C335
Computer Structures

Computer Abstractions and Technology
(Part #1)

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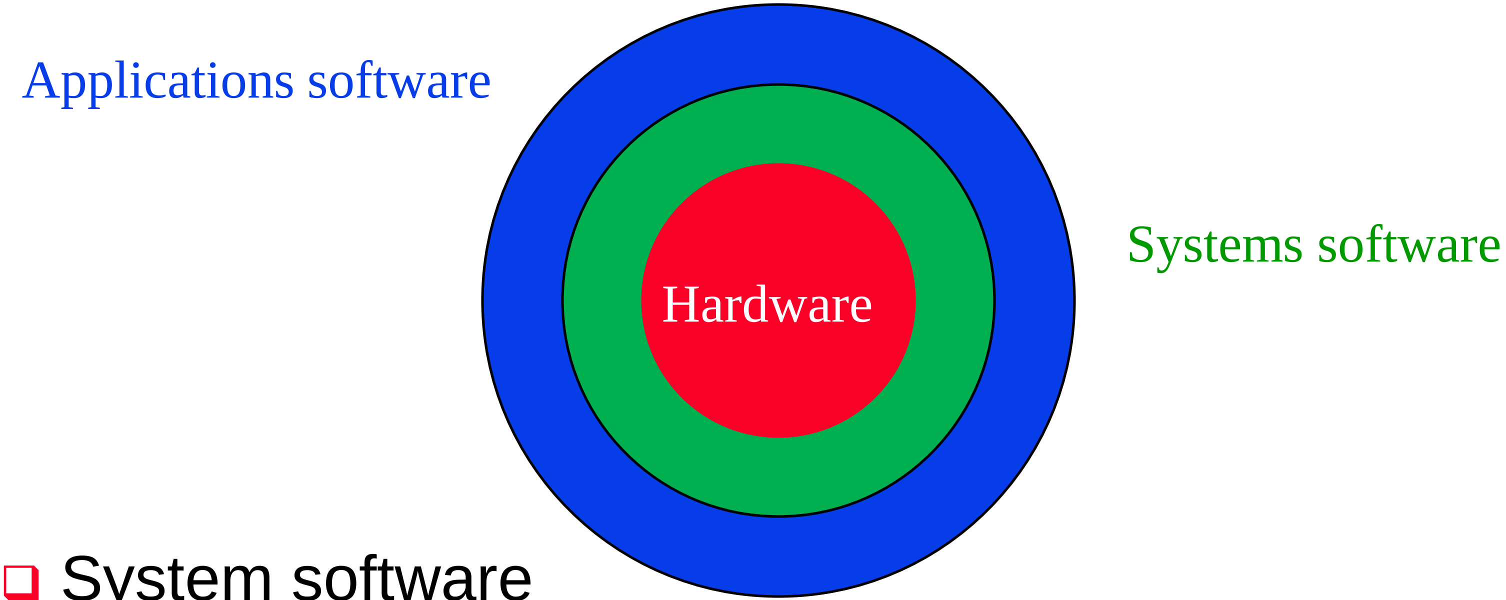
Computer Abstractions and Technology

- What is computer architecture?

- What forces drive computer architecture?

- Performance

Below the Program

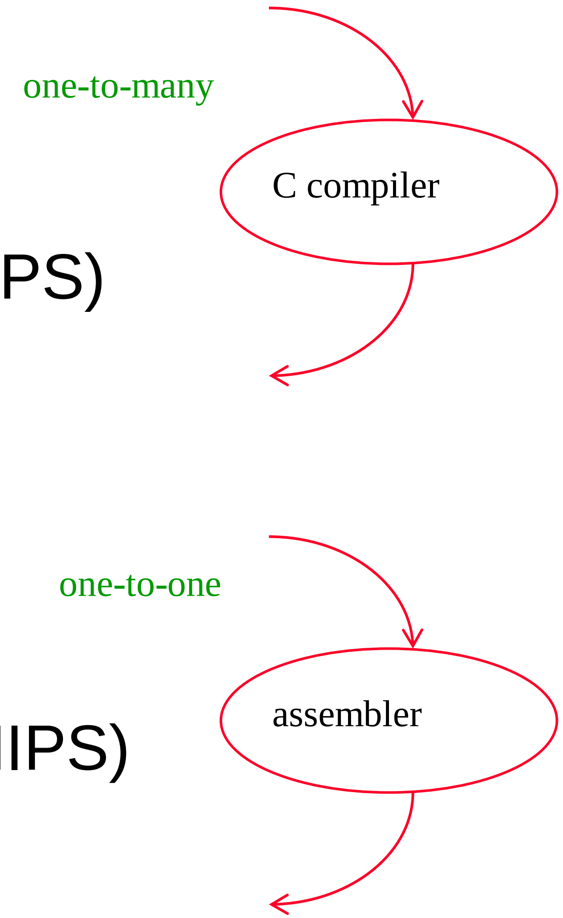


- System software
  - Operating system – supervising program that interfaces the user's program with the hardware (e.g., Linux, Mac OS, Windows)
    - Handles basic input and output operations
    - Allocates storage and memory
    - Provides for protected sharing among multiple applications
  - Compiler – translate programs written in a high-level language (e.g., C, Java) into instructions that the hardware can execute

Below the Program, Con’t

- High-level language program (in C)

```
swap (int v[], int k)
(int temp;
      temp = v[k];
      v[k] = v[k+1];
      v[k+1] = temp;
)
```



- Assembly language program (for MIPS)

```
swap:  sll    $2, $5, 2
       add    $2, $4, $2
       lw     $15, 0($2)
       lw     $16, 4($2)
       sw     $16, 0($2)
       sw     $15, 4($2)
       jr     $31
```

- Machine (object, binary) code (for MIPS)

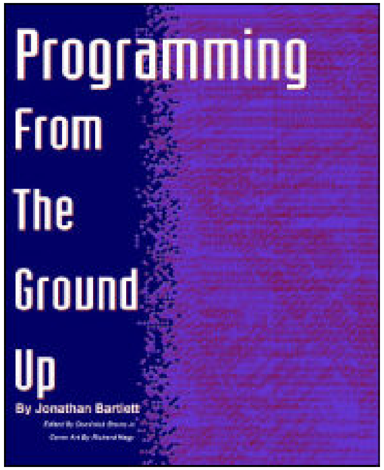
```
000000 00000 00101 0001000010000000
000000 00100 00010 0001000000100000
 . . .
```

Advantages of Higher-Level Languages ?

- Higher-level languages
  - Allow the programmer to think in a more natural language and for their intended use (Fortran for scientific computation, Cobol for business programming, Lisp for symbol manipulation, Java for web programming, …)
  - Improve programmer productivity – more understandable code that is easier to debug and validate
  - Improve program maintainability
  - Allow programs to be independent of the computer on which they are developed (compilers and assemblers can translate high-level language programs to the binary instructions of any machine)
  - Emergence of optimizing compilers that produce very efficient assembly code optimized for the target machine
- As a result, very little programming is done today at the assembler level

Why bother to learn assembly language?

- **"The difference between mediocre and star programmers is that star programmers understand assembly language, whether or not they use it on a daily basis."**



- **"Assembly language is the language of the computer itself. To be a programmer without ever learning assembly language is like being a professional race car driver without understanding how your carburetor works.** ***To be a truly successful programmer, you have to understand exactly what the computer sees when it is running a program.*** **Nothing short of learning assembly language will do that for you. Assembly language is often seen as a black art among today's programmers - with those knowing this art being more productive, more knowledgeable, and better paid, even if they primarily work in other languages."**

QUESTION: In Spring 2001, tens of thousands of dot.com workers have been laid off.

- How many of them were making car payments on a Jaguar?
- How many of them knew assembly language?

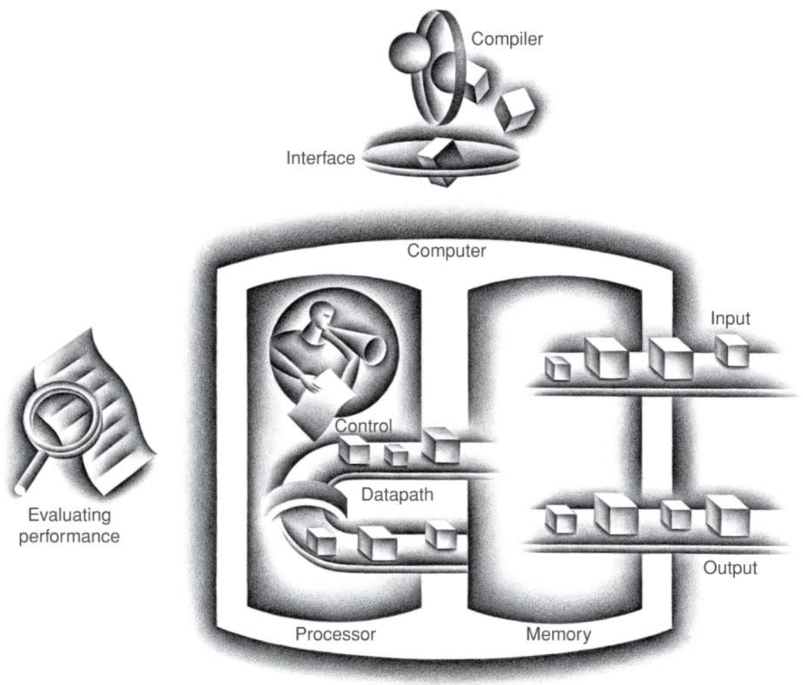
ANSWER:

- How many of them were making car payments on a Jaguar?
  - Many of them.
- How many of them knew assembly language?
  - Few of them.

The used car lots of Silicon Valley were full of repossessed Jaguars (according to a news story in 2001).

Under the Covers

The BIG Picture



datapath + control = processor (CPU)

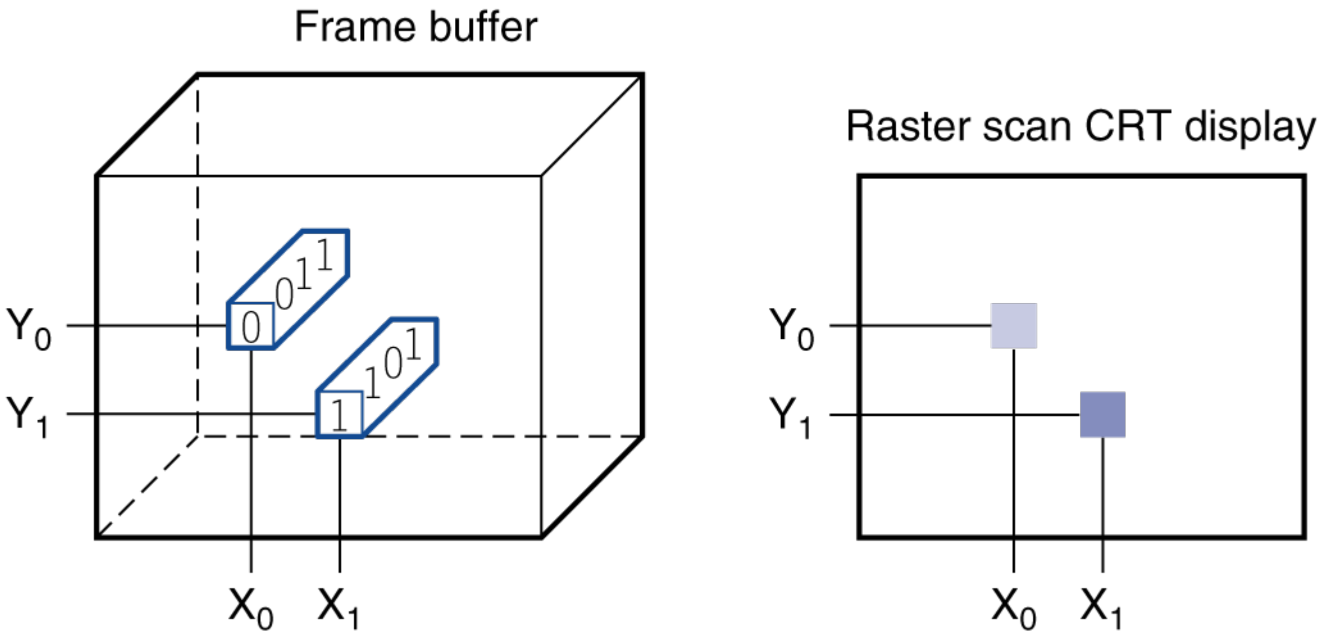
- Same components for all kinds of computer
  - Desktop, server, embedded
- Input/output includes
  - User-interface devices
    - Display, keyboard, mouse
  - Storage devices
    - Hard disk, CD/DVD, flash
  - Network adapters
    - For communicating with other computers

Touchscreen

- PostPC device
- Supersedes keyboard and mouse
- Resistive and Capacitive types
  - Most tablets, smart phones use capacitive
  - Capacitive allows multiple touches simultaneously

Through the Looking Glass

- LCD screen: picture elements (pixels)
  - Mirrors content of frame buffer memory

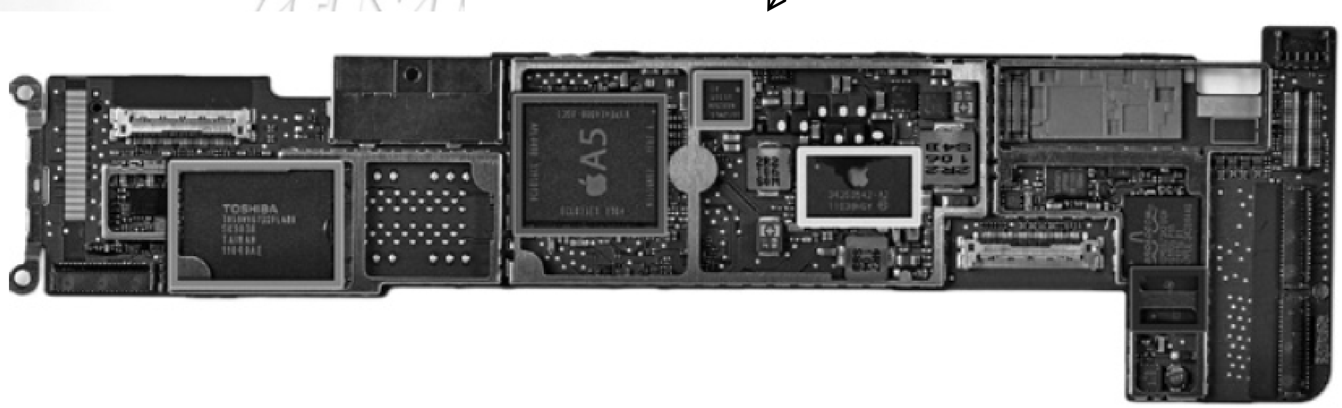


Opening the Box

Capacitive multitouch LCD screen

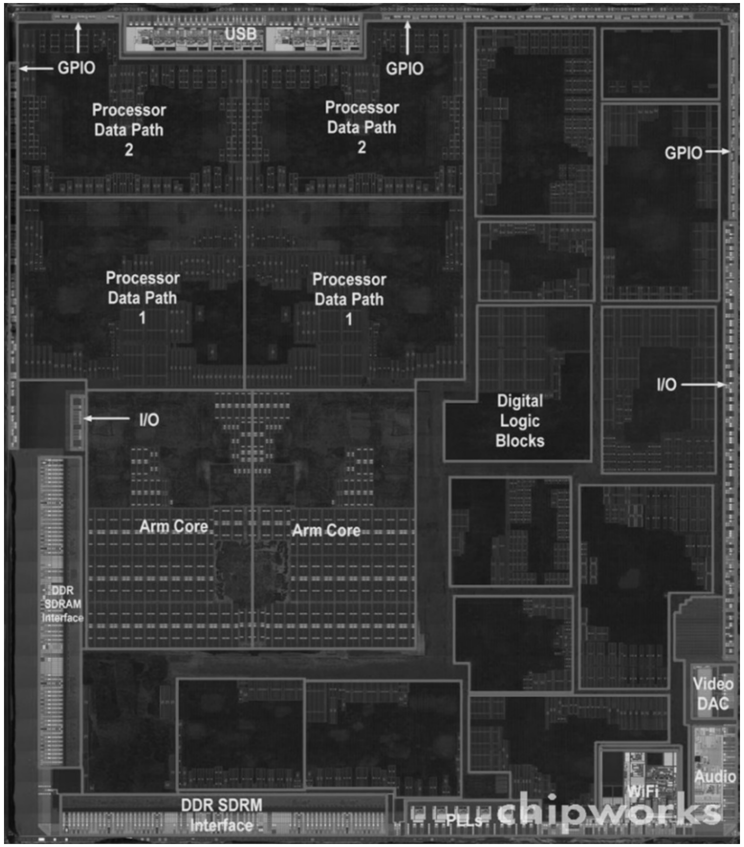
3.8 V, 25 Watt-hour battery

Computer board



Inside the Processor (CPU)

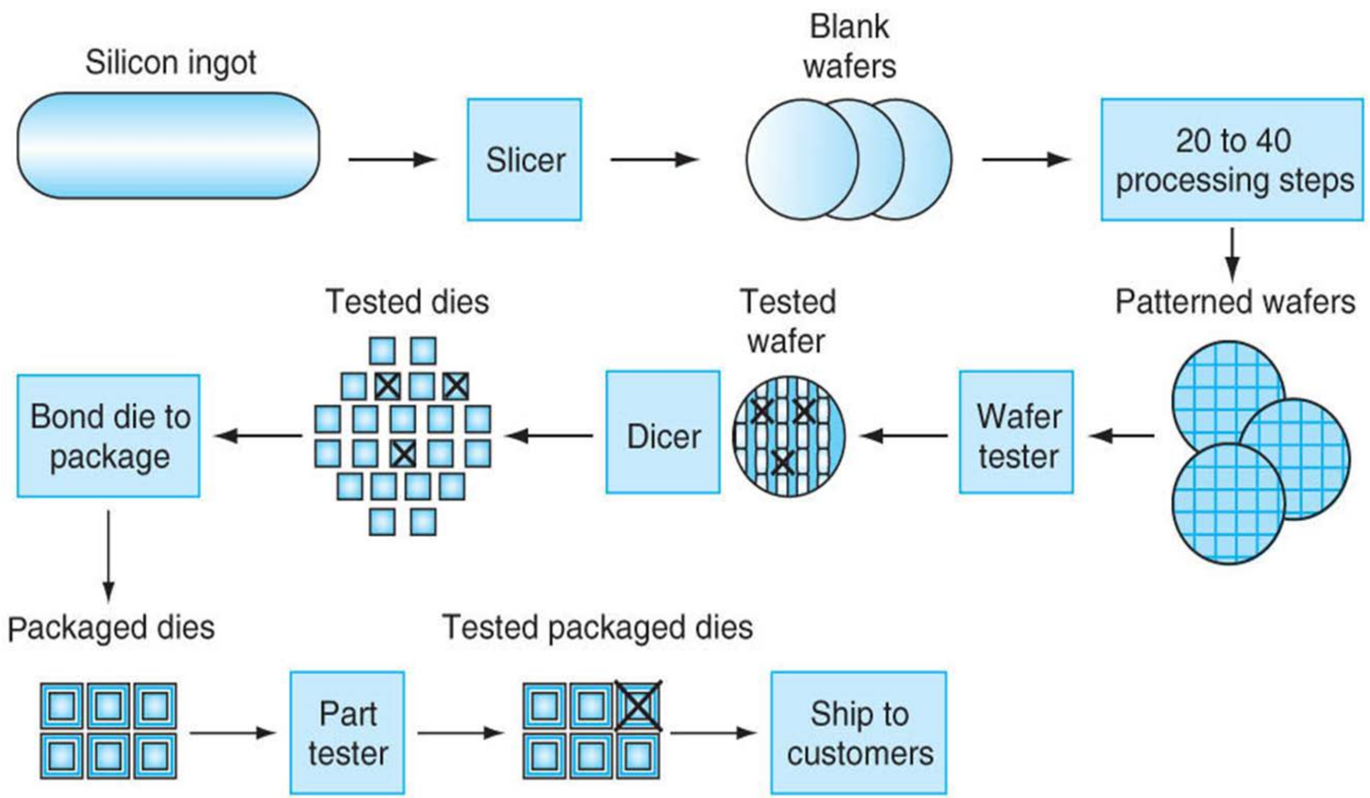
- Datapath: performs operations on data
- Control: sequences datapath, memory, ...
- Cache memory
  - Small fast SRAM memory for immediate access to data



A5 processor

Chip Manufacturing Process

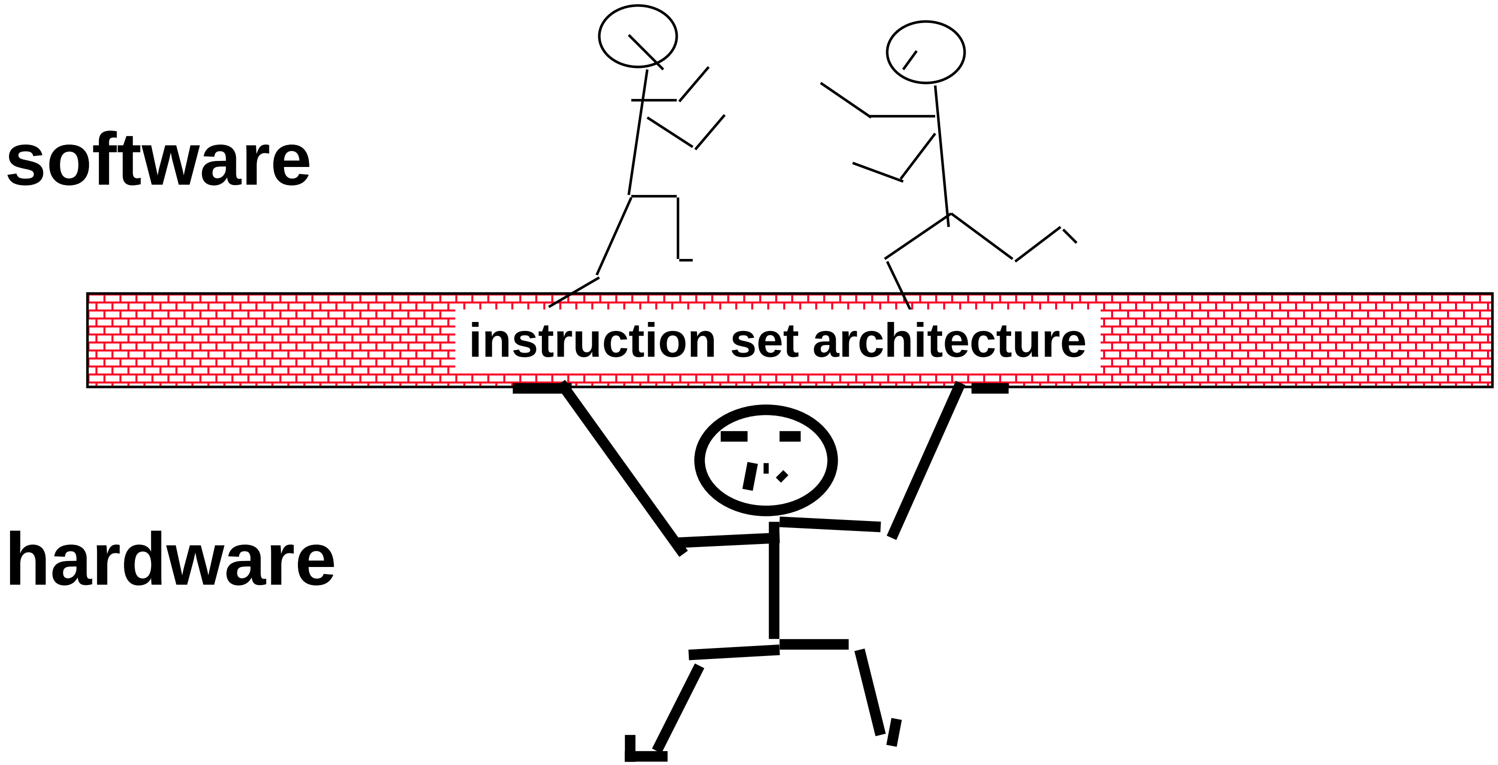
- Silicon: semiconductor
- Add materials to transform properties:
  - Conductors
  - Insulators
  - Switch



The Instruction Set Architecture (ISA)

- Instructions
  - The words of a computer's language are called instructions
- Instructions set
  - The vocabulary of a computer's language is called instruction set
- Instruction Set Architecture (ISA)
  - The set of instructions a particular CPU implements is an Instruction Set Architecture.

The Instruction Set Architecture (ISA)



The interface description separating the software and hardware

What is "Computer Architecture/Structure"?

- *Computer Architecture =*
  Instruction Set Architecture (ISA)
  - the one "true" language of a machine
  - *boundary* between hardware and software
  - the hardware's specification; defines "what" a machine does;

  +

  Machine Organization
  - the "guts" of the machine; "how" the hardware works; the implementation; must obey the ISA abstraction
- We will explore both, and more!

QUESTION: Do all processor chips have the same architecture?

ANSWER: No. Each family of processor chip (MIPS, ARM, PIC, SPARC, Alpha, Motorola, Intel, et al.) has its own architecture. .

QUESTION: Does your understanding of computers depend on which Assembly Language / ISA you study?

ANSWER: No. A well-designed modern assembly language /ISA is best, but any one is OK.

The MIPS ISA

- Instruction Categories
  - Load/Store
  - Computational
  - Jump and Branch
  - Floating Point
    - coprocessor
  - Special

Registers

R0 - R31
PC
HI
LO

- **3 Instruction Formats: all 32 bits wide**

OP	**rs**	**rt**	**rd**	**sa**	**funct**

OP	**rs**	**rt**	**immediate**

OP	**jump target**

Below the Program

- High-level language program (in C)

```
swap (int v[], int k); //swap v[k] and v[k+1]
. . .
```

C compiler

- Assembly language program (for MIPS)

```
swap:   sll     $2, $5, 2
        add     $2, $4, $2
        lw      $15, 0($2)
        lw      $16, 4($2)
        sw      $16, 0($2)
        sw      $15, 4($2)
        jr      $31
```

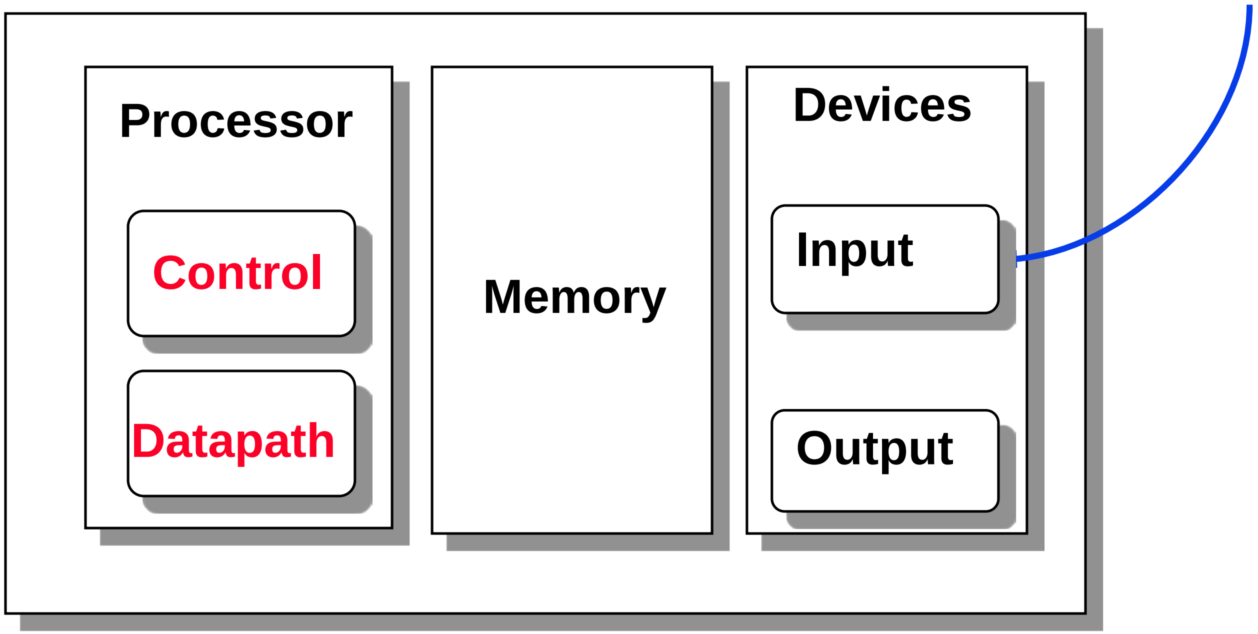
assembler

- Machine (object) code (for MIPS)

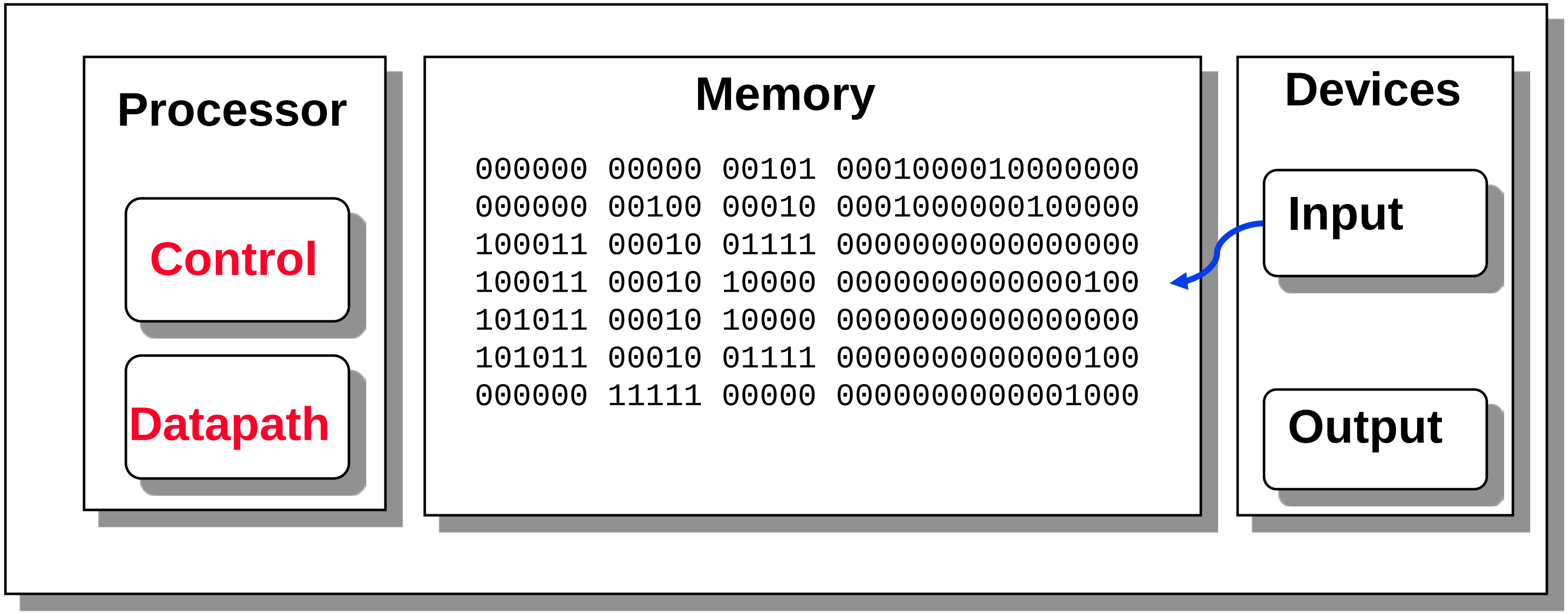
```
000000 00000 00101 0001000010000000
000000 00100 00010 0001000000100000
100011 00010 01111 0000000000000000
100011 00010 10000 0000000000000100
101011 00010 10000 0000000000000000
101011 00010 01111 0000000000000100
000000 11111 00000 0000000000001000
```

Input Device Inputs Object Code

```
000000 00000 00101 0001000010000000
000000 00100 00010 0001000000100000
100011 00010 01111 0000000000000000
100011 00010 10000 0000000000000100
101011 00010 10000 0000000000000000
101011 00010 01111 0000000000000100
000000 11111 00000 0000000000001000
```

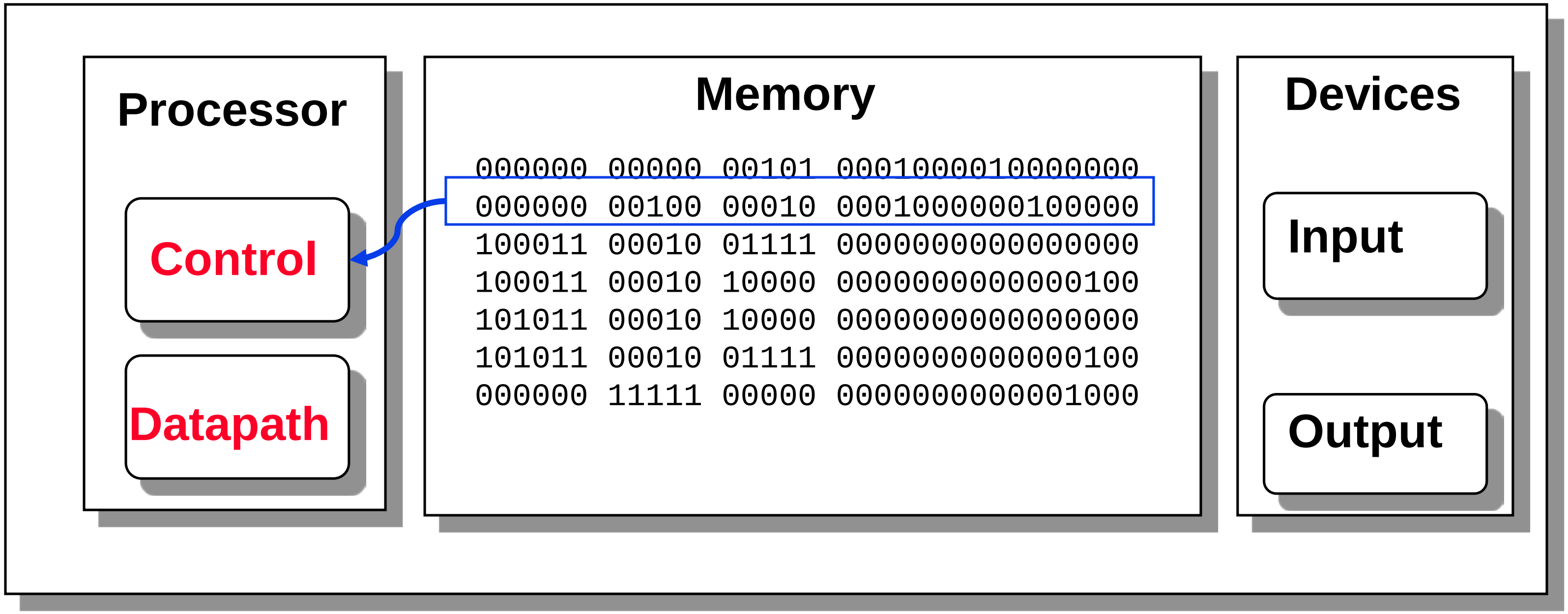


Object Code Stored in Memory



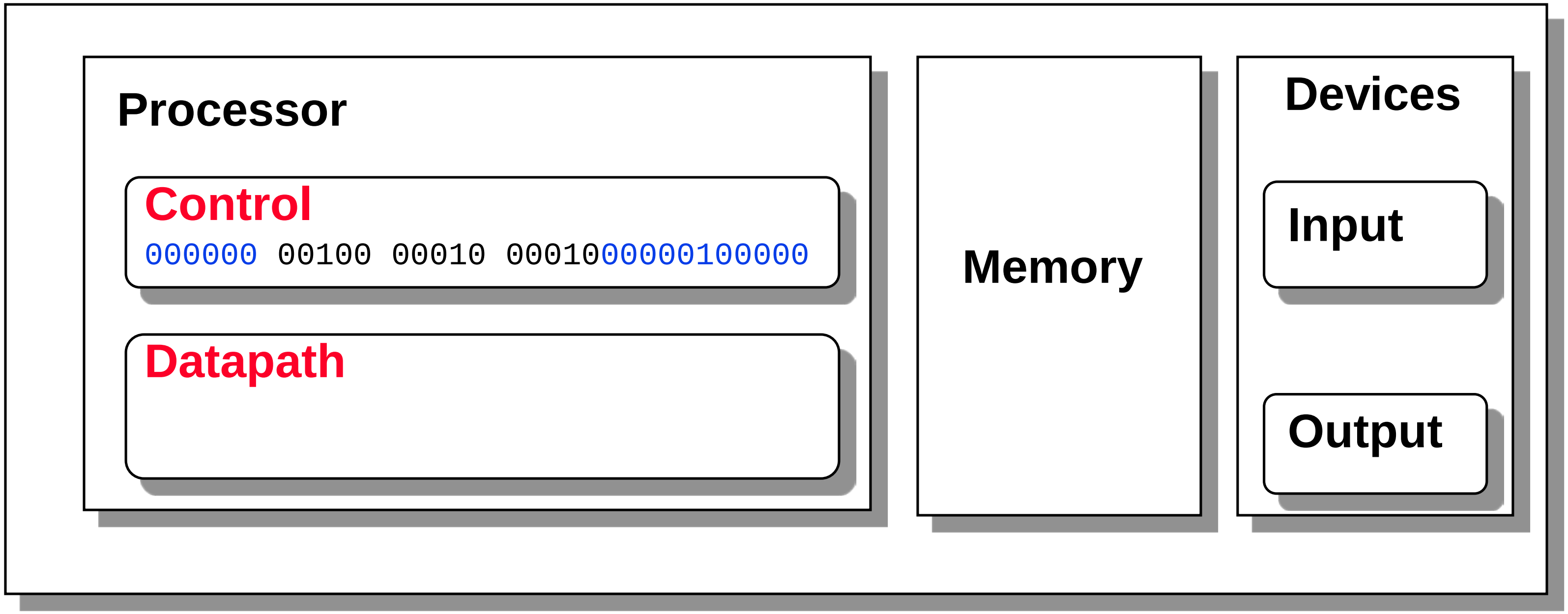
Processor Fetches an Instruction

Control fetches an instruction from memory



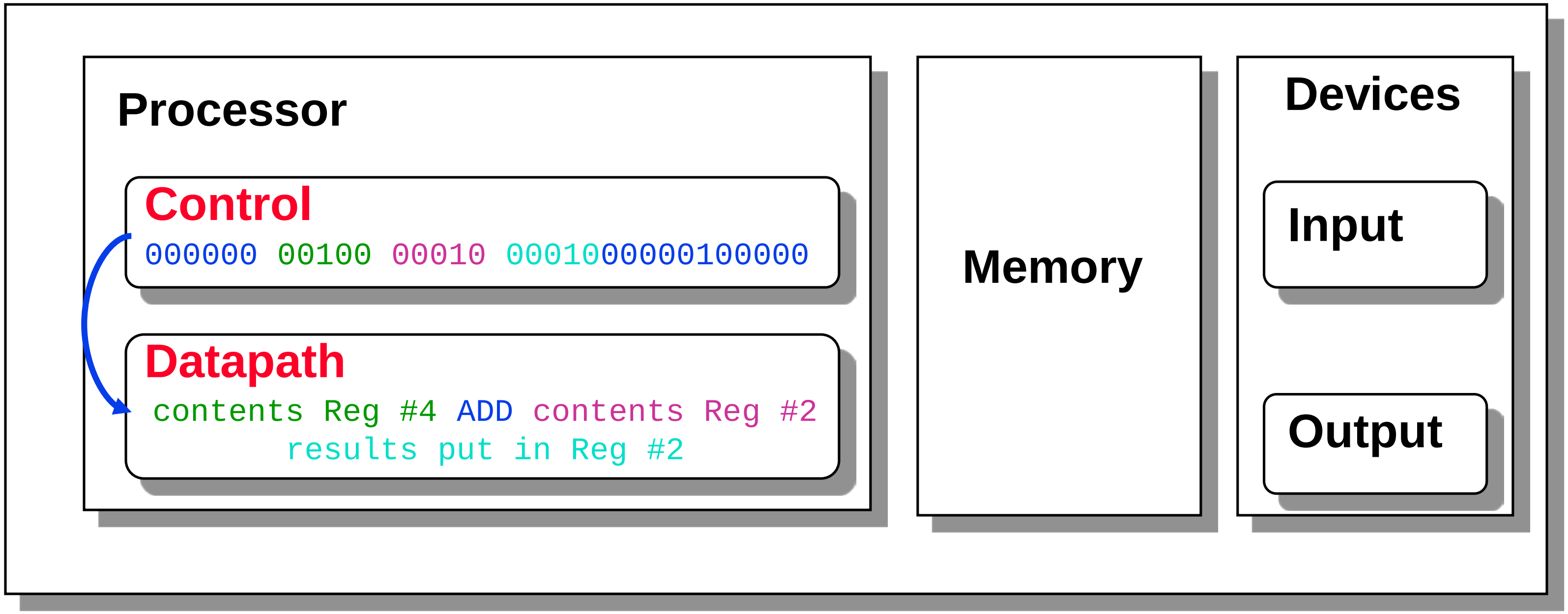
Control Decodes the Instruction

Control decodes the instruction to determine what to execute

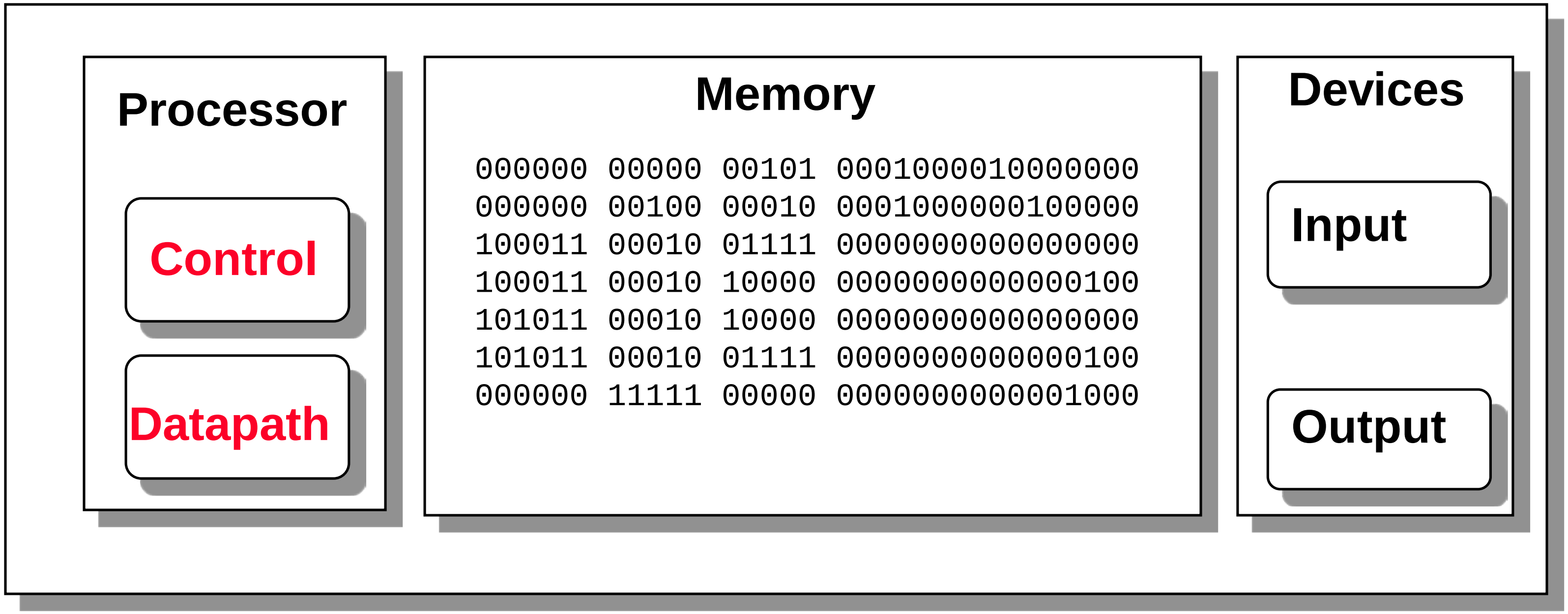


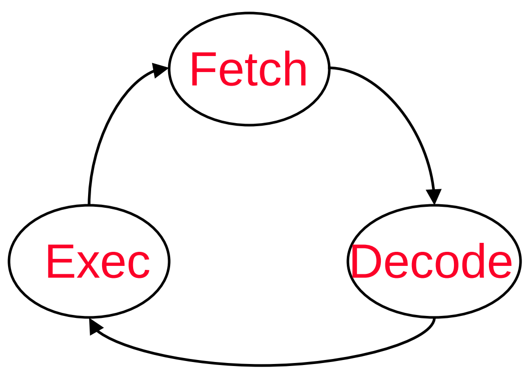
Datapath Executes the Instruction

Datapath executes the instruction as directed by control



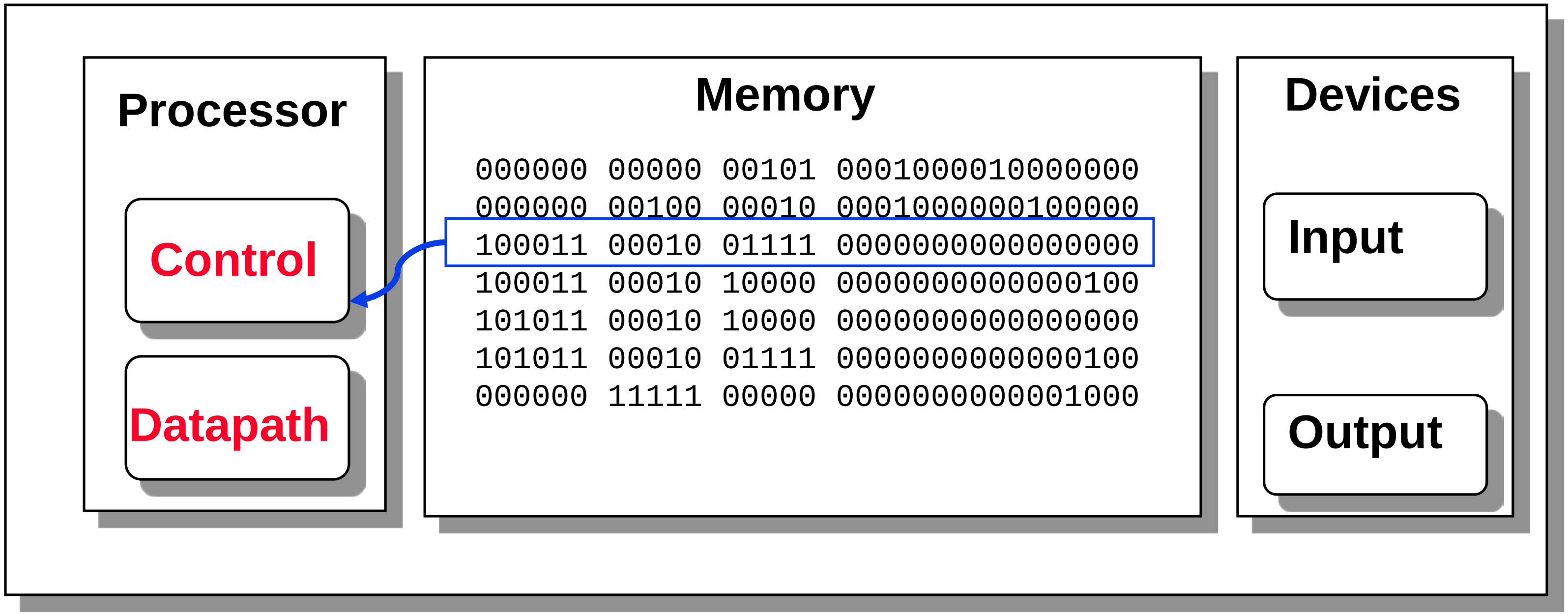
What Happens Next?





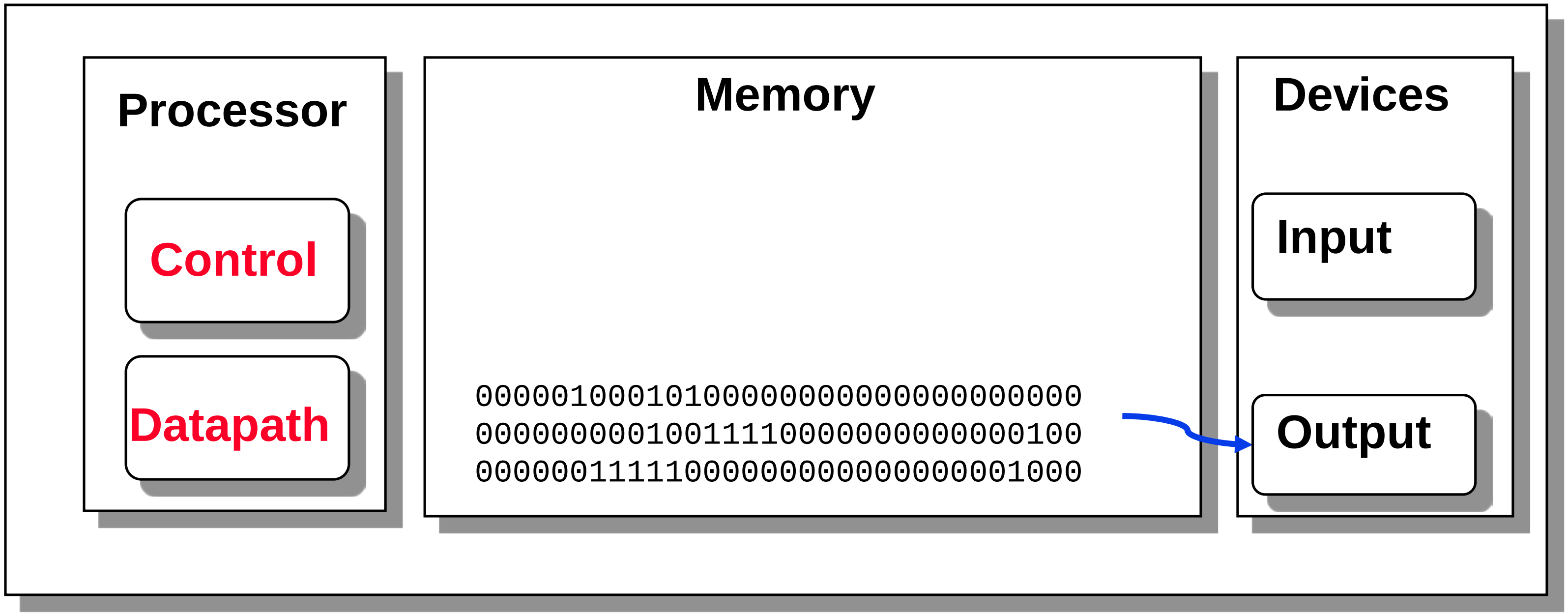
Processor Fetches the Next Instruction

Processor fetches the *next* instruction from memory

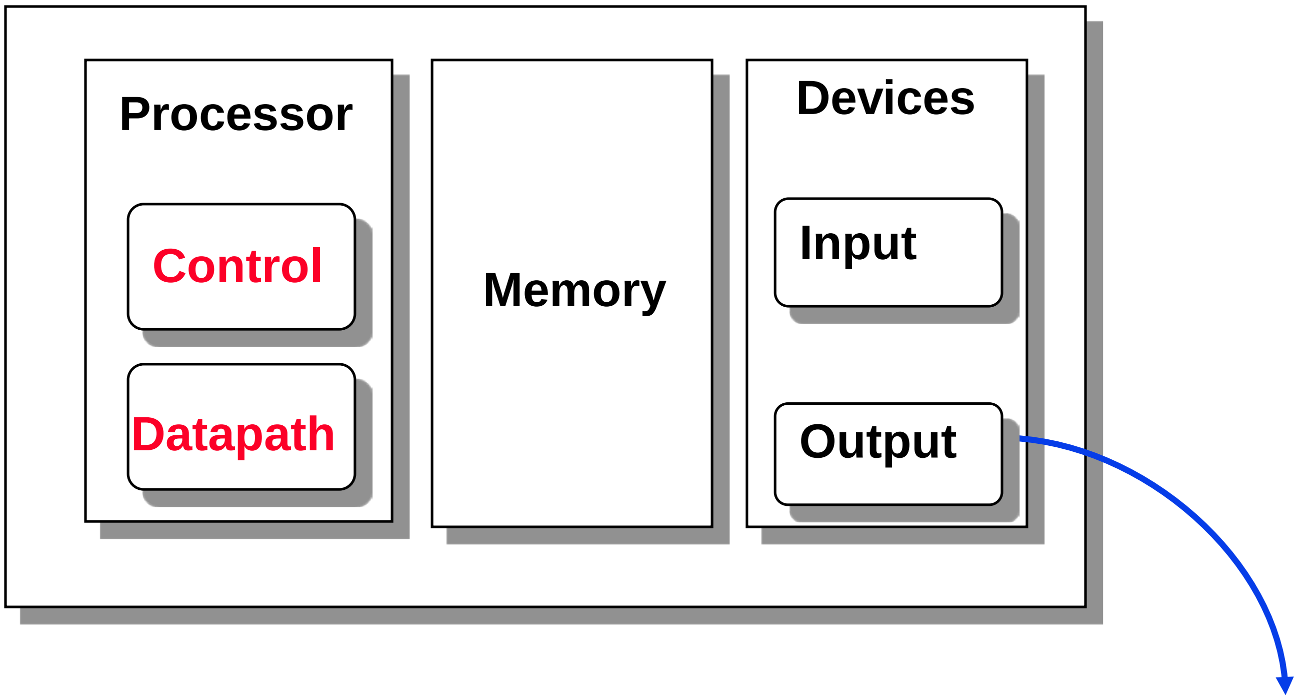


Output Data Stored in Memory

At program completion the data to be output resides in memory



Output Device Outputs Data




```
00000100010100000000000000000000
00000000010011110000000000000100
00000011111000000000000000001000
```