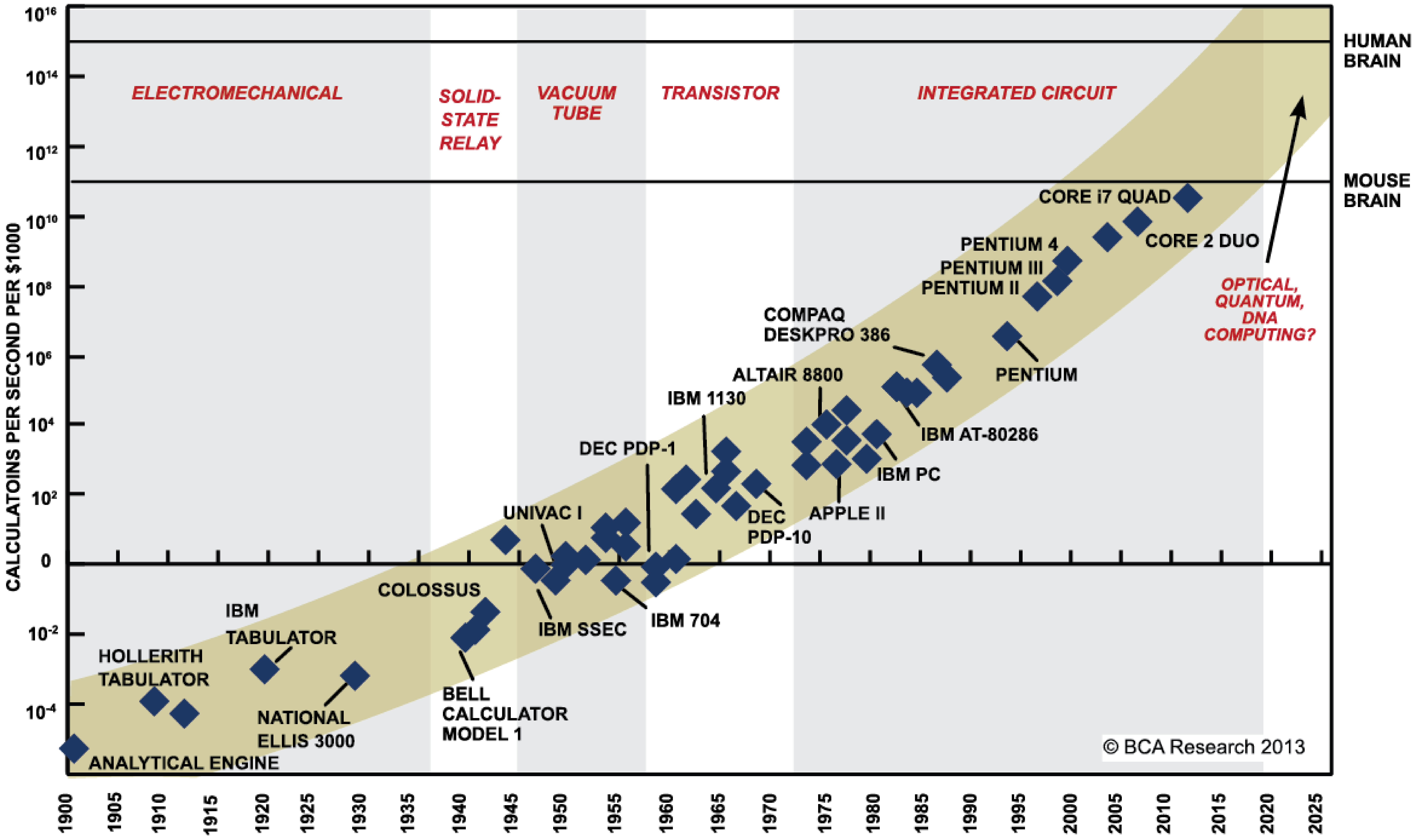
Patent Leader for 22nd Year
7,534 US Patents

Agenda

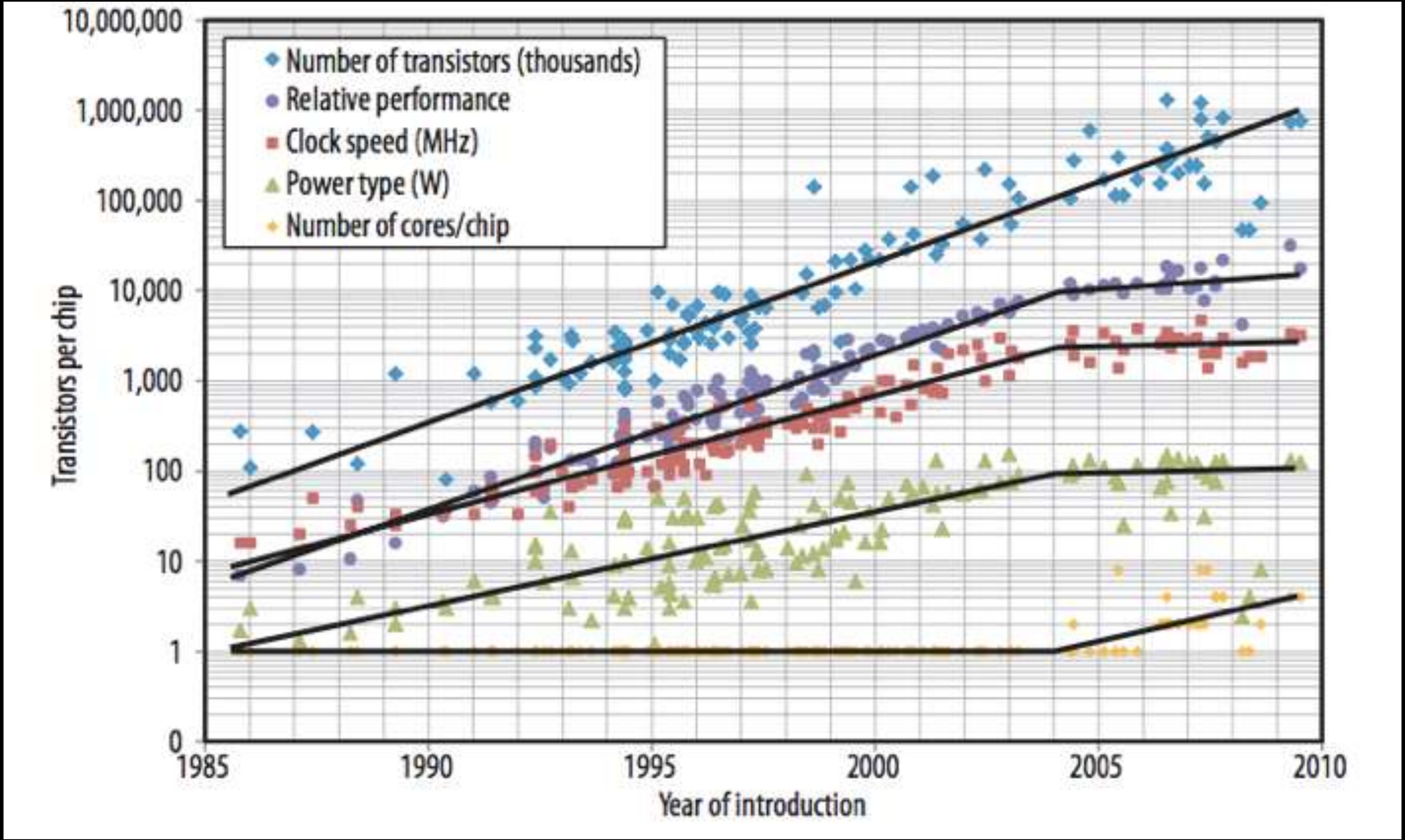
1. Von Neumann Computing
2. Big Data
3. Cognitive Computing
4. Post Von Neumann Computing

Von Neumann Computer





SOURCE: RAY KURZWEIL, "THE SINGULARITY IS NEAR: WHEN HUMANS TRANSCEND BIOLOGY", P.67, *THE VIKING PRESS*, 2006. DATAPOINTS BETWEEN 2000 AND 2012 REPRESENT BCA ESTIMATES.



Number of transistors (thousands)
Relative performance
Clock speed (MHz)
Power type (W)
Number of cores/chip
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
0
Transistors per chip
1985
1990
1995
2000
2005
2010
Year of introduction

Agenda

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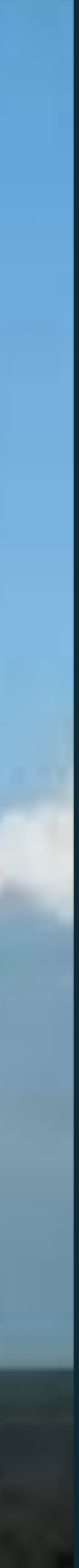
2.5 quintillion
bytes of data
created
every day.

90% of the data
in the world today
has been created in
the last **two years**
alone.

Every minute,
1.7 megabytes
of data is created for
every person on
the planet.
All 7.3 billion of us.

Unstructured data — “dark data” — accounts for 80% of all data generated today.



This is expect to grow to 93% by 2020.

Agenda

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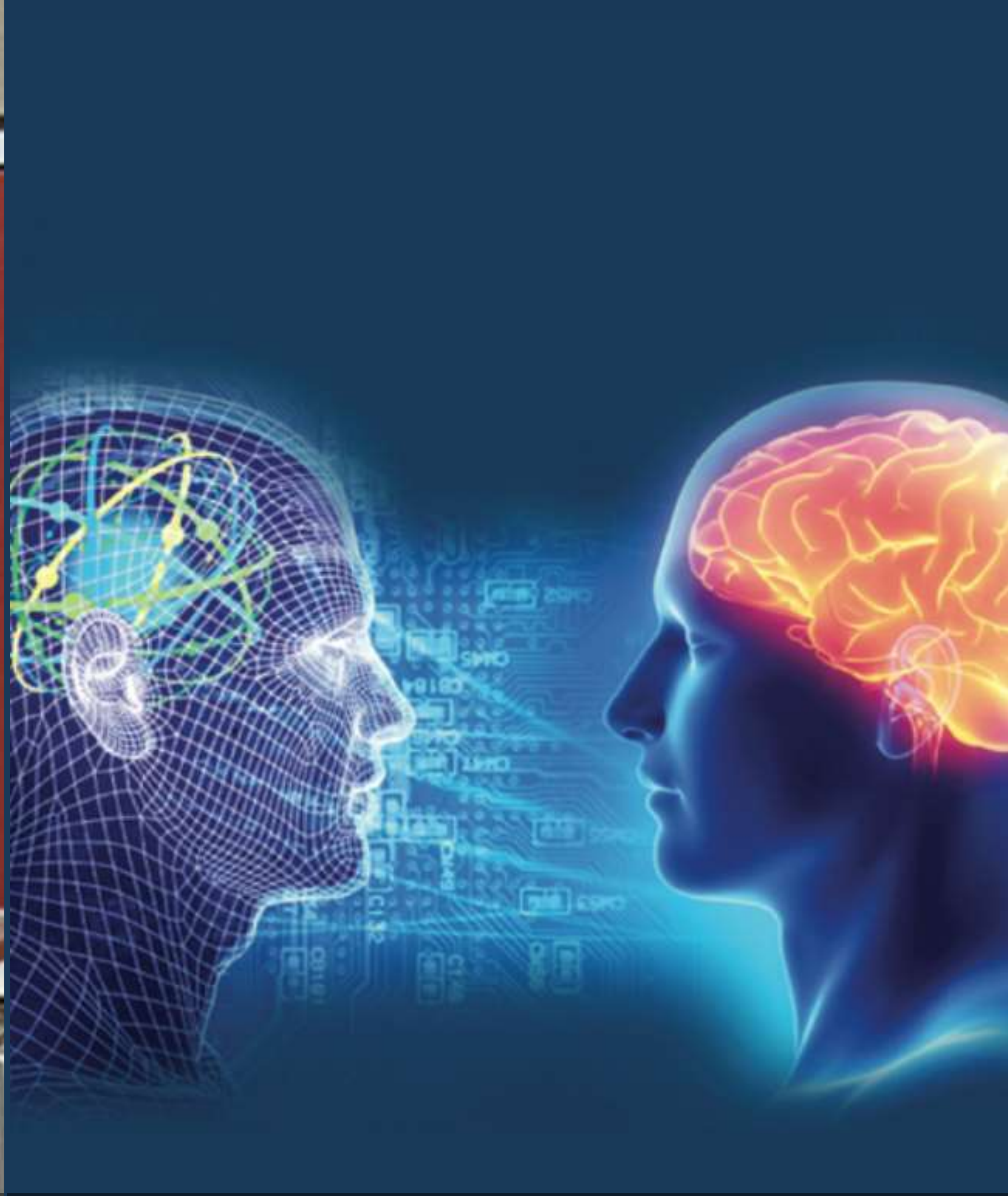
On February 14, 2011, IBM Watson made history

Tabulating
Systems Era
1900 - 1940s

Programmable
Systems Era
1950s - Present

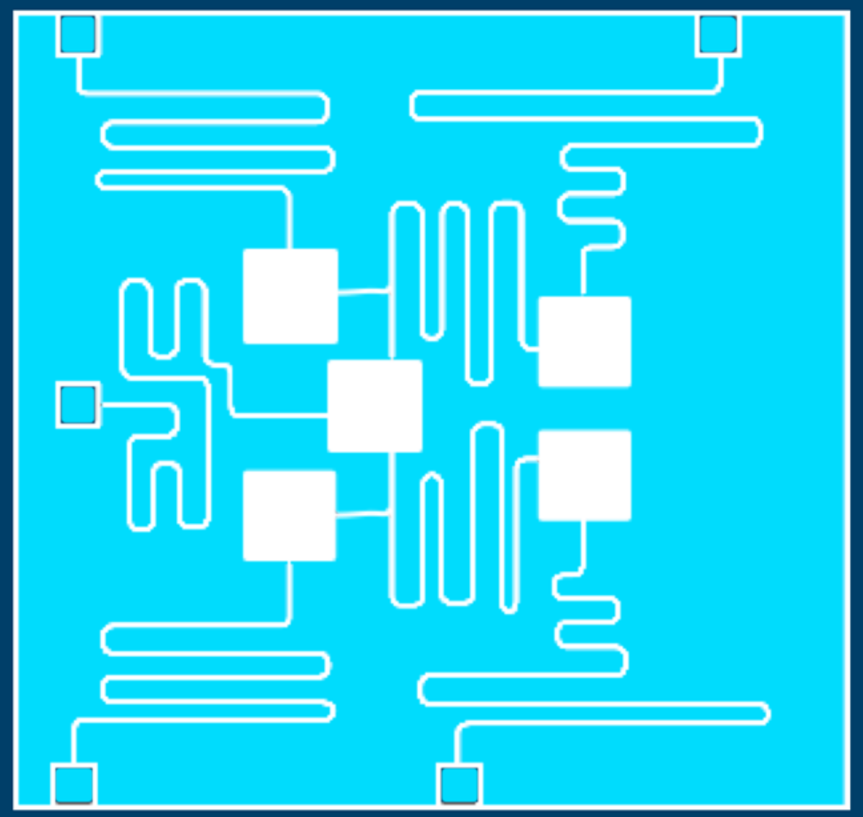


Cognitive
Systems Era
2011 -

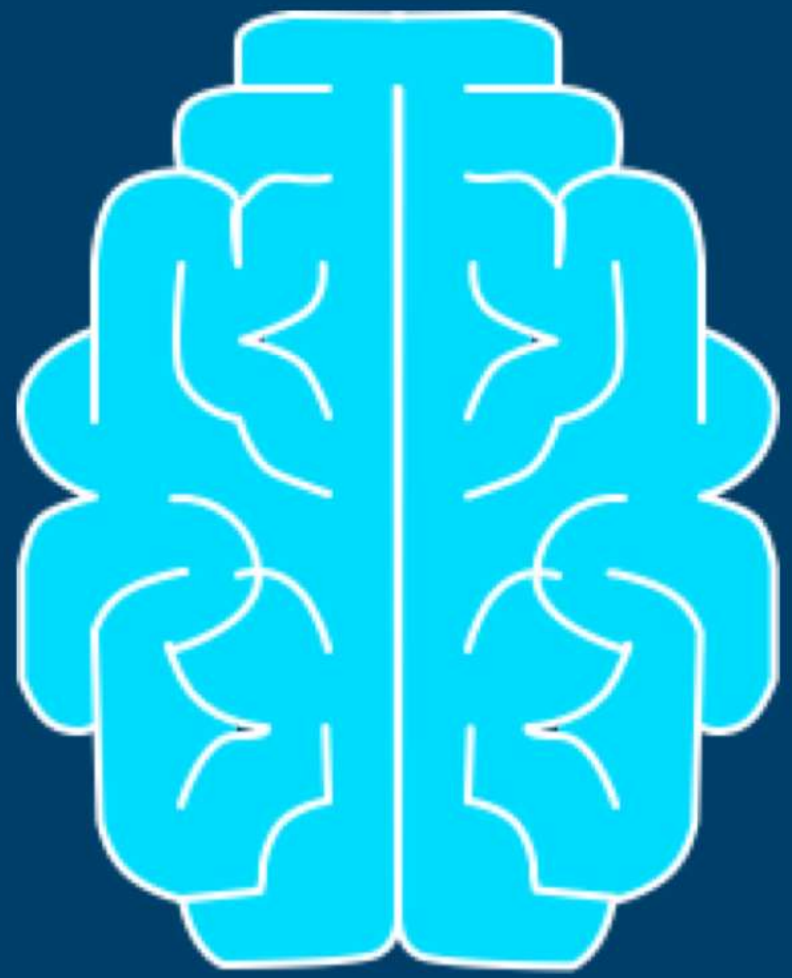
Welcome to the dawn of the Cognitive Era

The Future of Computing:
Non-Von Neuman for Next Generation Cognitive Applications

Physics of Nanoscale Systems



Quantum Computing



Neuromorphic Computing

Classic vs Quantum Computer

- A classical computer makes use of bits to process information, where each bit represents either a 1 or a 0.
- A quantum bit (qubit) can represent a 1, a 0, or both at once, which is known as superposition.
- This property along with other quantum effects enable quantum computers to perform certain calculations vastly faster than is possible with classical computers.

Three Known Types of Quantum Computing

Annealer

Potential applications
for optimization problems

Analog

First time we will likely see
a speed up over conventional computing

Universal

50-100 qubits:
none of today's TOP500 supercomputers
could successfully emulate it,

YEARS +0 +5 +25

D:Wave Google LOCKHEED MARTIN Microsoft IBM

intel NORTHROP GRUMMAN

Quantum Systems Era

"Nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem, because it doesn't look so easy."

Physicist Richard Feynman, Physics of Computation Conference, co-organized by MIT and IBM, May 6-8, 1981

IBM's Quantum System Milestones: 1970s - Today

- **1970 - Quantum money** (security) - *Wiesner/Bennett*
- **1984 - Quantum key distribution** (BB84) - *Bennett/Brassard*
- **1993 - Quantum teleportation** *Bennett et al.*
- **1996 - DiVincenzo Criteria** for building a quantum computer
- **2001 - Shor algorithm with NMR** *Steffen/Chuang/Vandersypen*
- **2015 - Error Correction** Demonstration with superconducting qubits (shown at IBM and other groups)
- **2016 - IBM Quantum Experience** (5 qubits in the cloud for the general public)

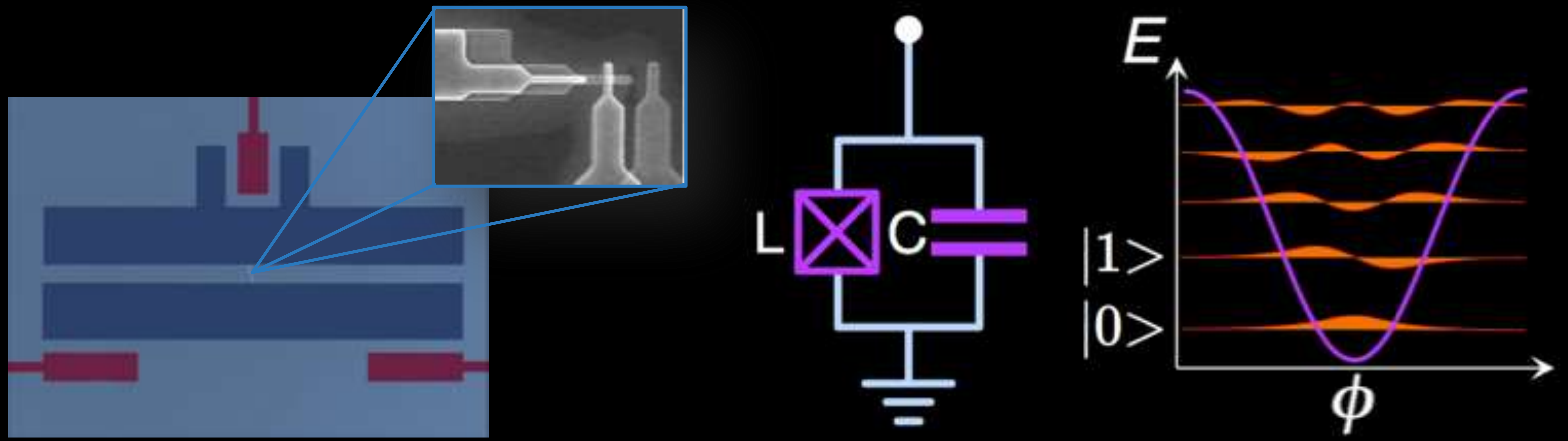
Try it today: http://bit.ly/5qubitcloud

Quantum Computing Platforms: Status Quo

	# of controllable qubits	main application	scalability	(2-qubit) gates per coherence	Clock speed	universal set of gates
Superconducting Qubits	~ 10	computing	+: micro-/ nanofabrication -: qubit size	100-1000	100 MHz	proven
Trapped Ions	~ 15	computing	surface traps	1000 - 10000	100 kHz	proven
Ultra-Cold Atoms	~ 5 / 1000	simulation	+: laser lattices -: individual control	1-10	1 MHz	controlled 2-qubit interactions ?
Quantum Dots	~ 3	computing	+: nanofabrication -: long range coupling	10-100	1 GHz	scalable 2-qubit gates ?
NV Centers	~ 2	sensing	-: 2-qubit interactions	1-10	1 kHz	2-qubit gates ?
Photons	~ 10	communication	-: single photon source	n. a.	1 Hz	2-qubit interactions ?

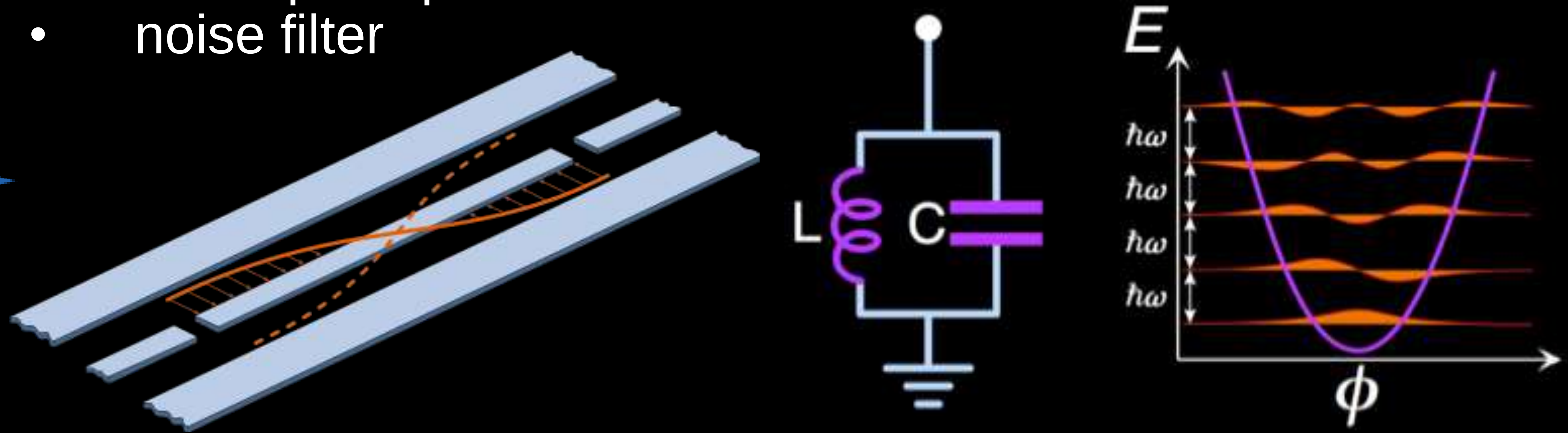
Superconducting Qubit Processor – A Closer Look

Superconducting Qubit:
- non-linear Josephson Junction (Inductance)
- anharmonic energy spectrum => qubit
- nearly dissipationless => T_1, T_2 ~ 70 µs



$E_{01} \approx 5$ GHz $\approx$ 240 mK

Microwave Resonator as:
- read-out of qubit states
- multi-qubit quantum bus
- noise filter



IBM **Quantum Computing** Account Logout

User Guide | Composer | My Scores

Welcome to the IBM Quantum Experience

If quantum physics sounds challenging to you, you are not alone. The intuitions we all have, based on our day-to-day experiences, are defined by classical physics -- so most of us find the concepts in quantum physics counterintuitive at first. If you try to interpret quantum mechanics with a classical physics mindset, you'll find it is not only a hindrance — it is impossible to do so. In order to comprehend the quantum world, you must let go of your beliefs about our physical world, and develop an intuition for a completely different (and often surprising) set of laws.

Our goal with the IBM Quantum Experience is to introduce this world through a set of tutorials, and by providing the hands-on opportunity to experiment with operations on a real quantum computing processor. In this way, we hope to foster a quantum intuition for the community at large, and spark interest in those who are curious. By making quantum concepts more widely understood—even on a general level— we can more deeply explore all the possibilities quantum computing offers, and more rapidly bring its exciting powers to a world that thinks it is limited to the laws of classical physics.

We have developed five short tutorials that explain how the IBM Quantum Experience and the quantum world works.

Section I

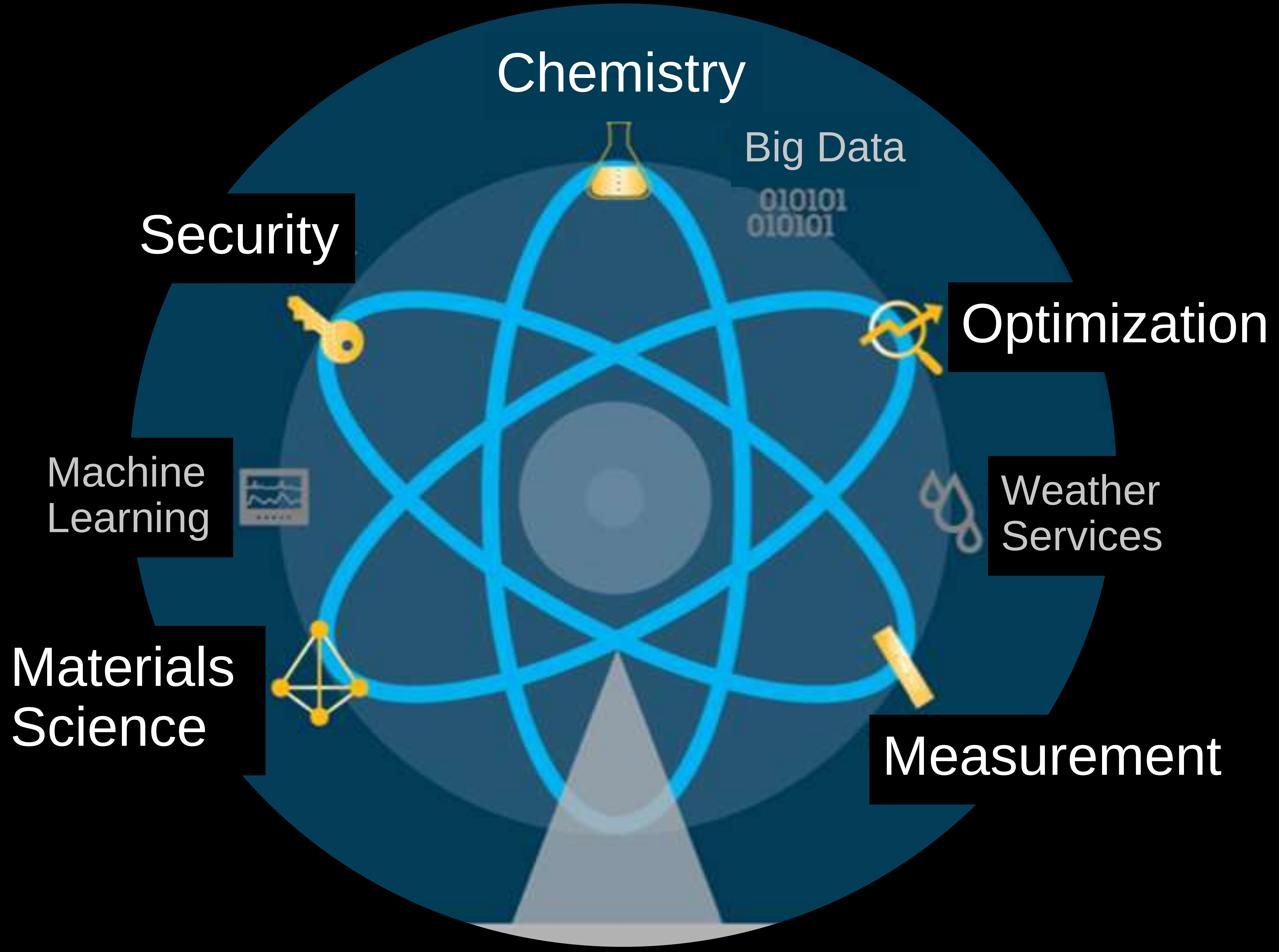
The IBM Quantum Experience

Introducing the world's first cloud-based quantum computer built for and useable by everyone!

Section II

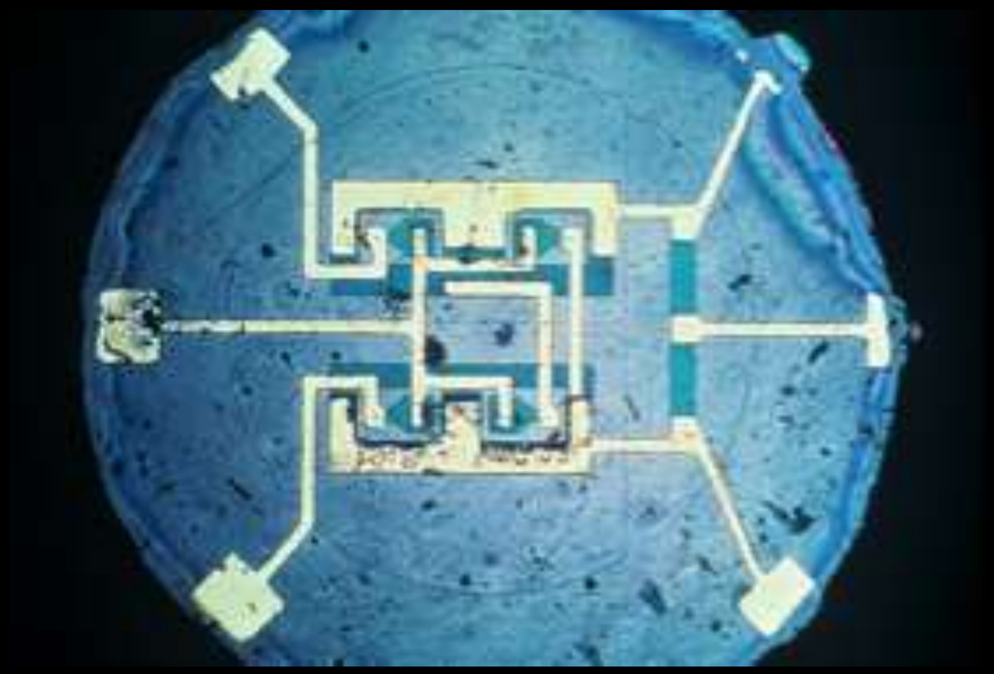
The Weird and Wonderful World of the Qubit

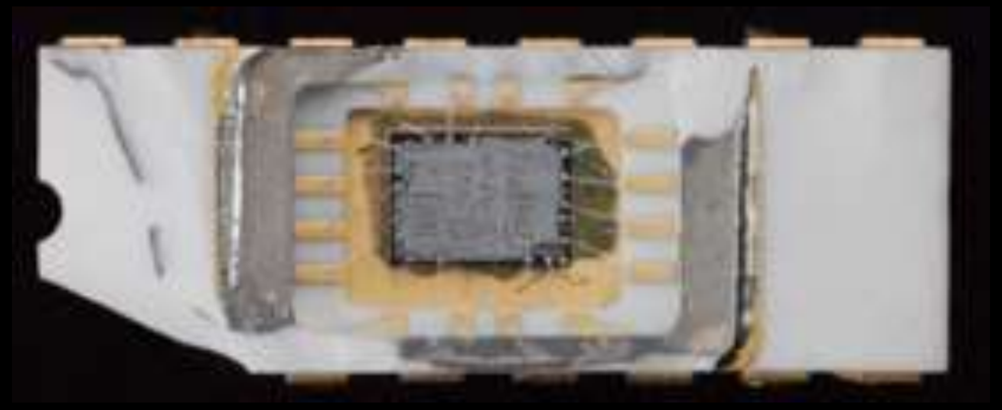
Industry Applications in Quantum Computing

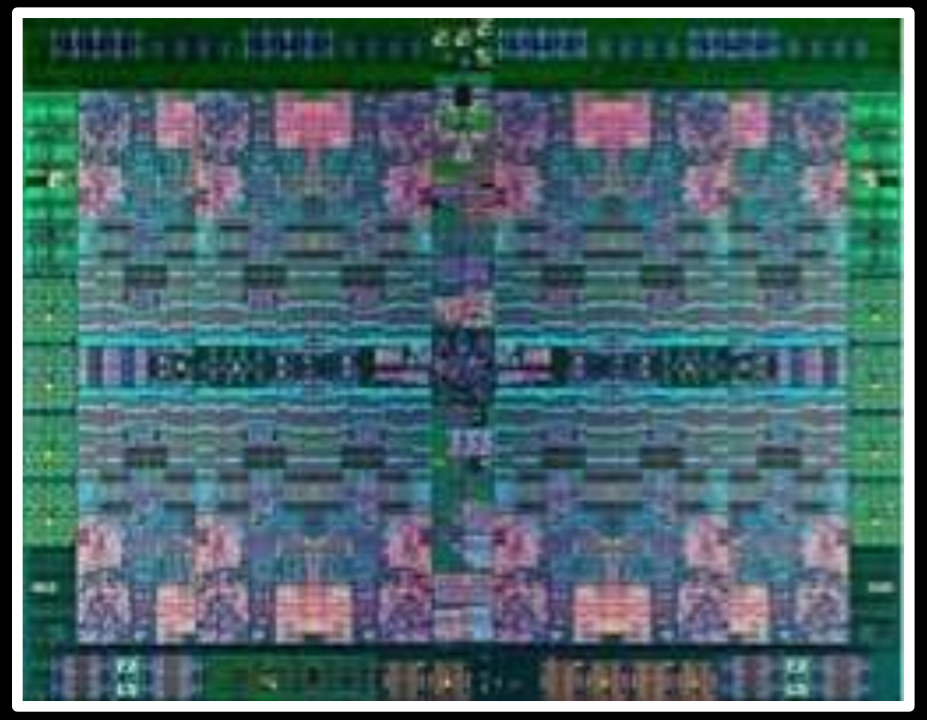


- **Chemistry**, e.g. for catalyst design
- **Material Science**, e.g. for energy efficient devices
- **Life Sciences**, e.g. for drug development
- **Optimization**, e.g. for cognitive computing and business processes
- **Cryptography**, e.g. for secure communication and information processing
- **Education**, e.g. to train engineers for the future quantum industry

Choose a Side: Naysayers or Feynman?







1958

First integrated circuit
Size ~1cm^2
2 Transistors

1971

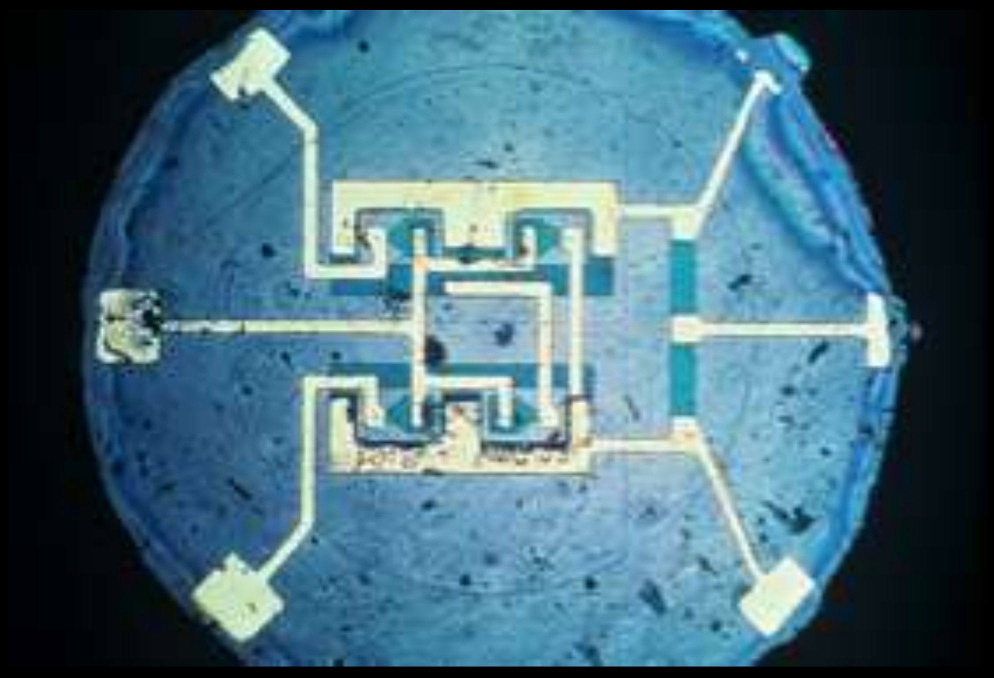
Moore's Law is Born
Intel 4004
2,300 transistors

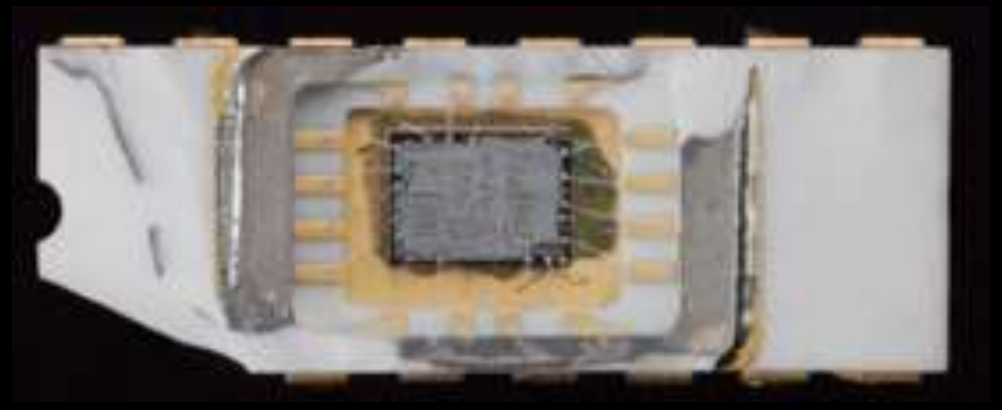
2014

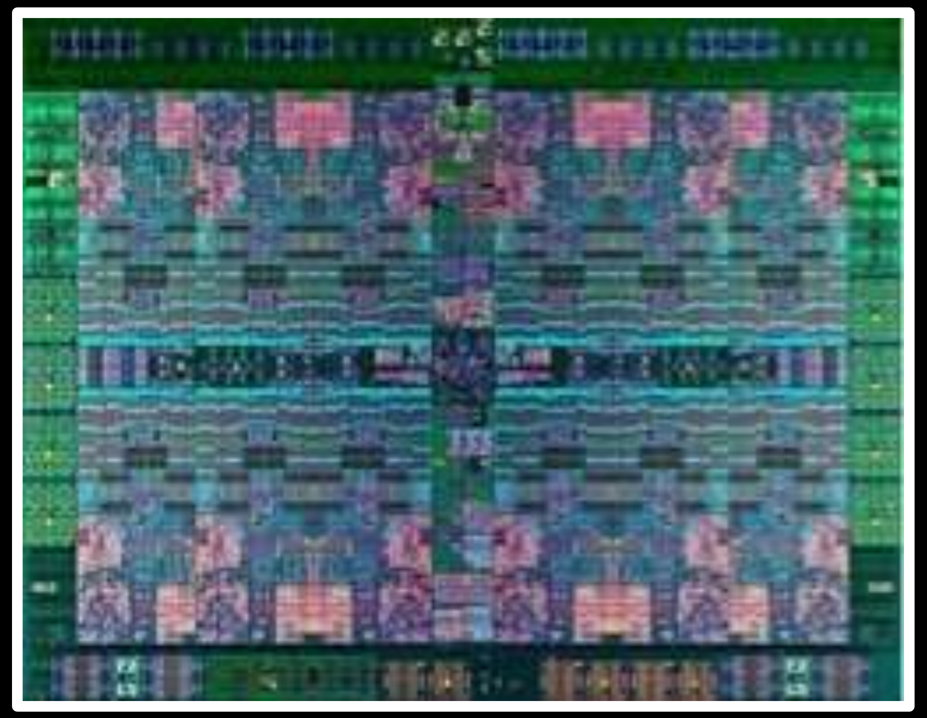
IBM P8 Processor
$<$650 mm^2
22 nm feature size
16 cores
> 4.2 Billion Transistors

2070

Choose a Side: Naysayers or Feynman?







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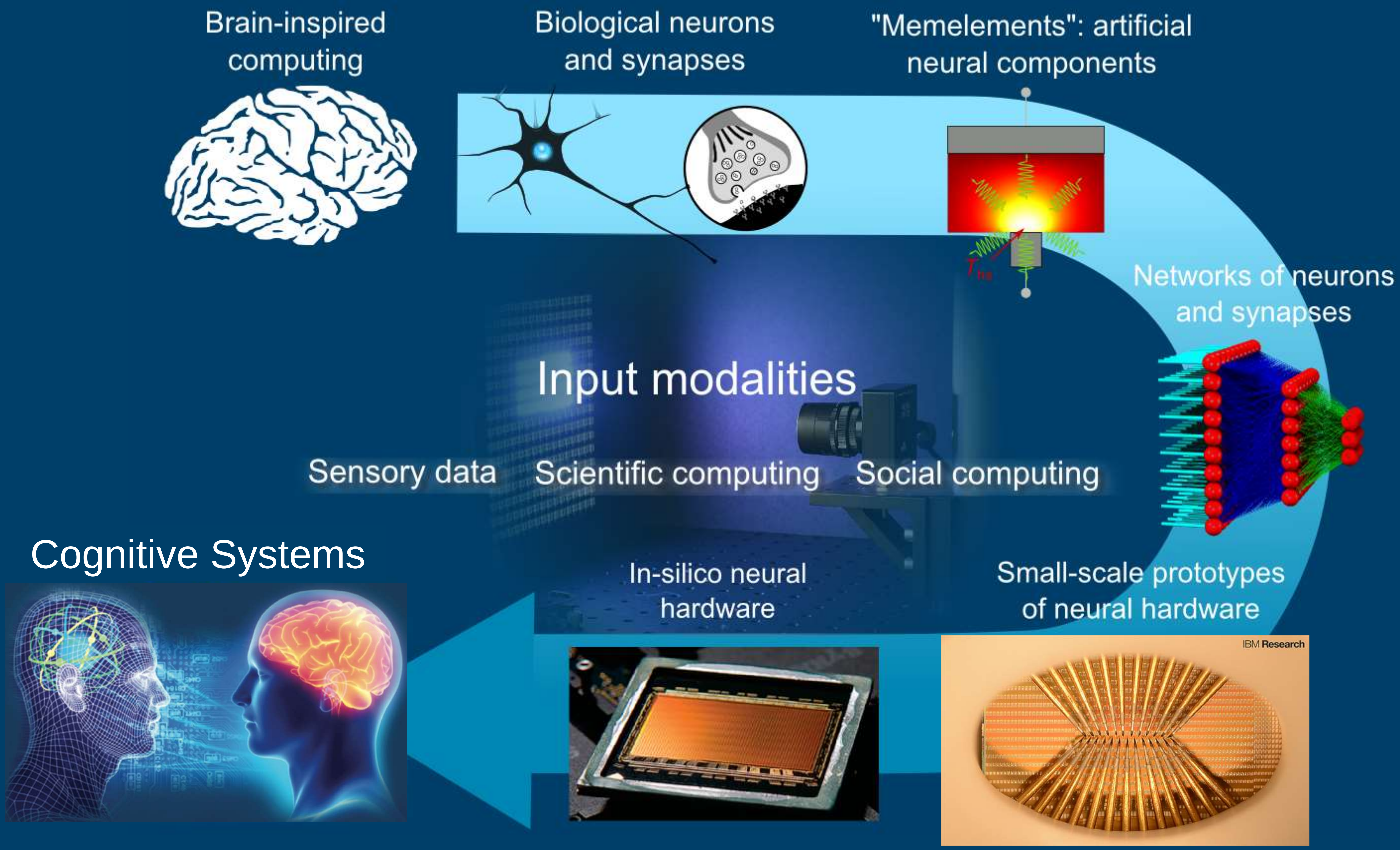
We are here

Neuromorphic Computing

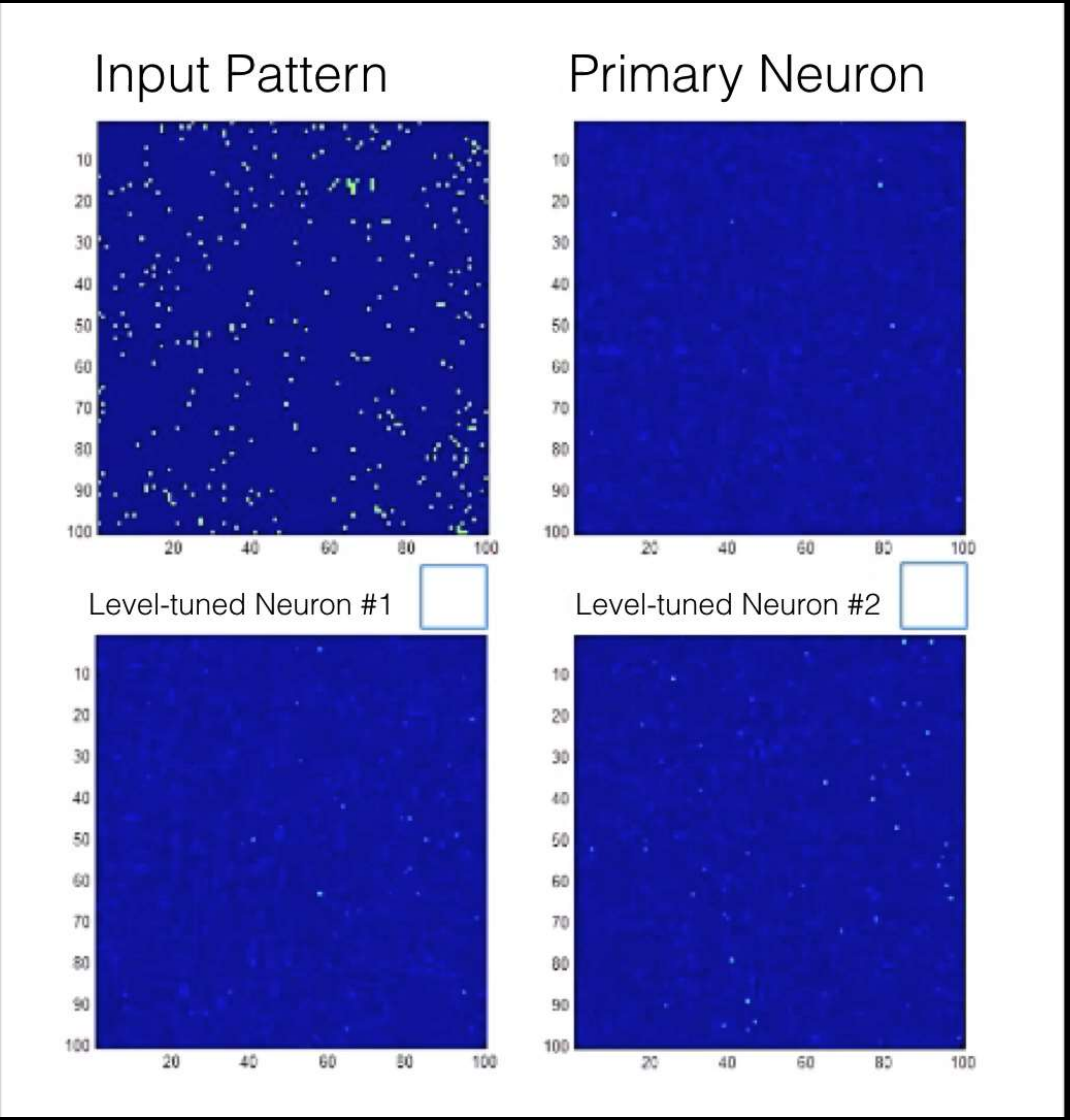


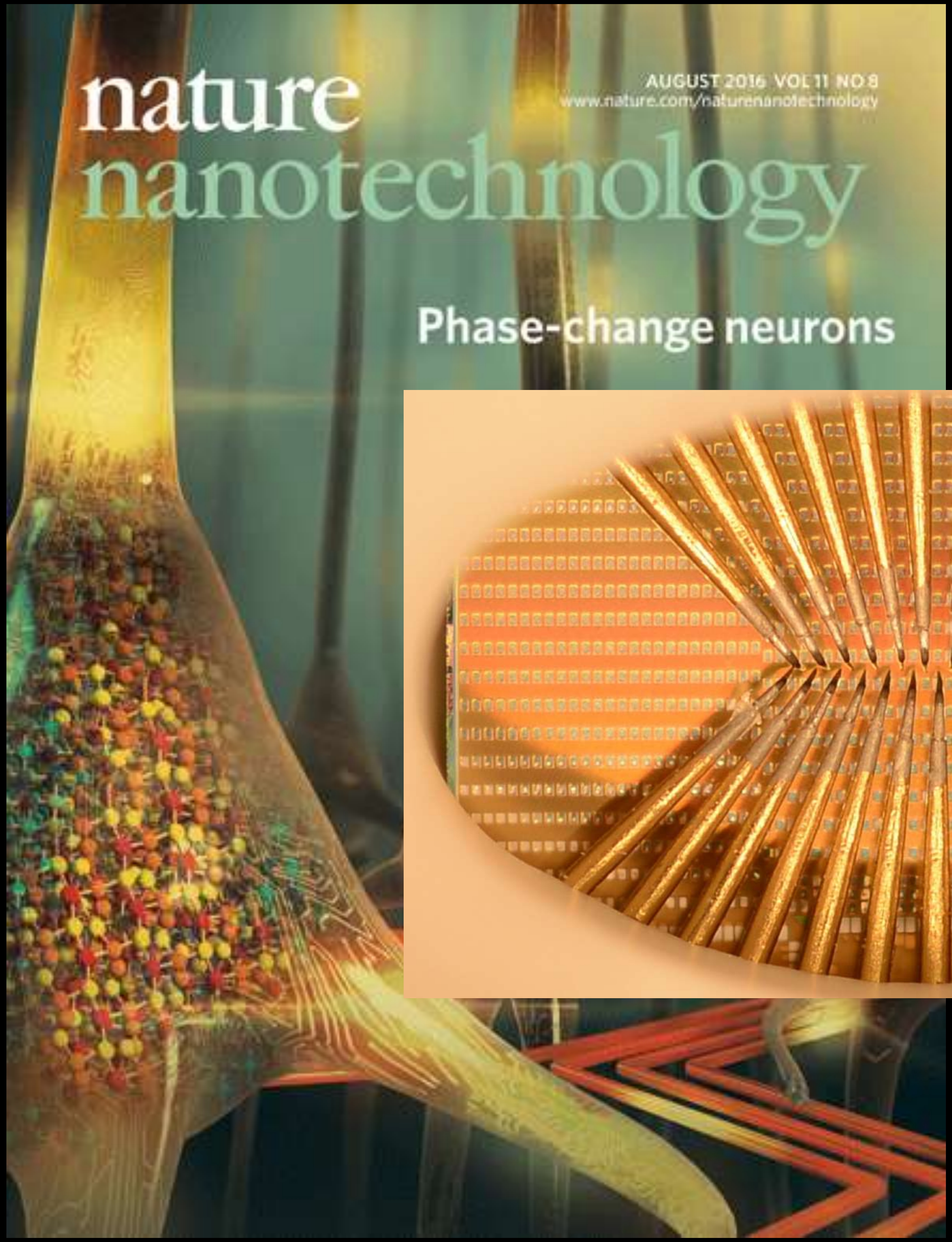
TrueNorth Chip (SyNAPSE)

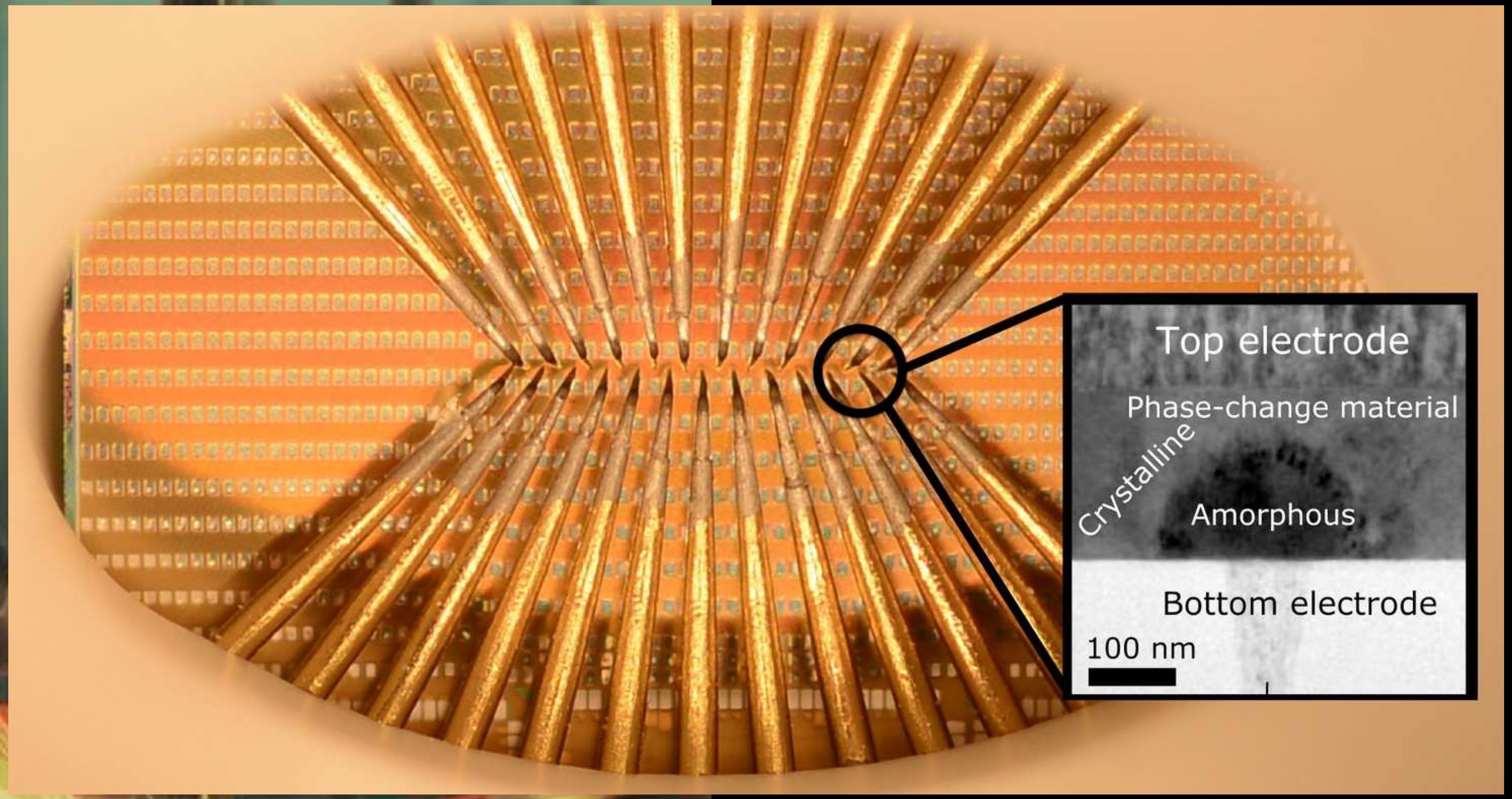
	2011	Now
Programmable Neurons	256	1 million
Programmable Synapses	262,144	256 million
Neurosynaptic Cores	1	4096


Saliency
Saliency + Classification
Object Centers
Output

Detecting Correlations with a Spiking Neural Network

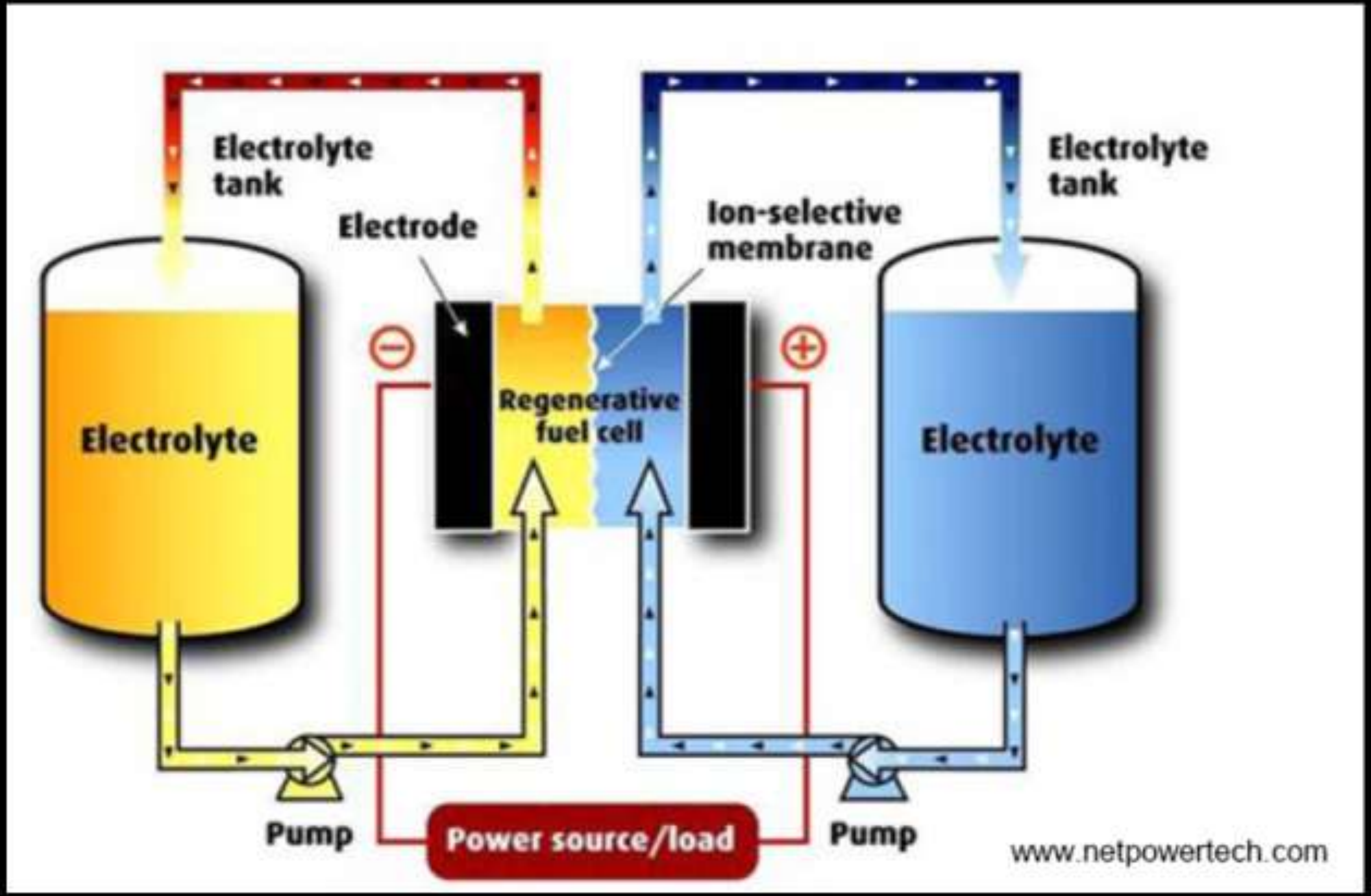


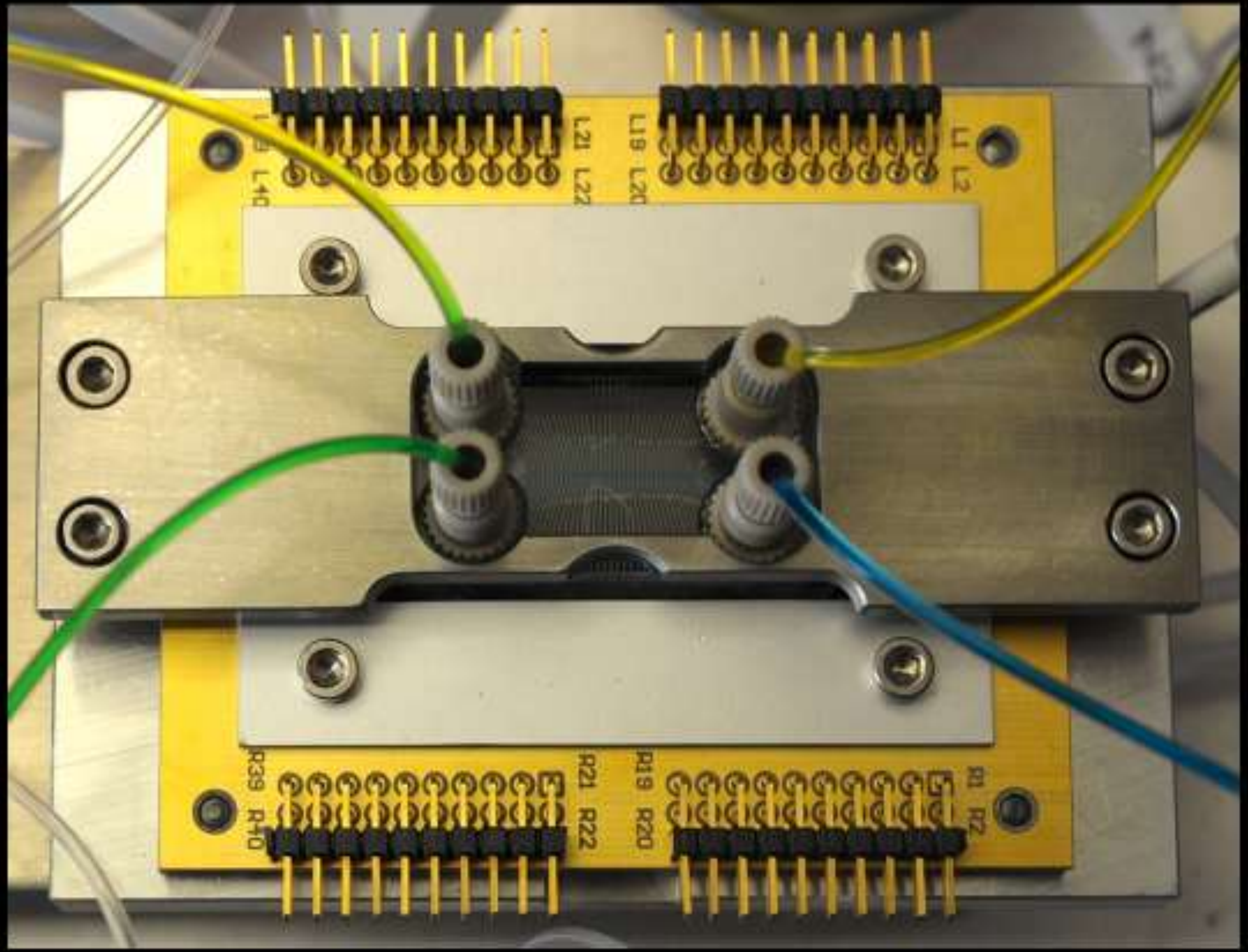


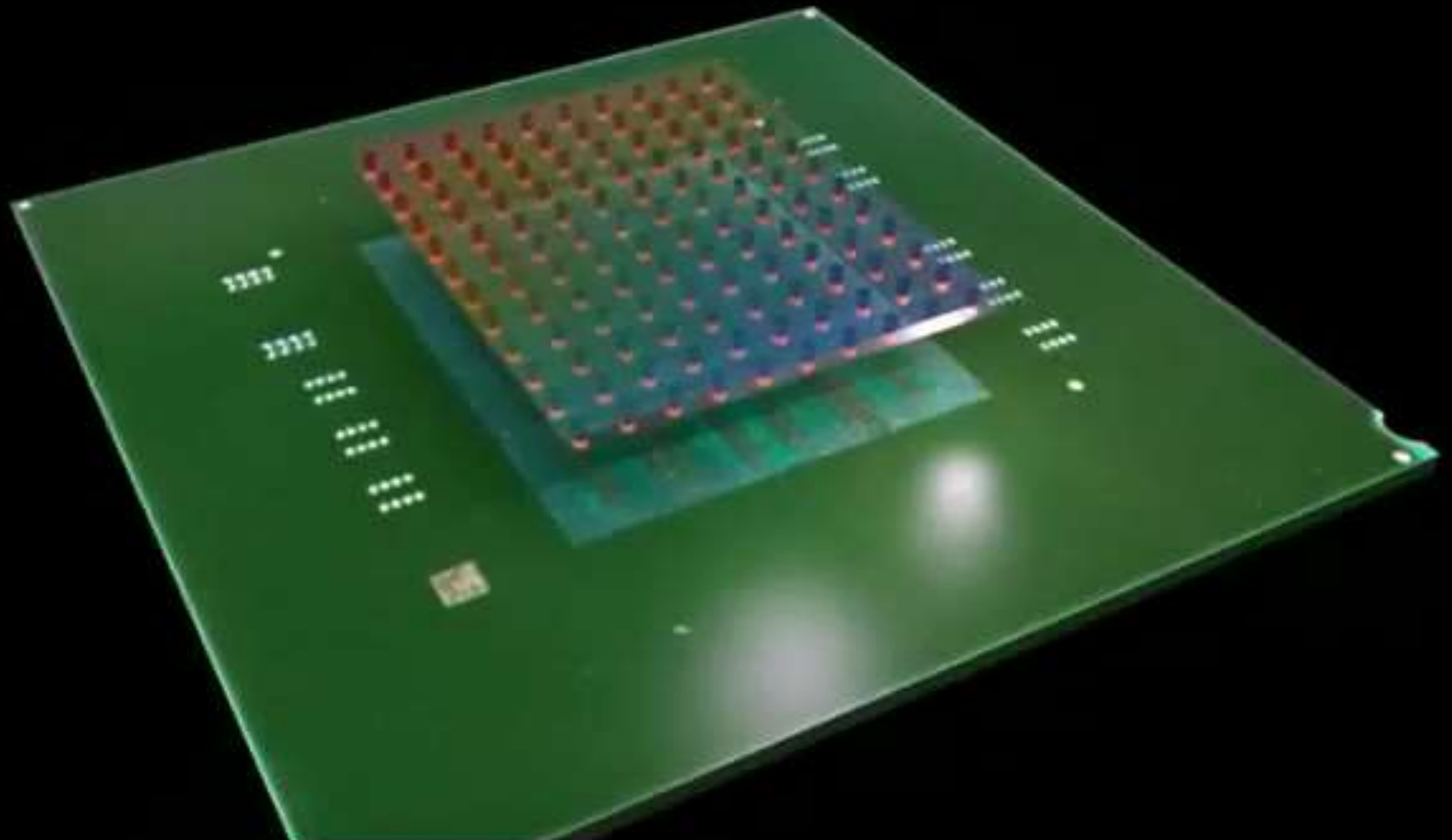


Brain Inspired Computing: Electronic Blood

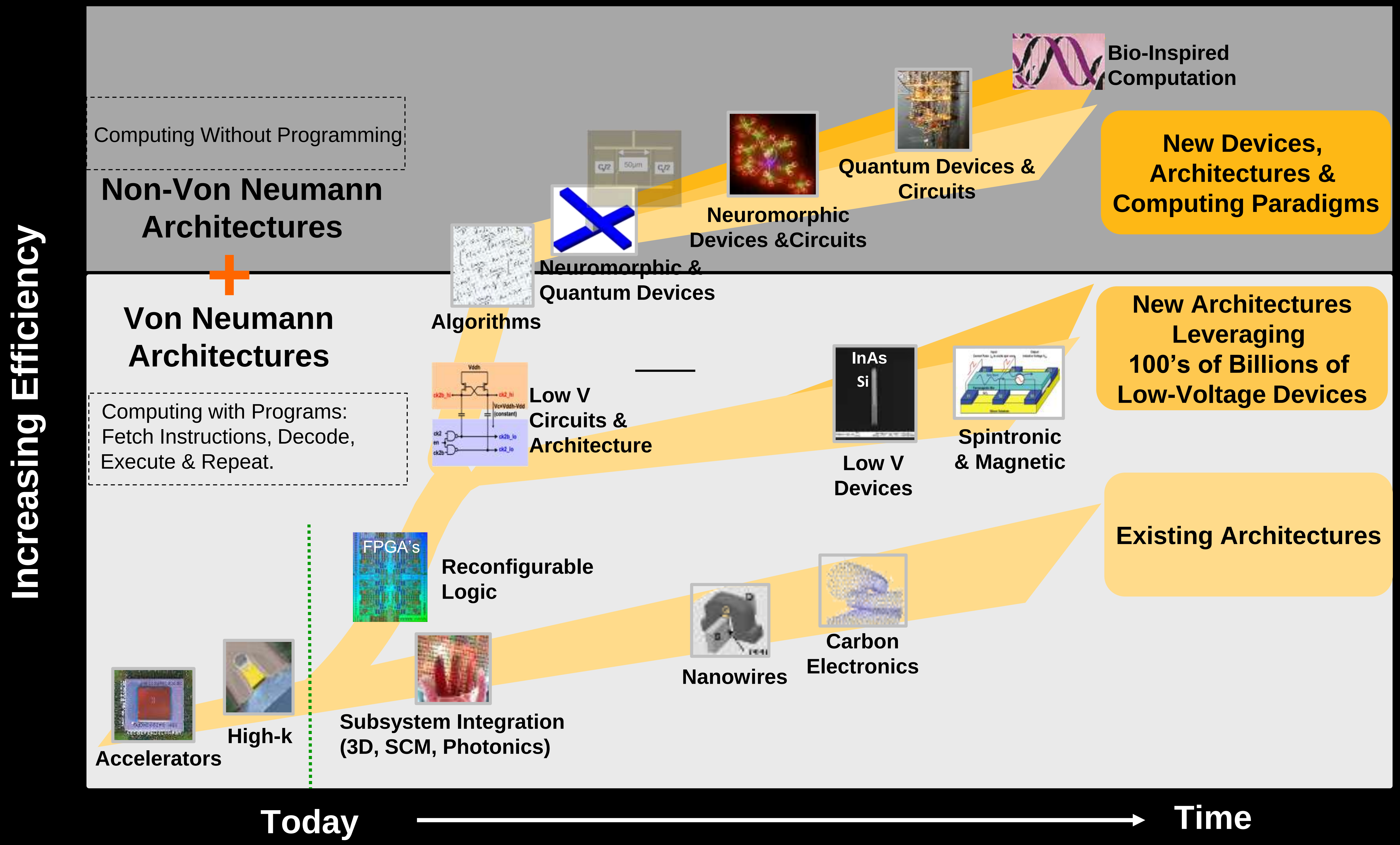
- 98% of the energy of a computer is for cooling
- Liquid removes heat 4000x more efficiently than air
- The brain is powered & cooled using liquid, can we do the same for computers?
- The result: a 1 PetaFlop supercomputer in 10 liters







Summary



Increasing Efficiency
Computing Without Programming
Non-Von Neumann Architectures
Von Neumann Architectures
Computing with Programs: Fetch Instructions, Decode, Execute & Repeat.
Bio-Inspired Computation
Quantum Devices & Circuits
Neuromorphic Devices &Circuits
Neuromorphic & Quantum Devices
Algorithms
New Devices, Architectures & Computing Paradigms
New Architectures Leveraging 100’s of Billions of Low-Voltage Devices
Low V Circuits & Architecture
InAs
Si
Low V Devices
Spintronic & Magnetic
Existing Architectures
FPGA’s
Reconfigurable Logic
Nanowires
Carbon Electronics
Subsystem Integration (3D, SCM, Photonics)
Accelerators
High-k
Today
Time

Questions?