CSE 333

Lecture 2 - gentle re-introduction to C

Steve Gribble

Department of Computer Science & Engineering

University of Washington

HW0 results

<table>
<tr><th>question</th><th>T</th><th>F</th></tr>
<tr><td>I have programmed in C before</td><td>89%</td><td>11%</td></tr>
<tr><td>I have programmed in C++ before</td><td>26%</td><td>74%</td></tr>
<tr><td colspan="3">languages: Java (100%), Python (9%), x86 (4%), C# (5%), Ruby (0%), JavaScript (10%), PHP (15%), Pascal (0%), Haskell (0%), visual basic (2%)</td></tr>
<tr><td>I am taking 332 right now</td><td>95%</td><td>5%</td></tr>
<tr><td>I know what a hash table is</td><td>100%</td><td>0%</td></tr>
</table>

HW0 results

question	T	F
I know what a hash table is	100%	0%
I have implemented a hash table	78%	22%
I know what a C pointer is	91%	9%
I have debugged pointer bugs	65%	35%
I know what `(*(x+5))[5] = &y;` means	54%	46%

HW0 results

```
unsigned char *mystery_function(unsigned short bufsize) {
  unsigned char *tmp_buf;

  if (bufsize == 0)
    return NULL;

  tmp_buf = malloc(bufsize);
  if (tmp_buf == NULL)
    return NULL;

  if (verify_something() == 0) // something bad happened
    return NULL;

  return tmp_buf;
}
```

HW0 results

question	T	F
spot the bug: I don’t know 50%, 25% memory leak, 10% type error, 5% multiple of 4 issue, 10% other		
Linux: 0% never, 85% < 1 year, 13% years, 2% expert		
I know what an inode is	7%	93%
I know what a socket is	17%	83%
I’ve written multithreaded code	89%	11%

HW0 results

what is the air-speed velocity of an unladen swallow?	
African or European?	48%
24 miles an hour	16%
8-11 m/s	30%
it depends	8%
500	1%
Red. No, blue. AHHHH....	1%

Today's goals:

- overview of the C material you learned from cse351

Next two weeks' goals:

- dive in deep into more advanced C topics
- start writing some C code
- introduce you to interacting with the OS

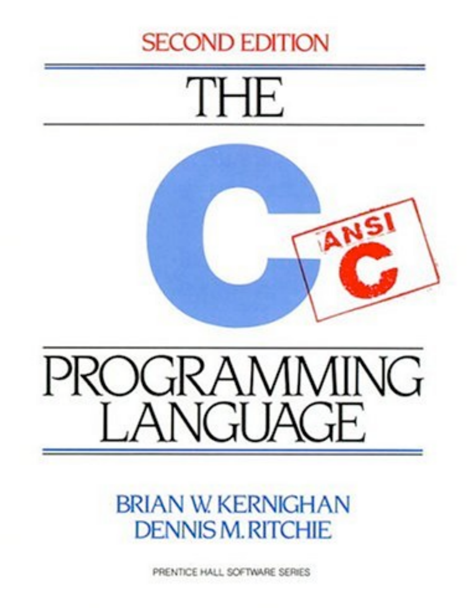
Attribution

The slides I'll be using are a mixture of:

- my own material
- slides from other UW CSE courses (CSE303, CSE351; thanks Magda Balazinska, Marty Stepp, John Zahorjan, Hal Perkins, and others!!)
- material from other universities' courses (particularly CMU's 15-213 and some Harvard courses; thanks Randy Bryant, Dave O'Hallaron, Matt Welsh, and others!!)

All mistakes are mine. (No, really.)

C



Created in 1972 by Dennis Ritchie

- designed for creating system software
- portable across machine architectures
- most recently updated in 1999 (C99)

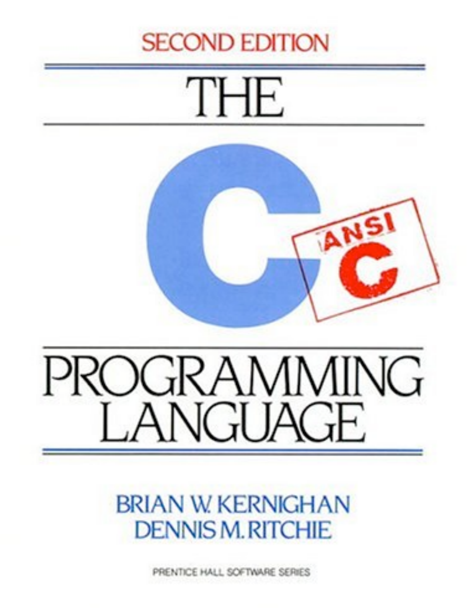
Characteristics

- low-level, smaller standard library than Java
- procedural (not object-oriented)
- typed but unsafe; incorrect programs can fail spectacularly

C

Created in 1972 by Dennis Ritchie

- designed for creating system software



This book was typeset **`(pic|tbl|eqn|troff -ms)`** using an Autologic APS-5 phototypesetter and a DEC VAX 8550 running the 9th Edition of the UNIX operating system.

- procedural (not object-oriented)
- typed but unsafe; incorrect programs can fail spectacularly

Mindset of C

“The PDP-11/45 on which our UNIX installation is implemented is a:

- 16-bit word (8-bit byte) computer with
  - 144K bytes of core memory; UNIX occupies 42K bytes
  - a 1M byte fixed-head disk
  - a moving-head disk with 40M byte disk packs
- The greater part of UNIX software is written in C.”

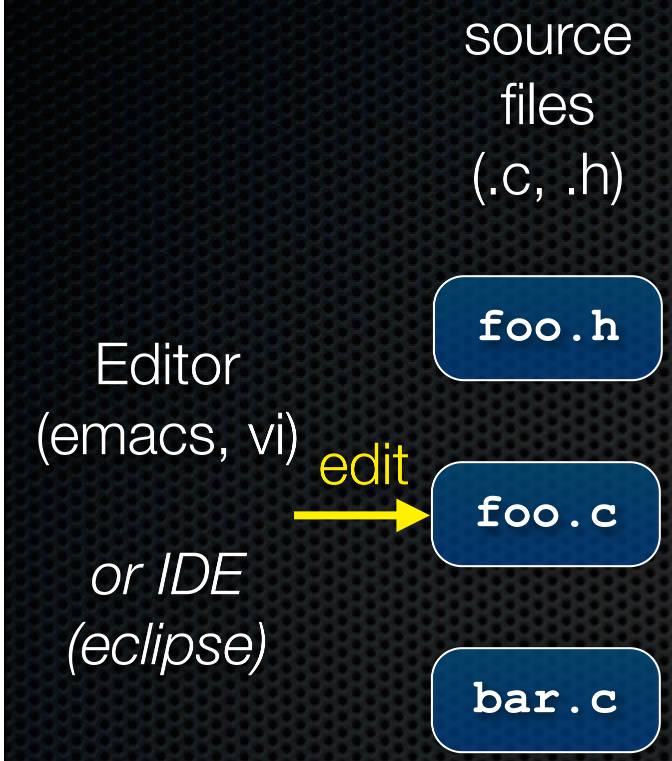
Dennis M. Ritchie and Ken Thompson
Bell Laboratories
1974

C workflow

Editor
(emacs, vi)

or IDE
(eclipse)

C workflow



source files (.c, .h)

foo.h

foo.c

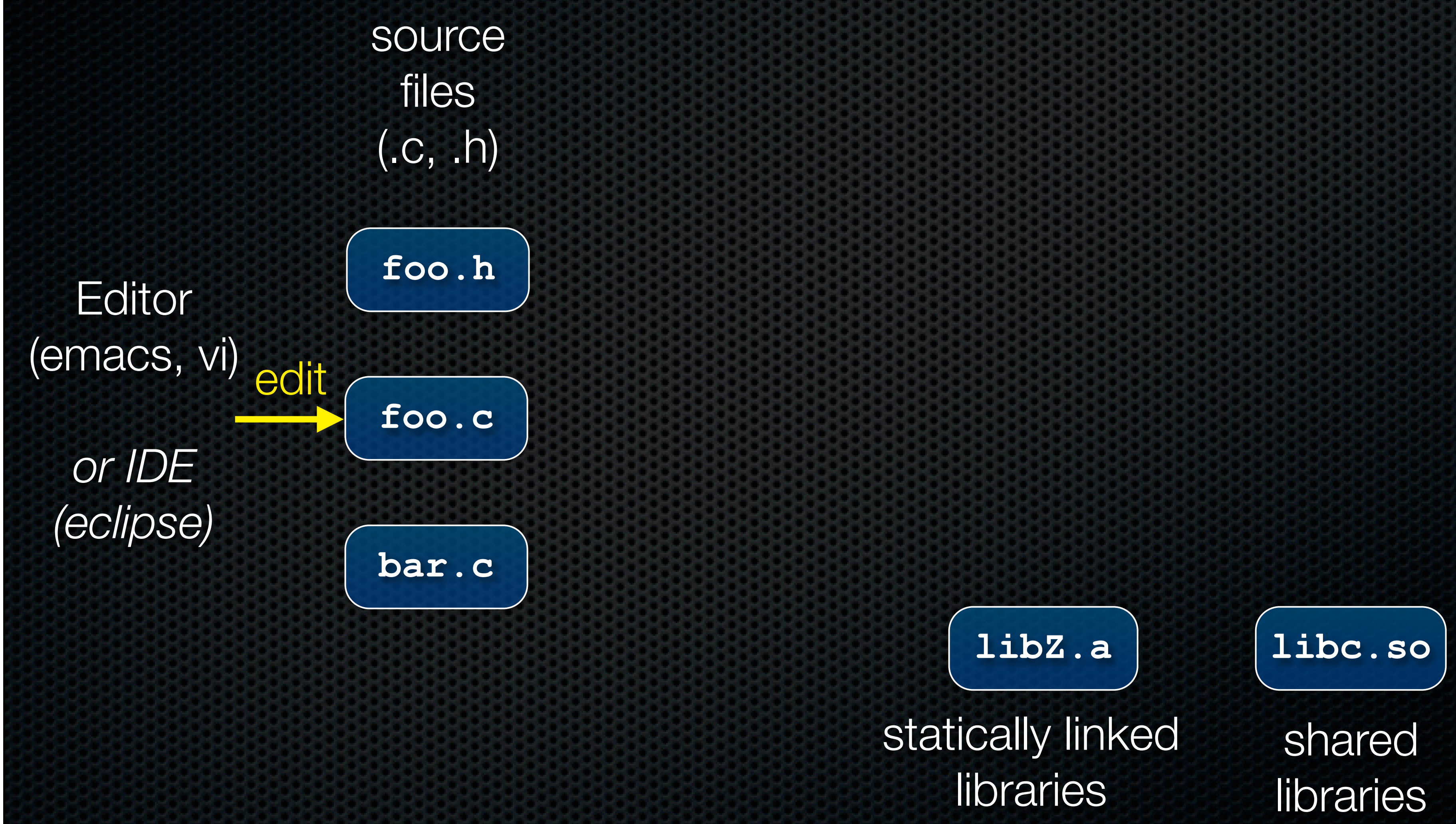
bar.c

Editor (emacs, vi)

or IDE (eclipse)

edit

C workflow



source
files
(.c, .h)

Editor
(emacs, vi)

or IDE
(eclipse)

edit

`foo.h`

`foo.c`

`bar.c`

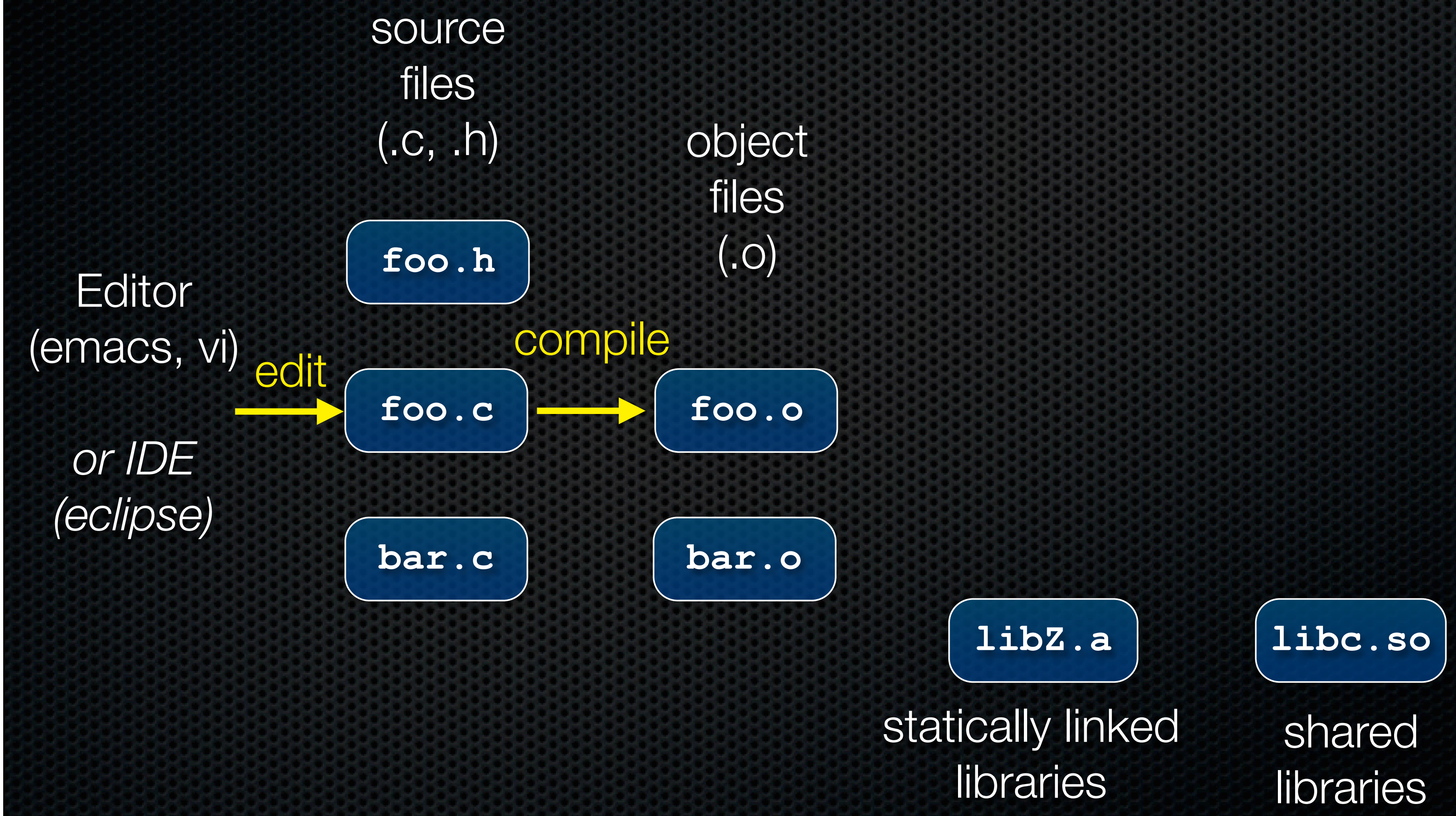
`libZ.a`

statically linked
libraries

`libc.so`

shared
libraries

C workflow



source
files
(.c, .h)

object
files
(.o)

Editor
(emacs, vi)

or IDE
(eclipse)

edit

compile

foo.h

foo.c

foo.o

bar.c

bar.o

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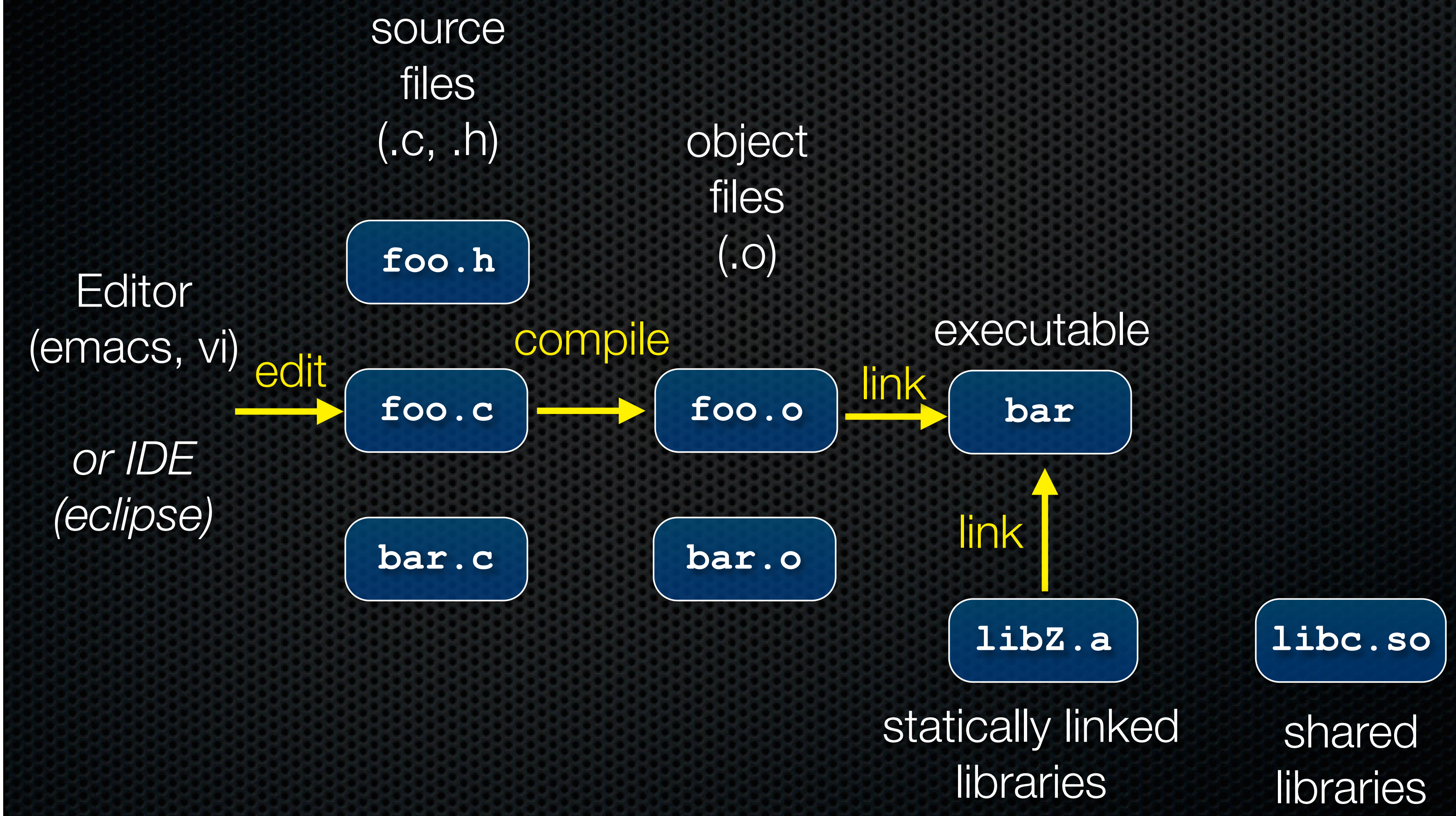
C workflow



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(emacs, vi)

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edit

source
files
(.c, .h)

foo.h

foo.c

bar.c

compile

object
files
(.o)

foo.o

bar.o

link

executable

bar

link

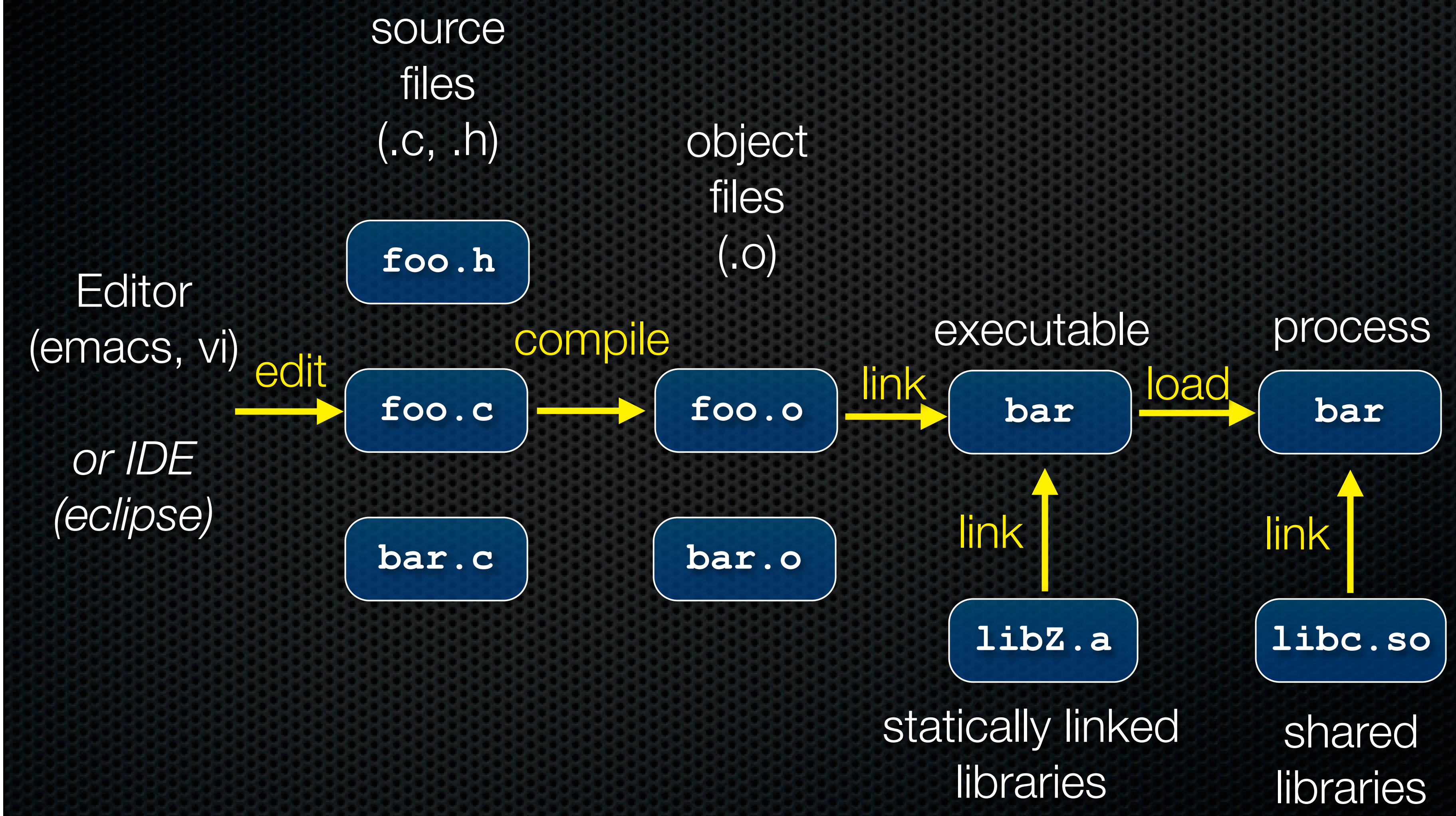
libZ.a

statically linked
libraries

libc.so

shared
libraries

C workflow



source
files
(.c, .h)

object
files
(.o)

Editor
(emacs, vi)

or IDE
(eclipse)

edit

`foo.h`

`foo.c`

`bar.c`

compile

`foo.o`

`bar.o`

link

executable

`bar`

load

process

`bar`

link

`libZ.a`

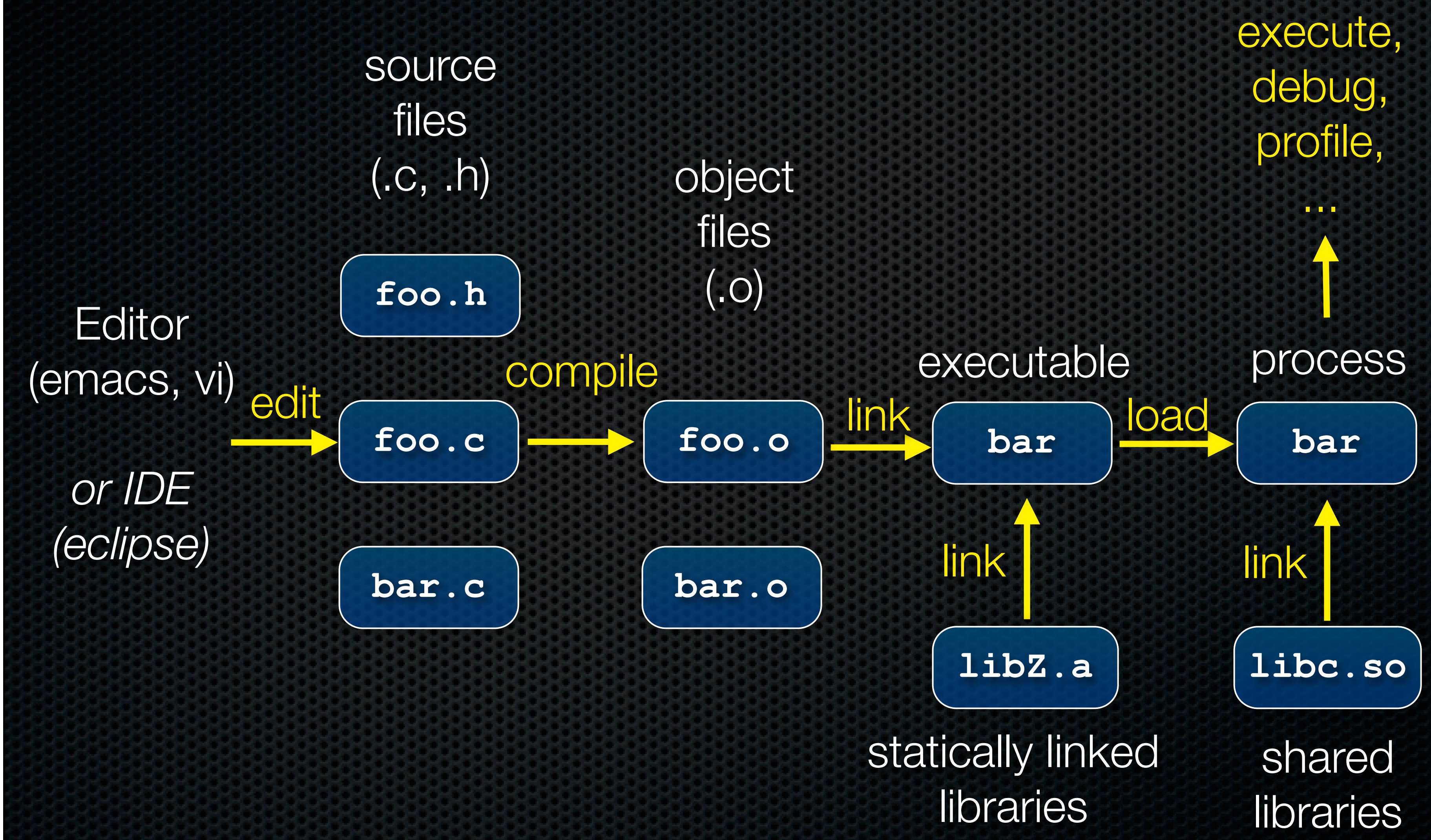
statically linked
libraries

link

`libc.so`

shared
libraries

C workflow



Editor (emacs, vi)

or IDE (eclipse)

edit

source files (.c, .h)

`foo.h`

`foo.c`

`bar.c`

compile

object files (.o)

`foo.o`

`bar.o`

link

executable

`bar`

link

`libZ.a`

statically linked libraries

load

process

`bar`

execute, debug, profile, ...

link

`libc.so`

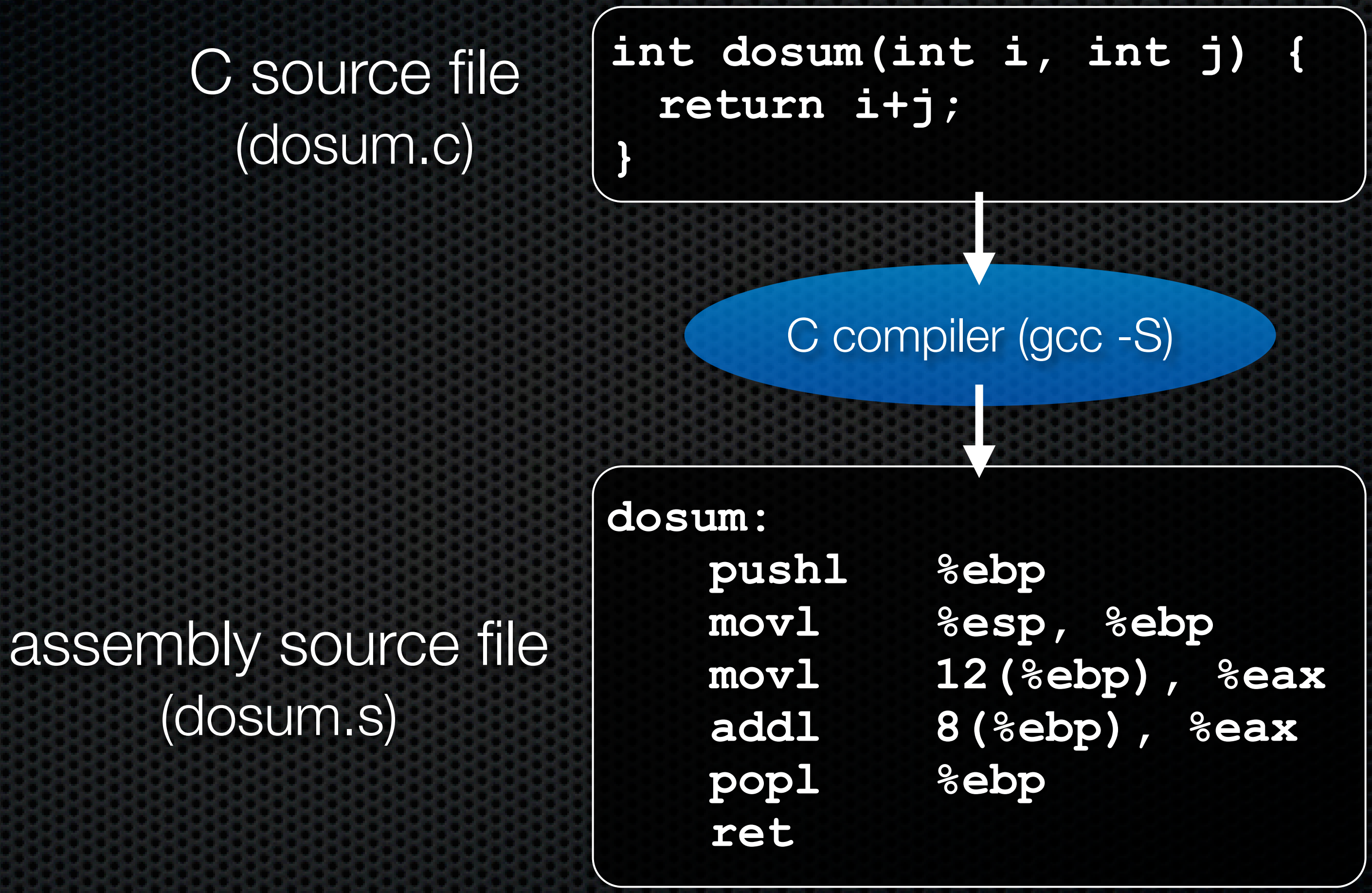
shared libraries

From C to machine code

C source file
(dosum.c)

```
int dosum(int i, int j) {
  return i+j;
}
```

From C to machine code



C source file
(dosum.c)

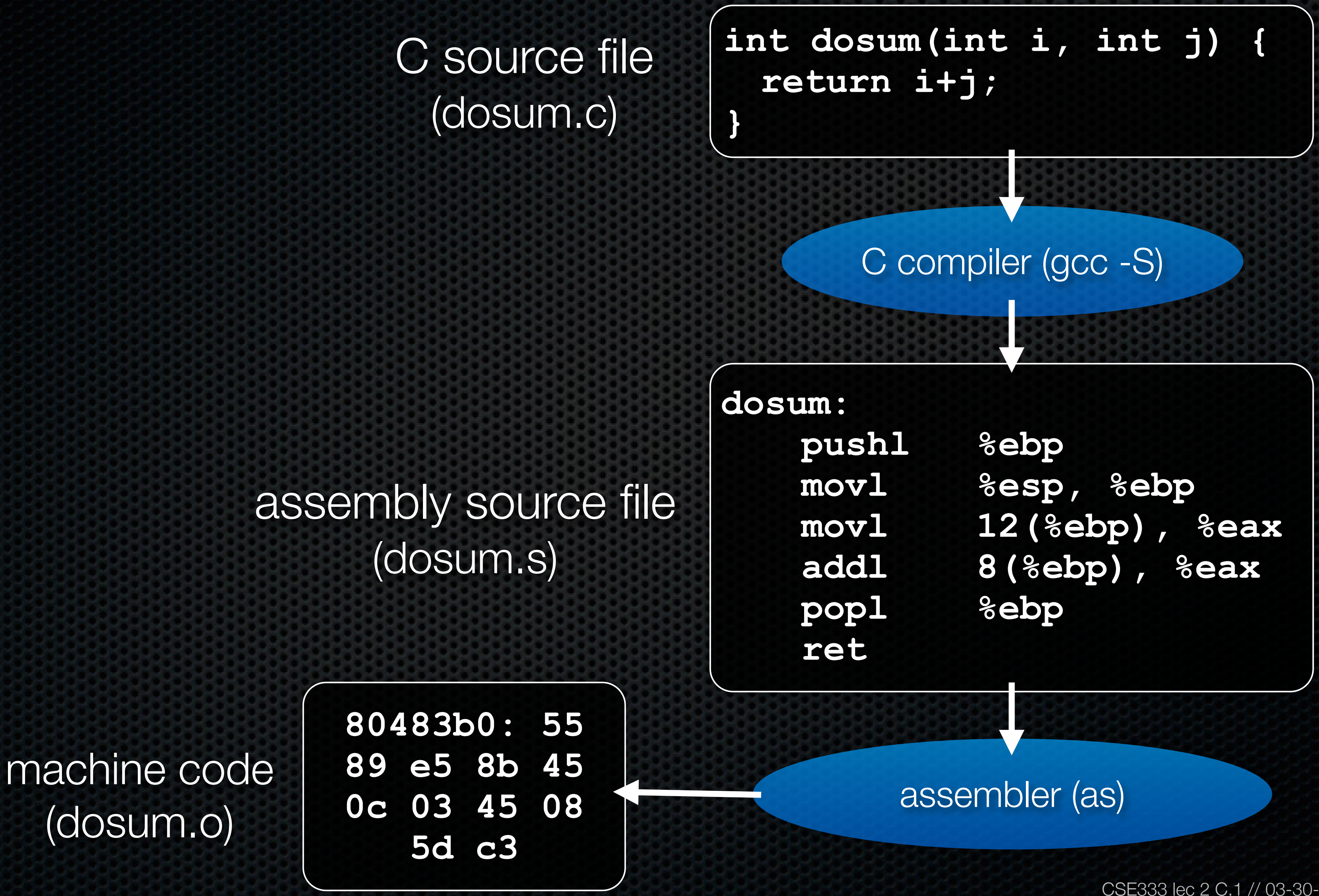
```
int dosum(int i, int j) {
  return i+j;
}
```

C compiler (gcc -S)

assembly source file
(dosum.s)

```
dosum:
    pushl   %ebp
    movl    %esp, %ebp
    movl    12(%ebp), %eax
    addl    8(%ebp), %eax
    popl    %ebp
    ret
```

From C to machine code



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    pushl   %ebp
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    movl    12(%ebp), %eax
    addl    8(%ebp), %eax
    popl    %ebp
    ret
```

assembler (as)

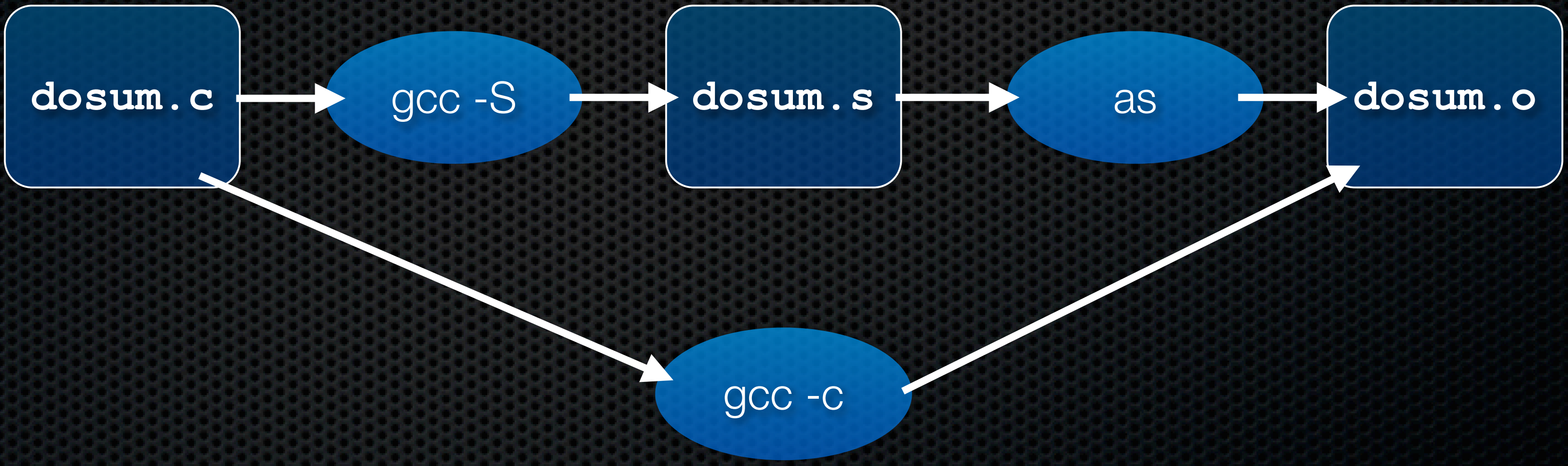
machine code
(dosum.o)

```
80483b0: 55
89 e5 8b 45
0c 03 45 08
   5d c3
```

Skipping assembly language

Most C compilers generate .o files (machine code) directly

- i.e., without actually saving the readable .s assembly file



`dosum.c`

gcc -S

`dosum.s`

as

`dosum.o`

gcc -c

Multi-file C programs

C source file
(dosum.c)

```
int dosum(int i, int j) {
  return i+j;
}
```

C source file
(sumnum.c)

```
#include <stdio.h>

int dosum(int i, int j);

int main(int argc, char **argv) {
  printf("%d\n", dosum(1,2));
  return 0;
}
```

Multi-file C programs

C source file
(dosum.c)

```
int dosum(int i, int j) {
  return i+j;
}
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C source file
(sumnum.c)

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#include <stdio.h>

int dosum(int i, int j);

int main(int argc, char **argv) {
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  return 0;
}
```

dosum( ) is
implemented
in sumnum.c

Multi-file C programs

C source file
(dosum.c)

```
int dosum(int i, int j) {
  return i+j;
}
```

this “prototype” of dosum( ) tells gcc about the types of dosum’s arguments and its return value

C source file
(sumnum.c)

```
#include <stdio.h>

int dosum(int i, int j);

int main(int argc, char **argv) {
  printf("%d\n", dosum(1,2));
  return 0;
}
```

dosum( ) is implemented in sumnum.c

Multi-file C programs

C source file
(dosum.c)

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int dosum(int i, int j) {
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Multi-file C programs

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int main(int argc, char **argv) {
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  return 0;
}
```

where is the
implementation
of printf?

Multi-file C programs

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C source file
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#include <stdio.h>

int dosum(int i, int j);

int main(int argc, char **argv) {
  printf("%d\n", dosum(1,2));
  return 0;
}
```

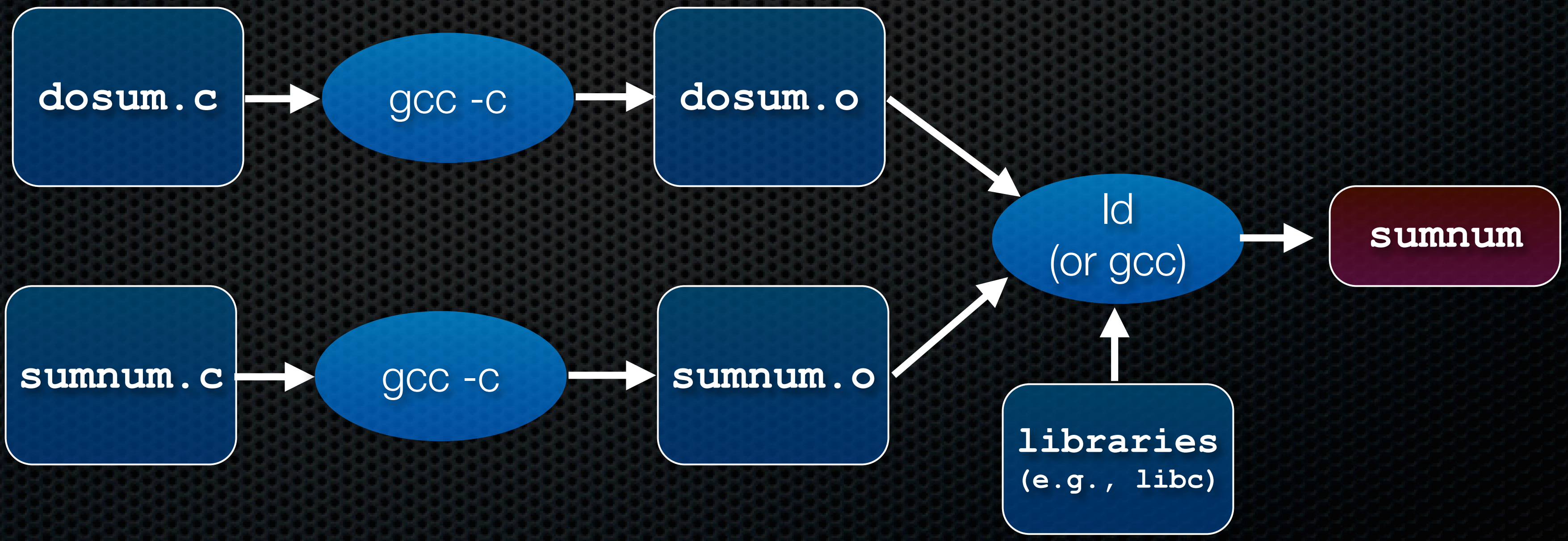
why do we need
this #include?

where is the
implementation
of printf?

Compiling multi-file programs

Multiple object files are ***linked*** to produce an executable

- standard libraries (libc, crt1, ...) are usually also linked in
- a library is just a pre-assembled collection of .o files



Object files

sumnums, dosum.o are **object files**

- each contains machine code produced by the compiler
- each might contain references to external symbols
  - variables and functions not defined in the associated .c file
  - e.g., sumnum.o contains code that relies on printf( ) and dosum( ), but these are defined in libc.a and dosum.o, respectively
- linking resolves these external symbols while smooshing together object files and libraries

Let’s dive into C itself

Things that are the same as Java

- syntax for statements, control structures, function calls
- types: `int, double, char, long, float`
- type-casting syntax: `float x = (float) 5 / 3;`
- expressions, operators, precedence

  `+ - * / % ++ -- = += -= *= /= %= < <= == != > >= && || !`
- scope (local scope is within a set of `{ }` braces)
- comments: `/* comment */` `// comment`

Primitive types in C

integer types

- char, int

floating point

- float, double

modifiers

- short [int]
- long [int, double]
- signed [char, int]
- unsigned [char, int]

see sizeofs.c

type	bytes (32 bit)	bytes (64 bit)	32 bit range	printf
char	1	1	[0, 255]	%c
short int	2	2	[-32768,32767]	%hd
unsigned short int	2	2	[0, 65535]	%hu
int	4	4	[-214748648, 2147483647]	%d
unsigned int	4	4	[0, 4294967295]	%u
long int	4	8	[-2147483648, 2147483647]	%ld
long long int	8	8	[-9223372036854775808, 9223372036854775807]	%lld
float	4	4	approx [10^{-38}, 10^{38}]	%f
double	8	8	approx [10^{-308}, 10^{308}]	%lf
long double	12	16	approx [10^{-4932}, 10^{4932}]	%Lf
pointer	4	8	[0, 4294967295]	%p

C99 extended integer types

Solve the conundrum of “how big is a long int?”

```
#include <stdint.h>

void foo(void) {
int8_t  w;    // exactly 8 bits, signed
int16_t x;    // exactly 16 bits, signed
int32_t y;    // exactly 32 bits, signed
int64_t z;    // exactly 64 bits, signed

uint8_t w;    // exactly 8 bits, unsigned
...etc.

}
```

Similar to Java...

- variables
    - must declare at the start of a function or block *(changed in C99)*
    - need not be initialized before use *(gcc -Wall will warn)*

varscope.c

```c
#include <stdio.h>

int main(int argc, char **argv) {
  int x, y = 5;   // note x is uninitialized!
  long z = x+y;

  printf("z is '%ld'\n", z); // what's printed?
  {
    int y = 10;
    printf("y is '%d'\n", y);
  }
  int w = 20;  // ok in c99
  printf("y is '%d', w is '%d'\n", y, w);
  return 0;
}
```

Similar to Java...

const

- a qualifier that indicates the variable’s value cannot change
- compiler will issue an **error** if you try to violate this
- why is this qualifier useful?

consty.c

```c
#include <stdio.h>

int main(int argc, char **argv) {
  const double MAX_GPA = 4.0;

  printf("MAX_GPA: %g\n", MAX_GPA);
  MAX_GPA = 5.0;   // illegal!
  return 0;
}
```

Similar to Java...

for loops

- can’t declare variables in the loop header *(changed in c99)*

if/else, while, and do/while loops

- no boolean type *(changed in c99)*
- any type can be used; 0 means **false**, everything else **true**

loopy.c

```c
int i;

for (i=0; i<100; i++) {
  if (i % 10 == 0) {
    printf("i: %d\n", i);
  }
}
```

Similar to Java...

parameters / return value

- C always passes arguments by value
- “pointers”
  - lets you pass by reference
  - more on these soon
  - least intuitive part of C
  - very dangerous part of C

pointy.c

```c
void add_pbv(int c) {
  c += 10;
  printf("pbv c: %d\n", c);
}

void add_pbr(int *c) {
  *c += 10;
  printf("pbr *c: %d\n", *c);
}

int main(int argc, char **argv) {
  int x = 1;

  printf("x: %d\n", x);

  add_pbv(x);
  printf("x: %d\n", x);

  add_pbr(&x);
  printf("x: %d\n", x);

  return 0;
}
```

Very different than Java

arrays

- just a bare, contiguous block of memory of the correct size
- an array of 10 ints requires 10 x 4 bytes = 40 bytes of memory
- arrays have no methods, do not know their own length
- C doesn't stop you from overstepping the end of an array!!
    - many, many security bugs come from this

Very different than Java

strings

- array of char
- terminated by the NULL character '\0'
- are not objects, have no methods; string.h has helpful utilities

```
char *x = "hello\n";
```

Very different than Java

errors and exceptions

- C has no exceptions (no try / catch)
- errors are returned as integer error codes from functions
- makes error handling ugly and inelegant

crashes

- if you do something bad, you'll end up spraying bytes around memory, hopefully causing a "segmentation fault" and crash

objects

- there aren't any; struct is closest feature (set of fields)

Very different than Java

memory management

- **you** must to worry about this; there is no garbage collector
- local variables are allocated off of the stack
  - freed when you return from the function
- global and static variables are allocated in a data segment
  - are freed when your program exits
- you can allocate memory in the heap segment using malloc( )
  - you must free malloc'ed memory with free( )
  - failing to free is a leak, double-freeing is an error (hopefully crash)

Very different than Java

console I/O

- C standard library has portable routines for reading/writing
  - scanf, printf

file I/O

- C standard library has portable routines for reading/writing
  - fopen, fread, fwrite, fclose, etc.
  - does **buffering** by default, is **blocking** by default
- OS provides (less portable) routines
  - we'll be using these: more control over buffering, blocking

Very different than Java

network I/O

- C standard library has no notion of network I/O
- OS provides (somewhat portable) routines
- lots of complexity lies here
  - errors: network can fail
  - performance: network can be slow
  - concurrency: servers speak to thousands of clients simultaneously

Very different than Java

Libraries you can count on

- C has very few compared to most other languages
- no built-in trees, hash tables, linked lists, sort , etc.
- you have to write many things on your own
  - particularly data structures
  - error prone, tedious, hard to build efficiently and portably
- this is one of the main reasons C is a much less productive language than Java, C++, python, or others

See you on Friday!