

CS 61C:
Great Ideas in Computer Architecture
Introduction to C, Part I

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<http://inst.eecs.Berkeley.edu/~cs61c/sp15>

Review & Correction: Two's-Complement Examples

- Assume for simplicity 4 bit width, -8 to +7 represented

$$\begin{array}{r} 3 \quad 0011 \\ +2 \quad 0010 \\ \hline 5 \quad 0101 \end{array}$$

$$\begin{array}{r} 3 \quad 0011 \\ + (-2) \quad 1110 \\ \hline 1 \quad 1 \quad 0001 \end{array}$$

$$\begin{array}{r} -3 \quad 1101 \\ + (-2) \quad 1110 \\ \hline -5 \quad 1 \quad 1011 \end{array}$$

*Overflow when
magnitude of result
too big to fit into
result representation*

$$\begin{array}{r} 7 \quad 0111 \\ +1 \quad 0001 \\ \hline -8 \quad 1000 \end{array}$$

$$\begin{array}{r} -8 \quad 1000 \\ + (-1) \quad 1111 \\ \hline +7 \quad 1 \quad 0111 \end{array}$$

Overflow!

Overflow!

Carry into MSB =
Carry Out MSB

Carry into MSB \neq
Carry Out MSB

Carry in = carry from less significant bits

Carry out = carry to more significant bits

Agenda

- Compile vs. Interpret
- C vs. Java vs. Python
- Administrivia
- Quick Start Introduction to C
- News/Technology Break
- Pointers
- And in Conclusion, ...

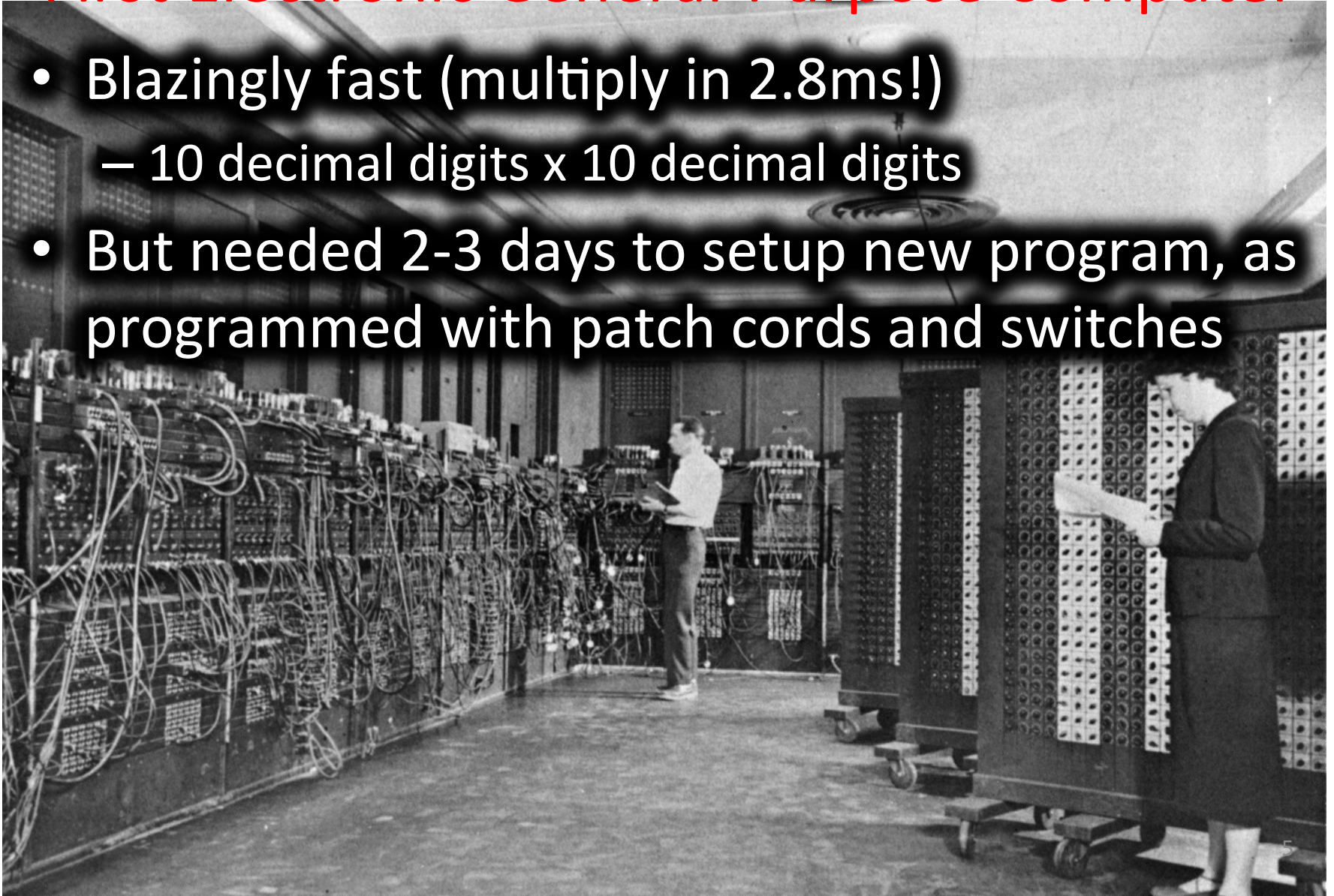
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ENIAC (U.Penn., 1946)

First Electronic General-Purpose Computer

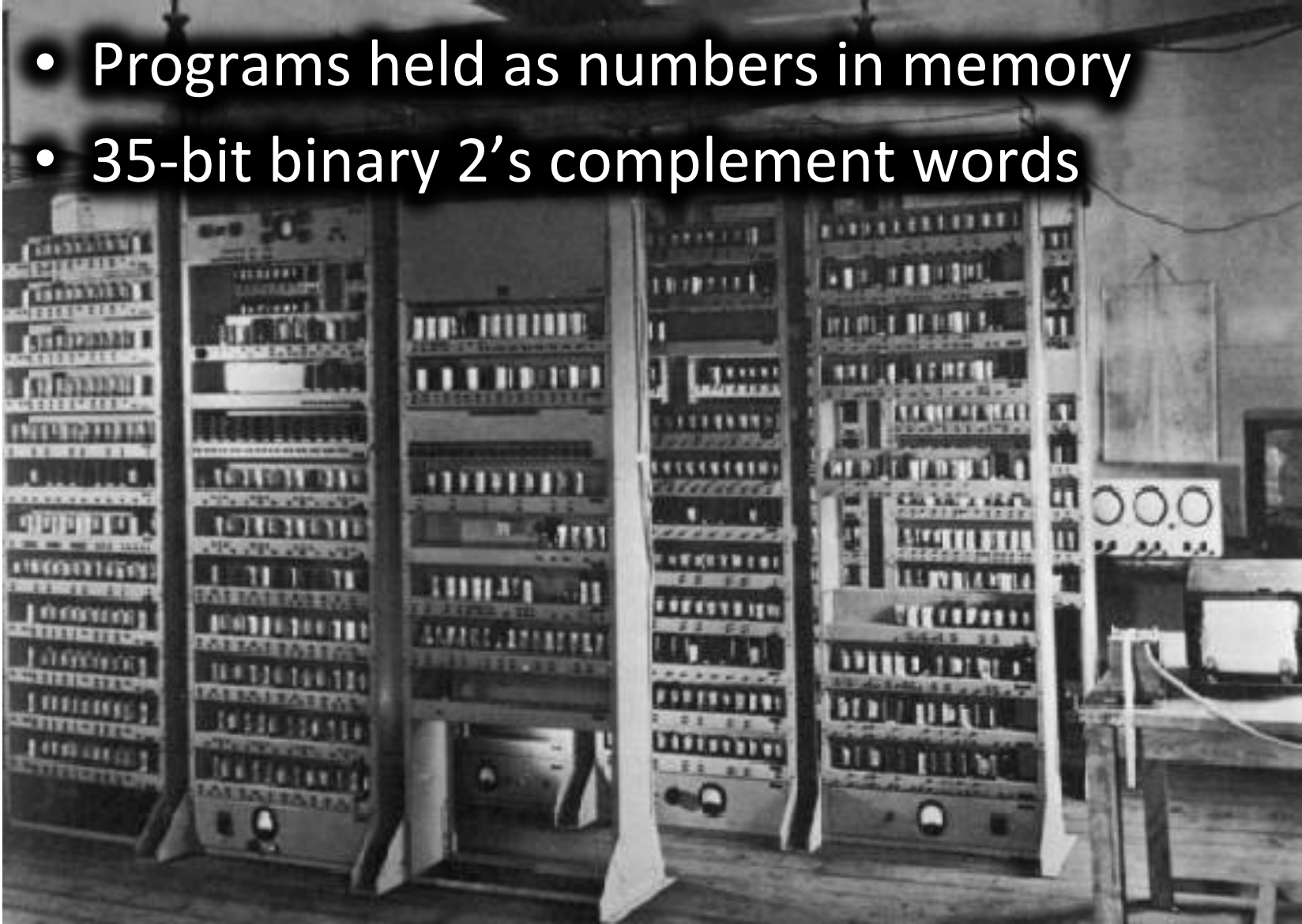
- Blazingly fast (multiply in 2.8ms!)
 - 10 decimal digits x 10 decimal digits
- But needed 2-3 days to setup new program, as programmed with patch cords and switches



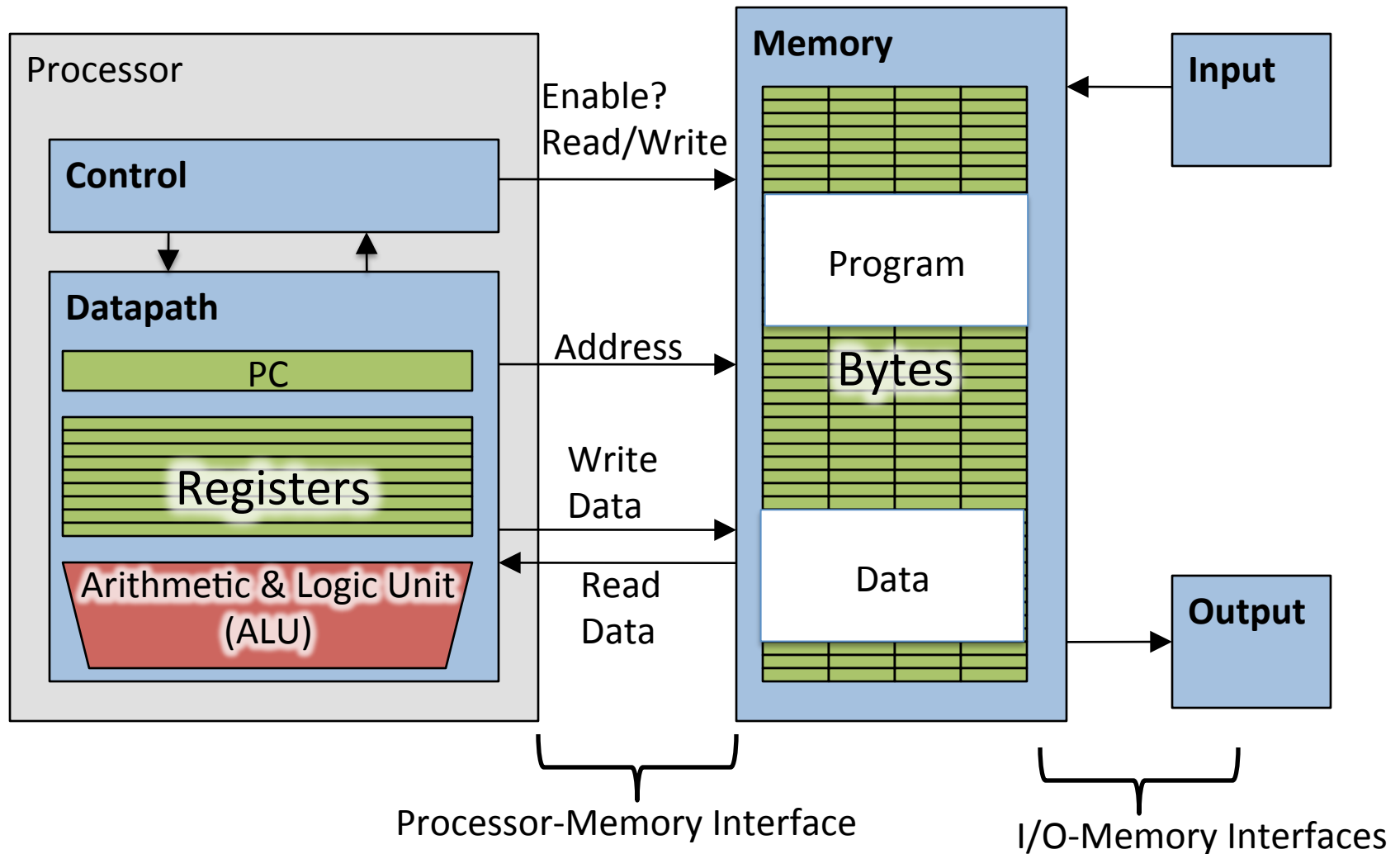
EDSAC (Cambridge, 1949)

First General Stored-Program Computer

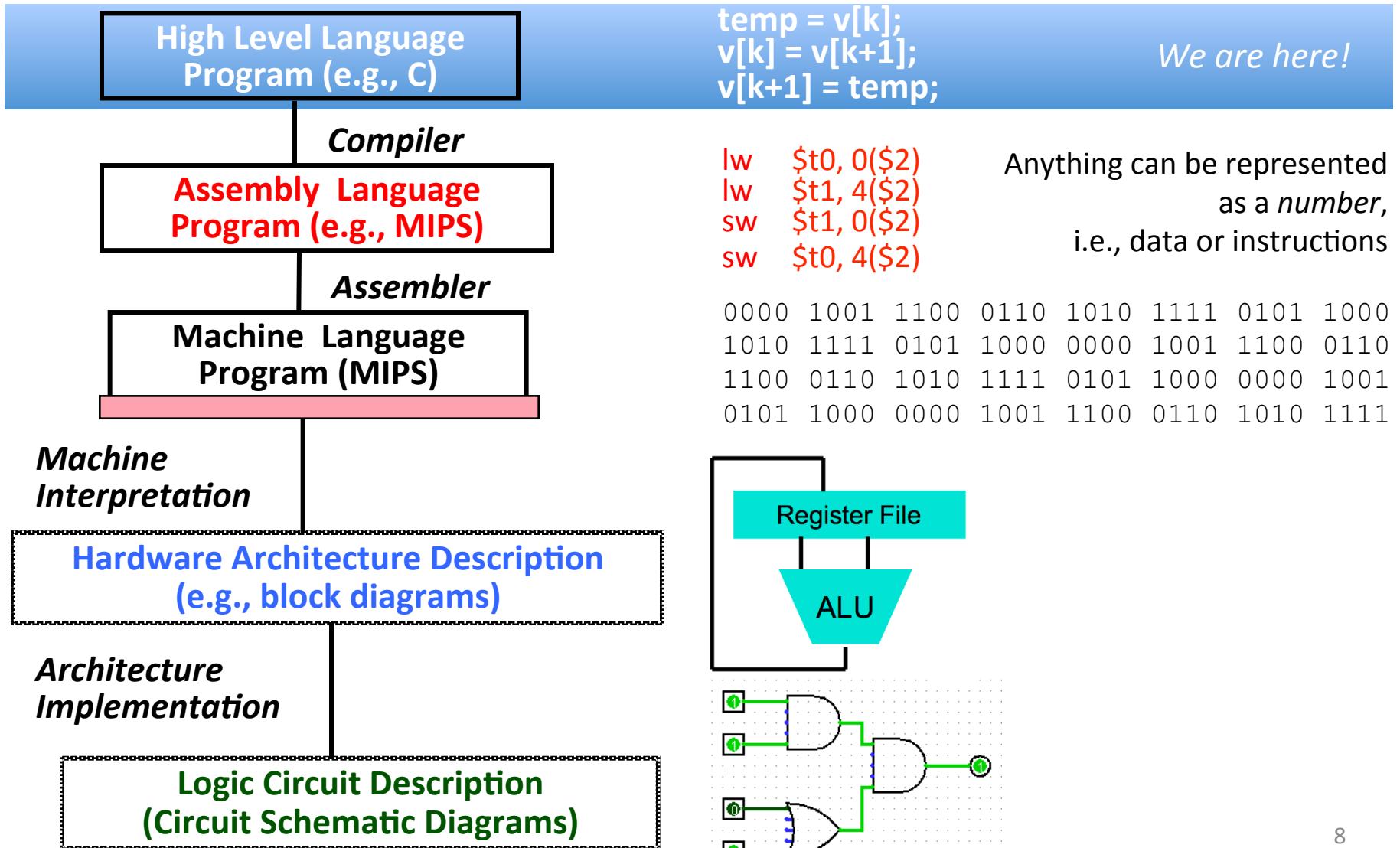
- Programs held as numbers in memory
- 35-bit binary 2's complement words



Components of a Computer



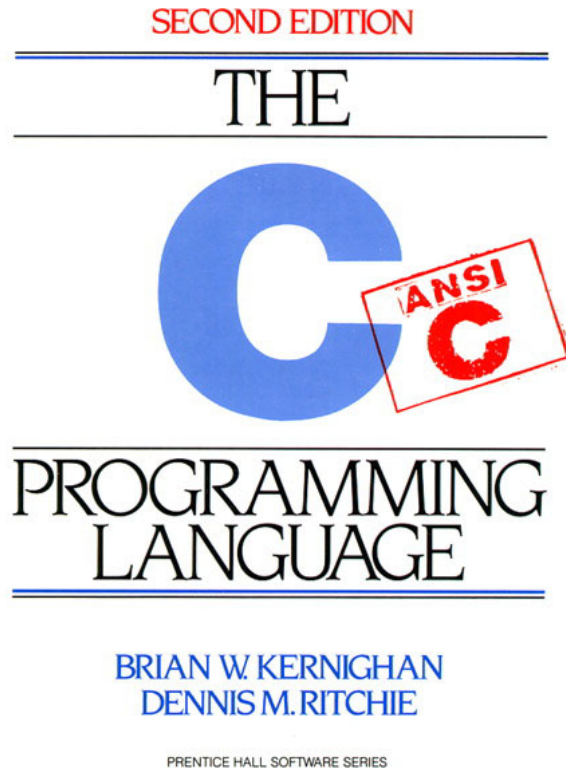
Great Idea: Levels of Representation/ Interpretation



Introduction to C

“The Universal Assembly Language”

- “Some” experience is required before CS61C
C++ or Java OK



- Class pre-req included classes teaching Java
- Python used in two labs and one project
- C used for everything else

Language Poll!

Please raise hand for *first* one of following you can say yes to

- ☐ I have programmed in C, C++, C#, or Objective-C
- ☐ I have programmed in Java
- ☐ I have programmed in FORTRAN, Cobol, Algol-68, Ada, Pascal, or Basic
- ☐ None of the above

Intro to C

- *C is not a “very high-level” language, nor a “big” one, and is not specialized to any particular area of application. But its absence of restrictions and its generality make it more convenient and effective for many tasks than supposedly more powerful languages.*

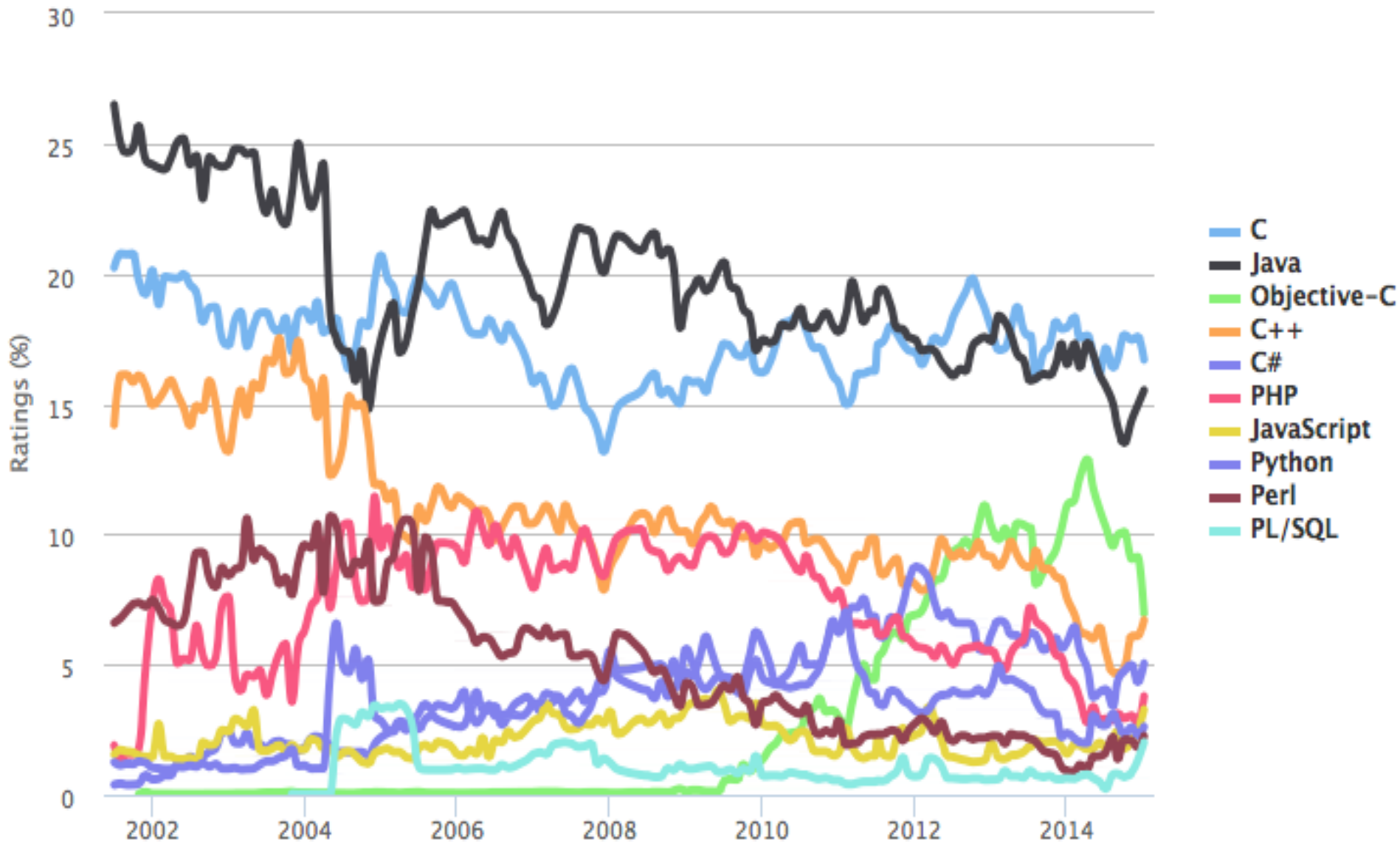
— Kernighan and Ritchie

- Enabled first operating system not written in assembly language: *UNIX* - A portable OS!
- C and derivatives (C++/Obj-C/C#) still one of the most popular application programming languages after >40 years!

TIOBE Index of Language Popularity

| Jan 2015 | Jan 2014 | Change | Programming Language | Ratings | Change |
|----------|----------|--------|----------------------|---------|--------|
| 1 | 1 | | C | 16.703% | -1.24% |
| 2 | 2 | | Java | 15.528% | -1.00% |
| 3 | 3 | | Objective-C | 6.953% | -4.14% |
| 4 | 4 | | C++ | 6.705% | -0.86% |
| 5 | 5 | | C# | 5.045% | -0.80% |
| 6 | 6 | | PHP | 3.784% | -0.82% |
| 7 | 9 | ⬆ | JavaScript | 3.274% | +1.70% |
| 8 | 8 | | Python | 2.613% | +0.24% |
| 9 | 13 | ⬆ | Perl | 2.256% | +1.33% |
| 10 | 17 | ⬆ | PL/SQL | 2.014% | +1.38% |

TIOBE Programming Community Index



Disclaimer

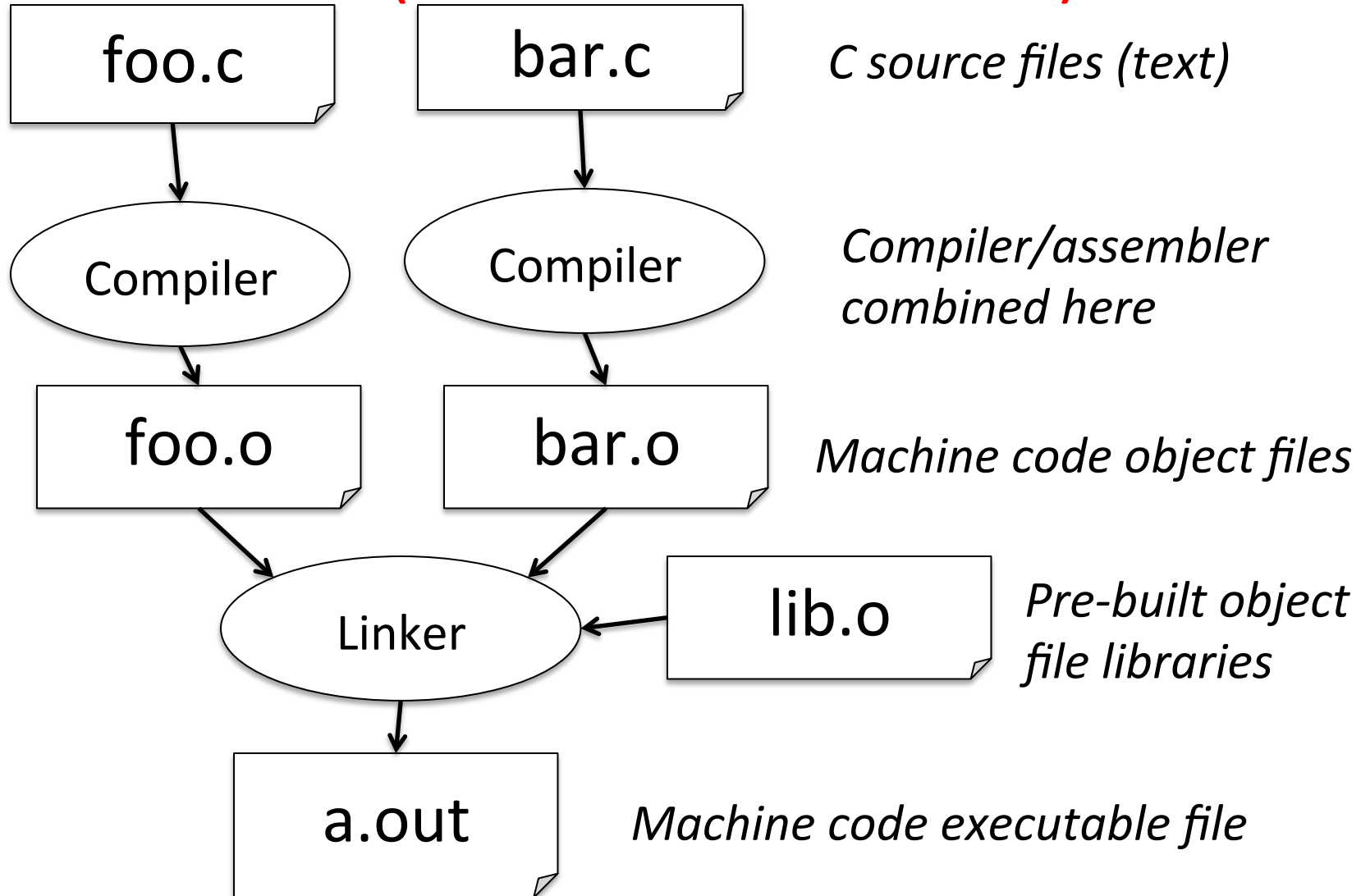
- You will not learn how to fully code in C in these lectures! You'll still need your C reference for this course
 - K&R is a must-have
 - Check online for more sources
 - “JAVA in a Nutshell,” O'Reilly
 - Chapter 2, “How Java Differs from C”
 - <http://oreilly.com/catalog/javanut/excerpt/index.html>
 - Brian Harvey's helpful transition notes
 - On CS61C class website: pages 3-19
 - <http://inst.eecs.berkeley.edu/~cs61c/resources/HarveyNotesC1-3.pdf>
- Key C concepts: Pointers, Arrays, Implications for Memory management

Compilation: Overview

- *C compilers* map C programs into architecture-specific machine code (string of 1s and 0s)
 - Unlike *Java*, which converts to architecture-independent *bytecode*
 - Unlike *Python* environments, which *interpret* the code
 - These differ mainly in exactly when your program is converted to low-level machine instructions (“levels of interpretation”)
 - For C, generally a two part process of compiling .c files to .o files, then linking the .o files into executables;
 - Assembling is also done (but is hidden, i.e., done automatically, by default); we’ll talk about that later

C Compilation Simplified Overview

(more later in course)



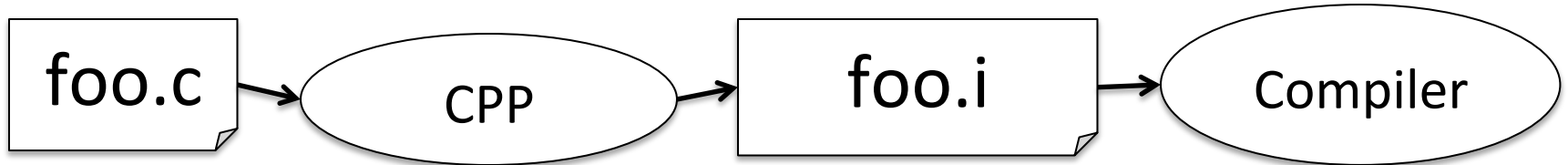
Compilation: Advantages

- Excellent run-time performance: generally much faster than Scheme or Java for comparable code (because it optimizes for a given architecture)
- Fair compilation time: enhancements in compilation procedure (Makefiles) allow only modified files to be recompiled
- *Why C?: we can write programs that allow us to exploit underlying features of the architecture – memory management, special instructions, parallelism*

Compilation: Disadvantages

- Compiled files, including the executable, are architecture-specific, depending on processor type (e.g., MIPS vs. RISC-V) and the operating system (e.g., Windows vs. Linux)
- Executable must be rebuilt on each new system
 - I.e., “porting your code” to a new architecture
- “Change → Compile → Run [repeat]” iteration cycle can be slow during development
 - but Make tool only rebuilds changed pieces, and can do compiles in parallel (linker is sequential though -> Amdahl’s Law)

C Pre-Processor (CPP)



- C source files first pass through macro processor, CPP, before compiler sees code
- CPP replaces comments with a single space
- CPP commands begin with “#”
- `#include “file.h” /* Inserts file.h into output */`
- `#include <stdio.h> /* Looks for file in standard location */`
- `#define M_PI (3.14159) /* Define constant */`
- `#if/#endif /* Conditional inclusion of text */`
- Use `–save-temps` option to gcc to see result of preprocessing
- Full documentation at: <http://gcc.gnu.org/onlinedocs/cpp/>

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C vs. Java

| | C | Java |
|-----------------------|--|--|
| Type of Language | Function Oriented | Object Oriented |
| Program- ming Unit | Function | Class = Abstract Data Type |
| Compilation | gcc hello.c creates machine language code | javac Hello.java creates Java virtual machine language bytecode |
| Execution | a.out loads and executes program | java Hello interprets bytecodes |
| hello, world | <pre>#include<stdio.h> int main(void) { printf("Hello\n"); return 0; }</pre> | <pre>public class HelloWorld { public static void main(String[] args) { System.out.println("Hello"); } }</pre> |
| Storage | Manual (malloc , free) | Automatic (garbage collection) |

C vs. Java

| | C | Java |
|-----------------------------|---------------------------------------|---|
| Comments | <code>/* ... */</code> | <code>/* ... */</code> or <code>// ...</code> end of line |
| Constants | <code>#define, const</code> | <code>final</code> |
| Preprocessor | Yes | No |
| Variable declaration | At beginning of a block | Before you use it |
| Variable naming conventions | <code>sum_of_squares</code> | <code>sumOfSquares</code> |
| Accessing a library | <code>#include <stdio.h></code> | <code>import java.io.File;</code> |

Typed Variables in C

```
int    variable1    = 2;  
float  variable2    = 1.618;  
char   variable3    = 'A';
```

- Must declare the type of data a variable will hold
 - Types can't change

| Type | Description | Examples |
|--------------|--------------------------------------|------------------|
| int | integer numbers, including negatives | 0, 78, -1400 |
| unsigned int | integer numbers (no negatives) | 0, 46, 900 |
| float | floating point decimal numbers | 0.0, 1.618, -1.4 |
| char | single text character or symbol | 'a', 'D', '?' |
| double | greater precision/big FP number | 10E100 |
| long | larger signed integer | 6,000,000,000 |

Integers: Python vs. Java vs. C

| Language | sizeof(int) |
|----------|---|
| Python | ≥ 32 bits (plain ints), infinite (long ints) |
| Java | 32 bits |
| C | Depends on computer; 16 or 32 or 64 |

- C: `int` should be integer type that target processor works with most efficiently
- Only guarantee: $\text{sizeof}(\text{long long}) \geq \text{sizeof}(\text{long}) \geq \text{sizeof}(\text{int}) \geq \text{sizeof}(\text{short})$
 - Also, `short` ≥ 16 bits, `long` ≥ 32 bits
 - All could be 64 bits

Consts and Enums in C

- Constant is assigned a typed value once in the declaration; value can't change during entire execution of program

```
const float golden_ratio = 1.618;  
const int days_in_week = 7;
```

- You can have a constant version of any of the standard C variable types
- Enums: a group of related integer constants used to parameterize libraries:

```
enum cardsuit {CLUBS,DIAMONDS,HEARTS,SPADES};
```

Clicker Test

- Clicker participation starting on Tuesday
- No web-based clickers or phone apps
- Participation only is recorded, not correctness of answers
- Register at: <https://www1.iclicker.com/register-clicker/>

Compare “`#define PI 3.14`” and
“`const float pi=3.14`” – which is true?

A: Constants “PI” and “pi” have same type

B: Can assign to “PI” but not “pi”

C: Code runs at same speed using “PI” or “pi”

D: “pi” takes more memory space than “PI”

E: Both behave the same in all situations

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Administrivia

- HW0 out
 - Mini-bio due in lab 1/30, 2/2, or 2/3
 - Rest due Sunday 2/1 @ 23:59:59
- Labs start tomorrow
 - 330 Soda should be open by then
 - watch for announcements if 330 not open!
- Tentative office hour schedule posted on website:
 - <http://inst.eecs.Berkeley.edu/~cs61c/sp15>
- Clickers!

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Typed Functions in C

```
int number_of_people ()
{
    return 3;
}
```

```
float dollars_and_cents ()
{
    return 10.33;
}
```

```
char first_letter ()
{
    return 'A';
}
```

- You have to *declare* the type of data you plan to return from a function
- Return type can be any C variable type, and is placed to the left of the function name
- You can also specify the return type as **void**
 - Just think of this as saying that no value will be returned
- Also necessary to declare types for values passed into a function
- Variables and functions **MUST** be declared before they are used

Structs in C

- Structs are structured groups of variables, e.g.,

```
typedef struct {  
    int length_in_seconds;  
    int year_recorded;  
} Song;
```

Dot notation: **x.y = value**

```
Song song1;
```

```
song1.length_in_seconds = 213;  
song1.year_recorded      = 1994;
```

```
Song song2;
```

```
song2.length_in_seconds = 248;  
song2.year_recorded     = 1988;
```

A First C Program: Hello World

Original C:

```
main()  
{  
    printf("\nHello World\n");  
}
```

ANSI Standard C:

```
#include <stdio.h>  
  
int main(void)  
{  
    printf("\nHello World\n");  
    return 0;  
}
```

C Syntax: `main`

- When C program starts
 - C executable `a.out` is loaded into memory by operating system (OS)
 - OS sets up stack, then calls into C runtime library,
 - Runtime 1st initializes memory and other libraries,
 - then calls your procedure named `main ()`
- We'll see how to retrieve command-line arguments in `main()` later...

A Second C Program: Compute Table of Sines

```
#include <stdio.h>
#include <math.h>

int main(void)
{
    int    angle_degree;
    double angle_radian, pi, value;
    /* Print a header */
    printf("\nCompute a table of the
    sine function\n\n");

    /* obtain pi once for all */
    /* or just use pi = M_PI, where */
    /* M_PI is defined in math.h */
    pi = 4.0*atan(1.0);
    printf("Value of PI = %f \n\n",
    pi);

    printf("angle      Sine \n");

    angle_degree = 0;
    /* initial angle value */
    /* scan over angle */
    while (angle_degree <= 360)
    /* loop until angle_degree > 360 */
    {
        angle_radian = pi*angle_degree/180.0;
        value = sin(angle_radian);
        printf (" %3d      %f \n ",
                angle_degree, value);
        angle_degree = angle_degree + 10;
        /* increment the loop index */
    }
    return 0;
}
```

Compute a table of the sine
function

Value of PI = 3.141593

| angle | Sine |
|-------|----------|
| 0 | 0.000000 |
| 10 | 0.173648 |
| 20 | 0.342020 |
| 30 | 0.500000 |
| 40 | 0.642788 |
| 50 | 0.766044 |
| 60 | 0.866025 |
| 70 | 0.939693 |
| 80 | 0.984808 |
| 90 | 1.000000 |
| 100 | 0.984808 |
| 110 | 0.939693 |
| 120 | 0.866025 |
| 130 | 0.766044 |
| 140 | 0.642788 |
| 150 | 0.500000 |
| 160 | 0.342020 |
| 170 | 0.173648 |
| 180 | 0.000000 |

Second C Program

Sample Output

| | |
|-----|-----------|
| 190 | -0.173648 |
| 200 | -0.342020 |
| 210 | -0.500000 |
| 220 | -0.642788 |
| 230 | -0.766044 |
| 240 | -0.866025 |
| 250 | -0.939693 |
| 260 | -0.984808 |
| 270 | -1.000000 |
| 280 | -0.984808 |
| 290 | -0.939693 |
| 300 | -0.866025 |
| 310 | -0.766044 |
| 320 | -0.642788 |
| 330 | -0.500000 |
| 340 | -0.342020 |
| 350 | -0.173648 |
| 360 | -0.000000 |

C Syntax: Variable Declarations

- Similar to Java, but with a few minor but important differences
- *All* variable declarations must appear before they are used (e.g., at the beginning of the block)
- A variable may be initialized in its declaration; if not, it holds garbage!
- Examples of declarations:
 - **Correct:**

```
{  
    int a = 0, b = 10;  
    ...  
}
```
 - **Incorrect:**

```
for (int i = 0; i < 10; i++)  
    }
```

Newer C standards are more flexible about this, more later

C Syntax : Control Flow (1/2)

- Within a function, remarkably close to Java constructs (shows Java's legacy) in terms of control flow
 - **if-else**
 - `if (expression) statement`
 - `if (expression) statement1`
`else statement2`
 - **while**
 - `while (expression)`
`statement`
 - `do`
`statement`
`while (expression);`

C Syntax : Control Flow (2/2)

– for

- `for (initialize; check; update)
statement`

– switch

- `switch (expression) {
 case const1: statements
 case const2: statements
 default: statements
}`
- `break`

C Syntax: True or False

- What evaluates to FALSE in C?
 - 0 (integer)
 - NULL (a special kind of *pointer*: more on this later)
 - *No explicit Boolean type*
- What evaluates to TRUE in C?
 - Anything that isn't false is true
 - Same idea as in Python: only 0s or empty sequences are false, anything else is true!

C and Java operators nearly identical

- arithmetic: +, -, *, /, %
- assignment: =
- augmented assignment: +=, -=, *=, /=, %=, &=, |=, ^=, <<=, >>=
- bitwise logic: ~, &, |, ^
- bitwise shifts: <<, >>
- boolean logic: !, &&, ||
- equality testing: ==, !=
- subexpression grouping: ()
- order relations: <, <=, >, >=
- increment and decrement: ++ and --
- member selection: ., ->
- conditional evaluation: ? :

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In the News

- Microsoft HoloLens
- Announced with Windows 10
- Virtual Reality headset
- Contains CPU and GPU, plus a holographic processing unit, or HPU!



Break

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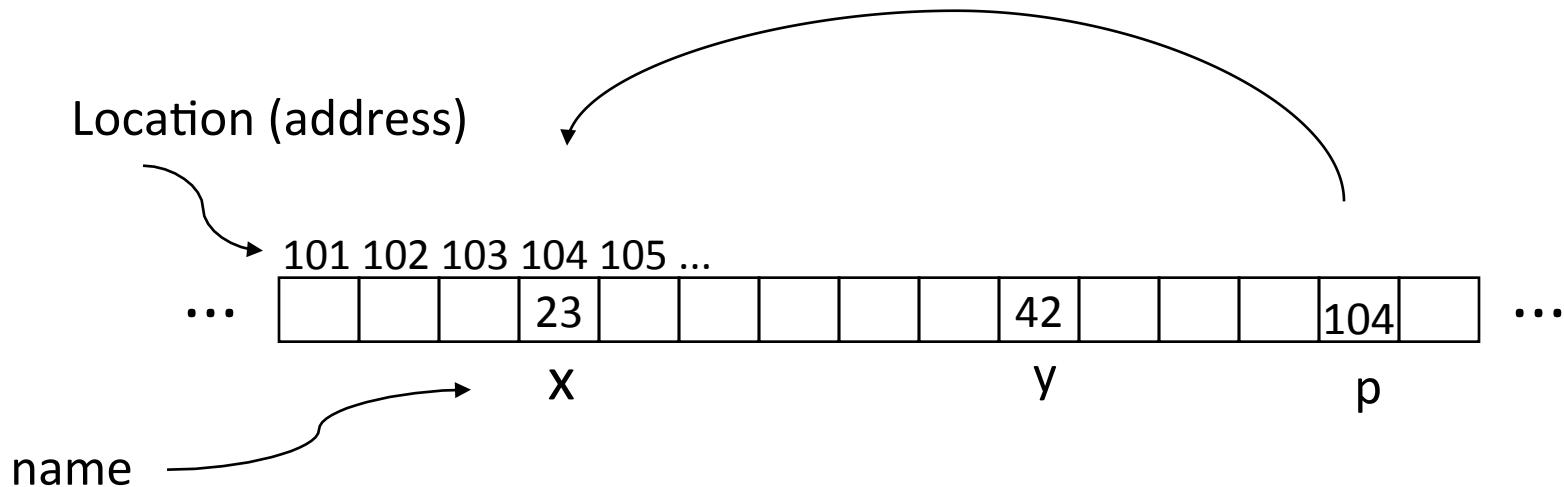
Address vs. Value

- Consider memory to be a single huge array
 - Each cell of the array has an address associated with it
 - Each cell also stores some value
 - Do you think they use signed or unsigned numbers? Negative address?!
- Don't confuse the address referring to a memory location with the value stored there



Pointers

- An *address* refers to a particular memory location; e.g., it points to a memory location
- *Pointer*: A variable that contains the address of a variable



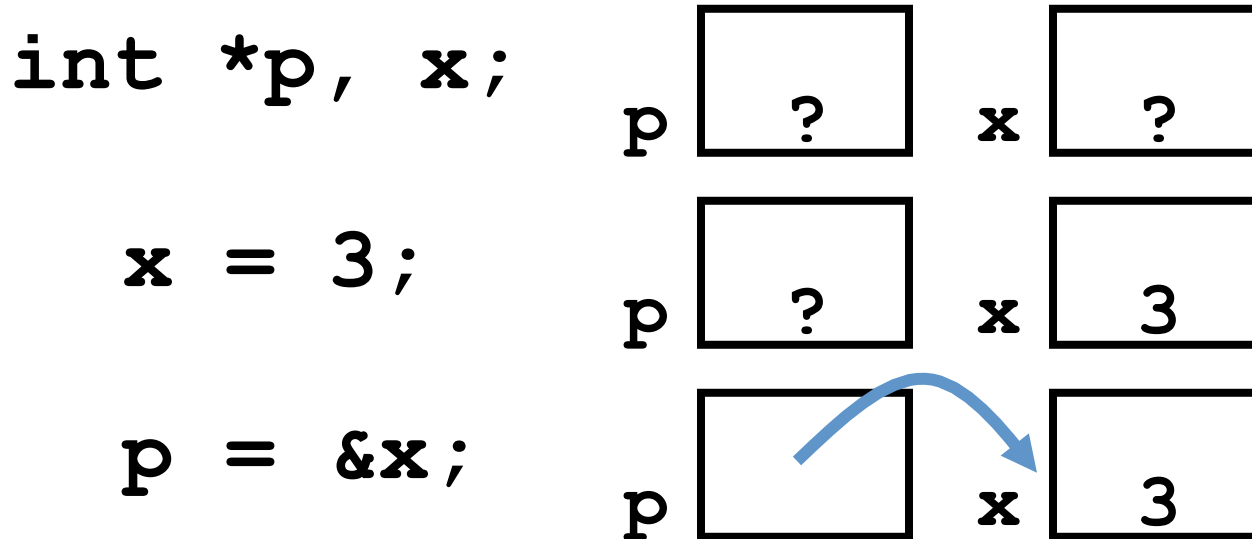
Pointer Syntax

- `int *x;`
 - Tells compiler that `variable x is address of an int`
- `x = &y;`
 - Tells compiler to assign `address of y` to `x`
 - `&` called the “address operator” in this context
- `z = *x;`
 - Tells compiler to assign `value at address in x` to `z`
 - `*` called the “dereference operator” in this context

Creating and Using Pointers

- How to create a pointer:

& operator: get address of a variable



Note the “*” gets used 2 different ways in this example. In the declaration to indicate that **p** is going to be a pointer, and in the **printf** to get the value pointed to by **p**.

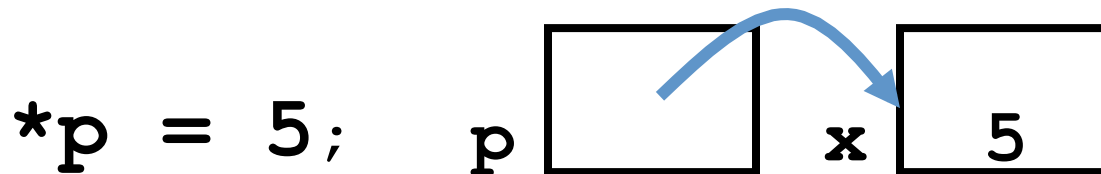
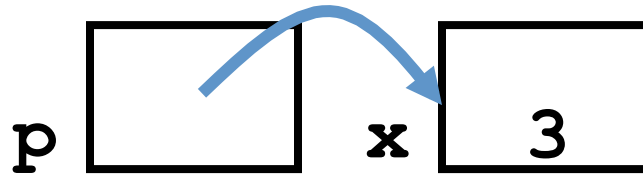
- How get a value pointed to?

“*” (dereference operator): get the value that the pointer points to

```
printf("p points to %d\n", *p);
```

Using Pointer for Writes

- How to change a variable pointed to?
 - Use the dereference operator ***** on left of assignment operator **=**



Pointers and Parameter Passing

- Java and C pass parameters “by value”
 - Procedure/function/method gets a copy of the parameter, *so changing the copy cannot change the original*

```
void add_one (int x) {  
    x = x + 1;  
}
```

```
int y = 3;  
add_one(y);
```

y remains equal to 3

Pointers and Parameter Passing

- How can we get a function to change the value held in a variable?

```
void add_one (int *p) {  
    *p = *p + 1;  
}
```

```
int y = 3;
```

```
add_one(&y);
```

y is now equal to 4

Types of Pointers

- Pointers are used to point to any kind of data (**int**, **char**, a **struct**, etc.)
- Normally a pointer only points to one type (**int**, **char**, a **struct**, etc.).
 - **void *** is a type that can point to anything (generic pointer)
 - Use **void *** sparingly to help avoid program bugs, and security issues, and other bad things!

More C Pointer Dangers

- Declaring a pointer just allocates space to hold the pointer – it does not allocate the thing being pointed to!
- Local variables in C are not initialized, they may contain anything (aka “garbage”)
- What does the following code do?

```
void f()  
{  
    int *ptr;  
    *ptr = 5;  
}
```

Pointers and Structures

```
typedef struct {          /* dot notation */
    int x;                int h = p1.x;
    int y;                p2.y = p1.y;
} Point;

                           /* arrow notation */
Point p1;                 int h = paddr->x;
Point p2;                 int h = (*paddr).x;
Point *paddr;

                           /* This works too */
p1 = p2;
```

Pointers in C

- Why use pointers?
 - If we want to pass a large struct or array, it's easier / faster / etc. to pass a pointer than the whole thing
 - In general, pointers allow cleaner, more compact code
- So what are the drawbacks?
 - Pointers are probably the single largest source of bugs in C, so be careful anytime you deal with them
 - Most problematic with dynamic memory management—coming up next week
 - *Dangling references* and *memory leaks*

Why Pointers in C?

- At time C was invented (early 1970s), compilers often didn't produce efficient code
 - Computers 25,000 times faster today, compilers better
- C designed to let programmer say what they want code to do without compiler getting in way
 - Even give compilers hints which registers to use!
- Today's compilers produce much better code, so may not need to use pointers in application code
- Low-level system code still needs low-level access via pointers

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And In Conclusion, ...

- All data is in memory
 - Each memory location has an address to use to refer to it and a value stored in it
- Pointer is a C version (abstraction) of a data address
 - * “follows” a pointer to its value
 - & gets the address of a value
 - Arrays and strings are implemented as variations on pointers
- C is an efficient language, but leaves safety to the programmer
 - Variables not automatically initialized
 - Use pointers with care: they are a common source of bugs in programs