01:198:211
Computer Architecture

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Instructors

- David Menendez
  - davemm@cs.rutgers.edu
    - Include “[CS211]” in subject line
  - Office Hours TBA, Hill 448
- Recitations
  - TAs TBA — recitations should begin next week

Textbooks

Required

- Bryant and O'Hallaron. *Computer Systems: A Programmer's Perspective.* Prentice Hall.

Recommended

- Patterson and Hennessy. *Computer Organization and Design: The Hardware/Software Interface.* Morgan Kauffman

- Jens Gustedt, *Modern C*. Manning Publications.

  - http://freecomputerbooks.com/Modern-C-by-Jens-Gustedt.html

  - Any good reference for C should be sufficient

  - There are many on-line resources, e.g. https://en.wikibooks.org/wiki/C_Programming

What You Should Know

- Prerequisites: 198:112
    - You should know some math
    - You should know some basic algorithms and data structures
    - You should know at least one programming language (e.g., Java)
    - You should know how to write, run, and test programs
- You will need to learn
    - Read the textbook
    - Participate in class
    - Start assignments early

How can we write programs to get good performance on modern architectures?

What You Will Learn

- A high-level language suitable for systems programming (C)
- A low-level language close to the machine (Assembly)
- Major hardware components in computer systems
- How hardware components are built from digital logic
- How programs are actually executed by the hardware
- How to understand and improve the performance of programs

Course Structure

- Assignments
    - 5 programming assignments
- Tests (on-line via Canvas)
    - Short, primarily multiple choice
    - Intended as a check on understanding
- Comprehensive final exam (on-line via Canvas)
- Expectations
    - Attend lectures and recitation
        - Read assigned material before lecture
        - Read carefully and think about assignments
    - Ask questions
    - Start assignments early

Seriously, start the assignments early

No Late Assignments

- We will not accept late assignments
- Programming assignments will be submitted through Canvas
  - Deadlines will be enforced by Canvas
  - You can submit multiple times, if you are working close to the deadline and worried you will miss it
  - I recommend submitting a day in advance
- Do not submit via e-mail

Collaboration vs Cheating

- Your submissions must be your work
    - No code copied from other students
    - No code copied from on-line sources
- Discussing problems with other students is encouraged
    - Do not look at anyone else's code
- Do not post code on-line!
- We will be checking submissions for cheating
    - If we find evidence of copying, everyone involved will be reported
    - If you are having trouble, talk to me or a TA

Rough Schedule

- Recent trends in hardware
- C Programming
- Information Representation
- Assembly programming (Intel X86)
- Digital Logic
- Processor Architecture
- Memory Hierarchy
- Compiling and Linking
- Measuring and Optimizing Performance

Programming Assignments

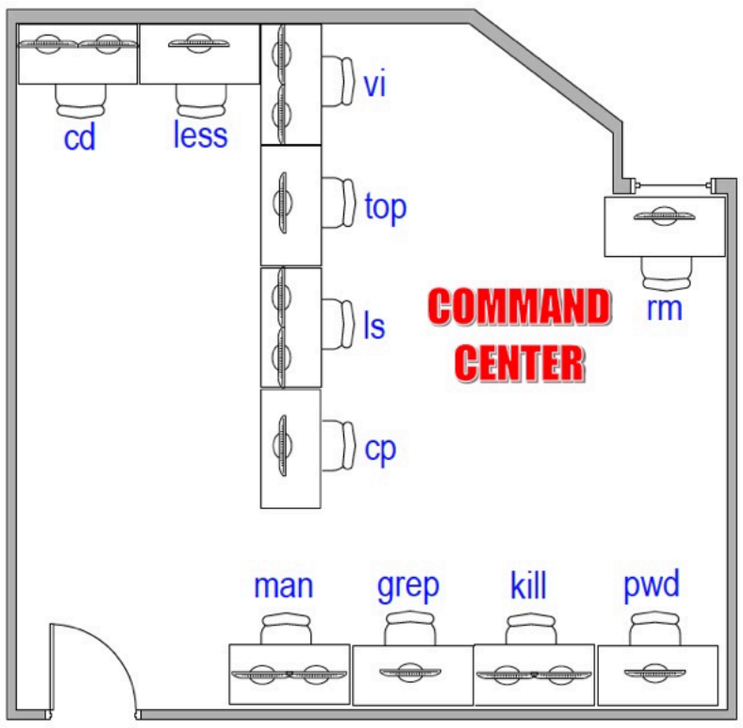
- Languages will be C and Assembly in a Linux environment
    - Start early
    - Learn how to use your tools
        - Don’t rely on luck or trying every possible solution
- We will use the Instructional Lab
    - https://resources.cs.rutgers.edu/docs/instructional-lab/
        - Sign up for an account if you do not have one
        - Includes directions for setting up remote access
    - You can write your program anywhere, but we will test in the lab

Instructional Lab

- For this class, we will use the machines in the Command Center, Cave, and Meltdown clusters as references
    - Obtain the current list of active machines at

      https://report.cs.rutgers.edu/nagiosnotes/iLab-machines.html

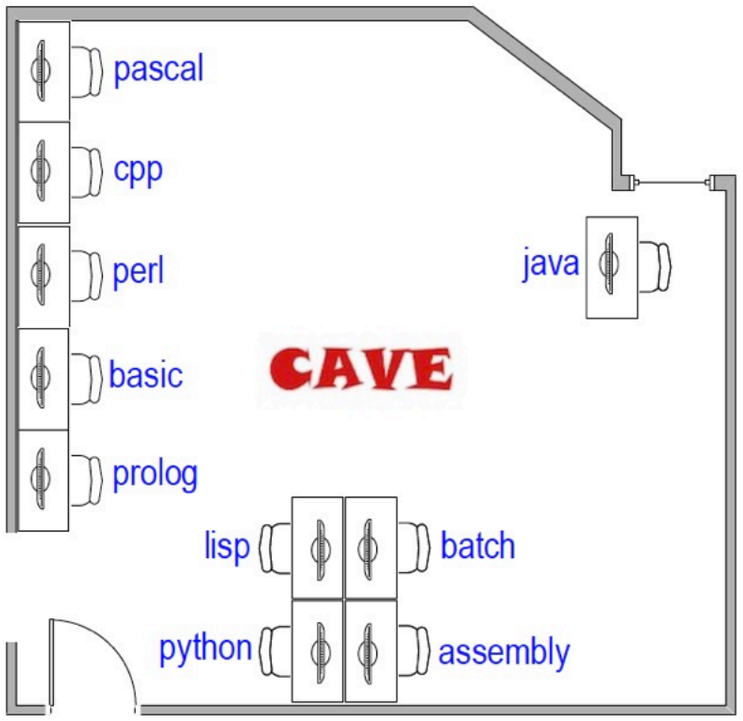
- These are actual machines located in the Hill Center Annex, rooms 248, 252, and 254
- Your files are stored in a network file system, so you may log into any machine
- You may use the machines in person, or log in remotely using ssh, X2Go, or Microsoft Remote Desktop
- You can transfer files between your machine and the iLab using scp or sftp
- *Do not use* ilab.cs.rutgers.edu — it is a different cluster with different software



H248 Machines Status (11 units)

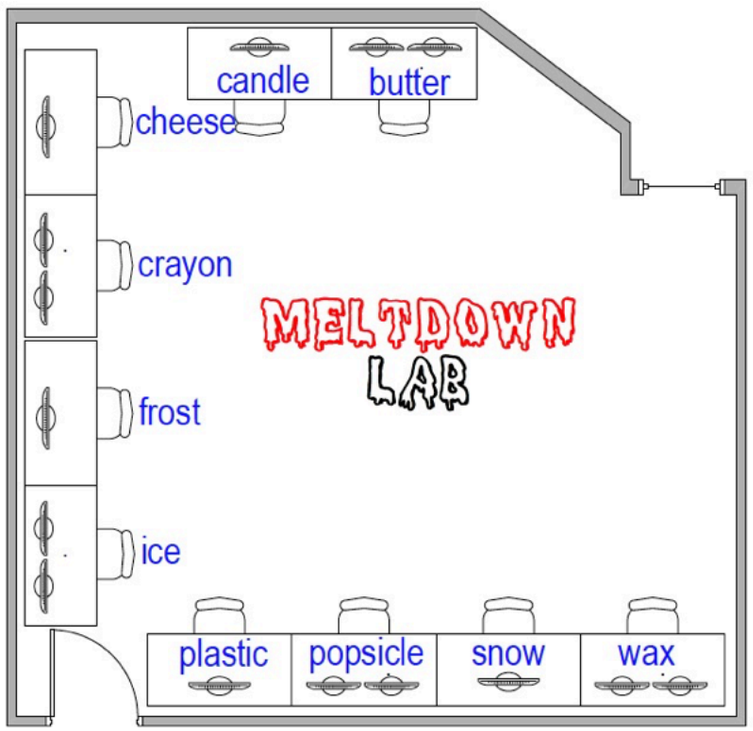
Hostname	GPU	Logins	Load	Status	Misc
cd.cs.rutgers.edu	idle	1	4.09	up	⇵ 🔥
cp.cs.rutgers.edu	idle	1	0.05	up	⇵ 🔥
grep.cs.rutgers.edu	idle	0	0.02	up	⇵ 🔥
kill.cs.rutgers.edu	idle	5	0.07	up	⇵ 🔥
less.cs.rutgers.edu	idle	0	0.05	up	⇵ 🔥
ls.cs.rutgers.edu	idle	0	0.08	up	⇵ 🔥
man.cs.rutgers.edu	idle	0	0.07	up	⇵ 🔥
pwd.cs.rutgers.edu	idle	0	0.02	up	⇵ 🔥
rm.cs.rutgers.edu	idle	0	0.04	up	⇵ 🔥
top.cs.rutgers.edu	idle	3	0.31	up	⇵ 🔥
vi.cs.rutgers.edu	idle	1	0.52	up	⇵ 🔥

OS: CentOS 7.6 | **CPU:** Intel® Core™ i7-7700 @ 3.60GHz - 8 vCores | **Memory:** 32GB
Make/Model: HP Prodesk 600 G3 Desktop | Aug 2017 | **CPUMark:**10727
GPU Specs: GT 730 | **Memory:**2 GB | **CUDA Cores:**384 | **CUDA capability** : 3.0 | **Version**: 9.0



H252 Machines Status (10 units)

Hostname	GPU	Logins	Load	Status	Misc
assembly.cs.rutgers.edu	-	0	0.05	up	⇵ 🔥
basic.cs.rutgers.edu	-	0	0.04	up	⇵ 🔥
batch.cs.rutgers.edu	-	0	0.06	up	⇵ 🔥
cpp.cs.rutgers.edu	-	0	0.05	up	⇵ 🔥
java.cs.rutgers.edu	-	0	0.08	up	⇵ 🔥
lisp.cs.rutgers.edu	-	0	0.06	up	⇵ 🔥
pascal.cs.rutgers.edu	-	0	0.09	up	⇵ 🔥
perl.cs.rutgers.edu	-	0	0.16	up	⇵ 🔥
prolog.cs.rutgers.edu	-	0	0.12	up	⇵ 🔥
python.cs.rutgers.edu	-	0	0.08	up	⇵ 🔥



H254 Machines Status (10 units)

Hostname	GPU	Logins	Load	Status	Misc
ice.cs.rutgers.edu	idle	2	0.03	up	⇵ 🔥
snow.cs.rutgers.edu	idle	0	0.02	up	⇵ 🔥
butter.cs.rutgers.edu	idle	0	0.04	up	⇵ 🔥
cheese.cs.rutgers.edu	idle	1	0.04	up	⇵ 🔥
candle.cs.rutgers.edu	idle	0	0.03	up	⇵ 🔥
frost.cs.rutgers.edu	idle	0	0.04	up	⇵ 🔥
popsicle.cs.rutgers.edu	idle	1	0.04	up	⇵ 🔥
plastic.cs.rutgers.edu	idle	0	0.05	up	⇵ 🔥
crayon.cs.rutgers.edu	idle	0	0.04	up	⇵ 🔥
wax.cs.rutgers.edu	idle	0	0.05	up	⇵ 🔥

Grading Assignments

- Most programming assignments will be tested by an automated system
- You will be provided a copy of the auto-grader and a subset of the tests
- Your program **must** work with the auto-grader on the iLab machines
- It is your responsibility to make sure auto-grader can compile and execute your program
  - Test early and often
  - If you are having problems with the auto-grader, ask me or a TA
- It is your responsibility to make sure your submission is formatted correctly

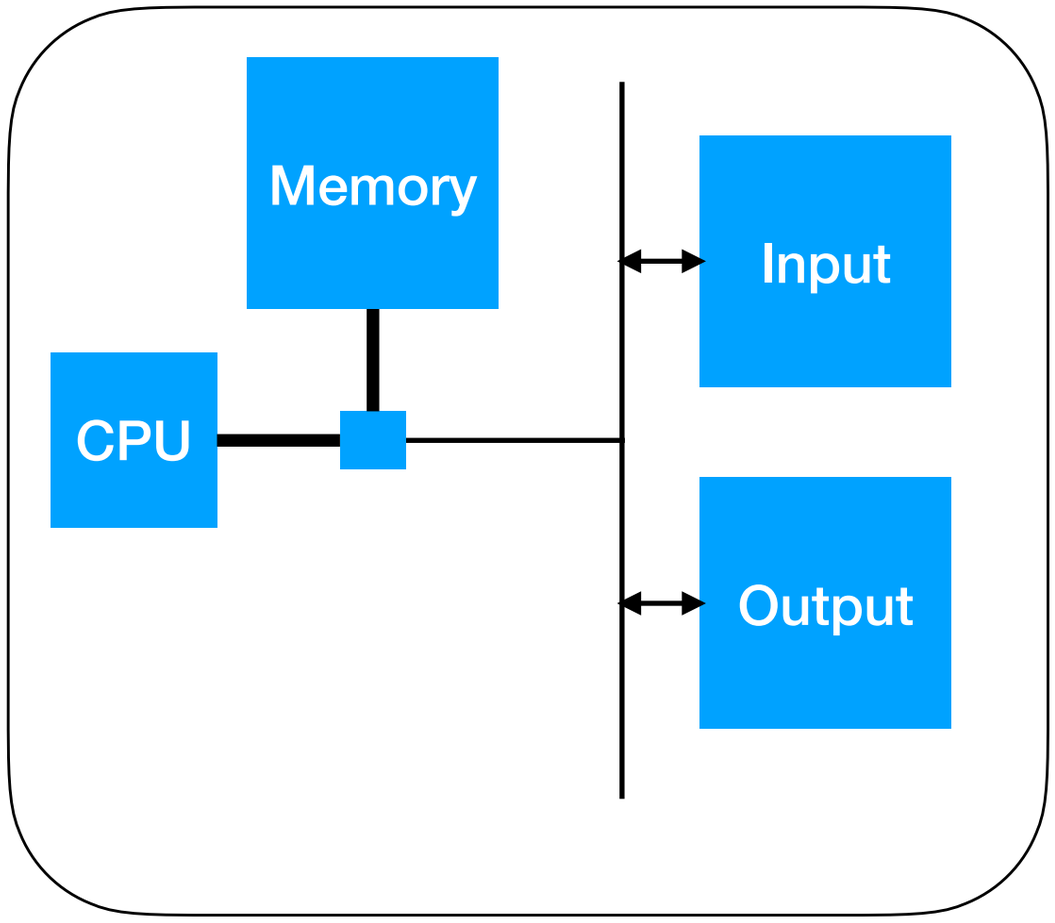
Grading

- Breakdown:
  - 25% midterm exam or tests
  - 25% final exam
  - 50% programming assignments
- No make-up exams, except for university-sanctioned reasons
  - You must inform me before the exam
  - Informing me does not guarantee that I will agree

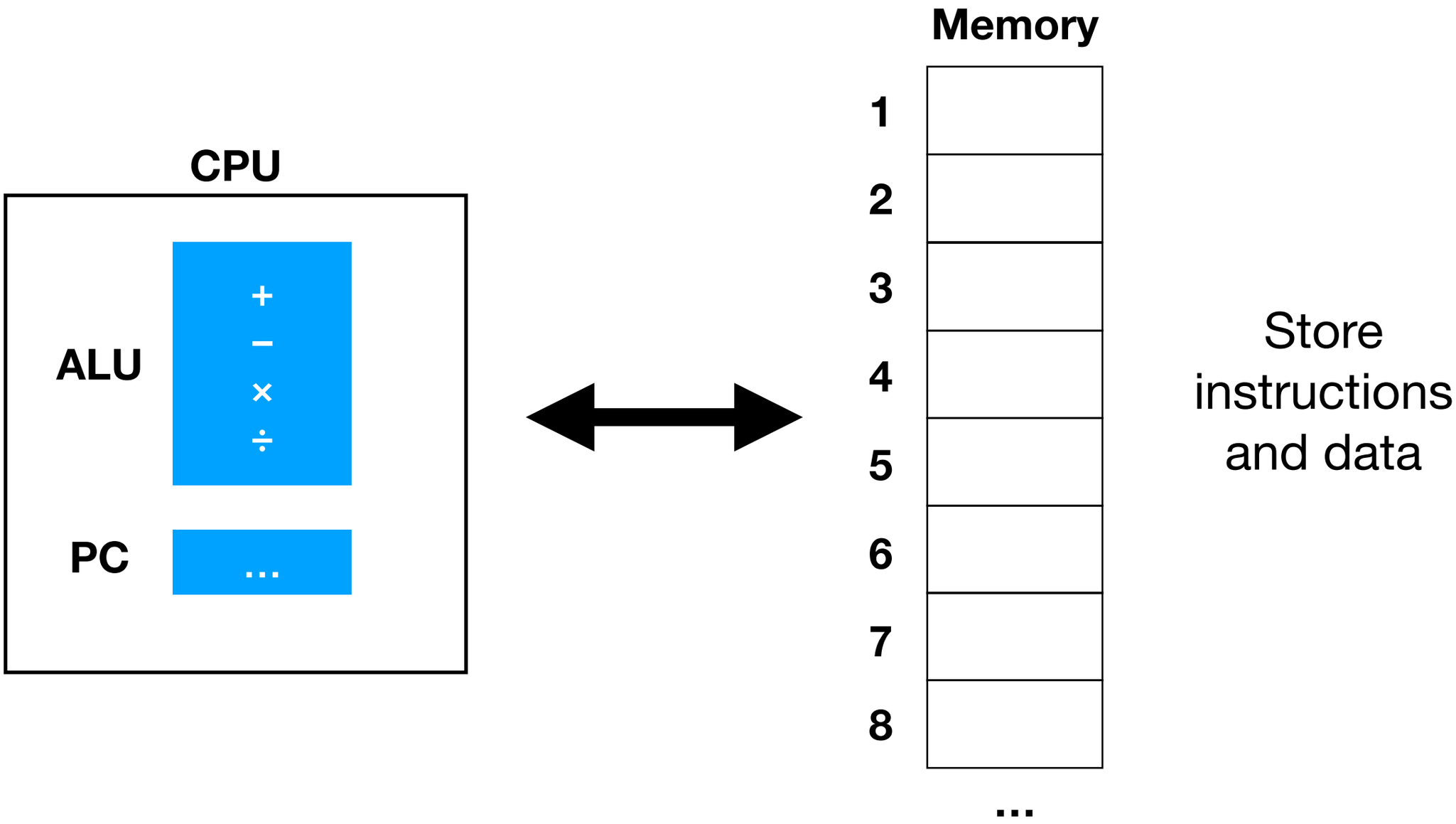
What is a computer?

Main Components

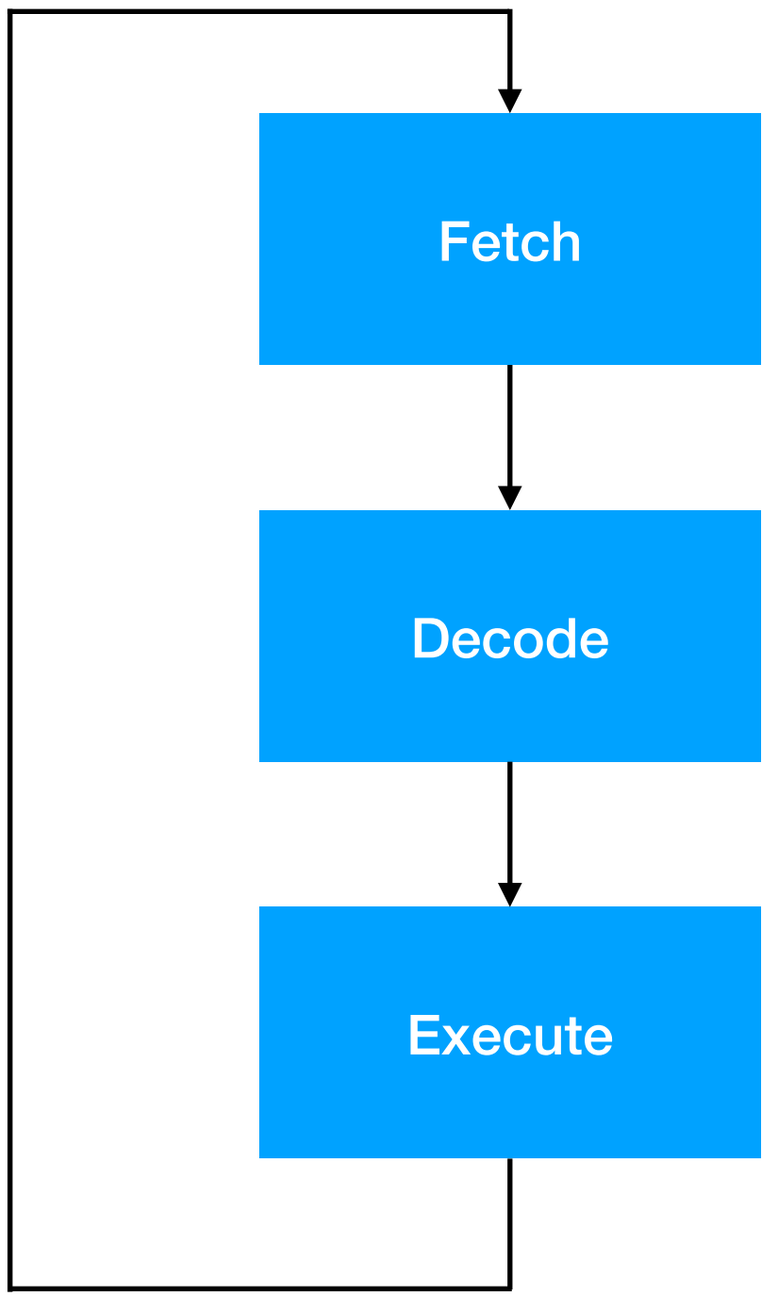
- CPU
- Memory
- Bus
- I/O devices
  - Human interface
  - Storage
  - Networking
  - Graphics



Von Neumann Model



Basic CPU Function

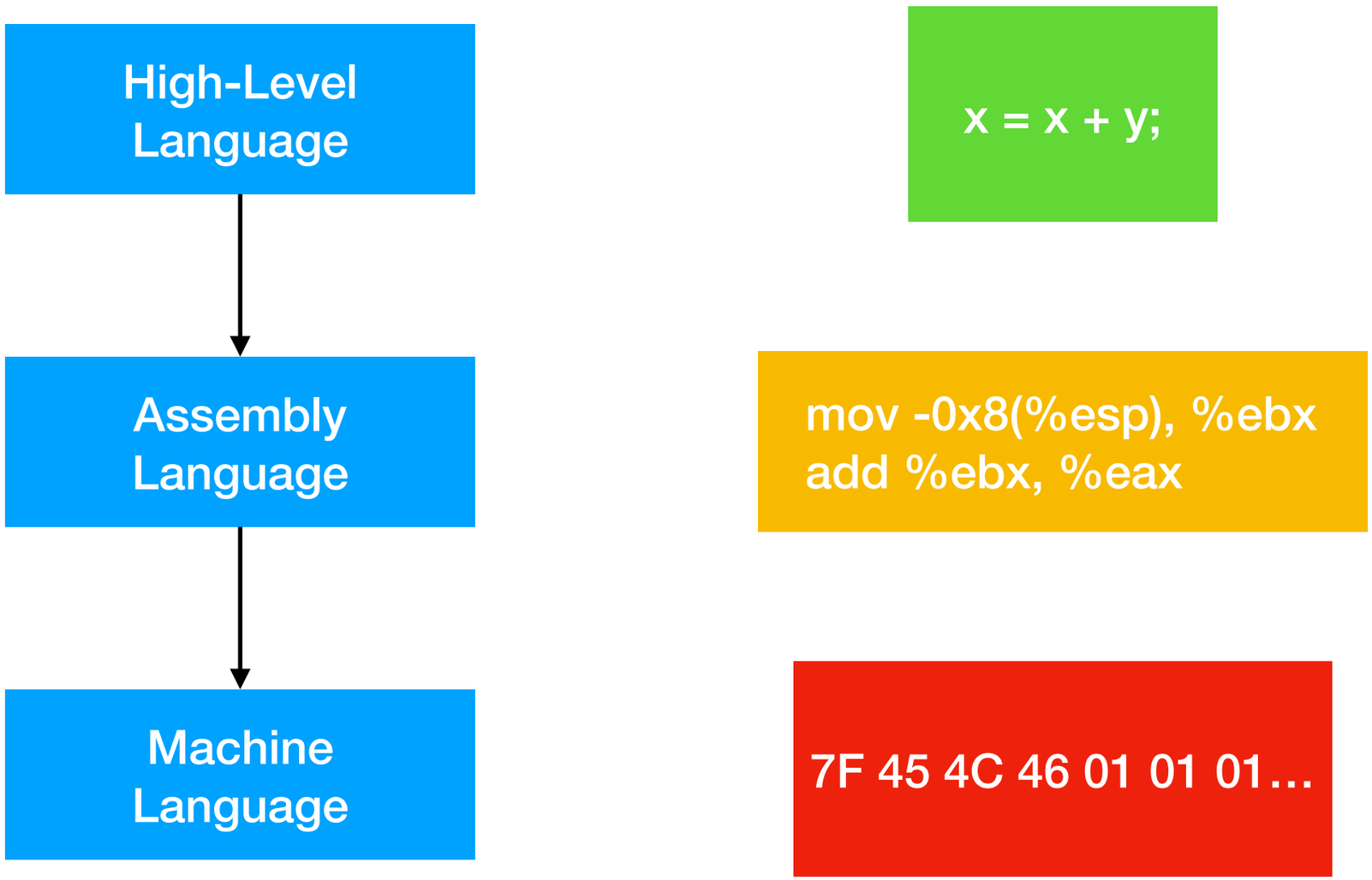


Advance PC

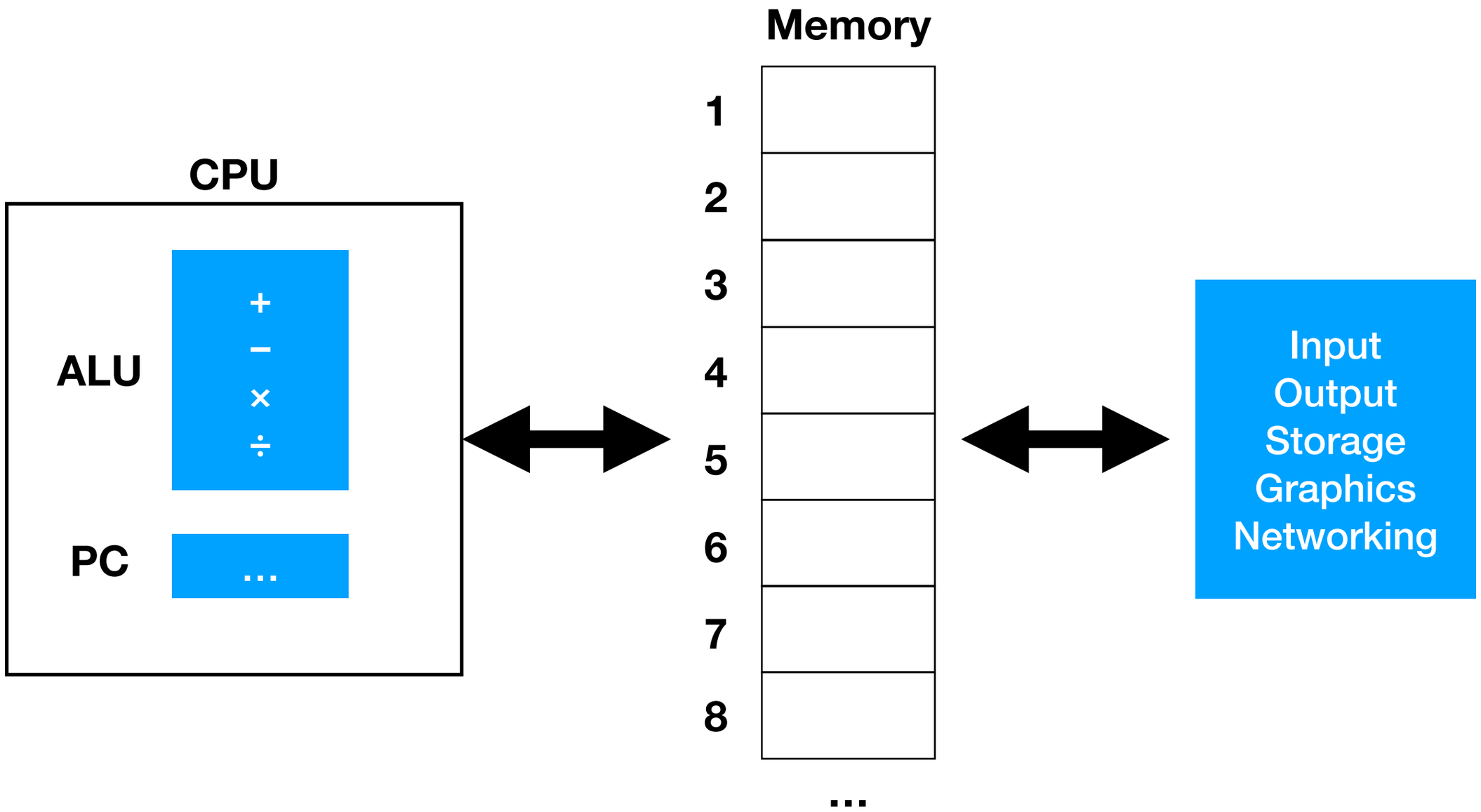
Arithmetic

Logic, Jumps

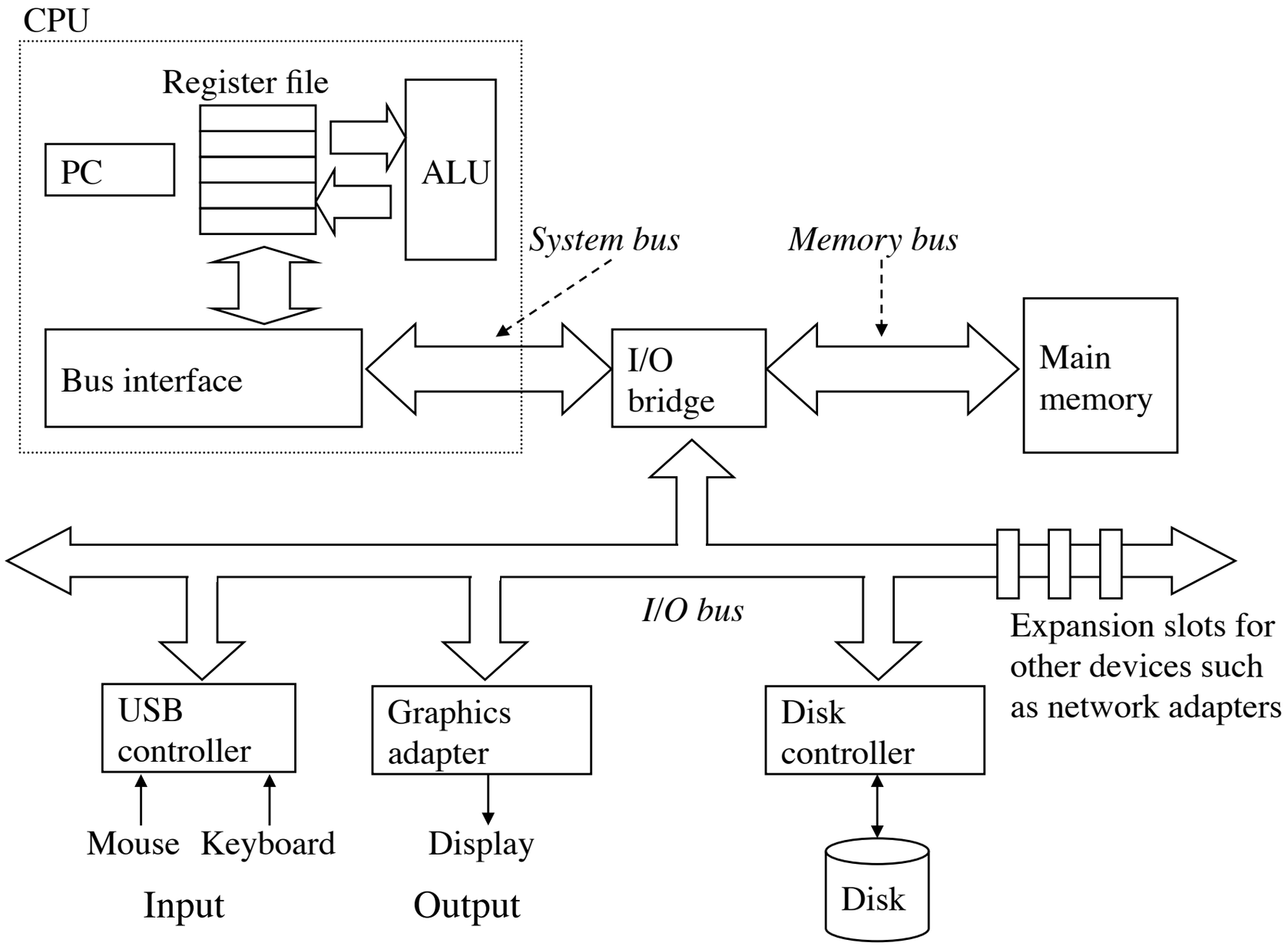
Running on Hardware



Input/Output



Von Neumann in Practice



The Operating System

- Programs run on the hardware, calling into OS for some services
- On modern systems, OS and hardware collaborate for some features
  - e.g., virtual memory, multitasking

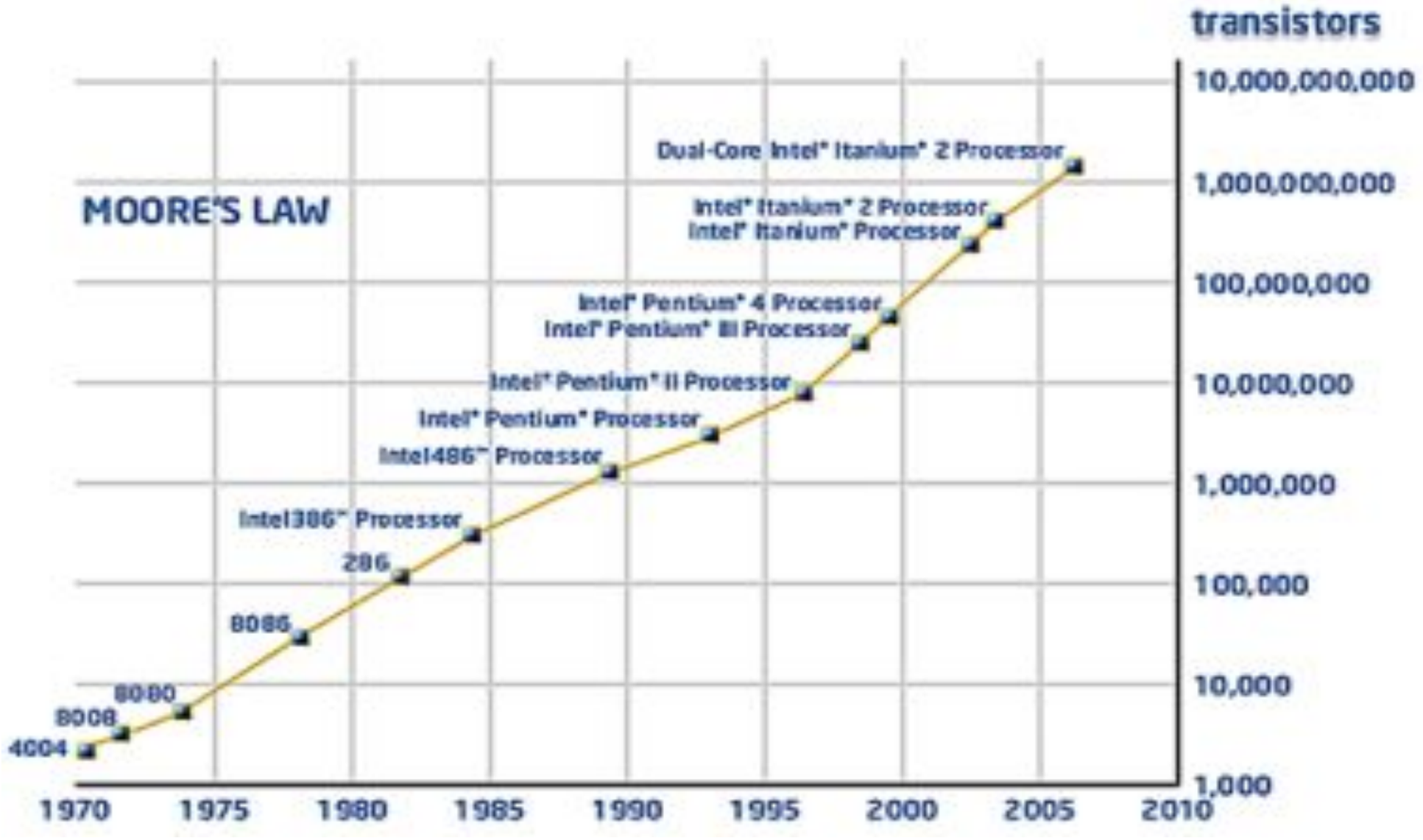
Computer Architecture

- How to build components
- How to design and build systems using components
- We will cover:
  - Basics of current components and systems
  - How programs run on current systems
  - How current architectures affect programs written in high-level languages

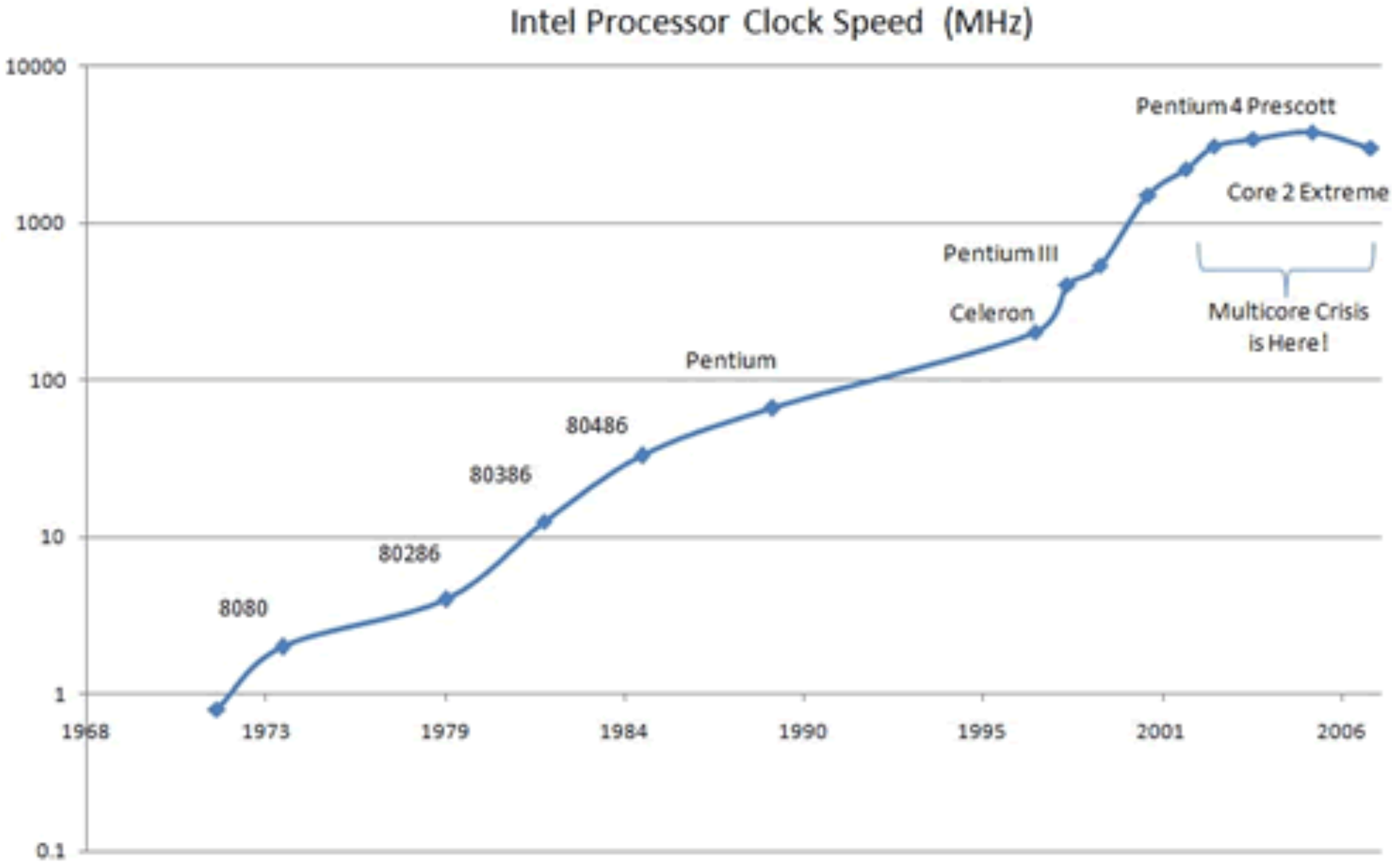
Moore’s Law

- Gordon Moore was an Intel Engineer
- Observed that the number of transistors on a chip doubles every 18 months
- Exponential growth also seen elsewhere:
  - Processor speed doubles every 18 months
  - Memory capacity doubles every two years
  - Disk capacity doubles every year

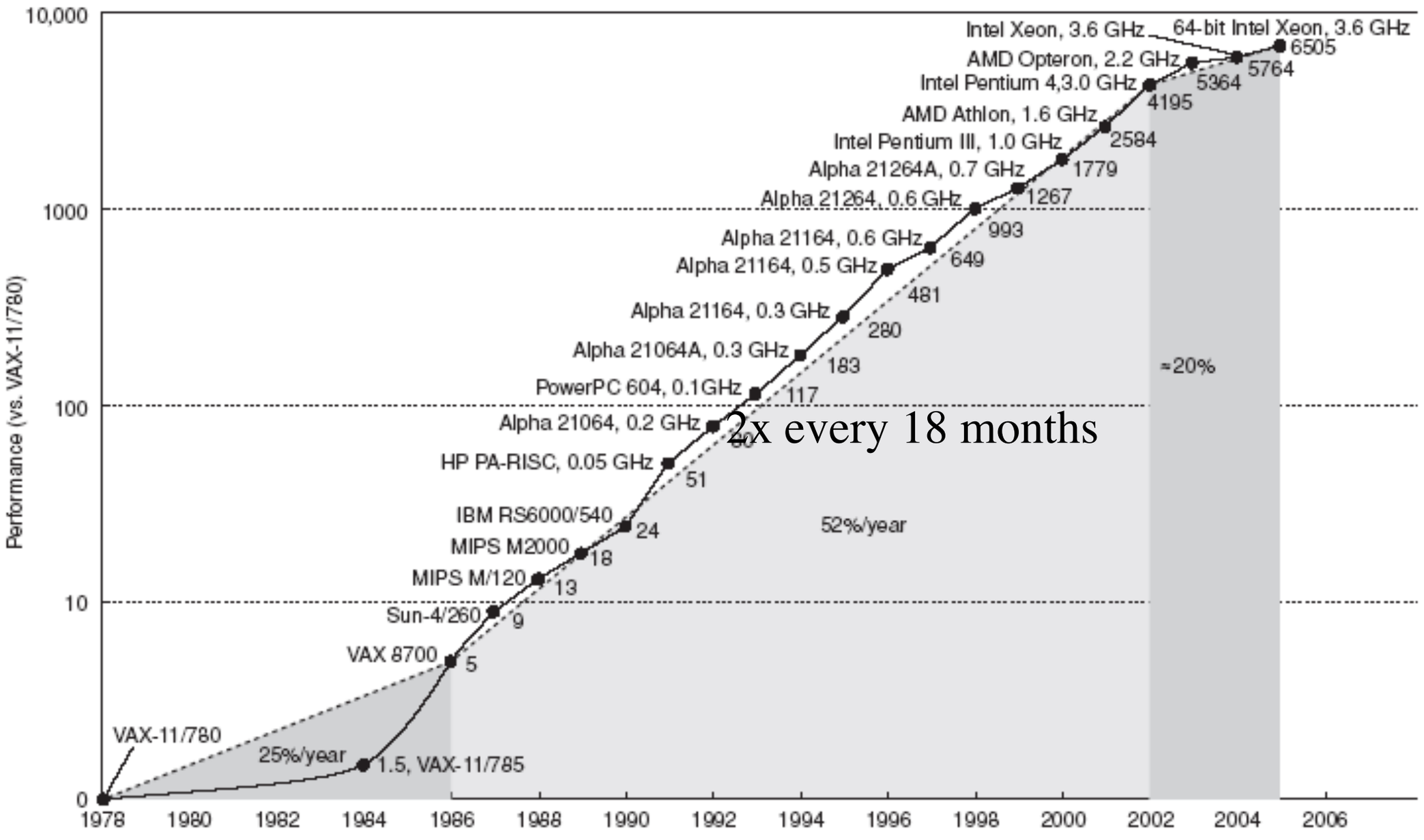
Transistors on a Chip



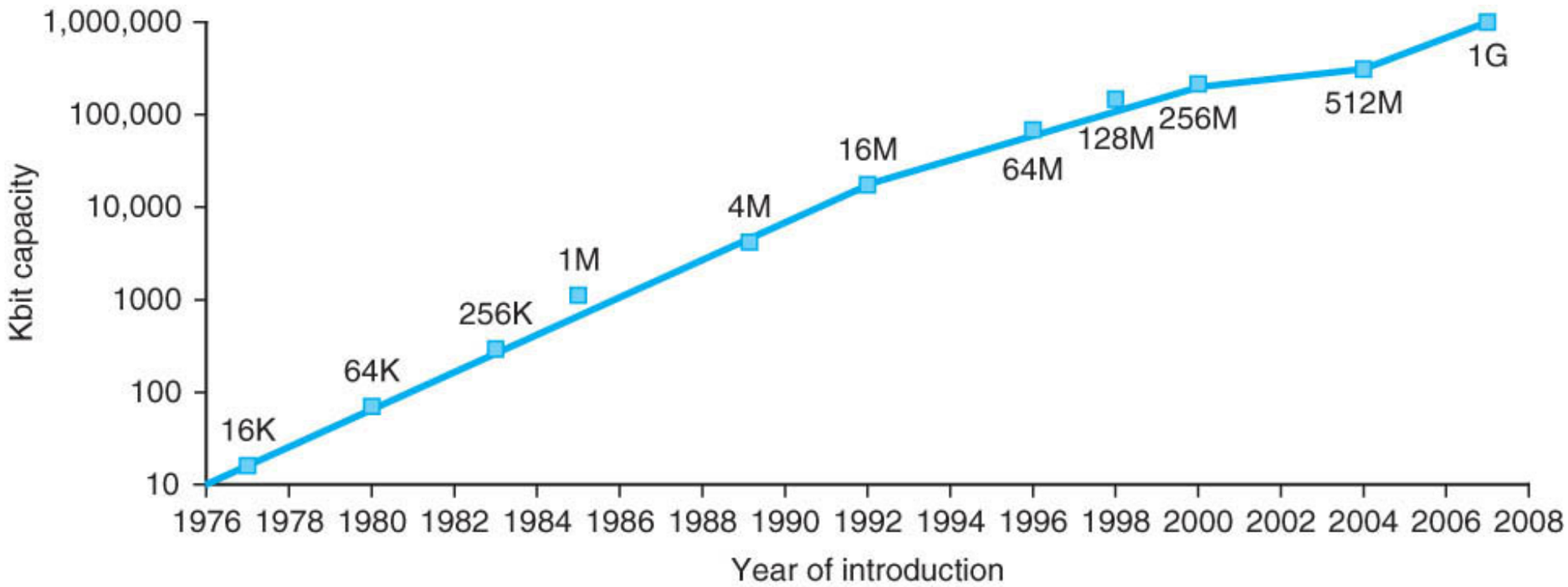
Clock Speed


Intel Processor Clock Speed (MHz)
10000
1000
100
10
1
0.1
1968
1973
1979
1984
1990
1995
2001
2006
8080
80286
80386
80486
Pentium
Celeron
Pentium III
Pentium 4 Prescott
Core 2 Extreme
Multicore Crisis is Here!

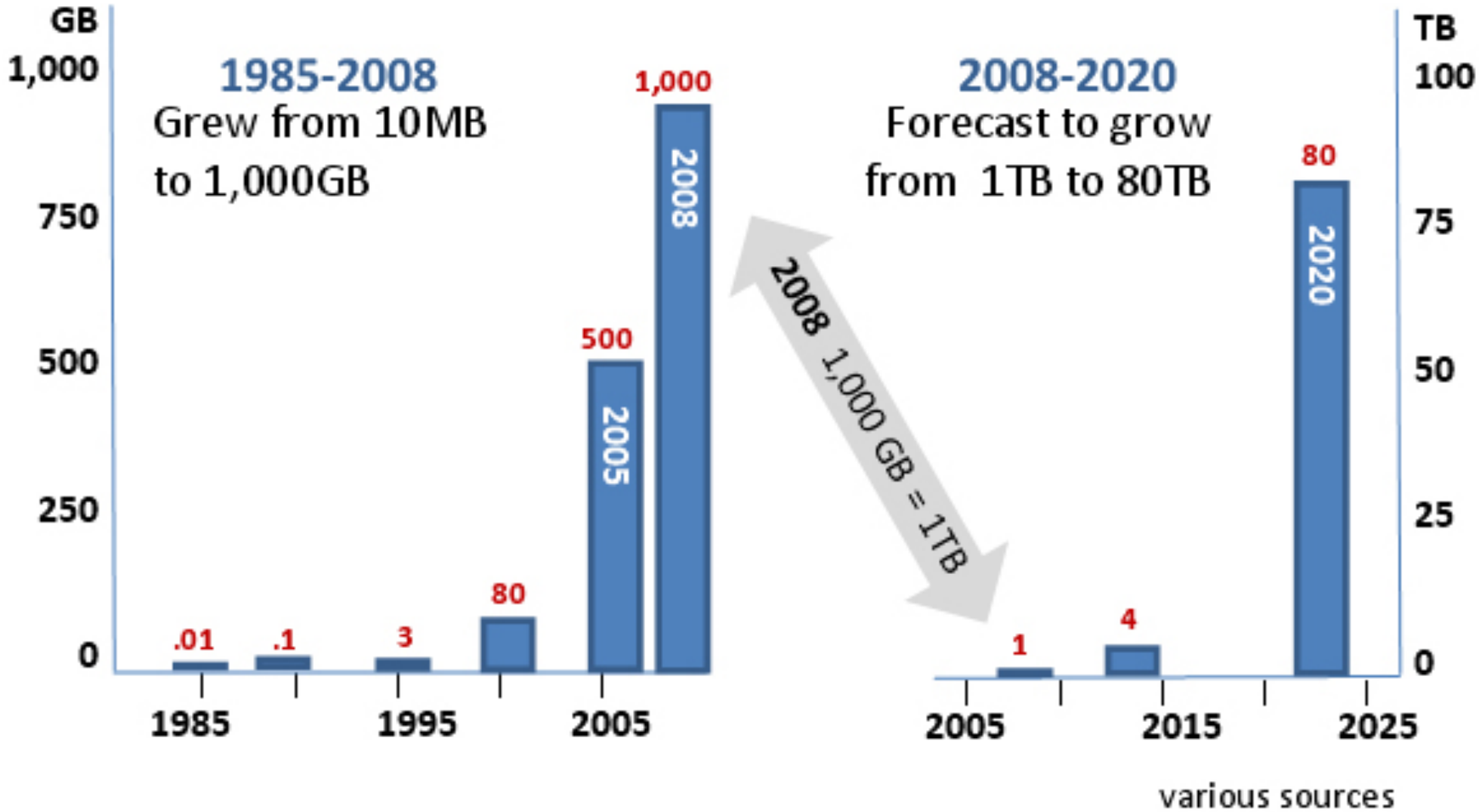
Processor Performance



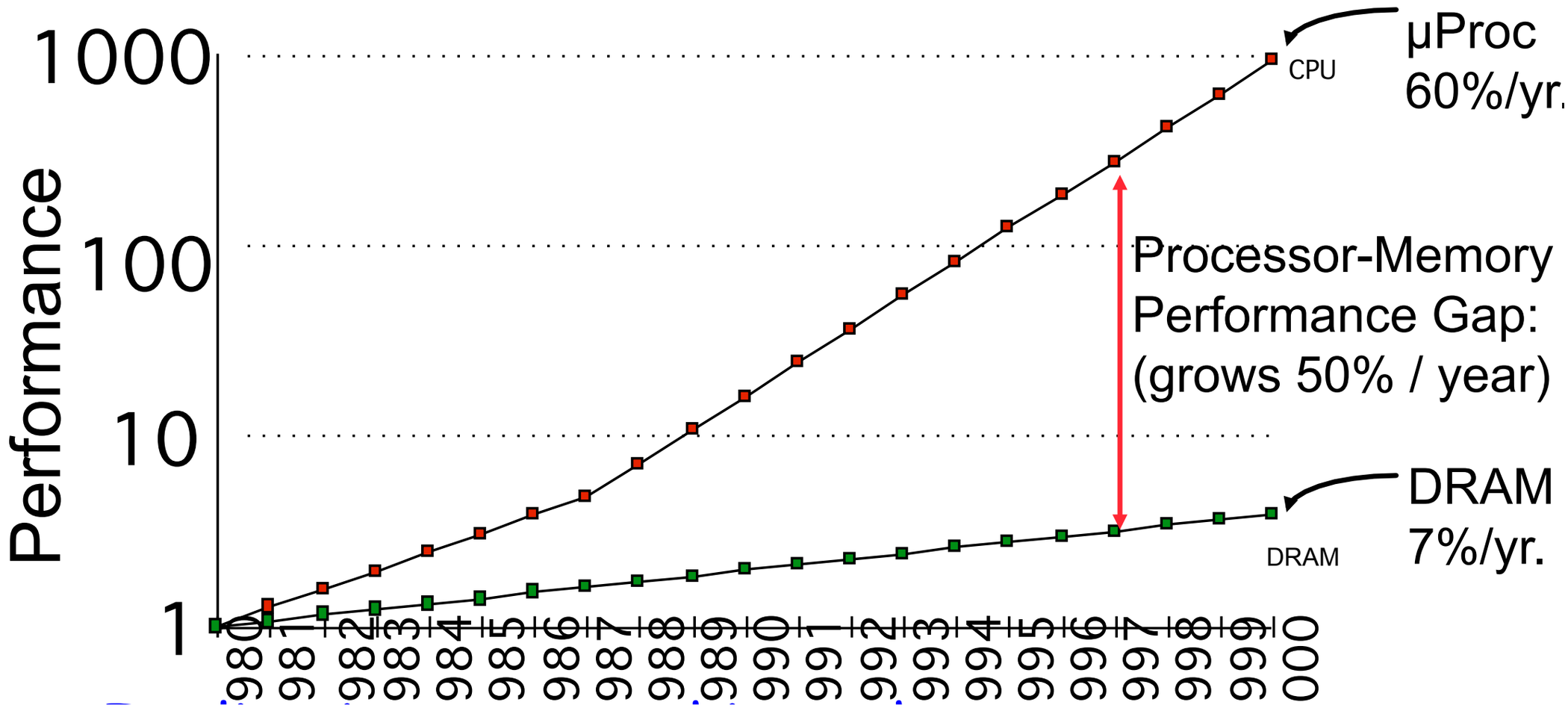
Memory Capacity



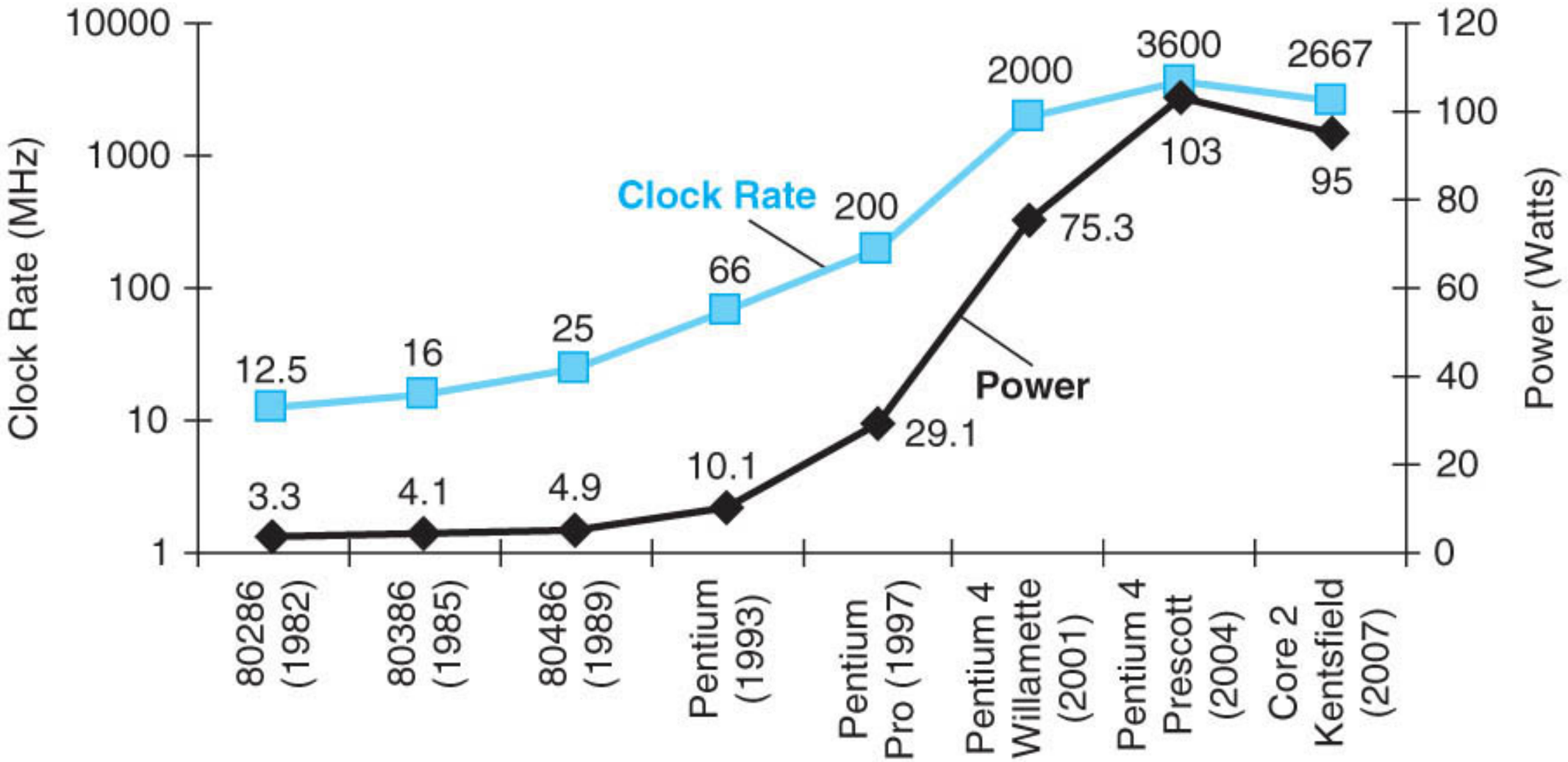
Disk Capacity



CPU–Memory Performance Gap



Power Wall


Clock Rate (MHz)
10000
1000
100
10
1
Power (Watts)
120
100
80
60
40
20
0
Clock Rate
Power
12.5
16
25
66
200
2000
3600
2667
3.3
4.1
4.9
10.1
29.1
75.3
103
95
80286 (1982)
80386 (1985)
80486 (1989)
Pentium (1993)
Pentium Pro (1997)
Pentium 4 Willamette (2001)
Pentium 4 Prescott (2004)
Core 2 Kentsfield (2007)

Summary

- Modern systems are complex
  - Don’t expect much speed-up for single-threaded programs
- Faster processors and systems enable new applications
- Understanding these systems is crucial
  - What are the trade-offs? E.g., power vs performance
  - Addressing CPU–memory gap, power wall, etc.