The Plan

Welcome to

CS 240:

Foundations of

Computer Systems

- Program, Application
- Programming Language
- Compiler/Interpreter
- Operating System
- Instruction Set Architecture
- Microarchitecture
- Digital Logic
- Devices (transistors, etc.)
- Solid-State Physics

Today

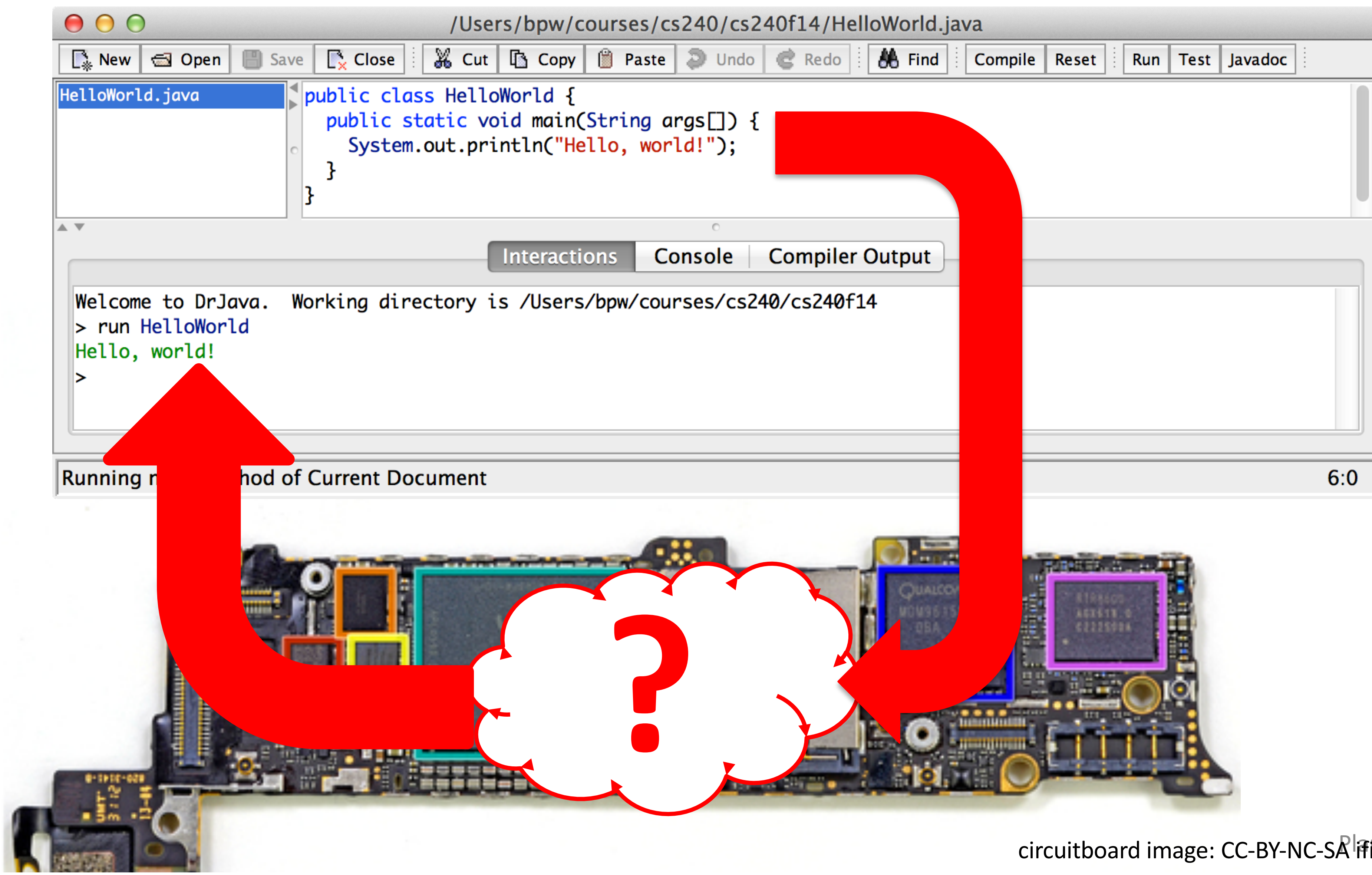
1. **What is CS 240?**
2. Why take CS 240?
3. How does CS 240 work?
4. Dive into foundations of computer hardware.

CS 111, 230, 231, 235, 251:

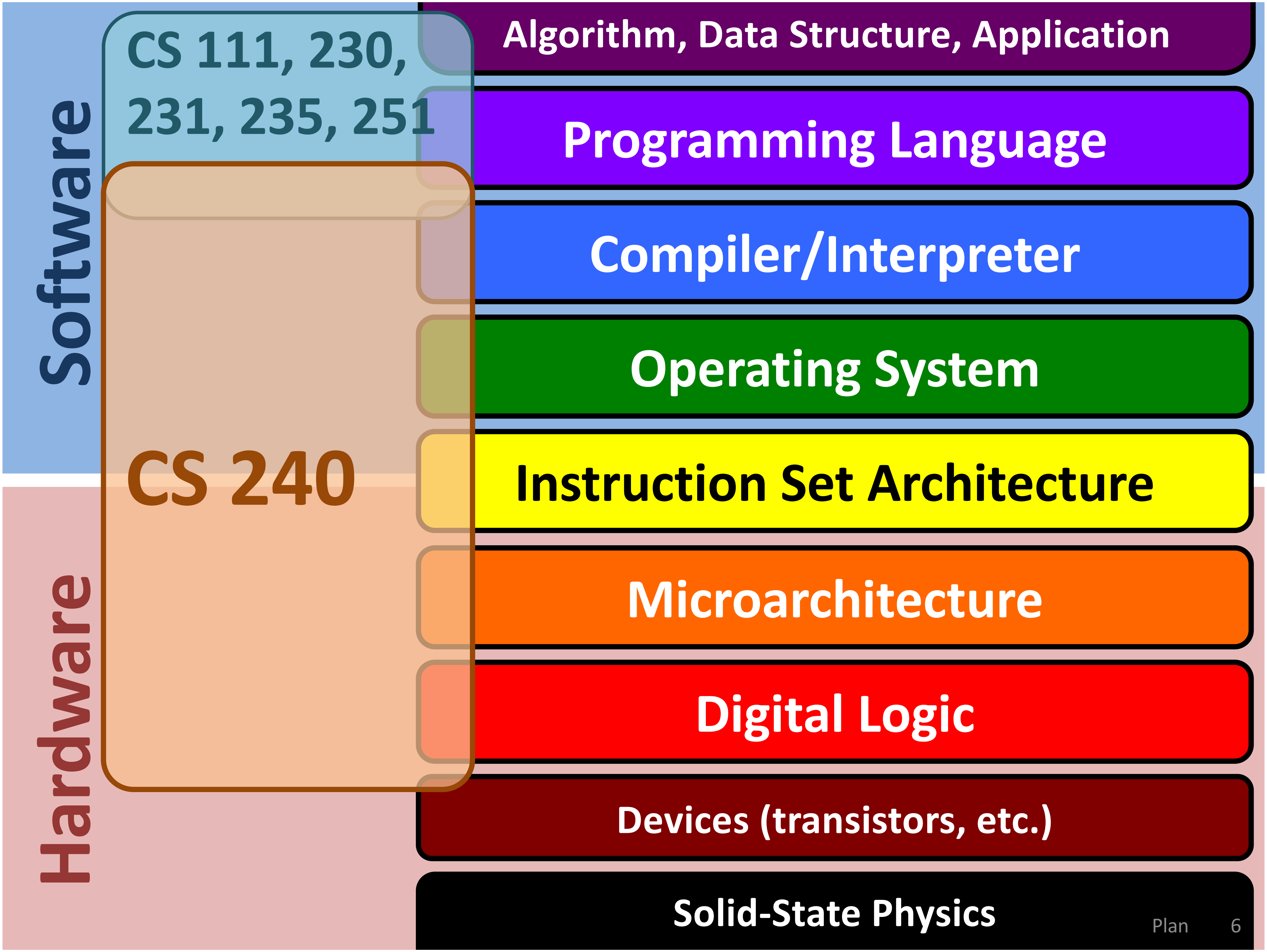
- What can a program do?
- How can a program solve a problem?
- How do you structure a program?
- How do you know it is correct or efficient?
- How hard is it to solve a problem?
- How is computation expressed?
- What does a program mean?
- …

A BIG question is missing…

1 CS 240: How do computers work?



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


Software
Hardware
CS 111, 230, 231, 235, 251
CS 240
Algorithm, Data Structure, Application
Programming Language
Compiler/Interpreter
Operating System
Instruction Set Architecture
Microarchitecture
Digital Logic
Devices (transistors, etc.)
Solid-State Physics

Big Idea: **Abstraction**

interface

implementation

Layers manage complexity.

- Algorithm, Data Structure, Application
- Programming Language
- Compiler/Interpreter
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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

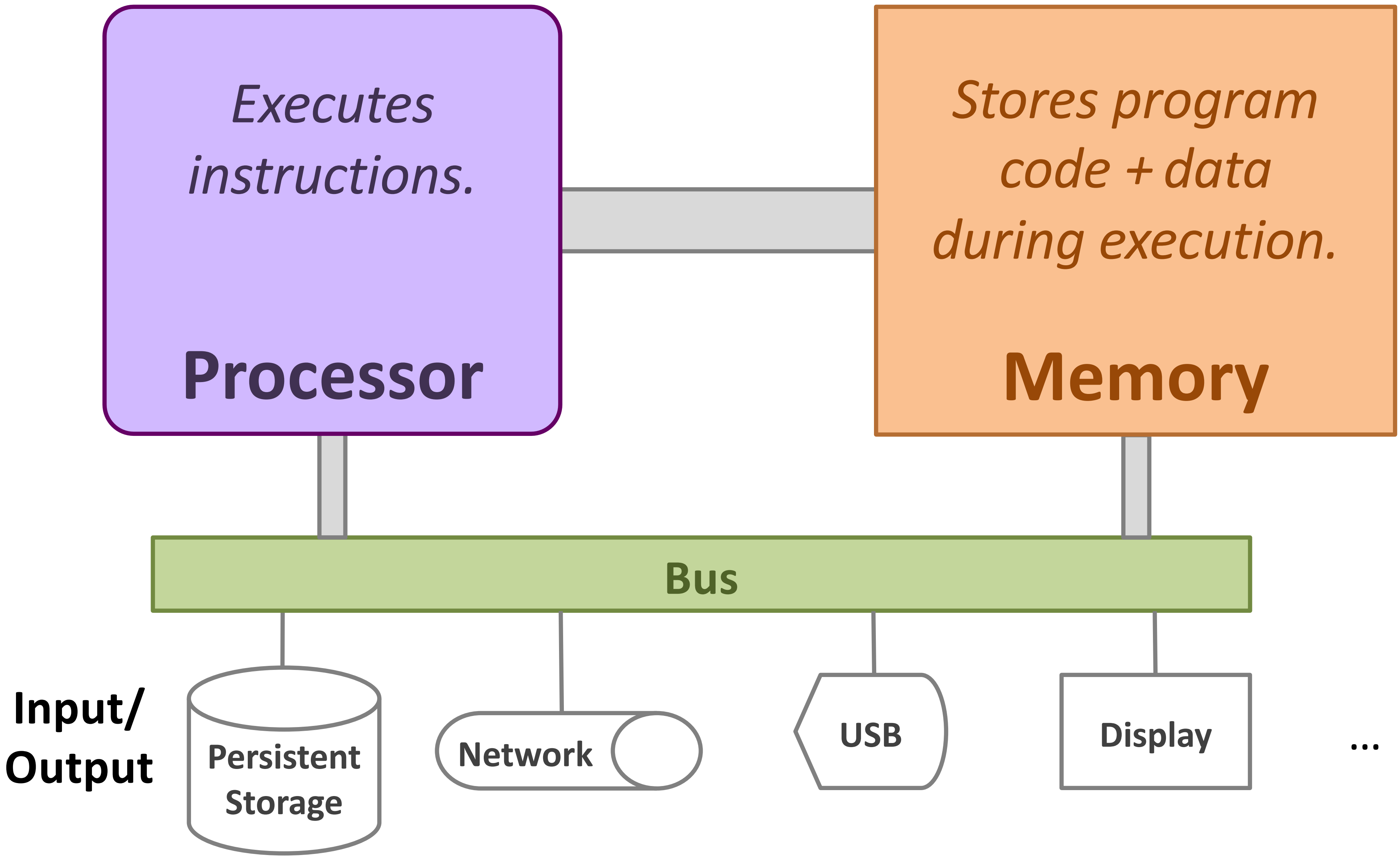
Translation of data and programs

compilers, assemblers, decoders

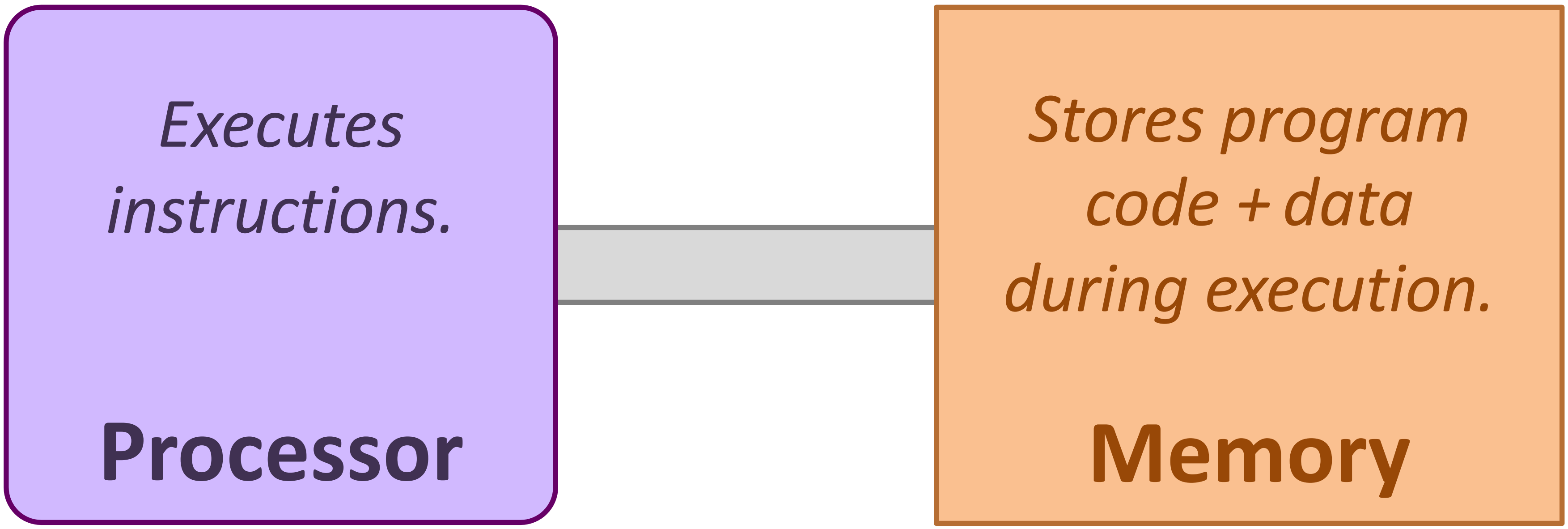
Control flow within/across programs

branches, procedures, OS

Modern Computer Organization



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

Software

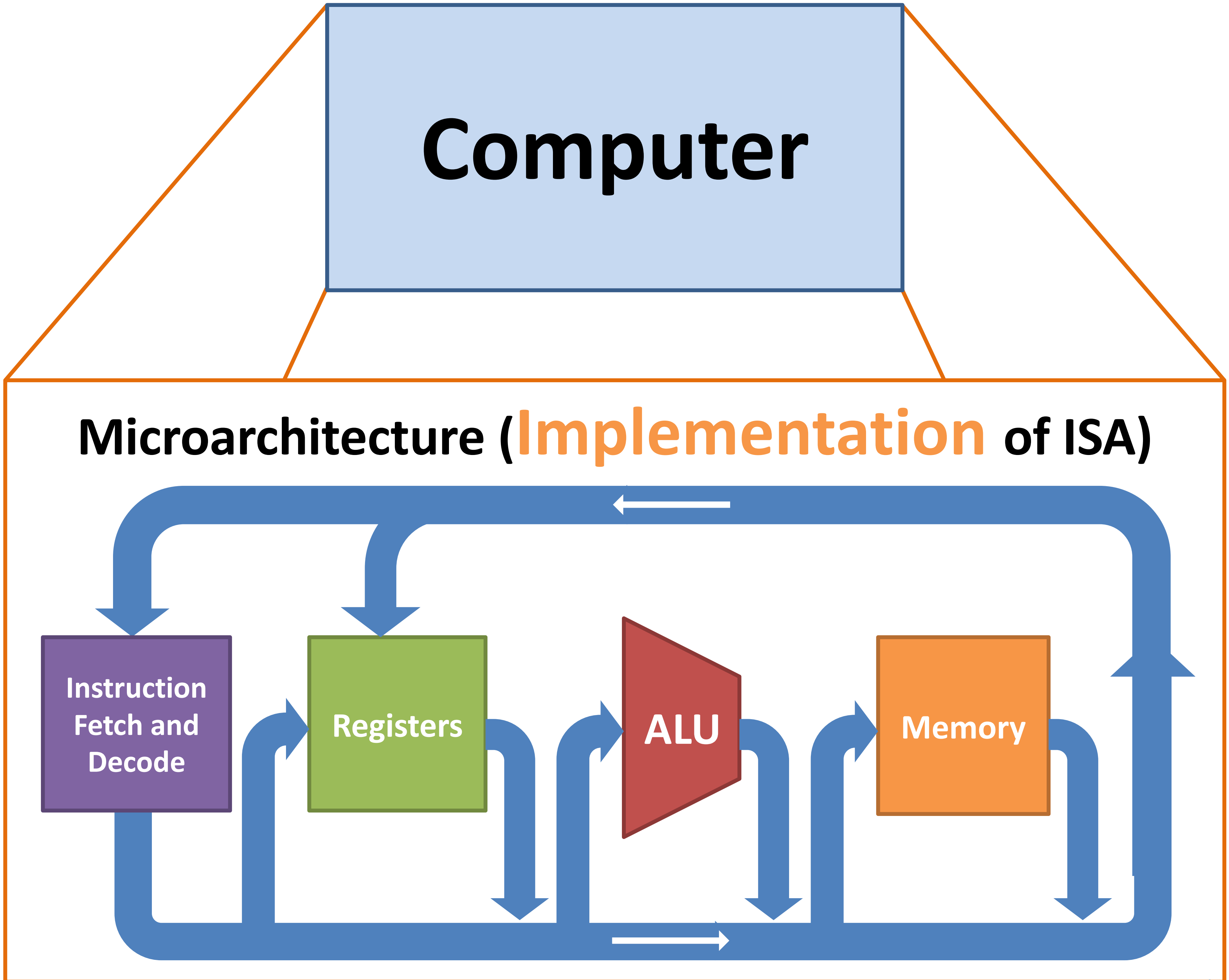
Desired computation represented as instructions.

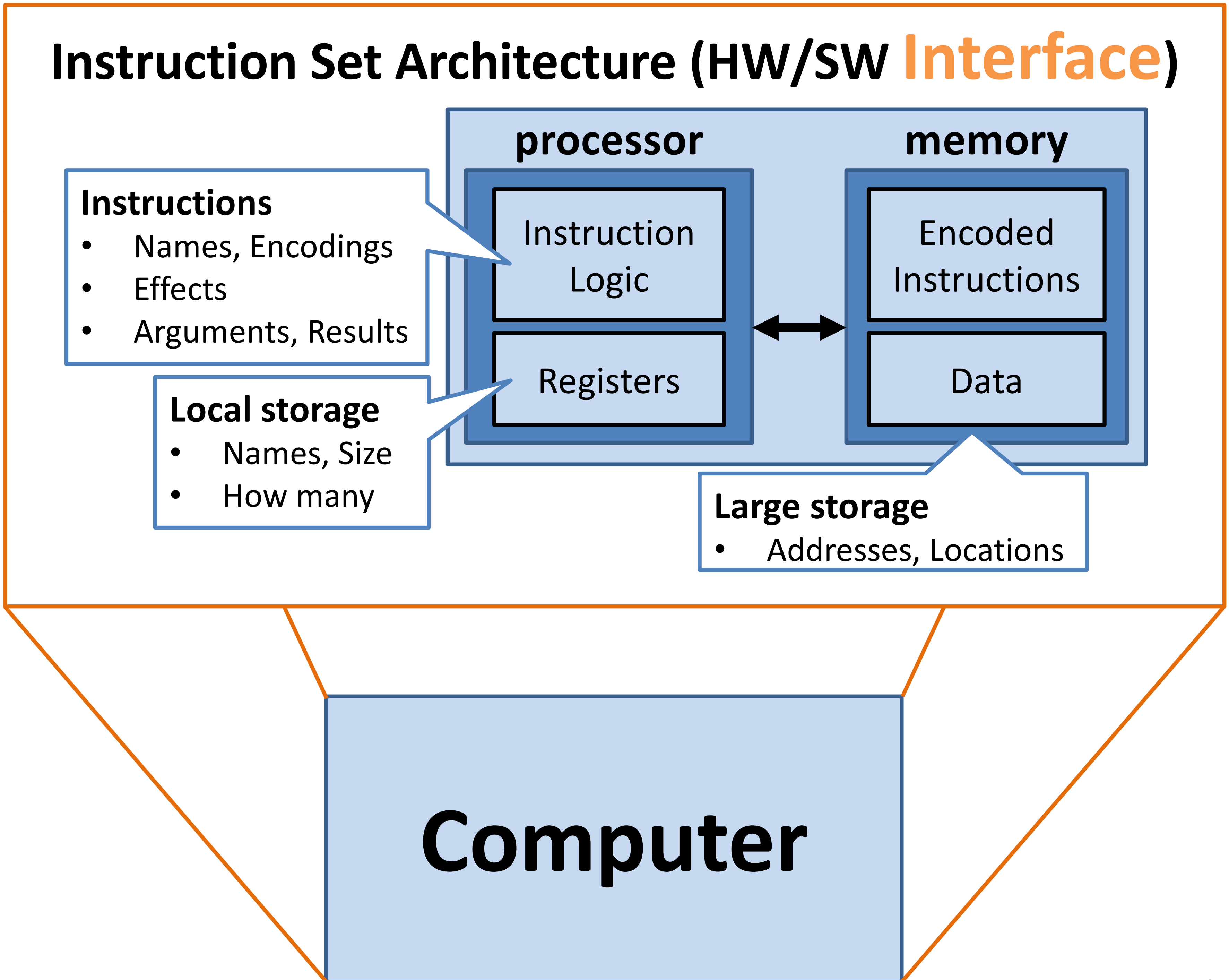
Abstraction!

Hardware/Software Interface

Hardware

Physical implementation of instructions and resources.


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

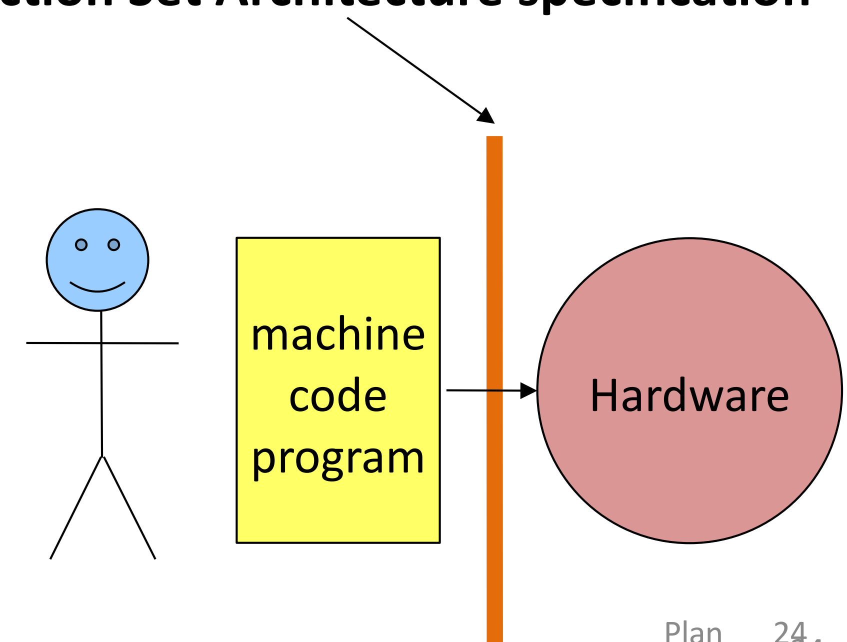

Instruction Set Architecture (HW/SW Interface)
processor
memory
Instructions
• Names, Encodings
• Effects
• Arguments, Results
Instruction Logic
Registers
Encoded Instructions
Data
Local storage
• Names, Size
• How many
Large storage
• Addresses, Locations
Computer

Machine Instructions

(adds two values and stores the result)

00000010100010101100100000010000

Instruction Set Architecture specification



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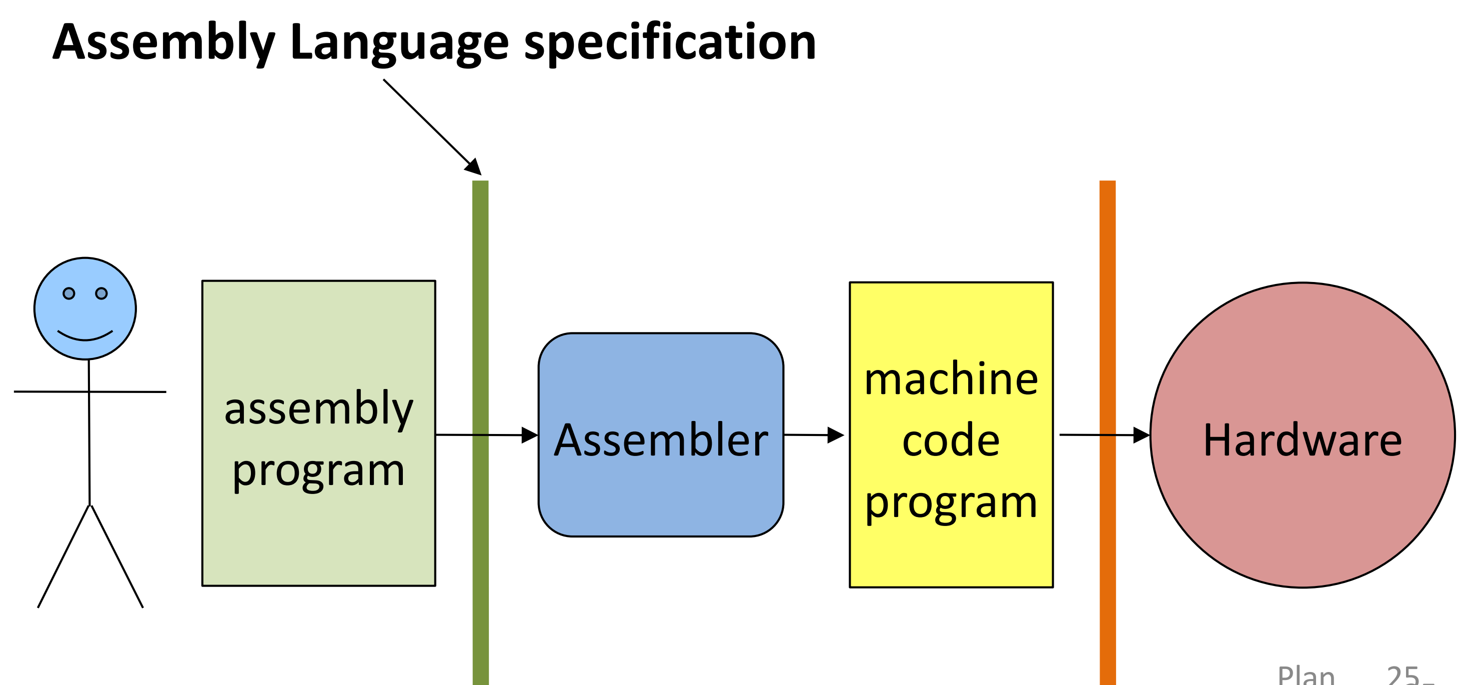
Assemblers and Assembly Languages

`addl %eax, %ecx` → `00000001000101011001000000010000`



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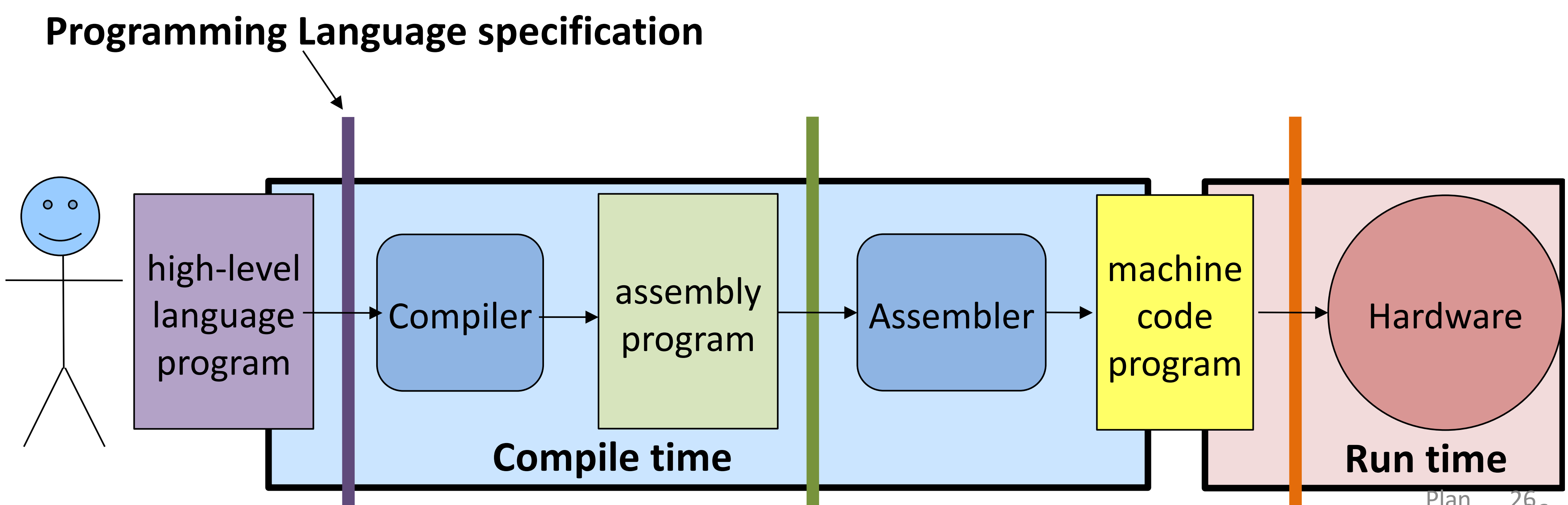
Higher-Level Programming Languages

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

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

```
00000010100010101100100000010000
```



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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**

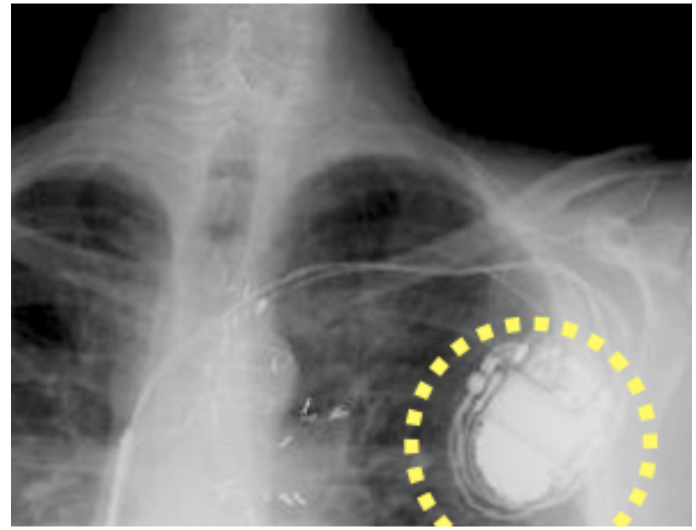
Memory Performance

```
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

The New York Times Business

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.

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!

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

3 Everything is here.

Please read it.