ECE 250 / CPS 250
Computer Architecture

Introduction

Benjamin Lee

Slides based on those from

Andrew Hilton (Duke), Alvy Lebeck (Duke)
Benjamin Lee (Duke), and Amir Roth (Penn)

Instructor and Graduate TAs

- Professor: Benjamin Lee
  - Office: Hudson Hall 210
  - Email: benjamin.c.lee@duke.edu
  - Office Hours: TuTh 4-5PM or by appointment

- Graduate TAs:
  - Alfredo Velasco (alfredo.velasco@duke.edu)
  - Pengfei Zheng (pengfei.zheng@duke.edu)

Undergrad Teaching Assistants

- Undergraduate TAs (UTAs)
  - A whole bunch of awesome undergrads who aced this class
- Will help with
  - Leading recitations
  - Answering questions about homeworks
  - Holding office hours to help with tools and software
- Will NOT bail you out at 3am when deadline is at 10am

Getting Info

- Course Web Page
  http://people.duke.edu/~bcl15/class/class_ece250fall15.html
  - syllabus, schedule, rules/policies, Prof/TA info, office hour info
  - lecture slides, links to useful resources
- Sakai: dynamic info
  - From me: announcements, assignments, grades
  - From you: uploaded homeworks
- Piazza: questions/answers
  - Post all of your questions here
  - Questions must be "public" unless very good reason otherwise

Consult these resources in this order

Notes About Lectures and Lecture Slides

- Lecture slides available on Sakai before class
  - Print them out and bring them with you to class
  - Value (just reading slides) << Value (attending class)
  - Missing class = missing important course material
- Lectures will be recorded on Panopto
  - Useful if you’re sick or out of town or if you want to review a previously attended lecture at your own pace
  - Value (watching on Panopto) < Value (attending class)

Getting Answers to Questions

- There are too many students for you all to email me
  - So now what do you do if you have a question?

1. Check the course website
2. Check Sakai
3. Check Piazza
   - If you have questions about homeworks, use Piazza – then everyone can see the answer(s) posted there by me, a TA, or your fellow classmate
   - Professor and TAs will NOT answer direct emails about homeworks or anything that pertains to more than 1 student

- Contact TA directly if: grading issue
- Contact professor directly if issue that is specific to you and that can't be posted on Piazza (e.g., missing exam)

Textbook

- Text: *Computer Organization & Design* (Patterson & Hennessy)
  - 5th edition of the textbook
  - You are expected to complete the assigned readings

- We will not cover material in the textbook in a strictly linear fashion

Other Resources

- There are many online resources, including:
  - Unix tutorials
  - C programming tutorials
  - Videos of Prof. Hilton (Duke ECE/CS) teaching C programming
  - Coursera course on computer architecture
  - Etc.

- Many useful links on course website
- Feel free to use these materials, but none are required

Workload

- Readings from textbook
- Homework assignments – **done individually**
  - Pencil and paper problems
  - Programming problems in C and assembly
  - Digital logic design problems (like designing a computer)
- Recitations – **done with partners**
  - During recitations, work with partners/groups (or individually) on "assignments" to help you learn skills useful for homeworks and tests
  - Goal: learning through hands-on, low-stress practice
  - UTAs will help students during recitations
  - Bring a laptop to work on – or work with a partner who has one

Grading

- Grade breakdown
  - Homework 50%
  - Midterm #1 12.5%
  - Midterm #2 12.5%
  - Final Exam 25%
- I strongly believe in partial credit
  - Please explain your answers to get as much credit as possible
- Late homework policy – **no exceptions, no extensions**
  - 0-24 hours late: 10% penalty
  - 24-48 hours late: 20% penalty
  - >48 hours late: no credit

Policy will be applied uniformly and consistently so as to be fair to all.

- Assignments take a lot of time, so start them early

Academic Misconduct

- Duke Community Standard
  - Homework is individual – you must do you own work
  - You violate academic integrity when
    - you obtain solutions and code from others, or
    - you provide solutions and code to others
  - Common examples of cheating:
    - Running out of time and using someone else's output
    - Borrowing code from someone who took course before
    - Using solutions found on the Web
    - Having a friend help you to debug your program

- I will not tolerate any academic misconduct!
  - Software for detecting cheating is very, very good … and I use it
  - 12 students were caught on Homework #1 in spring 2014

Goals of This Course

- By end of semester:
  - You will know how computers work
    - What's inside a computer?
    - How do computers run programs written in C, C++, Java, Matlab, etc.?
  - You will design hardware that computers use
  - You will understand the engineering tradeoffs to be made in the design of different types of computers
  - You will know how to program in C
  - You may, like me, decide to become an architect. ☺
- If, at any point, it's not clear why I'm talking about some topic, please ask!

Outline of Introduction

- Administrivia
- What is a computer?
- What is computer architecture?
- Why are there different types of computers?
- What does the rest of this course look like?

Reading Assignment

- Patterson & Hennessy
  - Chapter 1
  - This is a short and relatively easy-to-read chapter

What is a Computer?

- A computer is just a machine
  - A bunch of switches and logic that we'll talk about later
- Yes, but what does this machine do?
  - Whatever you tell it to do! No more, no less
- A computer just does what software tells it to do
  - Software is a series of **instructions**
- ICQ (In-Class Question): What instructions does a computer need?

Computers Execute Instructions

- What kinds of instructions are there?
  - Arithmetic: add, subtract, multiply, divide, etc.
  - Access memory: read, write
  - Conditional: if condition, then jump to other part of program
  - What other kinds of instructions might be useful?

- So how do computers run programs in Java or C/C++ or Matlab or ....?
  - None of us write programs in binary (zeros and ones) …
  - We'll get to this in a few minutes

Instruction Sets

- Computers can only execute instructions that are in their specific machine language
- Every type of computer has a different instruction set that it understands
  - Intel (and AMD) IA-32 (x86): Pentium Core i7, AMD Opteron, etc.
  - ARM: In many embedded processors (e.g., smartphones)
    - ISA used by many companies (e.g., Qualcomm)
  - Intel IA-64: Itanium, Itanium 2
  - PowerPC: In Cell Processor and old Apple Macs
  - SPARC: In computers from Sun Microsystems/Oracle
  - MIPS: MIPS R10000 → this is the example used in the textbook
- Note: no computer executes Java or C++

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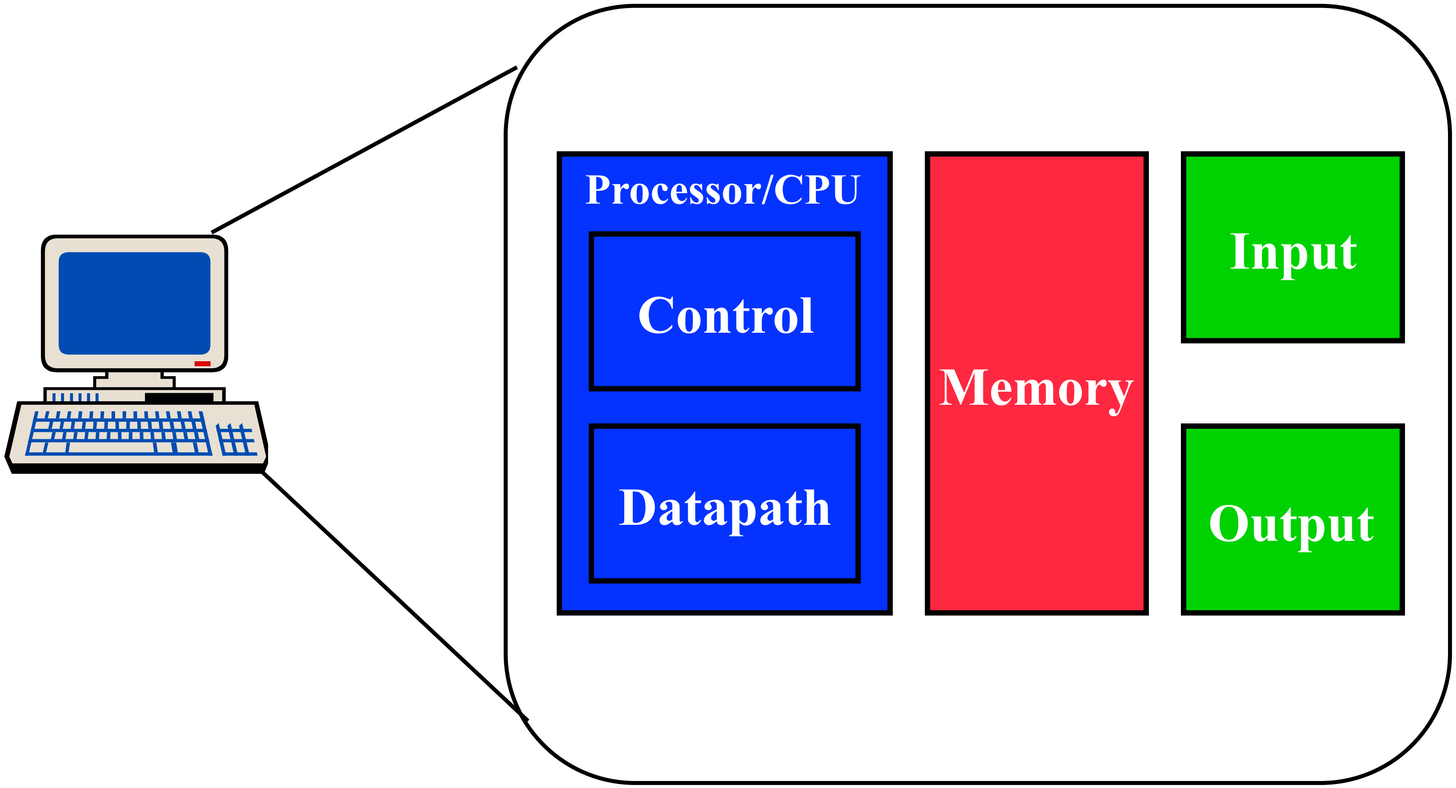
Hint: It Doesn't Involve Skyscrapers …

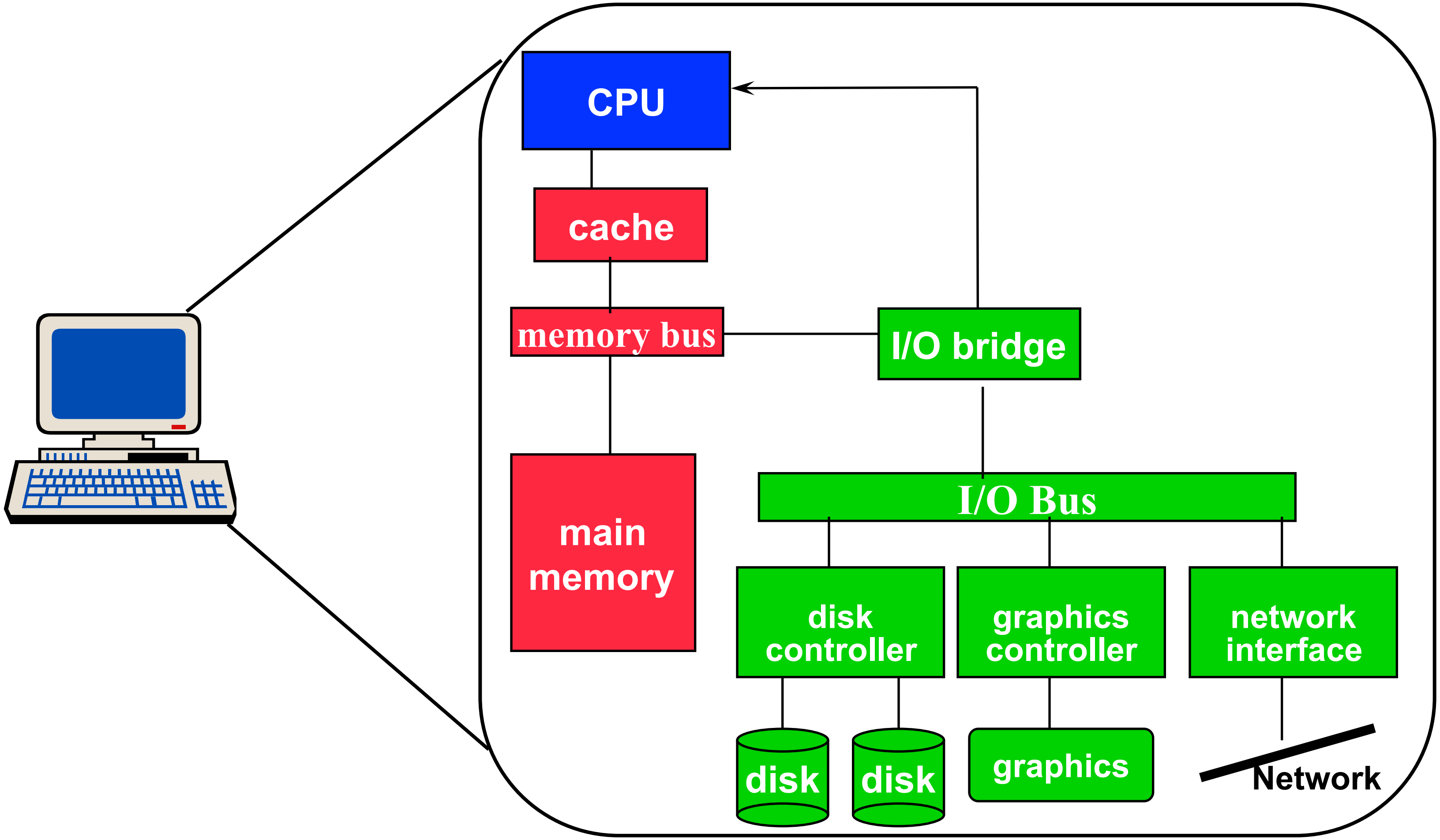
- Strictly speaking, a **computer architecture** specifies what the hardware looks like (its interface), so that we can write software to run on it
  - Exactly what instructions does it have
  - Number of storage locations it has
  - And more that we'll learn about later in semester
- **Important point:** there are many, many different ways to build machines that provide the same interface to software
  - There are many **microarchitectures** that conform to same architecture
  - Some are better than others! If you don't believe me, I'll trade you my original Intel Pentium for your Intel Core i7
- ICQ: So what's inside one of these machines?

The Inside of a Computer

- The Five Classic Components of a Computer

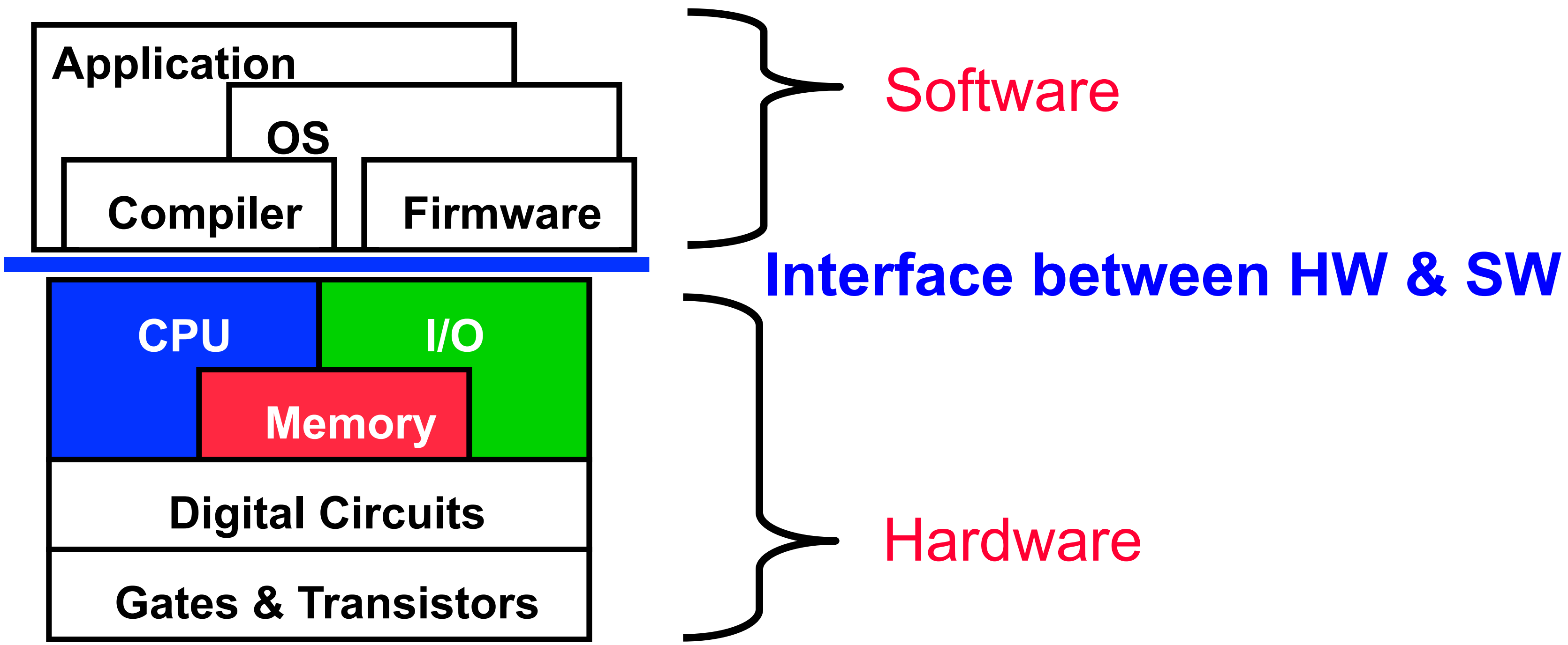


System Organization



What Is ECE/CS 250 All About?

- **Architecture = interface between hardware and software**



- **ECE/CS 250 = design of CPU, memory, and I/O**
- **ECE/CS 350 = building it in hardware**

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Differences Between Computers

- We have different computers for different purposes

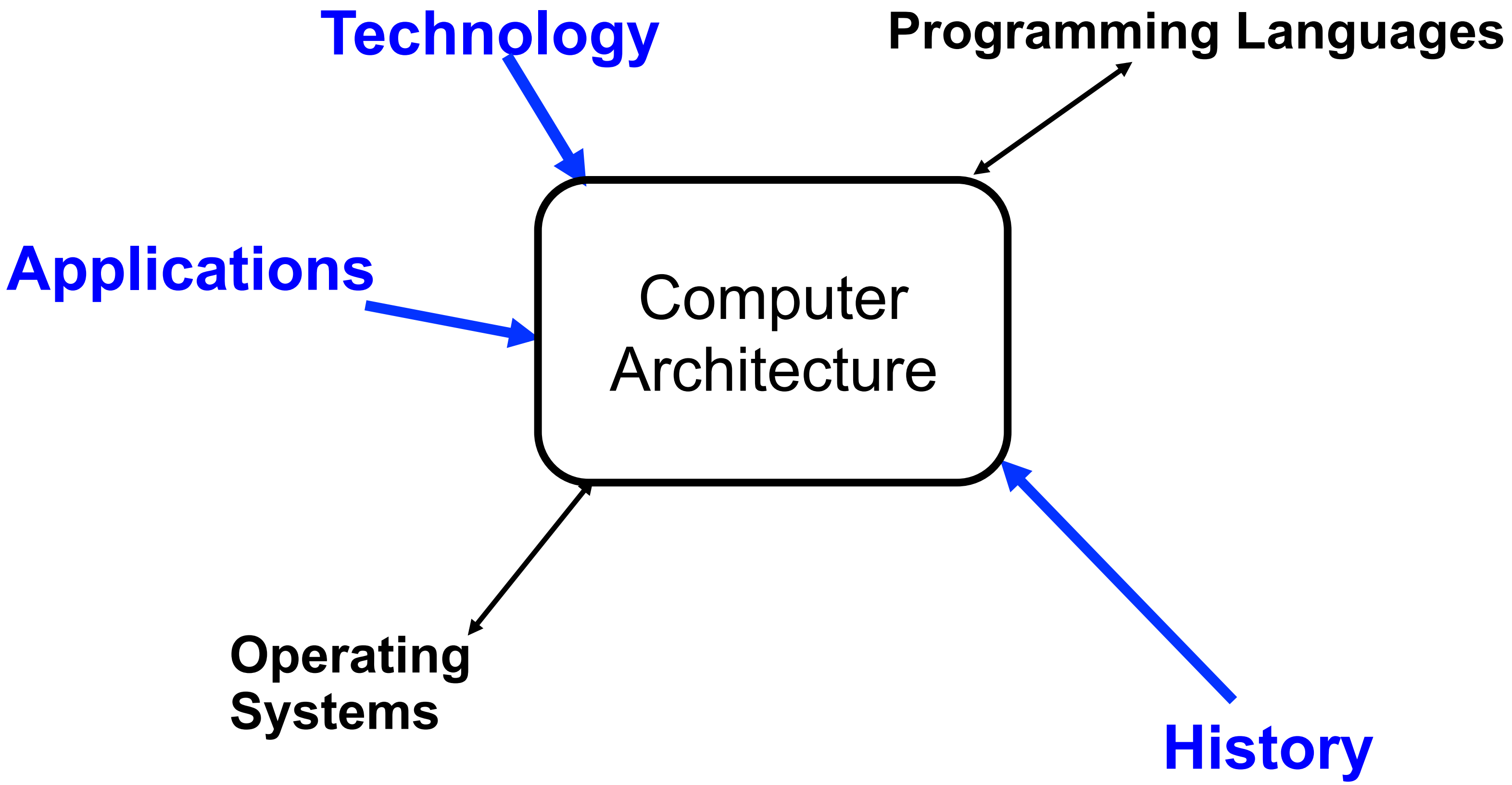
- Some can achieve performance needed for high-performance gaming
  - E.g., Cell Processor in PlayStation 3
- Others can achieve decent enough performance for laptop without using too much power
  - E.g., Intel Atom for Mobile
- And yet others can function reliably enough to be trusted with the control of your car's brakes

ICQ: What computers do you use?
ICQ: Which of those computers do you own?

Kinds of Computers

- "Traditional" personal computers
  - Laptop, desktop, netbook
- Less-traditional personal computers
  - iPad, iPhone, Samsung/Android smartphone, iPod, Xbox, etc.
- Hidden "big" computers (some are in the "cloud")
  - Mainframes and servers for business, science, government
    - E.g., the machines that run Duke email, ACES, etc.
  - Google has many thousands of computers (that you don't see)
- Hidden embedded computers
  - Controllers for cars, airplanes, ATMs, toasters, DVD players, etc.
  - Far and away the largest market for computers!
- Other kinds of computers??

Forces on Computer Architecture



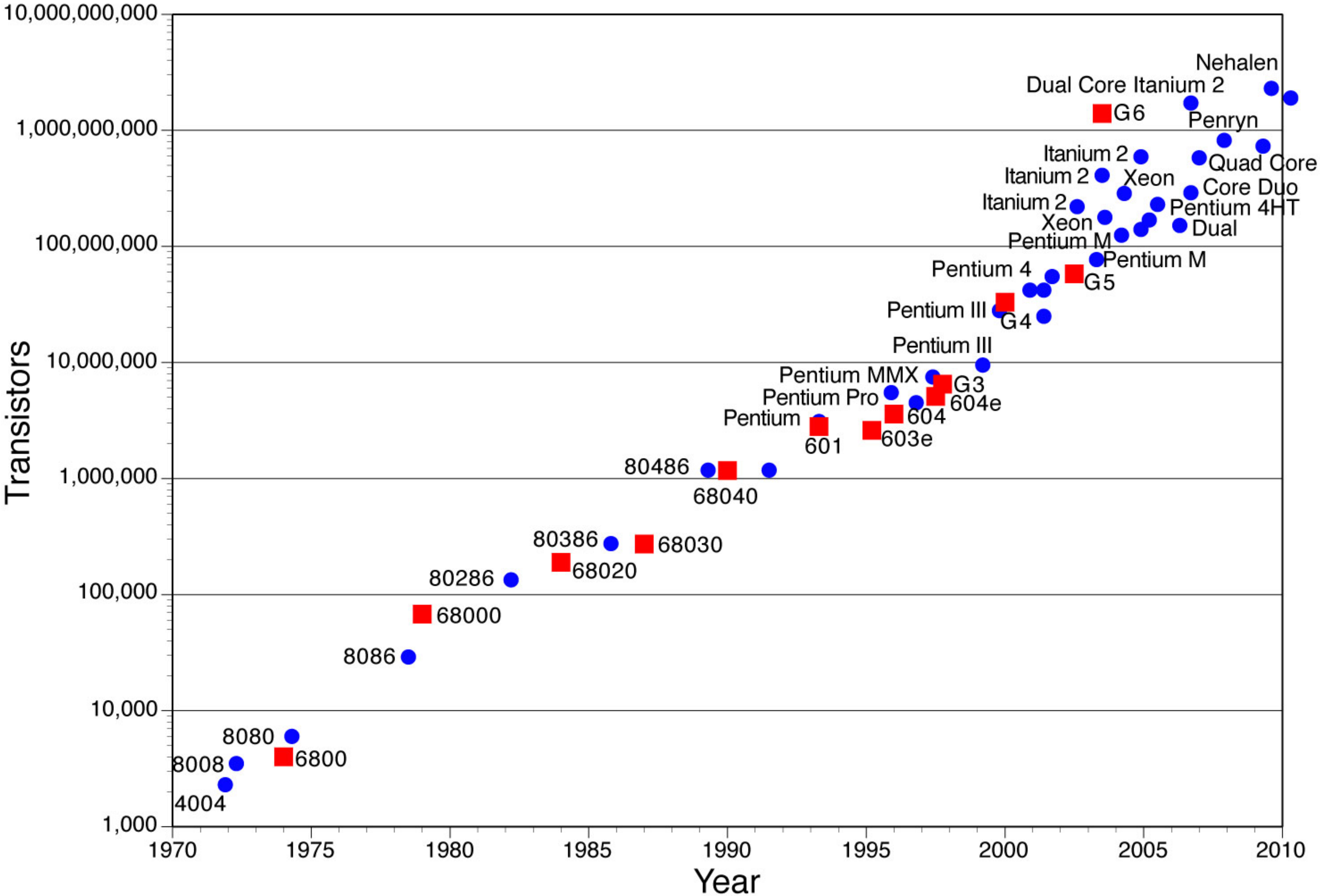
A Very Brief History of Computing

- 1645 Blaise Pascal’s Calculating Machine
- 1822 Charles Babbage
  - Difference Engine
  - Analytic Engine: Augusta Ada King first programmer
- < 1946 Eckert & Mauchly
  - ENIAC (Electronic Numerical Integrator and Calculator)
- 1947 John von Neumannn
  - Proposed the Stored Program Computer
  - Virtually all current computers are “von Neumann” machines
- 1949 Maurice Wilkes
  - EDSAC (Electronic Delay Storage Automatic Calculator)

Some Commercial Computers

Year	Name	Size (cu. ft.)	Adds/sec	Price
1951	UNIVAC I	1000	1,900	$1,000,000
1964	IBM S/360 Model 50	60	500,000	$1,000,000
1965	PDP-8	8	330,000	$16,000
1976	Cray-1	58	166 million	$4,000,000
1981	IBM PC	desktop	240,000	$3,000
1991	HP 9000 / model 750	desktop	50 million	$7,400
1996	PC with Intel PentiumPro	desktop	400 million	$4,400
2002	PC with Intel Pentium4	desktop/laptop/ rack	4 billion	$1-2K
2008	Cell processor	PlayStation3	~200 billion	~$350 (eBay)
2014	Nvidia K40 GPU	Desktop/rack	~4.3 trillion	$4,000

Microprocessor Trends (for Intel CPUs)



What Do Computer Architects Do?

- Full disclosure: I'm a computer architect
- Design new microarchitectures
  - Very occasionally, we design new architectures
- Design computers that meet ever-changing needs and challenges
  - Tailored to new applications (e.g., image/video processing)
  - Amenable to new technologies (e.g., faster and more plentiful transistors)
  - More reliable, more secure, use less power, etc.
- Computer architecture is engineering, not science
  - There is no one right way to design a computer → this is why there isn't just one type of computer in the world
  - This does not mean, though, that all computers are equally good

What You Will Learn In This Course

- The basic operation of a computer
  - Primitive operations (instructions)
  - Computer arithmetic
  - Instruction sequencing and processing
  - Memory
  - Input/output
  - Doing all of the above, just faster!
- Understand the relationship between abstractions
  - Interface design
  - High-level program to control signals (SW → HW)
- C programming → why?

Course Outline

- Introduction to Computer Architecture
- C Programming and From C to Binary (next!)
- Instruction Sets & Assembly Programming
- Processor Core Design
- Memory Systems
- I/O Devices and Networks
- Pipelined Processor Cores
- Multicore Processors

The Even Bigger Picture

- ECE/CS 250: Basic computer design
  - Finish 1 instruction every 1 very-long clock cycle
  - Finish 1 instruction every 1 short cycle (using pipelining)
- ECE/CS 350: Implementing digital computers/systems
- ECE 552/CS 550: High-performance computers + more
  - Finish ~3-6 instructions every very-short cycle
  - Multiple cores each finish ~3-6 instructions every very-short cycle
  - Out-of-order instruction execution, power-efficiency, reliability, security, etc.
- ECE 652/CS 650: Highly parallel computers and other advanced topics
- ECE 554/CS ???: Fault tolerant computers