# CS3330 — overview

# Changelog

Corrections made in this version not in first posting:

22 August 2017: slide 35: 2 time units becomes 2.5 time units

22 August 2017: slide 48: “pre/post lecture” becomes “pre/post week of lecture”

# layers of abstraction

| | |
|---|---|
| `x += y` | "Higher-level" language: C |
| `add %rbx, %rax` | Assembly: X86-64 |
| 60 $03_{\text{SIXTEEN}}$ | Machine code: Y86 |
| | ??? |
| | Gates / Transistors / Wires / Registers |

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# why C?

*almost* a subset of C++

- notably removes classes, new/delete, iostreams
- other changes, too, so C code often not valid C++ code

direct correspondence to assembly

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direct correspondence to assembly

> Should help you understand machine!
> Manual translation to assembly

# why C?

*almost* a subset of C++

- notably removes classes, new/delete, iostreams
- other changes, too, so C code often not valid C++ code

direct correspondence to assembly

> But "clever" (optimizing) compiler might be confusingly indirect instead

# homework: C environment

get a C compiler

options:

- lab accounts + SSH
- Linux (native or VM)
- online IDE (e.g. Cloud9, Koding)

# assignment compatibility

supported platform: lab machines

many use laptops

trouble? we'll say to use lab machines

most assignments: C and Unix-like environment

also: tool written in Rust — but we'll provide binaries

- previously written in D + needed D compiler

# layers of abstraction

`x += y` — "Higher-level" language: C

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Gates / Transistors / Wires / Registers

# X86-64 assembly

in theory, you know this (CS 2150)

in reality, ...

# 32 versus 64-bit note

some of you may have learned 32-bit in 2150

(the course has changed)

differences mostly: more, bigger registers

# layers of abstraction

`x += y` — "Higher-level" language: C

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# Y86-64??

Y86: our textbook's X86-64 subset

much simpler than real X86-64 encoding

- (which we will not cover)

not as simple as 2150's IBCM

- variable-length encoding
- mostly full register set
- full conditional jumps
- stack-manipulation instructions

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# hardware

most of the semester

# goals/other topics

understand how hardware works for...

program performance

what compilers are/do

weird program behaviors (segfaults, etc.)

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understand how hardware works for...

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what compilers are/do

weird program behaviors (segfaults, etc.)

# program performance

naive model:

one instruction = one time unit

number of instructions matters, but …

# program performance: issues

parallelism

fast hardware is parallel
needs multiple things to do

caching

accessing things recently accessed is faster
need reuse of data/code

(more in other classes: algorithmic efficiency)

# goals/other topics

understand how hardware works for...

program performance

what compilers are/do

weird program behaviors (segfaults, etc.)

# what compilers are/do

understanding weird compiler/linker rrors

if you want to make compilers

debugging applications

# goals/other topics

understand how hardware works for...

program performance

what compilers are/do

weird program behaviors (segfaults, etc.)

# weird program behaviors

what is a segmentation fault really?

how does the operating system interact with programs?

if you want to handle them — writing OSs

# interlude: powers of two

| | | |
|---|---|---|
| | ... | |
| $2^0$ | 1 | |
| $2^1$ | 2 | |
| $2^2$ | 4 | |
| $2^3$ | 8 | |
| $2^4$ | 16 | |
| $2^5$ | 32 | |
| $2^6$ | 64 | |
| $2^7$ | 128 | |
| $2^8$ | 256 | |
| $2^9$ | 512 | |
| $\mathbf{2^{10}}$ | **1 024** | **K** (or Ki) |

| | | |
|---|---|---|
| | ... | |
| $2^{11}$ | 2 048 | |
| $2^{12}$ | 4 096 | |
| $2^{13}$ | 8 192 | |
| $2^{14}$ | 16 384 | |
| $2^{15}$ | 32 768 | |
| $2^{16}$ | 65 536 | |
| | ... | |
| $\mathbf{2^{20}}$ | 1 048 576 | **M** (or Mi) |
| | ... | |
| $\mathbf{2^{30}}$ | 1 073 741 824 | **G** (or Gi) |
| $2^{31}$ | 2 147 483 648 | |
| $2^{32}$ | 4 294 967 296 | |
| | ... | |

# powers of two: forward

$2^{35}$

$2^{21}$

$2^{9}$

$2^{14}$

# powers of two: forward

$2^{35} = 2^5 \cdot 2^{30} = 32G$ (30 = G)

$2^{21}$

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# powers of two: forward

$2^{35} = 2^5 \cdot 2^{30} = 32G$ (30 = G)

$2^{21} = 2^1 \cdot 2^{20} = 2M$ (20 = M)

$2^9$

$2^{14}$

# powers of two: forward

$2^{35} = 2^5 \cdot 2^{30} = 32G$ (30 = G)

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$2^{14}$

# powers of two: forward

$2^{35} = 2^5 \cdot 2^{30} = 32G$ (30 = G)

$2^{21} = 2^1 \cdot 2^{20} = 2M$ (20 = M)

$2^9 = 512$

$2^{14} = 2^4 \cdot 2^{10} = 16K$

# powers of two: backward

16G

128K

4M

256T

# powers of two: backward

16G $= 16 \cdot 2^{30} = 2^{30+4} = 2^{34}$

128K

4M

256T

# powers of two: backward

16G $= 16 \cdot 2^{30} = 2^{30+4} = 2^{34}$

128K $= 128 \cdot 2^{10} = 2^{10+7} = 2^{17}$

4M

256T

# powers of two: backward

$$16\text{G} = 16 \cdot 2^{30} = 2^{30+4} = 2^{34}$$

$$128\text{K} = 128 \cdot 2^{10} = 2^{10+7} = 2^{17}$$

$$4\text{M} = 4 \cdot 2^{20} = 2^{20+2} = 2^{22}$$

$$256\text{T} = 256 \cdot 2^{40} = 2^{40+8} = 2^{48}$$

# rest of today/tomorrow

brief preview of circuits, CPUs

assembly and linking

selected things about C

# layers of abstraction

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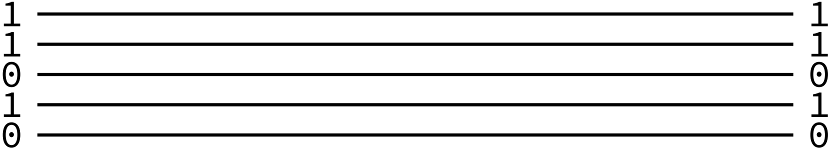
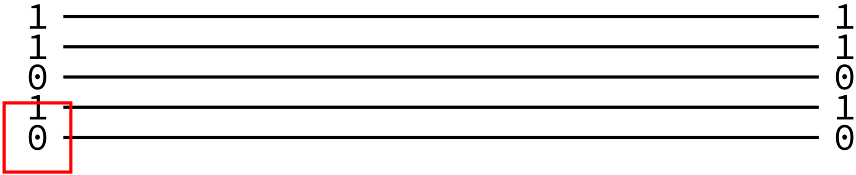
# circuits: wires

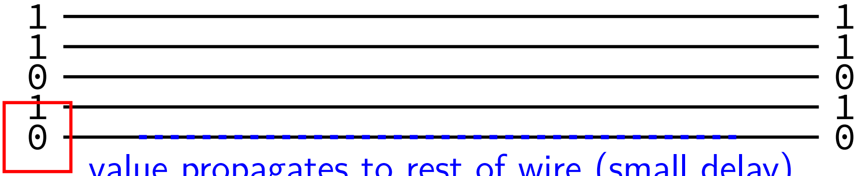


# circuits: wires




binary value — actually voltage

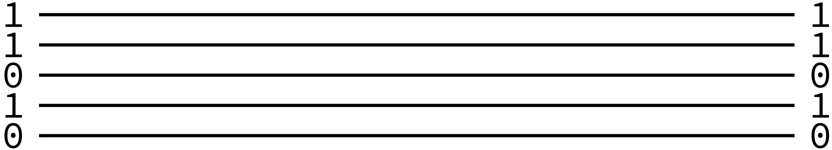
# circuits: wires




value propagates to rest of wire (small delay)

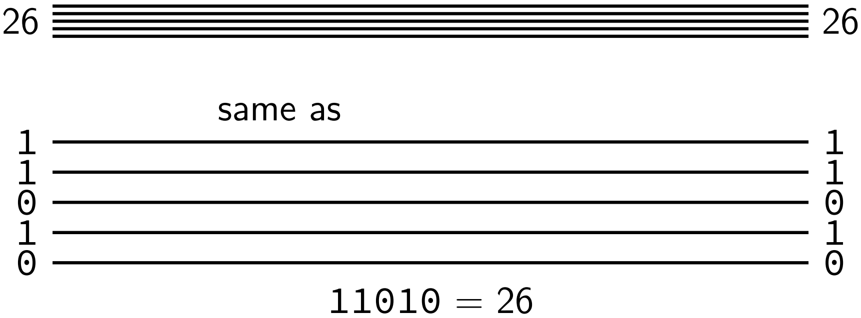
binary value — actually voltage

# circuits: wire bundles




`11010` $= 26$

# circuits: wire bundles



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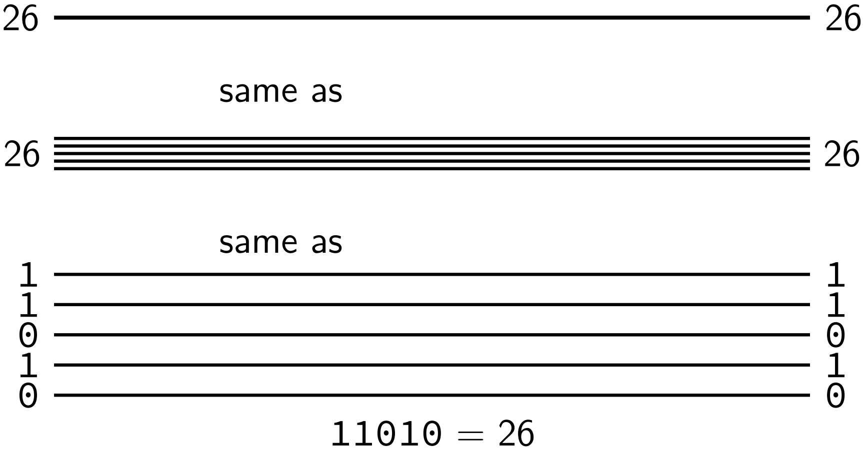
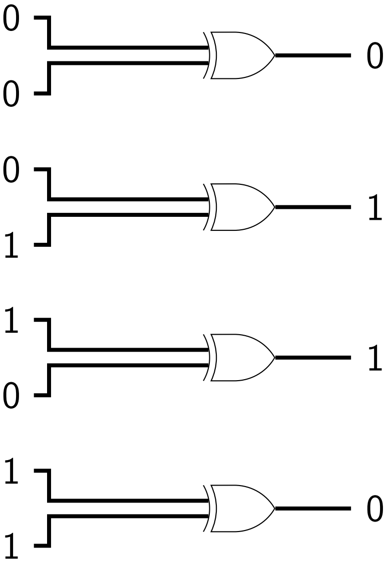


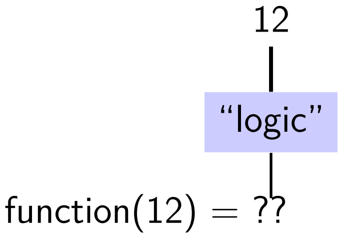
# circuits: gates



# circuits: logic

want to do calculations?

generalize gates:



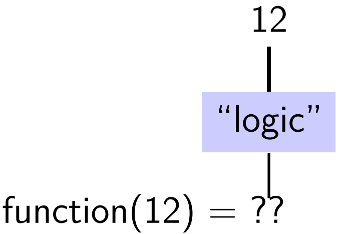
# circuits: logic

want to do calculations?

generalize gates:

output wires contain result of function on input

changes as input changes (with delay)



# circuits: logic

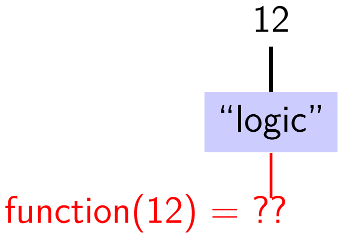
want to do calculations?

generalize gates:

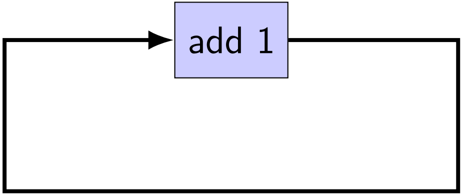
output wires contain result of function on input

changes as input changes (with delay)

need not be same width as output



# example: (broken) counter circuit



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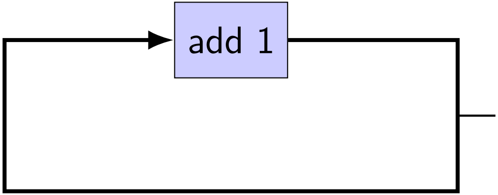
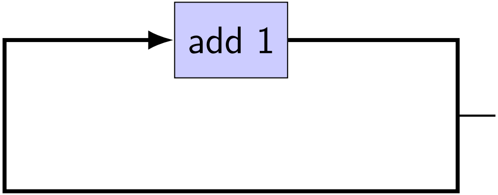



time 0: `000`

# example: (broken) counter circuit




time 0: `000`
time 1: `001?`
time 2: `010?`
time 3: `011?`

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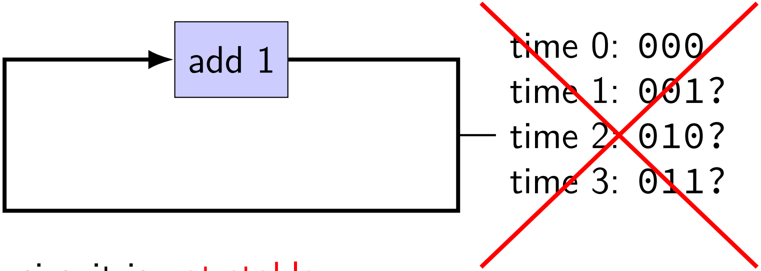


circuit is not stable

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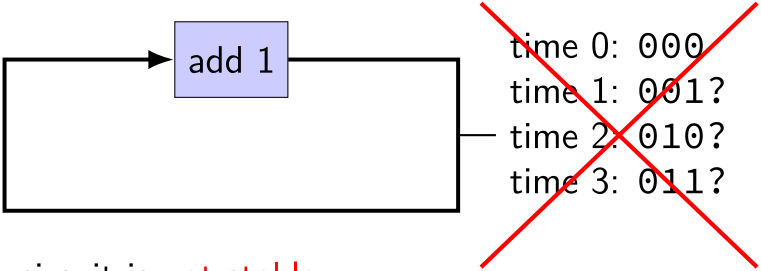


circuit is not stable

transient values during changes

can't transition from 001 to 010

without 011 or 000

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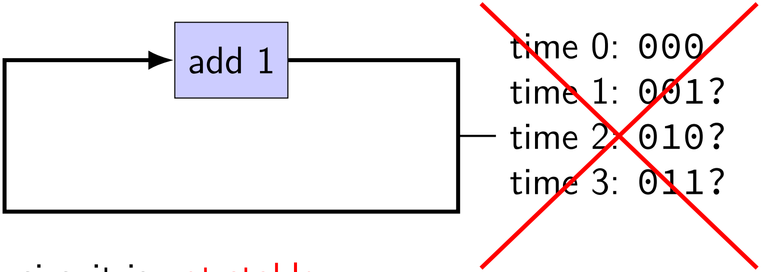



circuit is not stable

transient values during changes

can't transition from 001 to 010

without 011 or 000

halfway voltages — hard to predict behavior

# circuits: state

logic performs calculations all the time

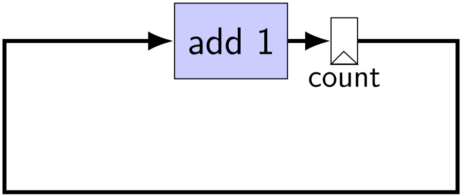
never stores values!

need extra elements to store values

registers, memory

more on these later in the course

# example: counter circuit (corrected)



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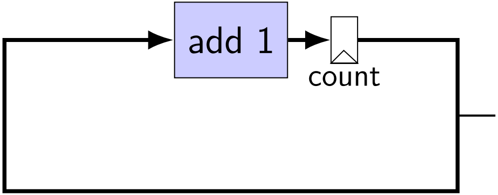


time 0: `000`

time 1: `001`

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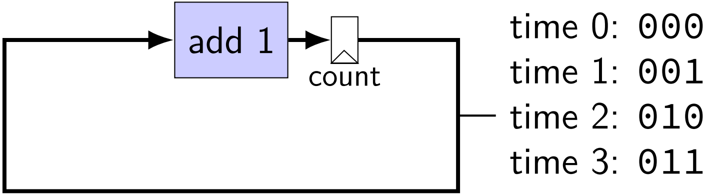
# example: counter circuit (corrected)




add register to store current count

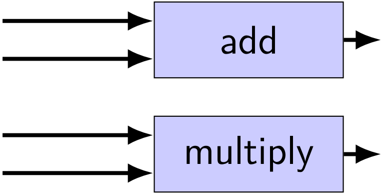
updates based on "clock signal" (not shown)

avoids intermediate updates

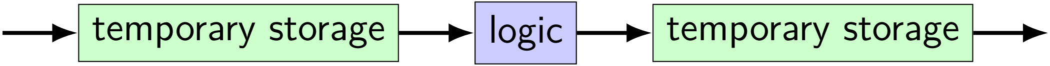
much more on this later in the semester

# parallel hardware

hardware is inherently parallel




most hardware design: making it sequential

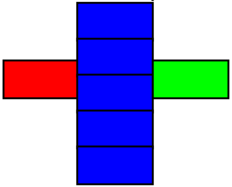


# parallelism and bottlenecks

Serial:

**7** time units

Parallel (blue 5x faster):



**3** time units

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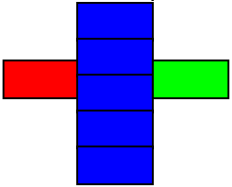
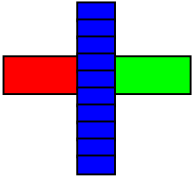


**3** time units

Parallel (blue 10x faster):



**2.5** time units

# Amdahl's Law

formula in textbook

benefits of speedup limited by non-sped-up parts

parallelism:

anything not parallelized will be significant

or in math:

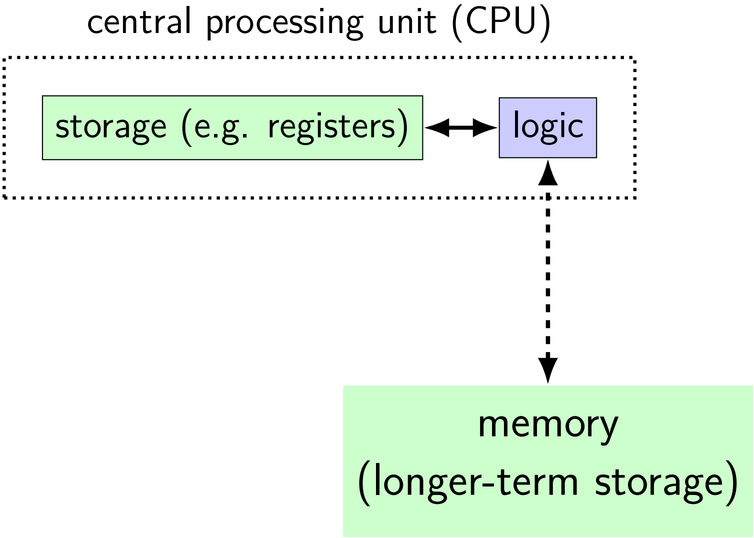
$$\text{time} = \text{serial part} + \text{parallel part} \div \text{parallelism}$$

# not just parallelism

$$\text{time} = \text{serial part} + \text{parallel part} \div \text{parallelism}$$

$$\text{time} = \text{unoptimized part} + \text{optimized part} \div \text{speedup}$$

# constructing a computer



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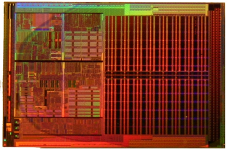
# processors and memory



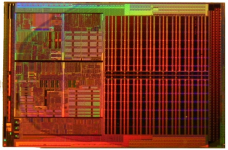
processor

memory

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

# processors and memory

memory bus
send address + send or get data



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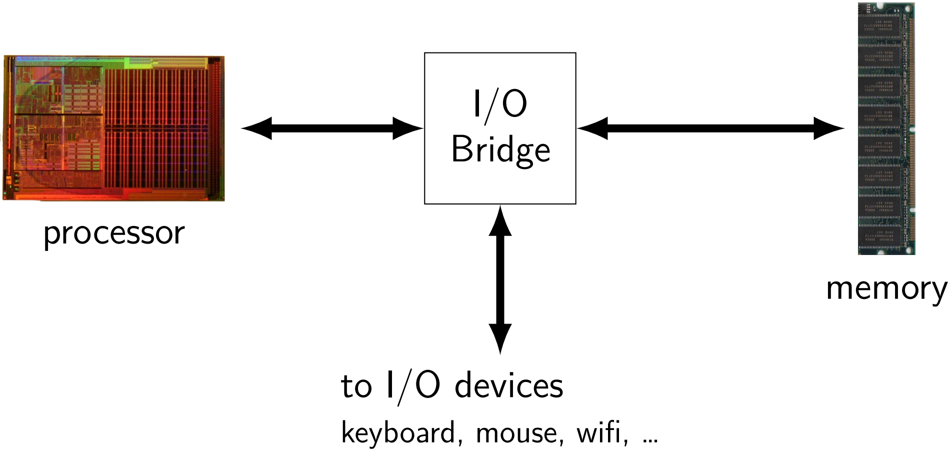


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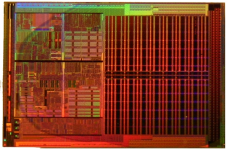
# processors and memory

system bus
send address + send or get data
(machine code/text/number...)



processor

Bridge

memory

to I/O devices

keyboard, mouse, wifi, ...

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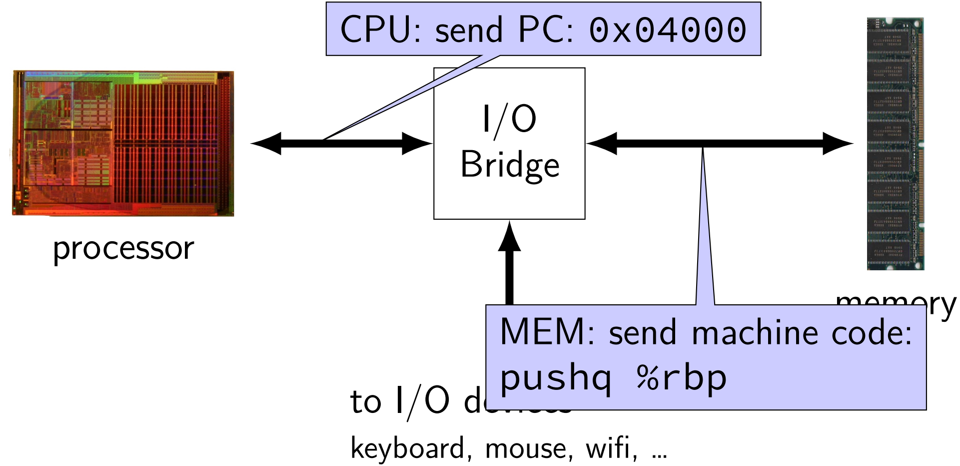
# processors and memory

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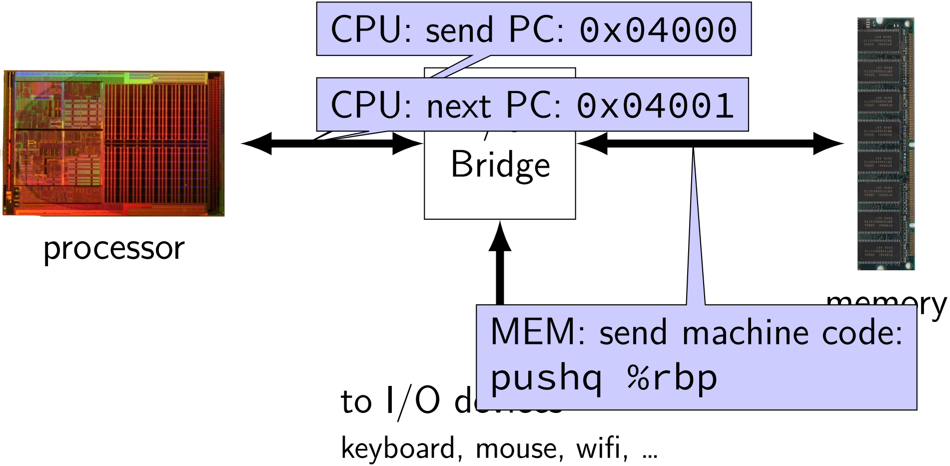


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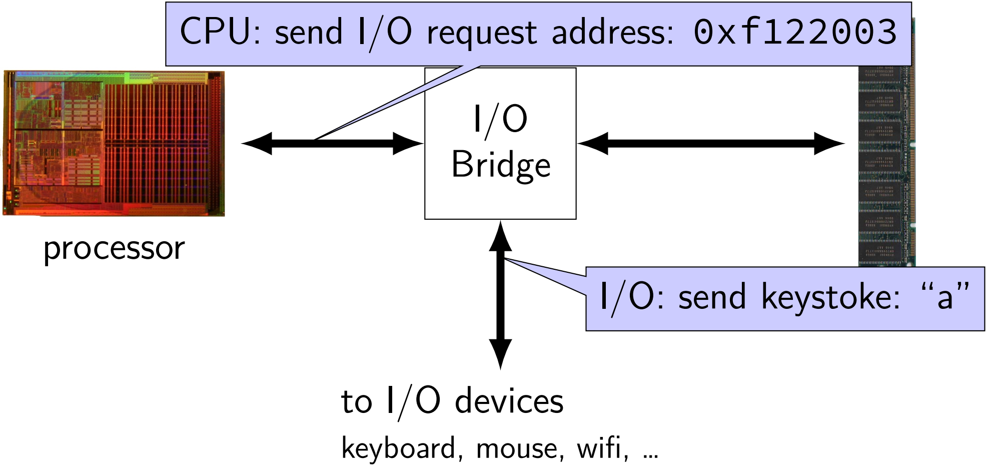


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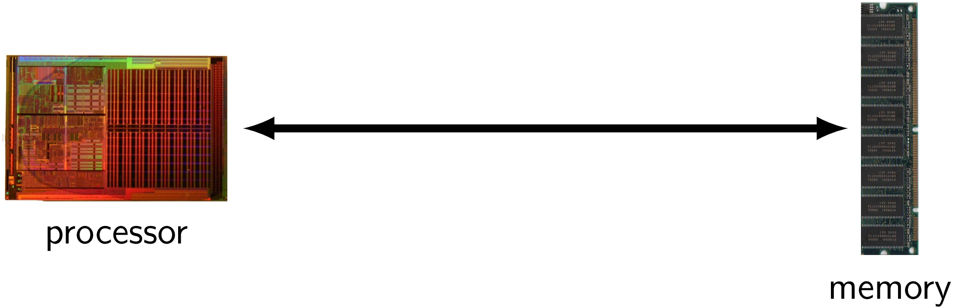


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# memory

| 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 |
| … | … |
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| 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 |
| 0x00000001 | 0xE0 |

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

# endianness

| address | value |
|---|---|
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| 0xFFFFFFFE | 0x45 |
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| … | … |
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| 0x00042005 | 0x05 |
| 0x00042004 | 0x04 |
| 0x00042003 | 0x03 |
| 0x00042002 | 0x02 |
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| … | … |
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```
int *x = (int*)0x42000;
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```

0x03020100 = 50462976

0x00010203 = 66051

# endianness

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|---|---|
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| 0xFFFFFFFE | 0x45 |
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| … | … |
| 0x00042006 | 0x06 |
| 0x00042005 | 0x05 |
| 0x00042004 | 0x04 |
| 0x00042003 | 0x03 |
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| 0x00041FFF | 0x03 |
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| … | … |
| 0x00000002 | 0xFE |
| 0x00000001 | 0xE0 |

```
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

| address | value |
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| 0xFFFFFFFF | 0x14 |
| 0xFFFFFFFE | 0x45 |
| 0xFFFFFFFD | 0xDE |
| … | … |
| 0x00042006 | 0x06 |
| 0x00042005 | 0x05 |
| 0x00042004 | 0x04 |
| 0x00042003 | 0x03 |
| 0x00042002 | 0x02 |
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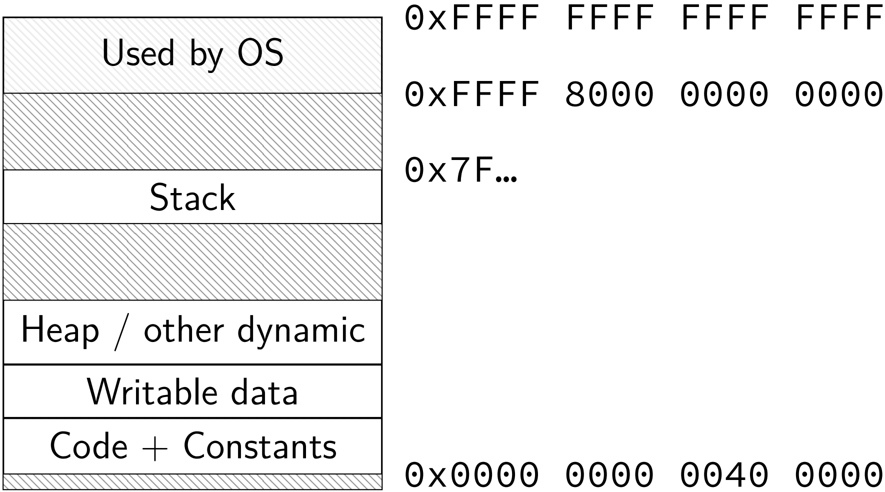
# program memory (x86-64 Linux)



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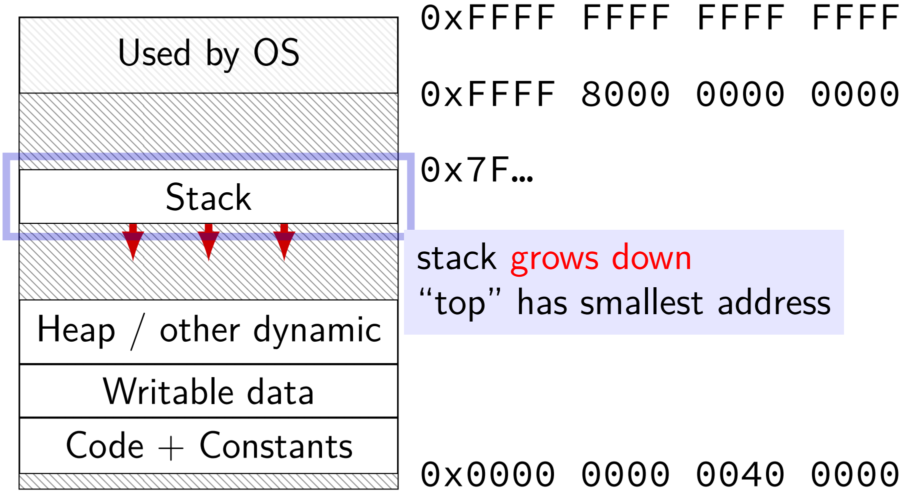
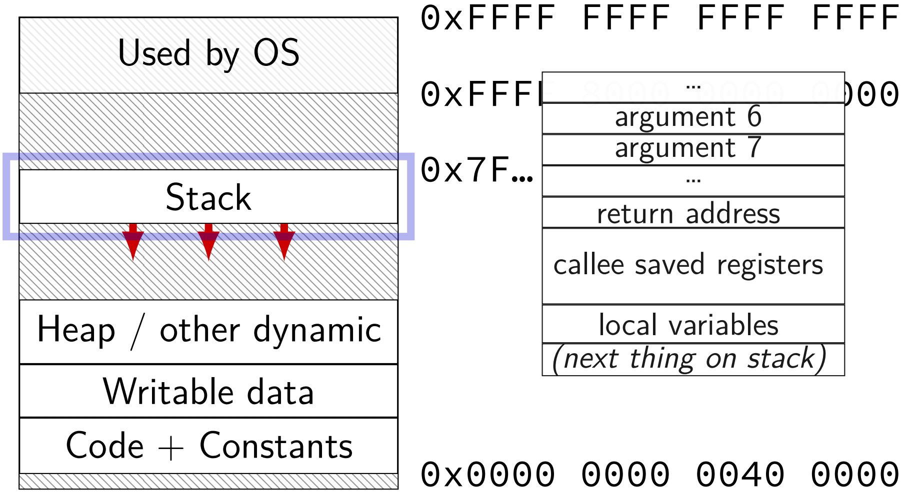
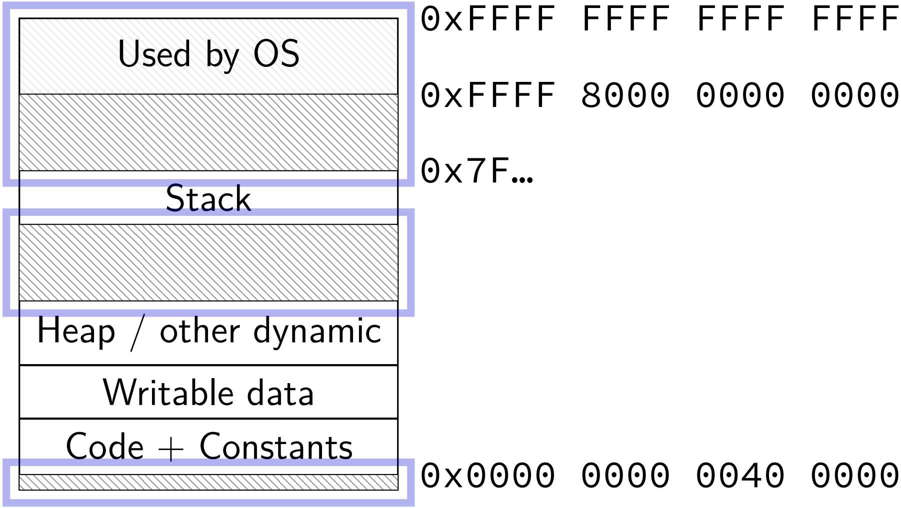



stack grows down
"top" has smallest address

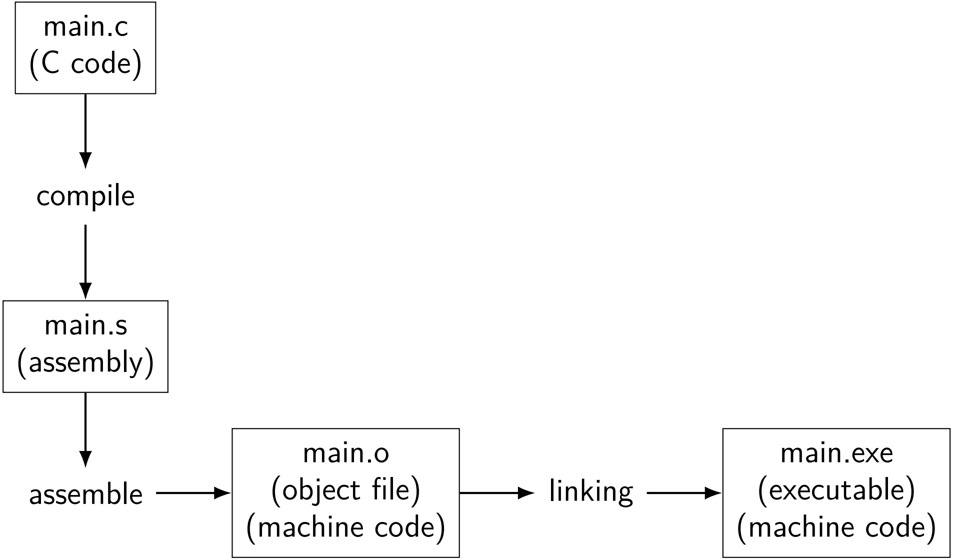
# program memory (x86-64 Linux)



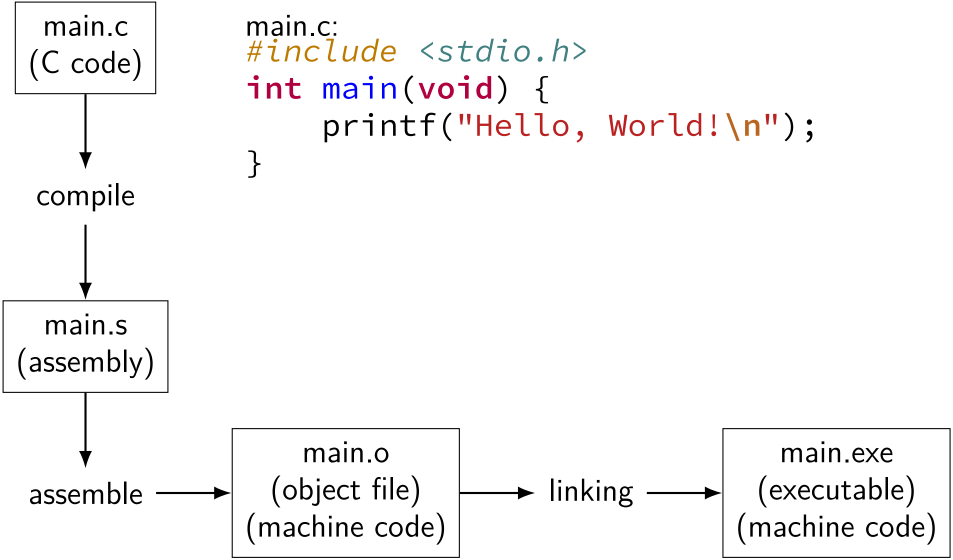
# program memory (x86-64 Linux)



# preview: compilation pipeline



# preview: compilation pipeline




main.c:

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

# preview: compilation pipeline

main.c:

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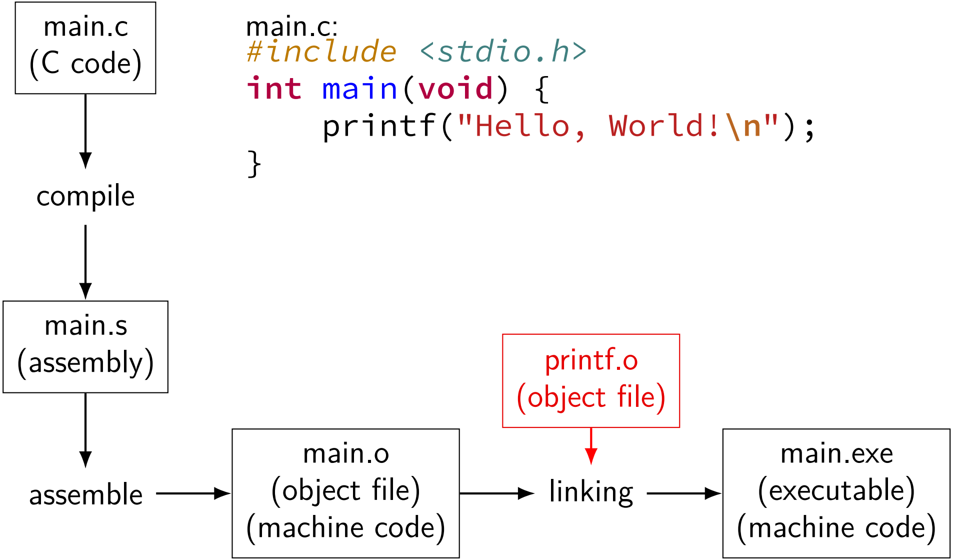

# *approximate* outline

Weeks 1–2: C, assembly

Weeks 3–5: Y86 instructions, bit fiddling, basic CPU design

**Exam 1**

Weeks 7–9: pipelined CPUs

Weeks 10: caching

**Exam 2**

Weeks 11–12: performance programming

Weeks 13–15: exceptions and virtual memory

**Final Exam**

# coursework

quizzes — pre/post week of lecture

  you will need to read

labs — grading: did you make reasonable progress?

  collaboration permitted

homework assignments — introduced by lab (mostly)

  due at noon on the next lab day (mostly)
  complete individually

exams — multiple choice/short answer — 2 + final

# on lecture/lab/HW synchronization

labs/HWs not quite synchronized with lectures

main problem: want to cover material **before you need it** in lab/HW

# quizzes?

linked off course website (demo)

pre-quiz, on reading – released by Saturday evening, due Tuesdays, 12:15 PM

post-quiz, on lecture topics — released Thursday evening, due following Saturday, 11:59PM

each quiz 90 minute time limit (+ adjustments if SDAC says)

lowest 10% (approx. 2 quizzes) will be dropped

first quiz — Thursday

- short — mainly to get you used to it

# attendance?

lecture: strongly recommended but not required.

lectures are recorded to help you review

lab: electronic, remote-possible submission, usually. one exception.

# late policy

exceptional circumstance? contact us.

otherwise, for homeworks only:

- -10% 0 to 48 hours late
- -15% 48 to 72 hours late
- -100% otherwise

late quizzes, labs: no

- we release answers
- talk to us if illness, etc.

# TAs/Office Hours

office hours will be posted on calendar on the website

should be plenty

use them

# your TODO list

Quizzes!

- post-quiz after Thursday lecture
- pre-quiz before Tuesday lecture

lab account and/or C environment working

- lab accounts should happen by this weekend

before lab next week

# grading

Quizzes: 10% (10% dropped)

Midterms (2): 30%

Final Exam (cumulative): 20%

Homework + Labs: 40%