VLSI Design Methodology

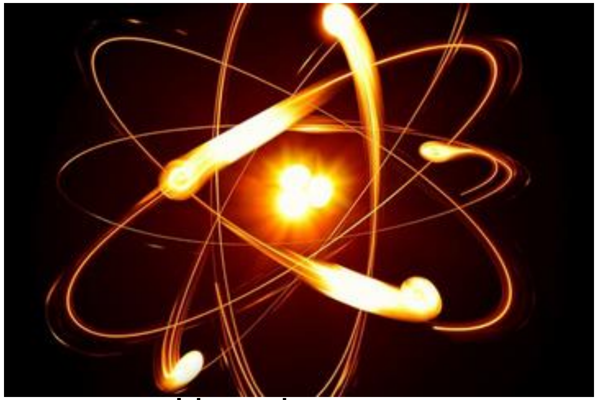
Introduction, Overview, and Semiconductor Sector Trends

Roman Genov

Sept 2025

Electronics

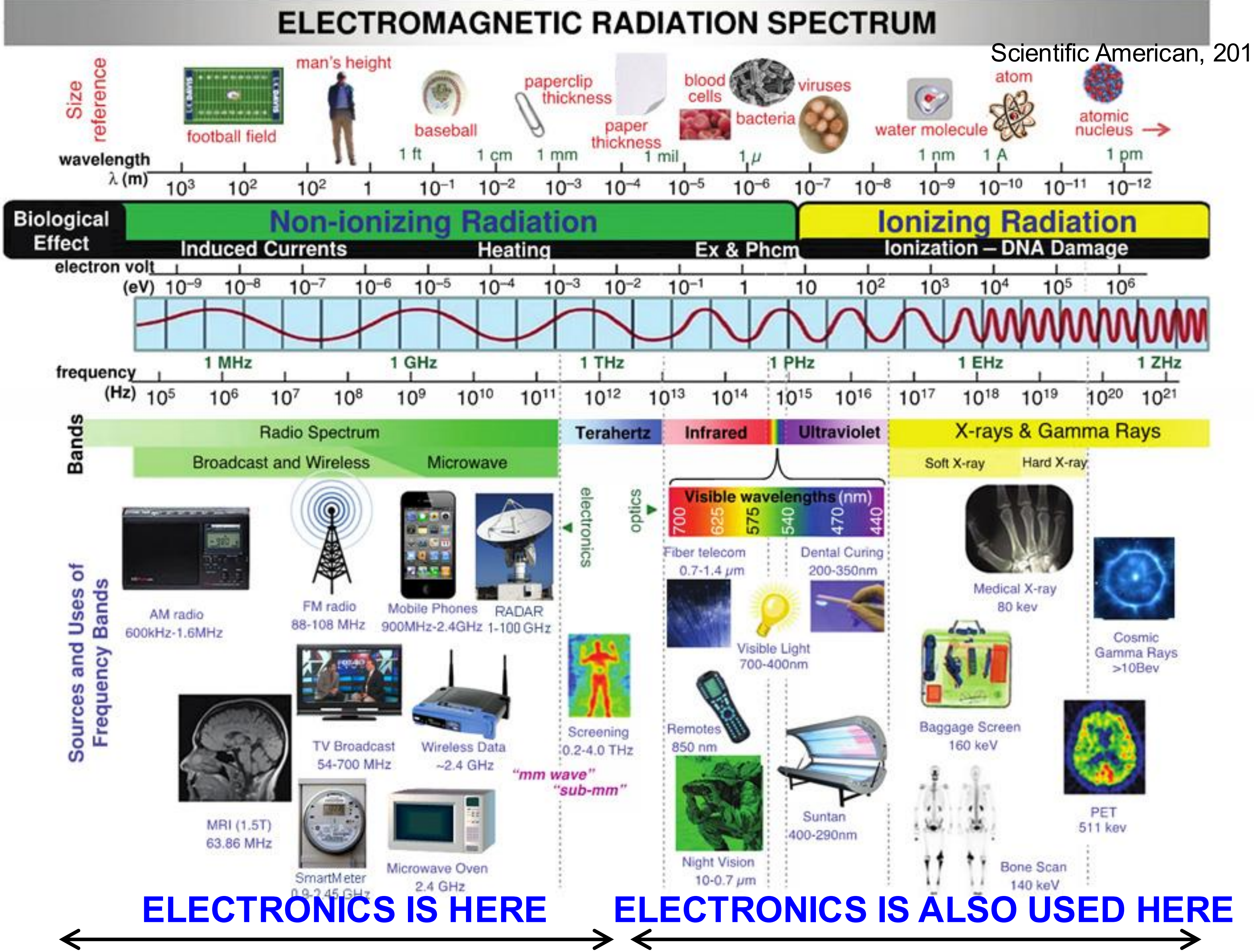
- A science about **uses and effects of electrons** (Webster Dict.)



Livescience.com

Apple iPhone microprocessor

- A science of how to control electric energy (Wikipedia)
  - **electrons** have a fundamental role in electrical circuits
  - such circuits involve **active electrical components**
    - **transistors**, diodes and
    - **integrated circuits (ICs)**
    - **primarily** or exclusively active **semiconductors**
    - + passive electrical components and interconnection technologies

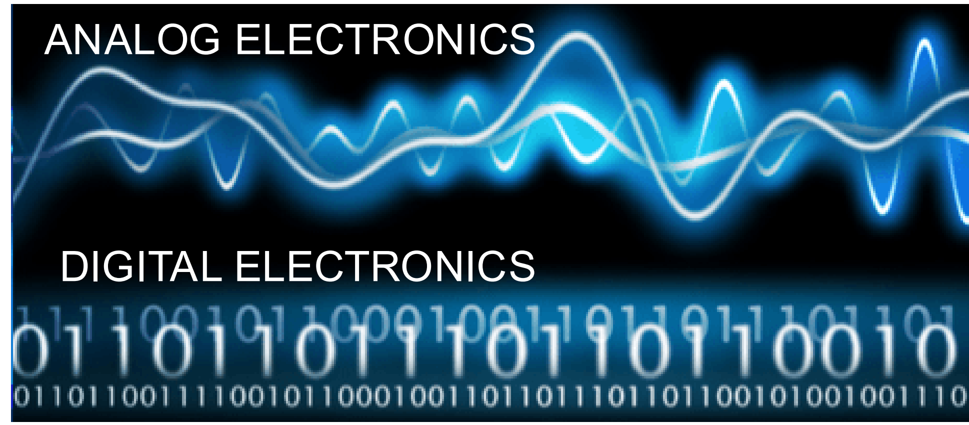


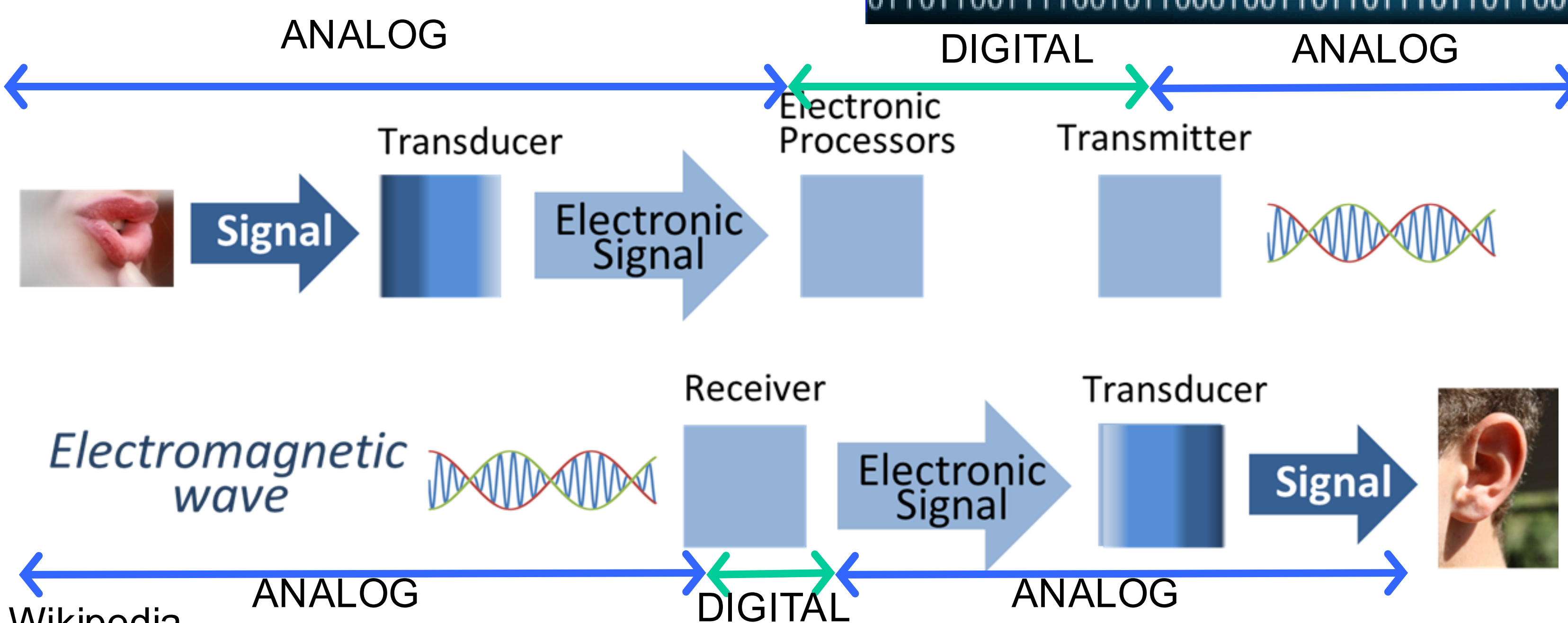
ELECTROMAGNETIC RADIATION SPECTRUM
Scientific American, 2011
Size reference
football field
man's height
baseball
paperclip thickness
paper thickness
blood cells
bacteria
viruses
water molecule
atom
atomic nucleus
wavelength λ (m)
1 ft
1 cm
1 mm
1 mil
1 μ
1 nm
1 A
1 pm
Biological Effect
Non-ionizing Radiation
Induced Currents
Heating
Ex & Phcm
Ionizing Radiation
Ionization – DNA Damage
electron volt (eV)
frequency (Hz)
1 MHz
1 GHz
1 THz
1 PHz
1 EHz
1 ZHz
Bands
Radio Spectrum
Broadcast and Wireless
Microwave
Terahertz
Infrared
Ultraviolet
X-rays & Gamma Rays
Soft X-ray
Hard X-ray
electronics
optics
Visible wavelengths (nm)
700 625 575 540 470 440
Sources and Uses of Frequency Bands
AM radio 600kHz-1.6MHz
FM radio 88-108 MHz
Mobile Phones 900MHz-2.4GHz
RADAR 1-100 GHz
MRI (1.5T) 63.86 MHz
TV Broadcast 54-700 MHz
Wireless Data ~2.4 GHz
SmartMeter 0.9-2.45 GHz
Microwave Oven 2.4 GHz
"mm wave"
"sub-mm"
Screening 0.2-4.0 THz
Fiber telecom 0.7-1.4 μm
Dental Curing 200-350nm
Visible Light 700-400nm
Remotes 850 nm
Night Vision 10-0.7 μm
Suntan 400-290nm
Medical X-ray 80 kev
Baggage Screen 160 keV
Bone Scan 140 keV
Cosmic Gamma Rays >10Bev
PET 511 kev
ELECTRONICS IS HERE
ELECTRONICS IS ALSO USED HERE

Analog versus Digital Electronics

- Electronics is used to process signals (e.g., CMOS)
  - Reliable / manufacturable
  - High-performance
  - Versatile
  - Low-cost

Coursera



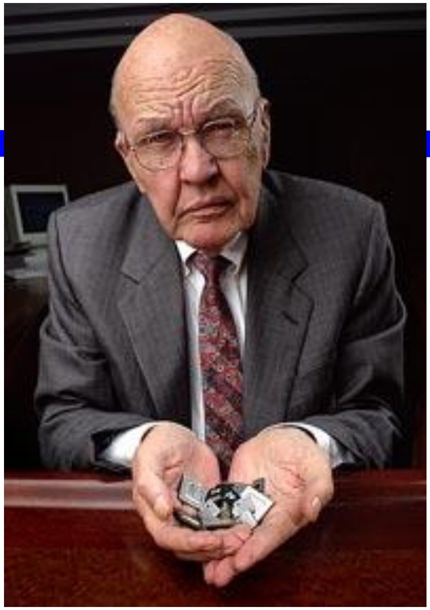


Wikipedia

History of Integrated Circuits

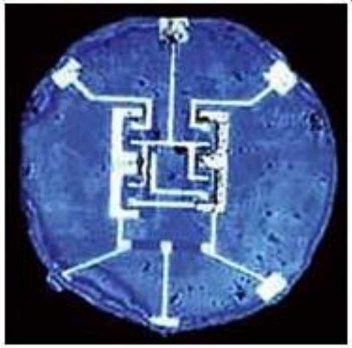
Germanium IC
Jack Kilby
Texas Instruments

1 Transistor
3 Resistors
1 Capacitor



2000 Physics Nobel Prize

1958



Silicon IC
Robert Noyce
Fairchild
Semiconductor
(then Intel)

Flip-flop (aluminium wires)

"The Mayor of Silicon Valley," co-founded Intel with Gordon Moore

History of Integrated Circuits

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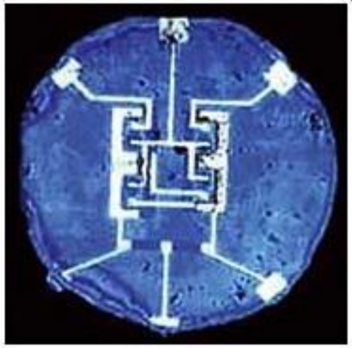
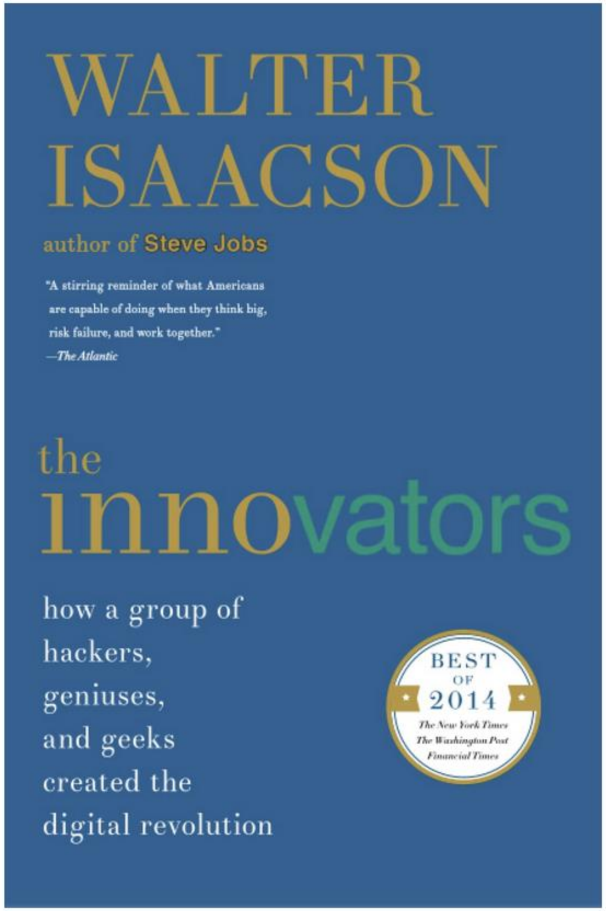


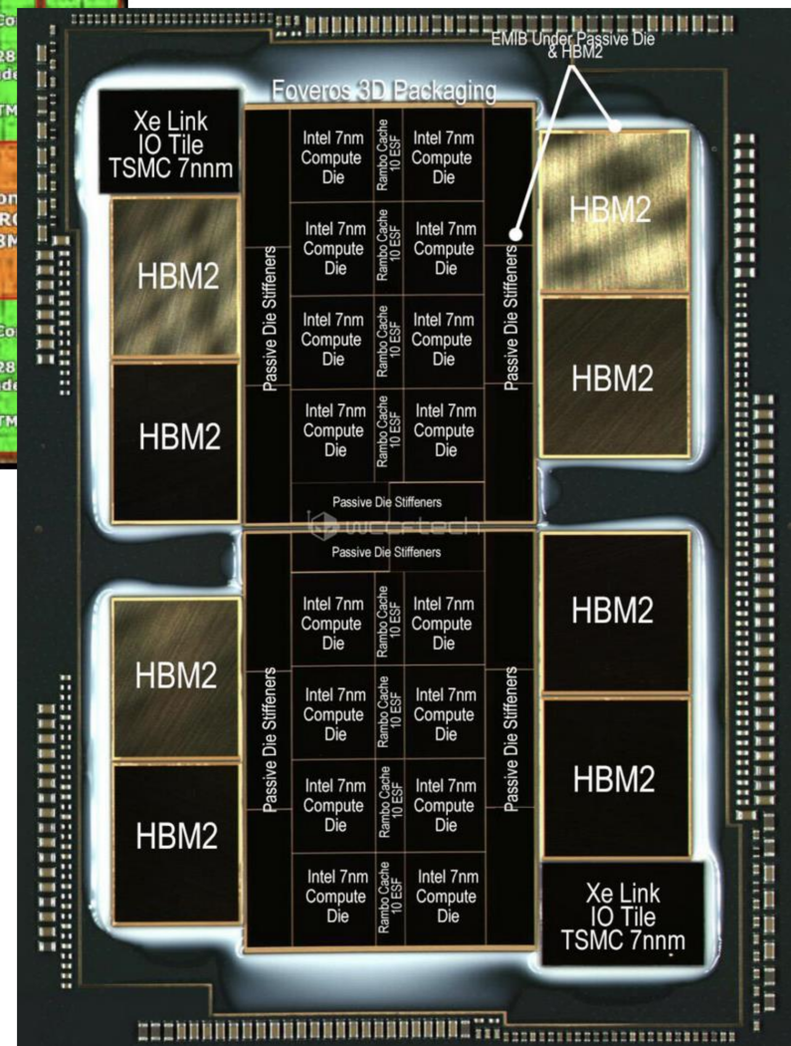
Silicon IC
Robert Noyce
Fairchild Semiconductor
(then Intel)

Flip-flop (aluminium wires)

- Progress driven primarily by microprocessor technology



Intel: 12-Gen Processor and GPU/AI Chip (7nm)

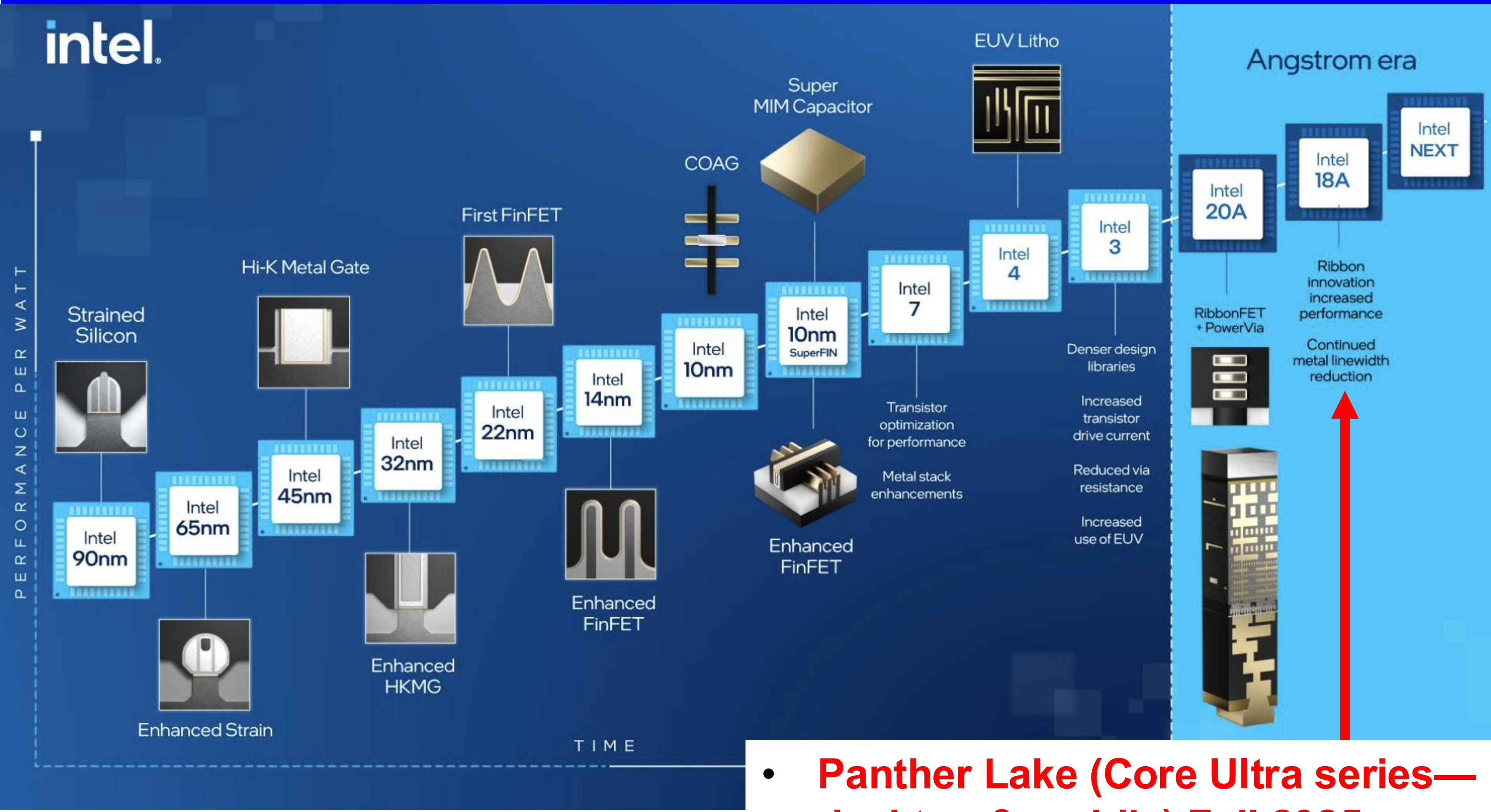


DESKTOP:
Intel Core 12th Gen Adler Lake Processor
(Raptor Lake - Fall 2022)
~25B Transistors

SERVER:
Pointe Veccio GPU/AI Chip
47 chiplets on interposer, 600 W!
(Realto Bridge - Fall 2022)
100 Billion Transistors!

(Intel)

Intel: What is Next?



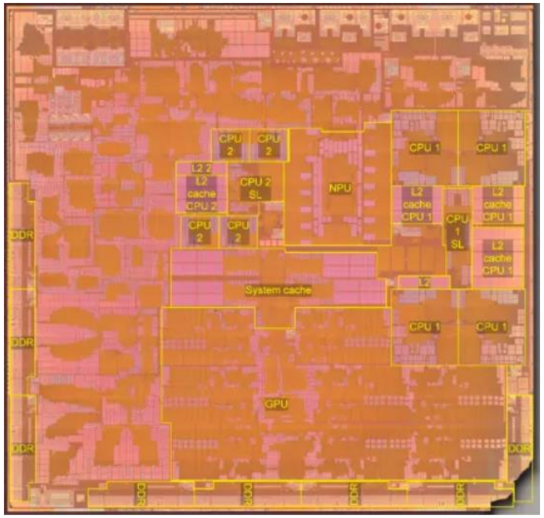
New naming convention for Intel technology nodes

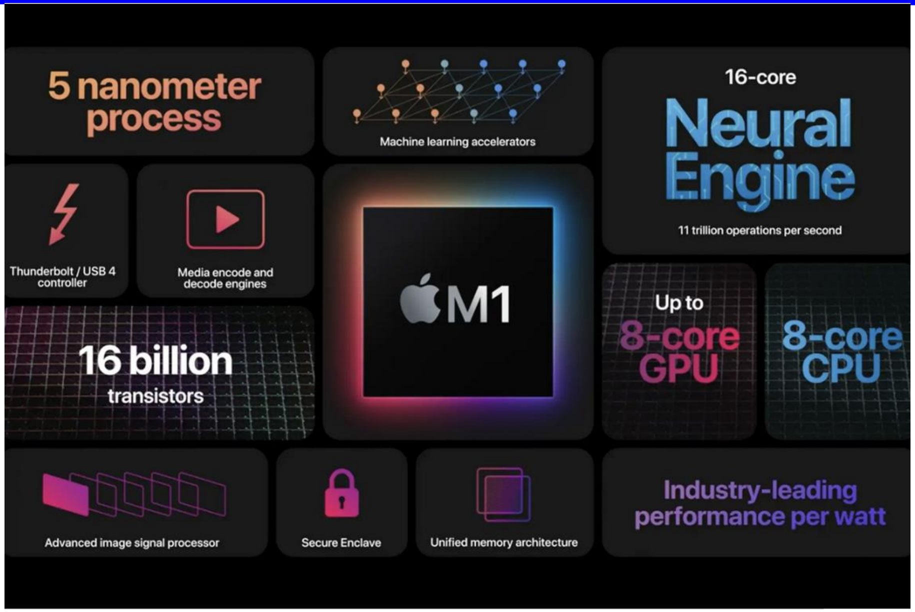
- no longer directly refers to nm

- **Panther Lake (Core Ultra series—desktop & mobile) Fall 2025**
- **Clearwater Forest (Xeon Server Processor) Announced Aug 2025**

Apple 2024: M4 (3nm, 28B Ts)

M1: 2021



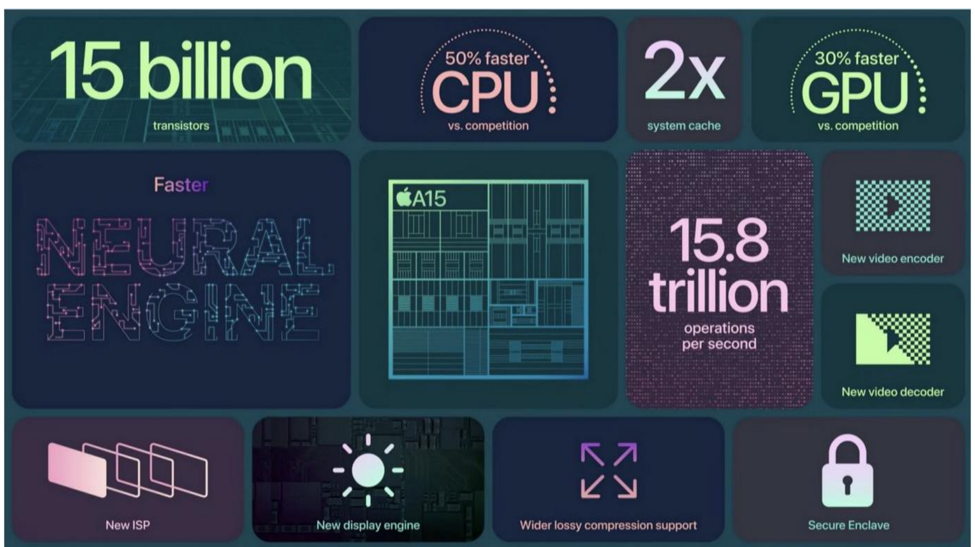


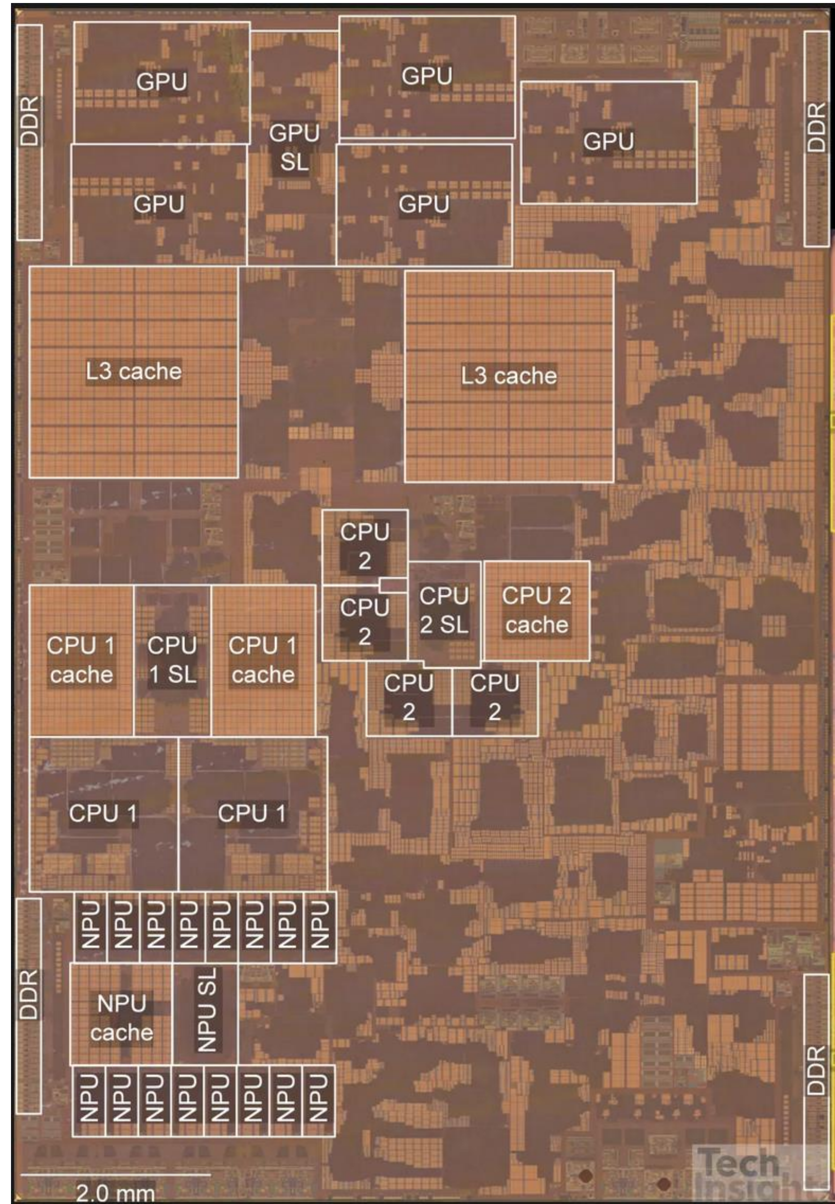
M4: 2024

(Apple)

Complex Systems-on-Chip: Apple iPhone

- A15 - main processor in iPhone 14 – teardown (from techinsight, chipworks)

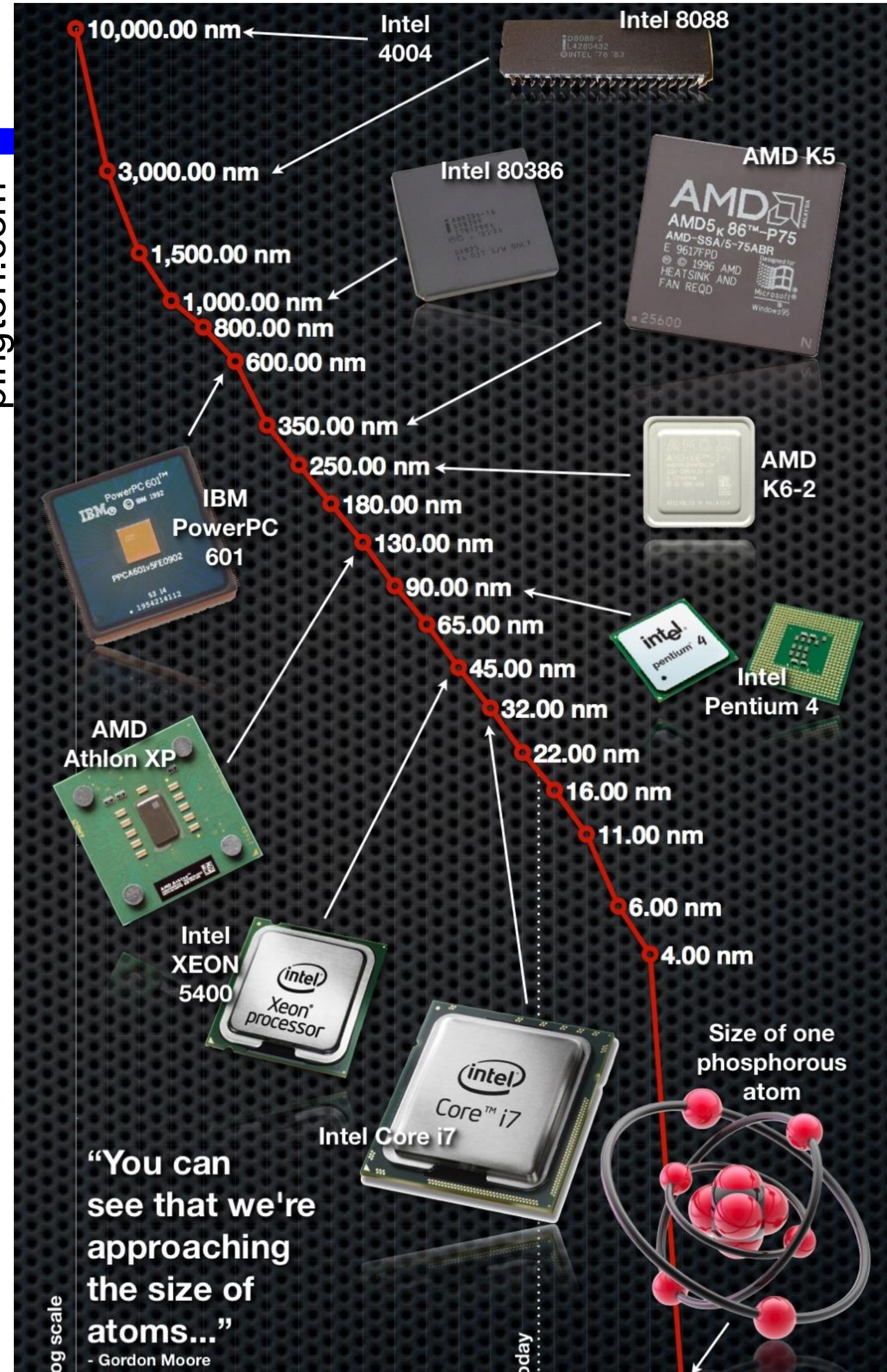




Technology Scaling

- Moore's law
  - # of transistors doubles every two years
  - Now at 1-2nm
  - What is next?
- "More Moore"
  - Beyond CMOS
  - 3D stacking
- "More than Moore"
  - ICs applications besides μPs
  - Diversification: new applications
    - IoT, AI, health, etc
    - interactive (robots etc)

pington.com



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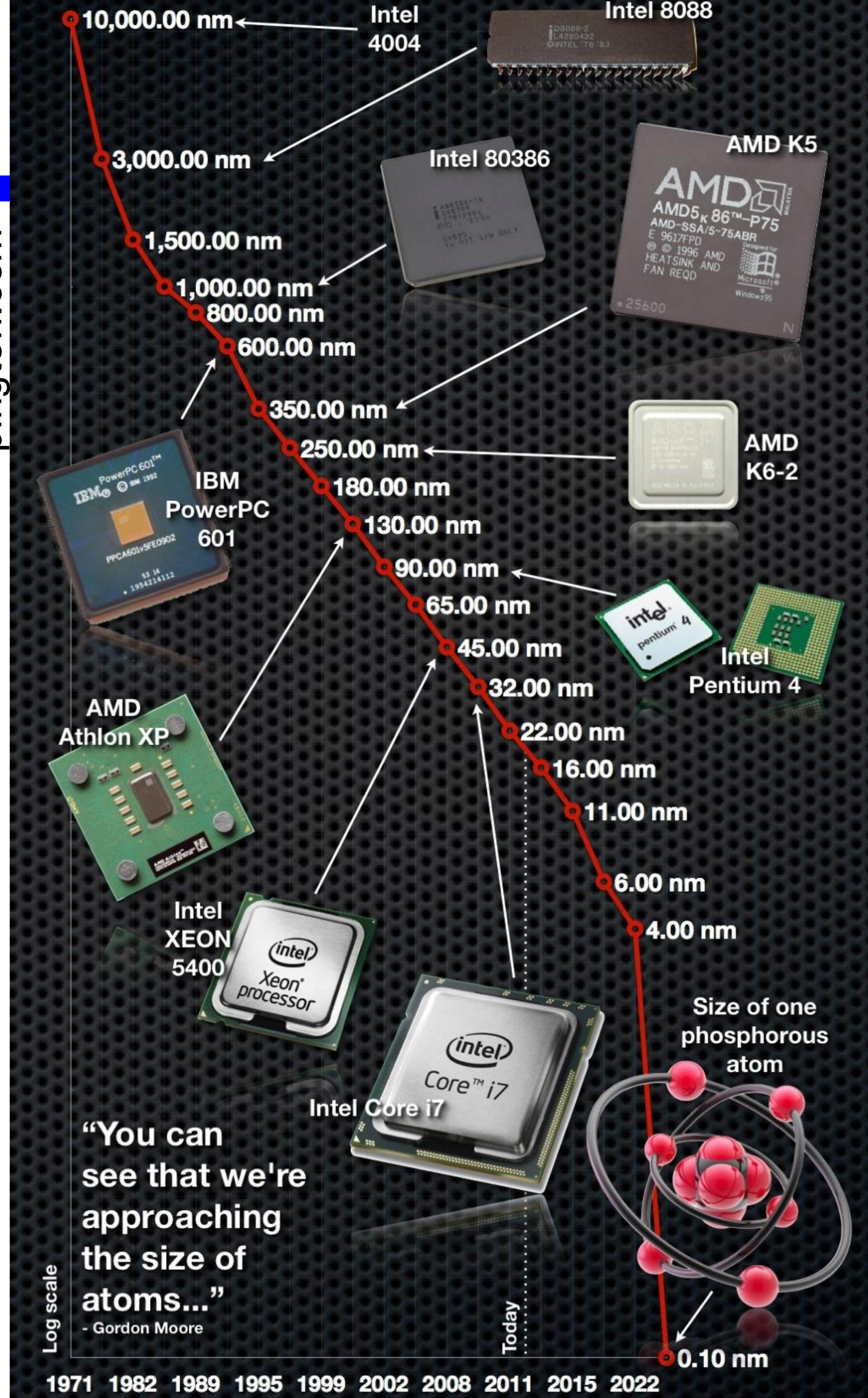
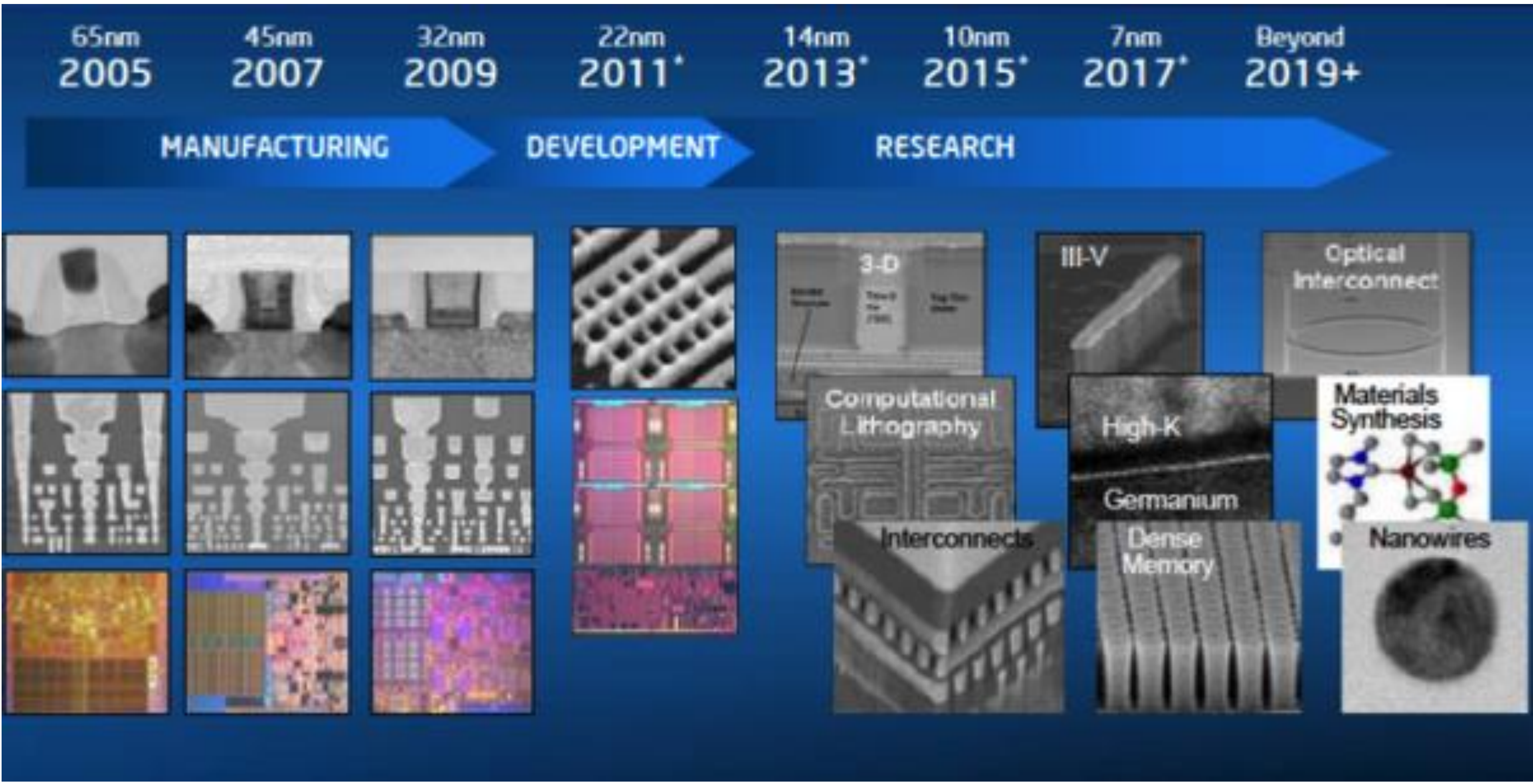


Semiconductor Devices: CMOS and Beyond

Intel



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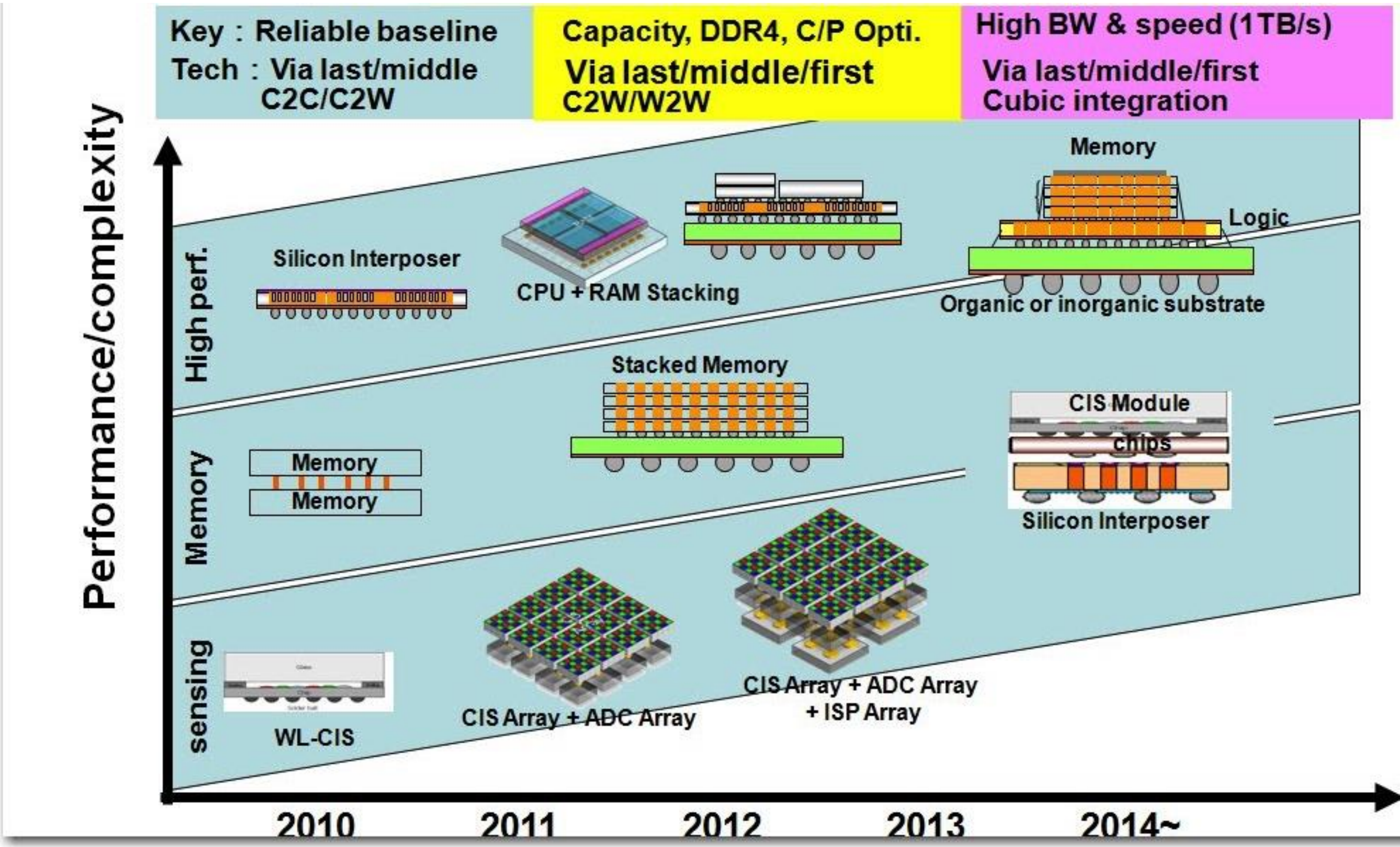
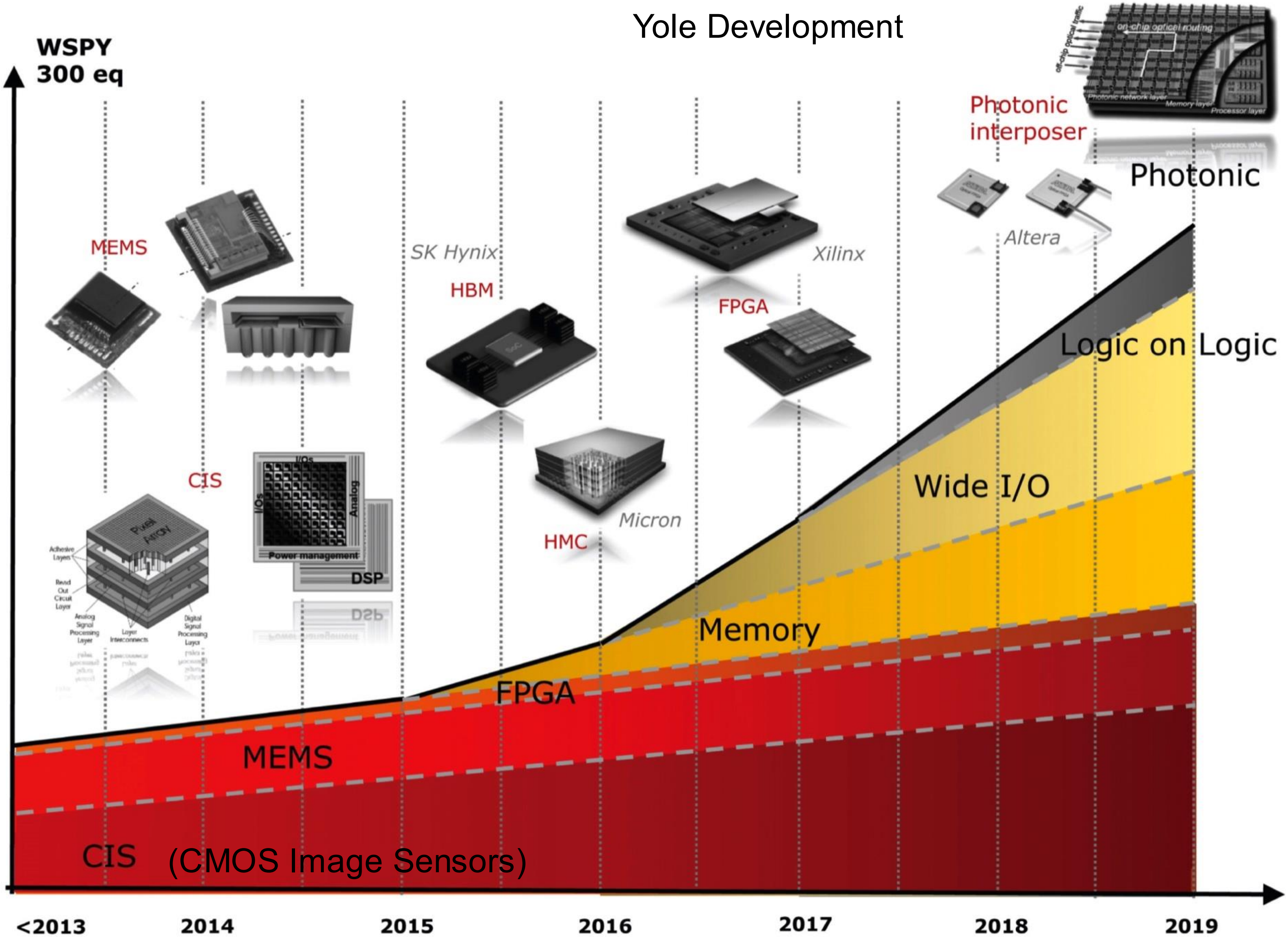
CMOS

3D Stacking

ITRI



3D Stacking Growth



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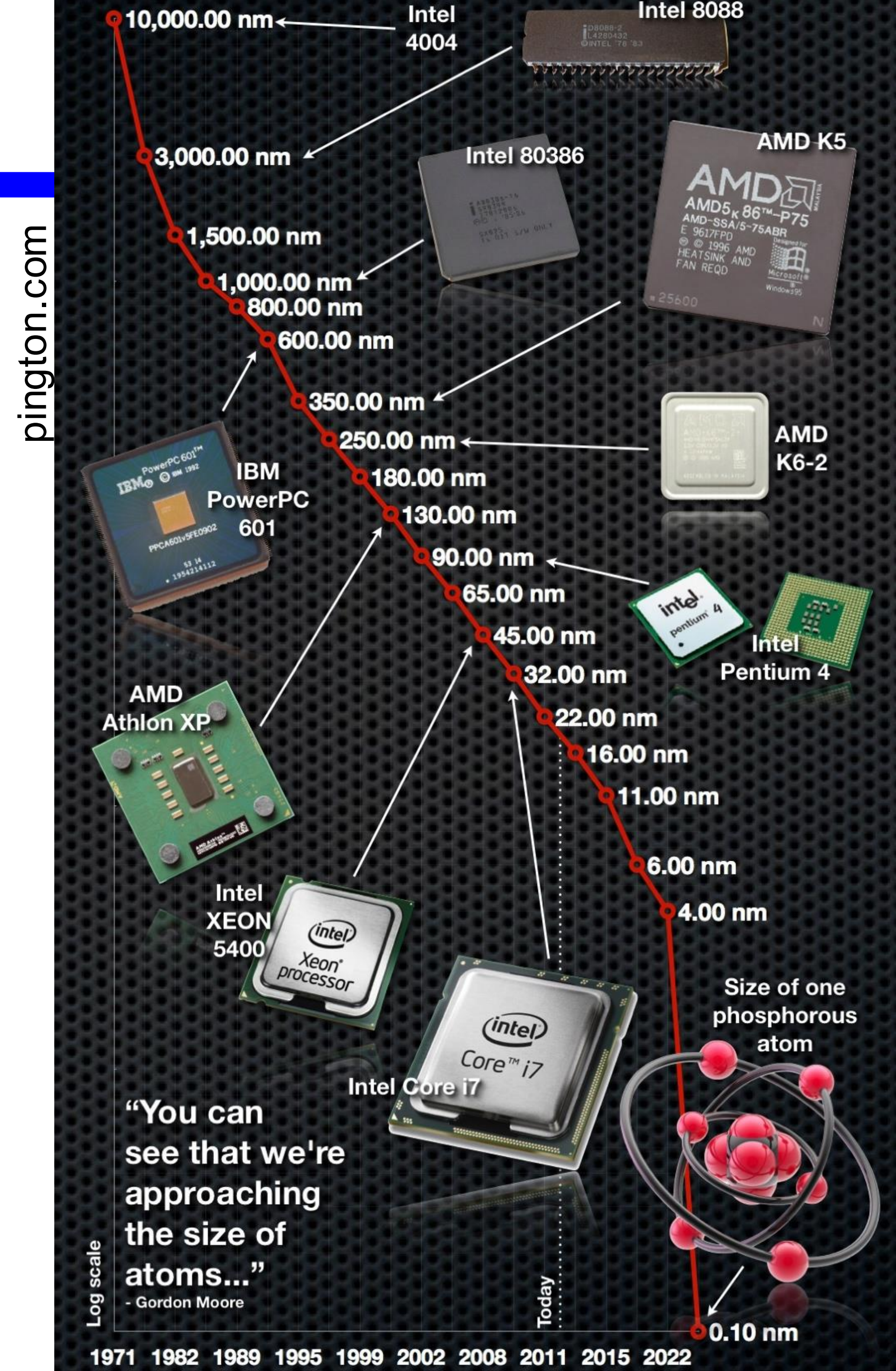

Technology Scaling

- Moore's law
  - # of transistors doubles every two years
  - Now at 5-10nm
  - What is next?
- "More Moore"
  - Beyond CMOS
  - 3D stacking
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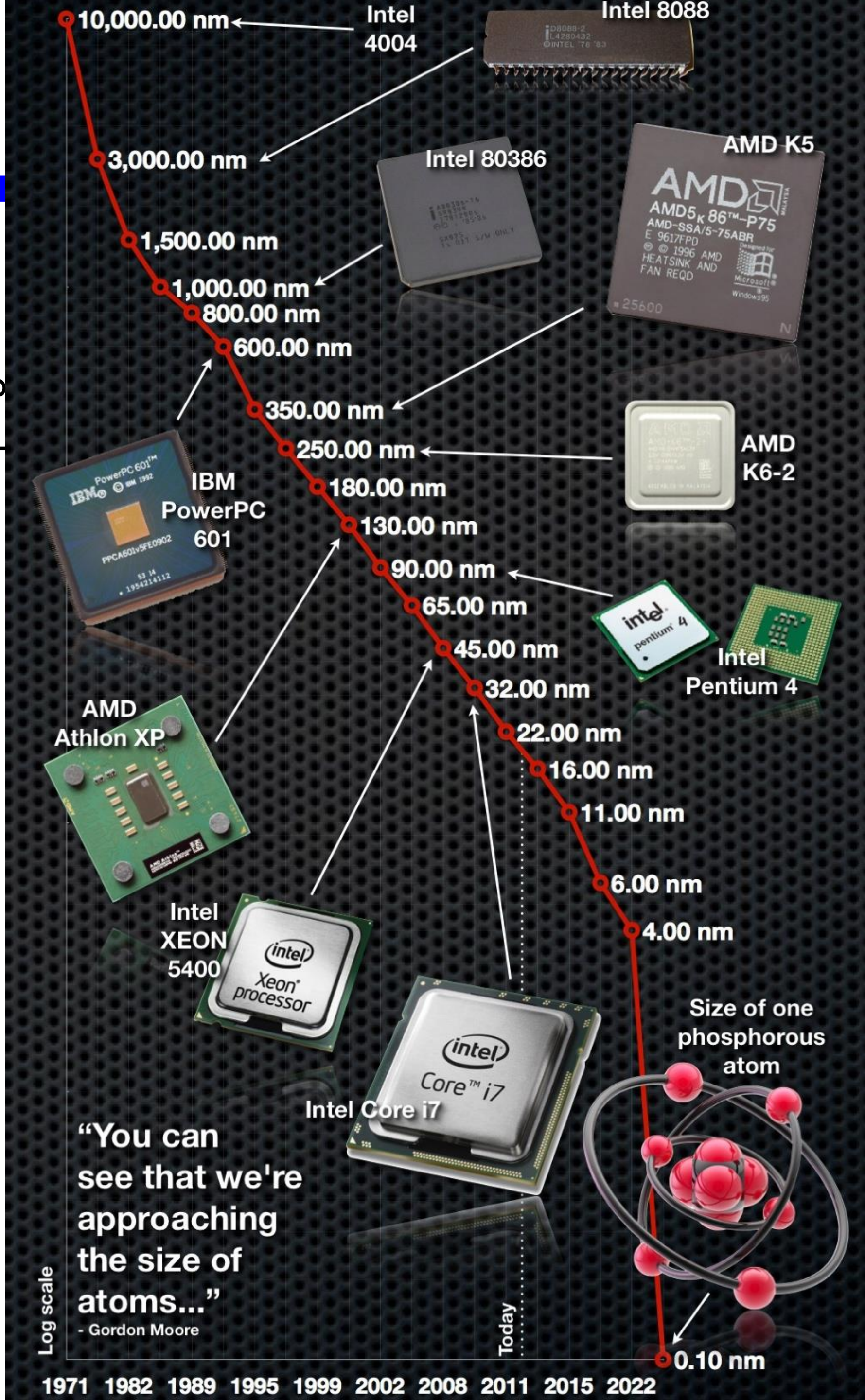
pington.com



Integrated Circuits Applications (besides μPs)

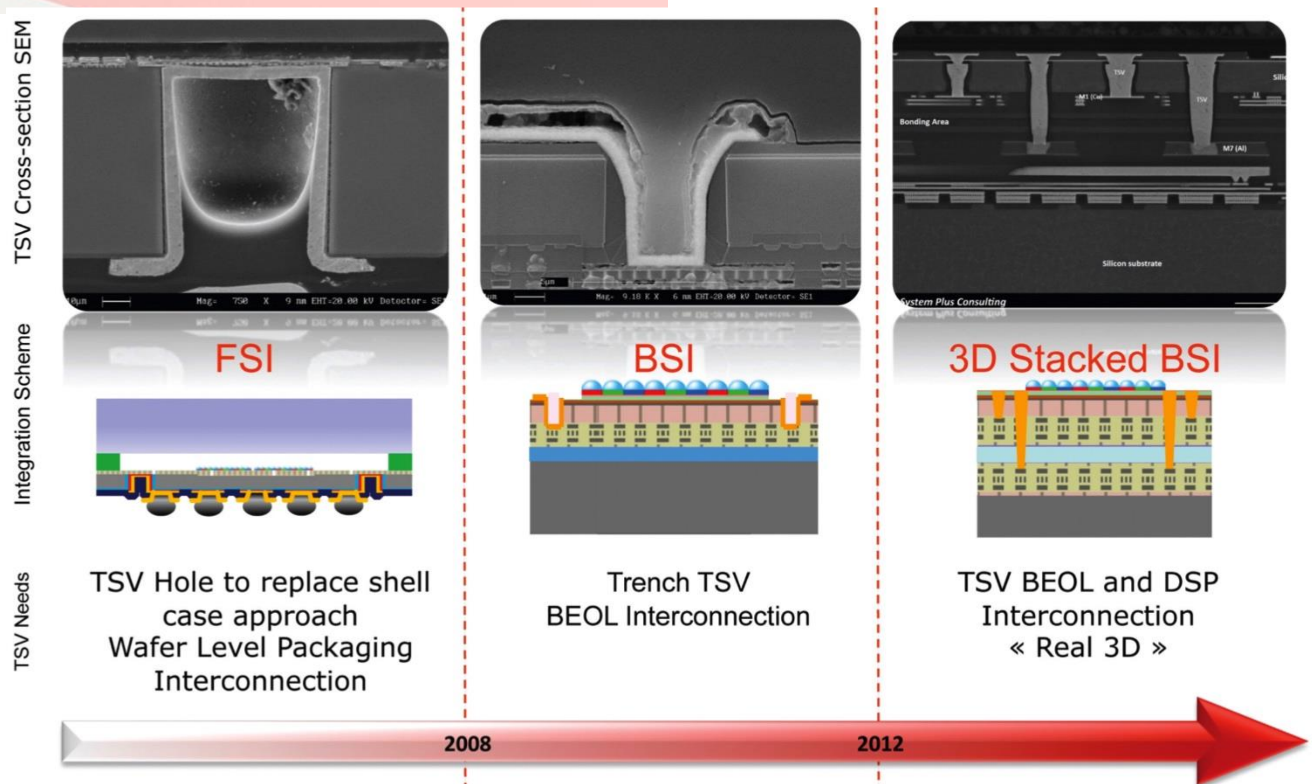
- Sensors / actuators
  - Image sensors
  - MEMS
- Communications
  - Wireless
  - Wireline
- Memories
  - Volatile (SRAM, DRAM)
  - Non-volatile (Flash)

- Emerging applications: interacting with people/environment
  - Acceleration of Artificial Intelligence / Machine learning algorithms
  - Biochips / medical / wellness (implantable, wearable, disposable)
  - New analog / RF
  - New sensors / actuators (MEMS, terahertz, ultrasound)

Neuropace

CMOS Image Sensors (CIS)

Apple



FSI - Front side illumination
BSI – Back side illumination
TSV – through-silicon via

Yole Development

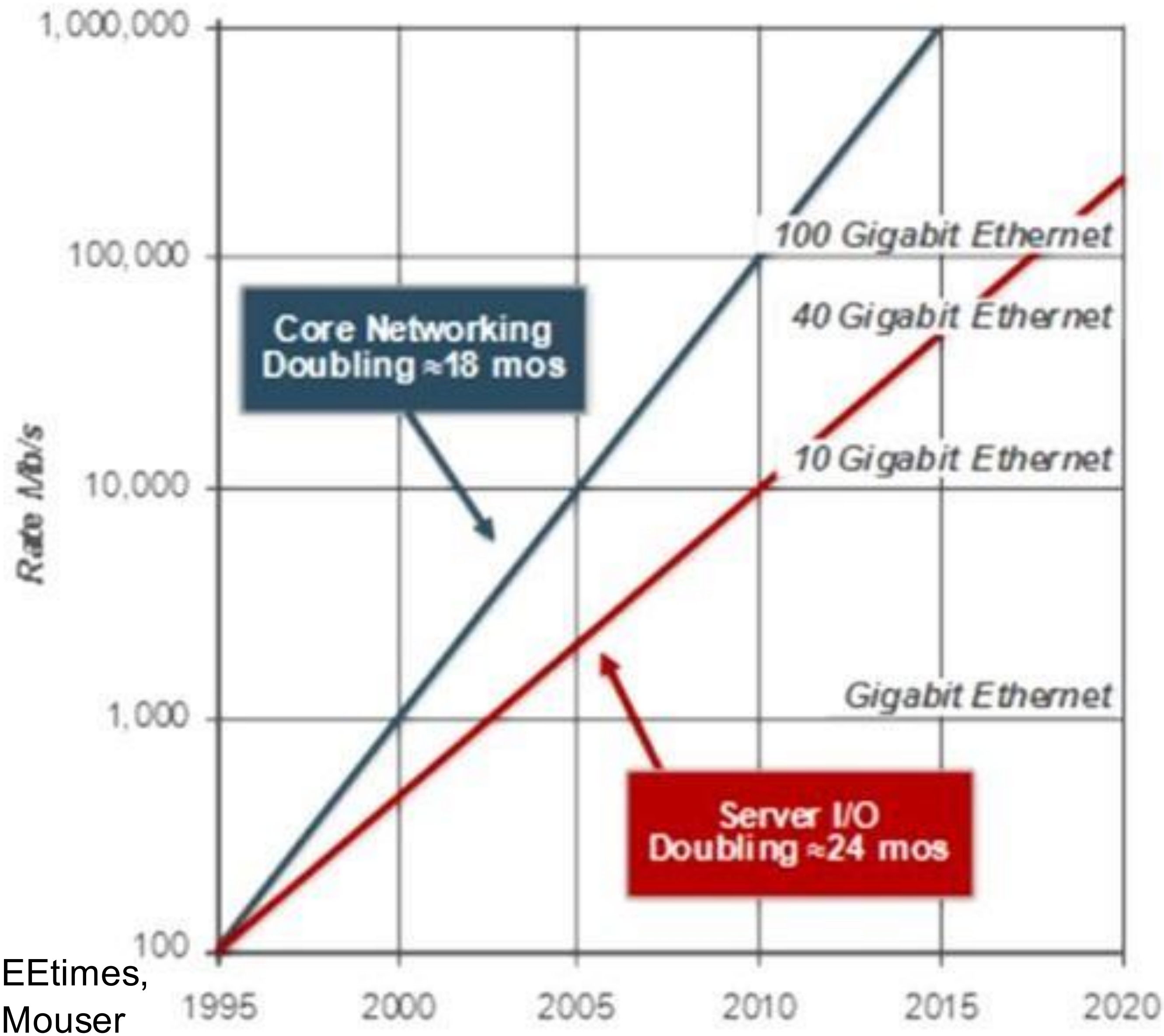
Wireless Communications

6G,
IoT
mm-wave
SDR
...

(30)

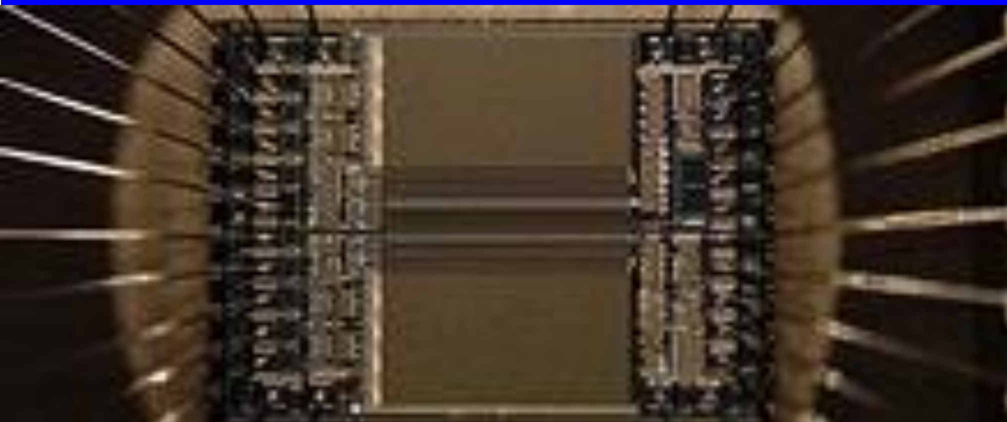
Intel

Wireline Communications (Cloud)



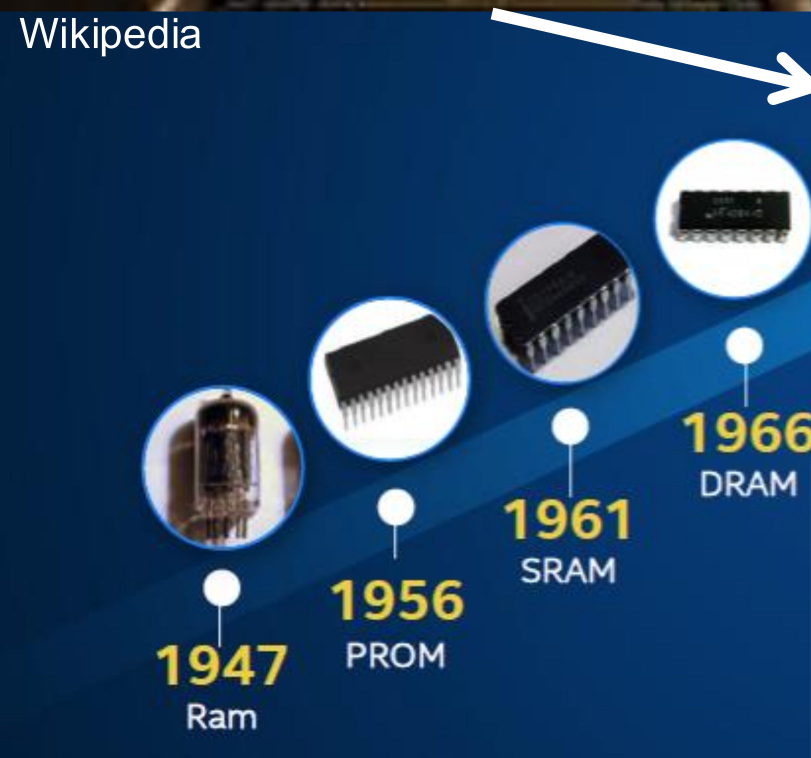
EEtimes,
Mouser

Semiconductor Memories

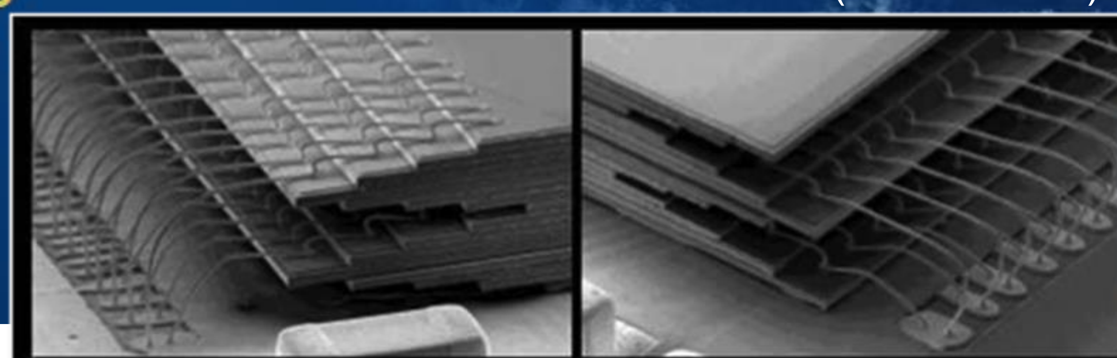


Wikipedia

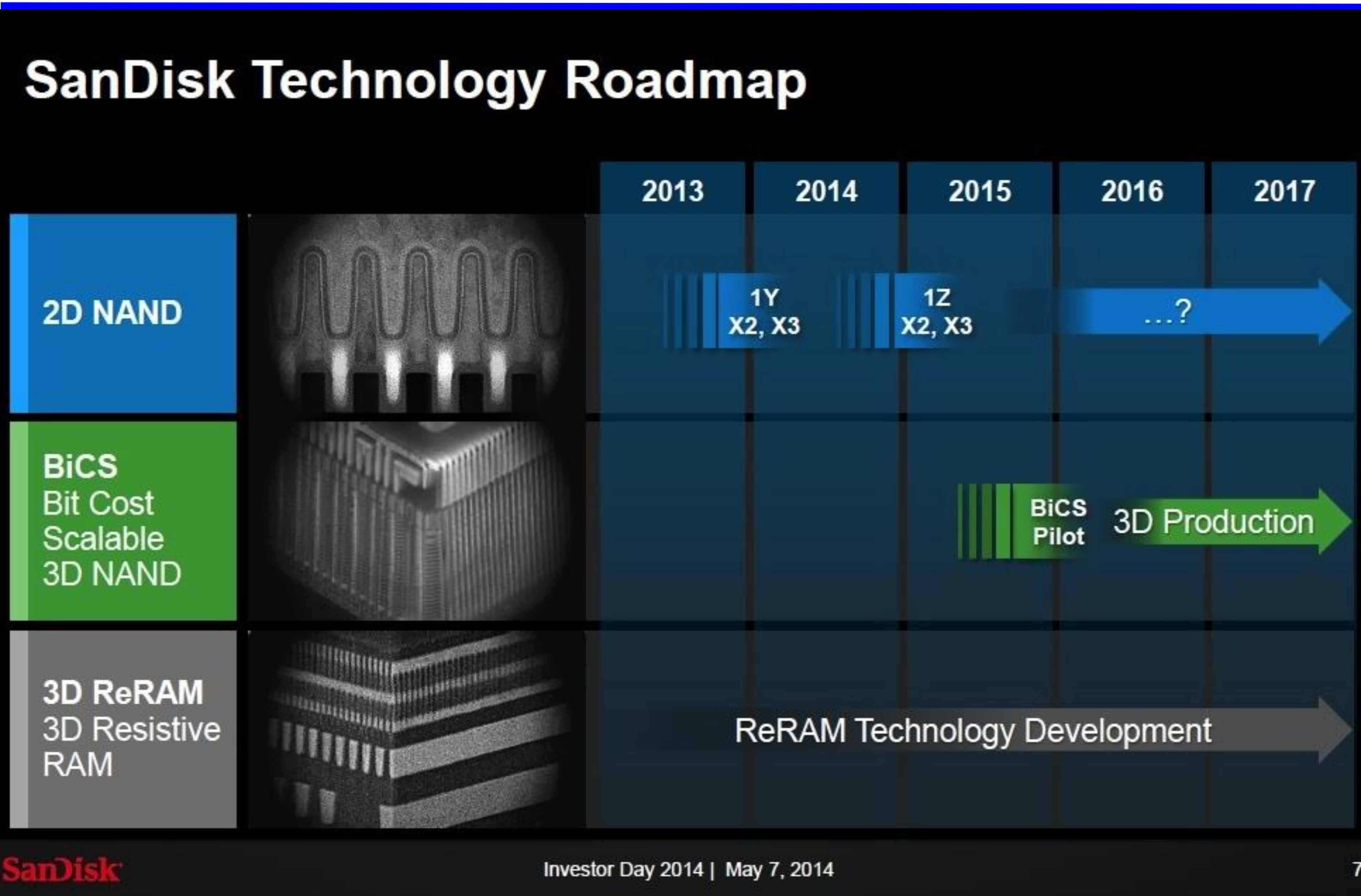
themememoryguy.com



SanDisk 16-die stack (3dincite.com)

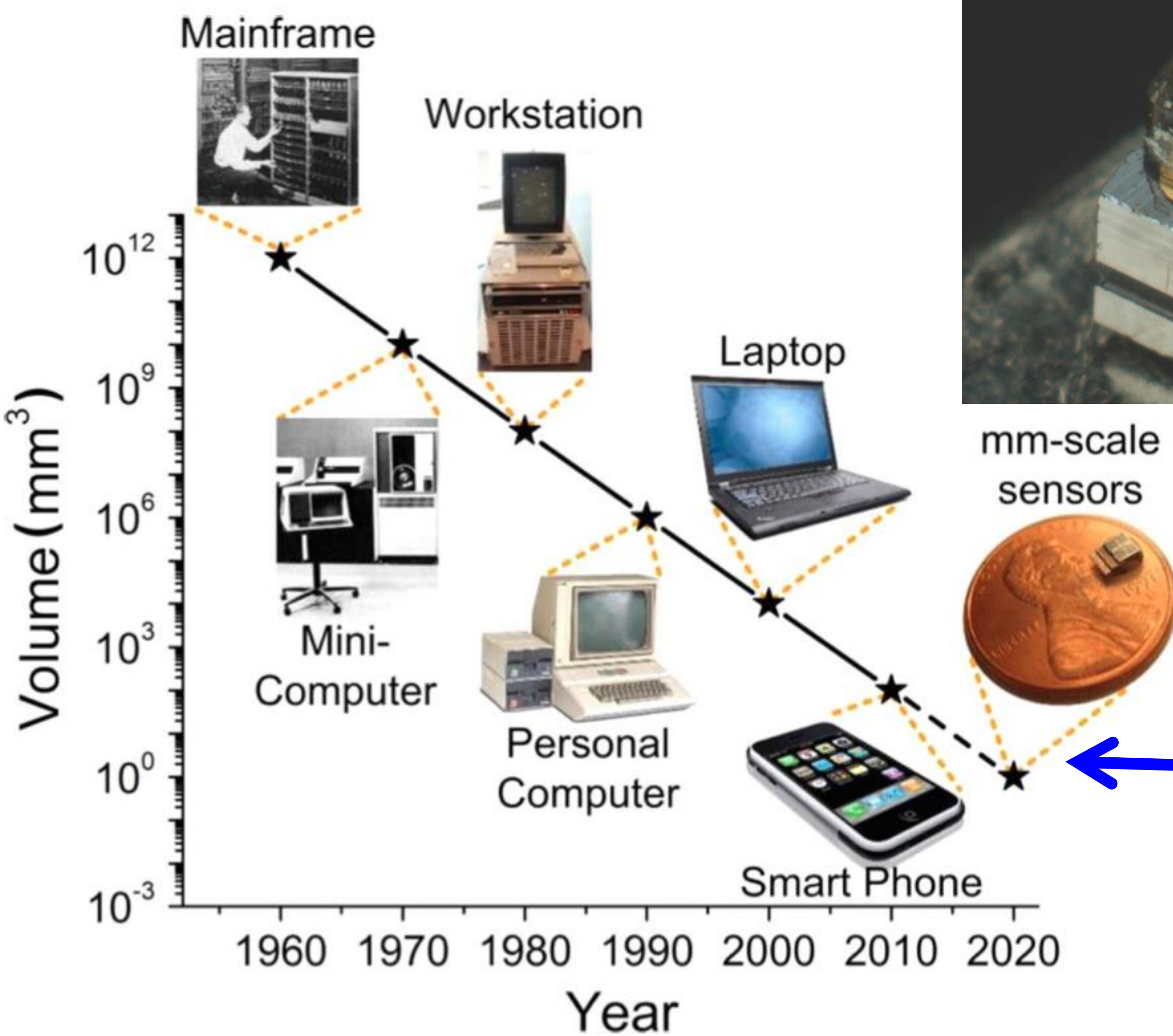


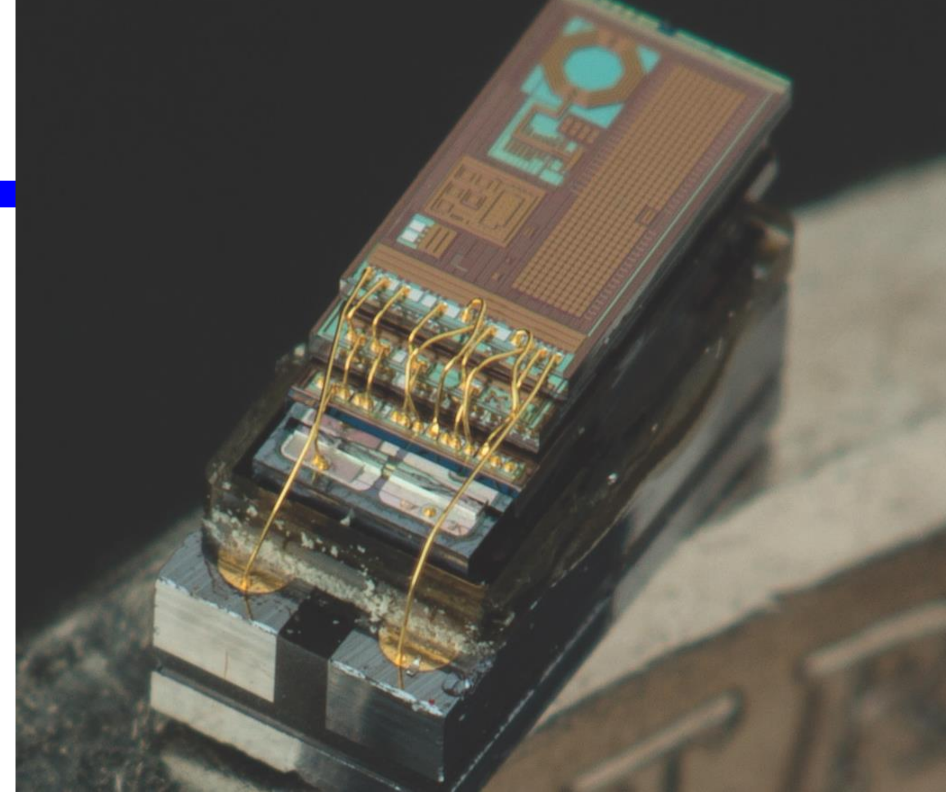
Example: Flash Memories



Bell's Law

- A new computer class forms about every decade





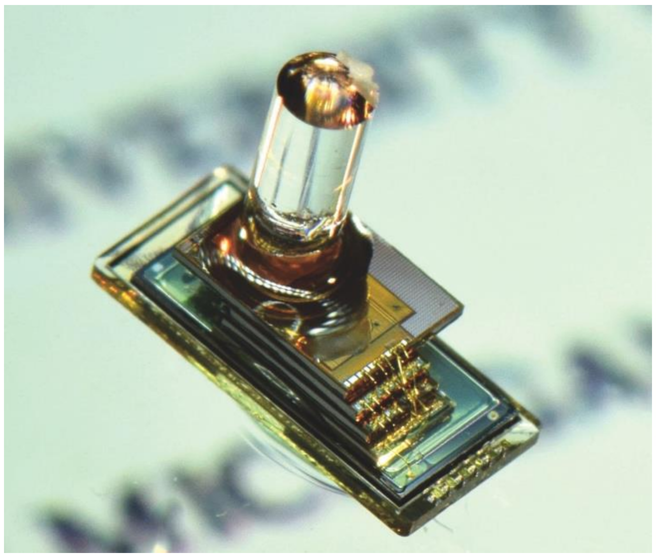
1mm^3 temperature sensor Profs. Blauuw and Sylvester, U Michigan

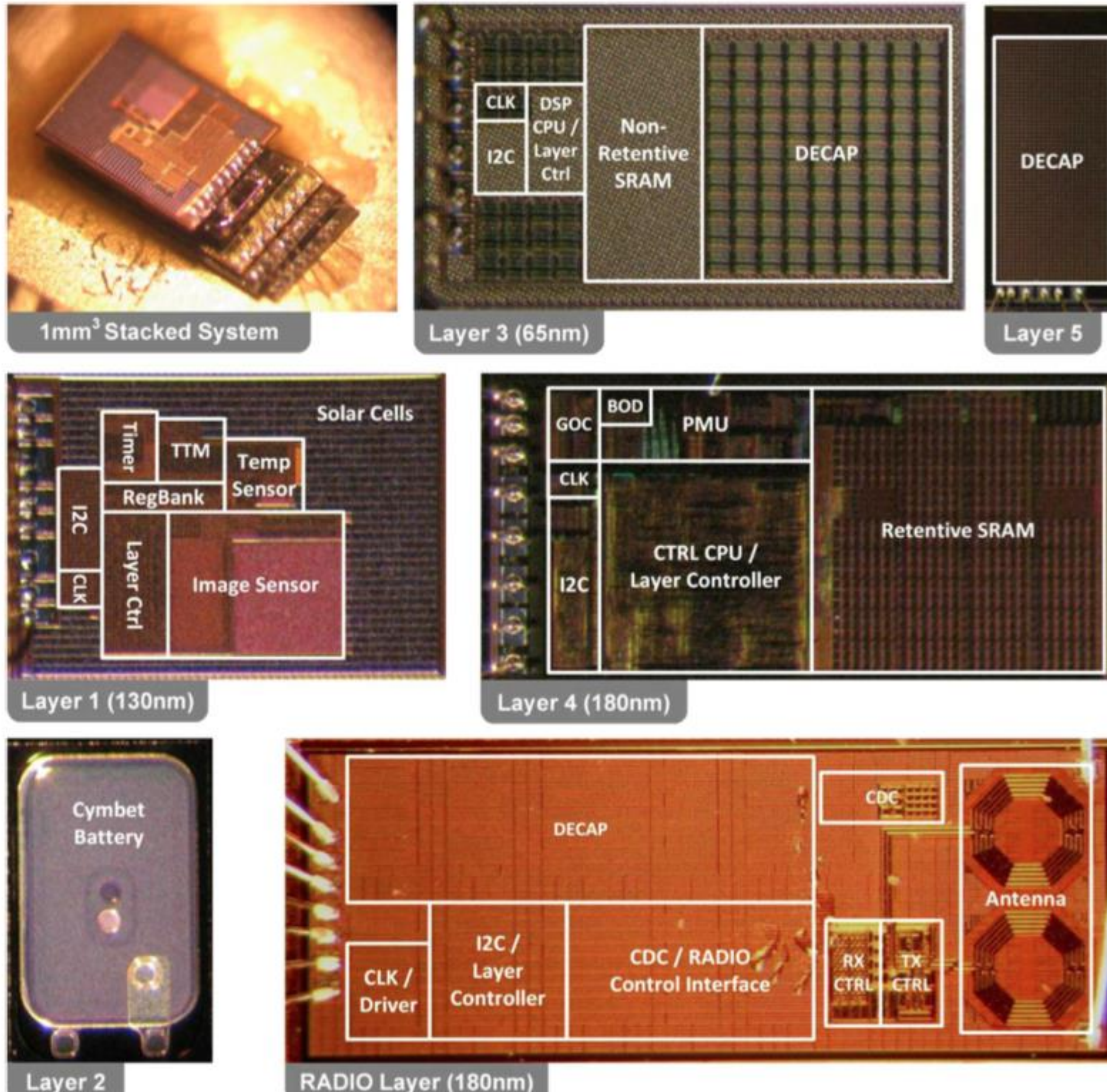
MICROSYSTEMS

computerhistory.org

Microsystems: Michigan Micro Mote

- Image Sensor
  - 1mm^3





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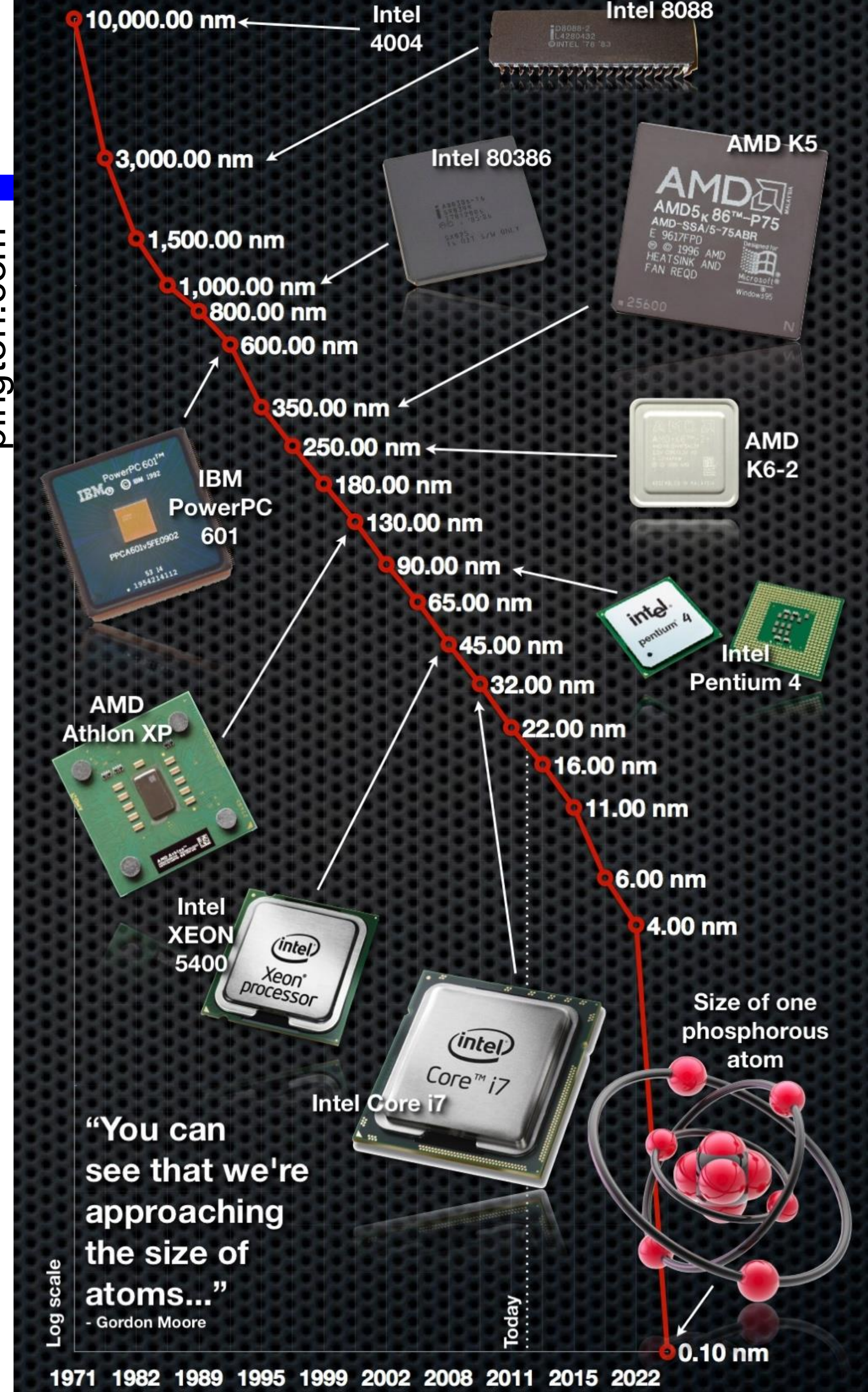
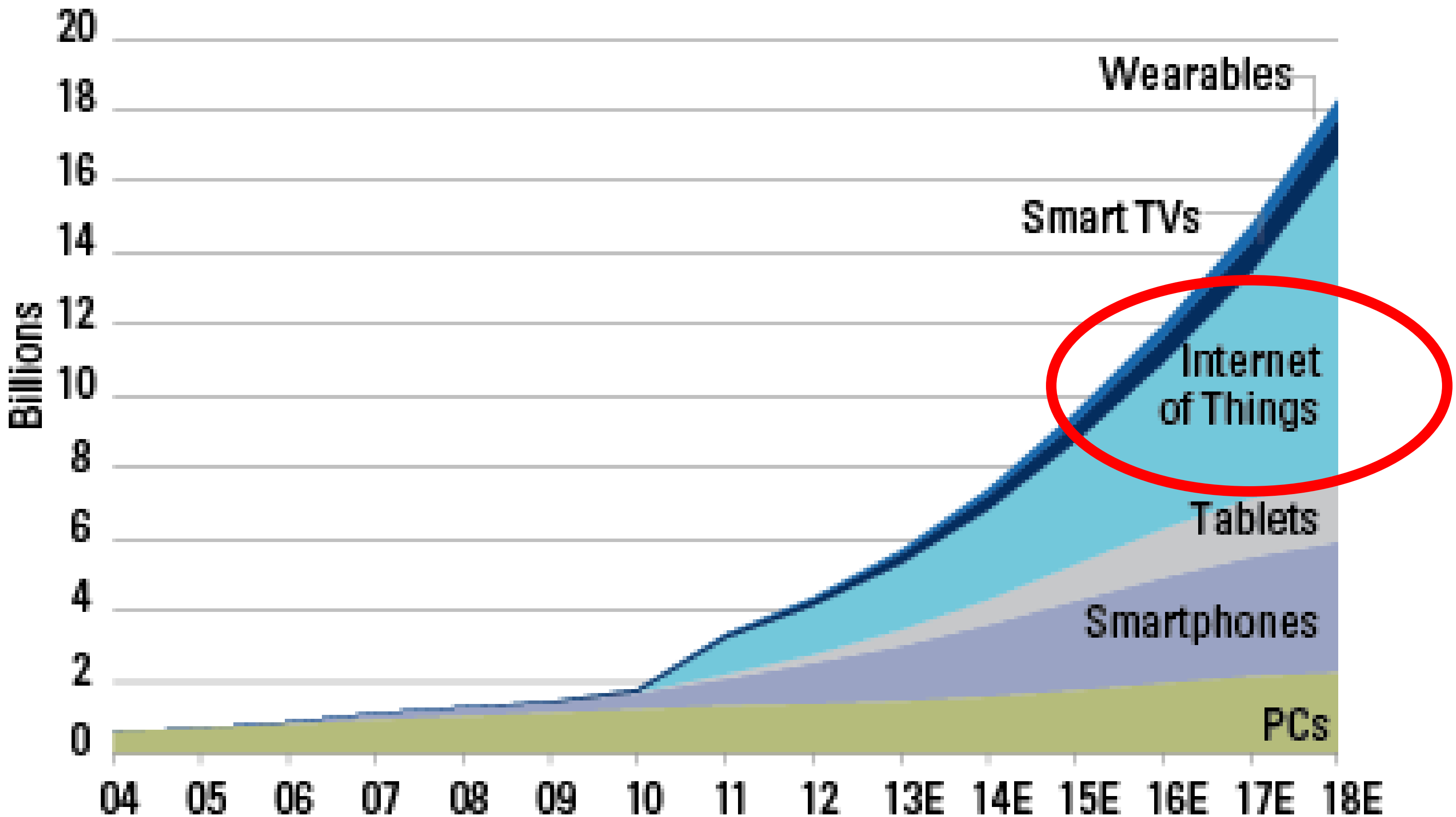
pington.com



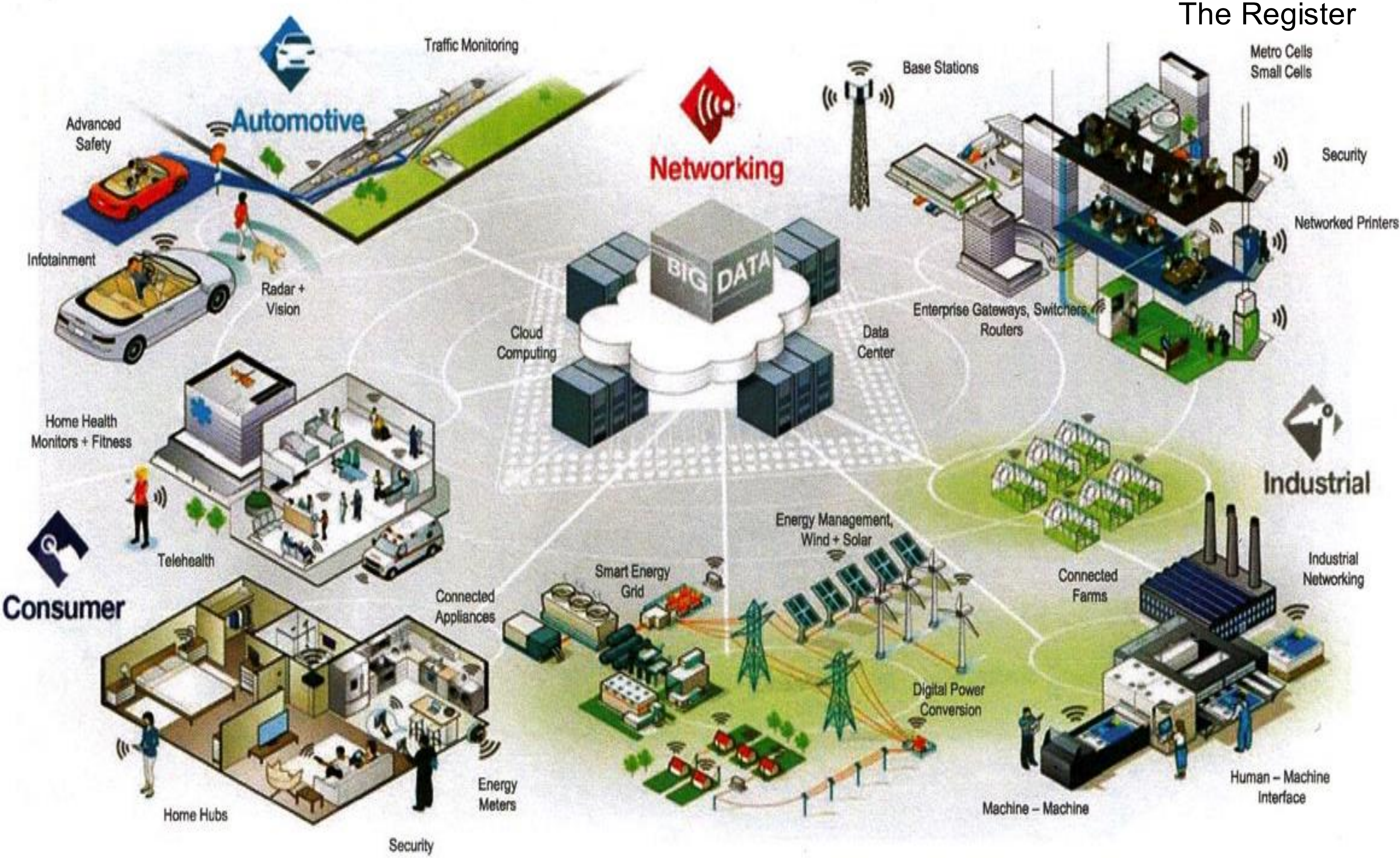
Future Markets: Internet-Connected Devices



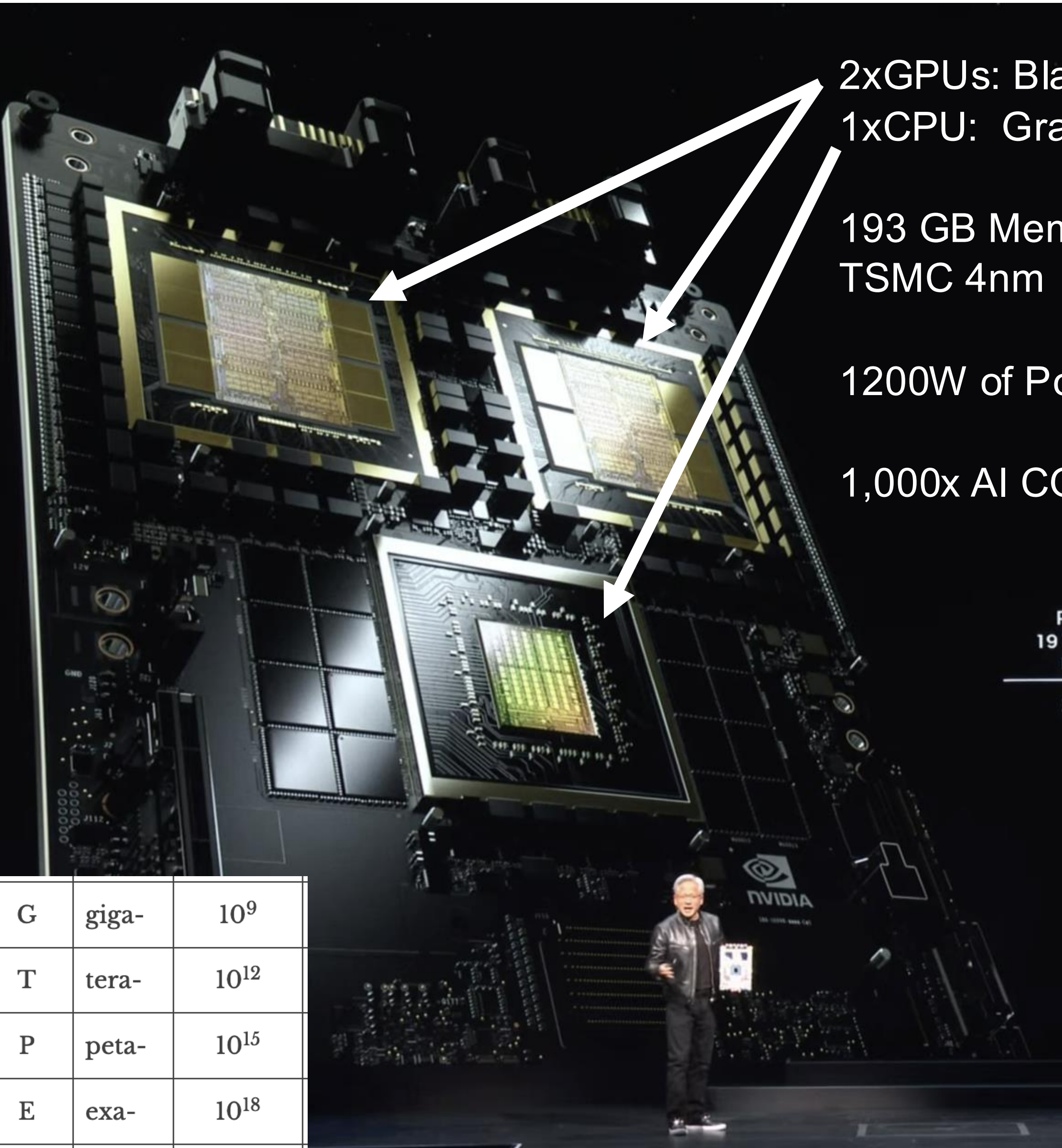
Sources: Gartner, IDC, Strategy Analytics, Machina Research, company filings, BII estimates

Future Markets: Internet of Things

The Register



NVIDIA: AI Chip GB200 Far Outpaces Moore's Law

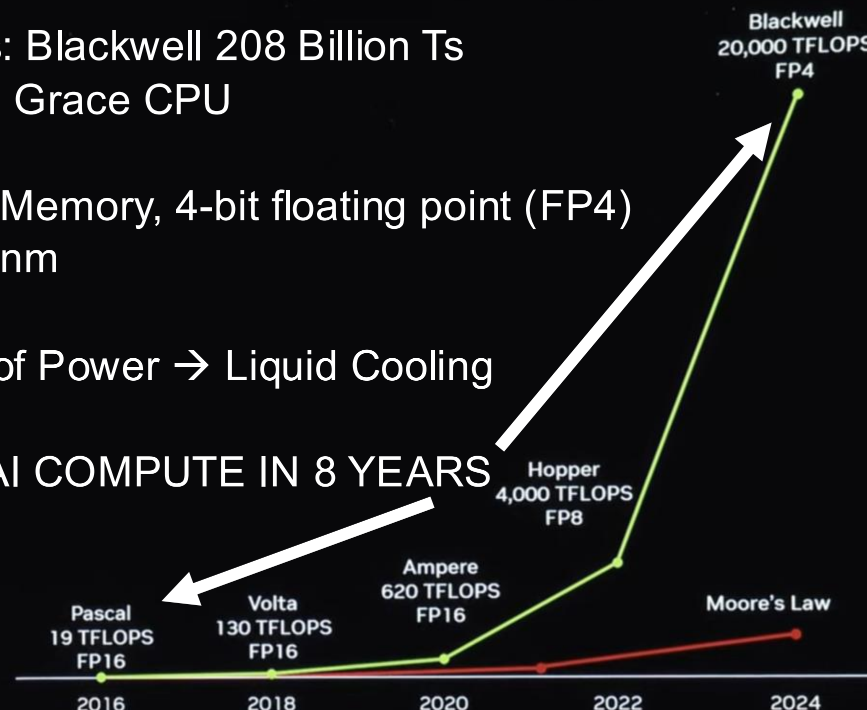


2xGPUs: Blackwell 208 Billion Ts
1xCPU: Grace CPU

193 GB Memory, 4-bit floating point (FP4)
TSMC 4nm

1200W of Power → Liquid Cooling

1,000x AI COMPUTE IN 8 YEARS



72x GPUs Rack

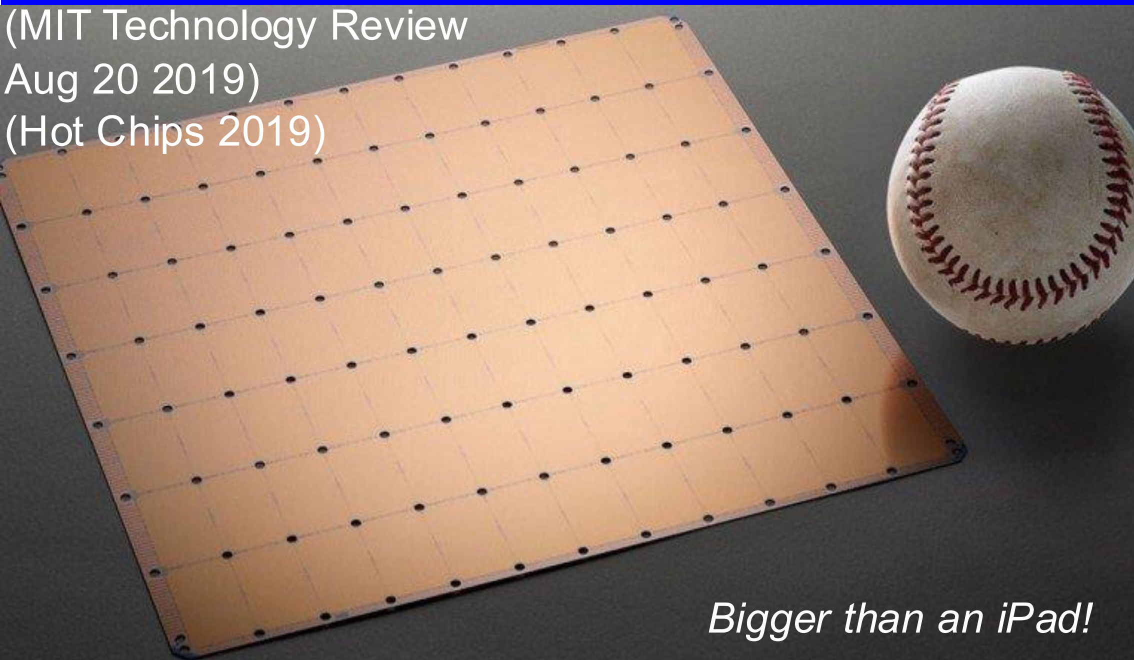
1,440 petaFLOPS
576 TB/s of GPU BW
10 trillion parameters

G	giga-	10^9
T	tera-	10^{12}
P	peta-	10^{15}
E	exa-	10^{18}

(NVIDIA

World’s Biggest Chip - Will Help Train AI

(MIT Technology Review
Aug 20 2019)
(Hot Chips 2019)



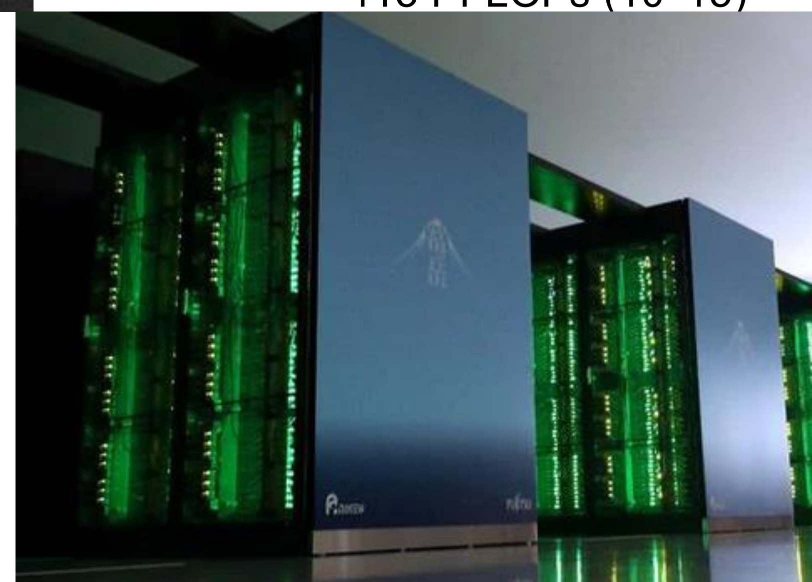
Bigger than an iPad!

Compare to: word’s fastest super-computer **as of 2020****:**

- Fugaku supercomputer by FUJITSU
- 415 PFLOPs (10^15)

Cerebras Systems’ Wafer-Scale Engine (16nm)

- 1.2 trillion transistors, 215 x 215mm^2, 400k cores
  - 40 TFLOPs (10^12)
- Compared to Nvidia’s largest GPU:
  - 57x bigger
  - 3,000x on-chip memory
- Saves power
  - by avoiding chip-to-chip communication
- Claim proprietary ways to improve yield
  - overcome defects / impurities



World’s Fasters Supercomputer as of 2024

Frontier supercomputer at Oak Ridge National Laboratory

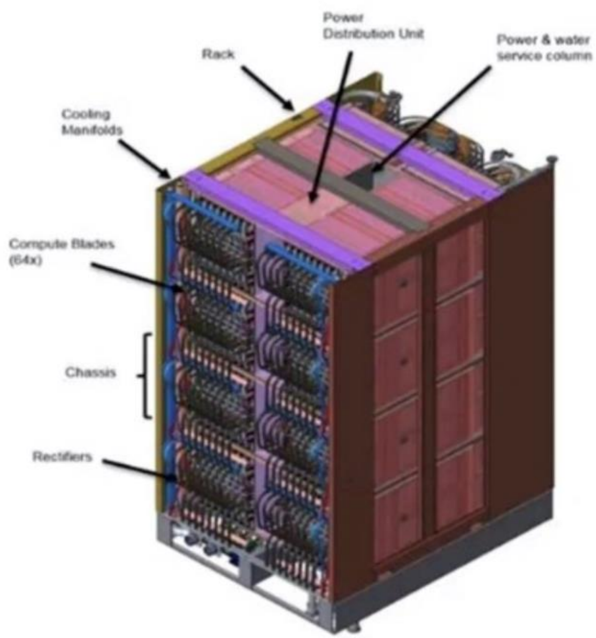
G	giga-	10^9
T	tera-	10^{12}
P	peta-	10^{15}
E	exa-	10^{18}

System

- 2 EF Peak DP FLOPS
- 74 compute racks
- 29 MW Power Consumption
- 9,408 nodes
- 9.2 PB memory
  (4.6 PB HBM, 4.6 PB DDR4)
- Cray Slingshot network with dragonfly topology
- 37 PB Node Local Storage
- 716 PB Center-wide storage
- 4000 ft² foot print

Olympus rack

- 128 AMD nodes
- 8,000 lbs
- Supports 400 KW

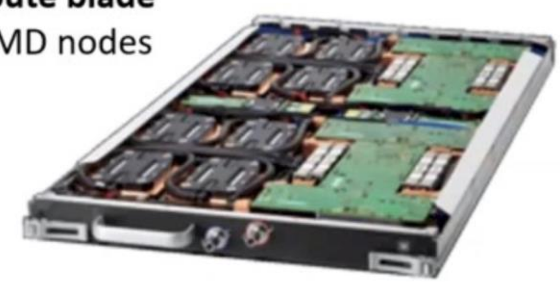


AMD node

- 1 AMD “Trento” CPU
- 4 AMD MI250X GPUs
- 512 GiB DDR4 memory on CPU
- 512 GiB HBM2e total per node
  (128 GiB HBM per GPU)
- Coherent memory across the node
- 4 TB NVM
- GPUs & CPU fully connected with AMD Infinity Fabric
- 4 Cassini NICs, 100 GB/s network BW

Compute blade

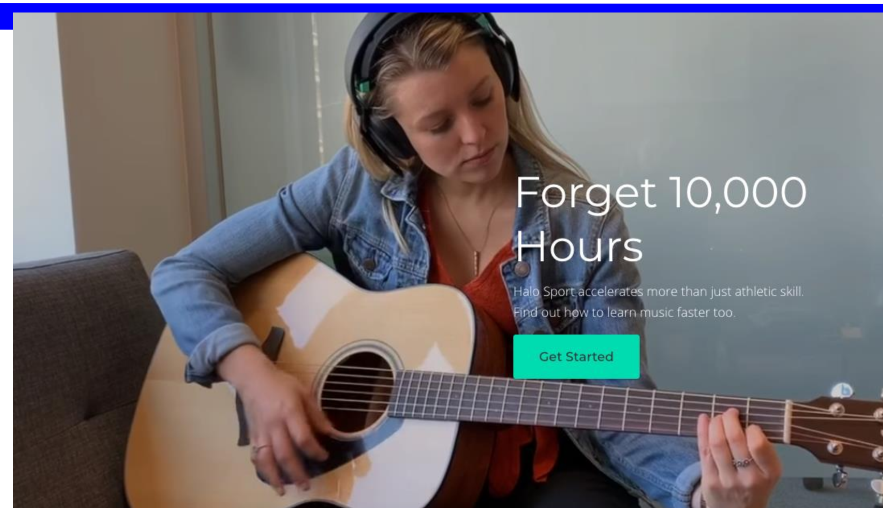
- 2 AMD nodes

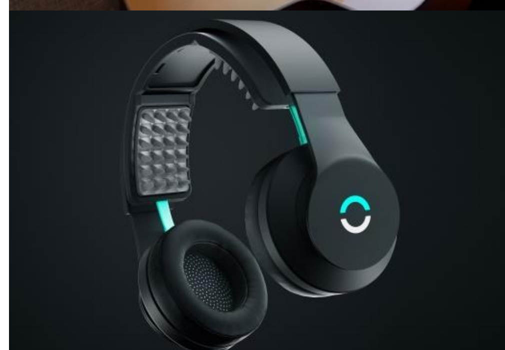


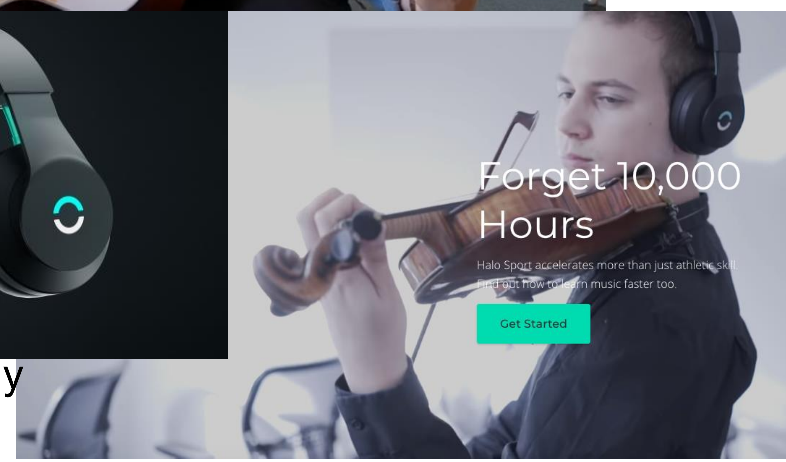
All water cooled, even DIMMS and NICs

Microelectronics in Medicine and Wellness

- **FLOW**, startup in Sweden
- Headset to treat depression
  - -Transcranial brain stimulation
  - - Medication free







(MIT Technology Review 2016)

- **Halo Neuroscience**, startup in Boston
- Headset for performance improvement
  - - Transcranial brain stimulation
- Headphones could make you a better
  - - Athlete, musician …?

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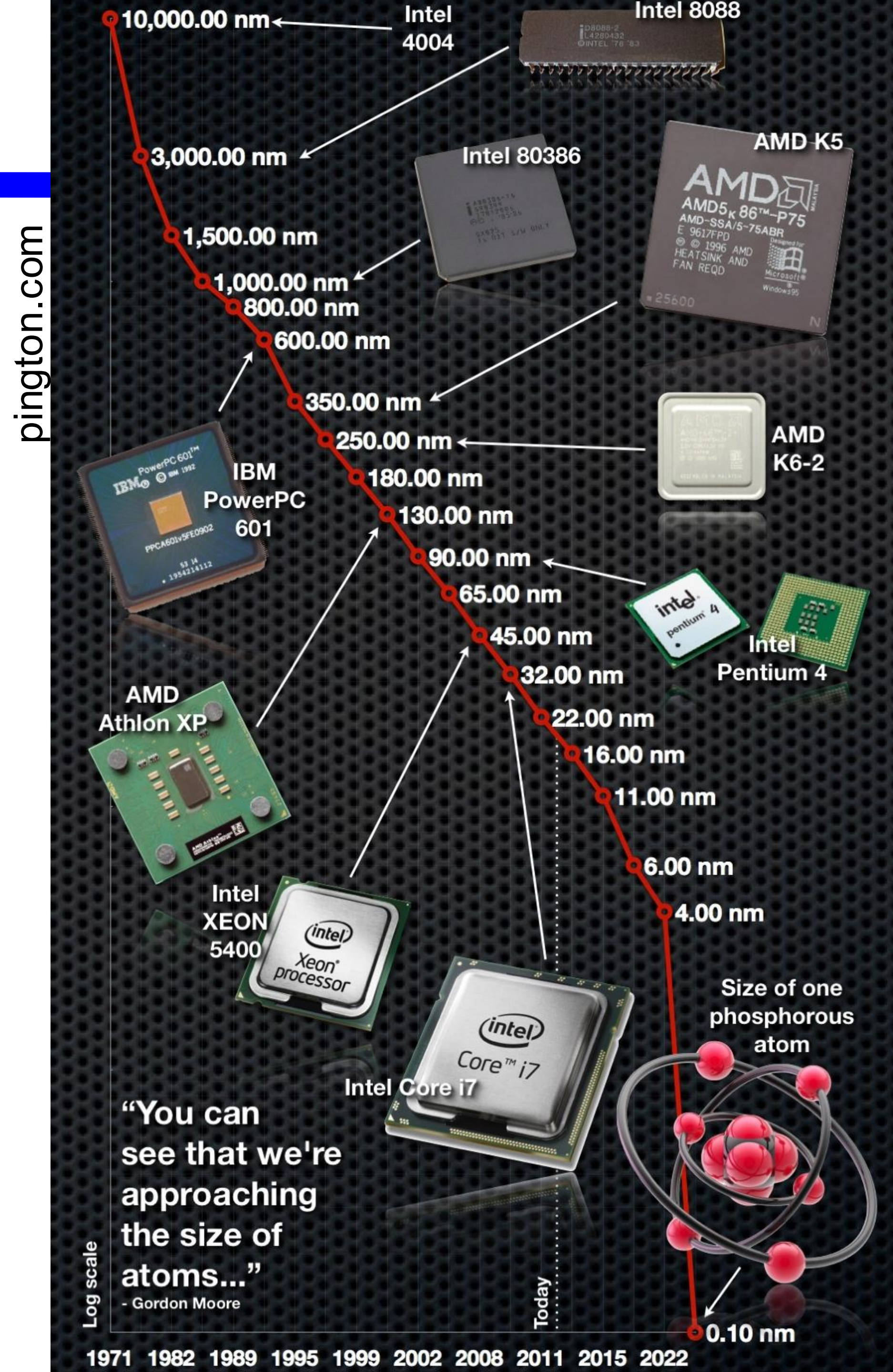
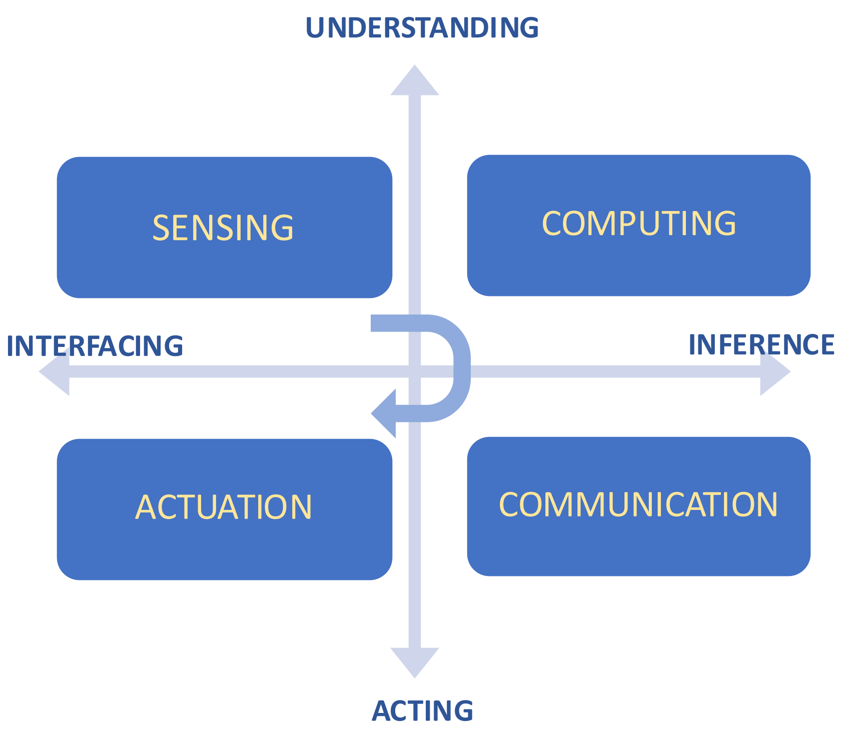


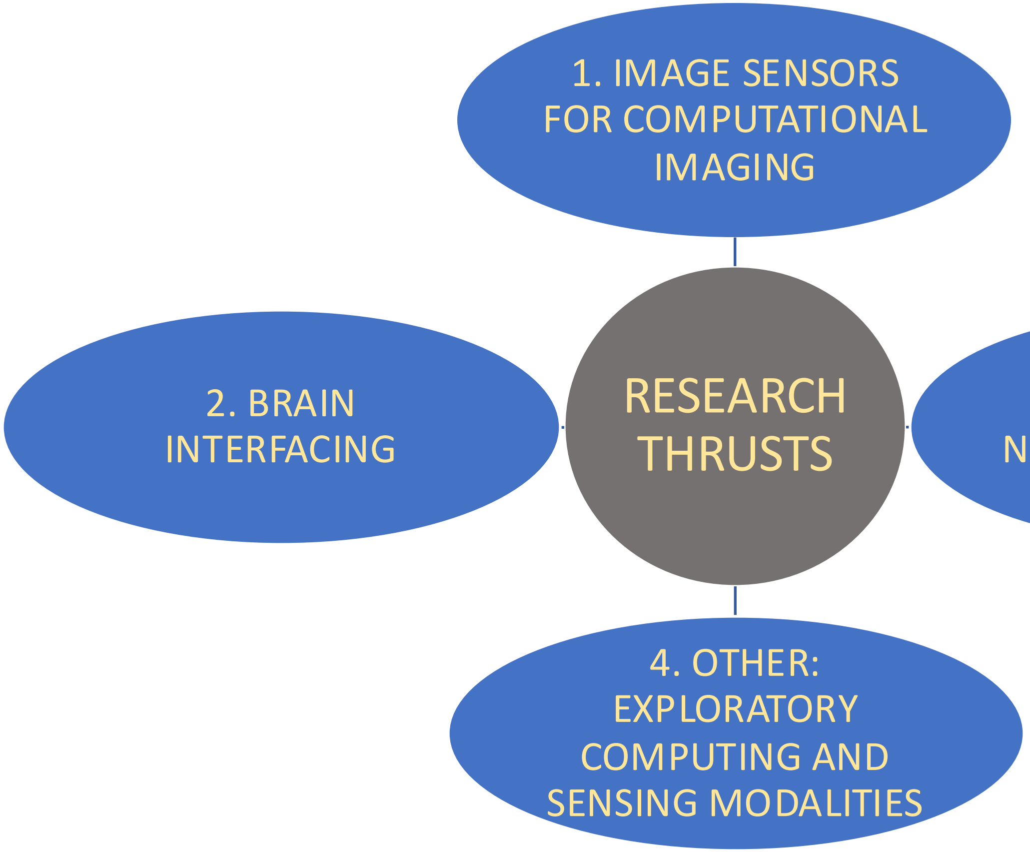
Genov Lab - Intelligent Sensory Microsystems Lab: Research Scope



NOVEL IC SOLUTIONS THAT ARE:

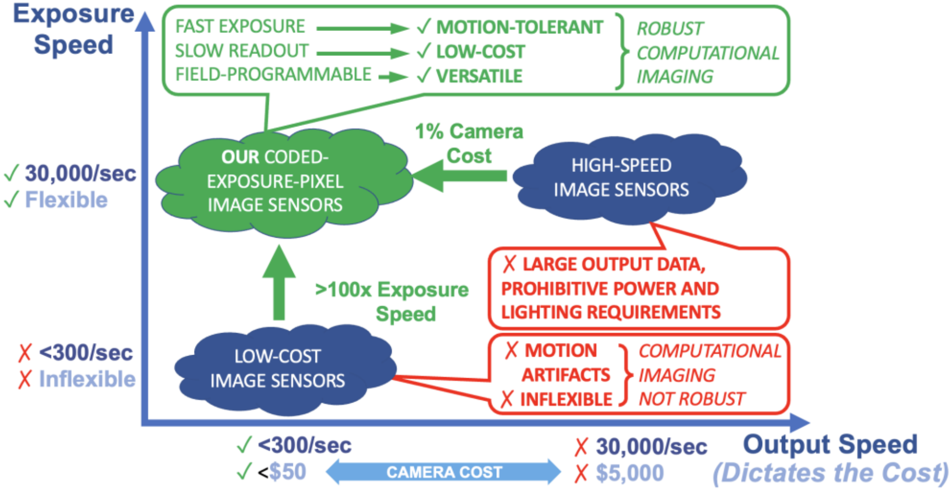
- **SYNERGISTIC**
  - Better than the sum of elements
- **ENABLING**
  - Energy-/cost-efficient, chip-scale
- **DISRUPTIVE**
  - New applications/markets

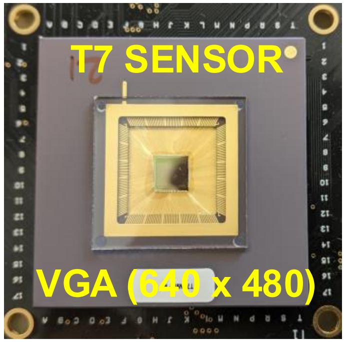
Genov Lab - Intelligent Sensory Microsystems Lab: Research Thrusts



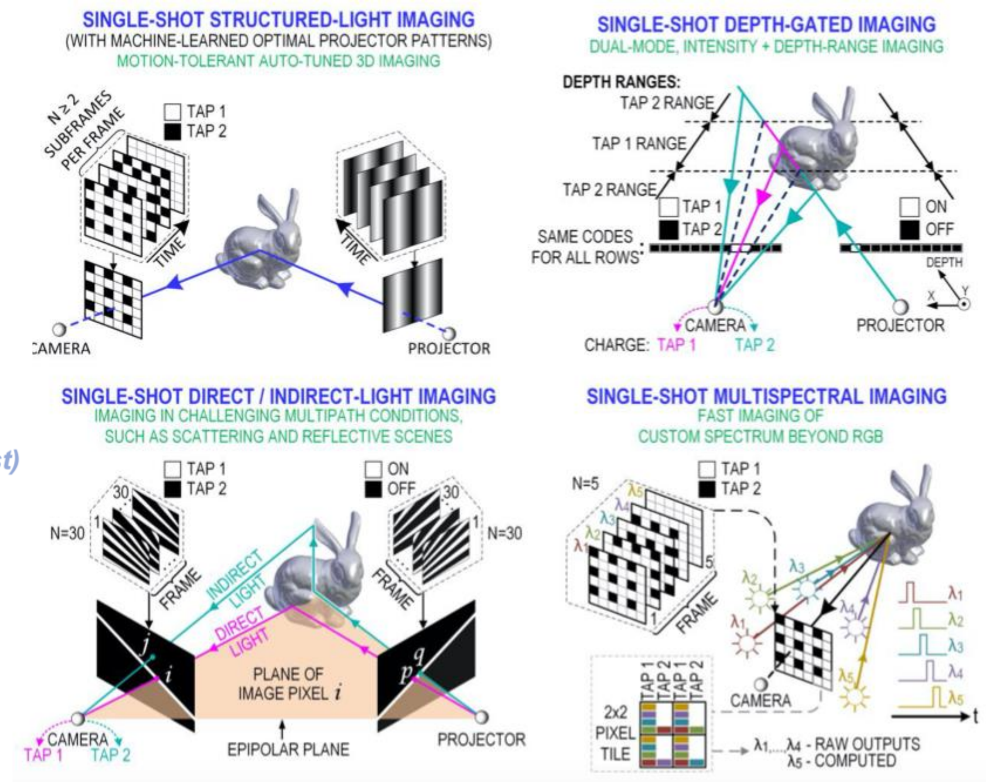
Thrust 1: Fast Software-Defined Image Sensors for Versatile Computational Imaging - the 'FPGAs' of the Image Sensors World
(ISSCC 19, 23; Symp. on VLSI 22, 24)

Motivation





Recent Sensor and Camera Prototypes

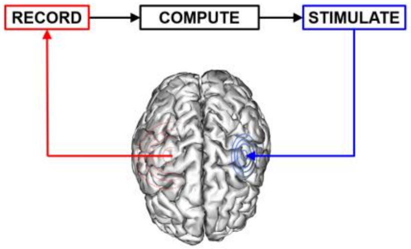


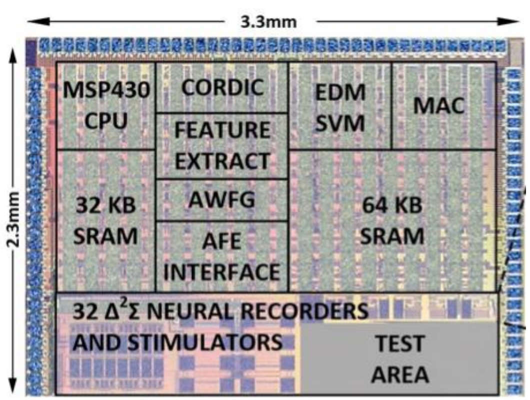
Computer vision application examples

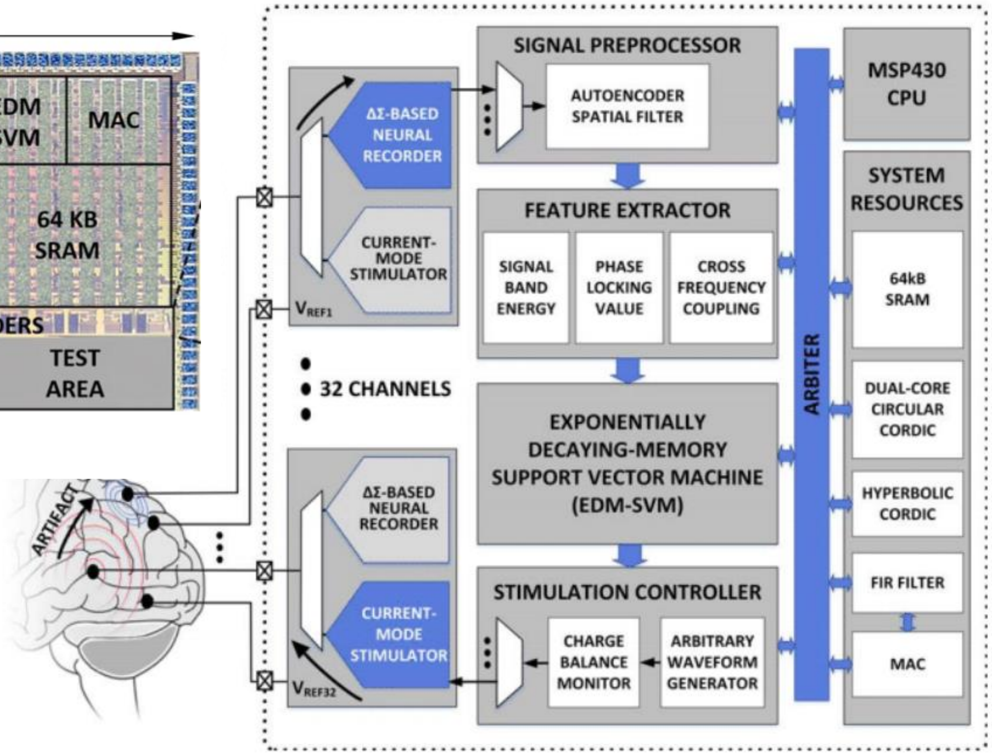
Image sensors with dynamically reconfigurable exposure time for every pixel: ie coded-exposure pixels

- *Multiple fast image captures and in-pixel charge-based processing → reduced motion artifacts*
- *Single slow read out at video rate → power dissipation/data rate comparable to conventional imagers*

Thrust 2: Artificially Intelligent **Brain Implants** for Automated Therapy *(ISSCC 2017, 2018 x2, 2019, 2020)*







Implantable brain implants to treat neurological disorders (eg epilepsy)

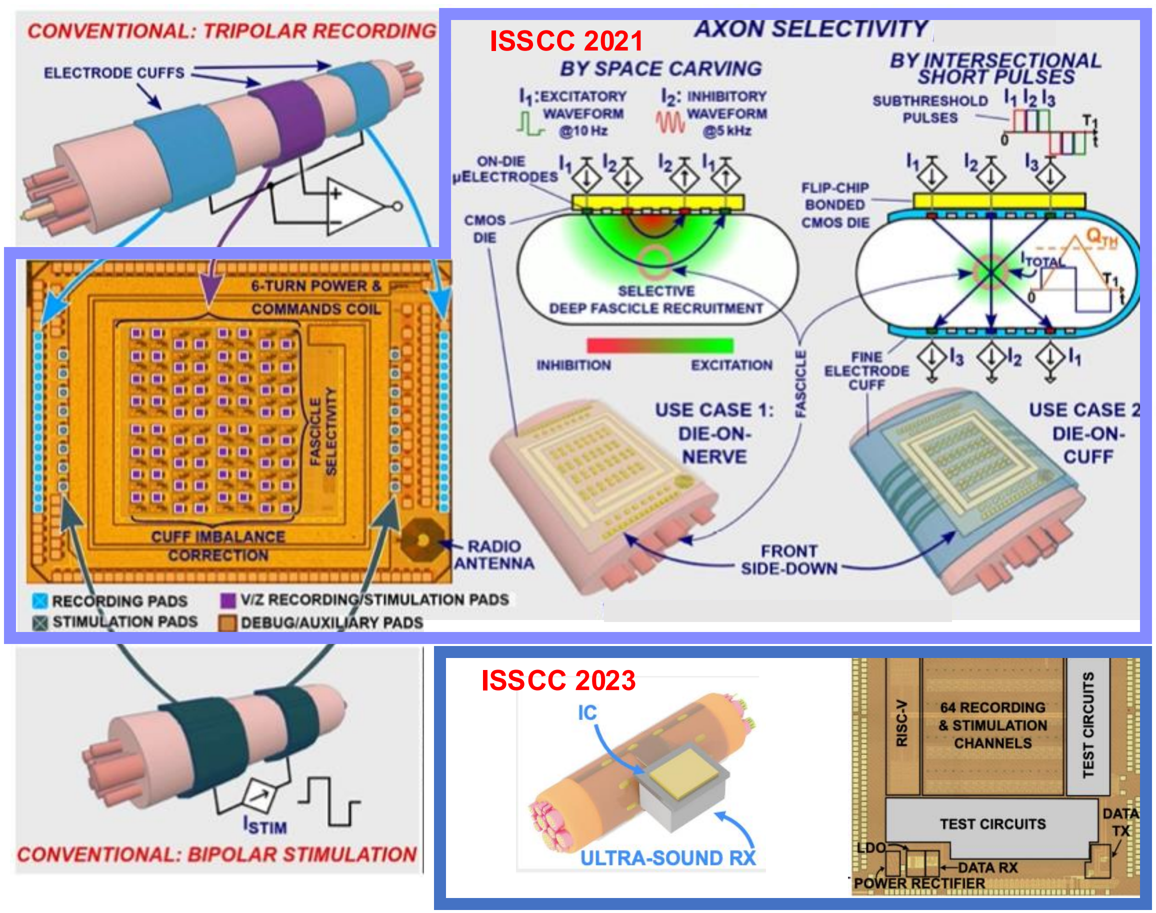
Brain-interfacing ICs:

- monitor brainwaves
- identify brain pathological brain states (such as epileptic seizures)
- trigger electrical stimulation to abort such states
- for automated neuromodulation therapy (e.g., epilepsy)

The designs includes:

- low-noise analog front-end
- wireless comm / power
- on-chip digital ML accelerator (SVM, decision trees)

Thrust 3: Smart Interfaces with Human Organs via ***Peripheral Nerves***
(ISSCC 2021, 2023)



Nerve-interfacing ICs:

- listen to PNS nerves
- interpret signals and
- alter brain-organ communication
- for automated neuromodulation therapy (e.g., spinal cord injury, chronic pain, autoimmune disorder, etc)

These designs include:

- low-noise analog front-end
- wireless comm / power
- wearable digital ML accelerator (CNN)

Research Opportunities

- **Participation in a research-oriented final project in ECE1388**
    - One or more such projects from my lab are available
    - Participation in a full-cycle IC design and prototyping, including tape-out
    - Can lead to a subsequent or concurrent MEng project ECE2500Y
- **ECE2500Y MEng projects are available** (worth 3 grad courses)
    - Apply by email any time - info @ https://www.eecg.utoronto.ca/~roman/