CS 240
Foundations of Computer Systems

WELLESLEY

The Plan

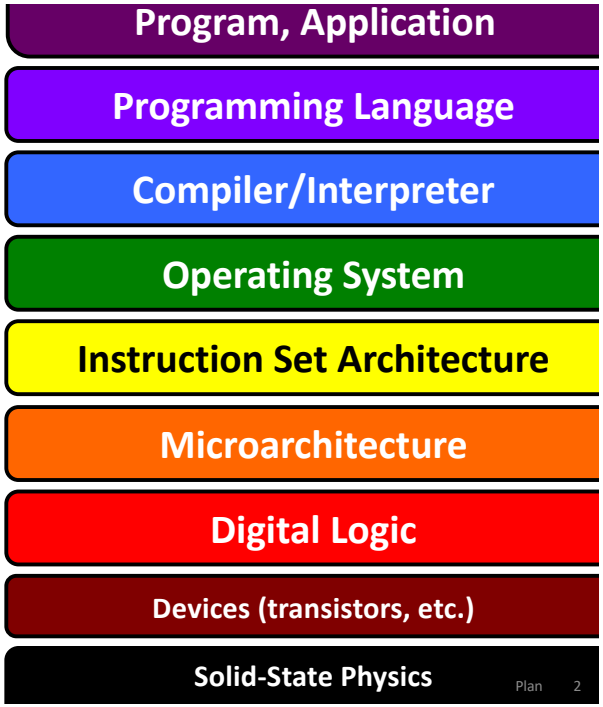
https://cs.wellesley.edu/~cs240/

Welcome to

CS 240:

Foundations of

Computer Systems



Today

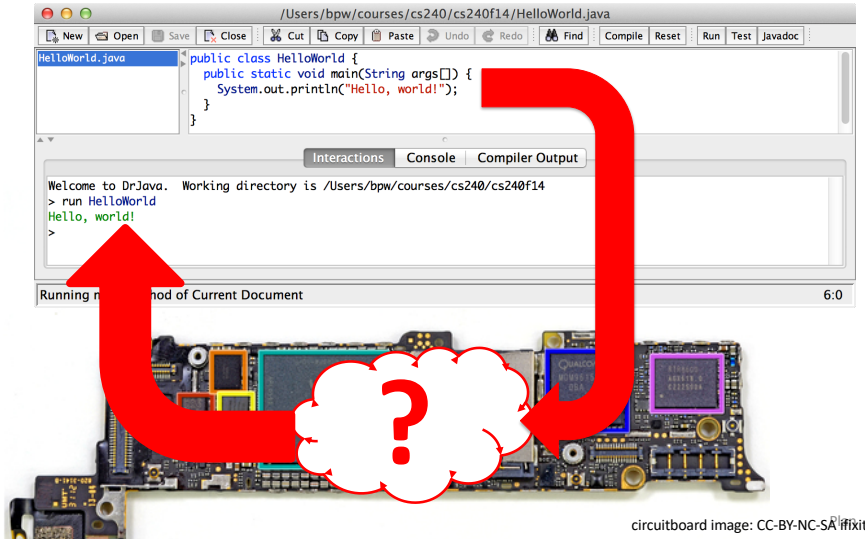
1. **What is CS 240?**
2. Why take CS 240?
3. How does CS 240 work?
4. Dive into foundations of computer hardware.

CS 111, 230, 231, 235, 251:

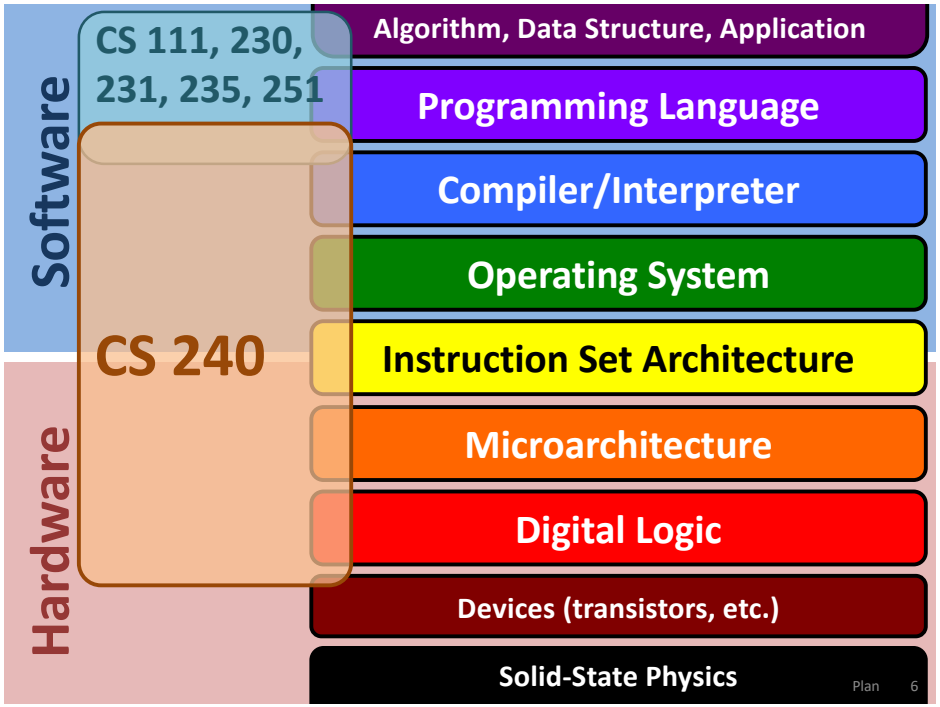
- What can a program do?
- How can a program solve a problem?
- How do you structure a program?
- How do you know it is correct or efficient?
- How hard is it to solve a problem?
- How is computation expressed?
- What does a program mean?
- …

A BIG question is missing…

1 CS 240: How do computers work?



circuitboard image: CC-BY-NC-SA ifixit.com



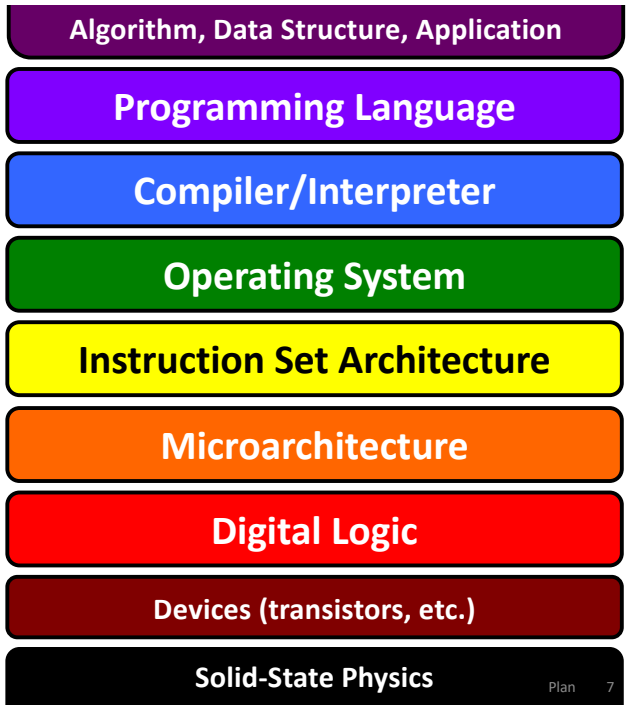
Big Idea:

Abstraction

interface

implementation

Layers manage complexity.



Big Idea: Abstraction

with a few recurring subplots

Simple, general interfaces:

Hide complexity of efficient implementation.
Make higher-level systems easy to build.
But they are not perfect.

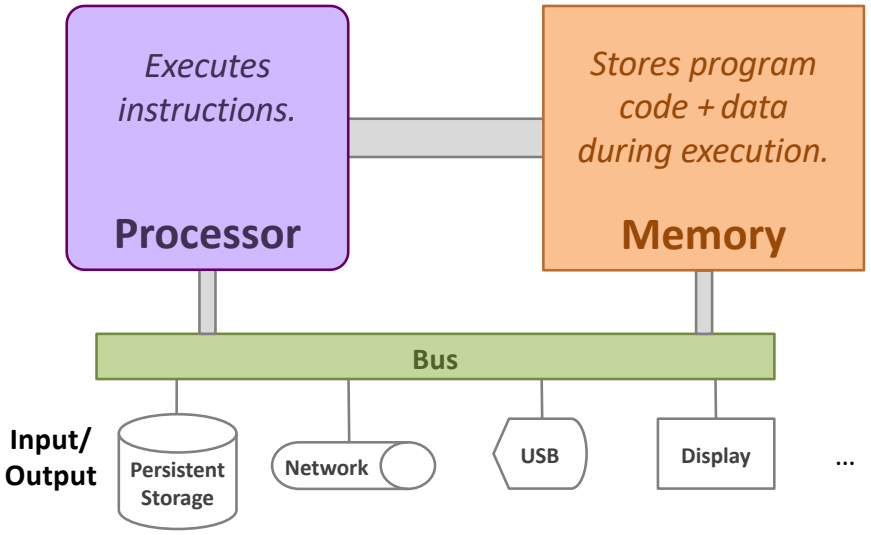
Representation of data and programs — 0s and 1s, electricity

Translation of data and programs — compilers, assemblers, decoders

Control flow within/across programs — branches, procedures, OS

1940s | 1950s | 1960s | 1970s | 1980s | 1990s | 2000s | 2010s | 2020s

Modern Computer Organization



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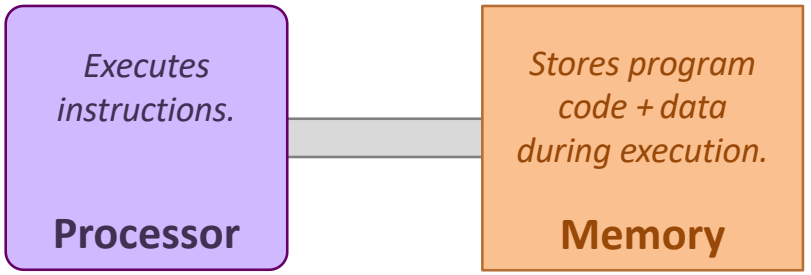
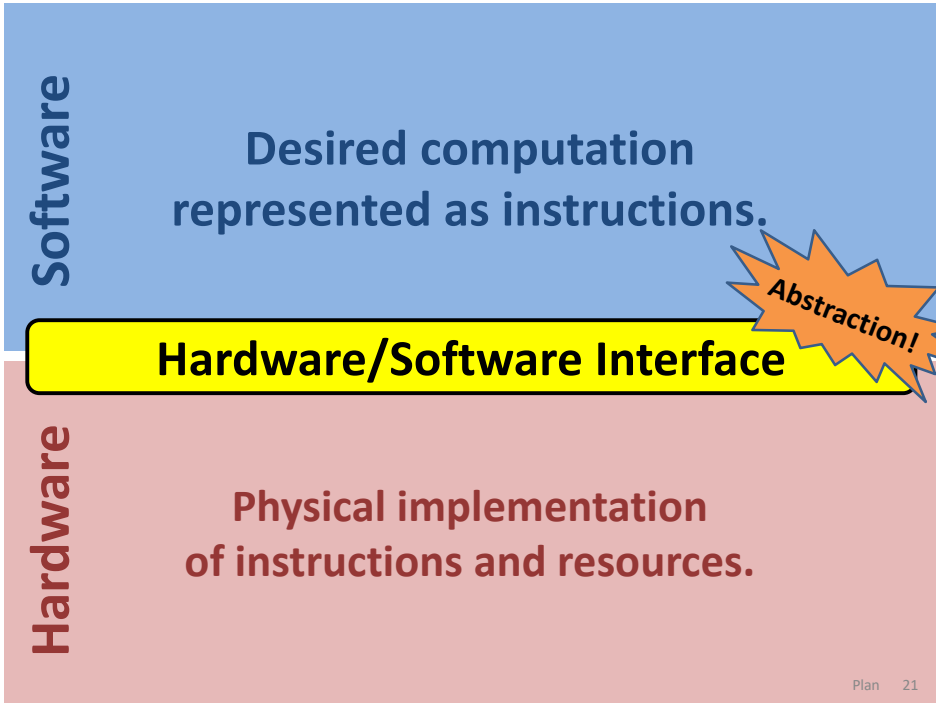
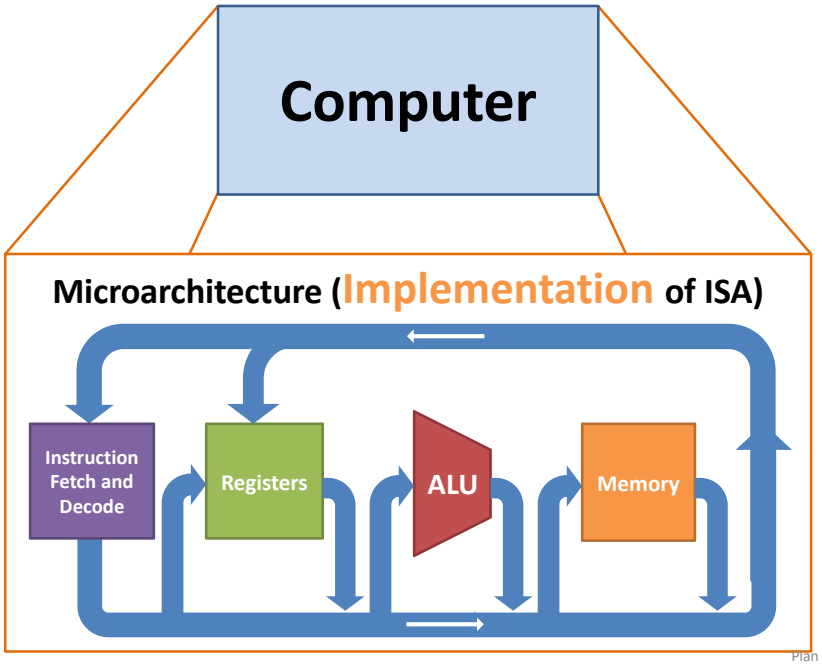
Modern Computer Organization



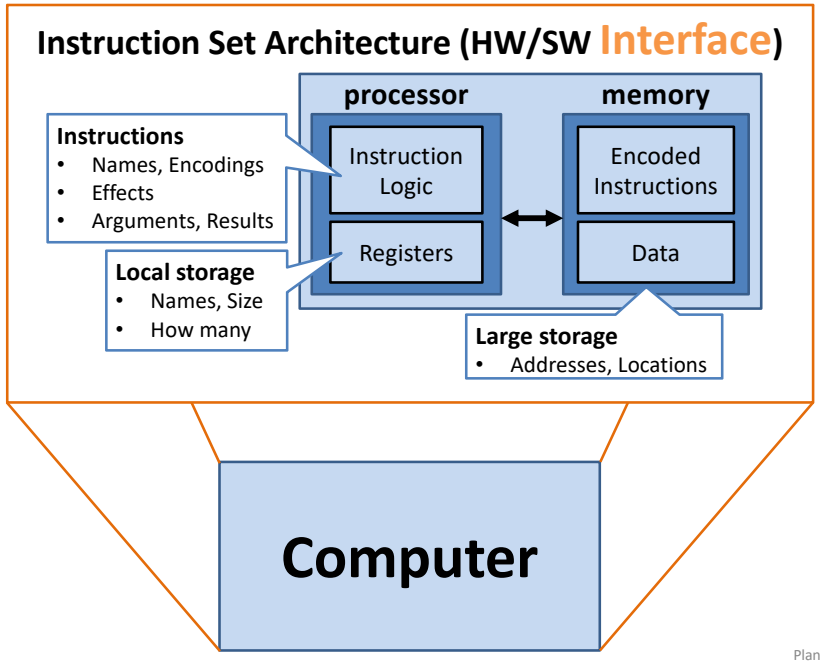
Processor repeats:

1. fetch instruction
2. fetch data used by instruction
3. execute instruction on data
4. store result or choose next instruction





Instruction Set Architecture (HW/SW Interface)

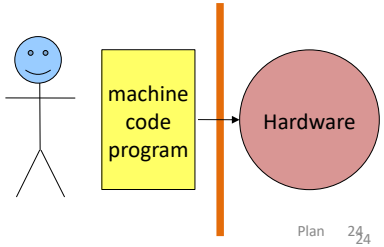


Machine Instructions

(adds two values and stores the result)

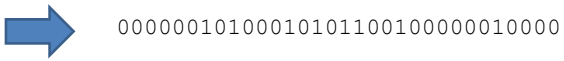
```
00000010100010101100100000010000
```

Instruction Set Architecture specification



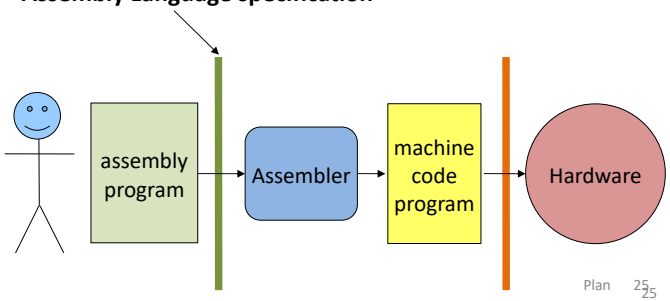
Assemblers and Assembly Languages

```
addl %eax, %ecx
```



```
00000010100010101100100000010000
```

Assembly Language specification



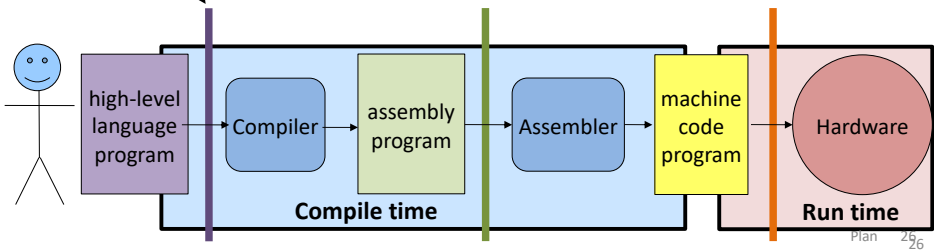
Higher-Level Programming Languages

```
x = x + y;
```

```
addl %eax, %ecx
```

```
00000010100010101100100000010000
```

Programming Language specification



1940s | 1950s | 1960s | 1970s | 1980s | 1990s | 2000s | 2010s | 2020s

More and more layers…

- Operating systems
- Virtual machines
- Hypervisors
- Web browsers
- …

2 *I just like to program. Why study the implementation?*

It's fascinating, great for critical thinking.

System design principles apply to software too.

Sometimes system abstractions "leak."
Implementation details affect your programs.

`int` ≠ integer
`float` ≠ real

```
int x=…;
x*x >= 0 ?
  40000 * 40000  ==  1600000000
  50000 * 50000  == -1794967296

float a=…, b=…, c=…;
(a + b) + c  ==  a + (b + c) ?
  (-2.7e23 +  2.7e23) + 1.0  == 1.0
   -2.7e23 + (2.7e23  + 1.0) == 0.0
```


Reliability?

Ariane 5 Rocket, 1996

Exploded due to **cast** of 64-bit floating-point number to 16-bit signed number. **Overflow.**

Boeing 787, 2015

"… a **Model 787 airplane** … can lose all alternating current (AC) electrical power … caused by a **software counter** internal to the GCUs that will **overflow** after **248 days** of continuous power. We are issuing this AD to prevent loss of all AC electrical power, which could result in **loss of control of the airplane**."
--FAA, April 2015

Arithmetic Performance

x / 973 **x / 1024**

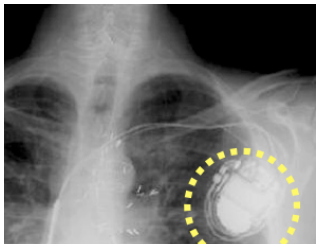
Memory Performance

```
void copyji(int src[2048][2048],
            int dst[2048][2048])
{
  int i,j;
  for (j = 0; j < 2048; j++)
    for (i = 0; i < 2048; i++)
      dst[i][j] = src[i][j];
}
```

```
void copyij(int src[2048][2048],
            int dst[2048][2048])
{
  int i,j;
  for (i = 0; i < 2048; i++)
    for (j = 0; j < 2048; j++)
      dst[i][j] = src[i][j];
}
```

several times faster due to hardware caches

Security



The *GHOST vulnerability* is a buffer overflow condition that can be easily exploited lo remotely, which makes it extremely dangerous. This vulnerability is named after the *GetHOS* function involved in the exploit.

Cyber-Safe

All computers are flawed -- and the fix will take years

by Selena Larson @selenalarson

January 26, 2018: 12:07 PM ET

Meltdown and Spectre

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A Heart Device Is Found Vulnerable to Hacker Attacks

By BARNABY J. FEDER

Published: March 12, 2008

To the long list of objects vulnerable to attack by computer hackers, add the human heart.

The threat seems largely theoretical. But a team of computer security researchers plans to report Wednesday that it had been able to gain wireless access to a combination heart defibrillator and pacemaker.

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Why take CS 240?

Learn how computers execute programs.
Build software tools and appreciate the value of those you use.
Deepen your appreciation of **abstraction.**
Learn enduring **system design principles**.
Improve your **critical thinking** skills.
Become a **better programmer**:

- Think rigorously about execution models.
- Program carefully, defensively.
- Debug and reason about programs effectively.
- Identify limits and impacts of abstractions and representations.
- Learn to use software development tools.

Foundations for:

- Compilers, security, computer architecture, operating systems, …

Have fun and feel accomplished!

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3 Everything is here.
Please read it.