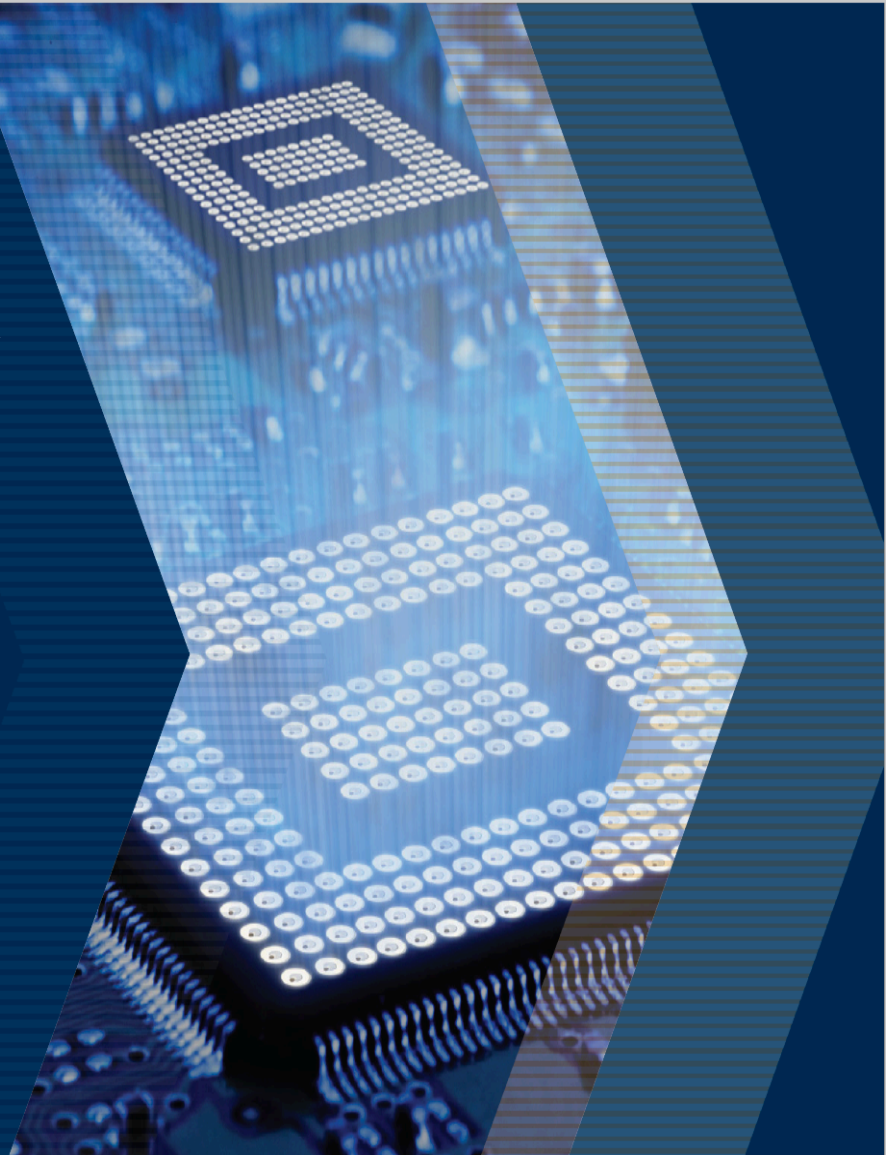
Into The Wild: Radically New Computing Methods for Science



Tom Conte
Co-Director, CRNCH
Georgia Tech

CREATING THE NEXT MOORE'S LAW

Georgia Tech | Center for Research into Novel Computing Hierarchies

For more information, visit our website at **www.crnch.gatech.edu** or send email to **crnch@gatech.edu**



Moore's law means:

Computers get twice as fast every two years



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Computers get twice as fast every two years

Well, that's not what Moore said……..

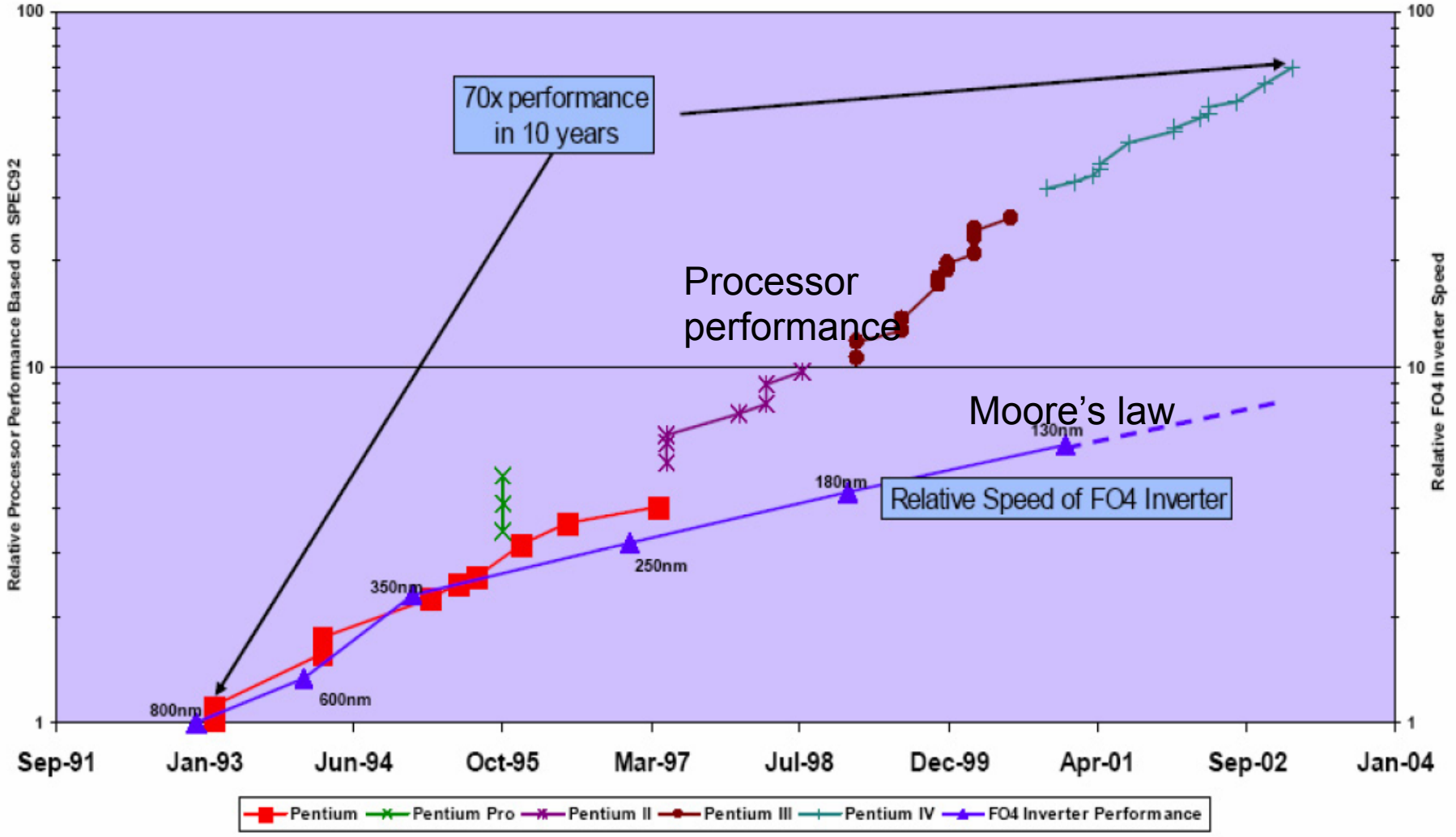


Moore's Law:

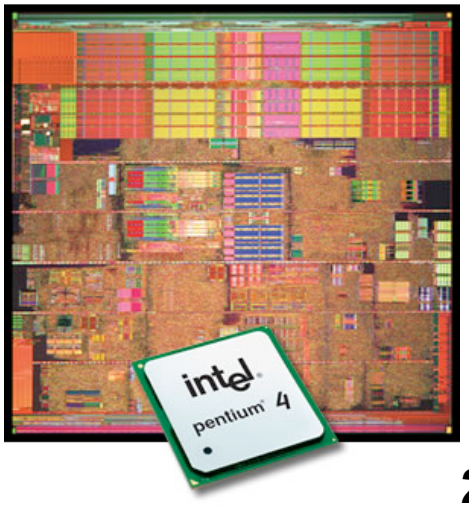
If **$1 gets you 1,000 transistors today**,
then wait
(1965: **one year**) or (1975: **two years**)
and
$1 will get you 2,000 transistors

Used to track 1 to 1 with computer speed, but then…

In 1995, wire delays grew: To cover it up, microprocessors got “More Complicated”

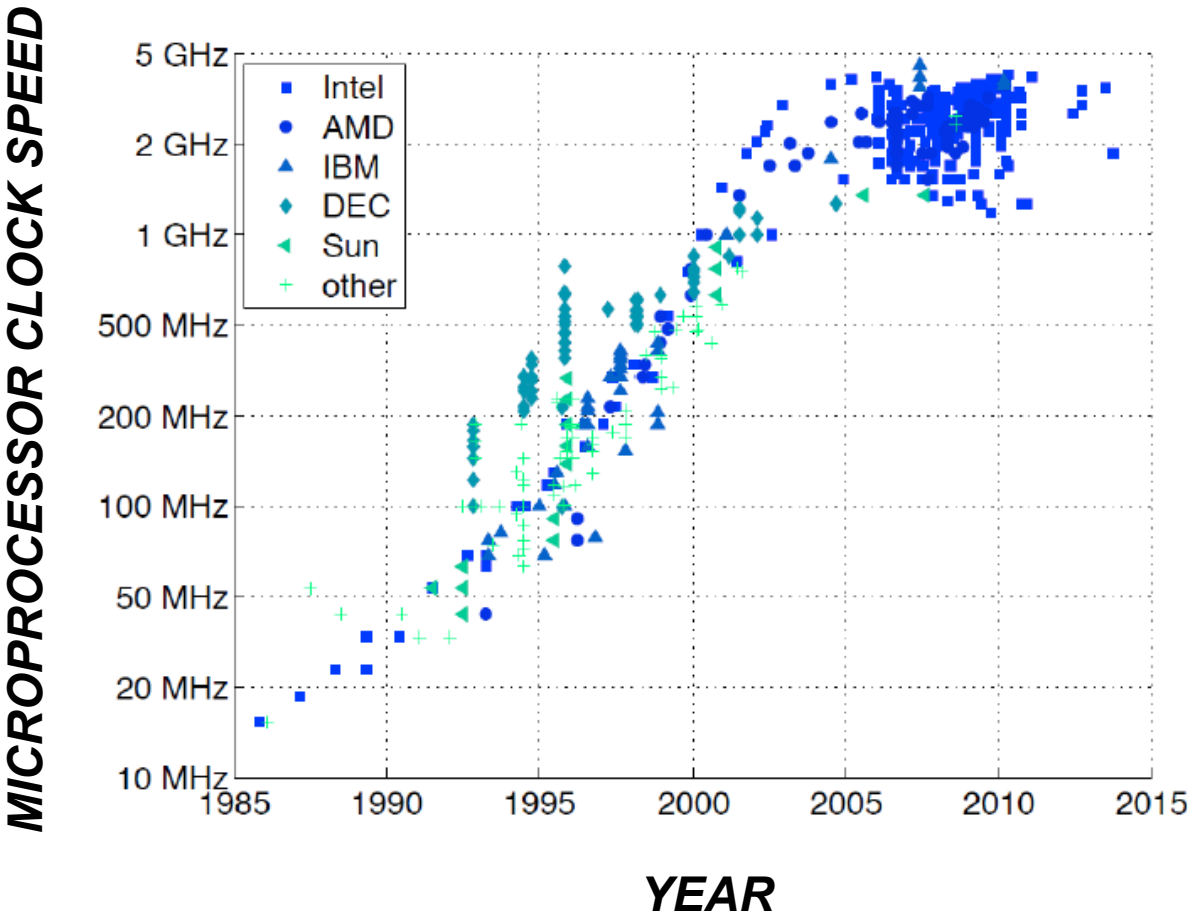


In 2005, we hit another wall: Intel P4 Prescott

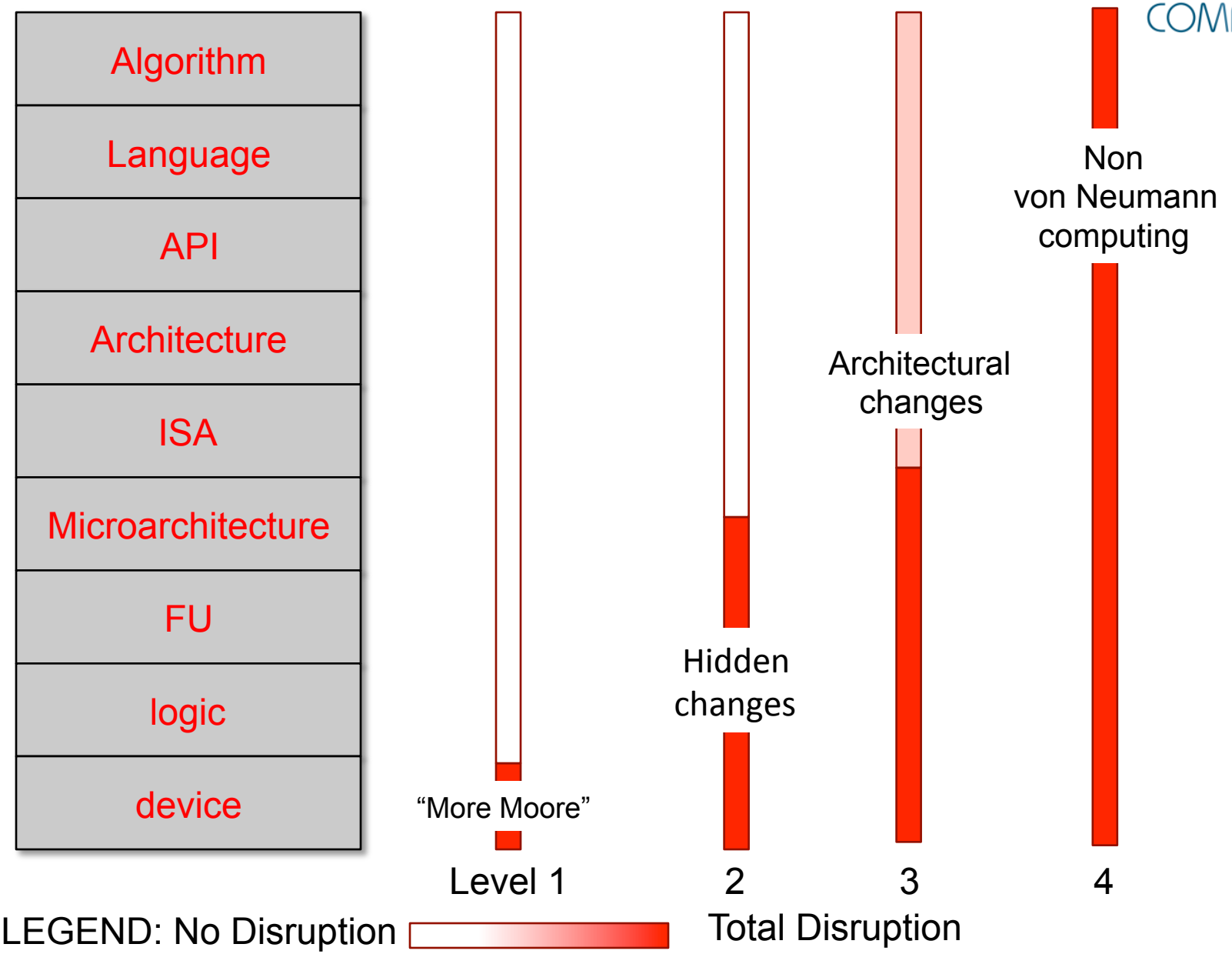


200W/cm^2

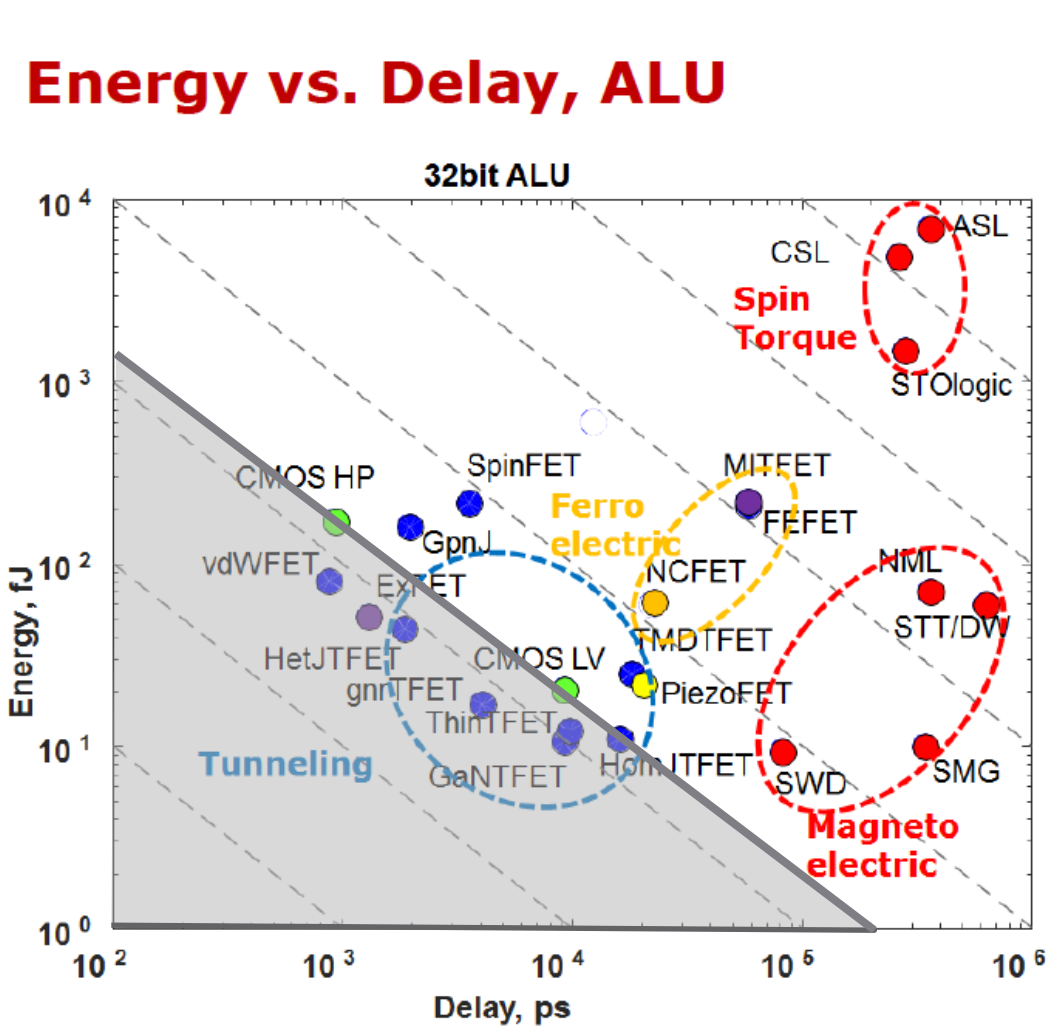
This is why clock speed stalled 2005



Potential Approaches vs. Disruption in Computing Stack



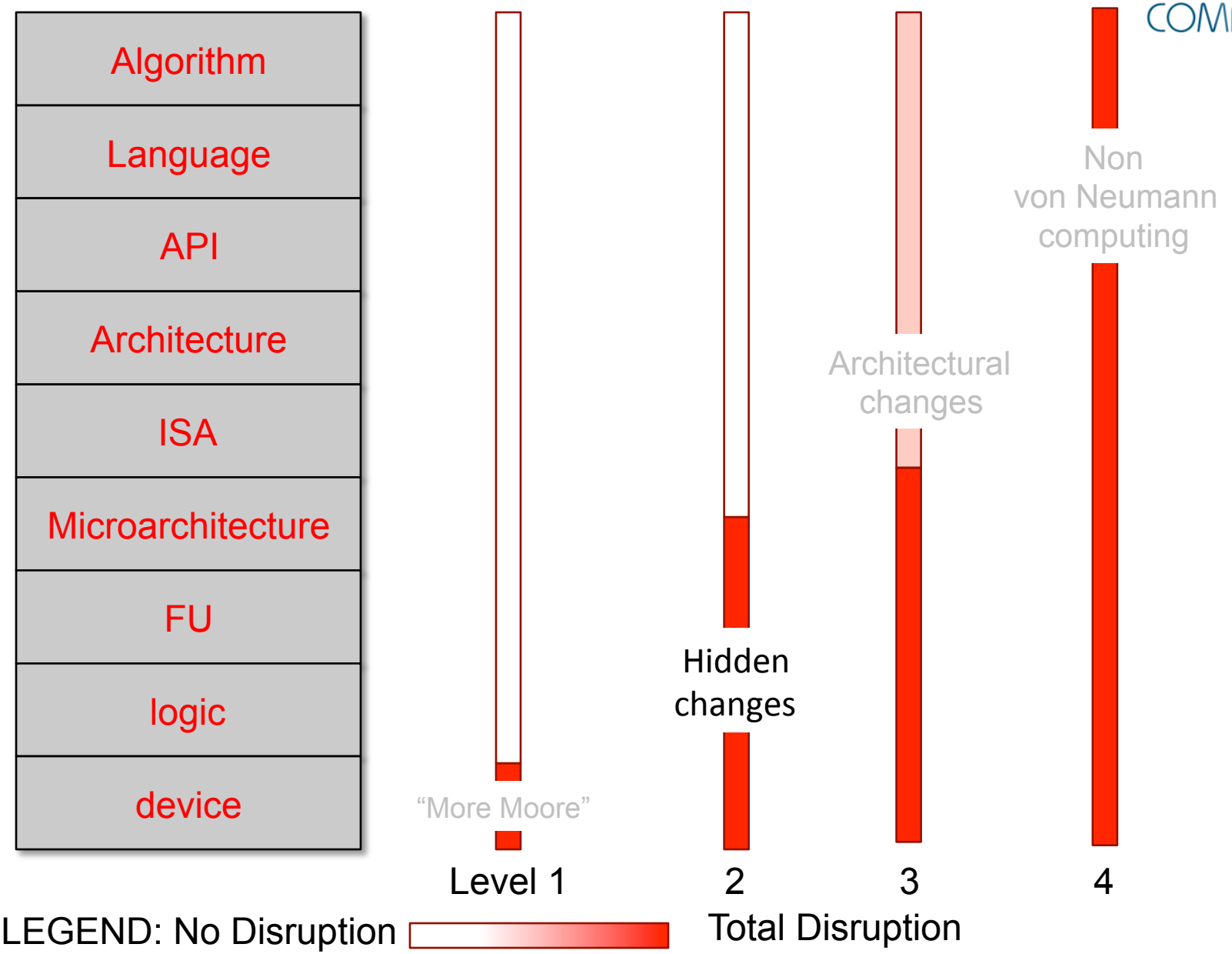
More Moore: A better transistor?



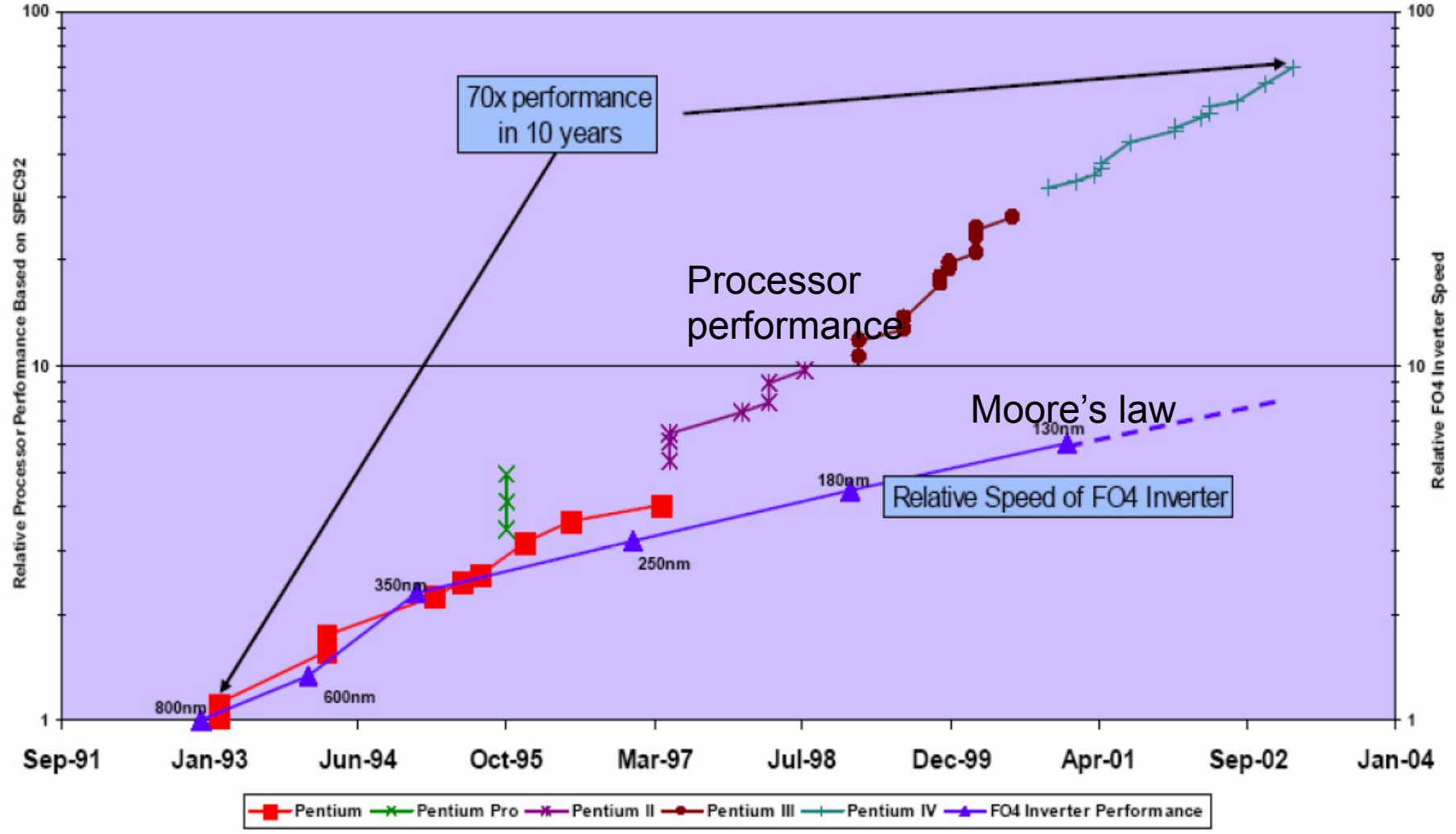
Courtesy Dimitri Nikonov and Ian Young

- CMOS ref
- Electronic
- Spintronic
- Ferroelectric
- Orbitronic
- Straintronic

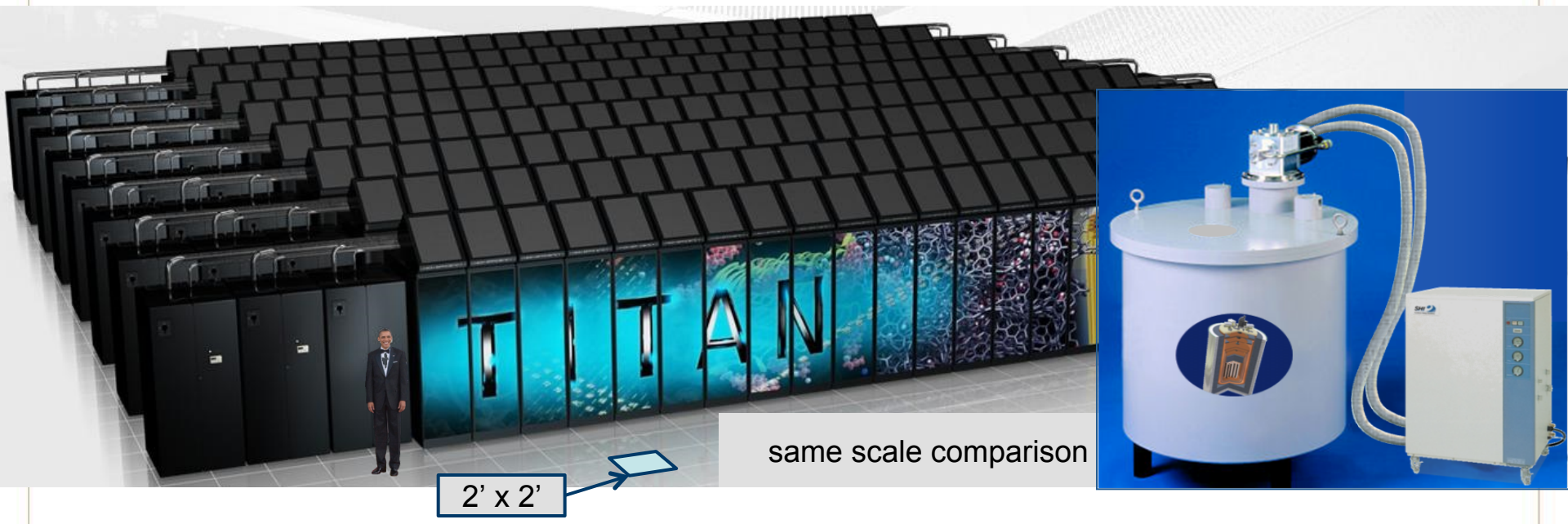
Potential Approaches vs. Disruption in Computing Stack



Level 2 example: in 1995, wire delays grew, so processors got “More Complicated”



Cryogenic computing: smaller, lower powe



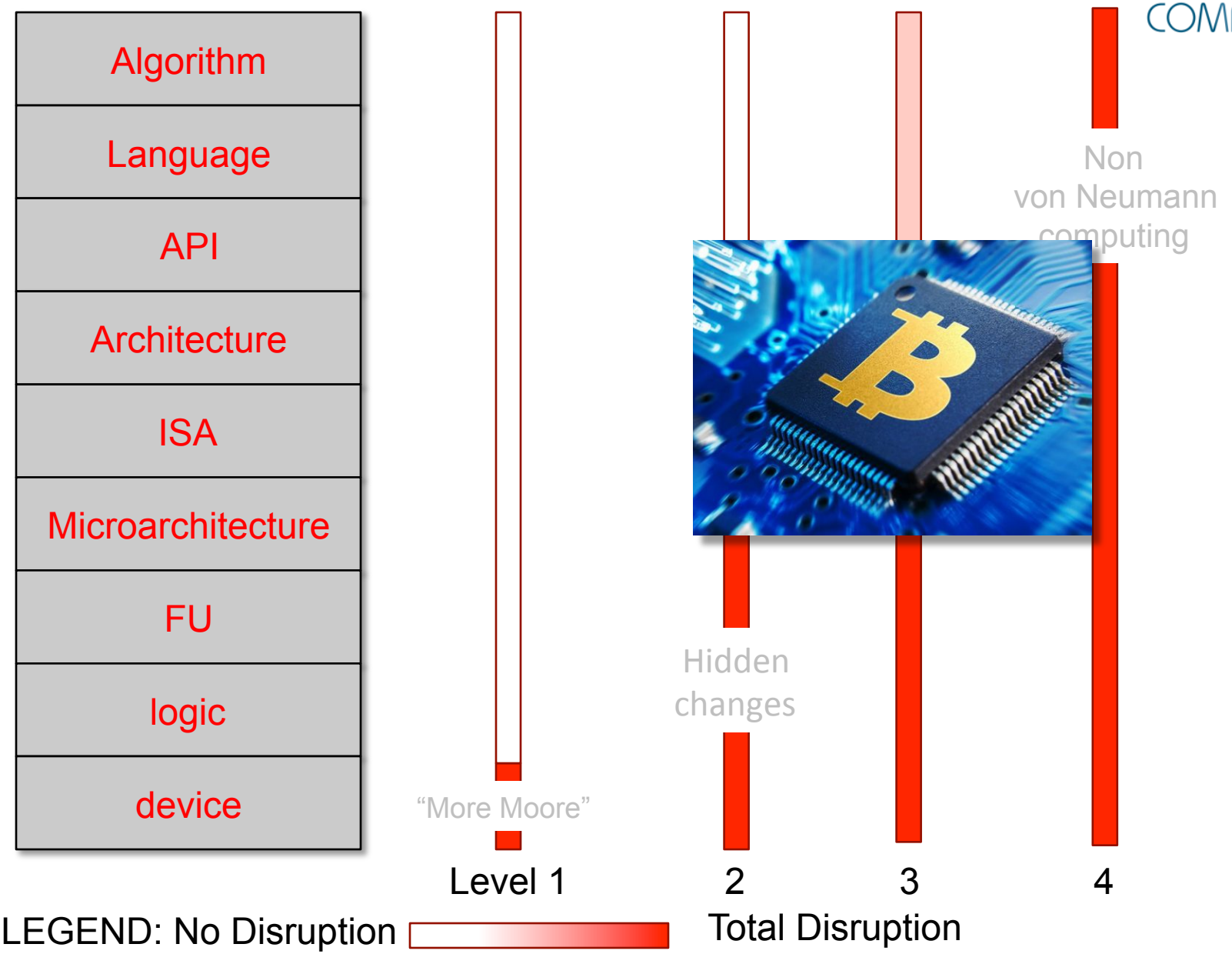
- **Superconduct at 4 degrees kelvin**
- **1/100th power (including cryocooling overhead!) vs. CMOS**
- **Potential to make data centers orders of magnitude lower power**

Courtesy of M. Manheimer

Georgia Tech comparch

Potential Approaches vs. Disruption in Computing Stack

IEEE rebooting COMPUTING





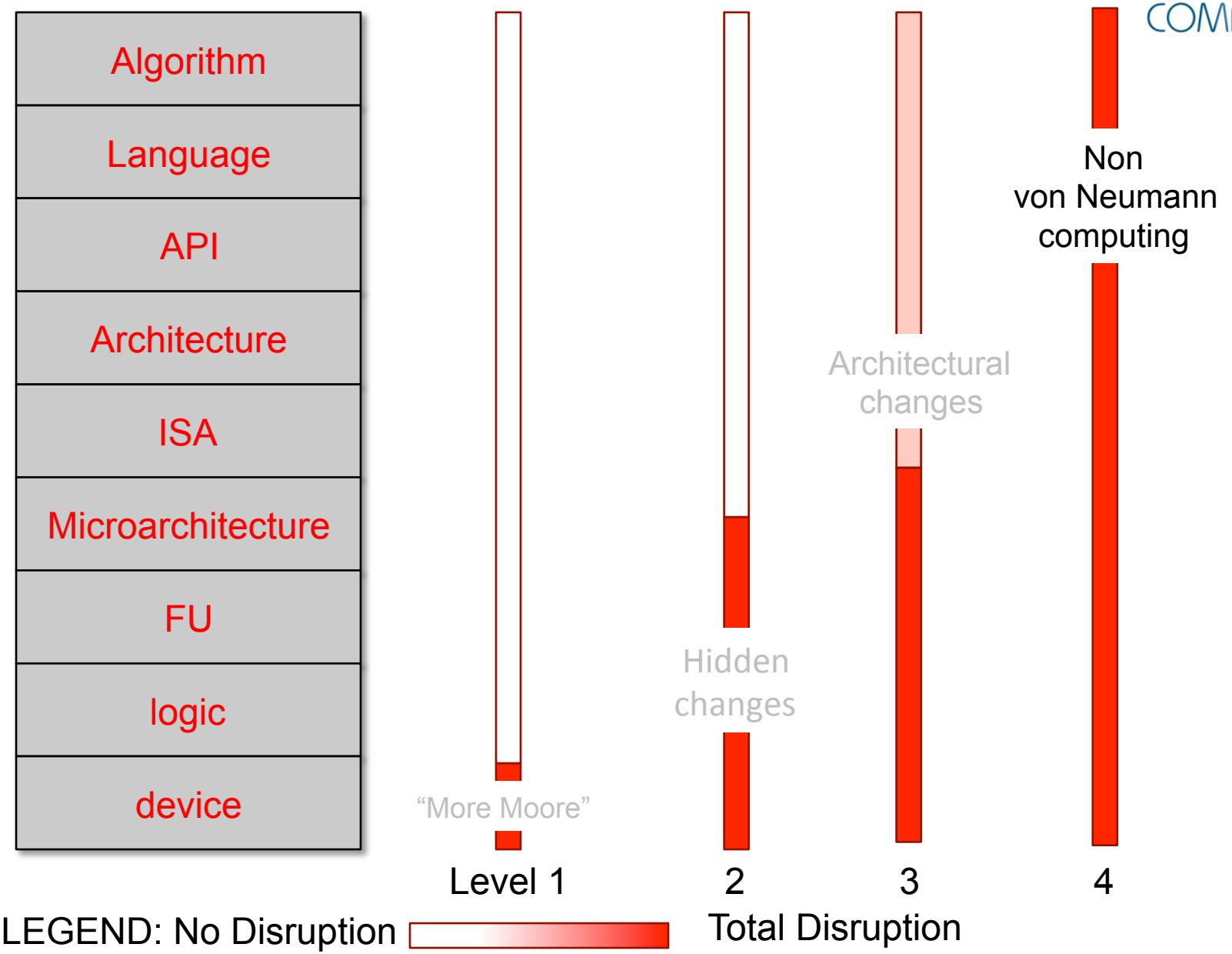
Digital Accelerators

Problems:

- Programmer must rewrite the program to use the accelerators!
- Long term solution?
  - Still uses *the same transistor technologies* that all other computers use
  - After you accelerate everything interesting, then what?

…you're back to the limits of today's transistors

Potential Approaches vs. Disruption in Computing Stack



Conventional computing is “von Neumann”

First Draft of a Report on the EDVAC

by

John von Neumann

June 30, 1945

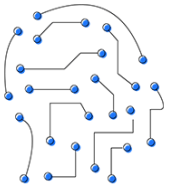
Moore School of Electrical Engineering
University of Pennsylvania

June 30, 1945

Non-Von #1: Quantum Computers

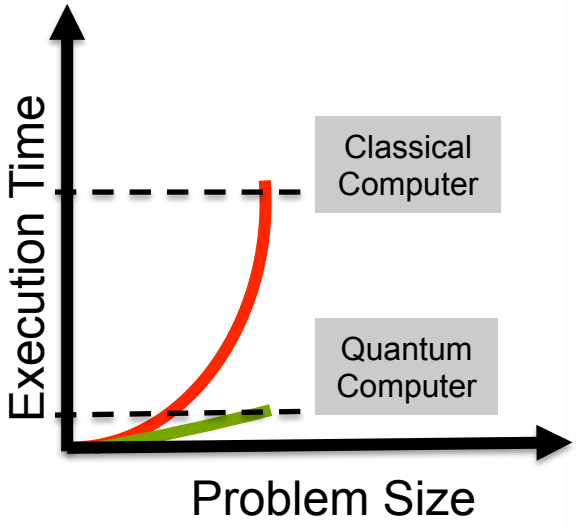
Logistics

Machine Learning



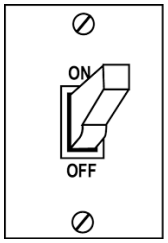
Energy

Drug Discovery



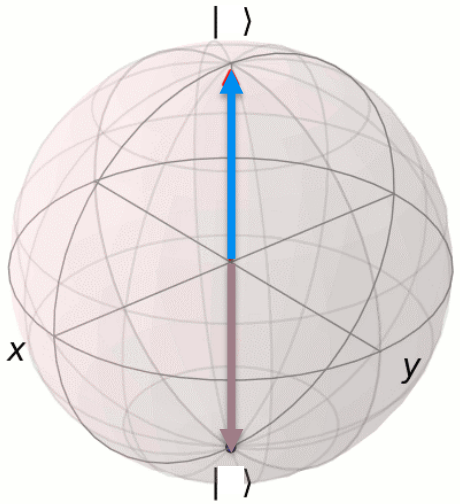
Slide Courtesy Prof. Moin Qureshi, Georgia Tech

Computing using Quantum Bits (Qubits)



Classical Bit

State of a *Classical Bit*
→ 1 or 0 two points on sphere



Quantum Bit

State of a *Quantum Bit*
→ Any point on the sphere
(Vector in Complex Hilbert Space)

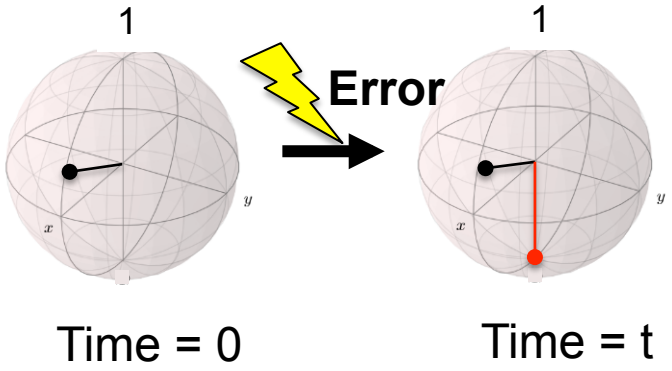
Secret sauce: Quantum Entanglement
("Spooky action at a distance")

Slide Courtesy Prof. Moin Qureshi, Georgia Tech

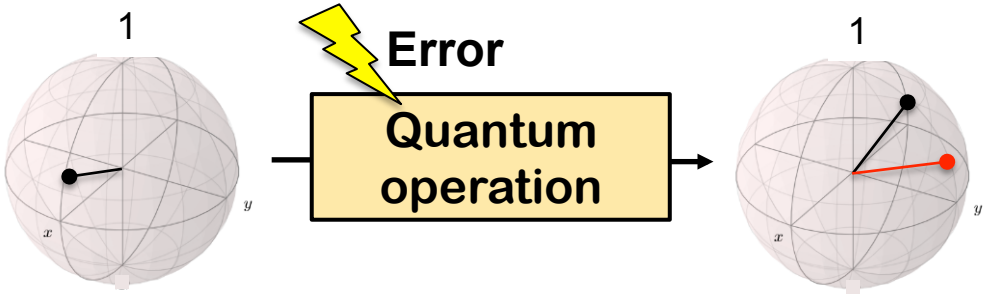
Qubits are *Fragile* and *Vulnerable to Errors*

- Qubits can "collapse" if they are "observed"

  Hey Schrödinger, the cat's alive!

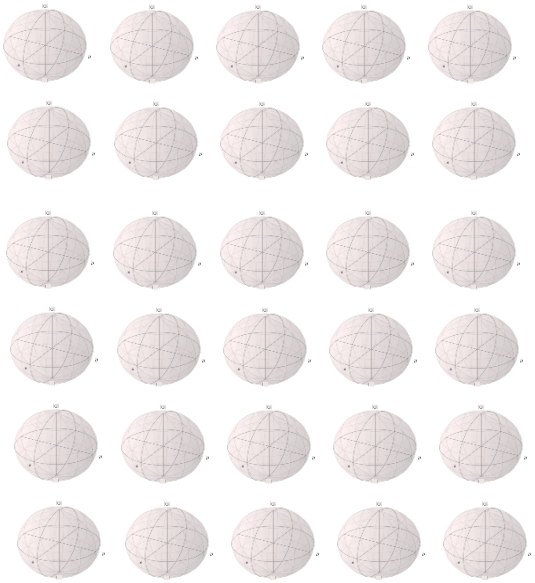


- Quantum operations can produce erroneous output

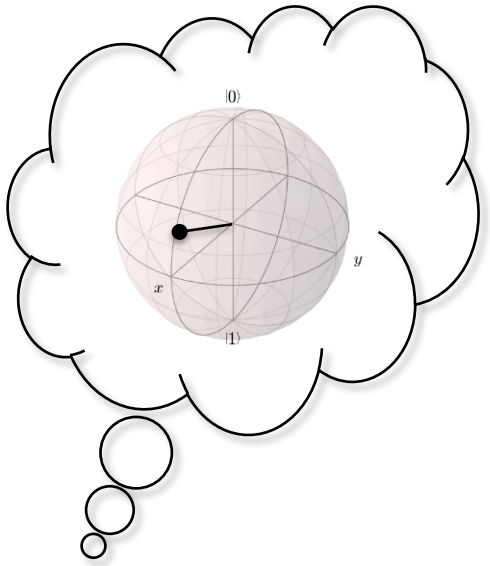


Dealing with Qubit Errors is the #1 problem in Quantum Computing

Quantum Error Correction is Expensive



Plus Quantum Error Correction Code

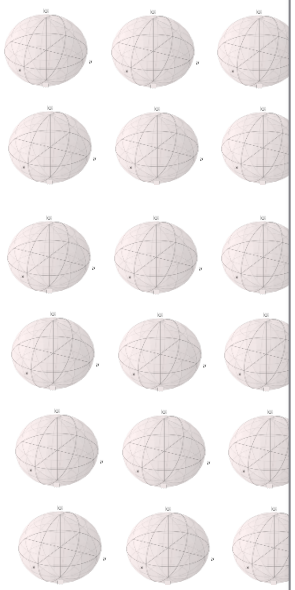


It takes a collection of noisy qubits … to make one "Logical" Qubiut

How many? Need 100s of noisy qubits to make one logical qubit

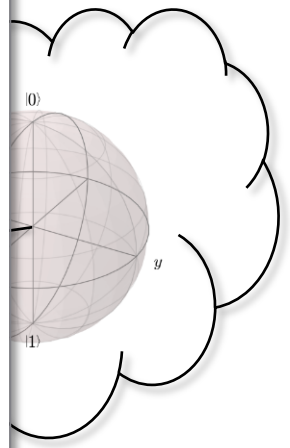
Slide Courtesy Prof. Moin Qureshi, Georgia Tech

Quantum Error Correction is Expensive



Quantum Machine	Number of Qubits Now
Google	53/72*
IBM	53
Intel	49
Rigetti	32
IonQ	11

* Fabricated but no data reported yet

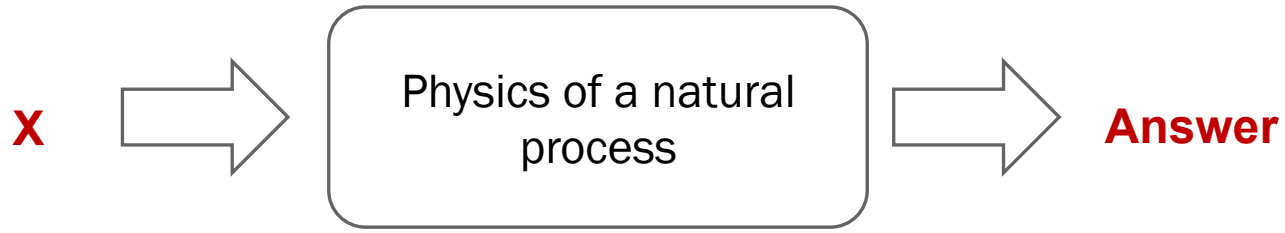


It takes a collec ogical" Qubiut

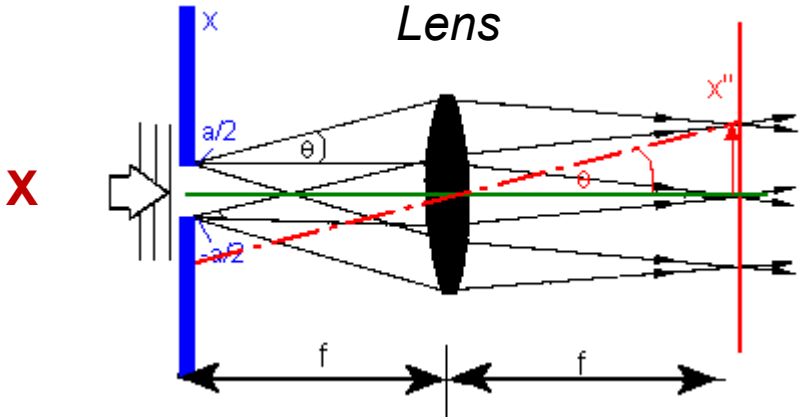
How many? Need 100s of noisy qubits to make one logical qubit

Slide Courtesy Prof. Moin Qureshi, Georgia Tech

Non-Von #2: Analog(ous) computing



Example #1: Find the Fourier transform of a signal X



X

Fourier Transform of X

Example #2:
Nature Optimizes Better than Von Neumann

Problem: *Assemble 1 100,000 salt molecules into their lowest energy configuration*

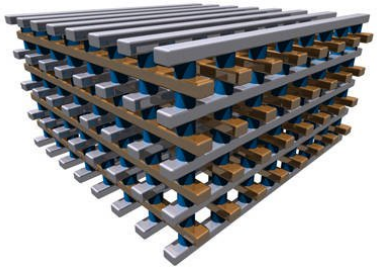
Von Neumann:
Try all combinations

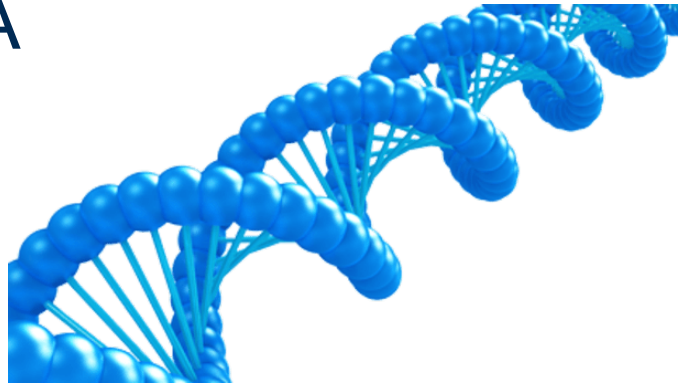
Will take longer than the remaining life of the universe to solve

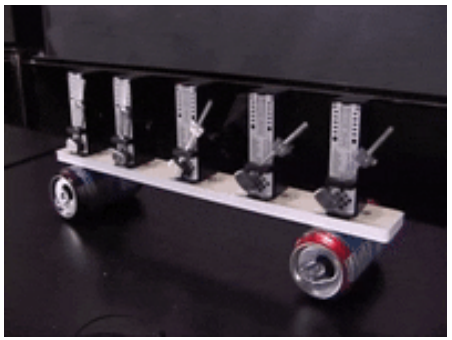
Nature: annealing

Some “interesting” physical processes

- Resistive crossbar networks
- Open system thermodynamics
- The Brian
- RNA/DNA







- Coupled oscillators
- **And <u>undiscovered</u> others**



INTO THE WILD: SUMMARY

- Moore's law will not save us anymore
- $oftware will need to be rewritten
- Digital accelerators are a stop-gap
- Non von Neumann: Huge potential
  - Quantum is … hard, but lots of potential to use today's "noisy quantum" computers
  - Analog(ous) computation shows promise… but we're in its infancy

Generalists needed!

For more…

IEEE rebooting COMPUTING

rebootingcomputing.ieee.org

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