18-447 Lecture 1:
Intro to Computer Architecture

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Housekeeping

- Your goal today
  - know what you are getting into
  - decide if you are coming back . . .
- Notices
  - complete student survey on Canvas, due 1/23
  - H01/H01a: syllabus & academic integrity statements
  - no lab meeting this week
- Readings
  - P&H Ch1
  - P&H Ch2.1~2.10 (next time)

What is 18-447?

- 18-213: Introduction to Computer Systems
  - "C" as a model of computation
  - interact with the computer hardware through OS
  - what about the details below the abstraction?

Somehow a program ends up executing as digital logic

- 18-240: Fundamentals of Computer Engineering
  - digital logic as a model of computation
  - gates and wires as building blocks
  - what about the details below this abstraction?

18-447: Fuzzy to Concrete

18-213

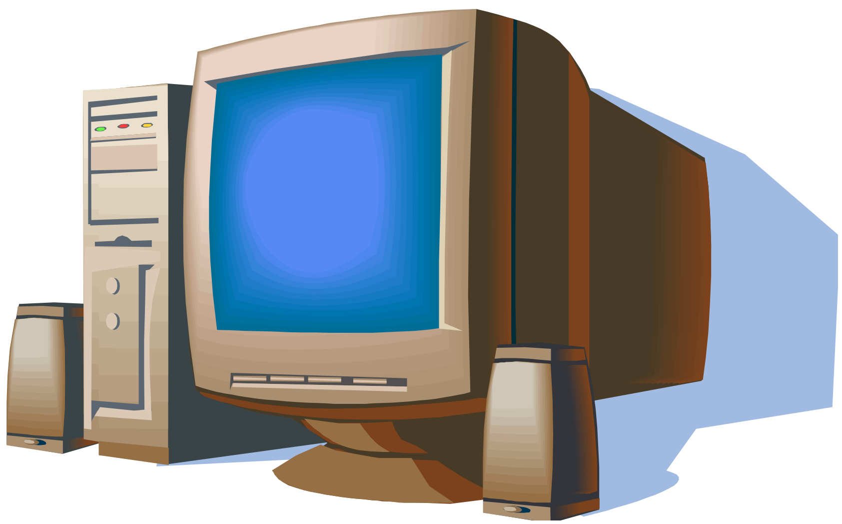
- "Computer Architecture"
  - functionality spec for software and programmers
  - design spec for the hardware people
- Computer Organization
  - take architecture to "micro"architecture
  - how to assemble/evaluate/tune
- Computation Structures
  - digital representations
  - processing, storage and I/O elements

18-240

What is a Computer?

- **Computer, 2. a.** A calculating-machine; esp. an automatic electronic device for performing mathematical or logical operations; freq. with defining word prefixed, as *analogue*, *digital*, *electronic computer*.

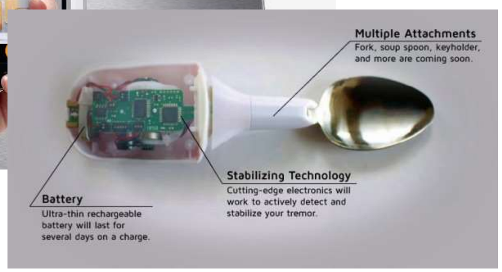
--- Oxford English Dictionary, circa 2000

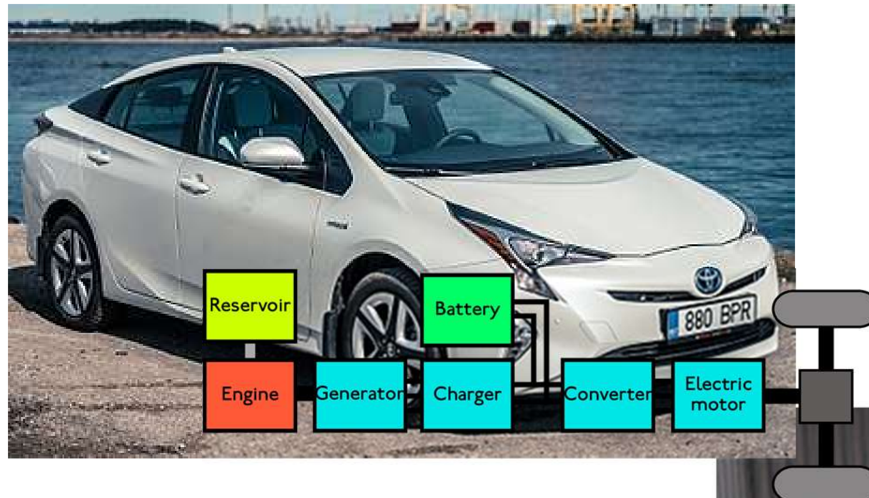


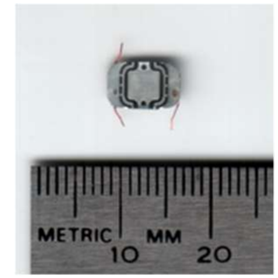
More Familiar Computers

[images from Wikipedia]

Where is the computer?







[images from Wikipedia]

Modern computing is as much about enhancing capabilities as data processing!!

Less Glamorous Computers

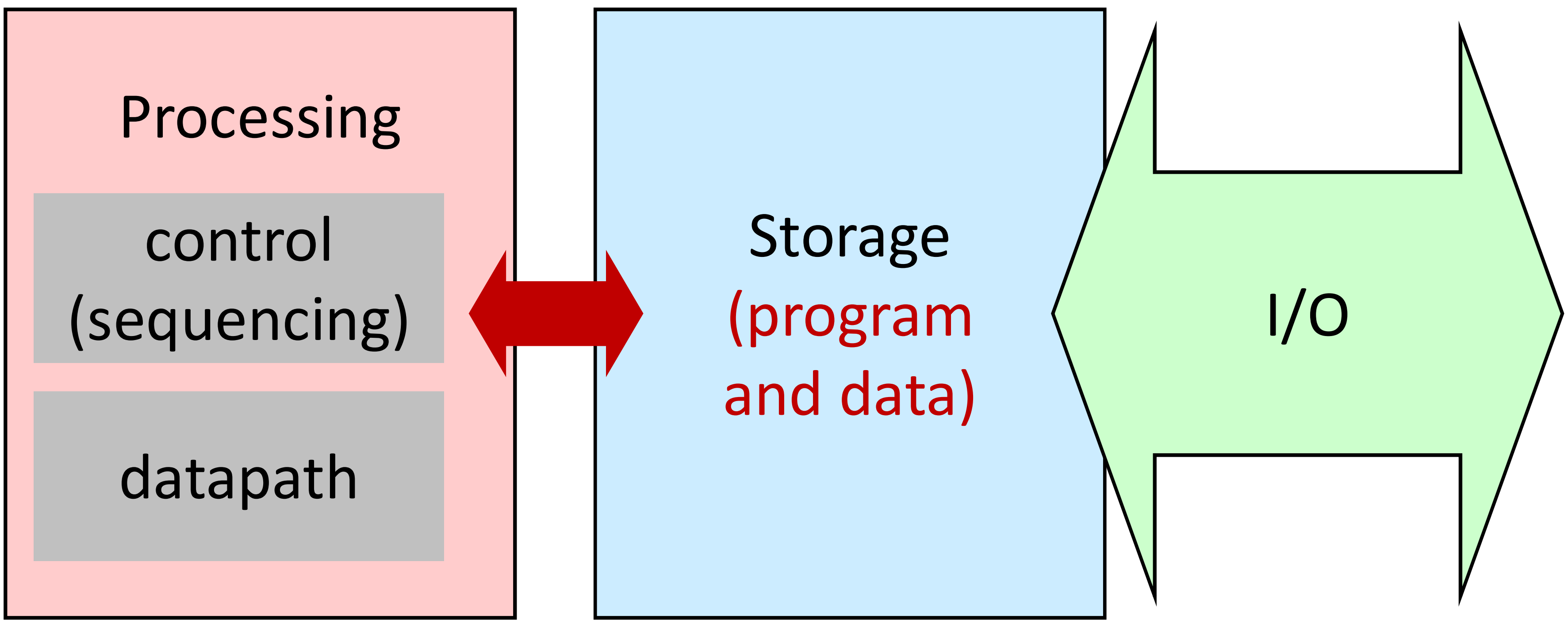
[images from Wikipedia]

Keeping up with the times

- Computer, 3. An electronic device (or system of devices) which is used to store, manipulate, and communicate information, perform complex calculations, or control or regulate other devices or machines, and is capable of receiving information . . . and of processing it in accordance with variable procedural instructions . . . used esp. for handling text, images, music, and video, accessing and **using the Internet, communicating with other people (e.g. by means of email), and playing games**.

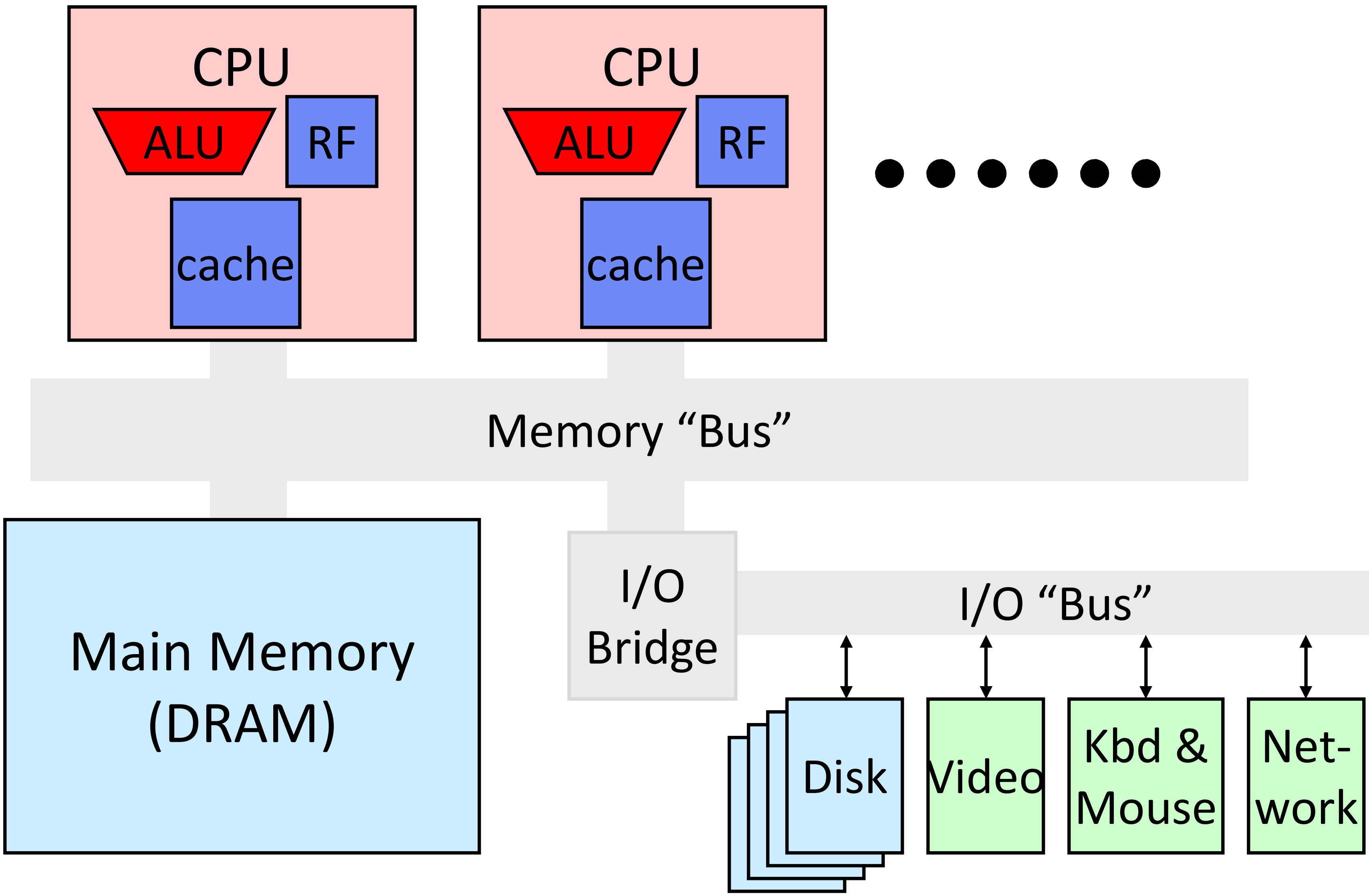
--- Oxford English Dictionary, circa 2018

So what makes a computer a computer?



Having program stored as data is an <u>extremely</u> important step in the evolution of computer architectures

"Canonical" Computer Organization



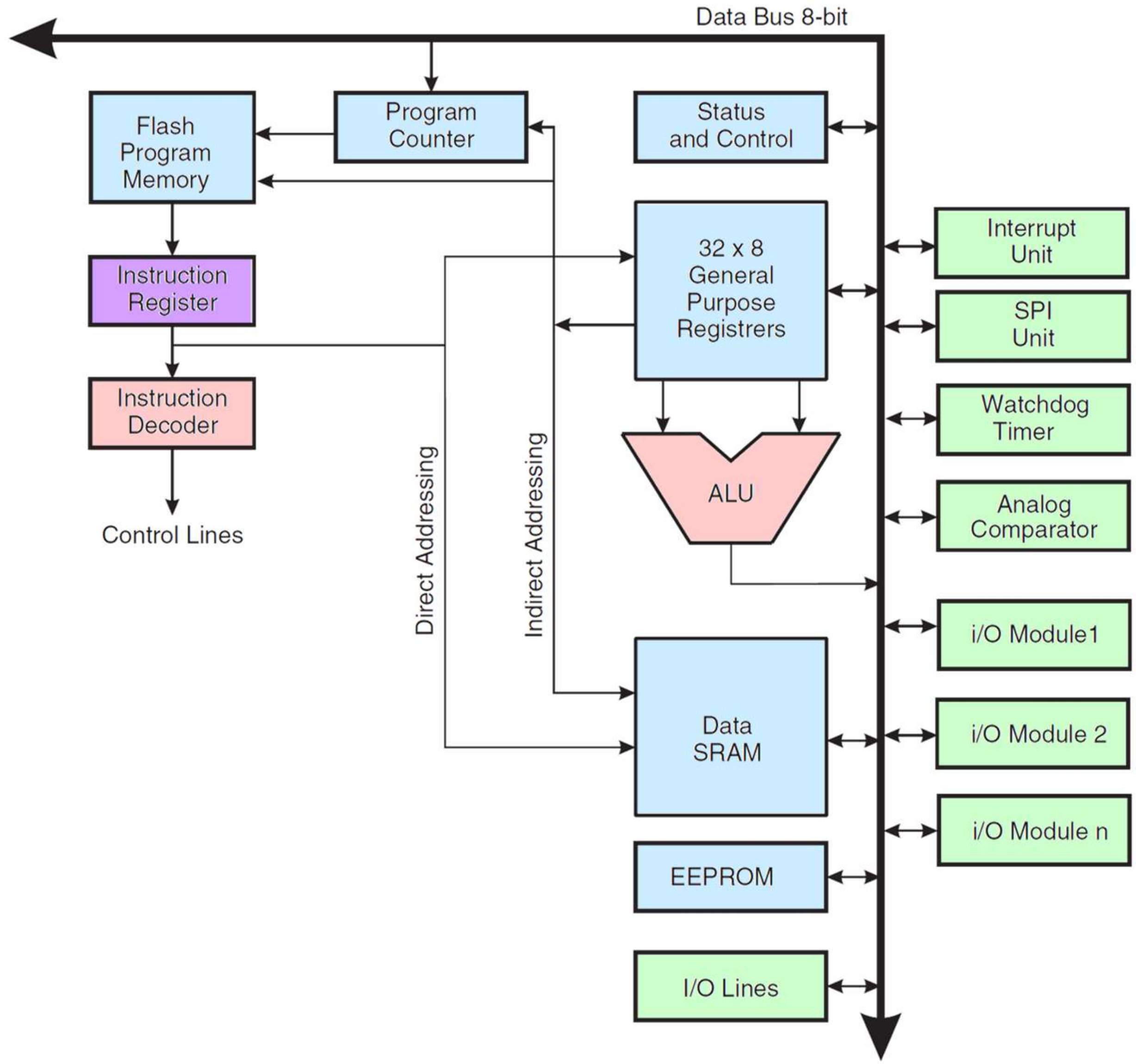
Atmel ATmega8

state

I/O

logic

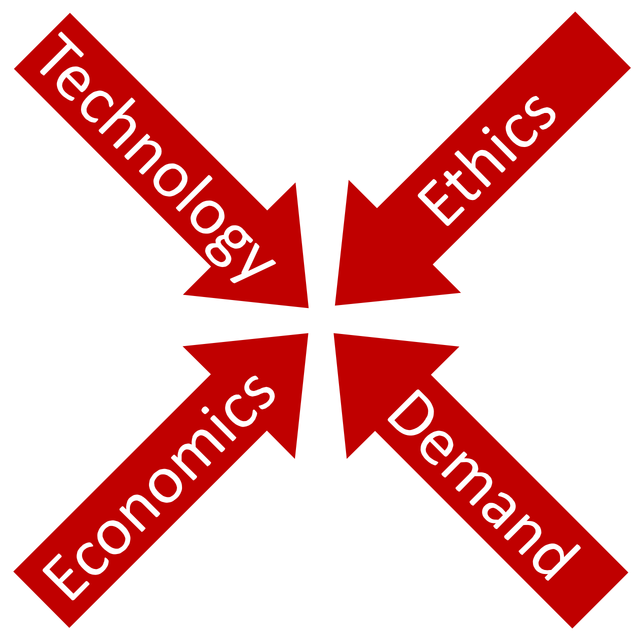
[image from Wikipedia]



Page 9 Atmel 8-bit AVR ATmega8 Databook

Computer Architecture is Engineering

- An applied discipline of finding and optimizing solutions under the joint constraints of demand, technology, economics, and ethics
- Thus, instances of what we practice evolve continuously
- Need to learn the principles that govern how to develop solutions to meet constraints
- **Don't memorize instances; understand why it is that way**



Course Logistics

- Please visit Canvas regularly for updates and announcements
- H01/H01a: Syllabus
  - this is our contract for the term
  - please read it (at least once)
- Lecture schedule online
  - http://www.ece.cmu.edu/~ece447/schedule.html
  - reading assignments are to be completed before lecture
  - pay attention to midterm dates; the time to resolve conflicts is right now

Special Notices about Labs

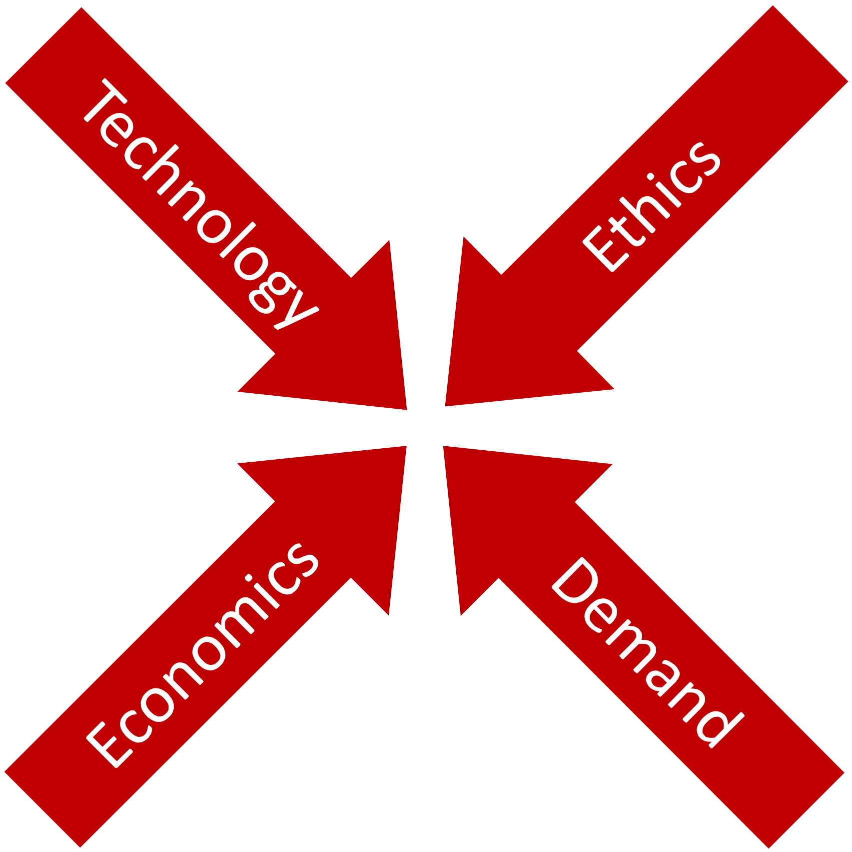
- Lab 1 starts on Wed
  - RISC-V simulator (C code)
  - single-cycle RISC-V (RTL Verilog)
- To get ready
  - get a GitHub account
  - find lab partners
- Please observe
  - lab assignments MUST be done in groups of 2 or 3
  - entire group MUST be present during check-off
  - 10% per day penalty for late labs, capped at 50%
  - **all labs MUST be checked off to pass the course**

Historical Perspectives:
prelude to modern computer architecture

Always read the "Historical Perspectives" at the end of P&H chapters. They are fun.

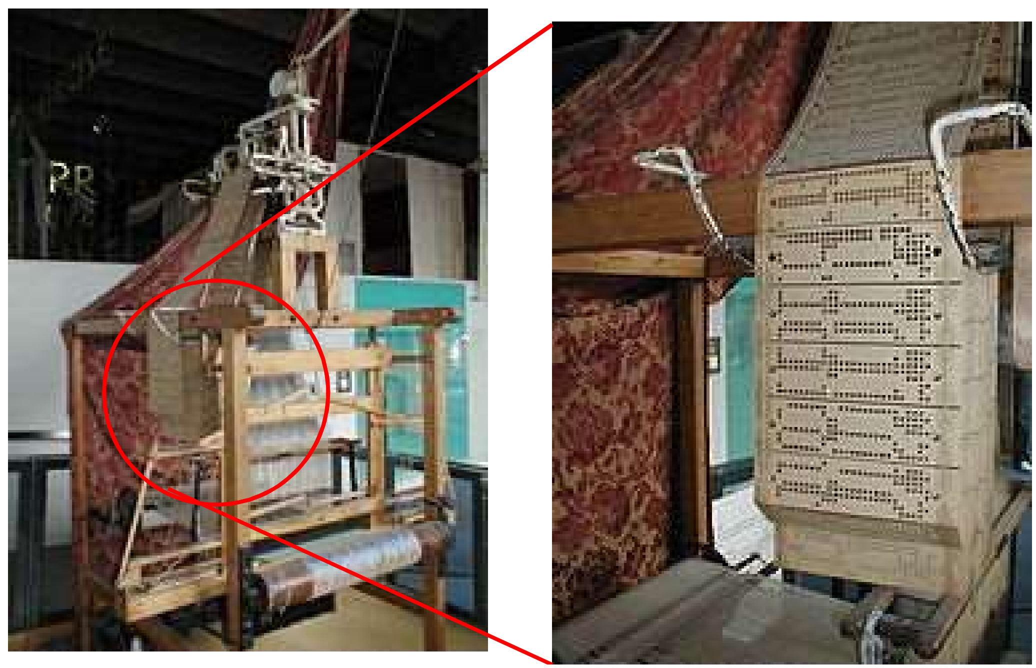
Forces on Innovation

- Timely innovations are rarely unique or original
- Similar constraints lead to similar engineering solutions



Beginnings of Digital Computing

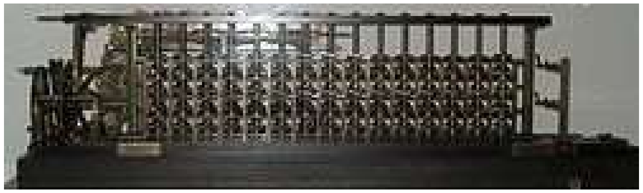
- Industrial Revolution era’s “hi-tech” in mechanization
  - steam engines
  - mechanical calculators,
  - Jacquard’s loom: gears, pulleys, chains and punch cards



[images from Wikipedia]

Charles Babbage (1791-1871)

- Difference Engine, 1823: a special-purpose computer
  - evaluated polynomial functions by Newton's method of successive differences (requiring only additions)
  - eventually built by Georg and Edvard Schuetz in 1855



- Analytical Engine, 1833: a general-purpose computer
  - programmed by punch cards, "assembly language" included loops and branches
  - 1000 word data store, punch card I/O
  - unfortunately never completed (would have been 10x30 meters, steam-engine powered)

[images from Wikipedia]

100 Years of Technology Advances

- Mechanical, 1800s
  - gears, chains, pulleys, and steam power
  - punch cards!!
- Electromechanical, early 1900s
  - switches, relays, “acoustic” delay line “memory”
  - e.g. Harvard/IBM Mark 1, Aiken 1939~1944, 50ft long, 5ton, 750K parts, 3~6 sec per addition

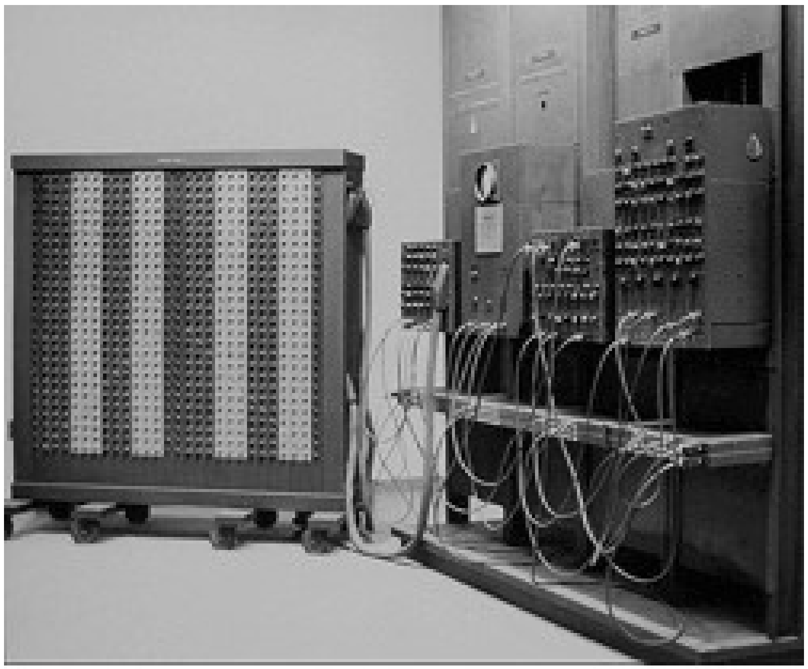
Used ideas from Analytical Engine

- Electrical, mid 1900s and on
  - plugboards, vacuum tubes, CRTs
  - and later DRUM, core, transistors and so on . . . . .

Changing demands and economics?

ENIAC, 1946

Eckert and Mauchly, U of Penn



from The ENIAC Museum,
http://www.seas.upenn.edu/about-seas/eniac/

- the first programmable electronic digital computer
- 18,000 vacuum tubes
- 30 ton, 80 by 8.5 feet
- 1900 additions per second
- 20 10-decimal-digit words (100-word core by 1952)
- Programmed by 3000 switches in the function table and plug-cables (became stored program in 1948 following von Neumann's advise)

Proliferation in 40s and 50s

- From "Moore School Lectures"
  - ENIAC, Eckert & Mauchly, 1946
  - EDVAC, von Neumann, 1944~1952
  - EDSAC, Wilkes, 1949 (first stored-program built)
  - IAS, Bigelow, 1952
  - ORDVAC, SEAC, MANIAC, JOHNIAC, ILLIAC ...
- They were not alone:
  - ABC, Atanasoff and Berry, 39~42
  - Z3, Z4, Konrad Zuse late 30's early 40's
  - Colossus, Alan Turing, 1943
- Don't forget software advances---Fortran was first done in 1954

Commercialization in the 50s

- UNIVAC (1951) the first commercial computer
  contract price $400K, actual cost ~$1M, sold 48 copies
- IBM 701 (1952) "leased" 19 units, $12K per month
  (www-1.ibm.com/ibm/history/exhibits/701/701_customers.html)
- IBM 650 (1953) sold ~2000 units at $200K ~ 400K
- IBM System/360, 1964 Redefined Industry!!
  – a family of **binary compatible** computer (previously, IBM had 4 incompatible lines)
  – 19 combinations of varying speed and memory capacity from $200K ~ $2M
  – ISA still alive today as zEnterprise Systems

Cheaper or Faster in 60s and 70s

- Minicomputers
  - DEC PDP-8, 1965, $20K, size of large refrigerators
  - less powerful than "mainframes", 10x cheaper
  - departmental computers, timesharing---PDP-11 and VAXs enjoyed extreme popularity in the 70s and 80s
- Supercomputers
  - performance at all cost!! (ECL, liquid-cool, hand-built)
  - biggest customers: national security, nuclear weapons, cryptography, (also aerospace, petroleum, automotive, pharmaceutical, sciences) check out www.top500.org
  - see Seymour Cray (1925~1996) on Wikipedia

What happened to these computer lines?

Early Examples

DEC PDP 8, 1963
an early mini

Xerox Alto, 1973
an early "PC" with
mouse and GUI

[images from Wikipedia]

Cray 3, 1993

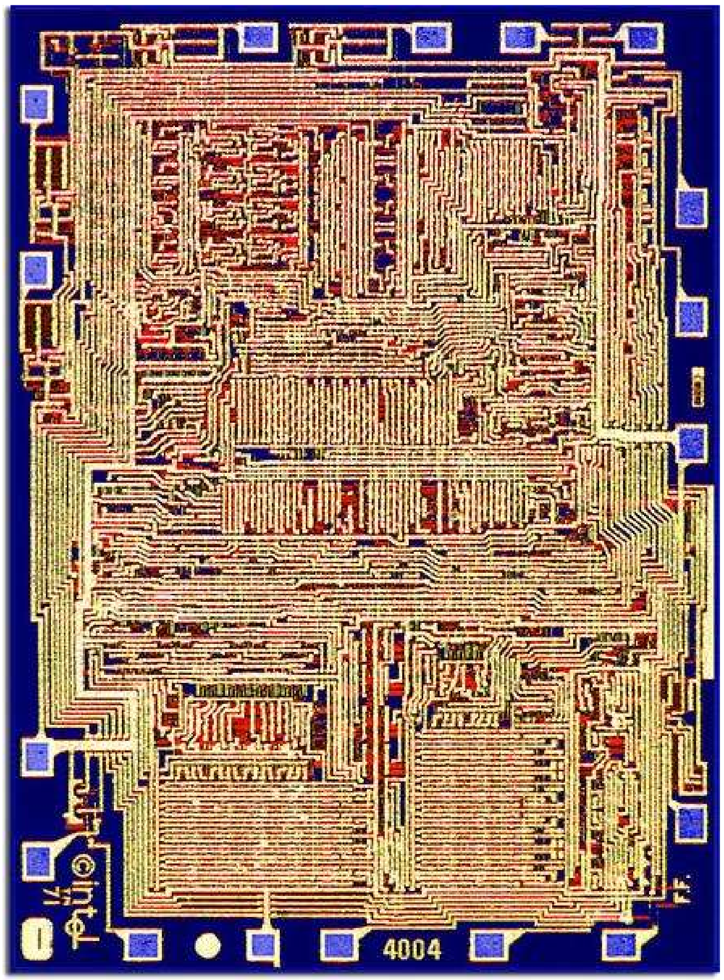
90KW: liquid cooled by “Fluorinert”

15 GFLOPS (1 sec on Cray3 ≈ 67 years ENIAC)

$30,000,000

[images from Wikipedia]

The "Killer Micros" from 70s and on

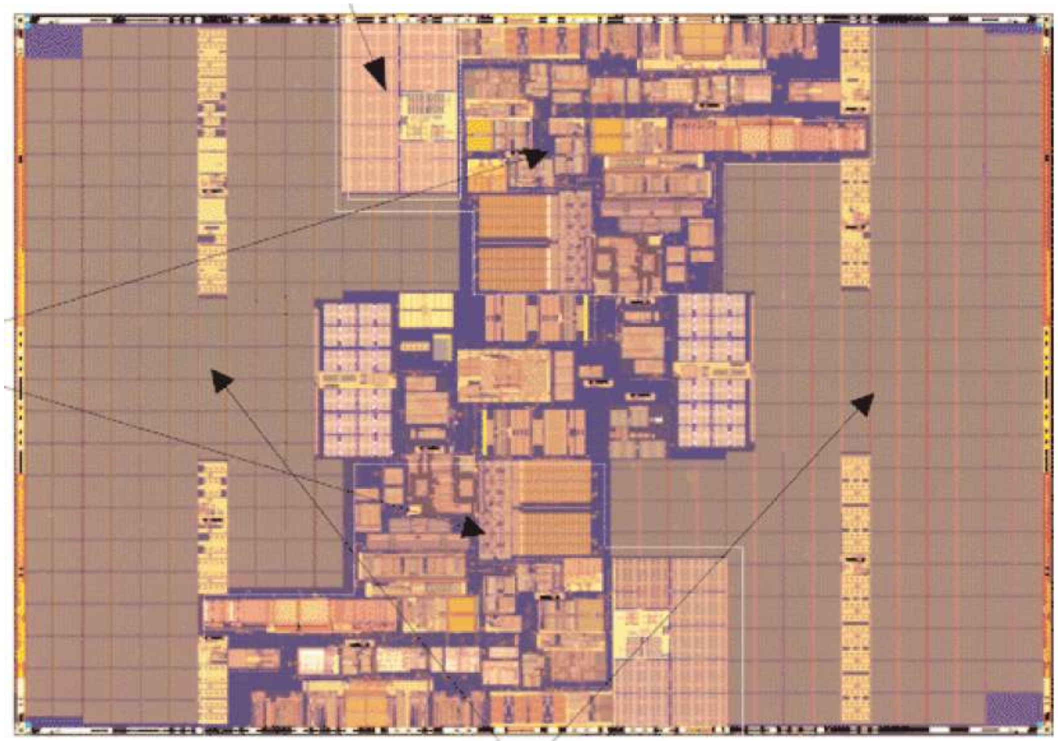


[from Molecular Expressions]

- **Intel 4004, first single chip CPU**
  - 4-bit processor for calculator
  - 2,300 transistors
  - 16-pin DIP package
  - 740kHz (eight clock cycles per CPU cycle of 10.8 μsec)
  - ~100K OPs per second

download the actual schematic from www.4004.com

Intel Itanium (Montecito) 2004

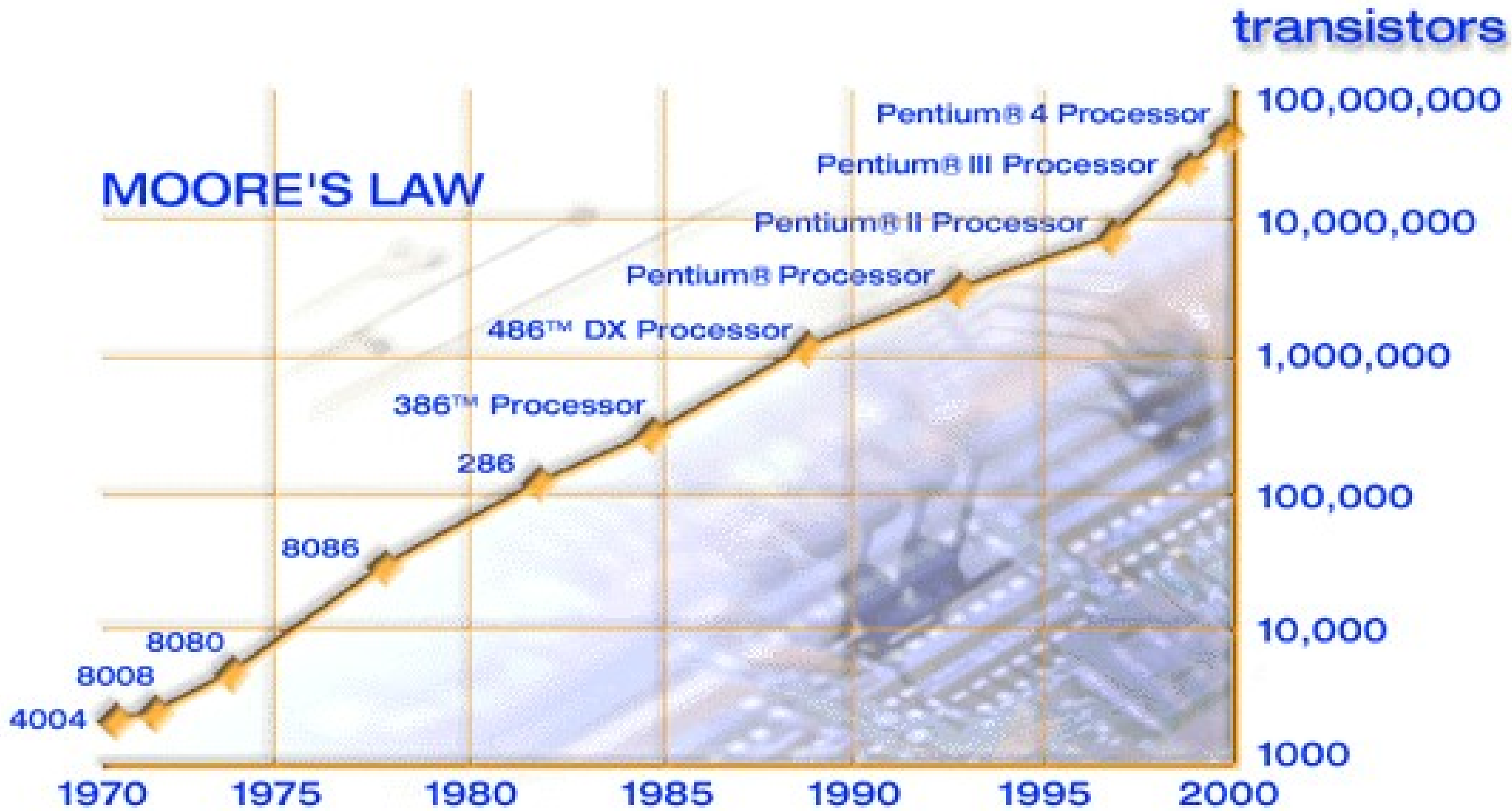


[from Best Servers of 2004,
Microprocessor Report, January 2005.]

- 64-bit processor
- 1.7 billion transistors
- 1.7 GHz, issue up to 8 instructions per cycle
- 26 MByte of cache!!

In ~30 years, about 100,000 fold growth in transistor count and performance!

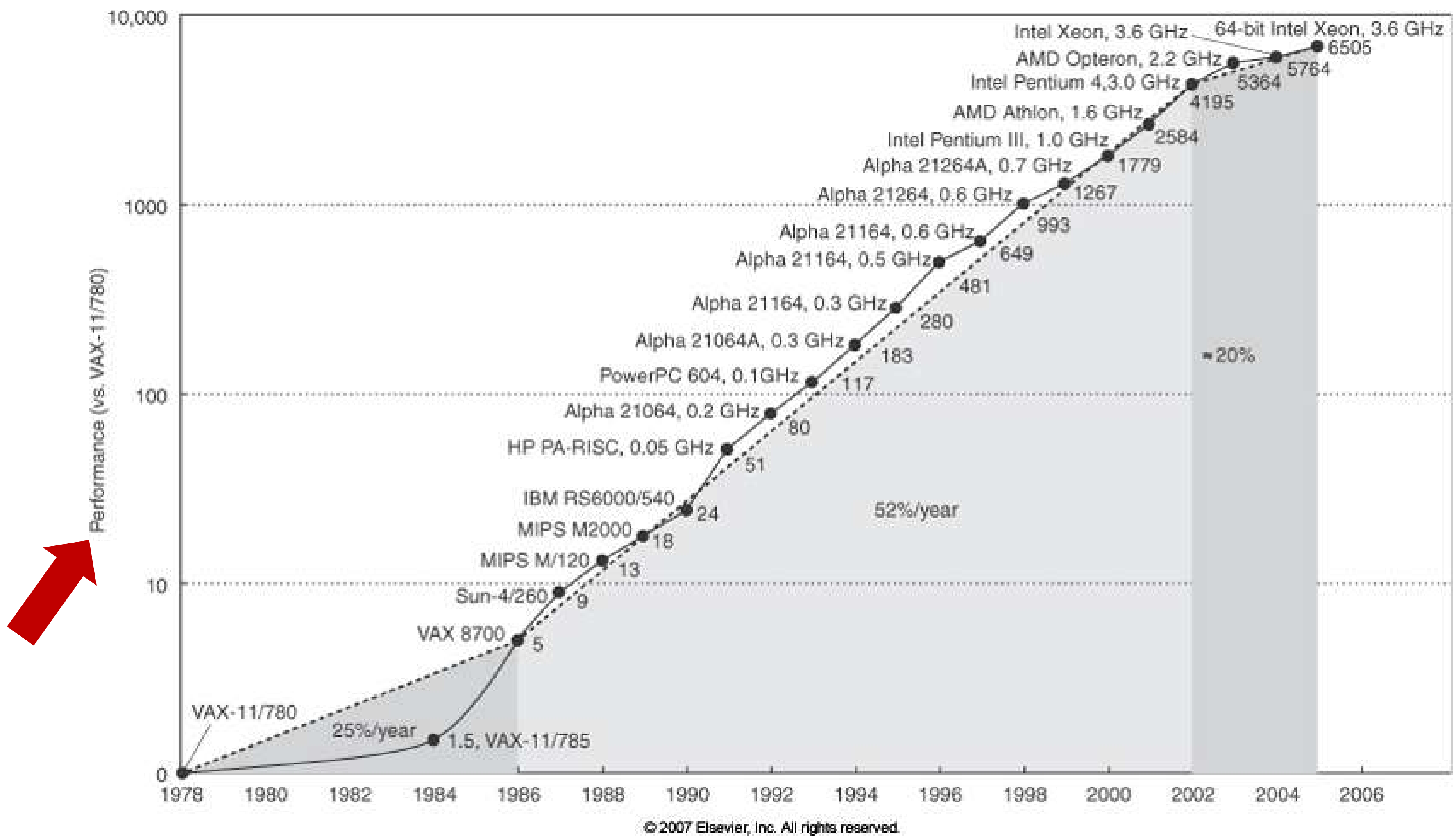
The Era of Moore's Law



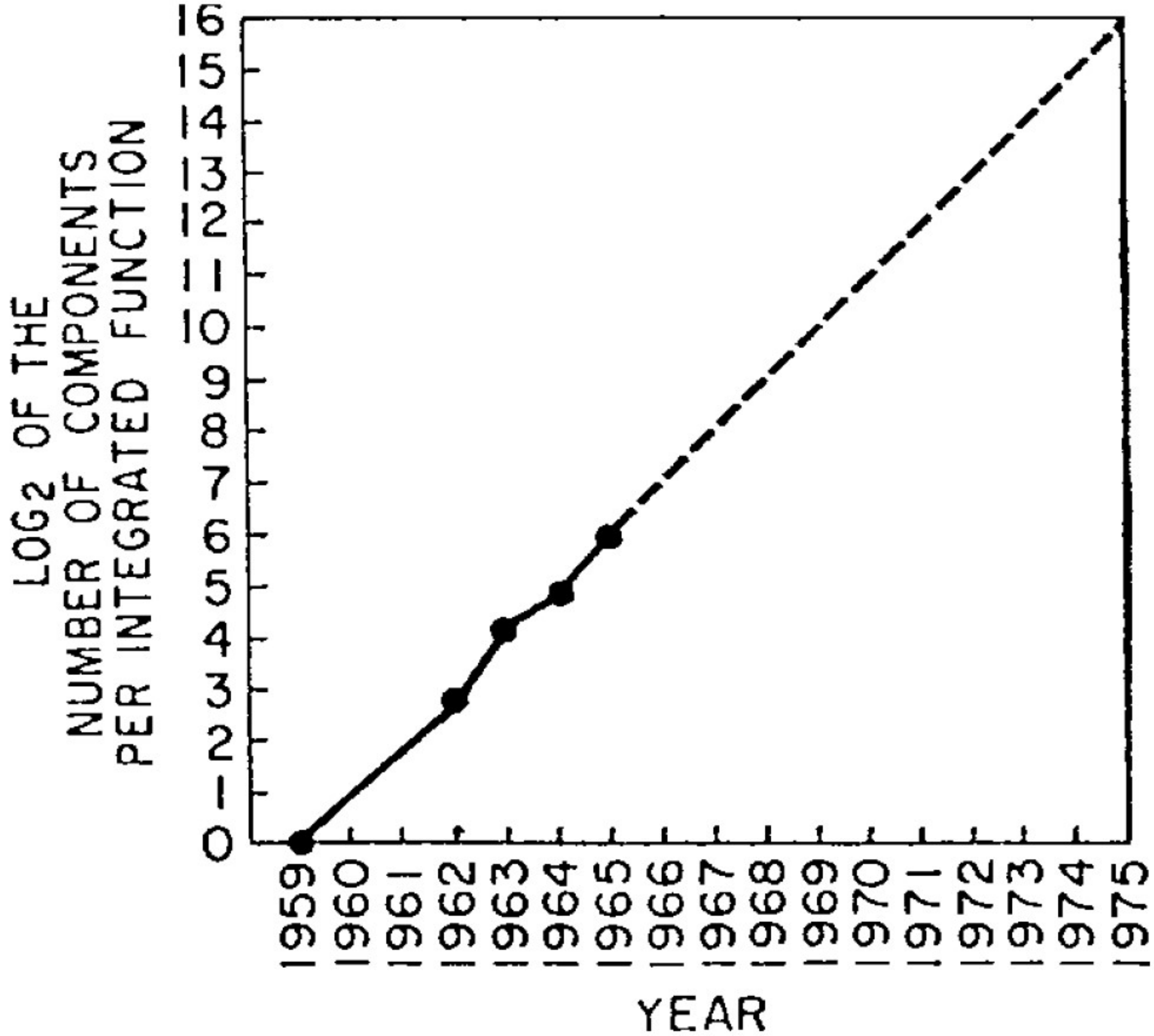
[http://www.intel.com/research/silicon/mooreslaw.htm]

Original article at http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=658762

The "Other" Moore's Law

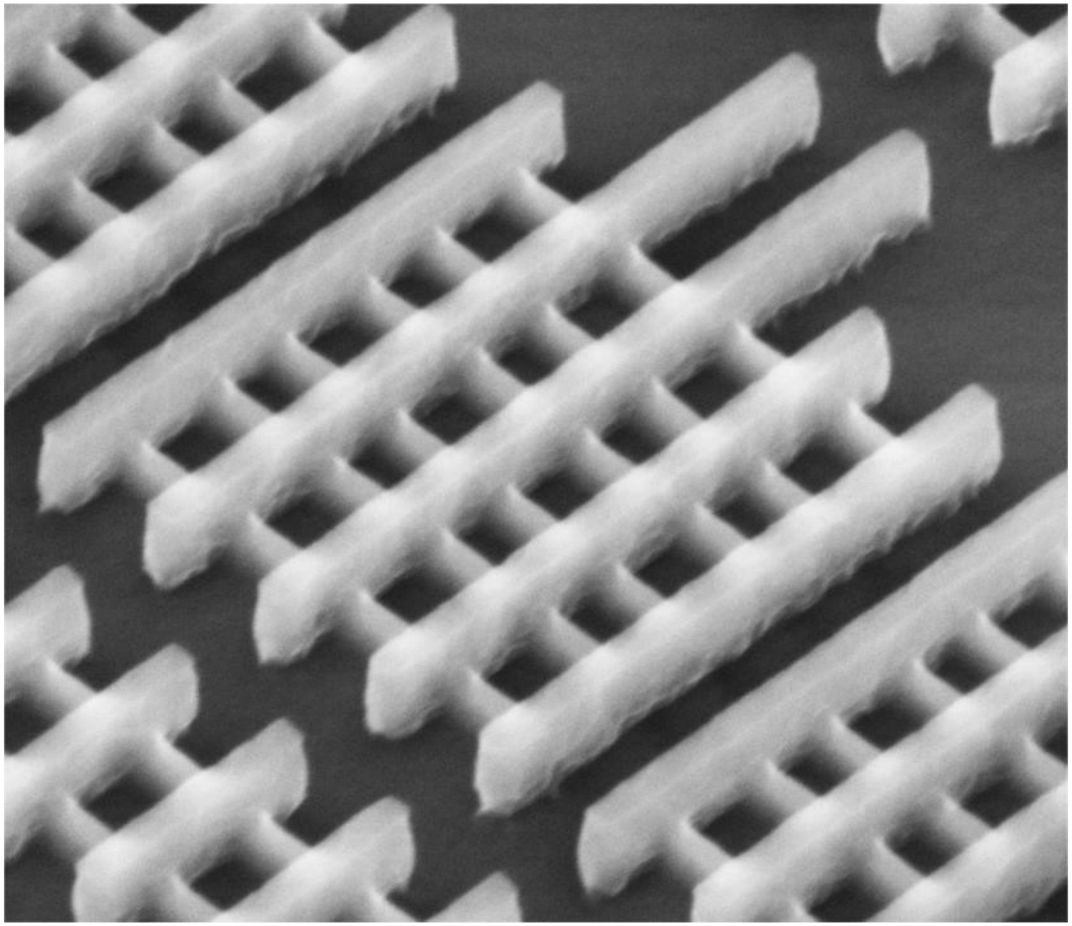


The Actual Moore's Law



[Cramming More Components Onto Integrated Circuits, G. E. Moore, 1965]

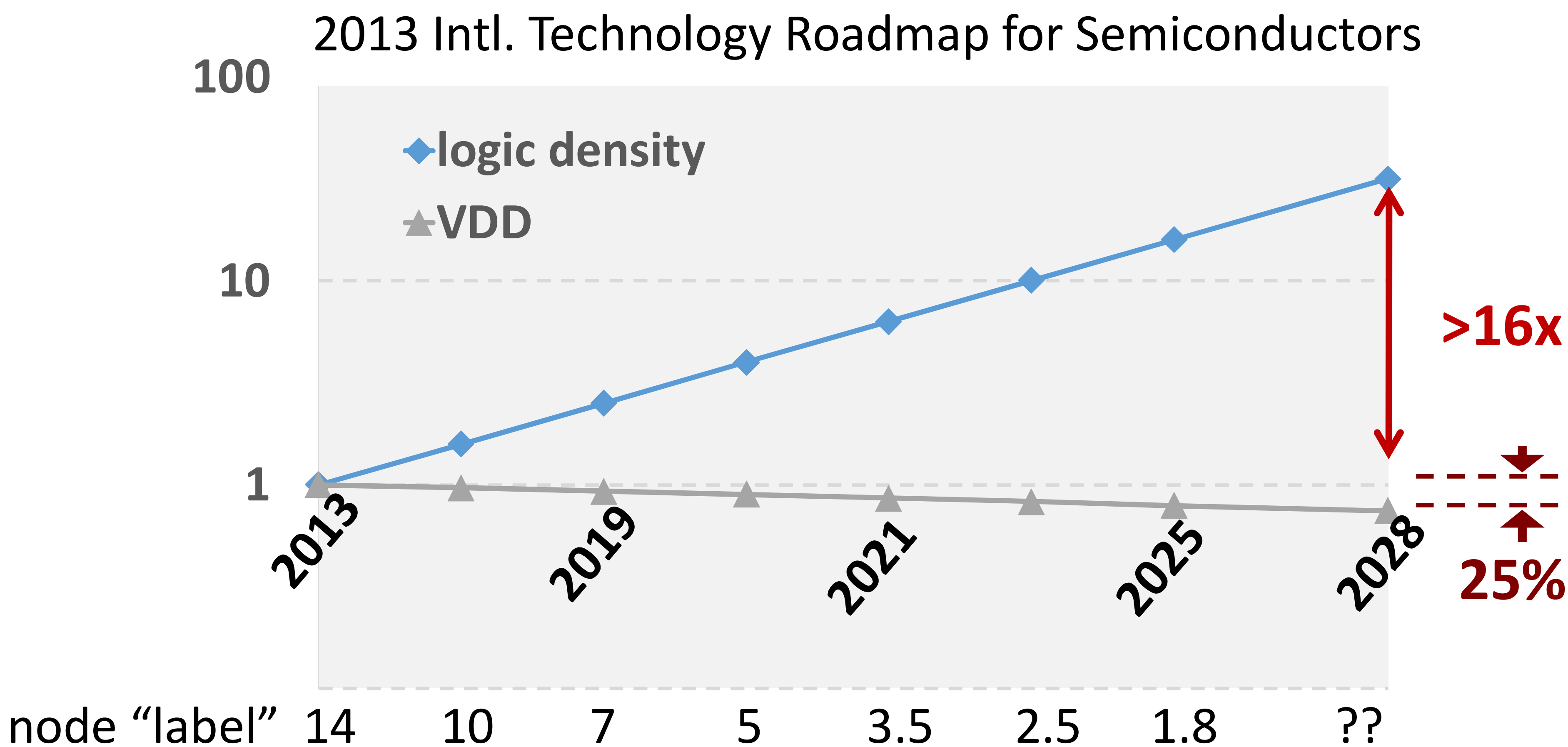
The End of Moore's Law?



[Tri-gate FinFET, Intel Newsroom, 2015]

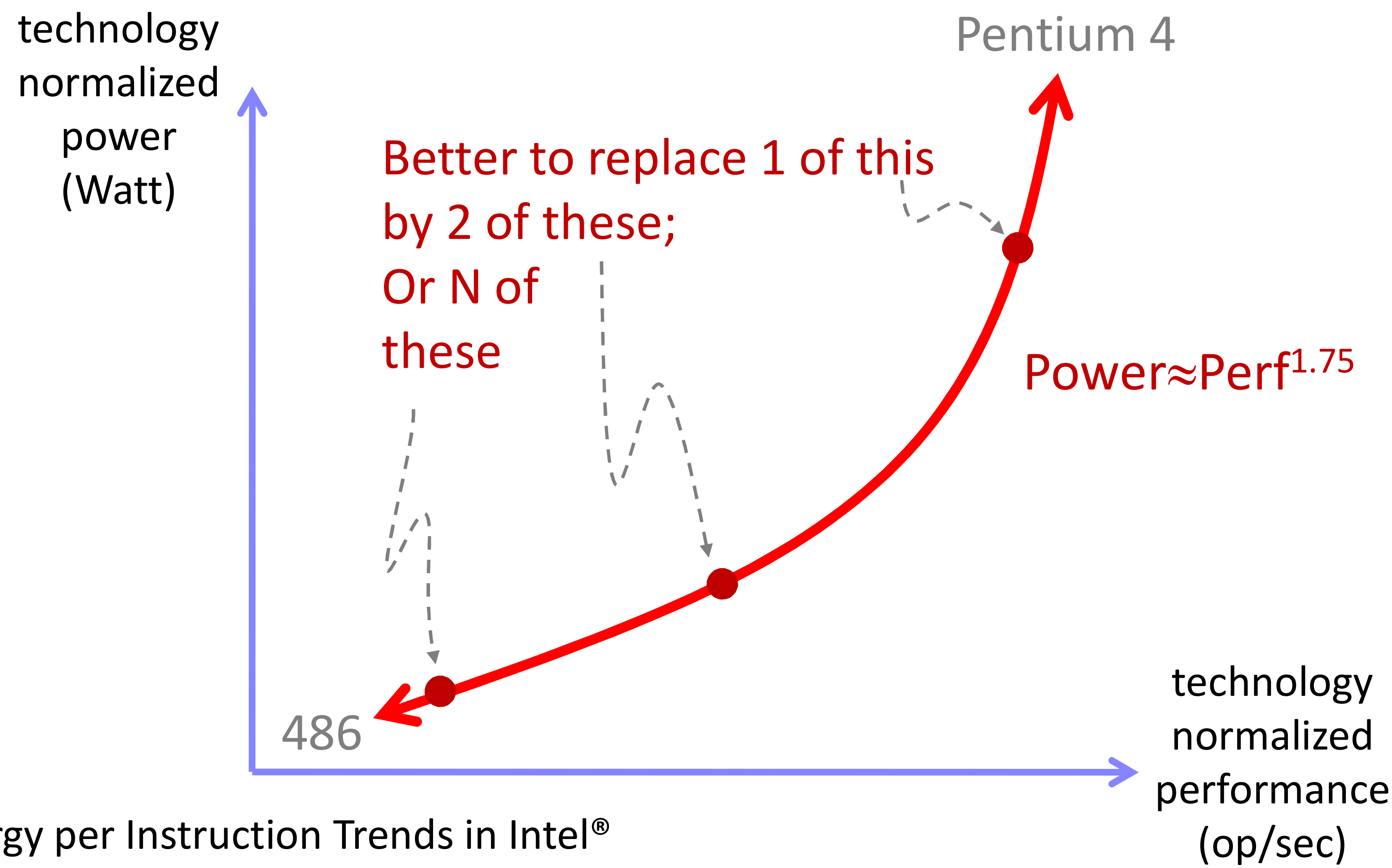
Distance between silicon atoms ~ 500 pm

Moore's Law without Dennard Scaling



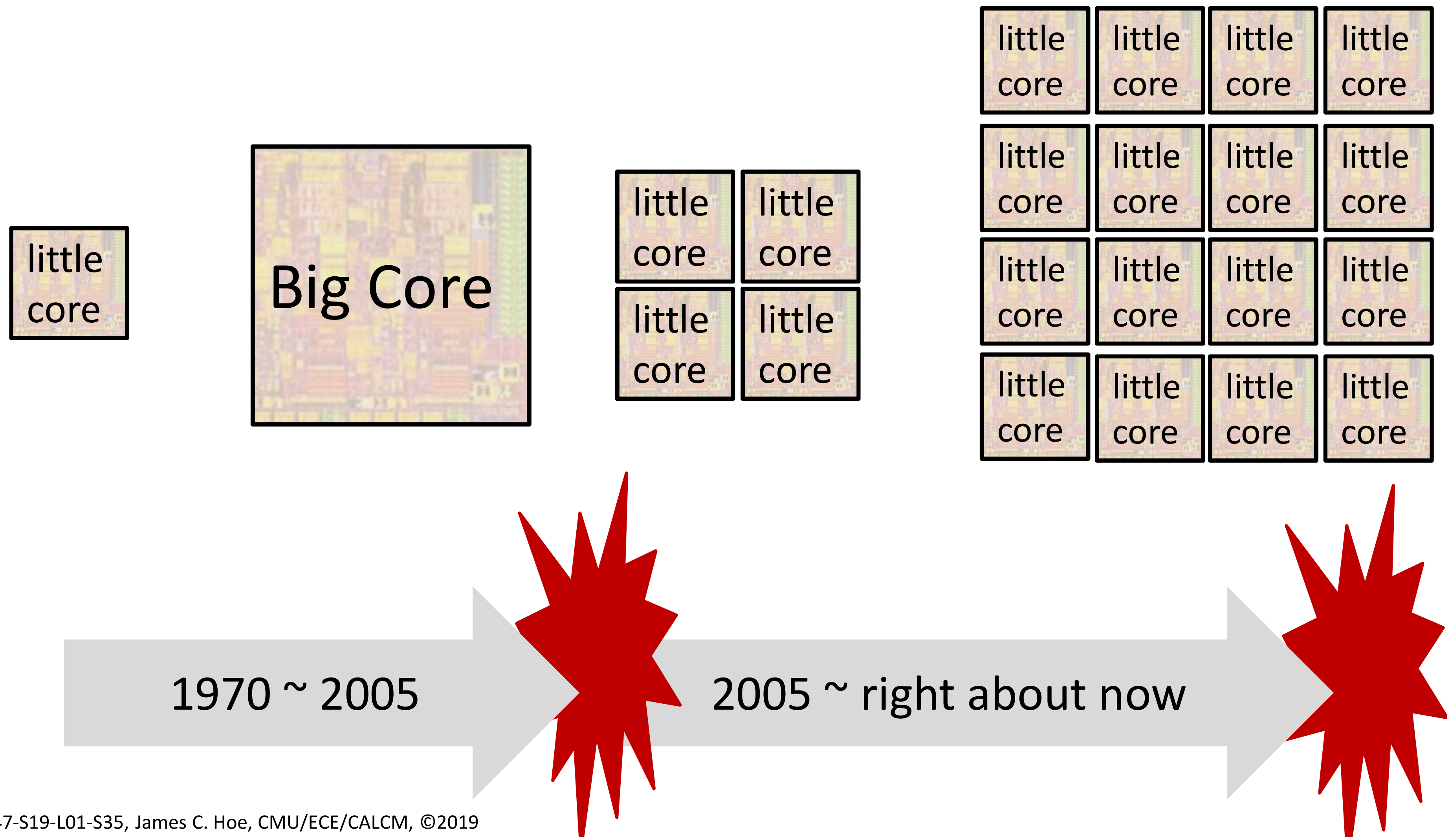
Under fixed power ceiling, more ops/second only achievable if less Joules/op?

Why multicores everywhere?



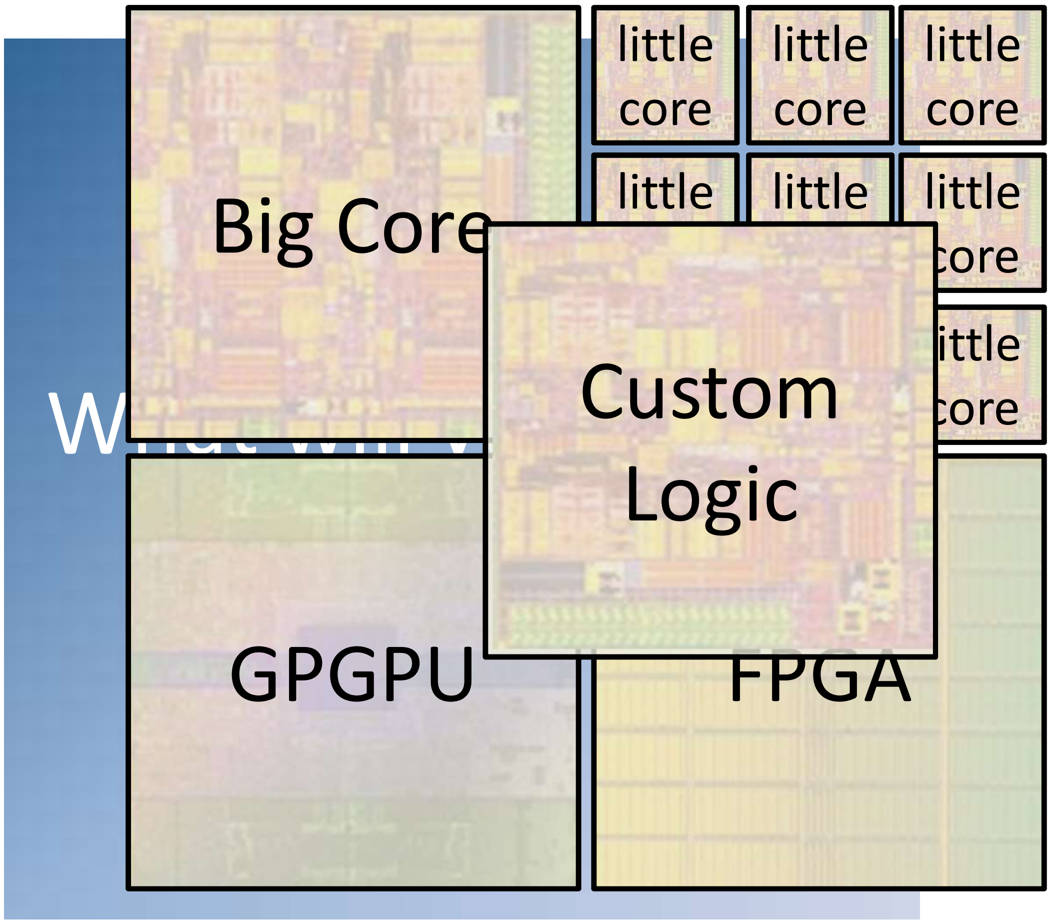
Energy per Instruction Trends in Intel®
Microprocessors, Grochowski et al., 2006

Moore’s Law Scaling with Cores



Future is about Performance/Watt and Ops/Joules

- By 2022 (11nm node), a large die (~500mm^2) will have over 10 billion transistors



Where do we go from here?

(http://www.ece.cmu.edu/~ece447/schedule.html)