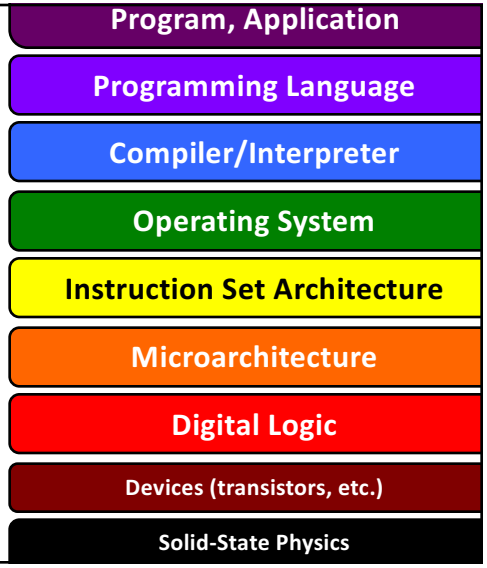
Welcome to

CS 240:

Intro to

Computer Systems



Today

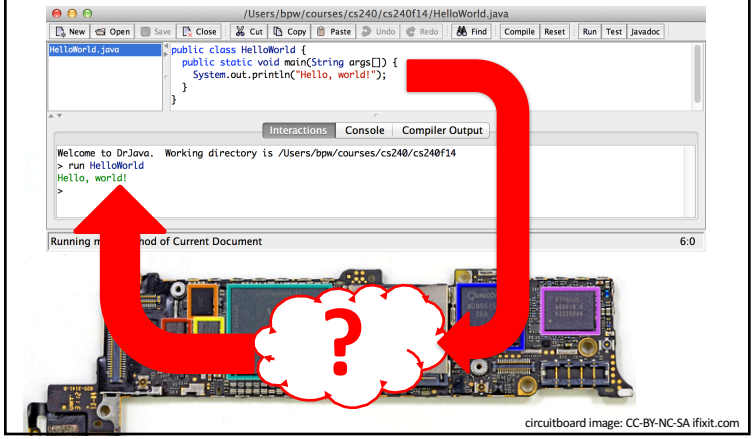
1. **What is CS 240?**
2. Why take CS 240?
3. How does CS 240 work?
4. Dive into foundations of computer hardware.

CS 111, 230, 231, 235, 251:

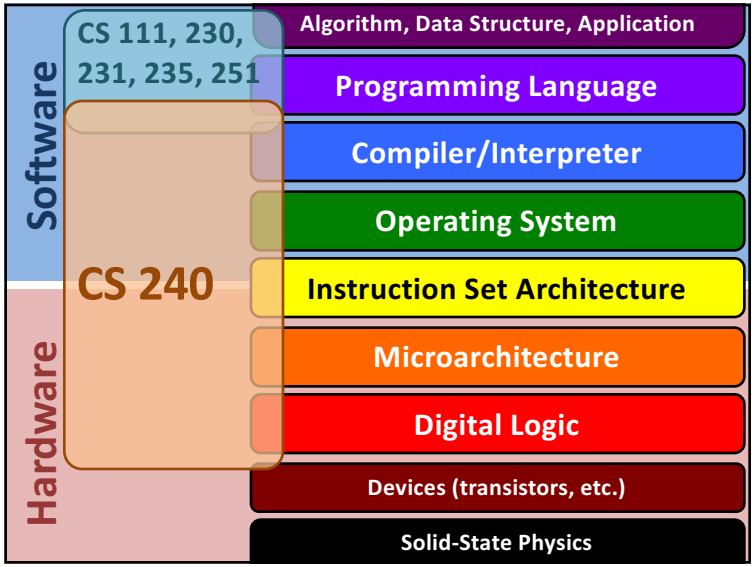
- What can a program do?
- How can a program solve a problem?
- How do you structure a program?
- How do you know it is correct or efficient?
- How hard is it to solve a problem?
- How is computation expressed?
- What does a program mean?
- …

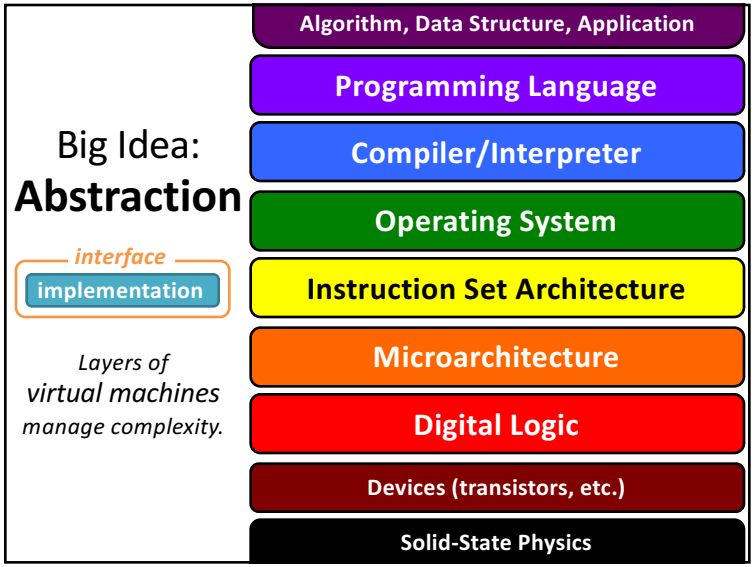
A BIG question is missing…

1 CS 240: How do computers work?



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





Big Idea: Abstraction

with a few recurring subplots

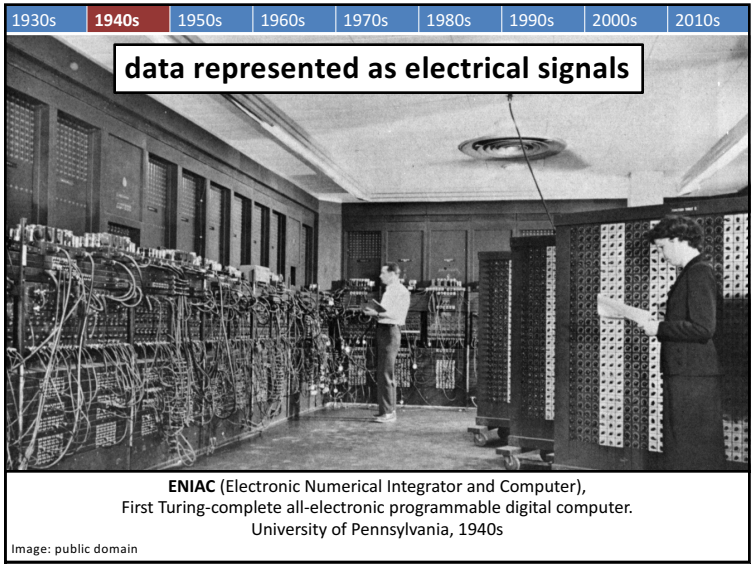
Simple, general interfaces:

- 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



ENIAC (Electronic Numerical Integrator and Computer),
First Turing-complete all-electronic programmable digital computer.
University of Pennsylvania, 1940s

Image: public domain

1930s | **1940s** | 1950s | 1960s | 1970s | 1980s | 1990s | 2000s | 2010s

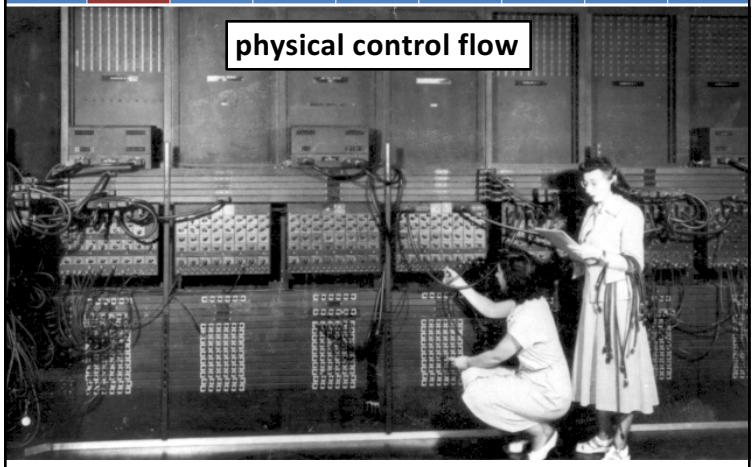
program controls general-purpose hardware

Jean Jennings Bartik and Frances Bilas Spence with part of ENIAC.
The programmers of ENIAC were six women.
http://eniacprogrammers.org/, http://sites.temple.edu/topsecretrosies/

Image: public domain

1930s | **1940s** | 1950s | 1960s | 1970s | 1980s | 1990s | 2000s | 2010s

physical control flow



Programming 1940s-style *with switches and cables.*

Image: public domain

1930s | 1940s | **1950s** | 1960s | 1970s | 1980s | 1990s | 2000s | 2010s

programs are data

machine translates instructions to control flow

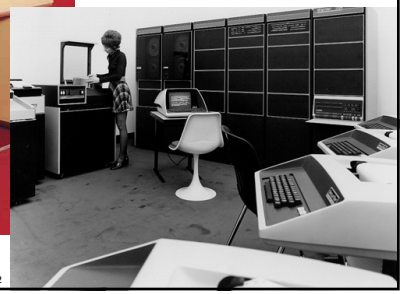
Manchester "Baby" SSEM (Small-Scale Experimental Machine), replica
first **stored-program computer** -- University of Manchester (UK), 1948

Image: "SSEM Manchester museum close up" by Parrot of Doom - Own work. Licensed under Creative Commons Attribution-Share Alike 3.0 via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:SSEM_Manchester_museum_close_up.jpg

1930s | 1940s | 1950s | **1960s** | **1970s** | 1980s | 1990s | 2000s | 2010s

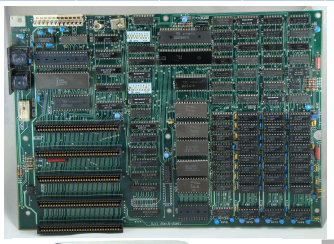
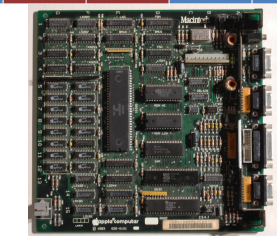
PDP-11 "**minicomputers**"

http://simh.trailing-edge.com/



http://www.pcworld.com/article/249951/if_it_aint_broke_dont_fix_it_ancient_computers_in_use_today.html?page=2

1930s | 1940s | 1950s | 1960s | 1970s | **1980s** | **1990s** | 2000s | 2010s

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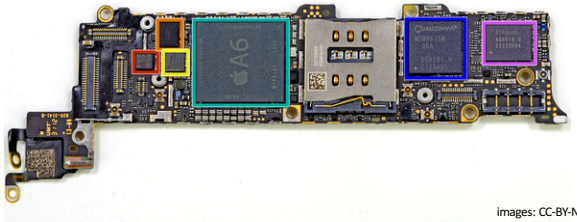
1930s | 1940s | 1950s | 1960s | 1970s | 1980s | 1990s | **2000s** | **2010s**





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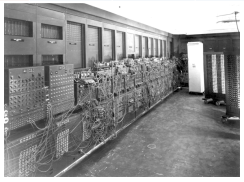
1930s | 1940s | 1950s | 1960s | 1970s | 1980s | 1990s | 2000s | **2010s**

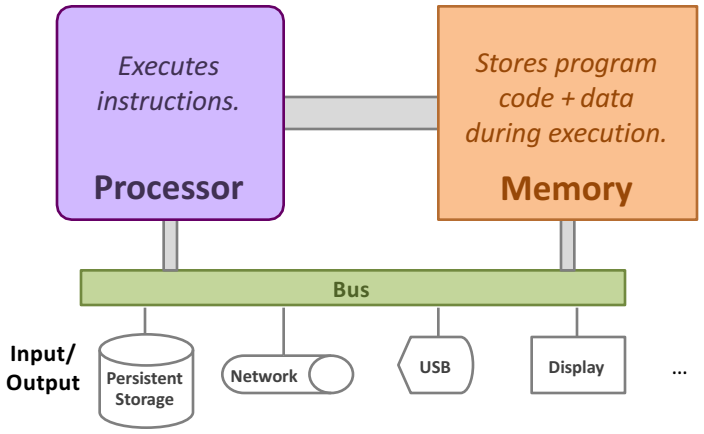


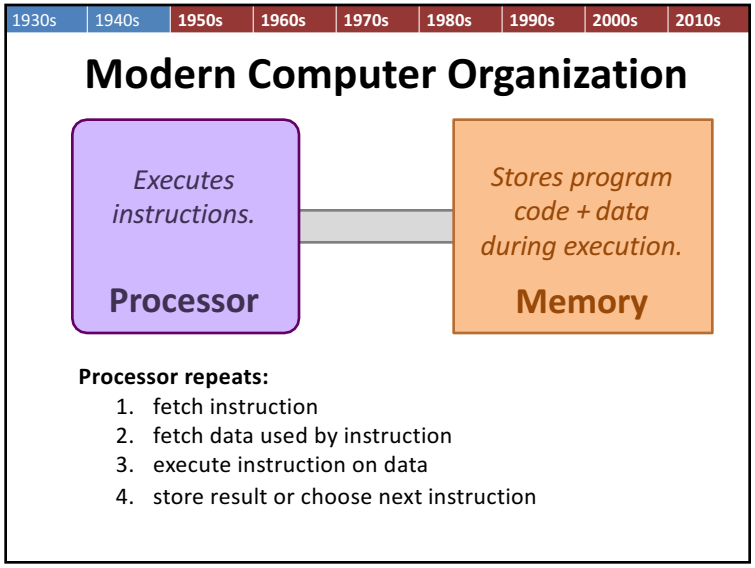

ENIAC image: public domain; iPhone image: CC-BY-NC-SA ifixit.com

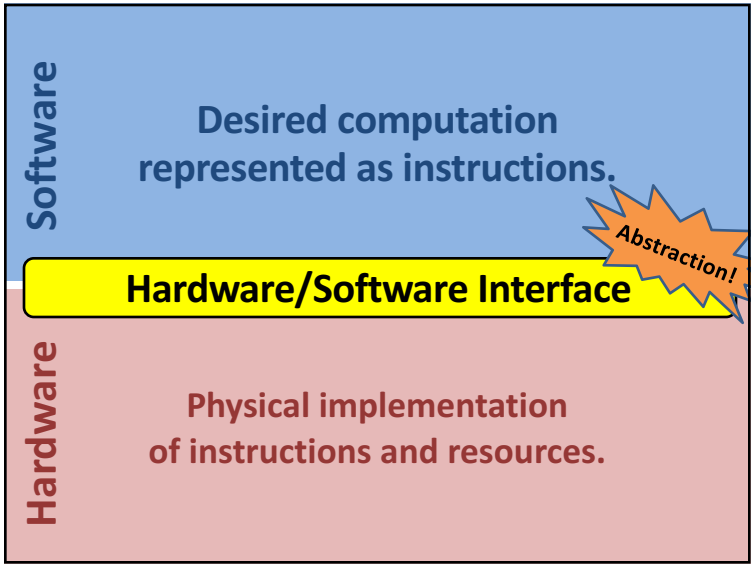
	ENIAC	**iPhone 5**
Year	1946	2012
Weight	30 tons	4 oz
Volume	2,400 ft^3	3.4 in^3
Cost (USD, 2014)	$6,000,000	$600
Speed	few 1000 ops/sec	2,500,000,000 ops/sec
Memory	~100 bytes	1,073,741,824 bytes (1 GB)
Power	150,000 W	<5W
Input/Output	Switches, lights, later punchcards	Touchscreen, audio, camera, wifi, cell, …
Production	1	5,000,000 sold in first 3 days

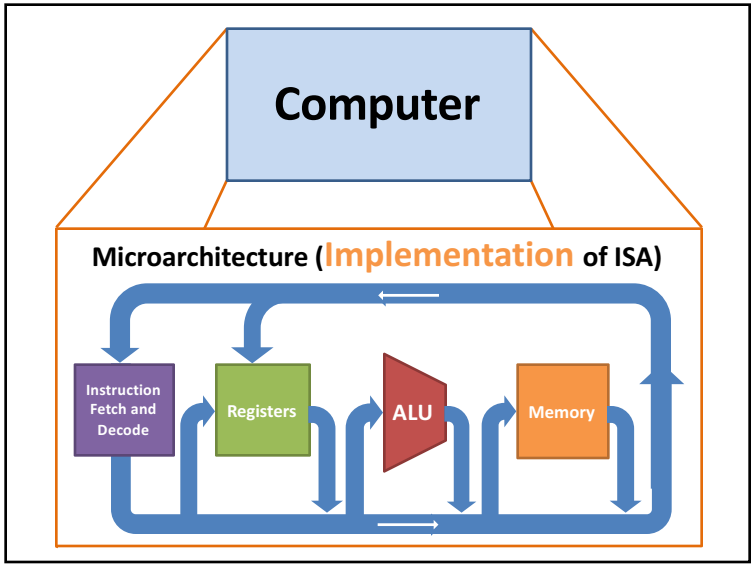
1930s | 1940s | **1950s** | **1960s** | **1970s** | **1980s** | **1990s** | **2000s** | **2010s**

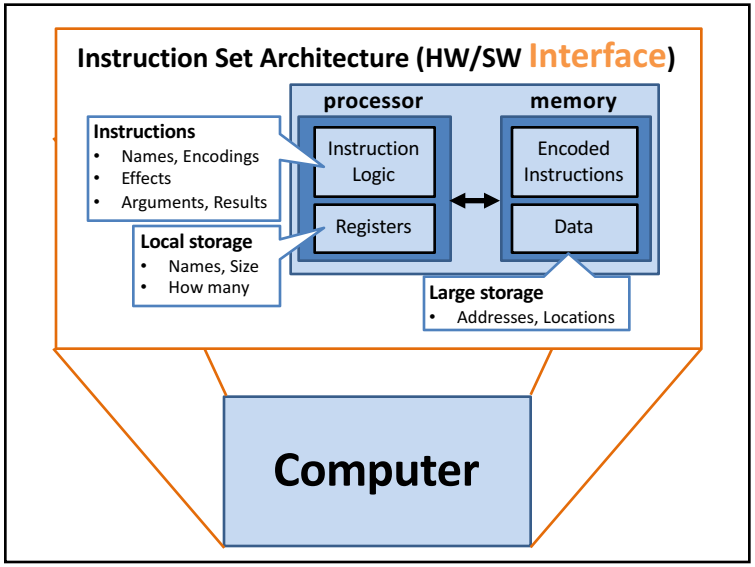
Modern Computer Organization




1930s
1940s
1950s
1960s
1970s
1980s
1990s
2000s
2010s
Modern Computer Organization
Executes instructions.
Processor
Stores program code + data during execution.
Memory
Processor repeats:
1. fetch instruction
2. fetch data used by instruction
3. execute instruction on data
4. store result or choose next instruction


Software
Desired computation represented as instructions.
Abstraction!
Hardware/Software Interface
Hardware
Physical implementation of instructions and resources.


Computer
Microarchitecture (Implementation of ISA)
Instruction Fetch and Decode
Registers
ALU
Memory


Instruction Set Architecture (HW/SW Interface)
processor
memory
Instructions
• Names, Encodings
• Effects
• Arguments, Results
Instruction Logic
Registers
Encoded Instructions
Data
Local storage
• Names, Size
• How many
Large storage
• Addresses, Locations
Computer

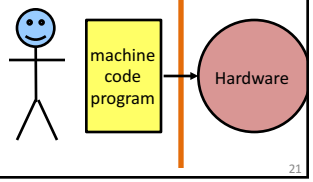
1930s 1940s 1950s 1960s 1970s 1980s 1990s 2000s 2010s

Machine Instructions

(adds two values and stores the result)

```
00000001010001010110010000010000
```

Instruction Set Architecture specification



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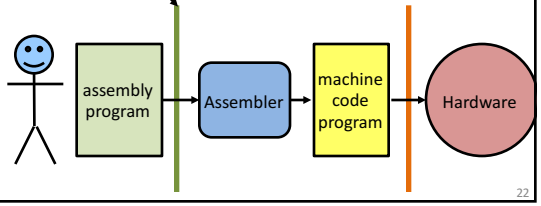
1930s 1940s 1950s 1960s 1970s 1980s 1990s 2000s 2010s

Assemblers and Assembly Languages

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

```
00000001010001010110010000010000
```

Assembly Language specification



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1930s 1940s 1950s 1960s 1970s 1980s 1990s 2000s 2010s

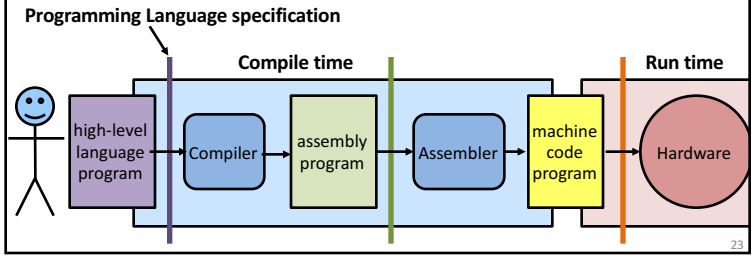
Higher-Level Programming Languages

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

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

```
00000001010001010110010000010000
```

Programming Language specification



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1930s 1940s 1950s 1960s 1970s 1980s 1990s 2000s 2010s

A-0: first compiler, by Grace Hopper

Early 1950s
Maybe closer to assembler/linker/loader

Later:
- B-0 → FLOW-MATIC
- → COBOL, late 50s

Jean Sammet also involved
- headed first sci comp group at Sperry in the '50s
- Later first female president of ACM.

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More and more layers…

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

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CS 240: a 3-stage sprint

(4-5 weeks each)

Hardware *implementation*

From transistors to a simple computer

Hardware-software *interface*

From instruction set architecture to C

Abstraction for practical systems

Memory hierarchy

Operating systems

Higher-level languages

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 + (y + c) ?
  (-2.7e23 +  2.7e23) + 1.0  == 1.0
   -2.7e23 + (2.7e23  + 1.0) == 0.0
```

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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

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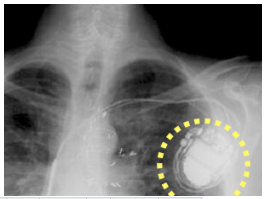
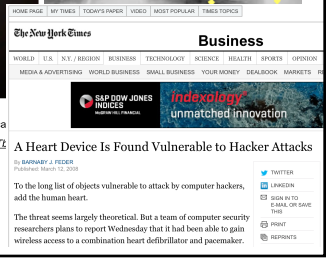
Security



e GHOST vulnerability is a buffer overflow condition that can be easily exploited loca
motely, which makes it extremely dangerous. This vulnerability is named after the GetHOSTb
nction involved in the exploit.



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!

Also: C programming language

- Invented to build UNIX operating system, 1970s
  - OS manages hardware, C close to machine model
- Simple pieces look like Java:
  - if, while, for, local variables, assignment, etc.
- Other pieces do not:
  - structs vs. objects, functions vs. methods
  - addresses, pointers
  - no array bounds checks
  - weak type system
- Important language, still widely used,
  but many better PL ideas have come along since.

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

Everything is here.

Please read it.