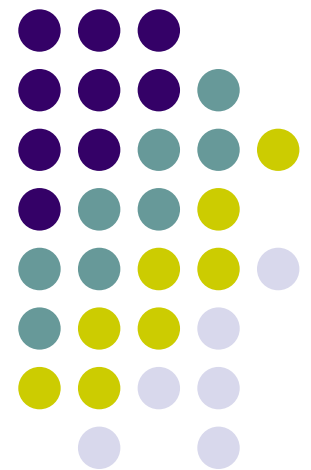
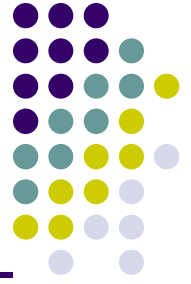


Computer Architecture- 01:198:211 Fall- 2010

Prof Badri Nath
Rutgers University
badri@cs.rutgers.edu

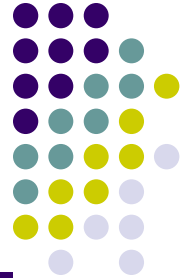


Acknowledgments



- Class notes partially based on
- 211 classes taught at Rutgers in prior years
- Material from textbook site
- Lots of material available on the web (via google search, wikipedia)

Detail...



Me: Prof Badri Nath

badri@cs.rutgers.edu

Office Hours: Mondays 1:40 to 2:40 (Core 320)

TAs: 1. Binh Pham

binhpham@cs.rutgers.edu

Office Hours: Mondays 3:30 to 4:30 (tentative), Hill 412

Recitation: Section 1: Monday ARC 107, 8:25 to 9:20 PM

2. Daniela Vianna

dvianna@cs.rutgers.edu

Office Hours: Tuesday 9 to 10, Hill 404

Recitation: Section 3 Monday ARC 203, 8:25 to 9:20 PM

Rajat Roy

rajatroy@cs.rutgers.edu

Office Hours: Friday 12-2 PM, Hill 257

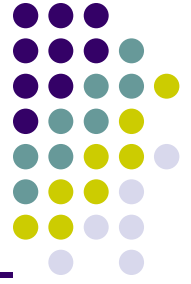
Recitation: Section 2 Wednesday ARC 205, 8:25 to 9:20 PM

Web: <https://sakai.rutgers.edu>

<http://www.cs.rutgers.edu/~badri/cs211/>

(You're required to check this page regularly)

Text



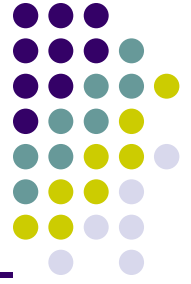
- Books:
 - Computer Systems by Randall Bryant and David O'Hallaron ... Required text
 - Computer Organization and Design by David Patterson and John Hennessy (4th edition)

Prerequisites: 198:112

What this really means:

- You know at least one programming language.
- You know something about how to write, run, and test programs.
- Elementary knowledge of math and algorithms

C resources



- ***The C Programming Language***
by Brian W. Kernighian & Dennis M. Ritchie
- C tutorial
 - <http://www.le.ac.uk/cc/tutorials/c/>
- Intro to C
 - <http://cprog.tomsweb.net/cintro.html>

Grading



Grading:

Mid-terms - 30%

Final Exam – 35%

Projects – 35% (PA1: 5, PA2: 10, PA3: 10, PA4: 10)

Written Homework

Final Exam is cumulative.

No make-up exams except for university sanctioned reasons.

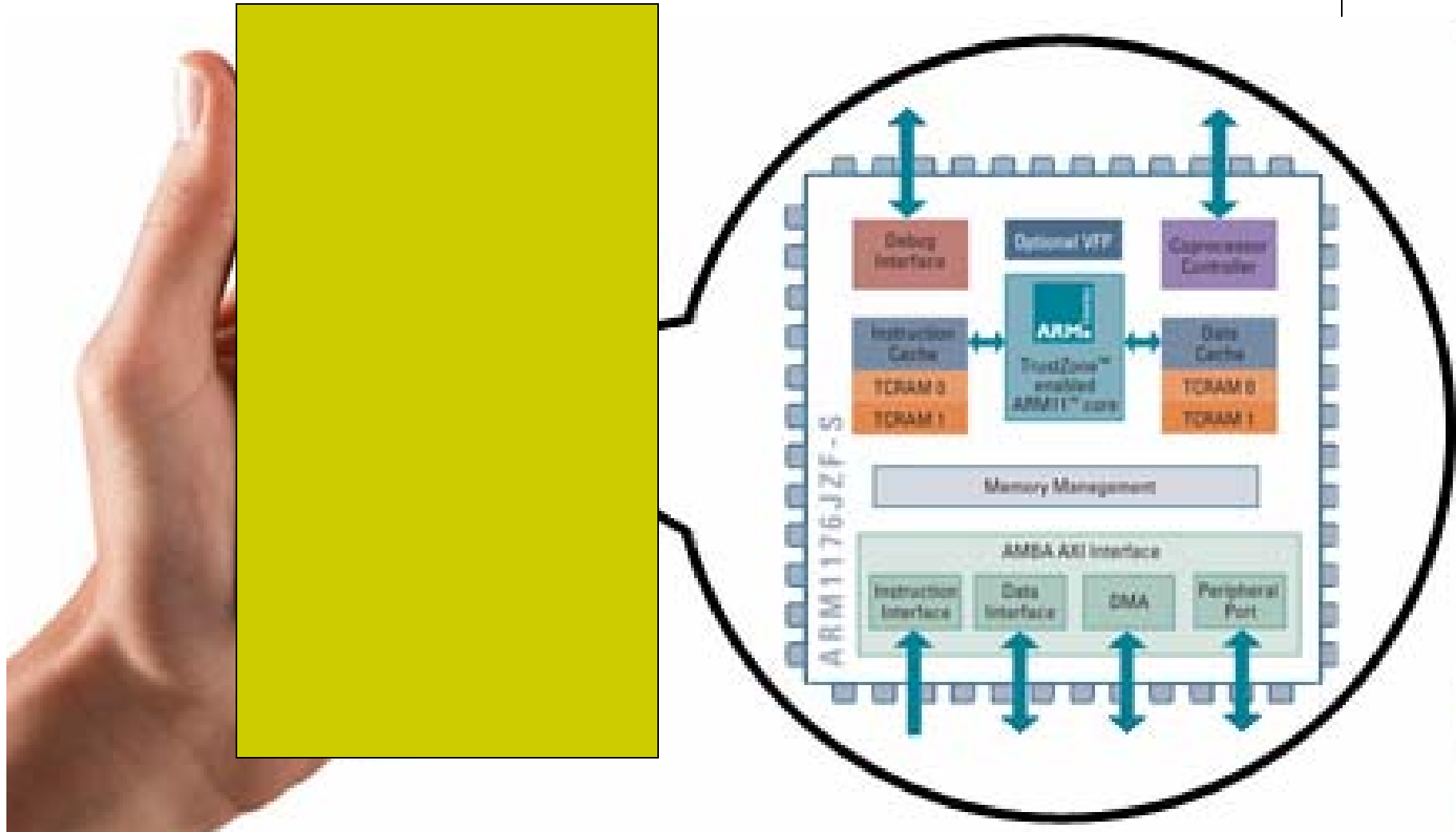
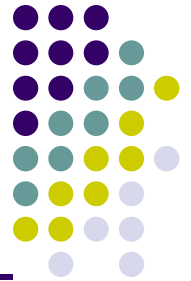
Must inform professor before the exam. Don't assuming informing implies being allowed to take a make-up (see above statement).

Make-up will be held the next day, early morning.

Projects are not created equally.

Later projects are harder and hence worth more.

Computer Architecture



620 Mhz L1 cache 32 KB

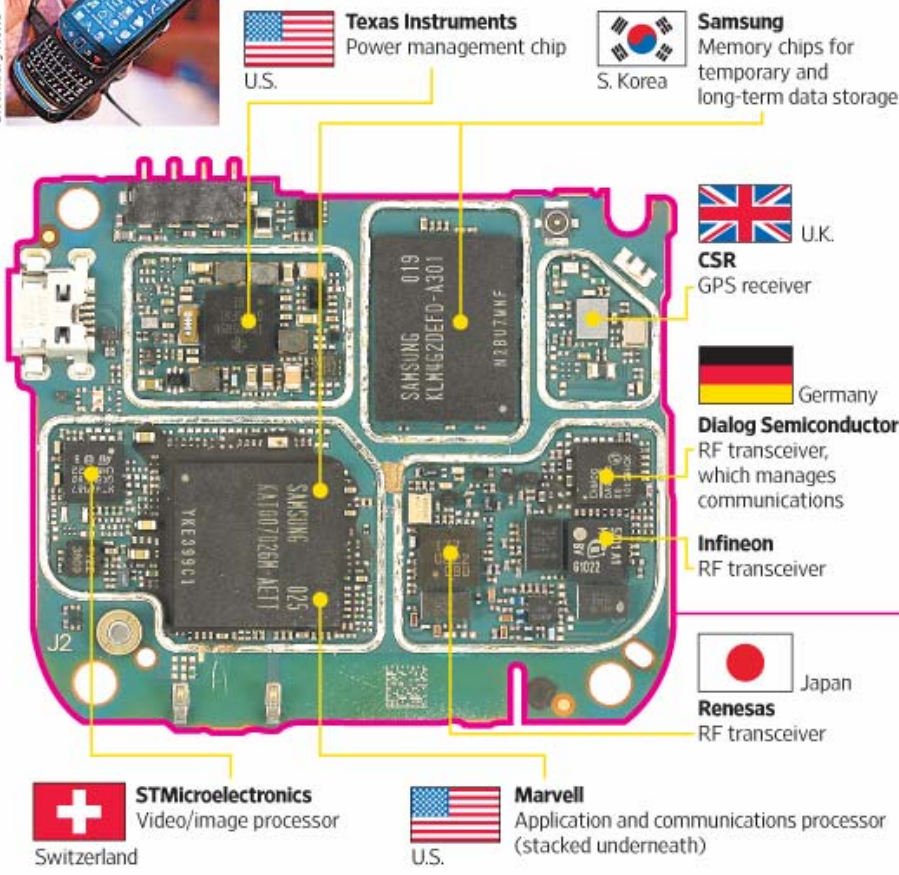


Inside BlackBerry Torch



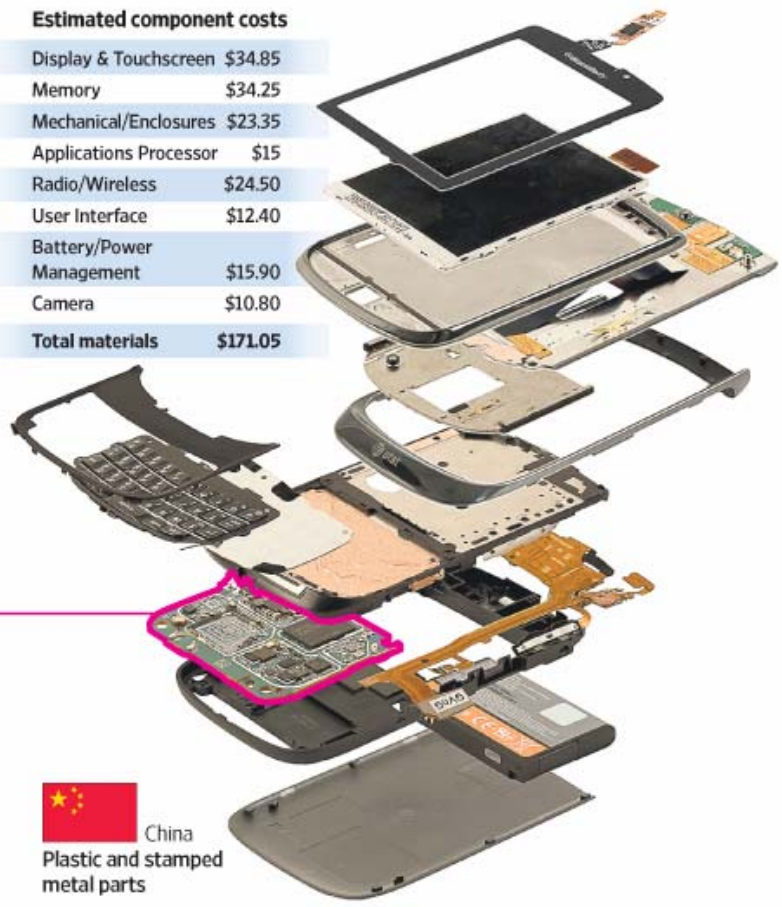
Bloomberg News

Research firm iSuppli took apart the new BlackBerry Torch 9800 to identify key suppliers and estimate the cost of components. Here's some of the findings about the smartphone, which the firm said was assembled for RIM in Mexico and likely relies on plastic and stamped metal parts from China.



Estimated component costs

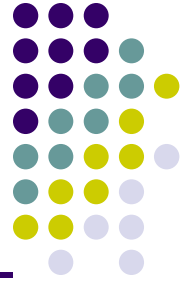
Display & Touchscreen	\$34.85
Memory	\$34.25
Mechanical/Enclosures	\$23.35
Applications Processor	\$15
Radio/Wireless	\$24.50
User Interface	\$12.40
Battery/Power Management	\$15.90
Camera	\$10.80
Total materials	\$171.05



China
Plastic and stamped metal parts

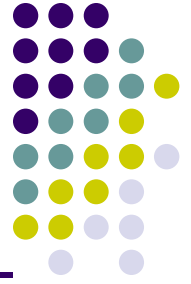
Source: iSuppli; With reporting by Don Clark, Phred Dvorak and Jennifer Valentino-DeVries

Ipap A4 Processor



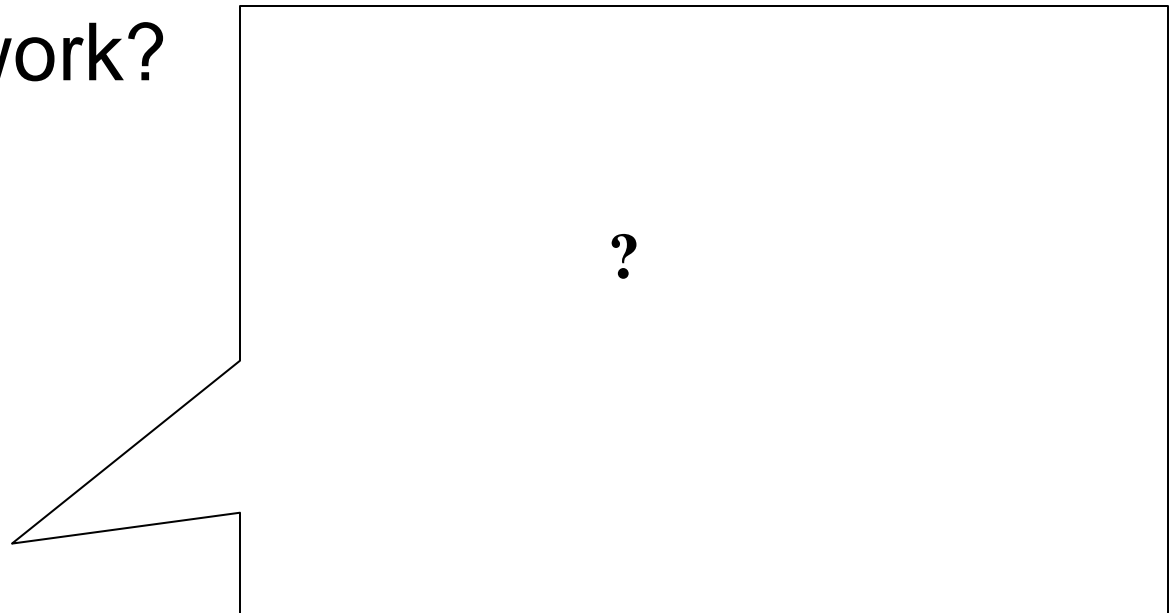
Max. CPU clock rate 1 GHz (iPad)
Instruction set ARM v7 32 bit RISC
Cores 1
L1 cache 64 KB
L2 cache 640 KB

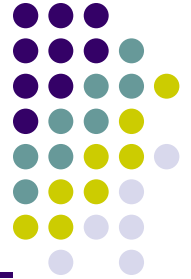




Computer Architecture

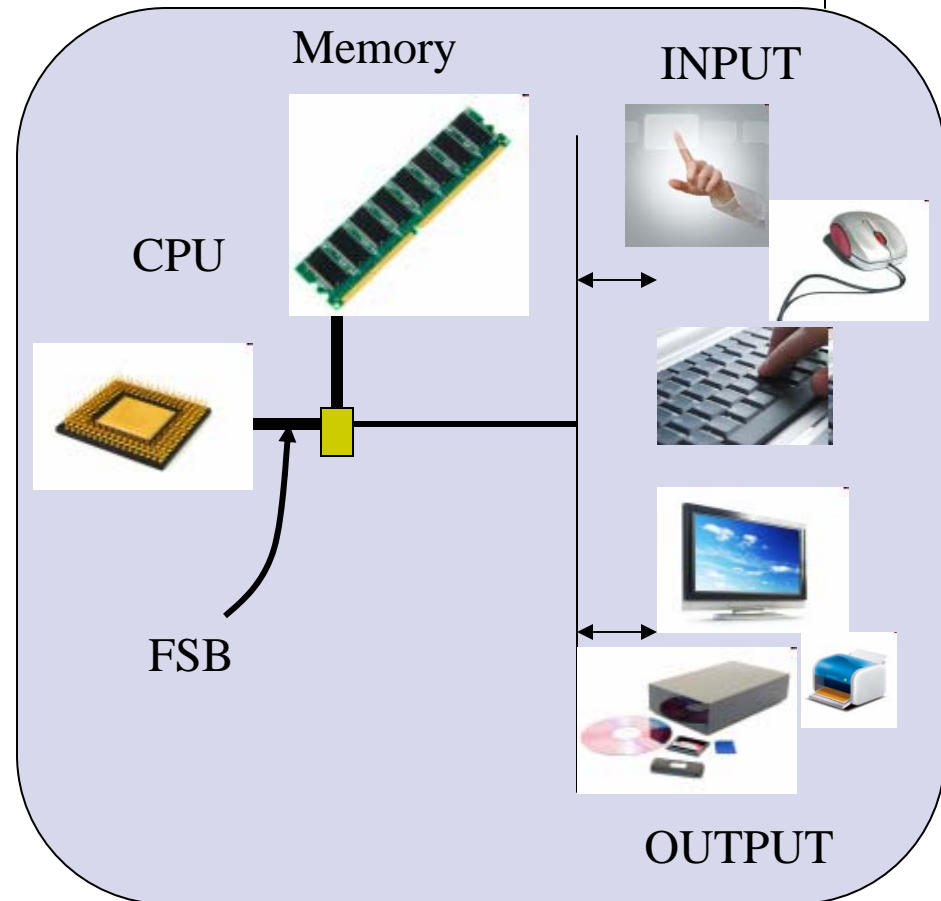
- Architecture: art or practice of designing
- What's Inside?
- How is it put together?
- How does it work?





Main Components

- CPU
 - Executes Instructions
- Memory
 - Stores Programs and data
- BUS
 - Transfers data
 - Front Side Bus (FSB)
- Storage
 - Permanent
- I/O devices
 - Input
 - Keypad, Mouse, Touch
 - Output
 - Printer, Screen
 - Both (input and output)
 - USB, Wifi, Touch screen,
 - DISK



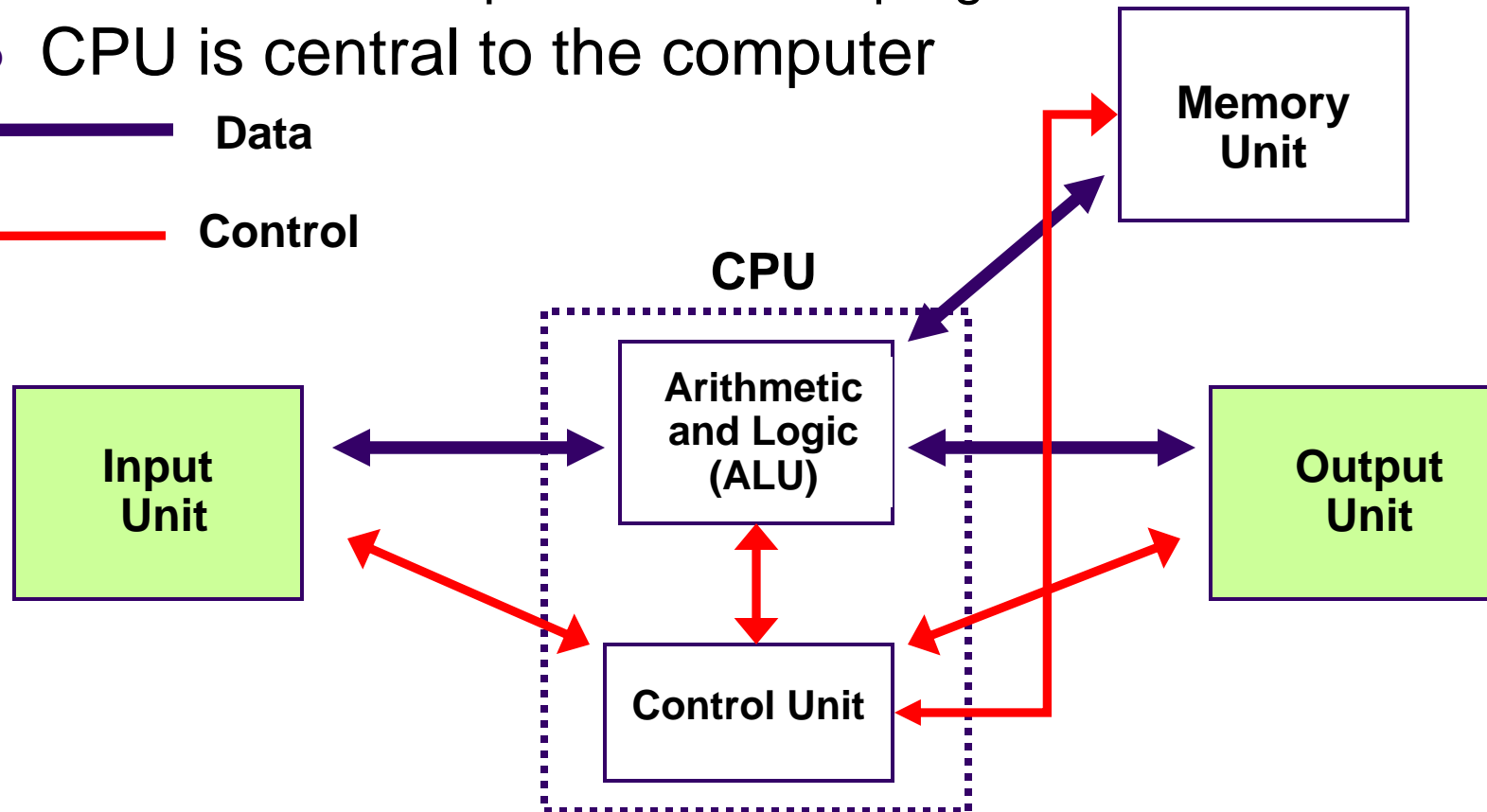


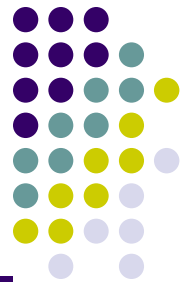
Von Neumann Architecture

- Model of a computer that used stores programs
 - Both Data and Program stored in memory
 - Allows the computer to be “Re-programmed”
- CPU is central to the computer

— Data

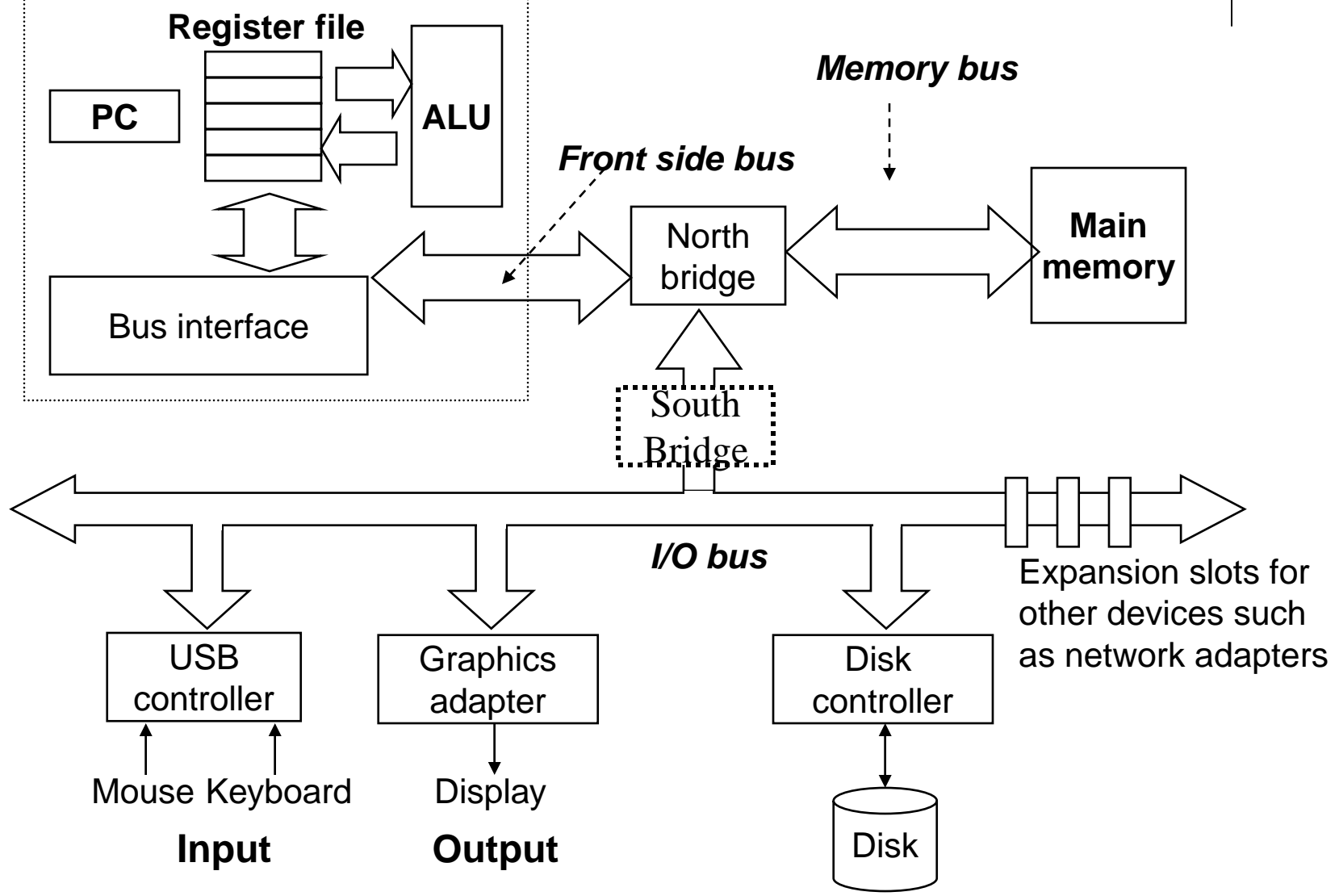
— Control



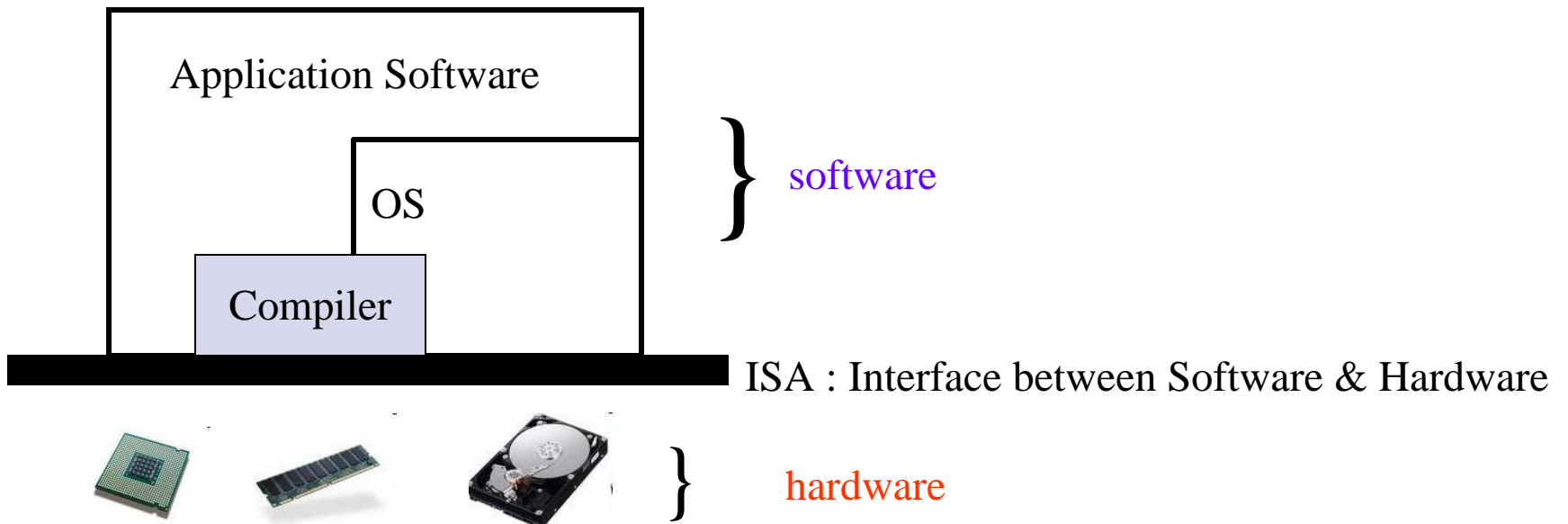
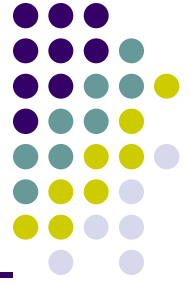


Von Neumann in Practice

CPU



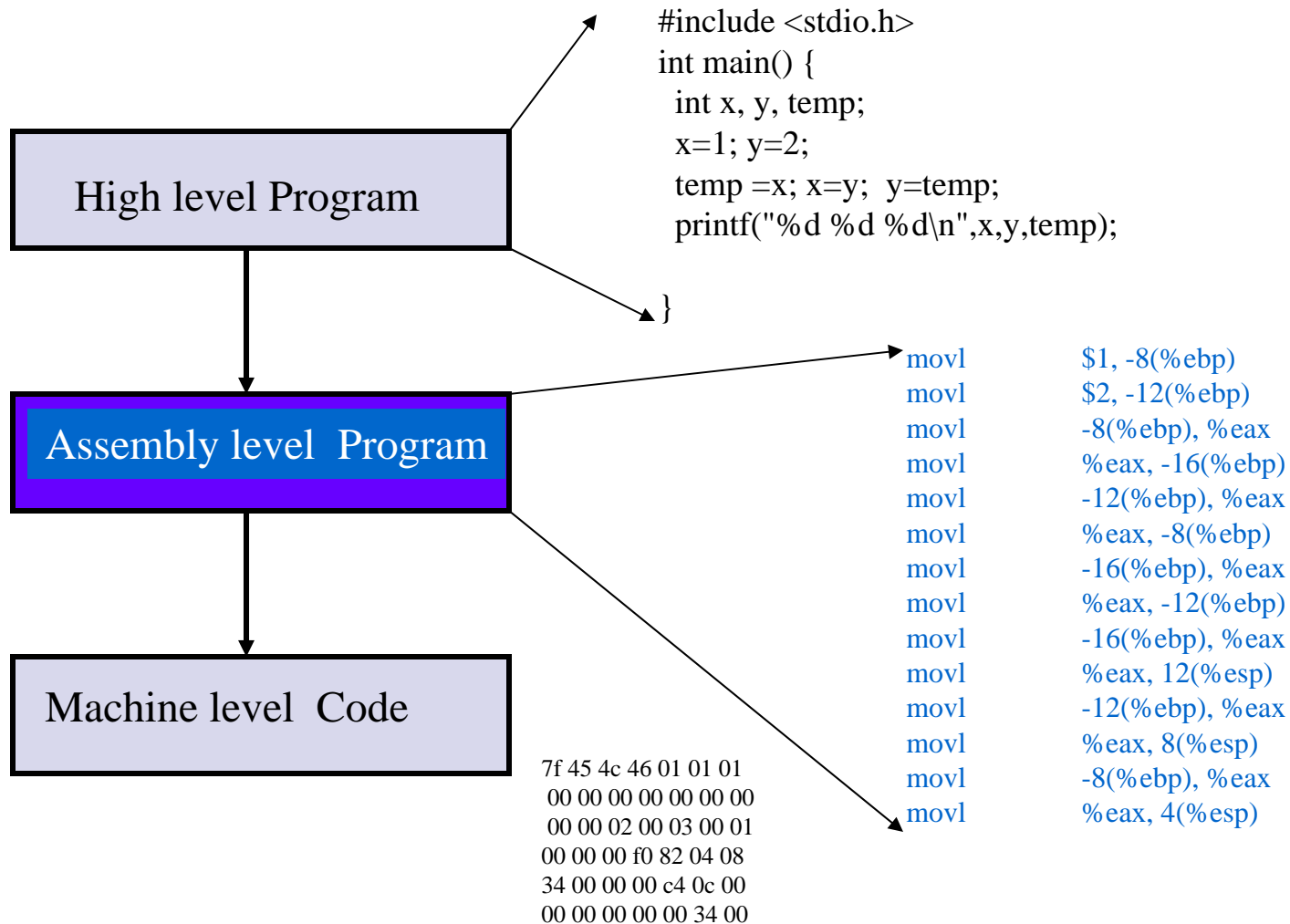
Instruction Set Architecture



Computer Architecture: ISA, memory, I/O, Power
Specialized H/W: GPU, co-processor



Prog Language to Hardware



What will you get out of the course?

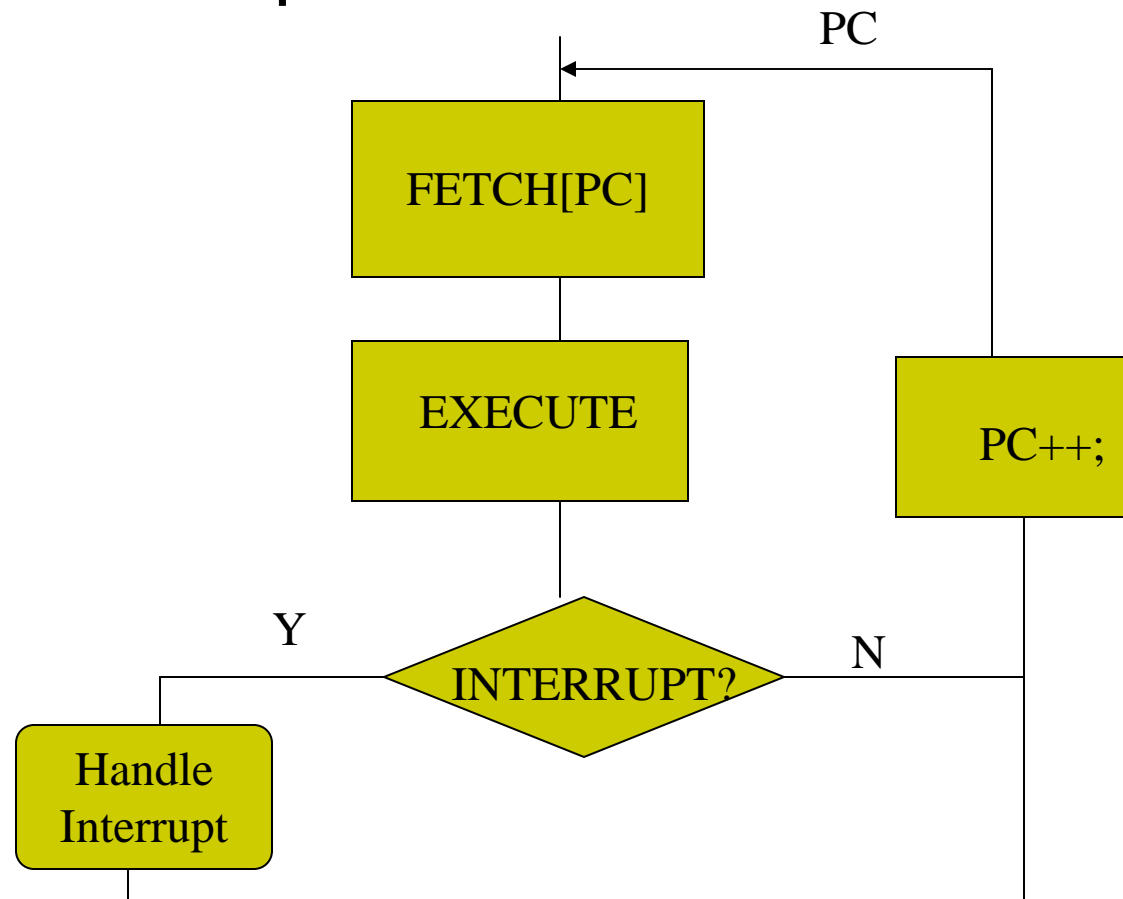


- Basic Elements of Computer Systems
 - CPU, Memory, I/O
- Workings of various sub systems
- Design issues
 - Performance vs cost tradeoffs
- Interaction of Software (programs) and the underlying hardware (on which programs execute)

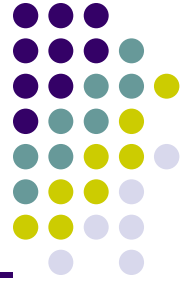
Understanding Processor/CPU performance



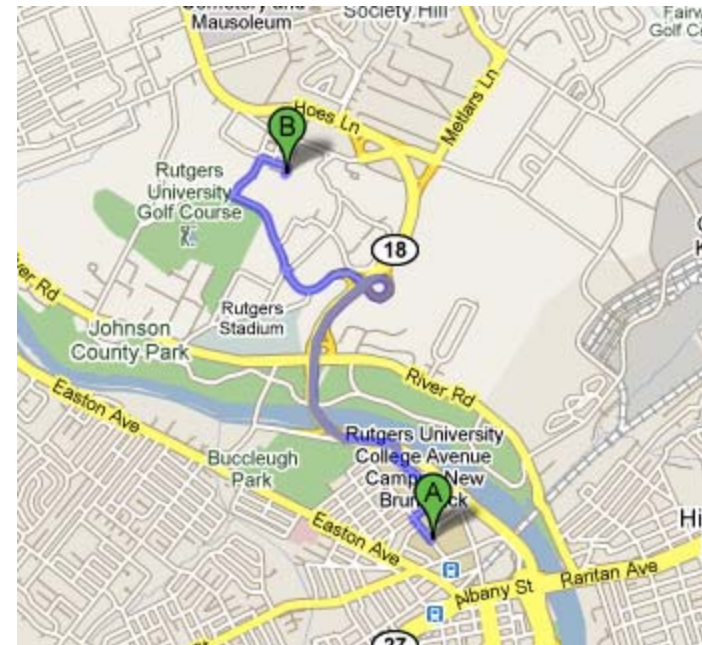
- What does a processor do?



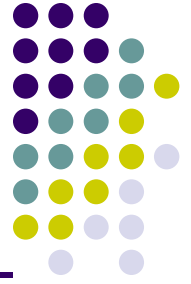
Measuring Processor Speed



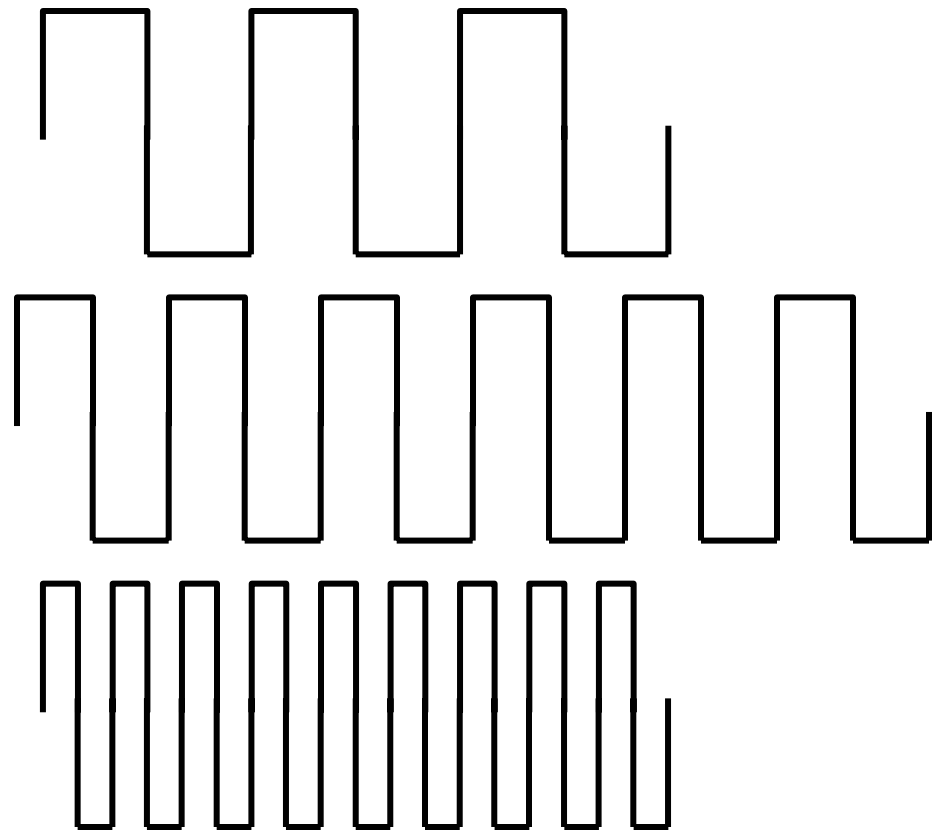
- How long does it take to execute a program
 - quicker the better
- How long does it take to go from point A to Point B
- Need to Know
 - Speed, Distance (or)
 - Start time, End time
- Speed
 - Constant, Average, Variable
 - RPM, Circumference, distance



CPU Clock



- Every action is driven by a clock in the CPU
- Clock time = $1/\text{Frequency}$
- Mhz clock = 10^{-6} seconds
- Ghz clock = 10^{-9} seconds
- From CPU speed, you know time for 1 clock cycle



Time for a program



- CPU executes various instructions
- A Program has several Instructions
 - How many?
 - Depends on program, compiler
- Each Instruction can take several CPU cycles
 - How many?
 - Depends on the Instruction Set Architecture (ISA)
 - ISA – Learn in this course
- Each cycle has a fixed time based on CPU , BUS speed
 - What is the clock time, memory speed etc?
 - Depends on the hardware, organization
 - Computer Architecture – Learn in this course



CPU Performance Equation

CPU time = # of Instructions × Cycles Per Instruction × Clock cycle time

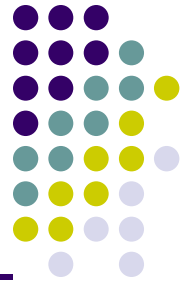
$$\text{CPU time} = \frac{\text{Seconds}}{\text{Program}} = \frac{\text{Instructions}}{\text{Program}} \times \frac{\text{Clock Cycles}}{\text{Instruction}} \times \frac{\text{Seconds}}{\text{Clock Cycle}}$$

How Good is the Compiler?

Defined by the Architecture

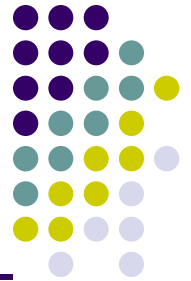
How fast is the processor?

Quantifying Computer components



- CPU Speed
 - Mhz or Ghz CPU Speed, MIPS, MFLOPS...
 - 1.33 Ghz ... Intel Atom processor
- Bus Speed
 - Front Side Bus (FSB) ... 533 Mhz Intel Atom
 - Number of channels, Number of data paths
- Memory capacity, memory speed
 - Gigabytes, Mhz x DataRate
 - 166 MHz DDR memory, Quad pump
- Disk capacity, Disk Bandwidth
 - GB, TB, MB/sec
- Power Consumption
 - Watts, mWatts,
 - Battery life time (standby vs active) Watt-Hr

Class of CPU



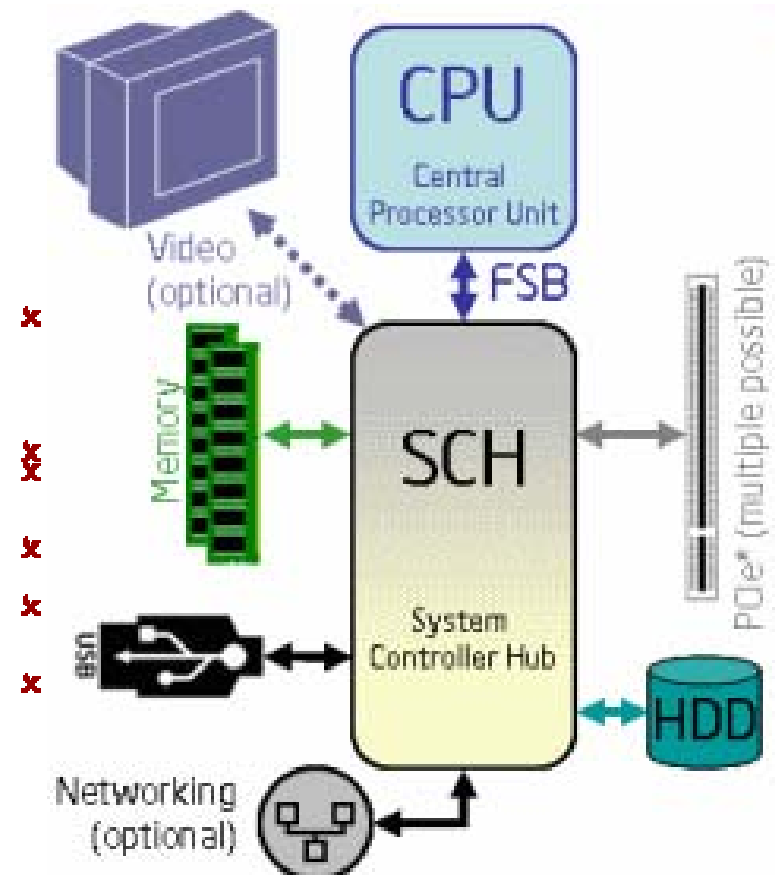
	Server	Desktop	Embedded
Cost of System	5K to 1 M	700\$ to 5K	100 to 700\$
Cost of CPU	50\$ to 1K	70 \$ to 200\$	\$ 1 to \$100
Performance metrics	Throughput Availability	Response time, price Graphics	Power, Battery life Graphics



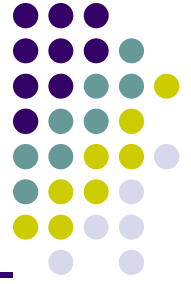
Intel atom

Essentials

Status	Launched
Launch Date	Q2'08
Processor Number	Z520
# of Cores	1
Clock Speed	1.33 GHz
L2 Cache	512 KB
FSB Speed	533 MHz
FSB Parity	
Instruction Set	32-bit
Embedded	
Supplemental SKU	
Lithography	45 nm
Max TDP	2 W
VID Voltage Range	0.75-1.1V

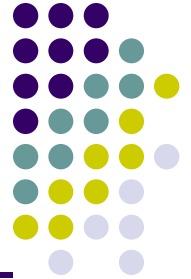


Other Systems



- iPhone
 - 620 Mhz ARM chip
 - SIMD, high performance integer CPU (8-stage pipeline, 675 Dhrystone, 2.1 MIPS)
 - 16 K/16 K cache
 - **0.45 mW/MHz power draw (with cache)**
- Wii
 - CPU: PowerPC-based "Broadway" processor, 729 Mhz
 - **GPU: ATI "Hollywood" GPU, 243 MHz**
- iPad
 - **1GHz Apple A4**
 - **Upto 10 hours of battery life**

Laptop Ratings

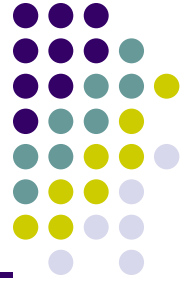


IBM ThinkPad T42 (Pentium M Processor 735 1.7GHz, 512MB RAM)



Intel® Core™ 2 Duo P8600 (2.4GHz/1066Mhz FSB/3MB cache), 4G memory,
100 G disk

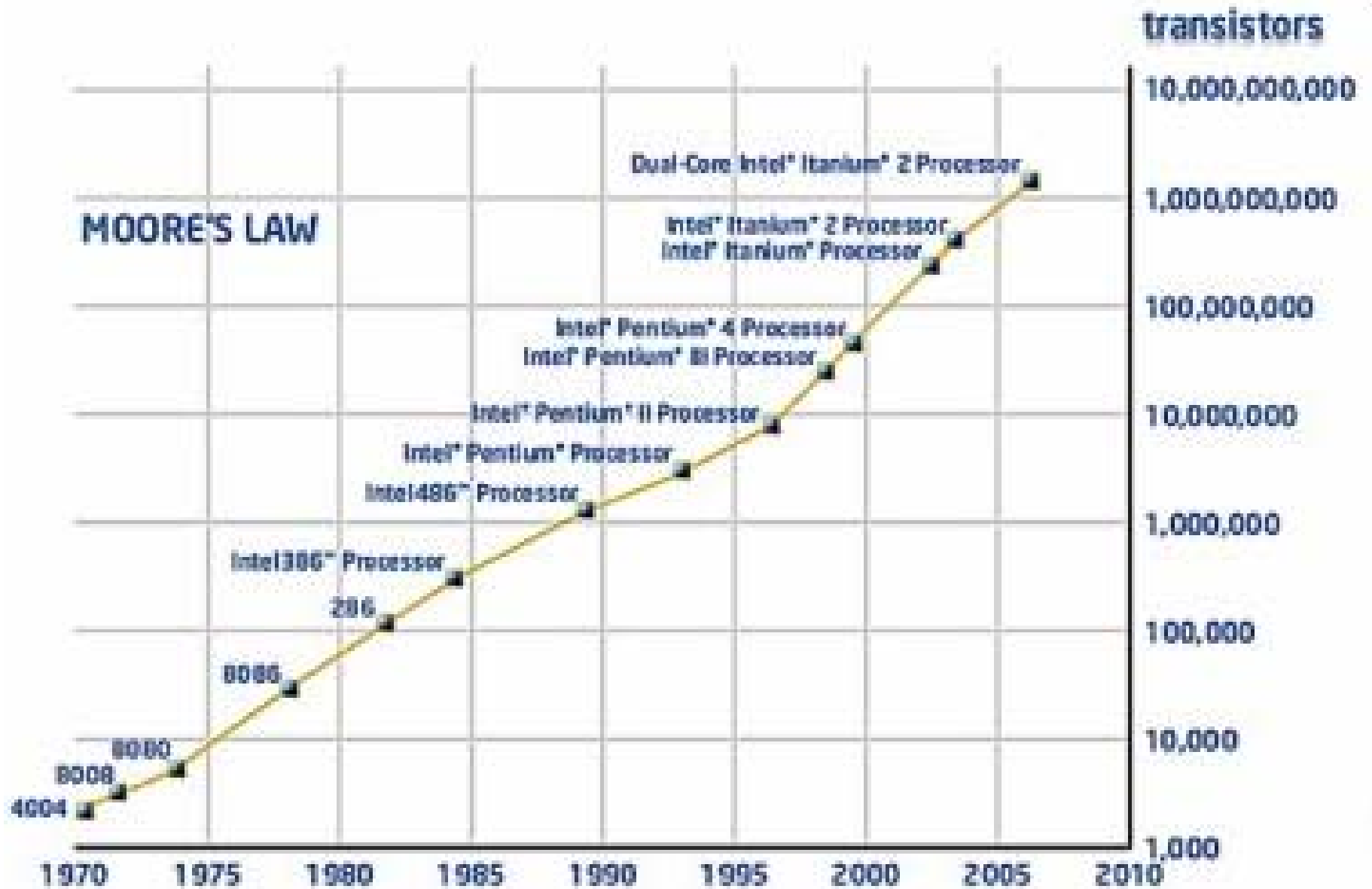
Moore's law



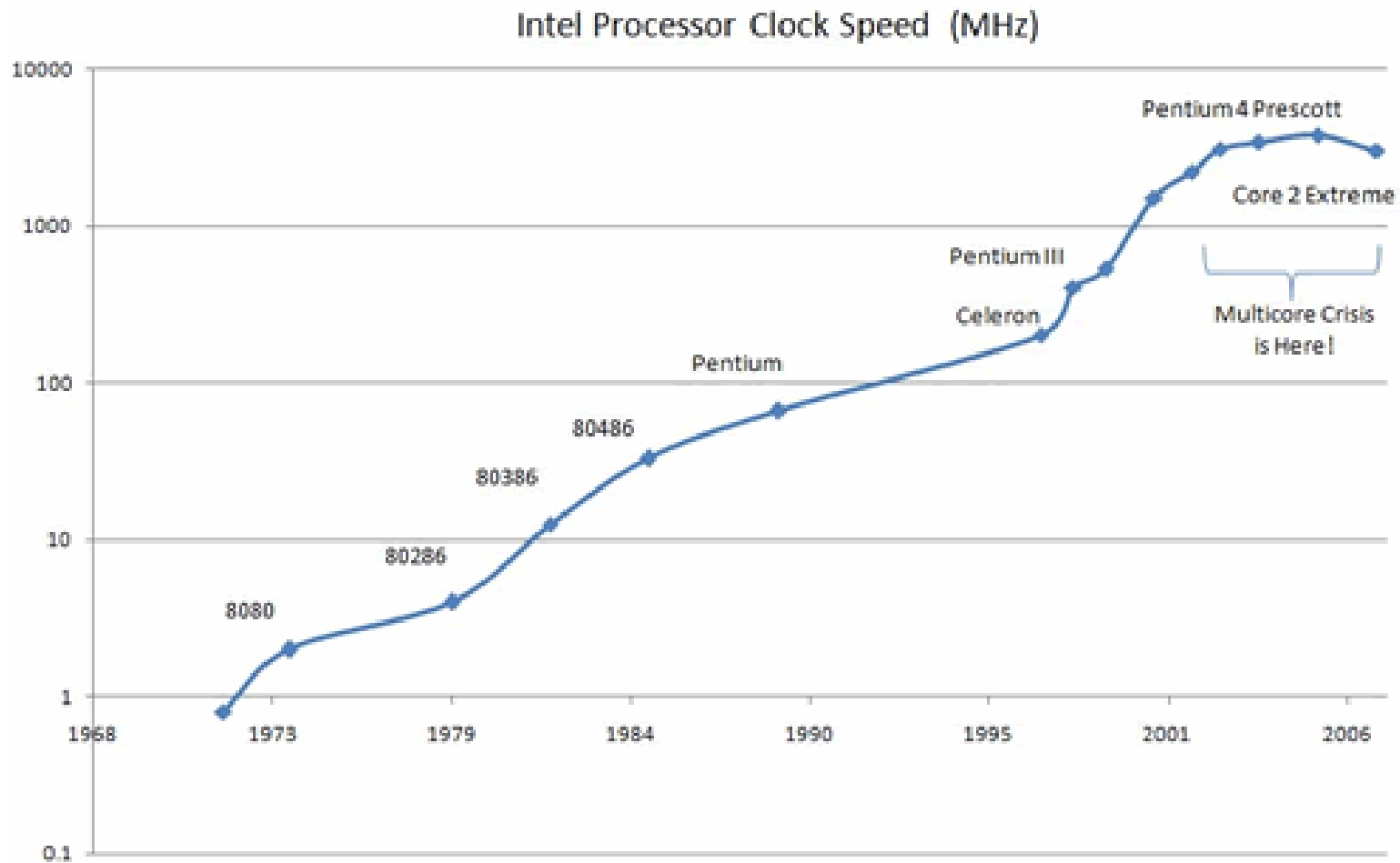
- Gordon Moore was an Intel Engineer
- An observation about improvements in hardware
- No of transistors on a chip double every 18 months
- Exponential growth seen in other hardware
 - Memory capacity
 - 2x every 2 years
 - Processors Speed
 - 2x every 18 months
 - Disk capacity
 - 2x every year



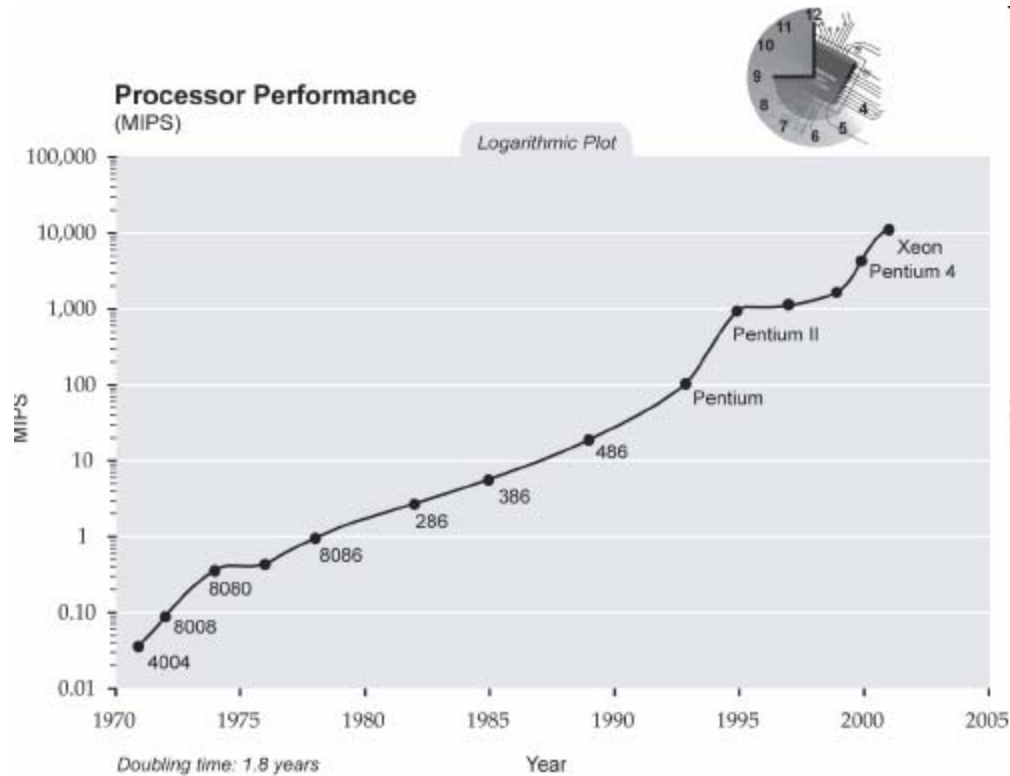
Moore's Law applied to transistors on a chip



Clock speed



Processor Performance



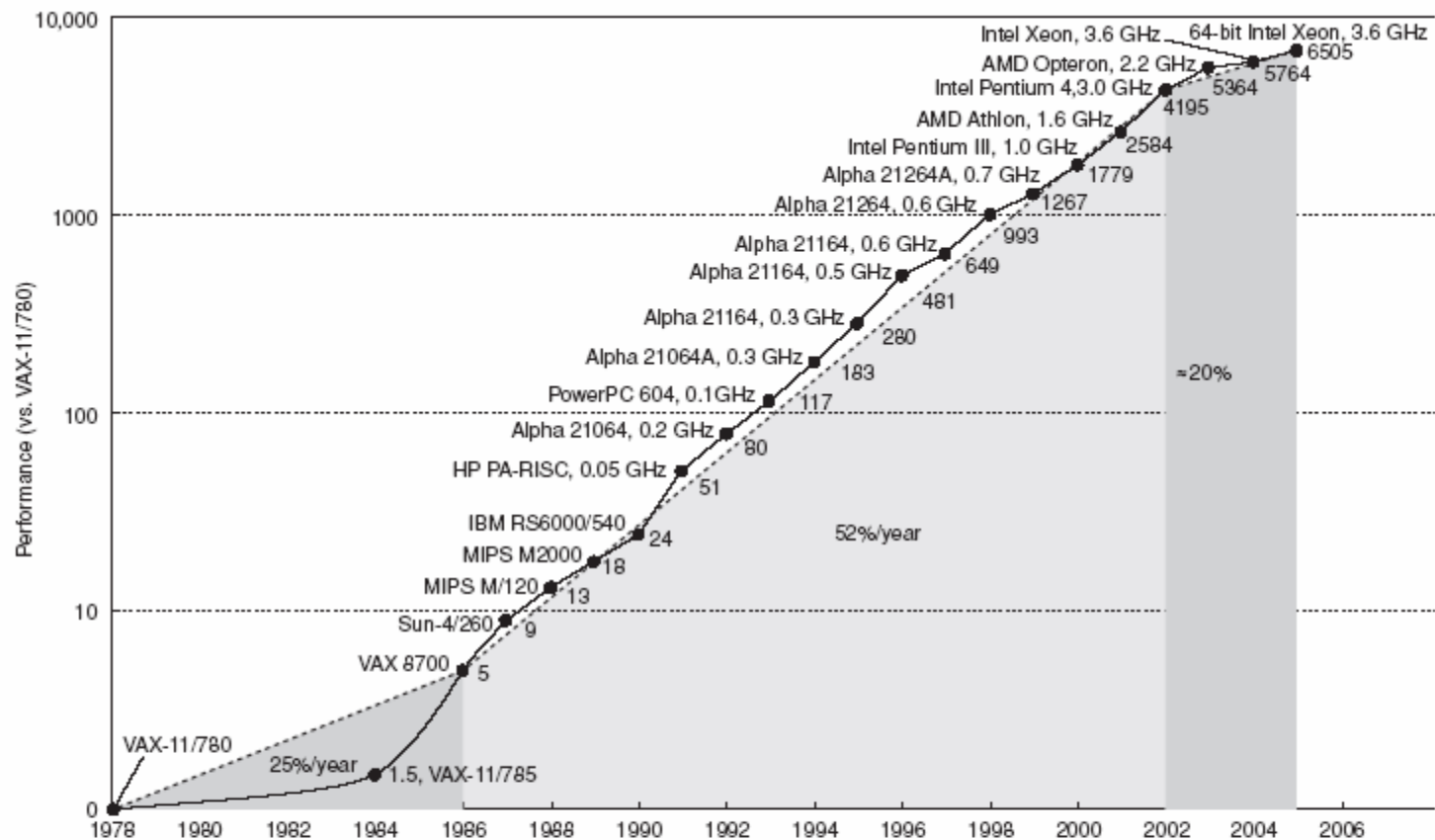
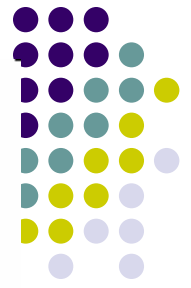
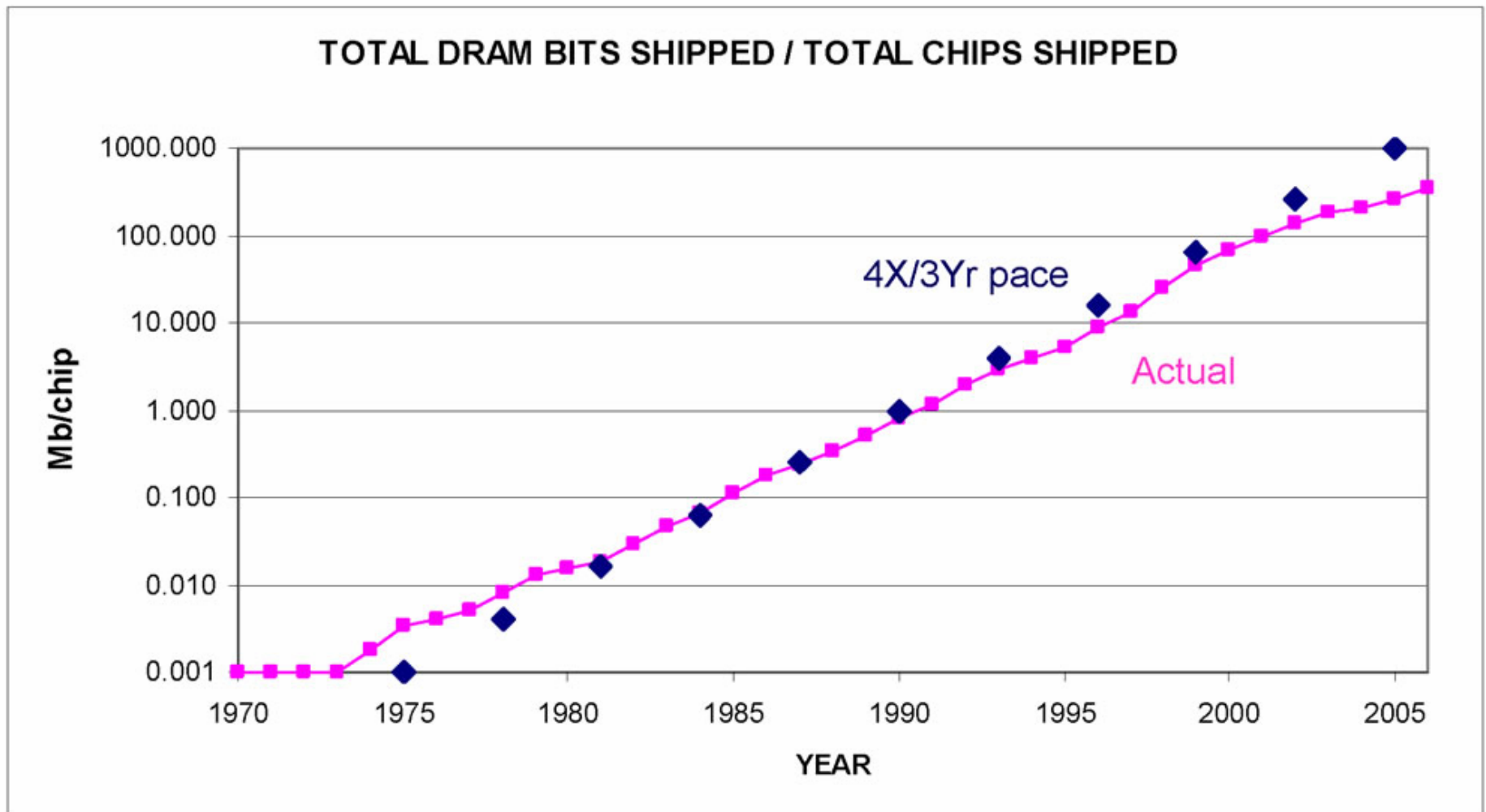


Figure 1.1 Growth in processor performance since the mid-1980s. This chart plots performance relative to the VAX 11/780 as measured by the SPECint benchmarks (see Section 1.8). Prior to the mid-1980s, processor performance growth was largely technology driven and averaged about 25% per year. The increase in growth to about 52% since then is attributable to more advanced architectural and organizational ideas. By 2002, this growth led to a difference in performance of about a factor of seven. Performance for floating-point-oriented calculations has increased even faster. Since 2002, the limits of power, available instruction-level parallelism, and long memory latency have slowed uniprocessor performance recently, to about 20% per year. Since SPEC has changed over the years, performance of newer machines is estimated by a scaling factor that relates the performance for two different versions of SPEC (e.g., SPEC92, SPEC95, and SPEC2000).

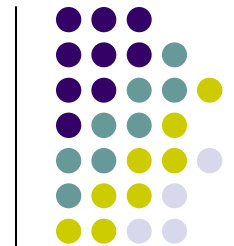




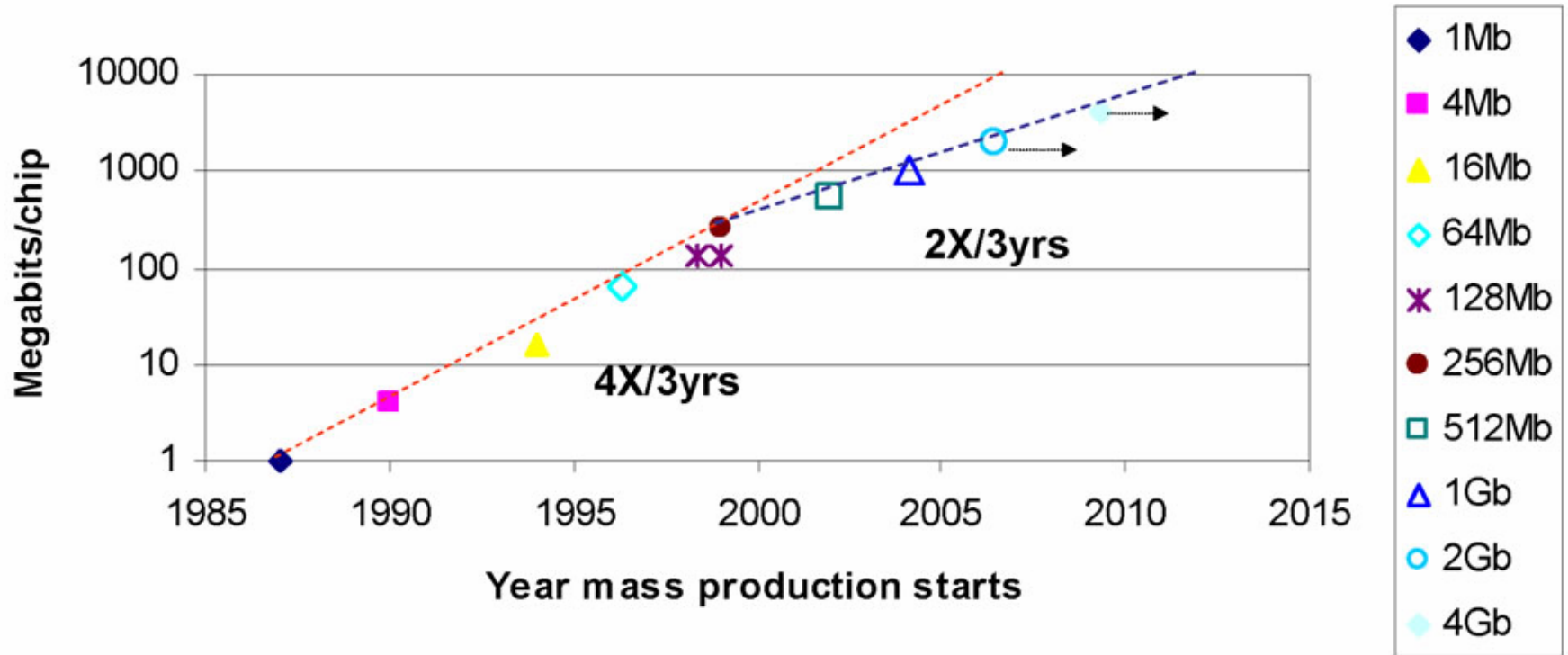
DRAM capacity



Source: WSTS

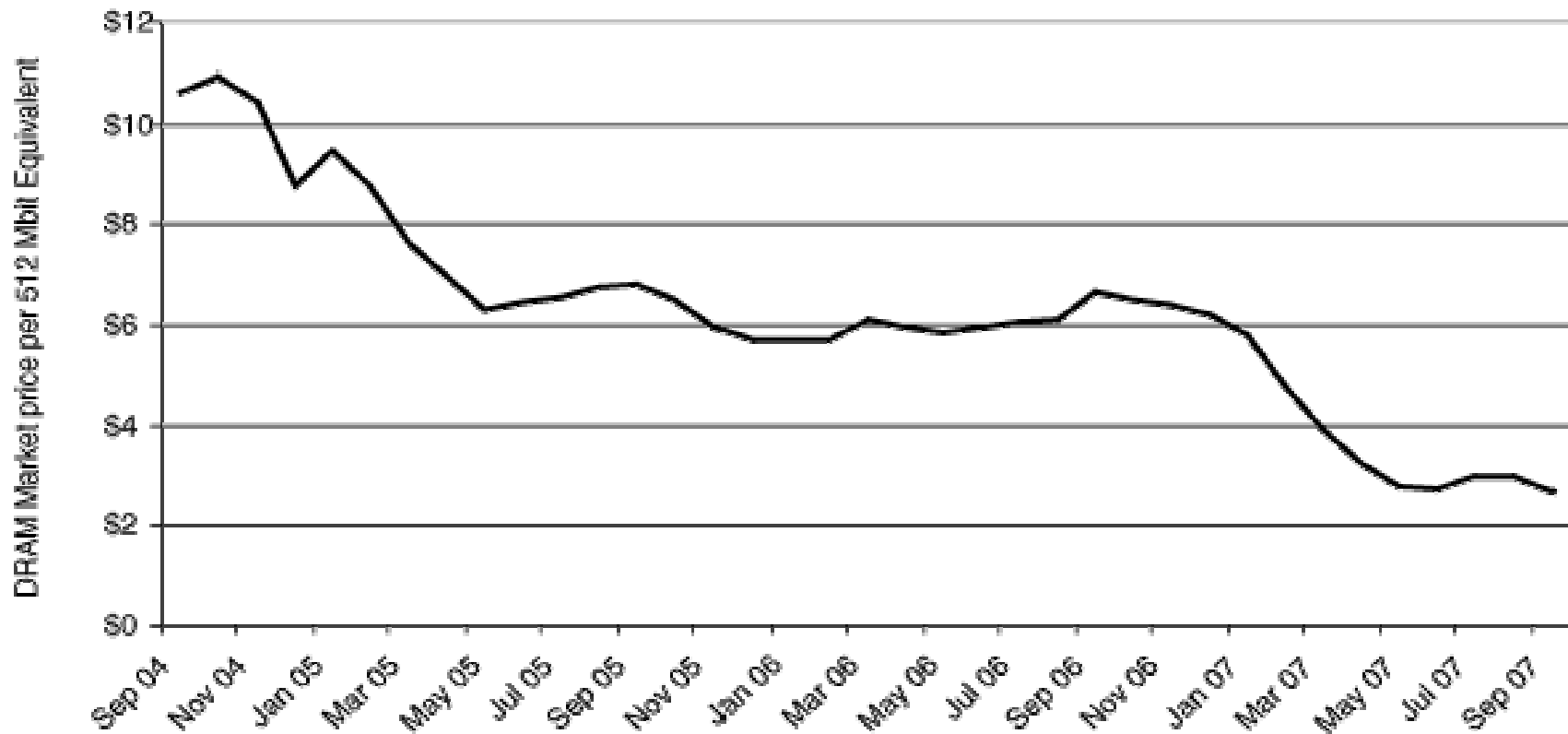
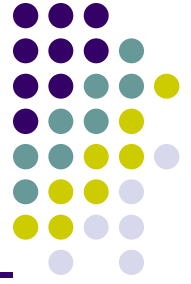


Evolution of memory granularity



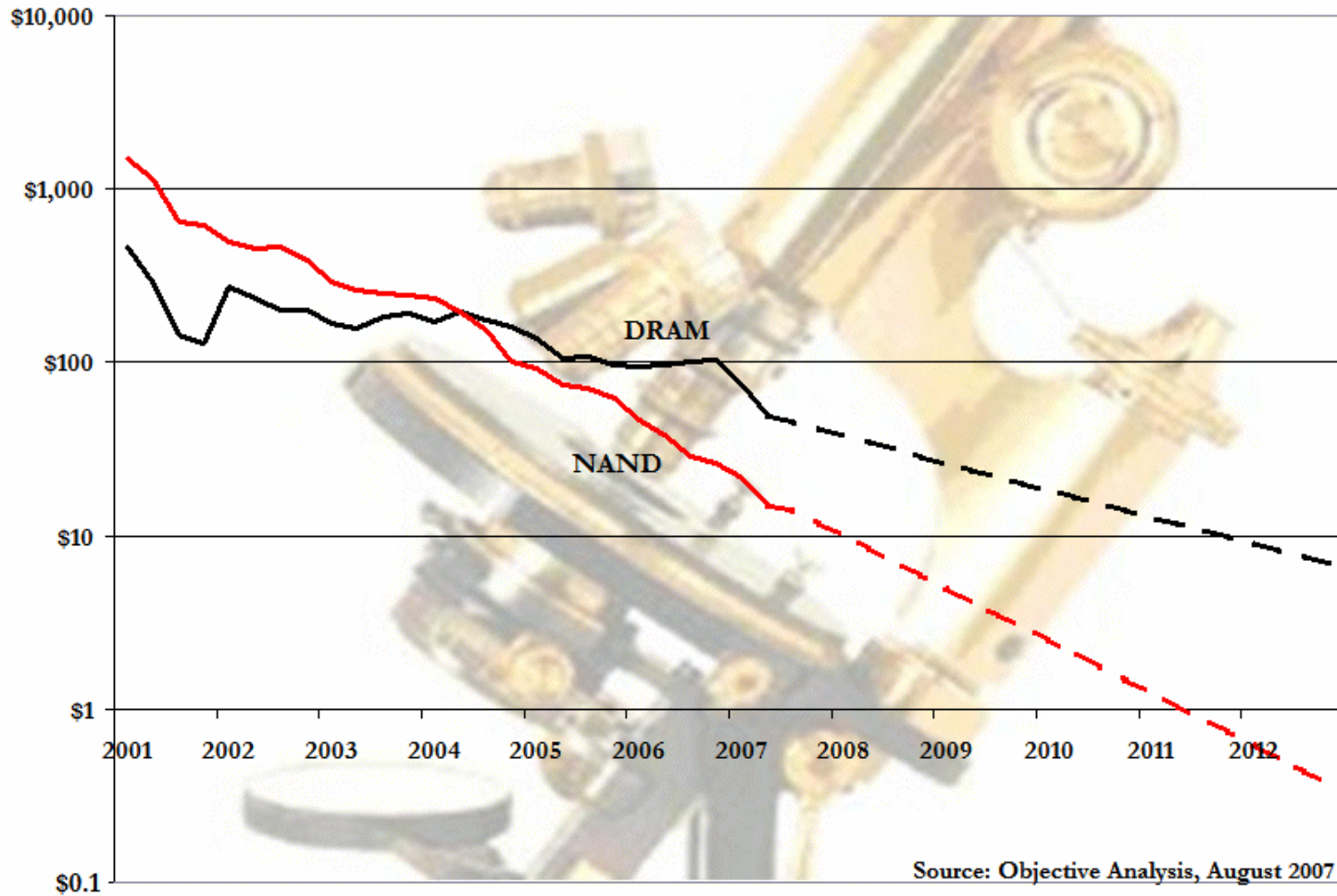
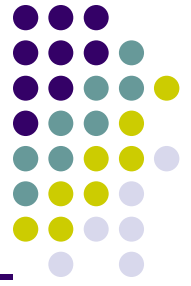
Source of image at:
www.ieee.org/.../08Winter&file=Isaac.xml

Memory Price

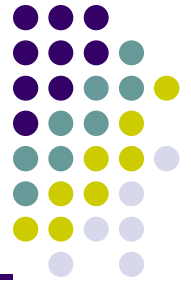


Retail \$ 50 to \$ 100/ GB

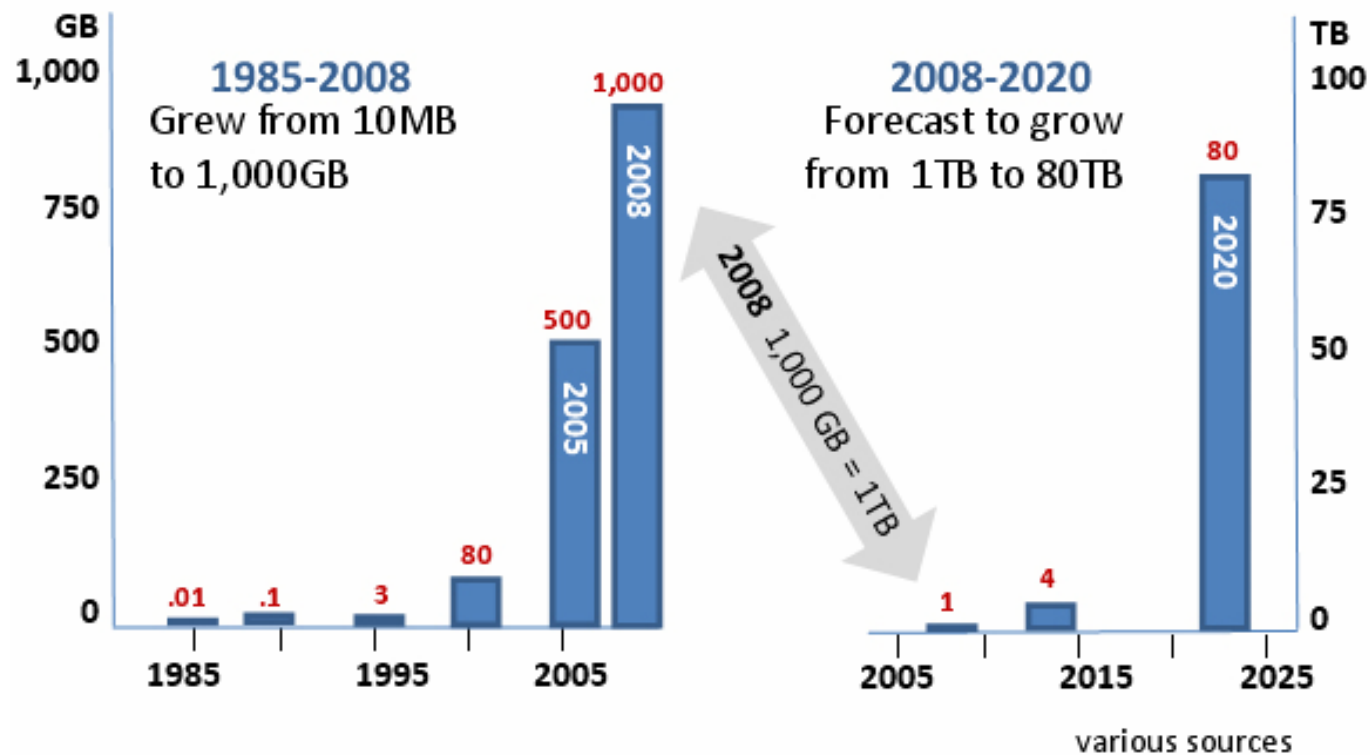
Memory Price



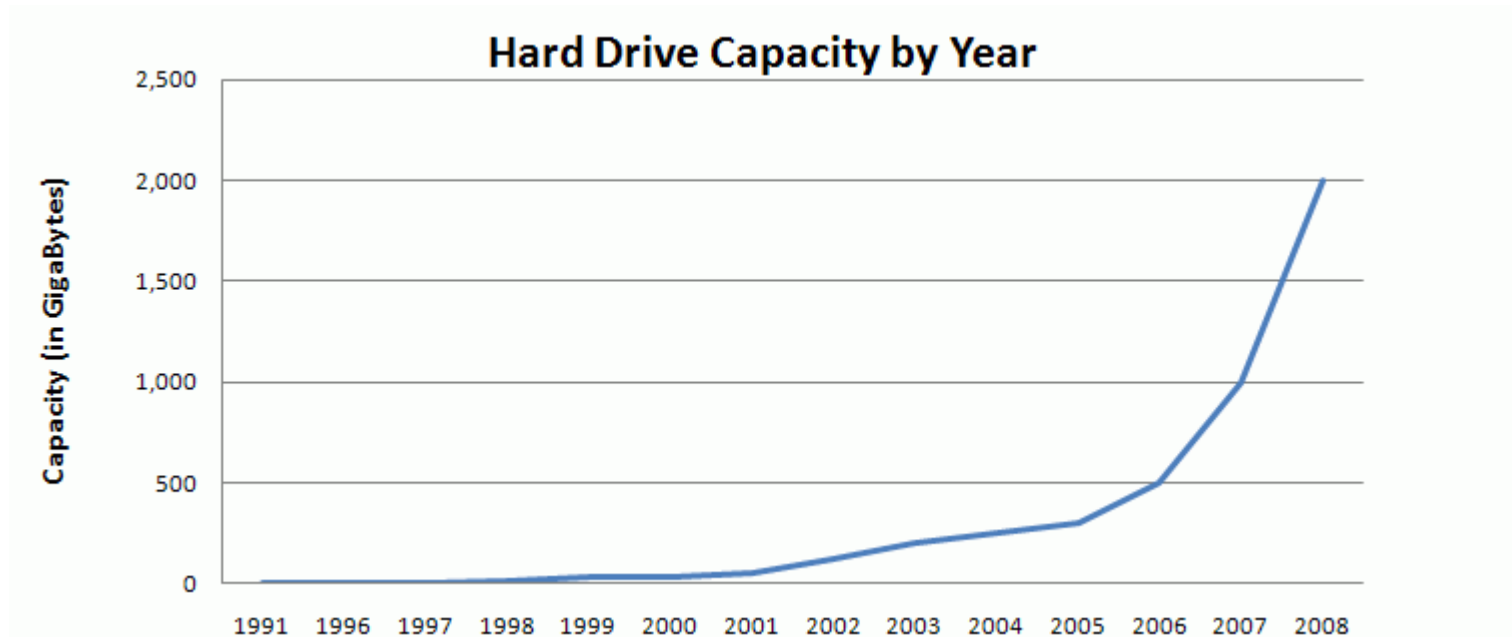
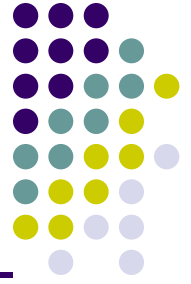
Doubles every year



Growth in Hard Disk Drive Capacity

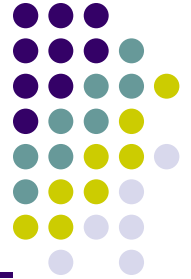


Disk Drive Growth



30\$ to 50 \$ per 100 G , 1 TB for 100 \$ to

Power Ratings



- **Atom Processor 1.6 Ghz , 4 W .. netbook**
- **AMD Athlon 1.4 Ghz, 64 W ... desktop**

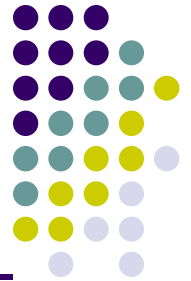
● Model	Clock Speed	Power	Clock Speed to Power Ratio (MHz/W)
● Pentium	75 MHz	8.0 W	9.4
● Pentium	90 MHz	9.0 W	10
● Pentium	100 MHz	10.1 W	9.9
● Pentium	120 MHz	11.9 W	10.1
● Pentium	133 MHz	11.2 W	11.5
● Pentium	150 MHz	11.6 W	12.9
● Pentium	166 MHz	14.5 W	11.4
● Pentium	200 MHz	15.5 W	12.9

Battery Lifetimes



- Netbook 5 to 6 hours
- Laptop 3 to 6 hours
- iPad 8 to 10 hours
- Smart Phones
- 7 to 8 hours, Standby 24 hours

Battery life being highlighted



Compare for yourself ⁴	HP EliteBook 6930p Notebook PC	Dell Latitude E6400	HP EliteBook 6930p Notebook PC* <small>*Configure to order only</small>
Battery Life (up to ...)	17.25 hours	19 hours	24 hours
Starting price	\$1,199	\$879	\$1,227
Included battery	6 cell	6 cell	6 cell
Upgrade primary battery	n/a	9 cell	n/a
Add on battery	Ultra Capacity Battery	12-Cell High Capacity Slice	Ultra Capacity Battery
Display	Standard WXGA	Not Disclosed	HP Illumi-Lite LED backlit display
Storage/Hard Drive	n/a Uses standard hard drive	64GB Ultra Performance Solid State Drive	80GB Intel SSD
Final Price	\$1,388	\$2,026	\$1,696

Upgrades

Source: www.hp.com

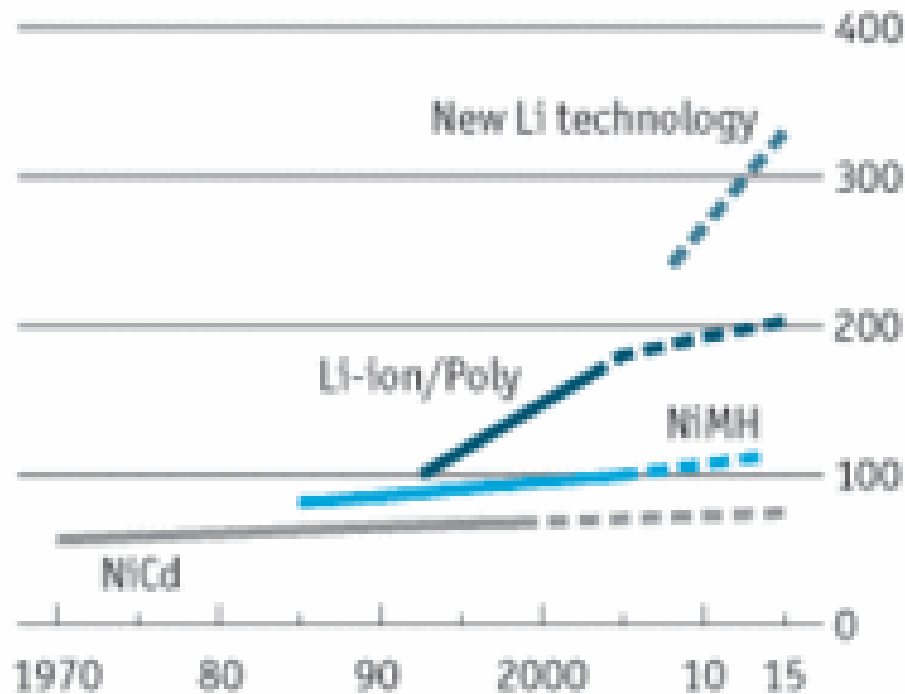


Battery Technology

Super store

Rechargeable-battery capacity

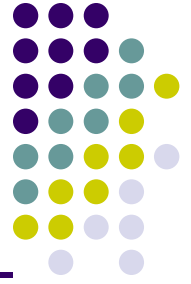
World trends, Wh/kg



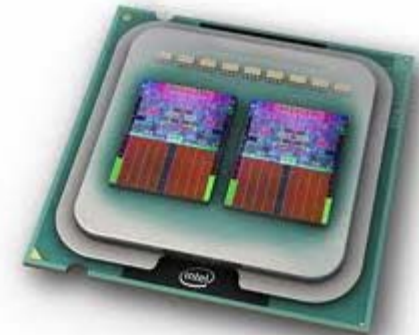
Source: Avicenne

NB: Dashed lines denote forecast data

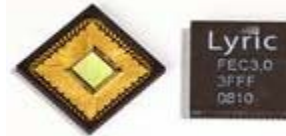
Future



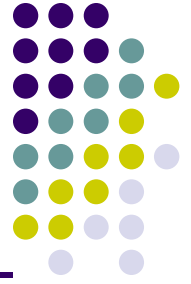
Dual Core CPU



- Advanced Architectures
 - Multi-core (more than 1 CPU on a chip)
- Performance Accelerators
 - Graphic chips (Xbox, Wii, nintendo)
 - Probability Processing
- Embedded Computing
 - Processors in vending machines, washer dryers, cars
- Cloud Computing
 - Computing as a utility
- Low Energy Design
 - Green is IN



Course Goals



Architecture course have been traditionally taught in two way: top-down or bottom-up.

We're going in from the middle. **Programmer-Centric Approach.**

Goals:

- Show that by knowing more about the underlying system, one can be more effective as a programmer.
 - Write programs that are more reliable and efficient.
 - Understand how programs interact with the underlying hardware.
- Learn the ins and outs of a computer's architecture.
- Learn how to do low-level programming.

Course expectations...



What to expect from the course:

Will cover key issues and concepts in class.

Recitations will provide review and teach you the tools you need.

4 Programming Projects (Don't freak out... yet)

2 mid-terms and a final

(maybe) practice homework and quizzes

So what do I expect of you:

Come to class

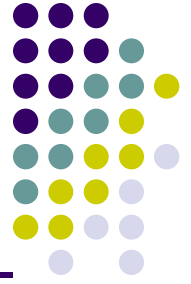
Read the book (Listening to me is not good enough)

Work through the problems in the book (not really homework... but it helps)

Do the projects

Ask questions (**IMPORTANT**)

Outline of Topics



Topics: Chapter Numbers from text

Intro **Chapter 1**

C programming

Information Representation Chapter 2

Assembly Language Programming (x86) Chapter 3

Digital Logic Chapter 4.2

Processor Architecture Chapter 4.3

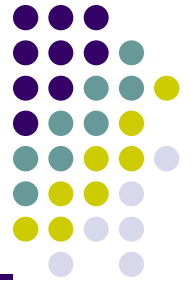
Pipelining Chapters 4.4, 4.5

Memory Hierarchy Chapter 6

Virtual Memory Chapter 10

I/O and System buses Chapter 11

Project Information



Projects Summary:

There will be 4 projects (not as bad as it sounds).

Most projects will require some degree of programming.

The high-level programming language of choice is C. No Java.

Projects are very “Do-able” if you don’t wait until the last minute to start them. If you do... well that’s your fault.

That being said, I will **NOT** accept any late projects. No excuses.

Projects posted on class web-page.

Cheating (the sad reality):

I know it happens.

I don’t like it, I won’t tolerate it, and I will be looking for it .

If you get caught, both parties will be punished.