

The background features a complex network diagram representing a neuromorphic computing architecture. It consists of multiple layers of circular nodes. The nodes are arranged in a grid-like fashion, with some nodes highlighted in a darker teal color. Numerous arrows connect the nodes, indicating the flow of information or data between them. The overall structure suggests a highly interconnected, distributed system.

Neuromorphic Computing

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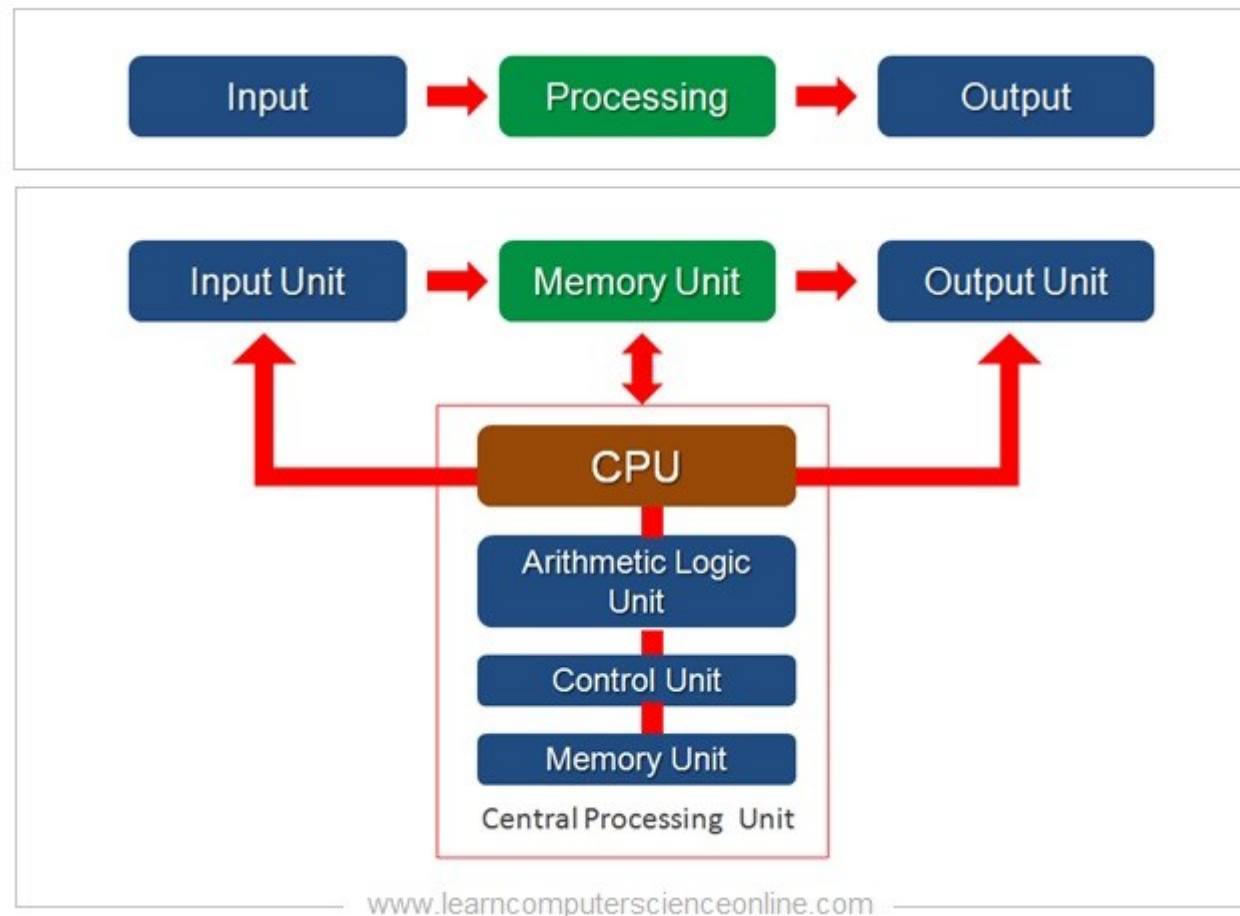
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Lecture series contents

- The state of computer hardware today.
- Challenges in hardware driven by societal needs (data science).
- What future solutions could answer current (and near future) data processing needs?
- How are brains like computers?
- How are computers like brains?
- What lessons learnt about human brains can we apply to computers?
- What is neuromorphic computing?
- The three main approaches to neuromorphic computing.
- Examples of the state of the art in neuromorphic computing.

How do computers work?

- Classic 'Von-Neumann' architecture
 - Separate memory and processing via 'bus'



Integrated circuits

- Transistors
 - an amplifier or a two state switch
 - (CMOS) complementary metal oxide semiconductor
 - As of 2011 > 99% of all integrated circuit (IC) chips made this way
 - Core i7-8700K has ~ 3 billion



A replica of the first working transistor,
Lucent Technologies 1997

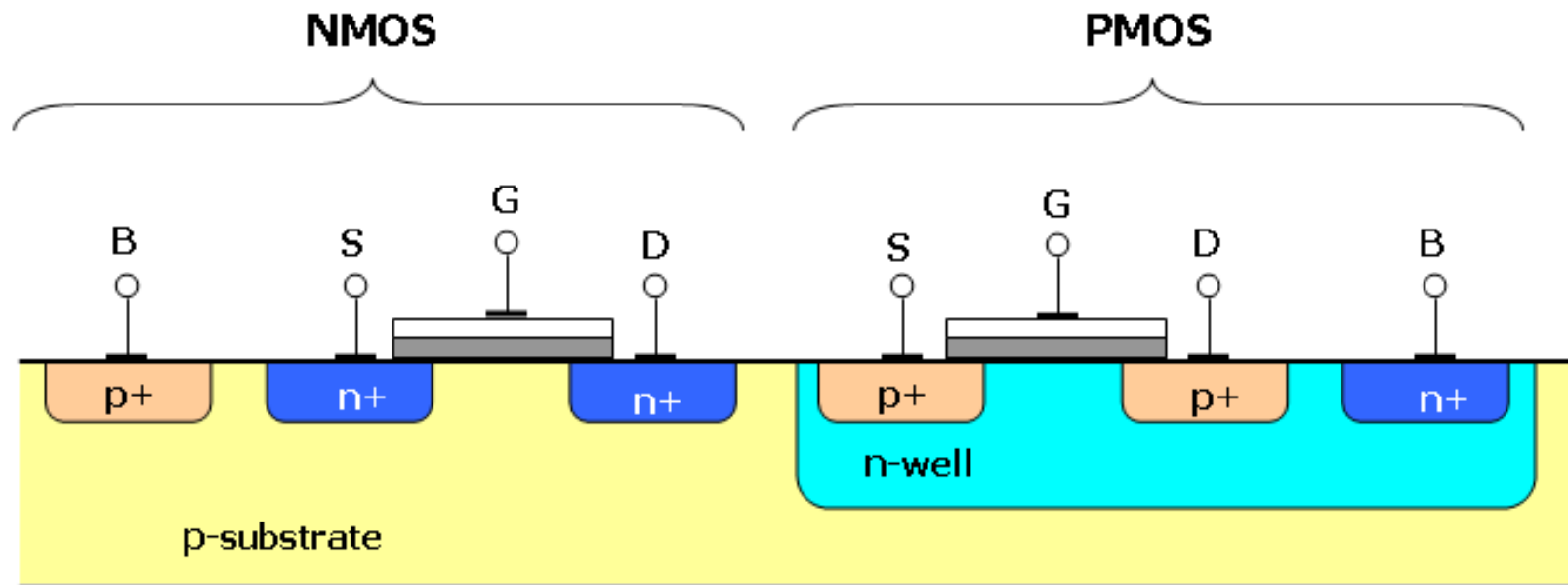


Integrated circuits

- What is a semiconductor?
 - Electrical conductivity between an insulator and a conductor
 - Resistivity falls as heat rises
 - May be doped to alter it's conducting properties
 - N-type or P-type depending on doping materials
 - P-type has more electron 'holes'
 - N-type has extra electrons
 - Silicon is the most commonly used material
 - MOSFET (Metal-Oxide-Semiconductor Field Effect Transistor)
 - The same signal that turns on a P-type turns of an N-type and vice-versa

Integrated circuits

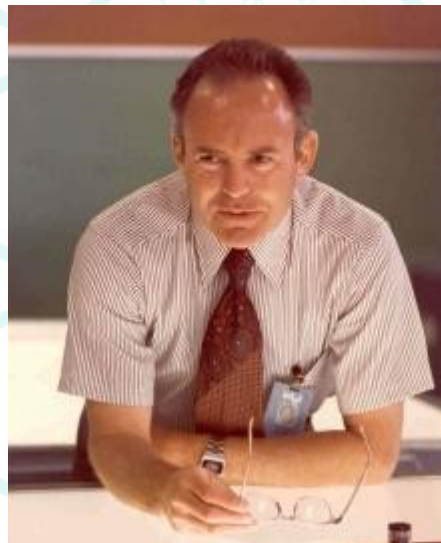
- (DRAM) Memory, a simple example
 - Switch allows/restricts current flow to a capacitor
 - A full capacitor is a 'one'
 - Capacitors slowly discharge so must be refreshed (DRAM)
 - Read by comparing voltage differences between full and empty capacitors



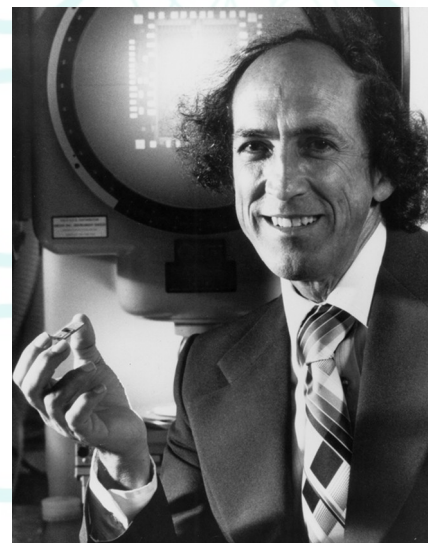
A CMOS switch.

Integrated circuits, it's the LAWS!

- Moore's 'law': The number of transistors in an integrated circuit doubles every two years
 - Gordon Moore co-founder of Intel, Electronics magazine, 1965.
- Dennard's scaling law: As transistor density doubles, chip performance improves while its power density remains the same.
 - Robert H. Dennard et al., IEEE Journal of Solid-State Circuits, 1974.



Moore



Dennard

Integrated circuits, it's the LAWS!

- Dennard's scaling law: If transistor dimensions can be scaled by $\sim 30\%$ then (a scaling argument):
 - Device area reduces by $\frac{1}{2}$ as $0.7 \times 0.7 = 0.49$ (area = $L \times W$)
 - Capacitance reduced by $\sim 30\%$ as $C = \epsilon(A/d)$
 - Voltage is reduced by $\sim 30\%$ as $-\Delta V = Ed$
 - Therefore other characteristics of energy and timing reduce
 - Frequency increases by around 40% as $f = 1/T$
 - Power scaling $P = CV^2f$ therefore $\sim P = 0.7 \times 0.49 \times 1.4 = 0.48$
- Area and power halved implies (\rightarrow) If density doubles power consumption of the new device halves.

You are not expected to know/understand these equations!

Integrated circuits, what really happened.

- Comparing computing power with the VAX 11/780 (1970)
- From 1986-2006 growth doubled
- Intel Xeon 3.2 GHz (2003) 6000 times more powerful than the VAX 11/780
- Hooray ... but wait ...
- Since 2015, growth in computing power is estimated at an annual rate of 3.5%
- But whhhhyyyyyyyy!!!



VAX 11/780

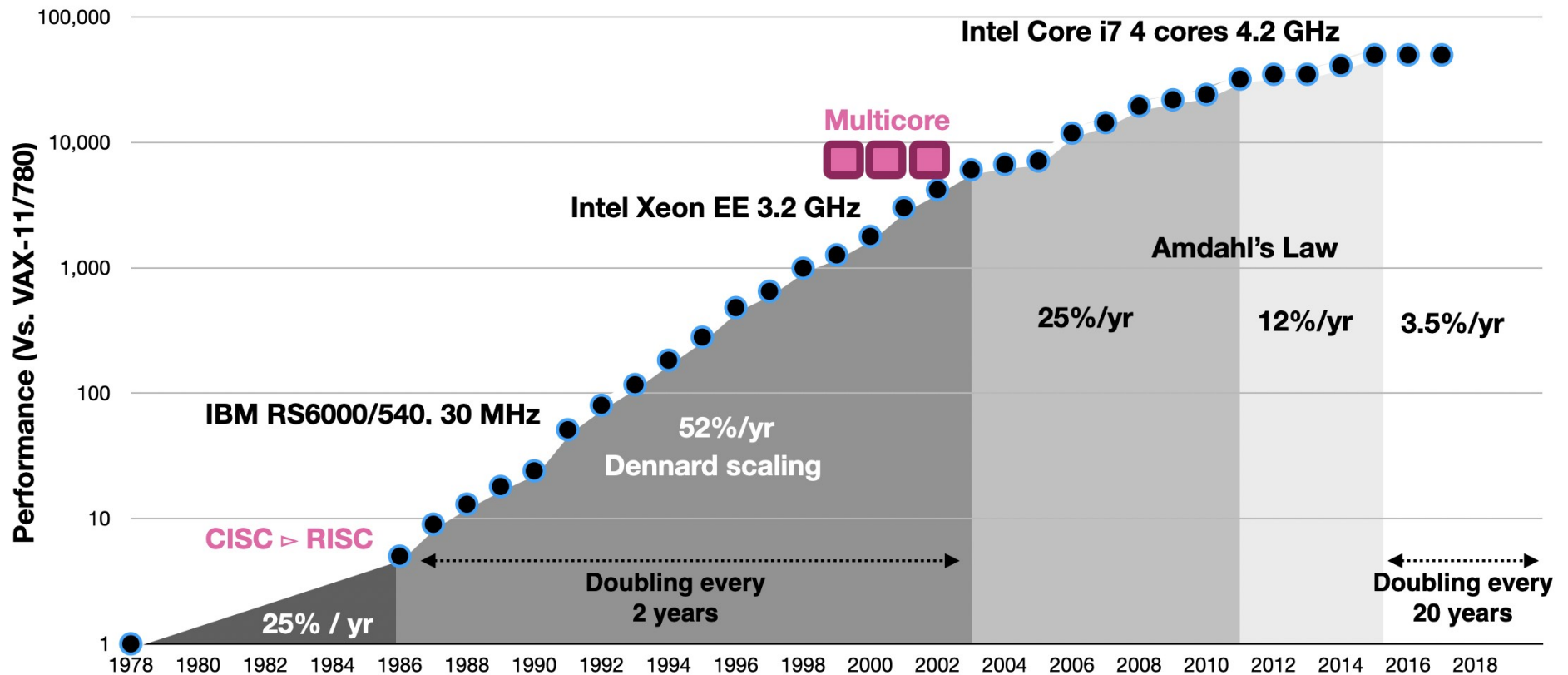


Dell Poweredge Server from 2003

Data from John L Hennessy and David A Patterson. Computer Architecture:
A Quantitative Approach. Elsevier, 2017

Integrated circuits, what really happened.

Performance, based on SPEC benchmarks and scaled to newer SPEC versions



Data from John L Hennessy and David A Patterson. Computer Architecture: A Quantitative Approach. Elsevier, 2017

Integrated circuits, it's the LAWS!

- Moore and Dennards laws imply that performance per watt doubles approximately every 18 months (Koomey's law)
- Given the laws what are the ways we can improve computer performance and why should we?
 - More transistors and faster speeds (clock rate)
 - Multiple cores, parallelism
 - We don't have the power!
 - Our needs only increase

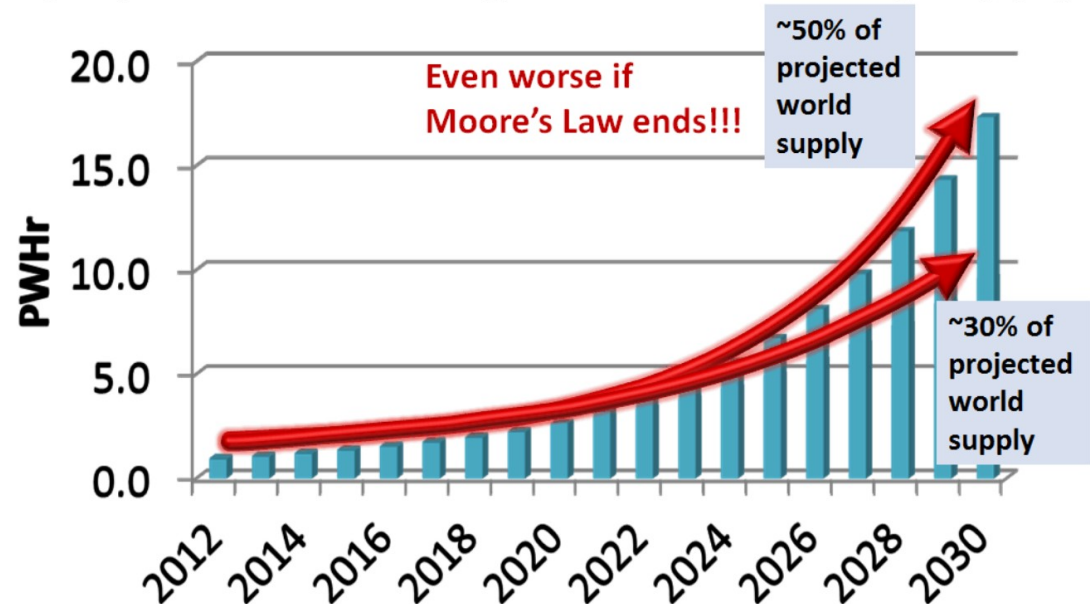
IT projected to challenge future electricity supply



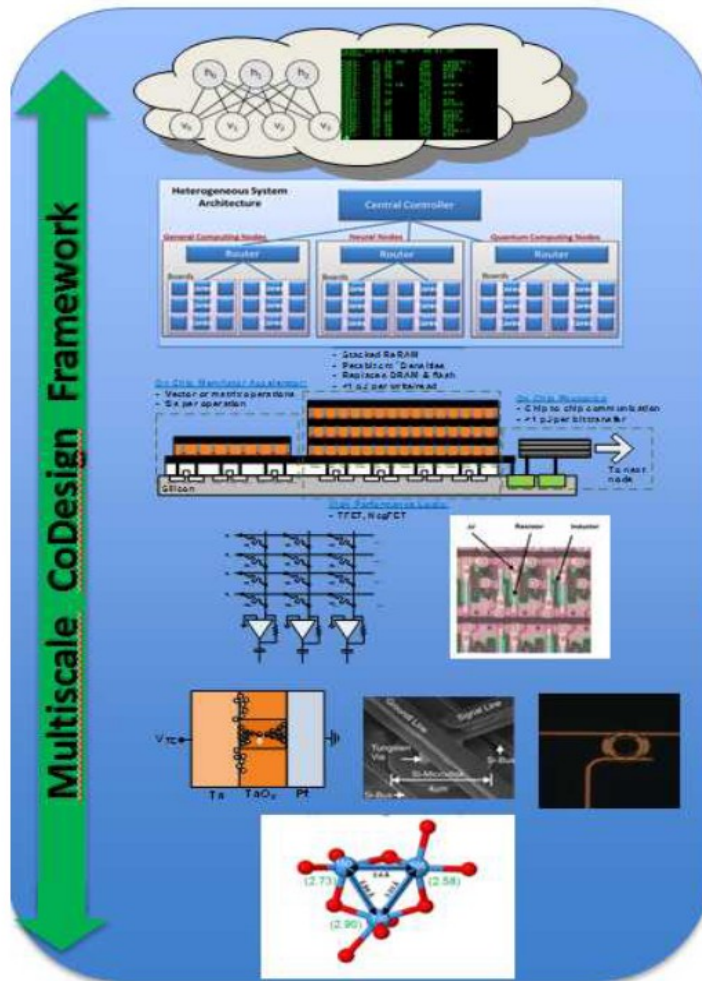
Scotty



Koomey



Integrated circuits, what shall we do?



Programming paradigms

System architecture modeling

Component hetero-integration

Device/Circuit integration

Device physics

Fundamental material science



Neuromorphic Computing

Thank you :)

A background diagram illustrating a neuromorphic computing network. It features a grid of circular nodes arranged in 5 rows and 5 columns. The nodes are colored in a gradient from light blue on the left to light green on the right. Each node is connected to its immediate neighbors (horizontally, vertically, and diagonally) by thin, light blue lines. The connections are bidirectional, as indicated by the lack of arrowheads on the lines. The overall structure represents a complex, interconnected system of nodes, typical of a neuromorphic architecture.