C

Changelog

Corrections made in this version not seen in first lecture:

- 24 August 2017: slide 3 (a note on next week's reading): adjust for lack of quiz
- 24 August 2017: slide 20 (logical operators): add parenthesis
- 24 August 2017: slide 27: remove extraneous * from line 4 (was not present on slide 27)

quiz demo

logistics notes

quizzes

- post-quiz: released Thursday night, due Sat
- pre-quiz: released Sat, due Tuesday morning

note on comments:

- we will eventually have TAs look at them
- (for answers autograded as wrong)

question order is *randomized* —

- avoid referring to answer letters in your comments

a note on next week's reading

we're starting x86-64 assembly

using AT&T syntax — not what you learned in 2150

- other syntax: "Intel syntax"

some important differences (described at end of section 3.3)

quiz will avoid assembly syntax issues

we will cover next week

lab accounts

they should work now

ignore typo of Spring for Fall in email body (subject is okay)

if you registered this week, likely today

let me know if you don't have one by Monday

slides + audio + feedback

slides and video and audio on website

when I don't mess up recording

anonymous feedback on Collab exists

office hours

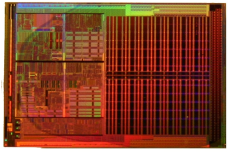
TA office hours should start next week

all office hours on course website

my office hours:

Monday: 1PM-2PM
Wednesday: 2PM-3PM
Friday this week: 10AM-11AM; 1PM-2PM
Friday future weeks: TBA

processors and memory

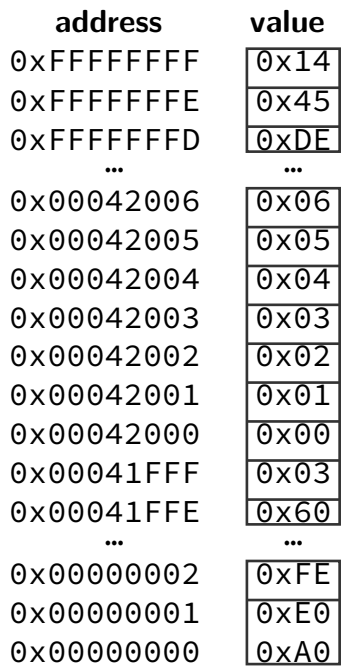


processor

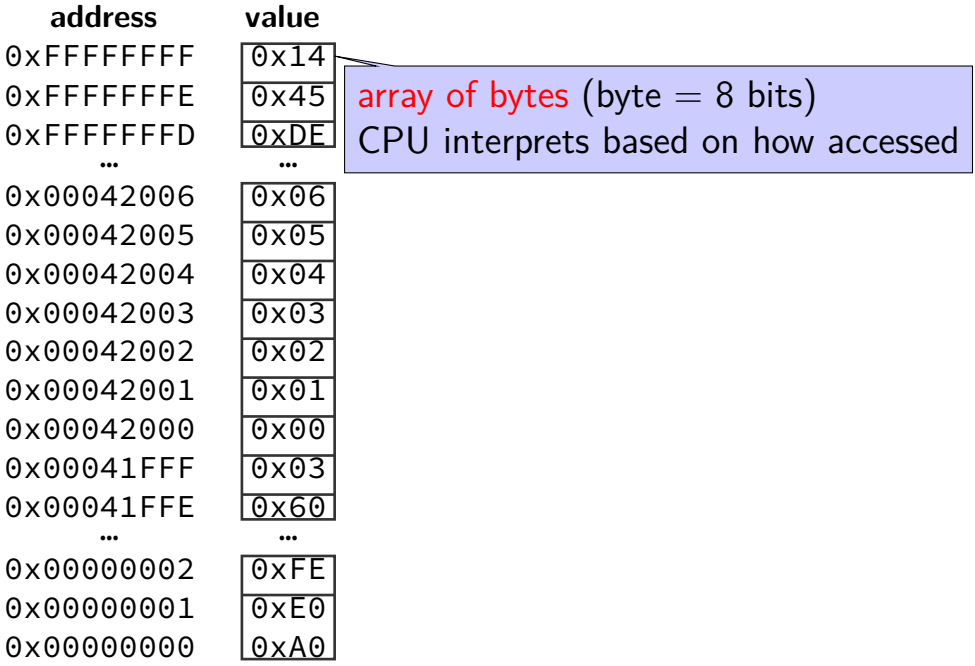
memory

Images:
Single core Opteron 8xx die: Dg2fer at the German language Wikipedia, via Wikimedia Commons
SDRAM by Arnaud 25, via Wikimedia Commons

memory


address
value
0xFFFFFFFF
0x14
0xFFFFFFFE
0x45
0xFFFFFFFD
0xDE
…
…
0x00042006
0x06
0x00042005
0x05
0x00042004
0x04
0x00042003
0x03
0x00042002
0x02
0x00042001
0x01
0x00042000
0x00
0x00041FFF
0x03
0x00041FFE
0x60
…
…
0x00000002
0xFE
0x00000001
0xE0
0x00000000
0xA0

memory


address
value
0xFFFFFFFF
0x14
0xFFFFFFFE
0x45
0xFFFFFFFD
0xDE
...
...
0x00042006
0x06
0x00042005
0x05
0x00042004
0x04
0x00042003
0x03
0x00042002
0x02
0x00042001
0x01
0x00042000
0x00
0x00041FFF
0x03
0x00041FFE
0x60
...
...
0x00000002
0xFE
0x00000001
0xE0
0x00000000
0xA0
array of bytes (byte = 8 bits)
CPU interprets based on how accessed

memory

address	value
0xFFFFFFFF	0x14
0xFFFFFFFE	0x45
0xFFFFFFFD	0xDE
…	…
0x00042006	0x06
0x00042005	0x05
0x00042004	0x04
0x00042003	0x03
0x00042002	0x02
0x00042001	0x01
0x00042000	0x00
0x00041FFF	0x03
0x00041FFE	0x60
…	…
0x00000002	0xFE
0x00000001	0xE0
0x00000000	0xA0

address	value
0x00000000	0xA0
0x00000001	0xE0
0x00000002	0xFE
…	…
0x00041FFE	0x60
0x00041FFF	0x03
0x00042000	0x00
0x00042001	0x01
0x00042002	0x02
0x00042003	0x03
0x00042004	0x04
0x00042005	0x05
0x00042006	0x06
…	…
0xFFFFFFFD	0xDE
0xFFFFFFFE	0x45
0xFFFFFFFF	0x14

endianness

address	value
0xFFFFFFFF	0x14
0xFFFFFFFE	0x45
0xFFFFFFFD	0xDE
…	…
0x00042006	0x06
0x00042005	0x05
0x00042004	0x04
0x00042003	0x03
0x00042002	0x02
0x00042001	0x01
0x00042000	0x00
0x00041FFF	0x03
0x00041FFE	0x60
…	…
0x00000002	0xFE
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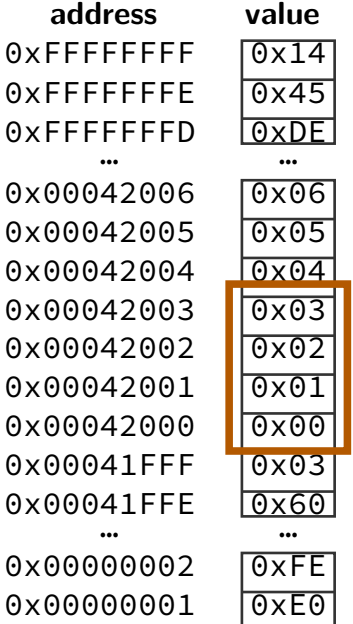
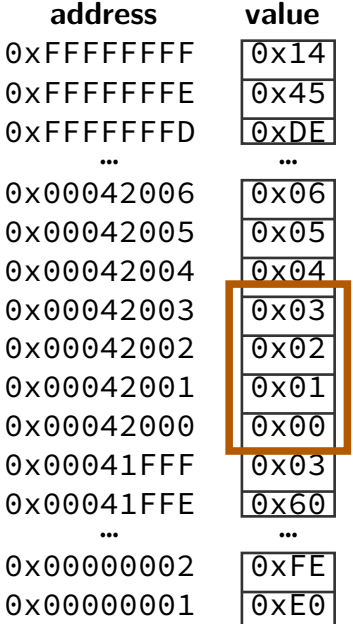
```
int *x = (int*)0x42000;
cout << *x << endl;
```

endianness




```
int *x = (int*)0x42000;
cout << *x << endl;
```

endianness

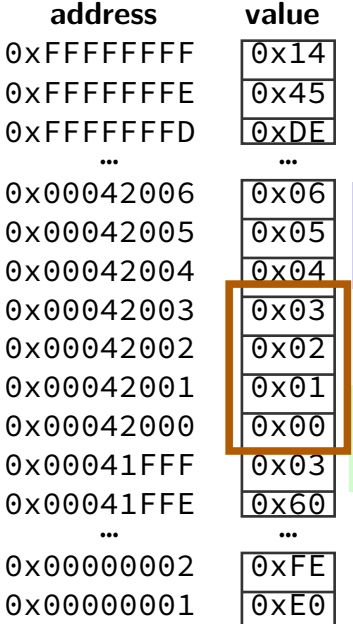



```
int *x = (int*)0x42000;
cout << *x << endl;
```

0x03020100 = 50462976

0x00010203 = 66051

endianness




```
int *x = (int*)0x42000;
cout << *x << endl;
```

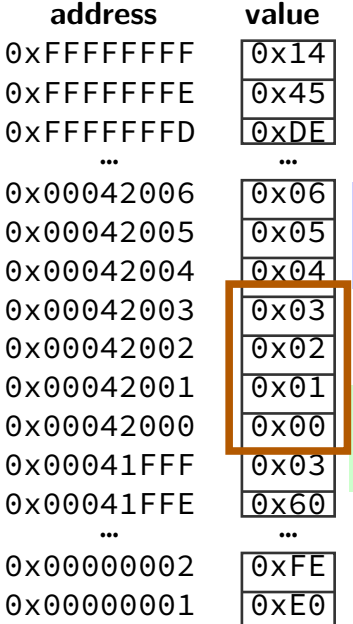
0x03020100 = 50462976

little endian
(least significant byte has lowest address)

0x00010203 = 66051

big endian
(most significant byte has lowest address)

endianness

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0x03020100 = 50462976

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(least significant byte has lowest address)

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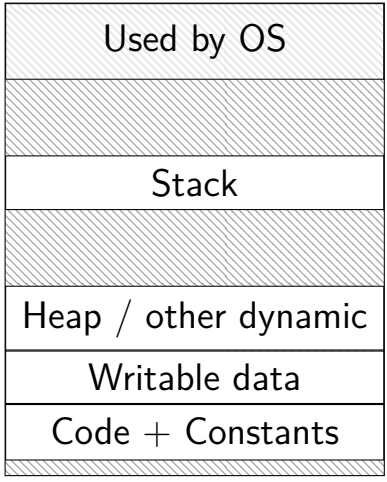
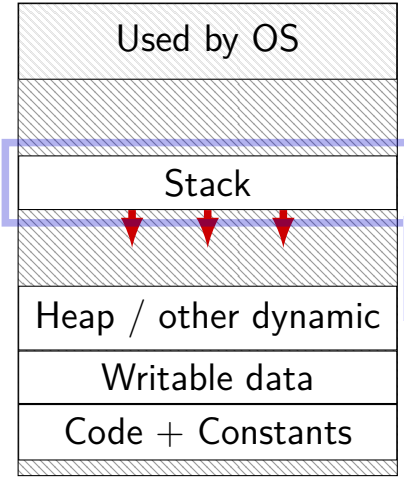
big endian
(most significant byte has lowest address)

program memory (x86-64 Linux)



program memory (x86-64 Linux)



0xFFFF FFFF FFFF FFFF

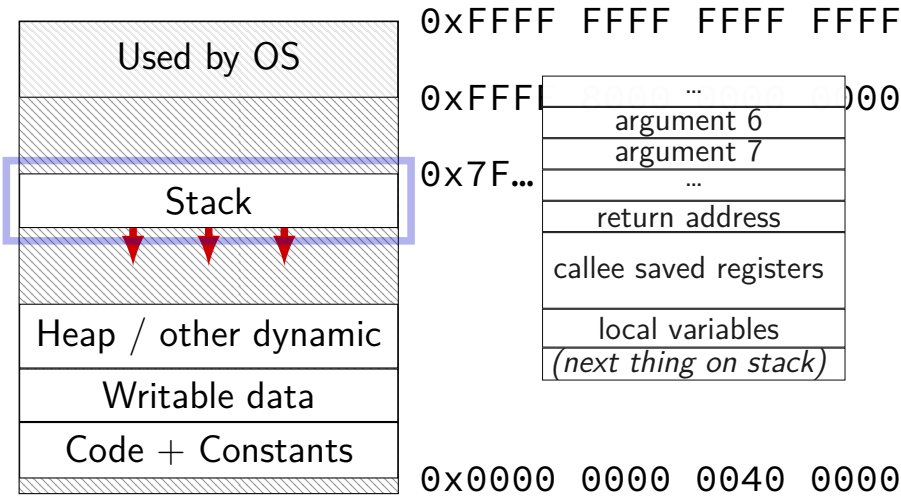
0xFFFF 8000 0000 0000

0x7F…

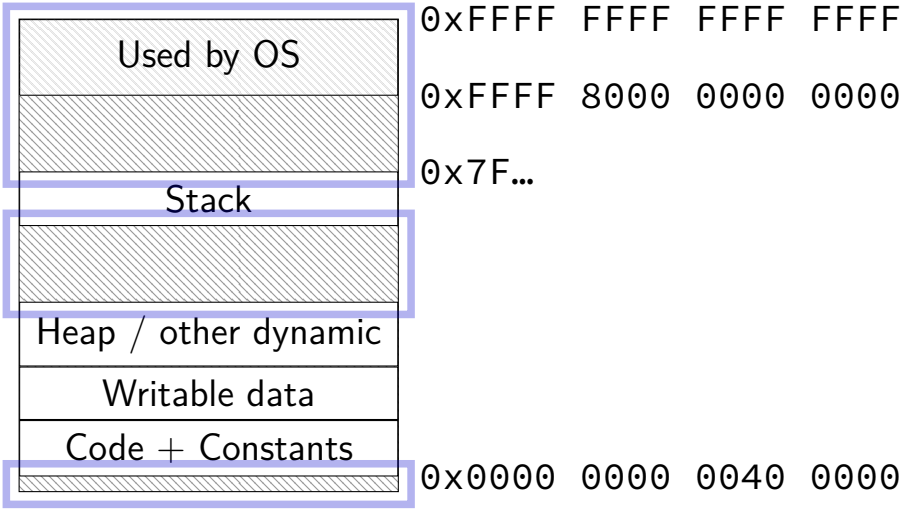
stack grows down
"top" has smallest address

0x0000 0000 0040 0000

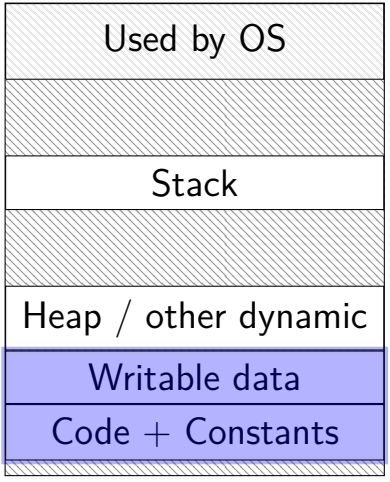
program memory (x86-64 Linux)



program memory (x86-64 Linux)



program memory (x86-64 Linux)



0xFFFF FFFF FFFF FFFF

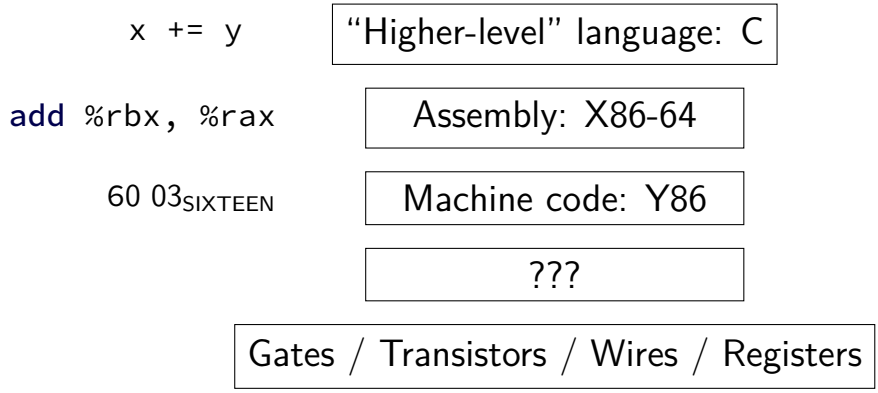
0xFFFF 8000 0000 0000

0x7F…

copied from executable file

0x0000 0000 0040 0000

layers of abstraction



compilation commands

compile:	`gcc -S file.c`	⇒	`file.s` (assembly)
assemble:	`gcc -c file.s`	⇒	`file.o` (object file)
link:	`gcc -o file file.o`	⇒	`file` (executable)
c+a:	`gcc -c file.c`	⇒	`file.o`
c+a+l:	`gcc -o file file.c`	⇒	`file`

...

what's in those files?

hello.c

```c
#include <stdio.h>
int main(void) {
  puts("Hello, World!");
  return 0;
}
```

what's in those files?

hello.c

```c
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int main(void) {
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  return 0;
}
```

hello.s

```
    .text
main:
    sub  $8, %rsp
    mov  $.Lstr, %rdi
    call puts
    xor  %eax, %eax
    add  $8, %rsp
    ret

    .data
.Lstr: .string "Hello, World!"
```

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    xor  %eax, %eax
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.Lstr: .string "Hello, World!"
```

hello.o

text (code) segment:

```
48 83 EC 08 BF 00 00 00 00 E8 00 00
00 00 31 C0 48 83 C4 08 C3
```

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int main(void) {
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  return 0;
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```

hello.s

```
    .text
main:
    sub  $8, %rsp
    mov  $.Lstr, %rdi
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    xor  %eax, %eax
    add  $8, %rsp
    ret

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```

hello.o

text (code) segment:

```
48 83 EC 08 BF 00 00 00 00 E8 00 00
00 00 31 C0 48 83 C4 08 C3
```

data segment:

```
48 65 6C 6C 6F 2C 20 57 6F 72 6C 00
```

what's in those files?

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int main(void) {
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  return 0;
}
```

hello.s

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main:
    sub  $8, %rsp
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    xor  %eax, %eax
    add  $8, %rsp
    ret

    .data
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```

hello.o

text (code) segment:

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48 83 EC 08 BF 00 00 00 00 E8 00 00
00 00 31 C0 48 83 C4 08 C3
```

data segment:

```
48 65 6C 6C 6F 2C 20 57 6F 72 6C 00
```

relocations:

take 0s at	*and replace with*
text, byte 6 ( )	data segment, byte 0
text, byte 10 ( )	address of puts

what's in those files?

hello.c

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```

hello.s

```
    .text
main:
    sub  $8, %rsp
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    call puts
    xor  %eax, %eax
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    ret

    .data
.Lstr: .string "Hello, World!"
```

hello.o

text (code) segment:

```
48 83 EC 08 BF 00 00 00 00 E8 00 00
00 00 31 C0 48 83 C4 08 C3
```

data segment:

```
48 65 6C 6C 6F 2C 20 57 6F 72 6C 00
```

relocations:

take 0s at	*and replace with*
text, byte 6 ( )	data segment, byte 0
text, byte 10 ( )	address of puts

symbol table:

main	text byte 0

what's in those files?

hello.c

```c
#include <stdio.h>
int main(void) {
  puts("Hello, World!");
  return 0;
}
```

hello.s

```
    .text
main:
    sub  $8, %rsp
    mov  $.Lstr, %rdi
    call puts
    xor  %eax, %eax
    add  $8, %rsp
    ret

    .data
.Lstr: .string "Hello, World!"
```

hello.o

text (code) segment:

```
48 83 EC 08 BF 00 00 00 00 E8 00 00
00 00 31 C0 48 83 C4 08 C3
```

data segment:

```
48 65 6C 6C 6F 2C 20 57 6F 72 6C 00
```

relocations:

take 0s at	*and replace with*
text, byte 6	data segment, byte 0
text, byte 10	address of puts

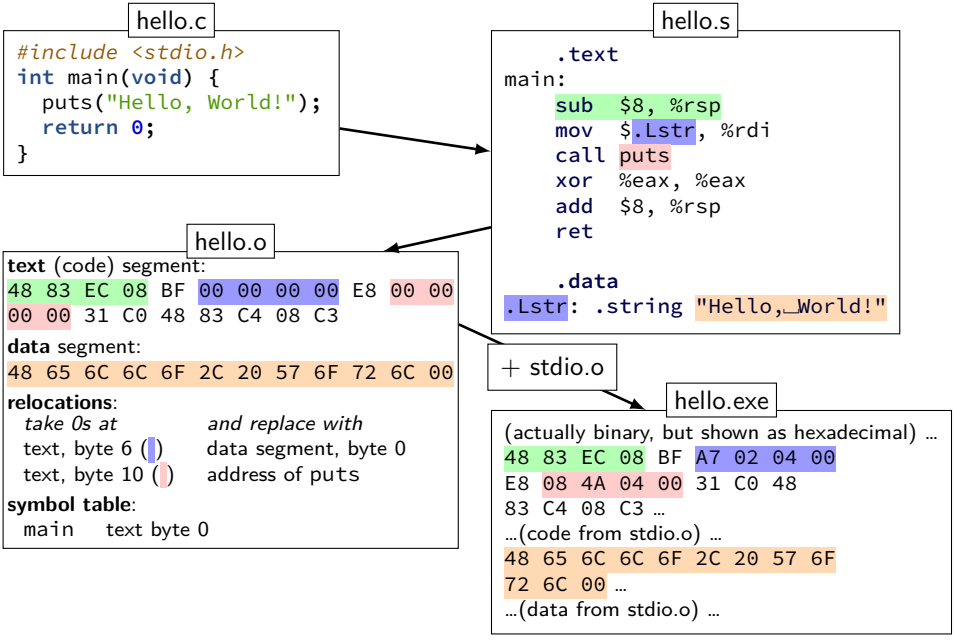
symbol table:

main	text byte 0

+ stdio.o

hello.exe

what's in those files?



exercise (1)

main.c:

```c
#include <stdio.h>
void sayHello(void) {
    puts("Hello, World!");
}
int main(void) {
    sayHello();
}
```

Which files contain the **memory address** of `sayHello`?

A. main.s (assembly)
B. main.o (object)
C. main.exe (executable)
D. B and C
E. A, B and C
F. something else

exercise (2)

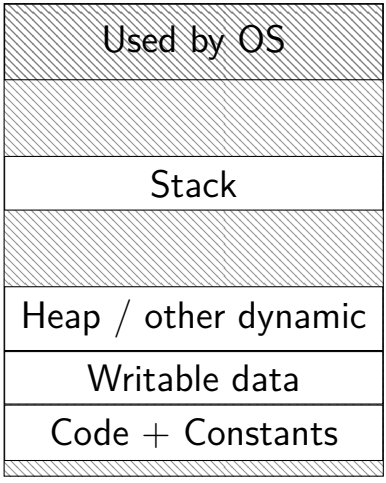
main.c:

```c
#include <stdio.h>
void sayHello(void) {
    puts("Hello, World!");
}
int main(void) {
    sayHello();
}
```

Which files contain the **literal ASCII string** of `Hello, World!`?

A. main.s (assembly)
B. main.o (object)
C. main.exe (executable)
D. B and C
E. A, B and C
F. something else

program memory (x86-64 Linux)



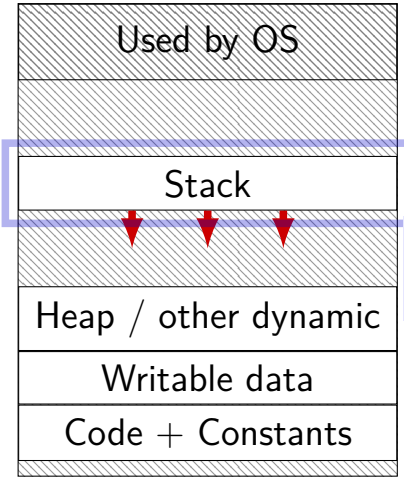
0xFFFF FFFF FFFF FFFF

0xFFFF 8000 0000 0000

0x7F…

0x0000 0000 0040 0000

program memory (x86-64 Linux)



0xFFFF FFFF FFFF FFFF

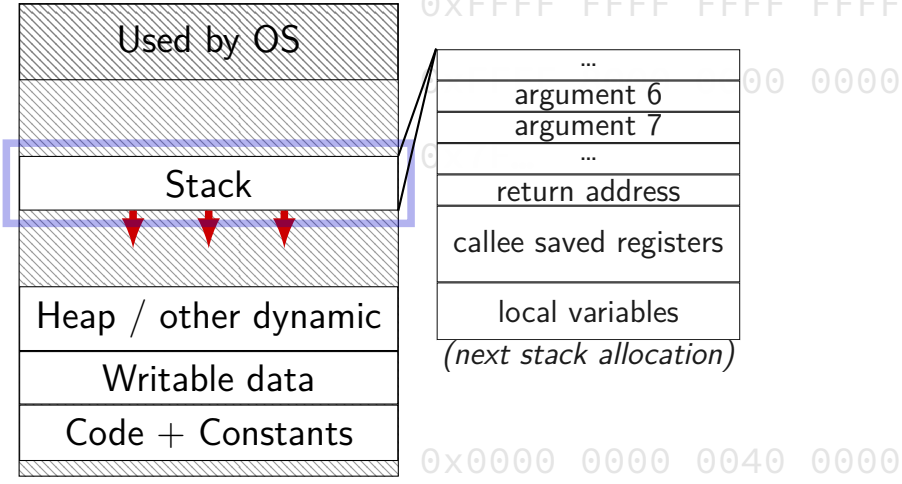
0xFFFF 8000 0000 0000

0x7F…

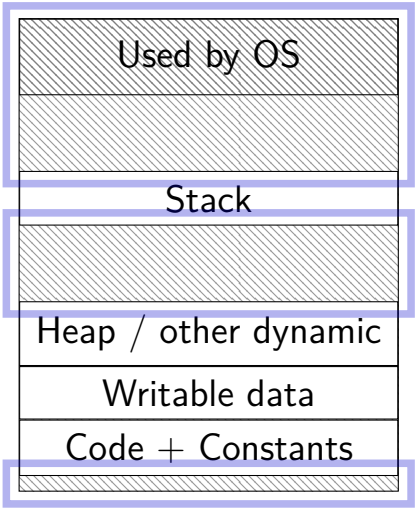
stack grows down
"top" has smallest address

0x0000 0000 0040 0000

program memory (x86-64 Linux)



program memory (x86-64 Linux)



0xFFFF FFFF FFFF FFFF

0xFFFF 8000 0000 0000

0x7F…

0x0000 0000 0040 0000

C Data Types

Varies between machines(!). For this course:

type	size (bytes)
`char`	1
`short`	2
`int`	4
`long`	8

C Data Types

Varies between machines(!). For this course:

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`float`	4
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C Data Types

Varies between machines(!). For this course:

type	size (bytes)
`char`	1
`short`	2
`int`	4
`long`	8
`float`	4
`double`	8
`void *`	8
`anything` `*`	8

truth

~~bool~~

truth

~~`bool`~~

x `==` `4` is an `int`

`1` if true; `0` if false

false values in C

`0`

including null pointers — `0` cast to a pointer

logical operators

return 1 for true or 0 for false

```
( 1 && 1 ) == 1
( 2 && 4 ) == 1
( 1 && 0 ) == 0
( 0 && 0 ) == 0
(-1 && -2) == 1
("" && "") == 1
! 1        == 0
! 4        == 0
!-1        == 0
! 0        == 1
```

```
( 1 || 1 ) == 1
( 2 || 4 ) == 1
( 1 || 0 ) == 1
( 0 || 0 ) == 0
(-1 || -2) == 1
("" || "") == 1
```

short-circuit (||)

```c
#include <stdio.h>
int zero() { printf("zero()\n"); return 0; }
int one() { printf("one()\n"); return 1; }
int main() {
    printf("> %d\n", zero() || one());
    printf("> %d\n", one() || zero());
    return 0;
}
```

```
zero()
one()
> 1
one()
> 1
```

OR	**false**	**true**
false	false	true
true	true	true

short-circuit (||)

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1 #include <stdio.h>
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3 int one() { printf("one()\n"); return 1; }
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6     printf("> %d\n", one() || zero());
7     return 0;
8 }
```

```
zero()
one()
> 1
one()
> 1
```

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one()
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one()
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one()
> 1
one()
> 1
```

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false	false	true
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short-circuit (&&)

```
1 #include <stdio.h>
2 int zero() { printf("zero()\n"); return 0; }
3 int one() { printf("one()\n"); return 1; }
4 int main() {
5     printf("> %d\n", zero() && one());
6     printf("> %d\n", one() && zero());
7     return 0;
8 }
```

```
zero()
> 0
one()
zero()
> 0
```

AND	**false**	**true**
false	false	false
true	false	true

short-circuit (&&)

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```
zero()
> 0
one()
zero()
> 0
```

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false	false	false
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```

```
zero()
> 0
one()
zero()
> 0
```

AND	**false**	**true**
false	false	false
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1 #include <stdio.h>
2 int zero() { printf("zero()\n"); return 0; }
3 int one() { printf("one()\n"); return 1; }
4 int main() {
5     printf("> %d\n", zero() && one());
6     printf("> %d\n", one() && zero());
7     return 0;
8 }
```

```
zero()
> 0
one()
zero()
> 0
```

AND	**false**	**true**
false	false	false
true	false	true

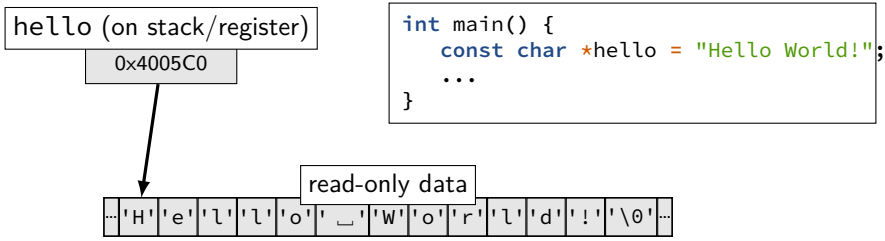
short-circuit (&&)

```
1 #include <stdio.h>
2 int zero() { printf("zero()\n"); return 0; }
3 int one() { printf("one()\n"); return 1; }
4 int main() {
5     printf("> %d\n", zero() && one());
6     printf("> %d\n", one() && zero());
7     return 0;
8 }
```

```
zero()
> 0
one()
zero()
> 0
```

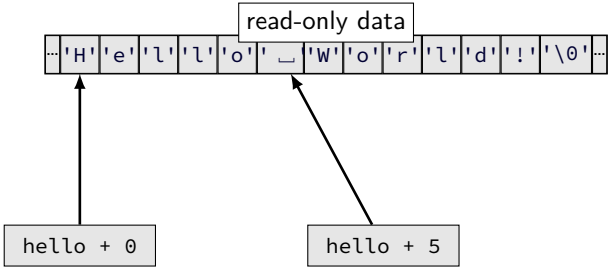
AND	**false**	**true**
false	false	false
true	false	true

strings in C

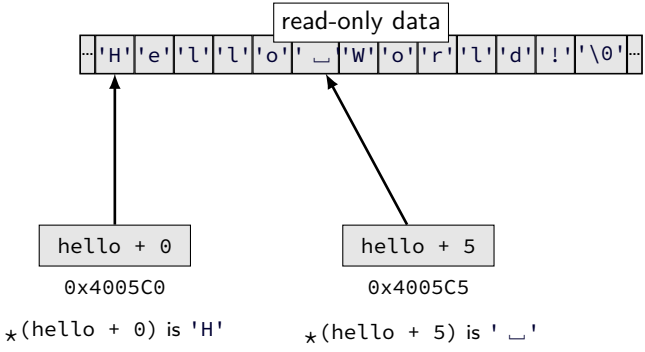



```c
int main() {
    const char *hello = "Hello World!";
    ...
}
```

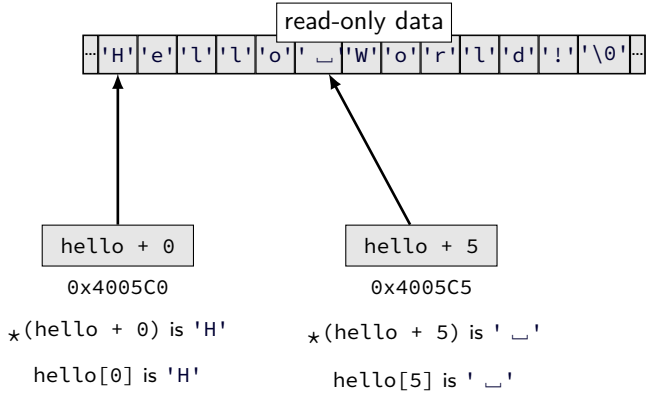
pointer arithmetic



pointer arithmetic



pointer arithmetic



arrays and pointers

`*(foo + bar)` exactly the same as `foo[bar]`

arrays ‘decay’ into pointers

exercise

```
1 char foo[4] = "foo";
2     // {'f', 'o', 'o', '\0'}
3 char *pointer;
4 pointer = foo;
5 *pointer = 'b';
6 pointer = pointer + 2;
7 pointer[0] = 'z';
8 *(foo + 1) = 'a';
```

Final value of `foo`?

A. `"fao"`

B. `"zao"`

C. `"baz"`

D. `"bao"`

E. something else/crash

exercise

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1 char foo[4] = "foo";
2     // {'f', 'o', 'o', '\0'}
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```

Final value of `foo`?

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exercise explanation

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1  char foo[4] = "foo";
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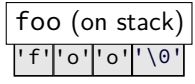

exercise explanation

```
1  char foo[4] = "foo";
2      // {'f', 'o', 'o', '\0'}
3  char *pointer;
4  pointer = foo;
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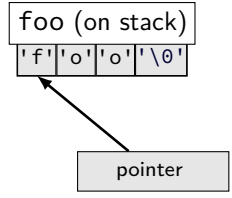
```



exercise explanation

```
1  char foo[4] = "foo";
2      // {'f', 'o', 'o', '\0'}
3  char *pointer;
4  pointer = foo;
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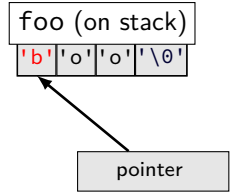
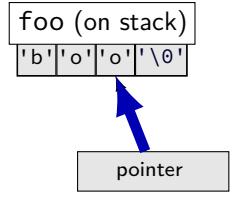
```



exercise explanation

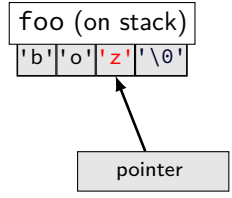
```
1  char foo[4] = "foo";
2      // {'f', 'o', 'o', '\0'}
3  char *pointer;
4  pointer = foo;
5  *pointer = 'b';
6  pointer = pointer + 2;
7  pointer[0] = 'z';
8  *(foo + 1) = 'a';
```



exercise explanation

```
1  char foo[4] = "foo";
2      // {'f', 'o', 'o', '\0'}
3  char *pointer;
4  pointer = foo;
5  *pointer = 'b';
6  pointer = pointer + 2;
7  pointer[0] = 'z';
8  *(foo + 1) = 'a';
```

better style: `*pointer = 'z';`

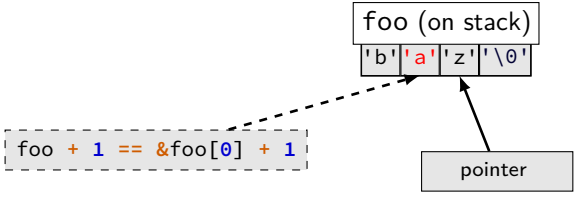


exercise explanation

```
1  char foo[4] = "foo";
2      // {'f', 'o', 'o', '\0'}
3  char *pointer;
4  pointer = foo;
5  *pointer = 'b';
6  pointer = pointer + 2;
7  pointer[0] = 'z';
8  *(foo + 1) = 'a';
```

better style: `*pointer = 'z';`

better style: `foo[1] = 'a';`



example: C that is not C++

valid C and invalid C++:

```
char *str = malloc(100);
```

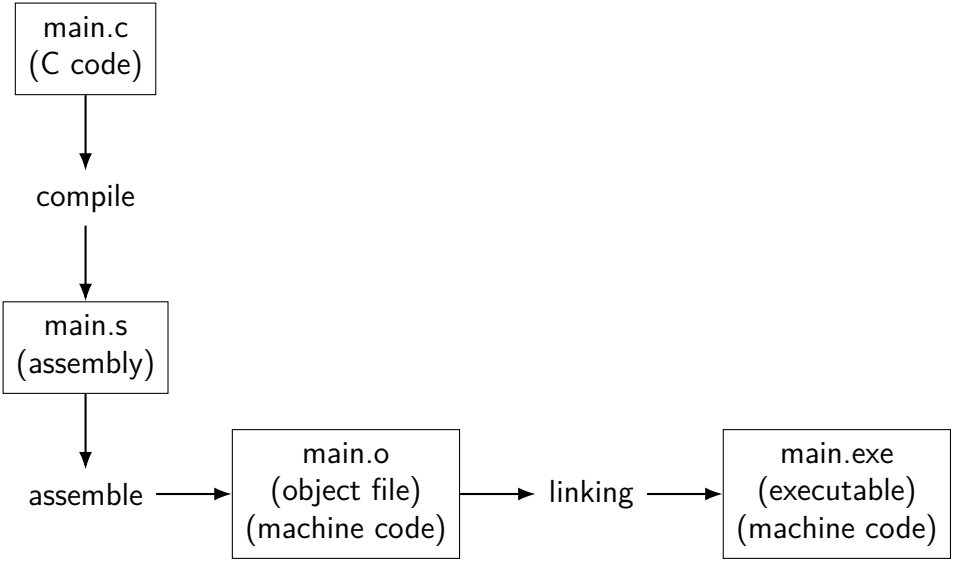
valid C and valid C++:

```
char *str = (char *) malloc(100);
```

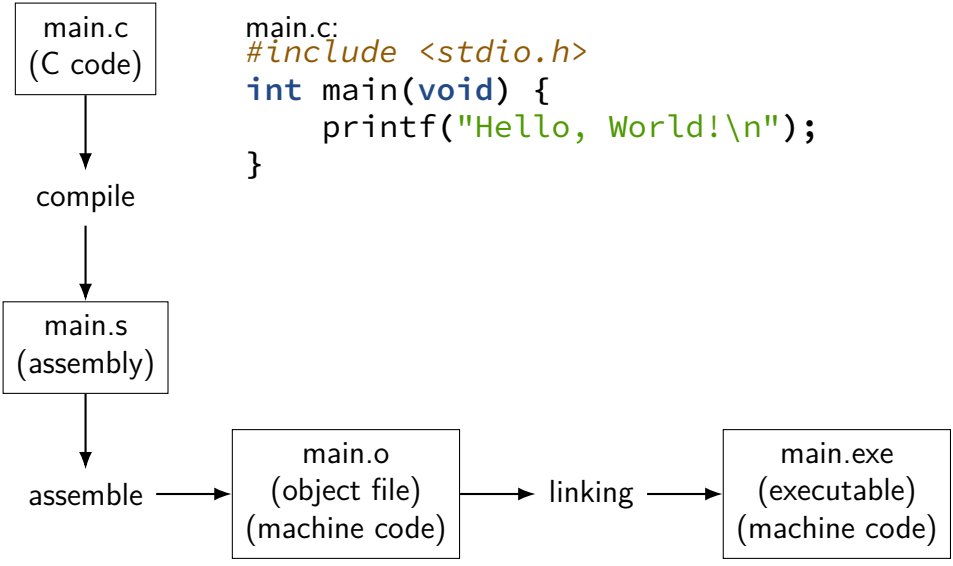
valid C and invalid C++:

```
int class = 1;
```

compilation pipeline



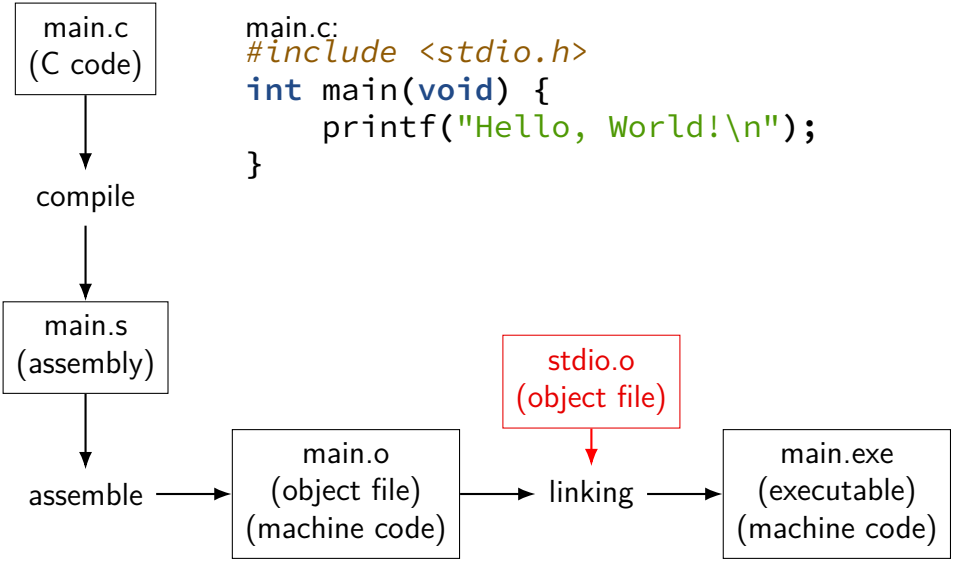
compilation pipeline



main.c:

```c
#include <stdio.h>
int main(void) {
    printf("Hello, World!\n");
}
```

compilation pipeline



main.c:

```c
#include <stdio.h>
int main(void) {
    printf("Hello, World!\n");
}
```