Neuromorphic Computing

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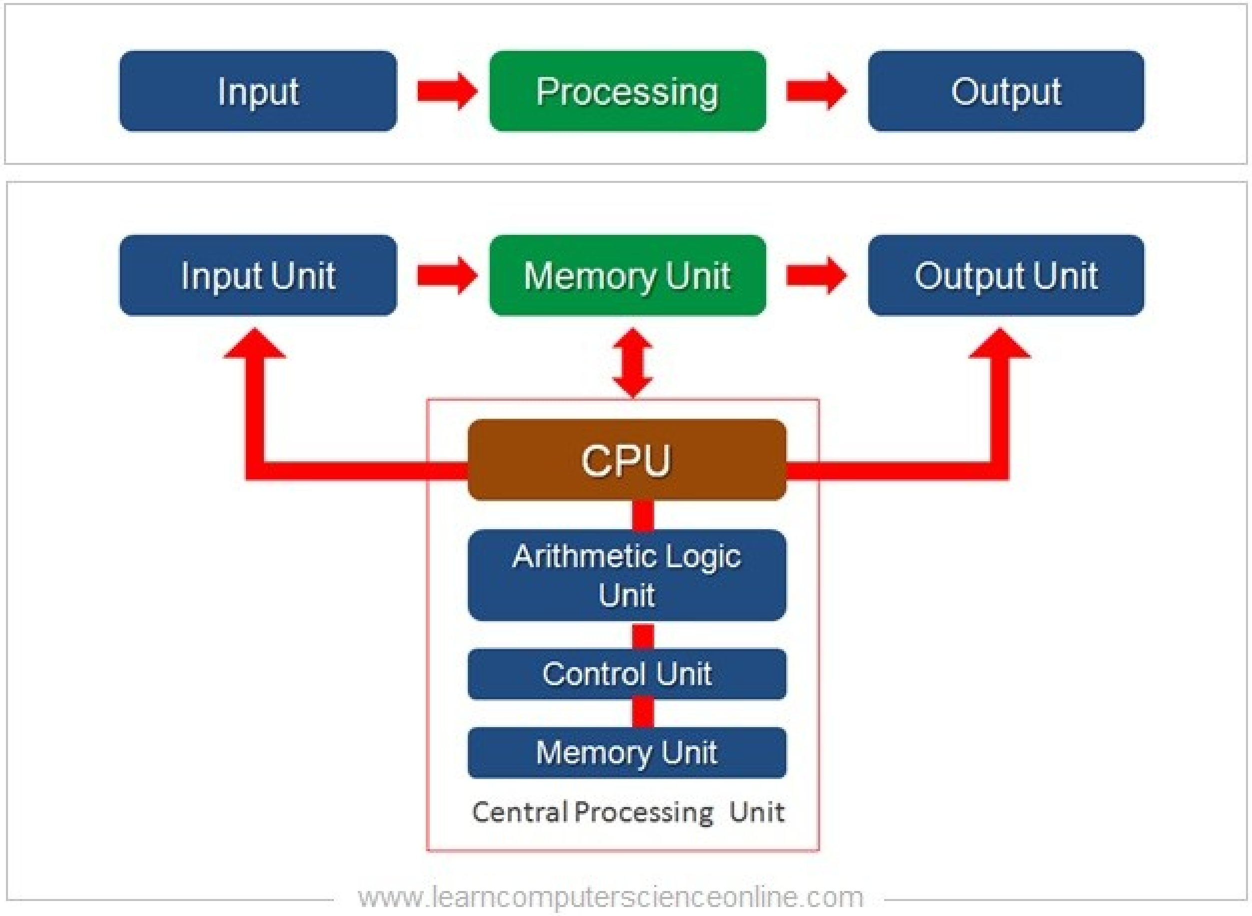
Lecture series contents

- 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

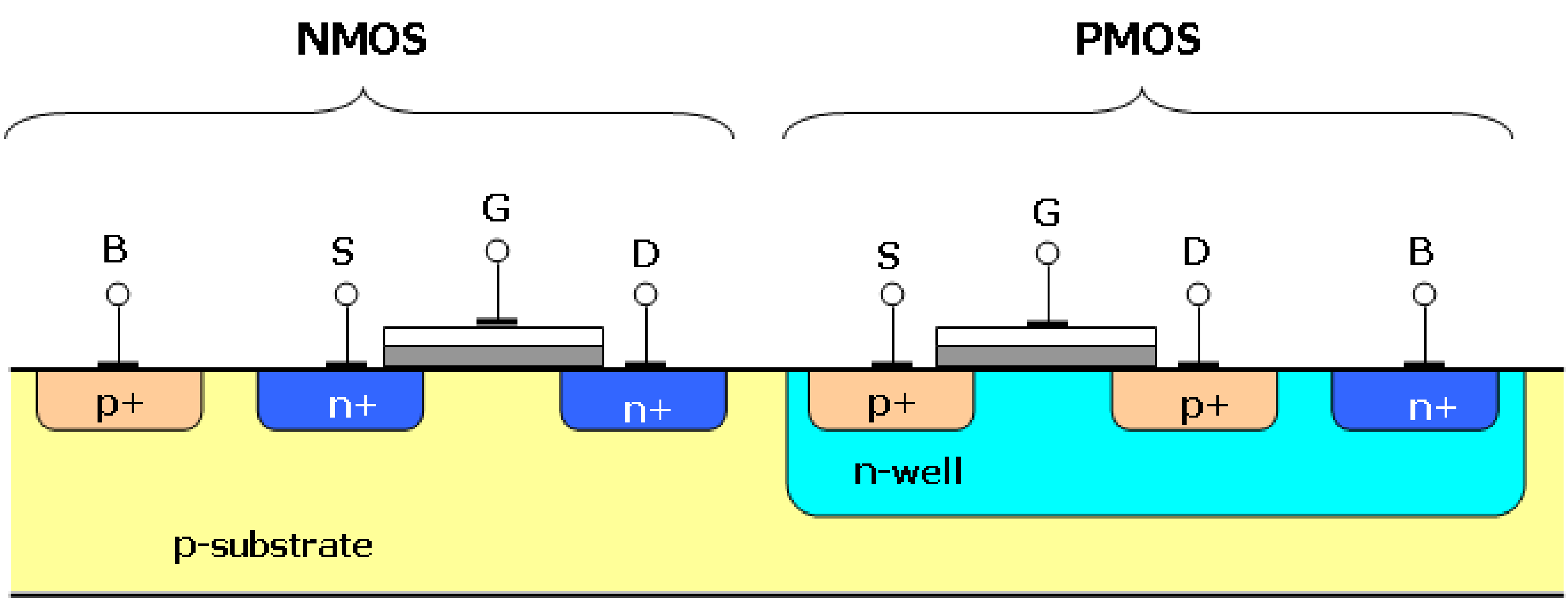
A replica of the first working transistor,
Lucent Technologies 1997

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

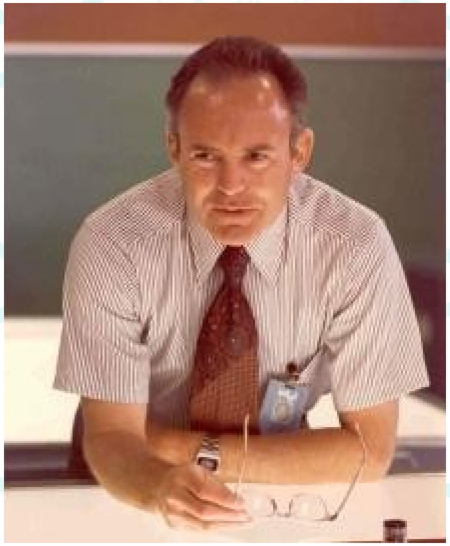
- (DRAM) Memory, a simple example
  - Switch allows/restricts current flow to a capacitor
  - A full capacitor is a ‘one’
  - Capacitors slowly discharge so must be refreshed (DRAM)
  - Read by comparing voltage differences between full and empty capacitors



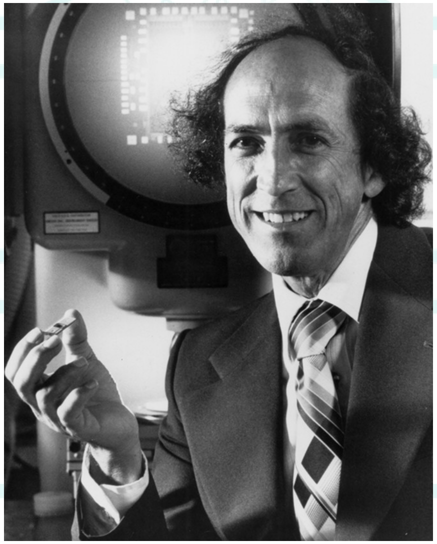
A CMOS switch.

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 dimenions can be scaled by ~30% then (a scaling argument):
  - Device area reduces by ½ as 0.7*0.7 = 0.49 (area=L*W)
  - Capacitance reduced by ~30% as C=ε(A/d)
  - Voltage is reduced by ~30% as -ΔV = Ed
  - Therefore other characterstics of energy and timing reduce
  - Frequency increases by around 40% as f=1/T
  - Power scaling P=CV^2f therefore ~ P=0.7*0.49*1.4=0.48
- Area and power halved implies (→) 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 whhhyyyyyyy!!!

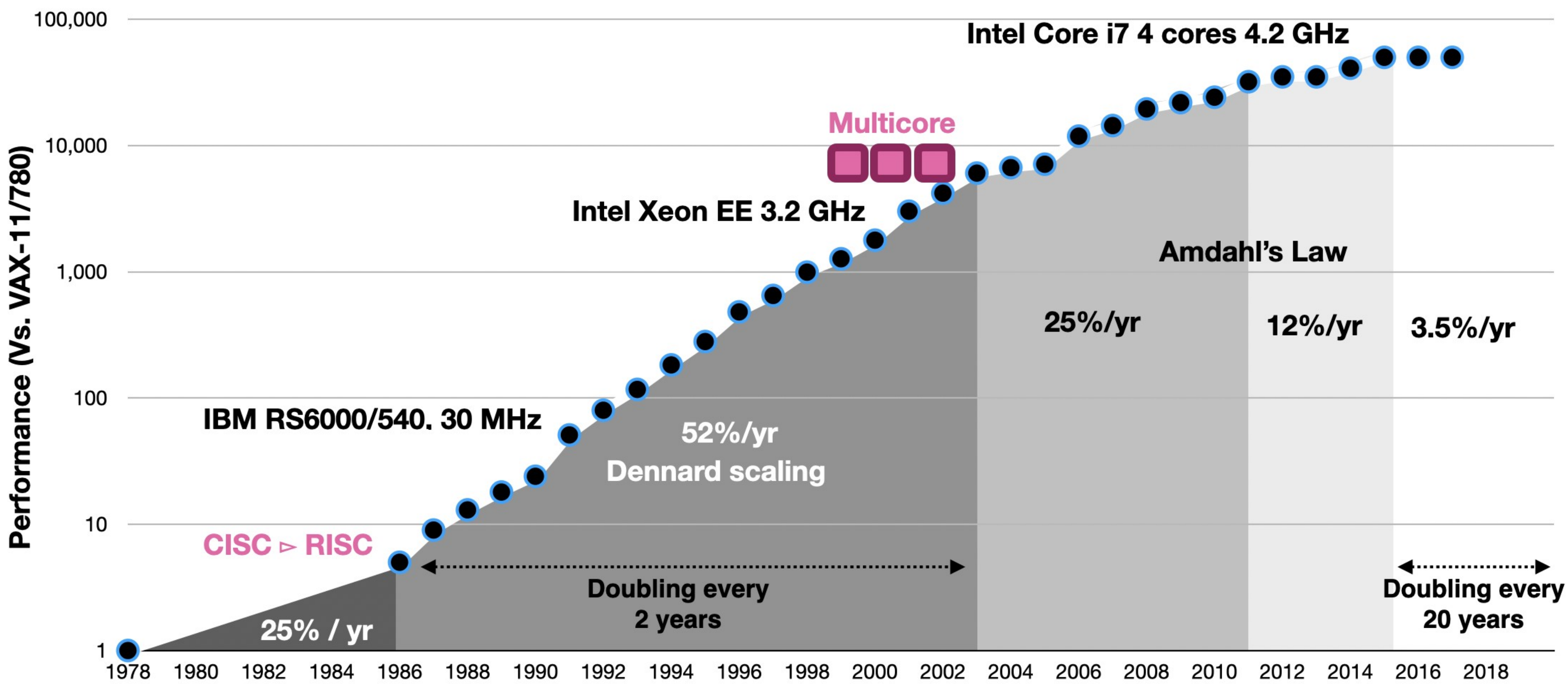
VAX 11/780

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.

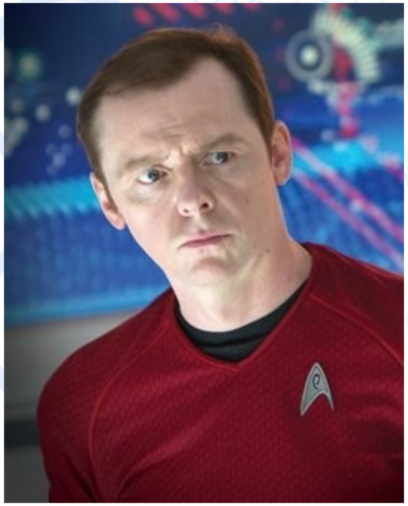
Performance, based on SPEC benchmarks and scaled to newer SPEC versions



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

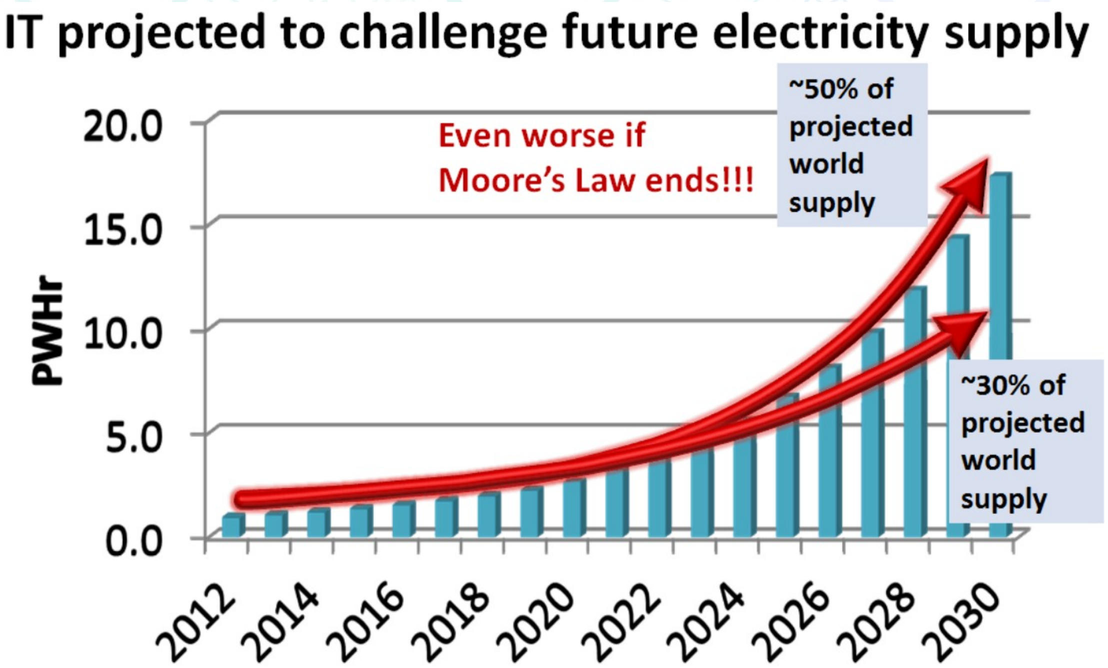
Integrated circuits, it's the LAWS!

- 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

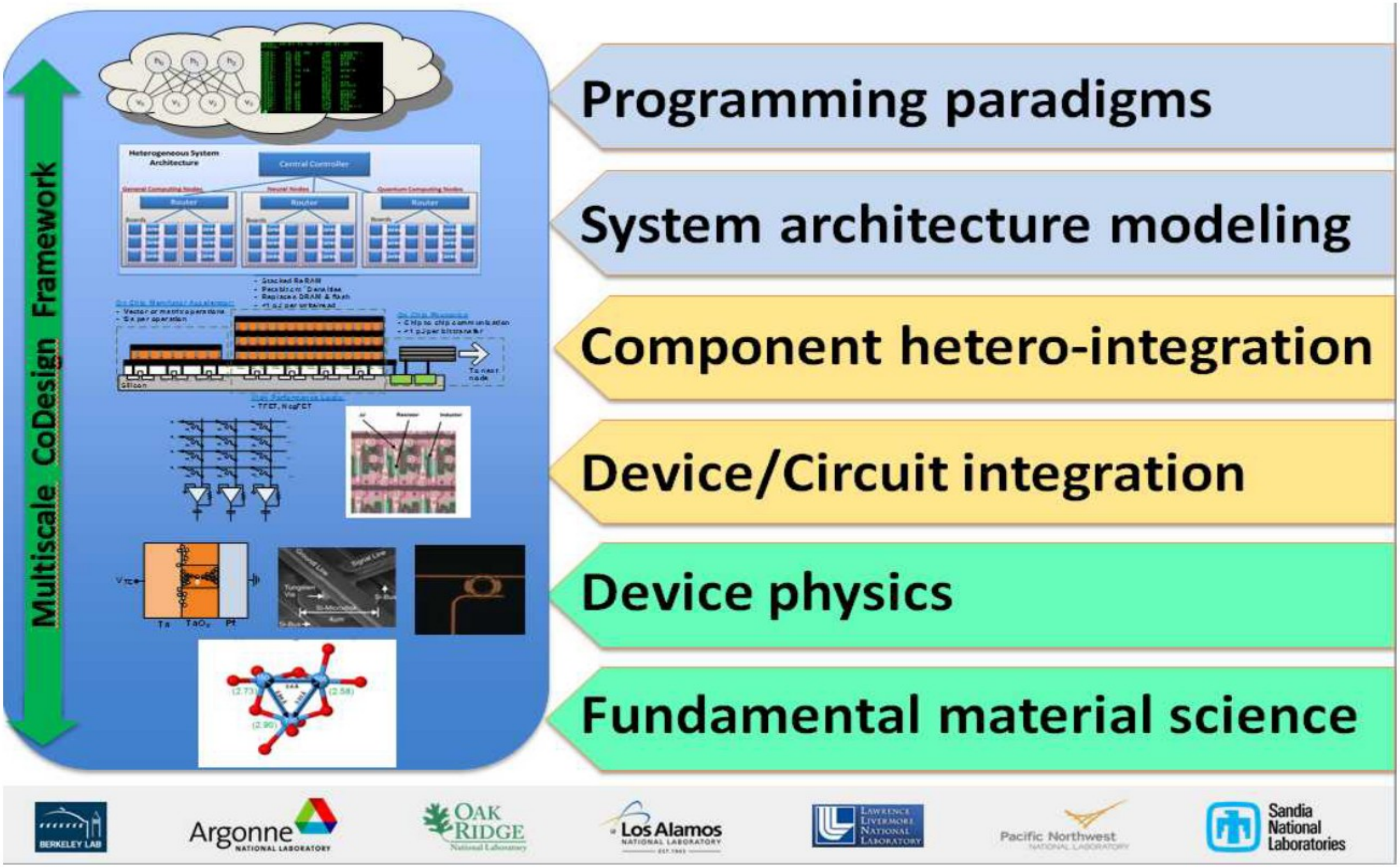


Scotty

Koomey



Integrated circuits, what shall we do?



DOE BIG IDEA SUMMIT III: BEYOND MOORE'S LAW 2016

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Thank you :)