Computer Systems Principles

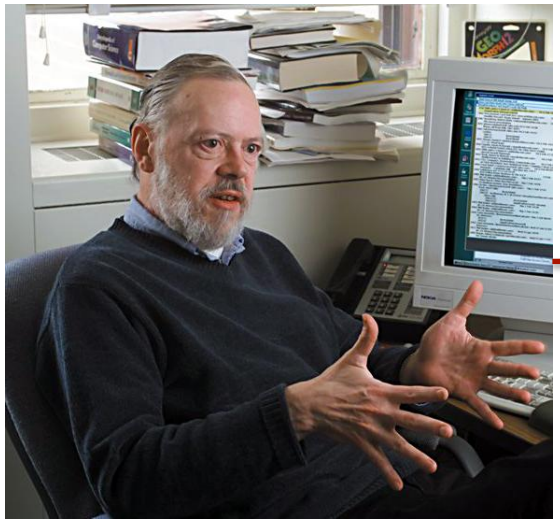
C Programming

UMASSCS
SCHOOL OF COMPUTER SCIENCE

Learning Objectives

- **C Programming**
  - Understand where C comes from
  - Understand why we use C
  - Understand C compilation
  - Understand the difference between Java and C
  - Learn the structure of C programs
  - Learn and apply C basic input/output
  - Understand basic C example programs

What is C?



Dennis Ritchie

C → Unix

C was created for **systems programming**.

C was created to **write Unix**.

Evolution of C – K&R, ANSI C

- **Based on B, a simplified version of BCPL.**
  - **B lacked byte-addressability.**
- **K&R (Brian Kernighan & Dennis Richie)**
  - Bell Labs
  - "The C Programming Language", 1st Edition (1978)
- **ANSI C (American National Standards Institute)**
  - Departed from Bell Labs C
  - "The C Programming Language", 2nd Edition (1989)

Evolution of C – ISO C90, ISO C99

- **ISO C90 (International Standards Organization)**
  - Mostly the same as ANSI C in 1990
- **ISO C99 (International Standards Organization)**
  - New data types
  - Support for text strings with characters not found in the English language

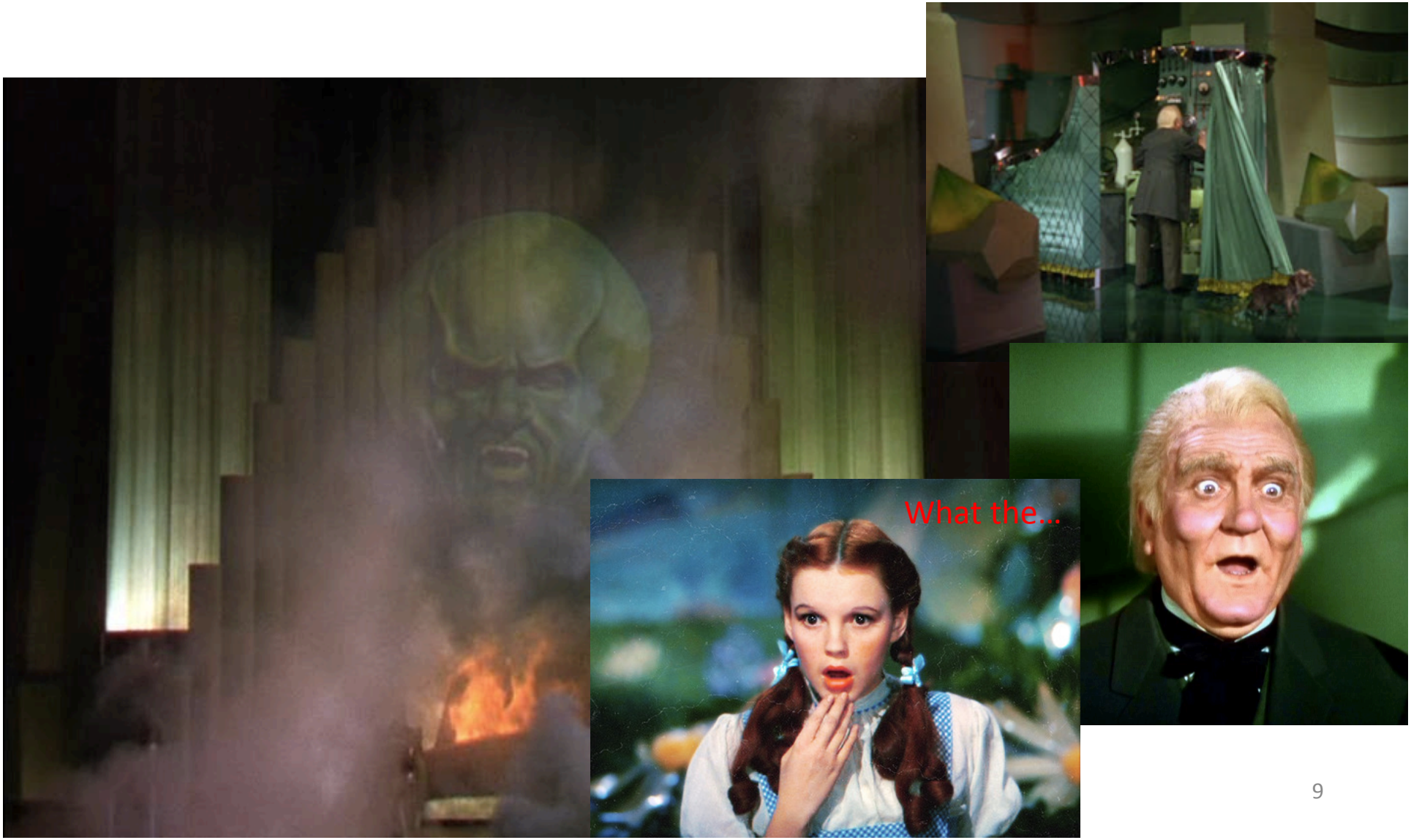
Why C in this course?

- **Did you ever see the wizard of Oz?**

What was going on behind the curtains?

More than what you would think!

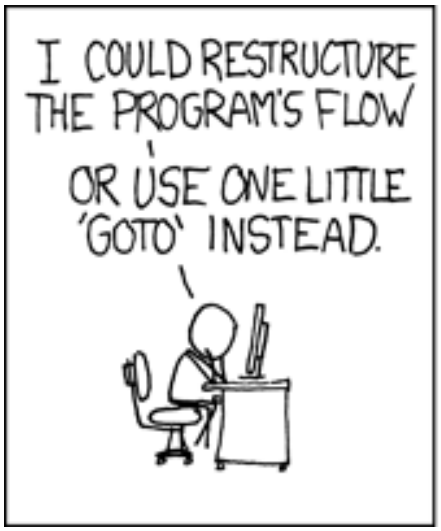
The mystery revealed!

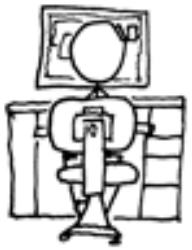


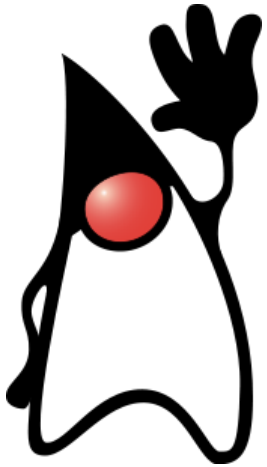
So, why C in this course?

- **Closed Curtains (e.g., Java)**
  - A safe place for programmers!
  - Java hides certain aspects of reality
  - This is good!
- **Behind The Curtains Programming (e.g., C)**
  - The Operating System (OS)
  - Access to memory and memory management
  - Dangerous! … but necessary
  - Important to understand how the real system works
  - Makes you a **better** programmer!

So, what are some differences between C and Java?







Java versus C: Paradigms

- **Java and C follow different programming paradigms.**
- **Java is Object-Oriented while C is Procedural.**

Most differences between the features of the two languages arise due to the use of different programming paradigms.

C breaks down to Functions while Java breaks down to Objects.

C is more procedure-oriented while Java is object-oriented.

Java versus C: Native

- **Java is an "interpreted" language while C is a "compiled" language**
- **Java is compiled to bytecode and that bytecode is "interpreted" by the Java Virtual Machine (JVM).**
- **C is compiled to machine code that is "executed" by the underlying processor.**

Java versus C: High/Low

- **Java is a high-level language**
- **C is a low-level language**
  - C is closer to the machine. It gives you access to aspects of the machine not accessible in Java.
  - Types in C are dependent on the machine on which you are running. Java types are the same across all machines.
  - Both arrangements are intentional!

Java versus C: Memory

- **Java does not allow direct access to memory.**
  - Instead you have references to objects in memory. You can pass these references to methods and even re-assign what that reference refers to.
- **C does allow direct access to memory.**
  - In C, you have pointers to data in memory. These allow you to manipulate memory in arbitrary ways, sometimes helpful, sometimes dangerous.
  - You can interpret that data as you wish.
  - You can (and will) shoot yourself in the foot.

Java versus C: Memory Management

- **Java has automatic memory management.**
  - In Java, you can dynamically allocate objects. You use the **`new`** operator. When you are finished with an object you simply forget about it.
- **C provides manual memory management.**
  - In C, you can dynamically allocate "objects". You use the **`malloc`** library function. When you are finished with that "object" you must use the **free** library function. If you do not, you will have a *memory leak*.*

Java versus C: Exceptions

- **Java provides "exceptions".**
  - If your program has an error at run-time it will throw an exception. You get a nice "stack" trace.
- **C does not.**
  - If you are lucky (and smart) your program will check "error conditions" and fail gracefully.
  - If you are somewhat lucky your program will crash and simply tell you: **`segfault`**.
  - Otherwise it will just produce incorrect output, or loop forever, or some other nasty behavior.

So, the point(er) is….?

- **Programming Languages Are Tools**
  - Java is one language and it does its job well
  - C is another language and it does its job well
- **Pick The Right Tool for the Job**
  - C is a good language to explore how the system works under-the-hood.
  - It is the right tool for the job we need to accomplish in this course!

GNU Compiler Collection

```
unix> gcc –std=c99 prog.c
```

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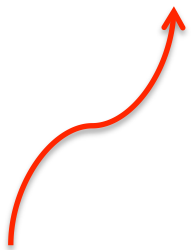


Can compile programs according to conventions of several different versions of the C programming language.

GNU Compiler Collection

```
unix> gcc –std=c99 prog.c
```

Can compile programs according to conventions of several different versions of the C programming language.

This command line option specifies the specific version of C you wish to compile.

GNU Compiler Collection

```
unix> gcc –std=c99 prog.c
```

Linux is built using the GNU compiler collection.

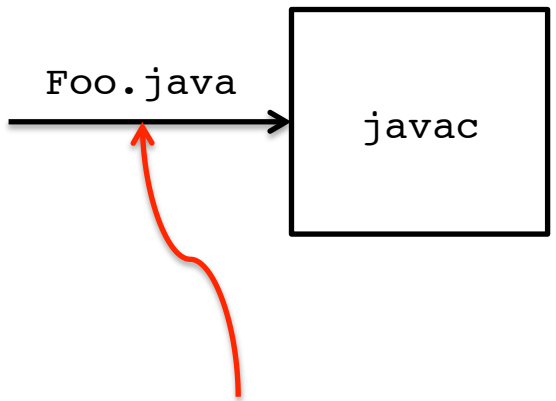
GNU = GNU's Not Unix

GOAL: Develop a complete Unix-like system that is **open source**.

GCC GDB EMACS

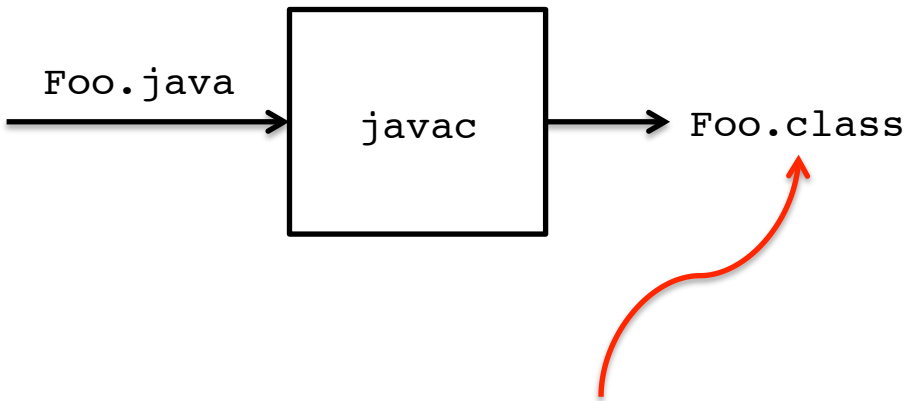
And many, many other useful tools and utilities for working with and manipulating binary programs

Java Compilation



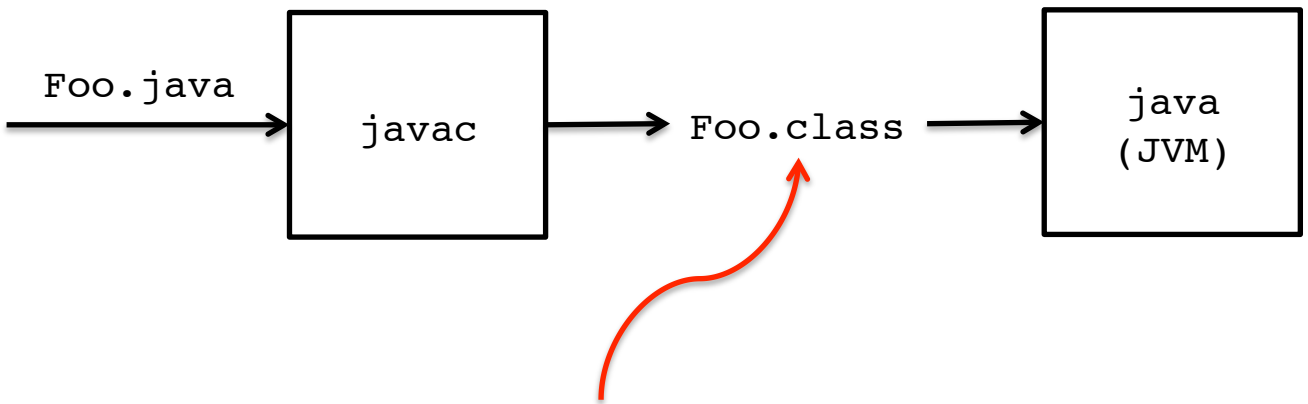
Source program
(text)

Java Compilation



Binary program
(Java bytecodes)

Java Compilation



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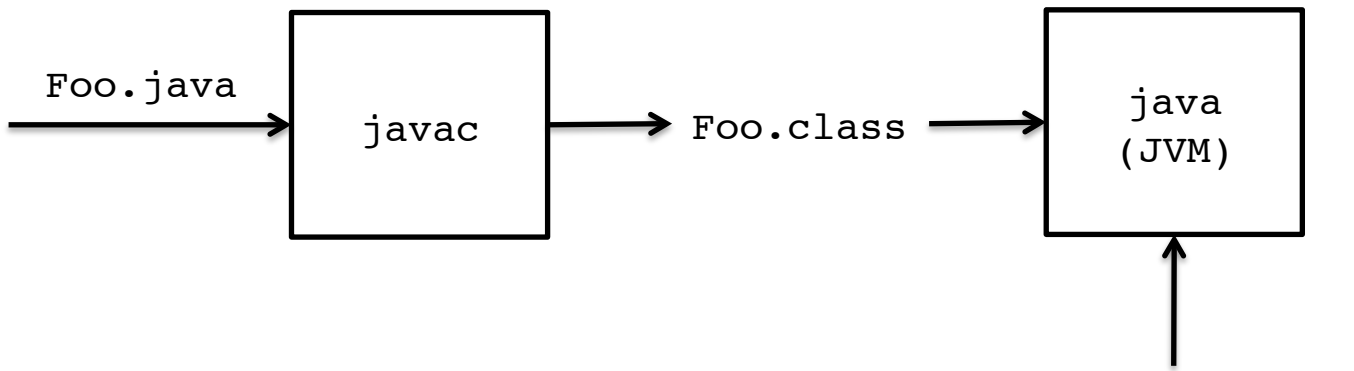
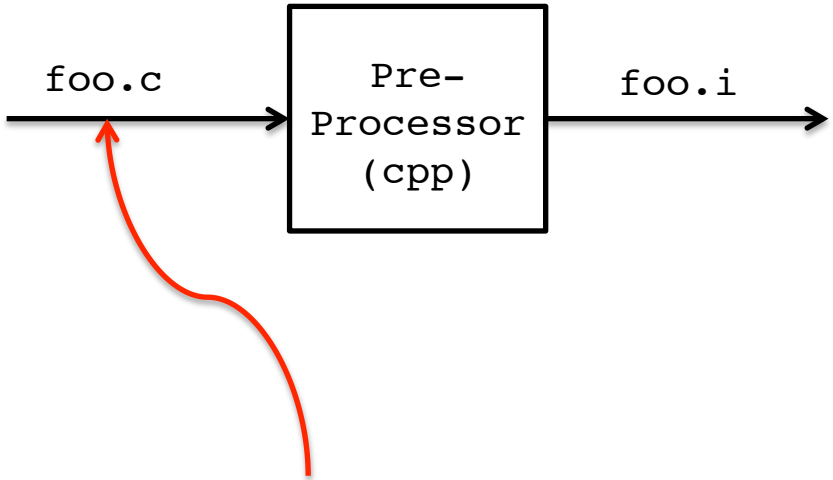
Java Compilation



Dynamically loads and links libraries at run time.

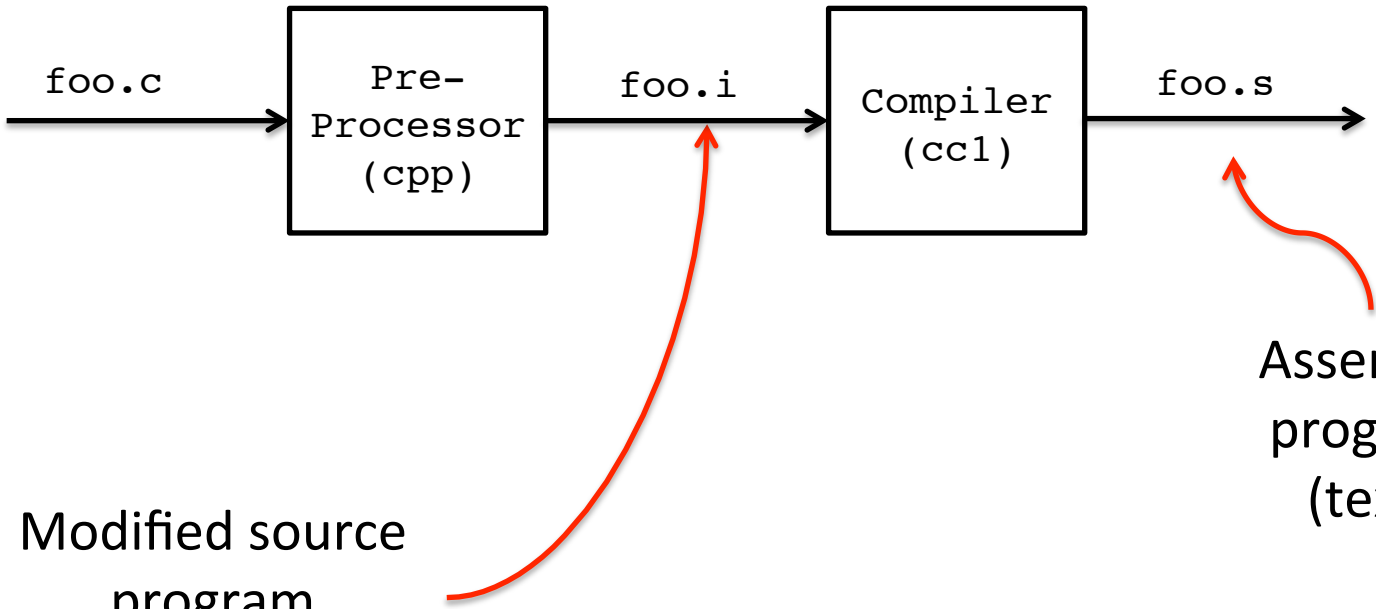
C Compilation



The C pre-processor modifies the original C program according to directives that begin with the '#' character.

```
unix> gcc –E foo.c > foo.i
```

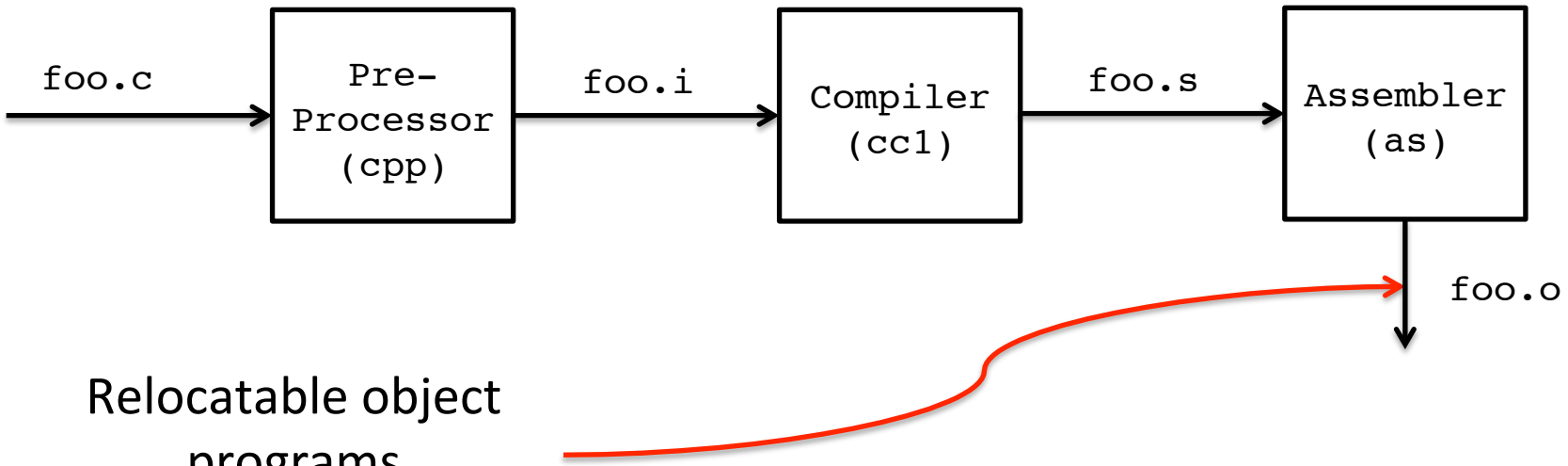
C Compilation



The **`cc1`** compiler translates the modified C program into "human" readable *assembly* representing machine instructions.

```
unix> gcc –S foo.i
```

C Compilation

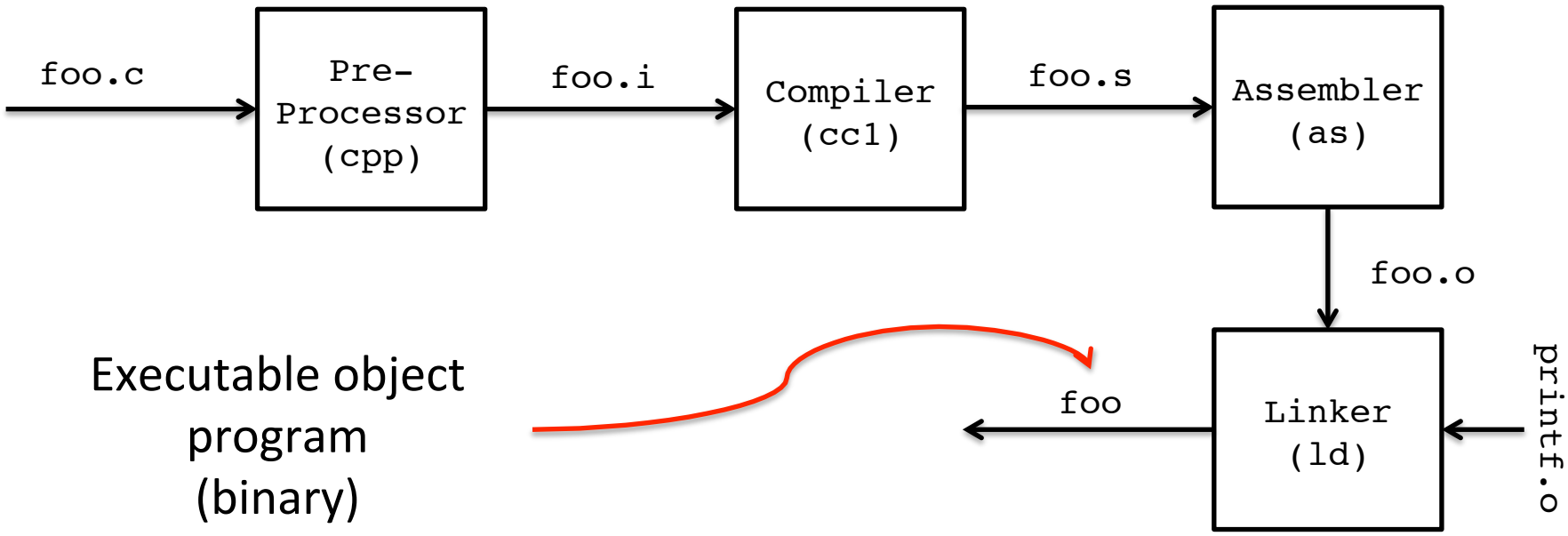


Relocatable object programs (binary)

The **as** assembler translates the assembly program into machine readable *binary* object files containing relocatable machine instructions.

```
unix> gcc –c foo.s
unix> objdump –d foo.o
```

C Compilation



The **`ld`** linker composes the object files into a machine readable *binary* binary file executable for the machine it is compiled for.

```
unix> gcc foo.o –o foo
```

C Data Types and Sizes

C declaration	32-bit (# bytes)	64-bit (# bytes)
`char`	1	1
`short int`	2	2
`int`	4	4
`long int`	4	8
`long long int`	8	8
`char *`	4	8
`float`	4	4
`double`	8	8

Basic Declarations

```
/* basic declarations & sizes on
   64-bit machines */

int x;              /* 4 bytes */
short int x;        /* 2 bytes */
long int x;         /* 8 bytes */
char x;             /* 1 byte  */

unsigned int x; /* 4 bytes */
```

Basic Constants

```
int x = 32;

short int x = 32;

long int x = 32L;

char x = 'c';

/* Can also specify hexadecimal
   (base-16, octal, binary formats */
x = 0x20 /* hex */
x = 040; /* octal */
x = 0b1010;  /* binary: a gcc thing */
```

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```

There are also string constants
"hello, world"
We will hold off on this for now.

#define

- **Processed by the preprocessor**
  - Remember: C source to C source
- **Simple way to define "constants"**
  - Advanced usage involves "macros"

```
#define LETTERCOUNT 26
#define LETTER 'a'

char foo = LETTER;
int alphabet_length = LETTERCOUNT;
```

Arithmetic Operators

```
/* binary arithmetic: +,-,*,/,%  */
int x;
x = 32 + 2;
x = 32 – 2;
x = 32 * 2;
x = 32 / 3;  /* truncates fraction part */
x = 32 % 3;  /* produces remainder      */

/* unary: +,-                          */
x = +3;
x = -3;
```

Relational

```
/* relational operators:
      >,>=,<,<=,!=,== */

int x = 4;
x >  3; /* => 1 */
x <  3; /* => 0 */
x >= 3; /* => 1 */
x <= 3; /* => 0 */
x != 3; /* => 1 */
x == 3; /* => 0 */
```

Logical Connectives

```
/* relational operators:
      &&, || */

int x = 4;
x > 3 && x < 3; /* => 0 */
x > 3 || x < 3; /* => 1 */
```

Evaluation is from **left to right**.

The evaluation **stops** as soon as the truth or falsehood of the result is known.
(*short-circuit evaluation*)

Increment/Decrement

```
/* increment operators: x++, ++x
   decrement operators: x--, --x
*/

int x = 4;
x++;          /* x == 5 */
++x;          /* x == 5 */
x--;          /* x == 3 */
--x;          /* x == 3 */

int y = x++; /* y == ??, x == ?? */
int y = ++x;
```

iClicker question:

A: y == 5, x == 4

B: y == 4, x == 4

C: y == 5, x == 5

D: y == 4, x == 5

E: none of the above

Increment/Decrement

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/* increment operators: x++, ++x
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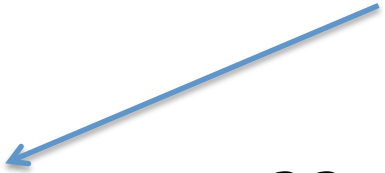
B: y == 4, x == 4

C: y == 5, x == 5

D: y == 4, x == 5

E: none of the above



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int x = 4;
x++;          /* x == 5 */
++x;          /* x == 5 */
x--;          /* x == 3 */
--x;          /* x == 3 */

int y = x++; /* y == 4, x == 5 */
int y = ++x; /* y == 5, x == 5 */
```

Conditionals

```
/* if (c) { stmts } else { stmts }
   c ? e1 : e2;
*/

int x = 4;
if (x >= 4) {
  printf("x >= 4\n");
}
else {
  printf("x < 4\n");
}

int y = x >= 4 ? 1 : 0;
```

Conditionals

```
/* if (c) { stmts } else { stmts }
   c ? e1 : e2;
*/

int x = 4;
if (x >= 4) {
  printf("x >= 4\n");
}
else {
  printf("x < 4\n");
}

int y = (x >= 4 ? 1 : 0);
```

Switch

```
/* switch (c) {
     cases
   } */
```

c must be a character or integer value, and the cases must be character or integer constants

```
char c;
switch (0) {
  case 0:
  case 1:
    c = 'a';
  case 2:
    c = 'b'; break;
  default:
    c = 'c';
}
```

What is the value of c after executing this switch statement?

Switch

```
/* switch (c) {
     cases
   } */

char c;
switch (0) {
  case 0:
  case 1:
    c = 'a'; break;
  case 2:
    c = 'b'; break;
  default:
    c = 'c';
}
```

How about now?

Loops

```
/*
   while (c) { stmts }

   do { stmts } while (c);

   for (e1; e2; e3) { stmts }
*/
```

break and continue

- **Sometimes it is useful to control loop exits other than by testing and the top or bottom.**

- **break:** provides an early exit from a loop just as from a switch statement.

- **continue:** causes a *next iteration* of the enclosing loop – “jump to start of loop”

Comments

```
/*
   Multi-line comments!
*/

// Single line comments!
```

C does not have a *boolean* type

- **If, while, etc., all work like this:**
  - 0 means ‘false’
  - Anything else means ‘true’
- **The boolean negation operator is !**
  - !0 gives 1
  - !(anything else) gives 0
- **Not to be confused with ~, ones complement**
- **Not to be confused with -, twos complement**
- **Different from Unix success code convention!**

A simple program

```
#include <stdio.h>

int main(int argc, char *argv[]) {
   puts("Hello, world.");
   return 0;
}
```

A simple program

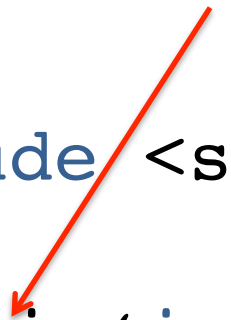
includes the definition of `puts`

```
#include <stdio.h>

int main(int argc, char *argv[]) {
  puts("Hello, world.");
  return 0;
}
```

A simple program

main is the program entry point

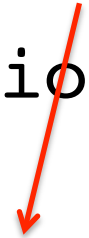


```
#include <stdio.h>

int main(int argc, char *argv[]) {
   puts("Hello, world.");
   return 0;
}
```

A simple program

The first argument to main is the number of arguments passed to your program on the command line



```
#include <stdio.h>

int main(int argc, char *argv[]) {
  puts("Hello, world.");
  return 0;
}
```

A simple program

The second argument to main are the program arguments passed to your program on the command line

```
#include <stdio.h>

int main(int argc, char *argv[]) {
  puts("Hello, world.");
  return 0;
}
```

A simple program

The return value from main is an integer

```
#include <stdio.h>

int main(int argc, char *argv[]) {
  puts("Hello, world.");
  return 0;
}
```

A return value of 0 indicates success.
Other values indicate failure and they are programmer defined

Let’s look at some C programs!

- **simple.c**
- **simple2.c**
- **simple3.c**
- **echo.c**
- **lines.c**
- **wc.c**