ECE/ENGRD 2300
Digital Logic & Computer Organization

Spring 2025

Course Overview

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Today's Lecture

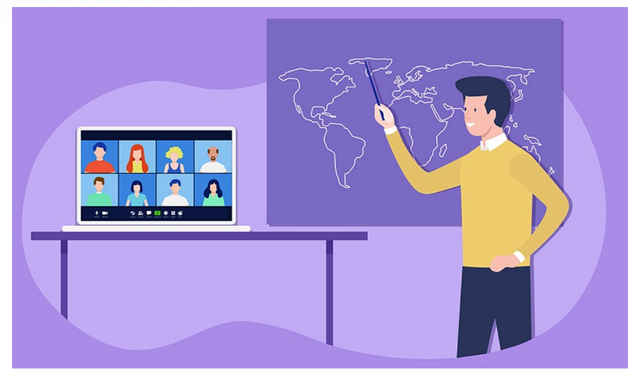
Part 1. About this course

One of the ECE core courses and serves as a gateway to *computer engineering* (CE)

Part 2. Digital abstraction

Digital Computers are Everywhere

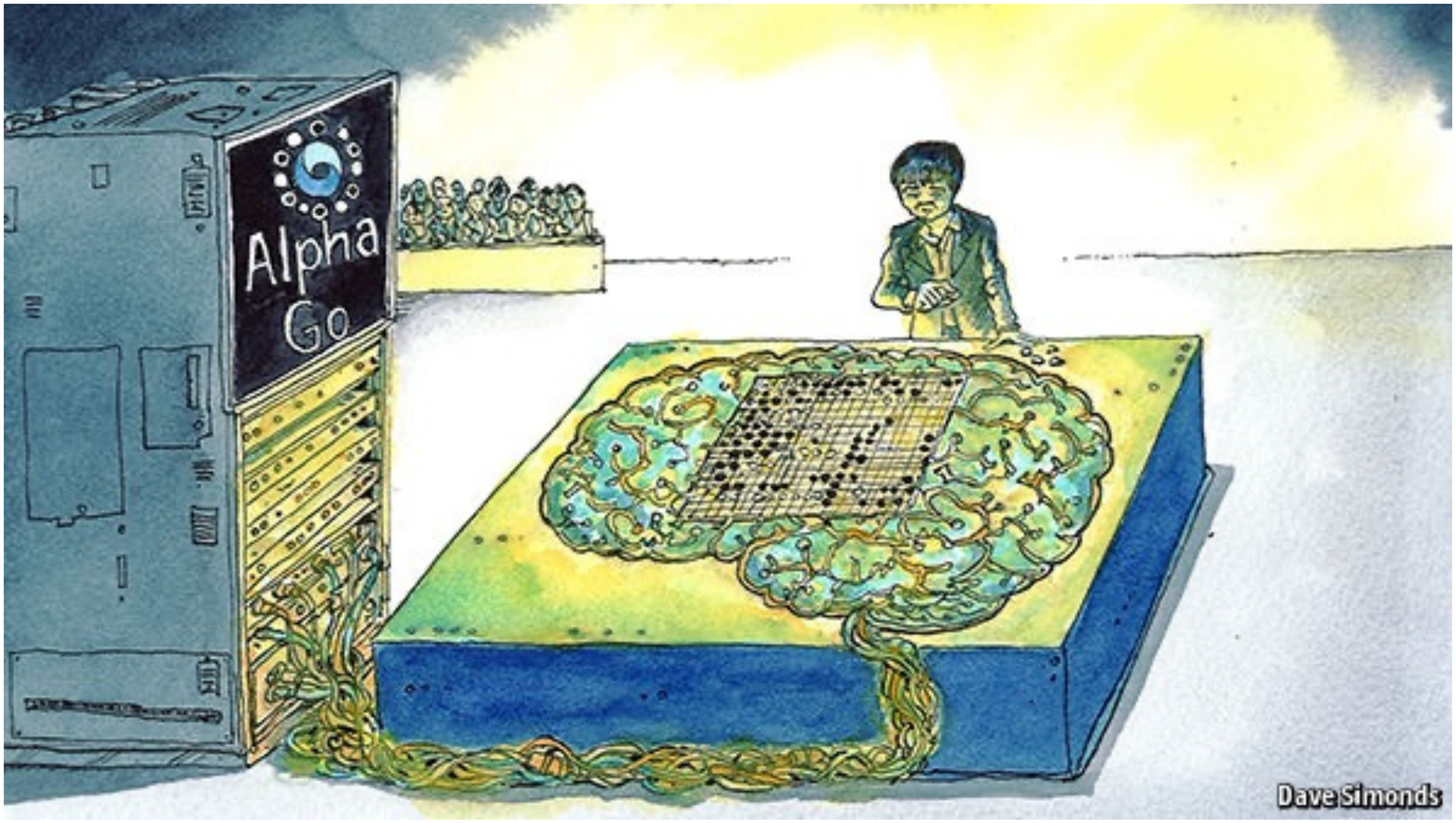
Changing Every Aspect of Our Life



many more
(to come)

Digital (Super)Intelligence?

Google's AlphaGo defeated top Go player Lee Sedol on March 12, 2016



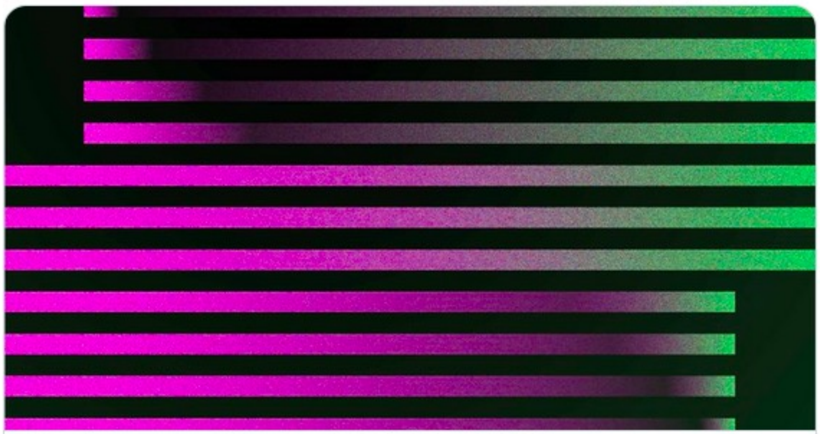
Source: www.economist.com/science-and-technology/2016/03/12/showdown

AlphaGo training is reported to use 1920 CPUs, 280 GPUs, and additional TPUs

Digital (Super)Intelligence?

OpenAI @OpenAI

Try talking with ChatGPT, our new AI system which is optimized for dialogue. Your feedback will help us improve it.



openai.com
ChatGPT: Optimizing Language Models for Dialogue
We've trained a model called ChatGPT which interacts in a conversational way.

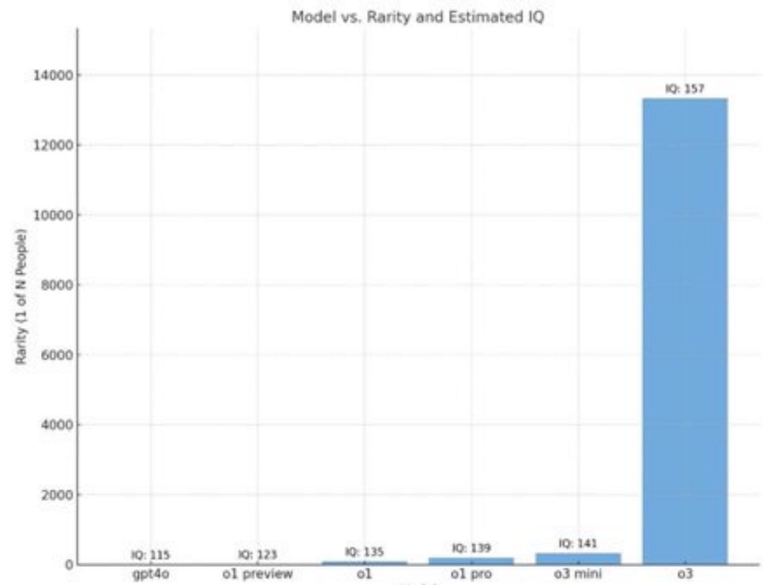
Here's how much it costs to run OpenAI's ChatGPT chatbot per day

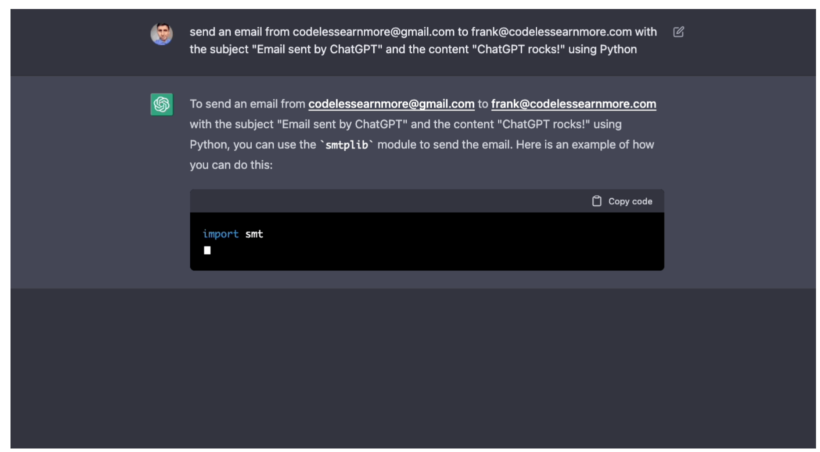
It might cost around $3 million per month for OpenAI to run ChatGPT.

AI bot ChatGPT writes smart essays — should professors worry?

The bot is free for now and can produce uncannily natural, well-referenced writing in response to homework questions.

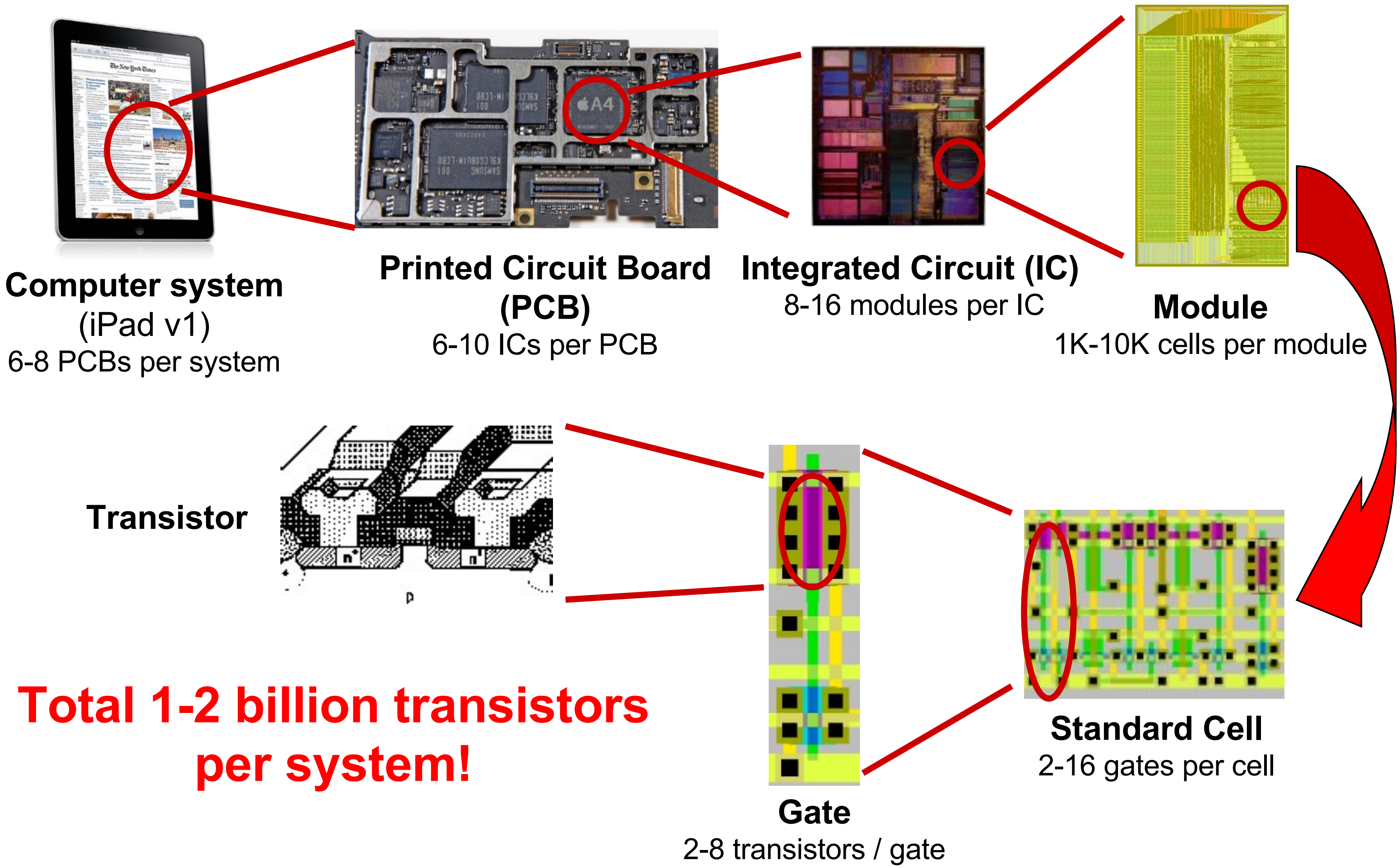
AI IQs skyrocketed in 2024





Training GPT-4 is estimated to cost at over $10 million

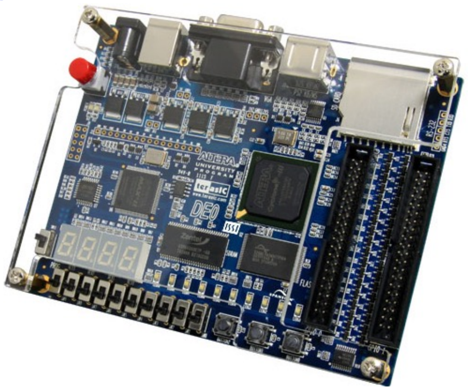
How is a Digital Computer Composed?



Total 1-2 billion transistors per system!

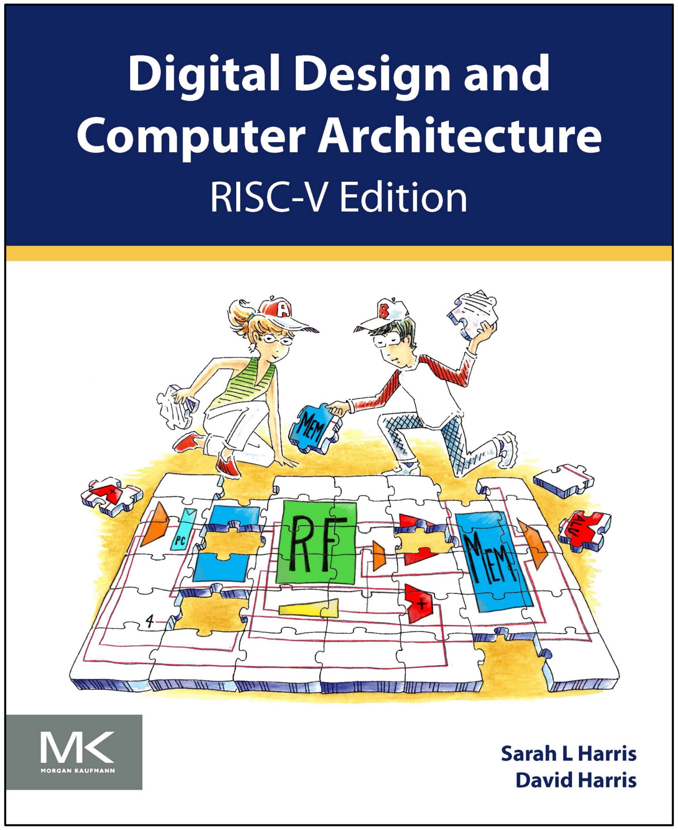
Our Plan to Tackle the Complexity

- Understand how things work, bottom-up
- Encapsulate our understanding using appropriate abstractions
- Develop hands-on experience by implementing digital circuits on a real FPGA board



Textbook

- We will use the RISC-V edition of the Harris & Harris (H&H) book
  - Cornell library also has an e-book of the 2nd edition (MIPS), which works as an alternative for most readings



Class Resources

- Course Website
  - https://www.csl.cornell.edu/courses/ece2300/
  - Lecture slides, syllabus, and other handouts

- Ed Discussion
  - Announcements and Q&A
  - Links to lecture recordings

- CMSX: Course Management System
  - Assignments and grades
  - Electronic submissions required

Teaching Assistants

- **PhD TAs**
  - Andrew Butt (atb78)
  - Hank Chen (bc546)
- **MEng TAs**
  - Jay Chawrey (jpc369)
  - Xingze (Aki) Xu (xx353)

To reach entire staff:
<ece2300-staff-L@cornell.edu>

- **Undergrad TAs**
  - Anthony Song (abs343)
  - Abigail Kim (ahk89)
  - Cynthia Shao (cys36)
  - Juhyoung Lee (jl3896)
  - Kaelem Bent (kab472)
  - Mohammad Al-Labadi (maa366)
  - Md Shad (mss464)
  - Nimish Goel (ng449)
  - Nathan Rakhlin (npr29)
  - Stephen Barlett (sjb336)
  - Srinithi Krishnamoorthy (sk2693)
  - Rachel Lee (sl2847)
  - Stanley Shen (ss3679)
  - Simeon Turner (smt259)
  - Wei Zheng (wz328)
  - Zarif Karim (zk67)
  - Zachary Jessup (zsj5)

Seeking Help After Class

- Ed Discussion
  - Questions on lectures, assignments, and labs
  - Monitored by instructor & TAs
- Staff email
  - Grading related questions to instructor & TAs
- Instructor email
  - Private matters/appointment
- Office hours
  - Instructor: Thursday, 4:30-6:00pm (Online)
  - TA office hours to be announced soon (In-person)

Grading

- Participation: 3%
- Quizzes: 5%
- Homework: 12%
- Labs: 30%
- Prelim 1: 14%
- Prelim 2: 16%
- Final: 20%

Participation (3%)

- Participating in-class activities
  - Asking & answering questions in class
  - Live challenges, polls, and discussion

- Contributing to online discussion forum
  - Posting questions & helping other students

- A rough rubric
  - Active = 3pts
  - Somewhat engaged = 2pts
  - Little impression = 0-1pt

Labs and Homework (42%)

- Labs (30%)
  - Five labs in total
  - Prelab: write-up of your (partial) design
  - Lab section: implement and test your design
  - Report (labs 3 & 4): write up your findings

- Homework (12%)
  - Eight problem sets in total

Exams and Quizzes (55%)

- Prelims (30%)
  - Thursday, February 27, in class
  - Thursday, April 10, 7:30pm @ Goldwin Smith G76

- Final Exam (20%)
  - Date TBD

- Quizzes (5%)
  - You will need to answer pop quiz questions in most lectures, using Google Forms
    - Make-up quizzes can be arranged if you miss lectures due to legitimate reasons
  - Four lowest scores will be dropped

Important Policies

- **Late Policy**
  - **We collect assignments the instant they are due**
    - Late submissions = 0 points
    - Applies to homework, prelabs, and lab reports
  - **Total <u>10 slip days</u>, intended to cover minor illnesses or "crunch time"**
    - At most TWO slip days for prelab
    - If you have a serious illness or family emergency, contact me

- **Regrade Policy**
  - **Submit regrade form to course staff <ece2300-staff-L@cornell.edu> within one week if you feel a grading mistake has been made**

How to Do Well in This Class

- Attend every lecture and participate
- Read the book sections before class
- Keep up with the week to week assignments
- Seek help if necessary

Academic Integrity

- https://cuinfo.cornell.edu/aic.cfm
- Discussion of homework and lab concepts? YES
- Misrepresenting someone else's work as your own is prohibited
  - Getting someone else's work? NO
  - Sharing your work with others? NO
  - Finding solutions on the web? NO
  - Outsourcing lab/homework to AI? NO
- Buying or selling course materials to commercial vendors (including Internet sites)? NO

Course Schedule

Date	Lecture	Reading	Lab	HW/Exam
Tue 1/21	**1: Course Overview** [slides] [syllabus]	1.1-1.4.2, 1.5-1.6.2, 2.1-2.3		
Thu 1/23	**2: Boolean Algebra** [slides]	2.4-2.7		HW 1 out
Tue 1/28	**3: Combinational Logic Minimization** [slides]	1.7		
Wed 1/29			Lab 1 out	
Thu 1/30	**4: CMOS Logic** [slides]	2.8		HW 2 out
Fri 1/31				**Due: HW 1**
Tue 2/4	**5: Combinational Building Blocks** [slides]	3.1-3.2		
Thu 2/6	**6: Sequential Logic: Clocks, Latches, FFs** [slides]	4.1-4.5 (skip VHDL), 5.4		HW 3 out
Fri 2/7			**Due: Lab 1**	**Due: HW 2**
Tue 2/11	**7: More Sequential Logic, Verilog** [slides]	3.4, 4.6	Lab 2 out	
Thu 2/13	**8: Finite State Machines (FSMs) 1** [slides]	4.9		
Fri 2/14				**Due: HW 3**

A tentative schedule is on course website

Course Content

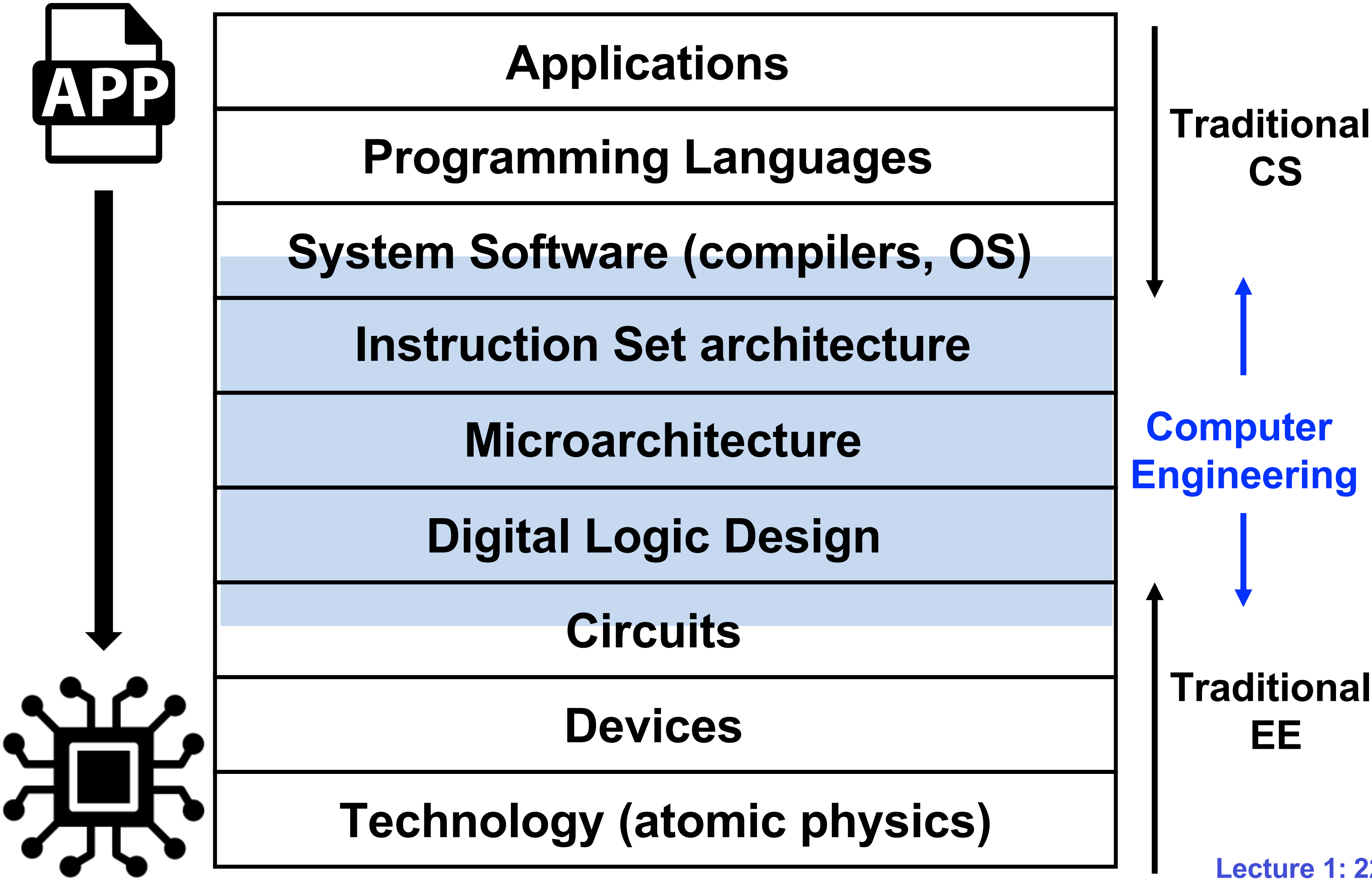
- Binary numbers and logic gates
- Boolean algebra and combinational logic
- Sequential logic and state machines
- Binary arithmetic
- Memories

Digital Logic

Computer Organization

- Instruction set architecture
- Processor organization
- Caches and virtual memory
- Input/output
- Advanced topics

Where This Course Sits in the “Stack”



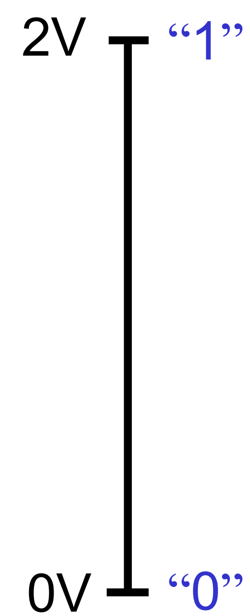
Binary Digital Systems

- Digital system:
  Finite number of values
- Binary (base 2) system
  Use two states: 0 and 1

- **Basic unit of information: the *binary digit*, or *bit***
  - Two values: 0 and 1

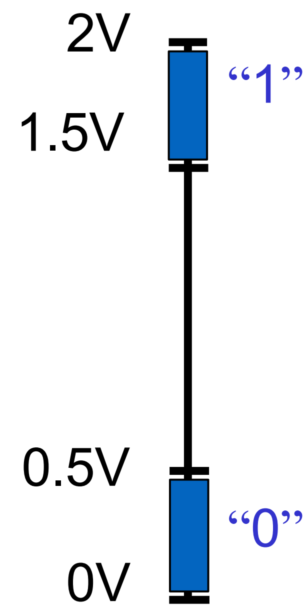
- **0 and 1 represented by voltages**

- **Key advantage: efficient circuits (cheap, small, fast, low power)**



0 and 1 Don’t Have to be Exact

- **0 and 1 represented by voltage ranges *(logic levels)***
- **Electronic circuits do not need to be perfect**
- **We can tolerate some noise and computers still work**



Binary Encoding is Ubiquitous

- **Activity**: Look around and identify one item that can be represented using a binary digit

Binary Encoding is Ubiquitous

- **<u>Activity</u>: Look around and identify one item that can be represented using a binary digit**

Can We Represent More Than 2 Values?

- Yes – just use multiple bits
  - A collection of 2 bits gives 4 possible values
    - 00, 01, 10, 11
  - A collection of 3 bits gives 8 possible values
    - 000, 001, 010, 011, 100, 101, 110, 111

- A collection of n bits gives 2^n possible values

Positional Number Representation

- **Recall positional notation for decimal numbers**

$$\begin{array}{ccc} & 329 & \\ 10^2 & 10^1 & 10^0 \end{array}$$

base 10
(decimal)

$$\boxed{3 \times 100 + 2 \times 10 + 9 \times 1 = 329}$$

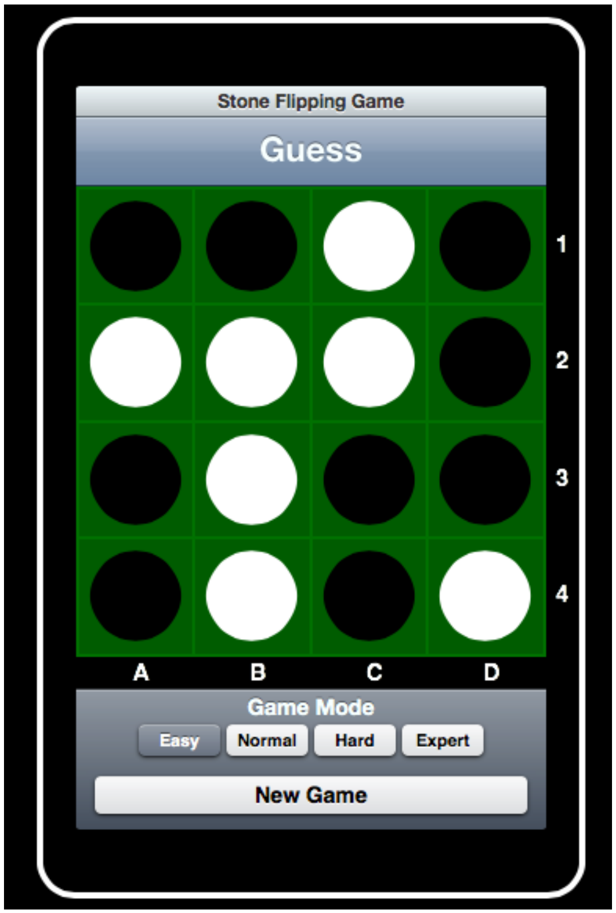
- **Similar positional system for binary**

$$\begin{array}{ccc} & 101 & \\ 2^2 & 2^1 & 2^0 \end{array}$$

base 2
(binary)

$$\boxed{1 \times 4 + 0 \times 2 + 1 \times 1 = 5}$$

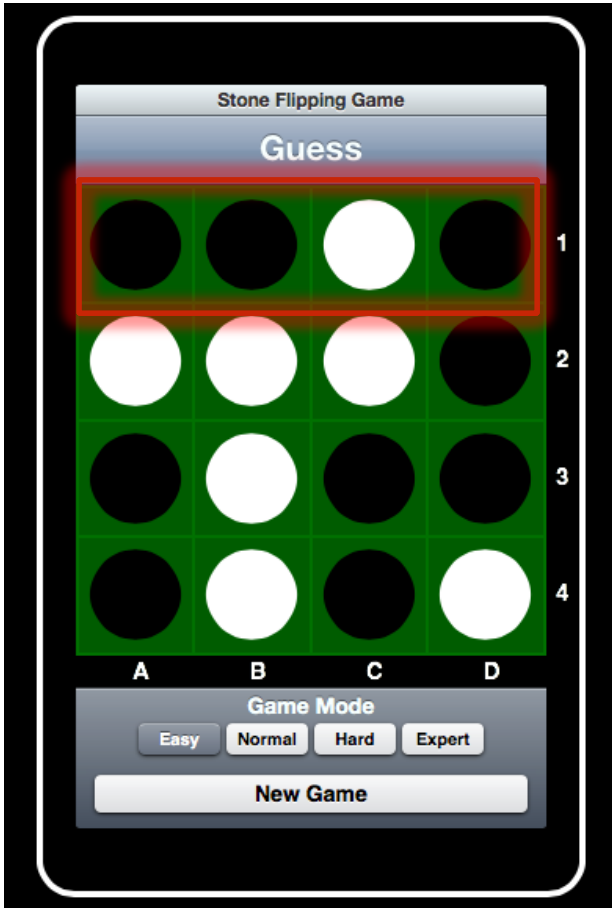
Exercise: Binary-to-Decimal Conversion



- White stone = 0
- Black stone = 1

- Convert the first row into a decimal number

From Stones to Numbers

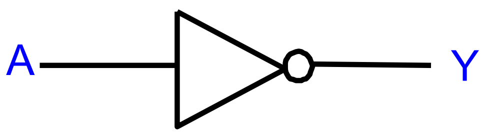


- White stone = 0
- Black stone = 1

$$1*2^3+1*2^2+0*2^1+1*2^0$$
$$= 8 + 4 + 0 + 1 = 13$$

Logic Gates

- **Logic gates are functions: take one or more binary inputs and produce a binary output**

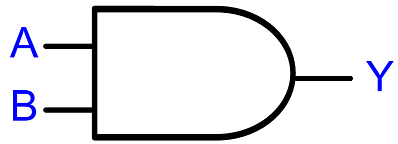


NOT Gate

NOT A, $\overline{A}$, A'

A	Y
0	1
1	0

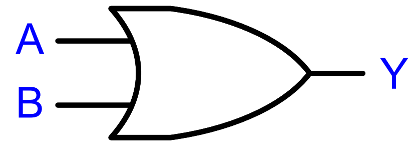
Truth Table



AND Gate

A AND B, A•B

A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1



OR Gate

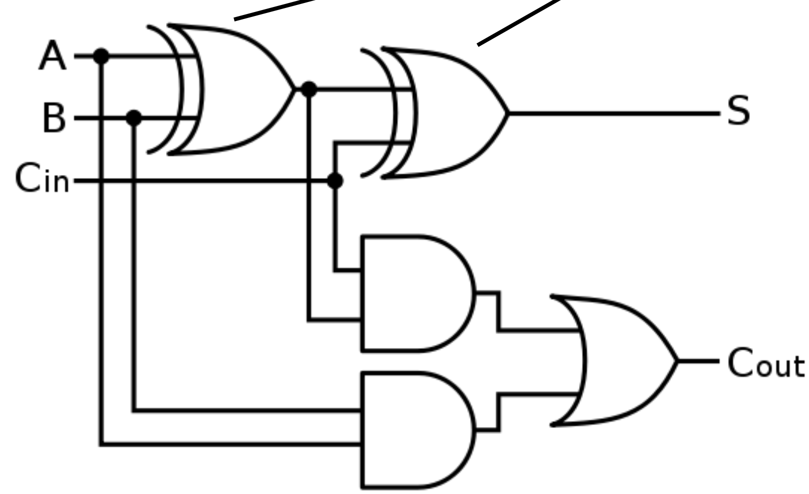
A OR B, A+B

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

Build a 1-Bit Adder

- Inputs: A, B and C_{in} (carry-in)
- Outputs: S (sum) and C_{out} (carry-out)

A	B	C_{in}	C_{out}	S
0	0	0	0	0
0	0	1	0	1
0	1	0	0	1
0	1	1	1	0
1	0	0	0	1
1	0	1	1	0
1	1	0	1	0
1	1	1	1	1

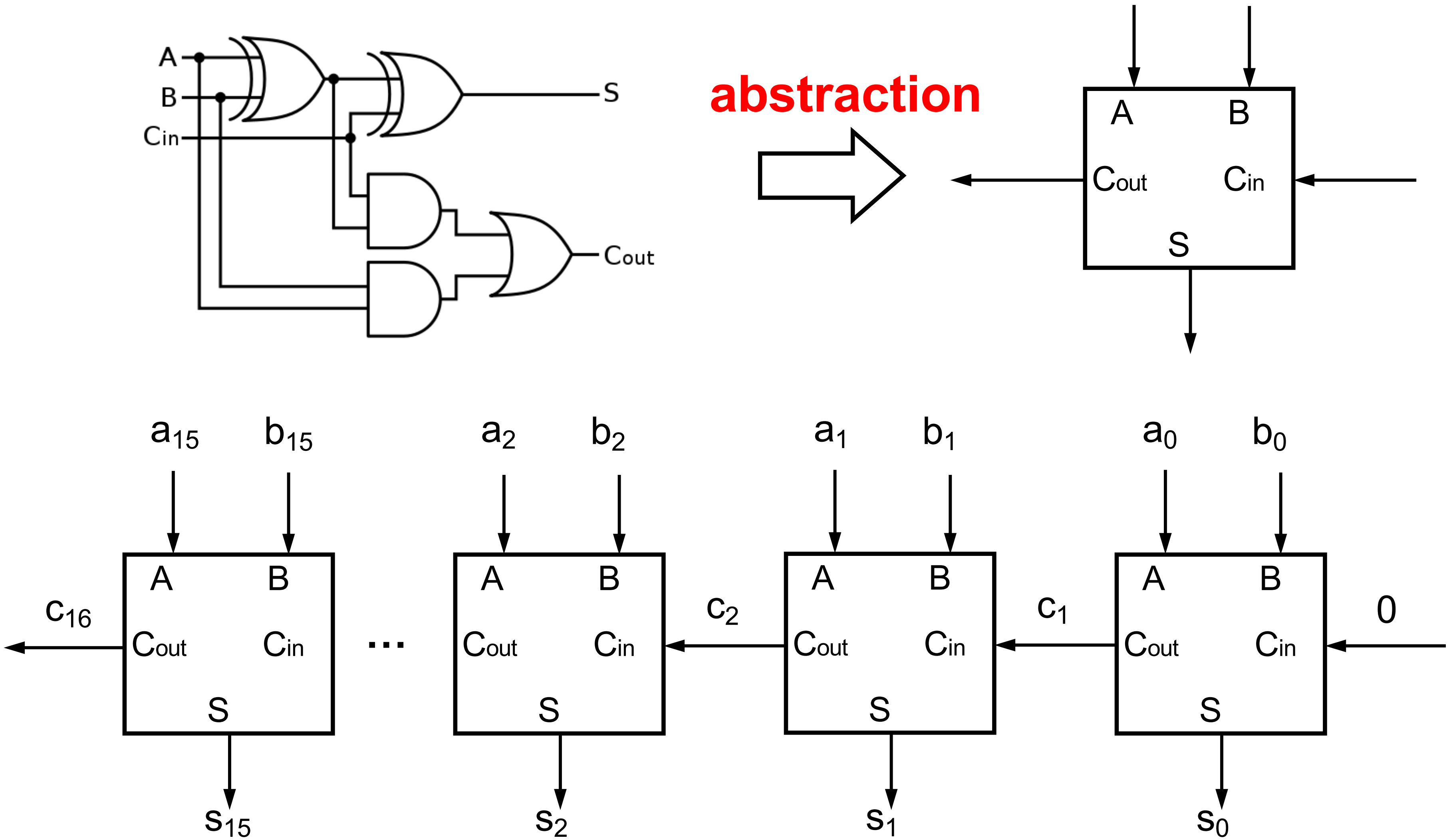


XOR Gate

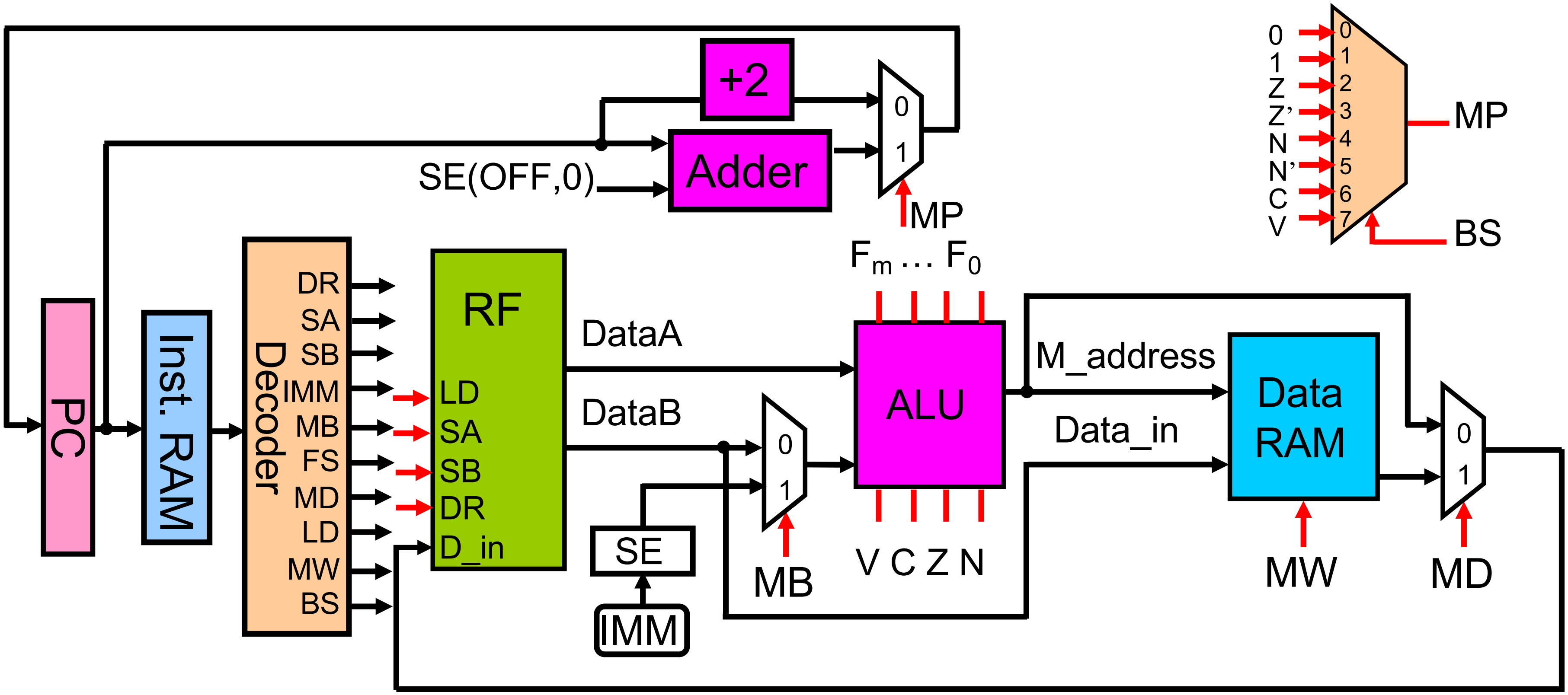
A•B' + A'•B

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

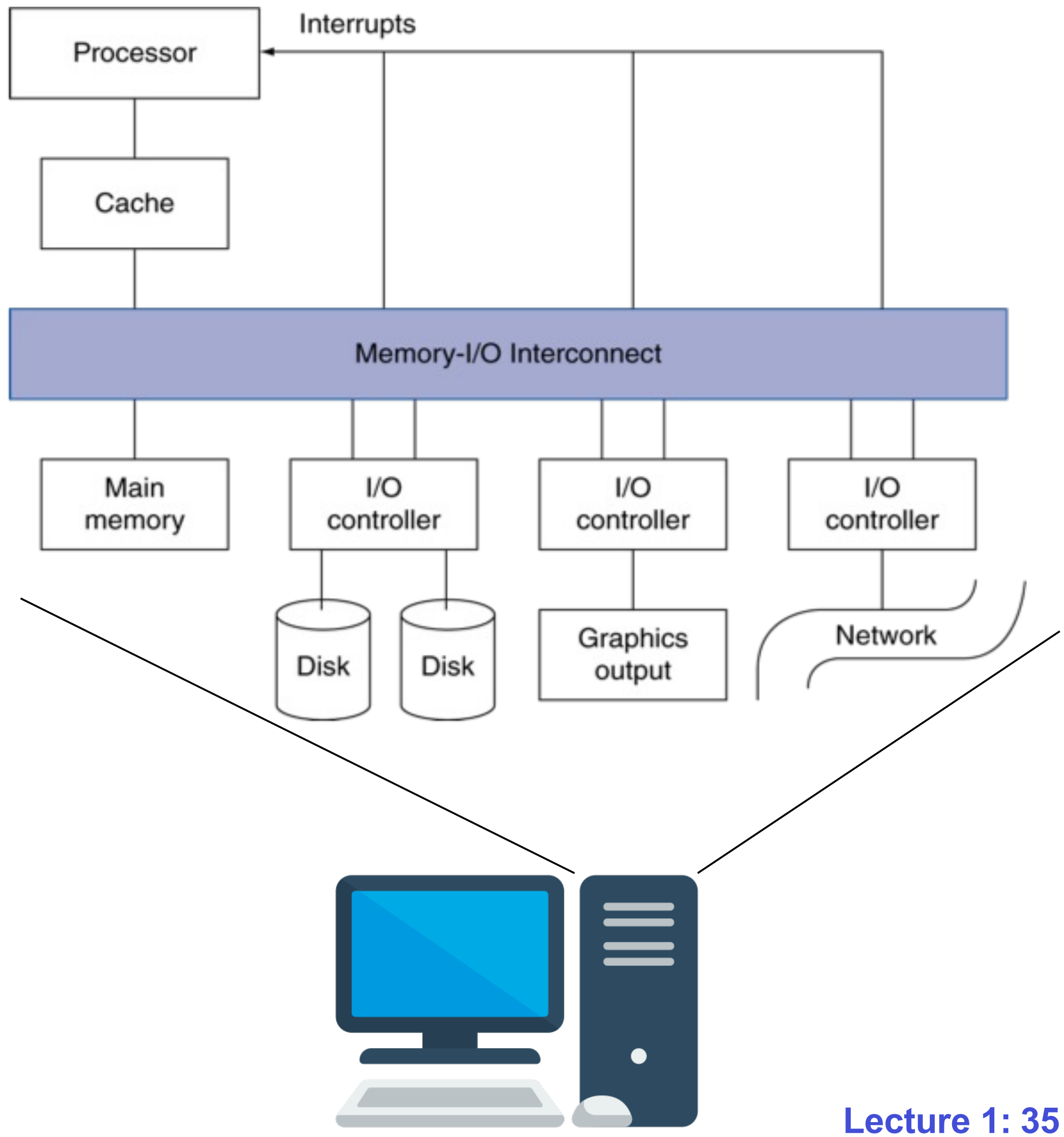
Build a Multi-Bit Adder

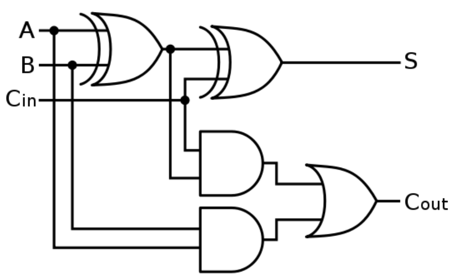


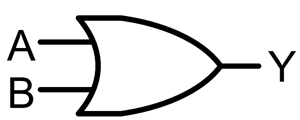
Build a Programmable Microprocessor



Build a Complete Computer







Before Next Class

- Read the syllabus!
- H&H 1.1-1.4.2, 1.5-1.6.2

Next Time

Boolean Algebra
(H&H 2.1-2.3)