Lecture 1: Introduction to Computer Systems

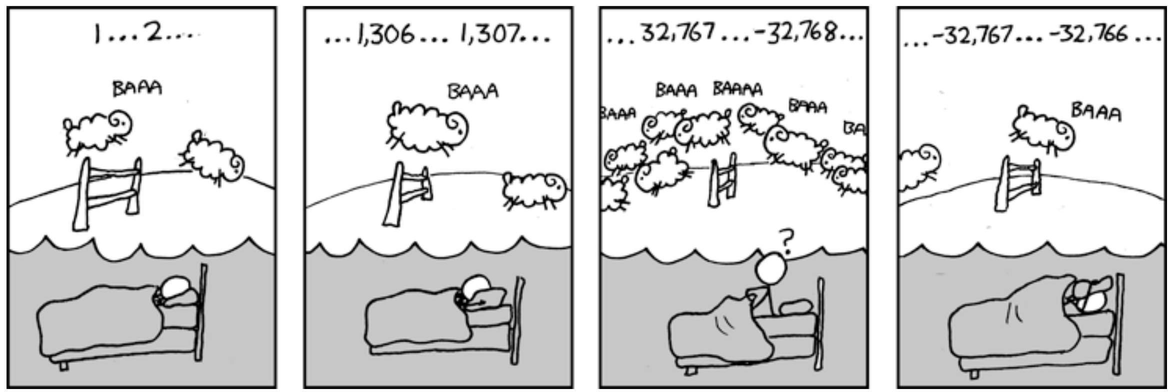
CS 105

January 23, 2019

Abstraction

Correctness

- **Example 1: Is $x^2 \geq 0$?**
  - Float's: Yes!



  - Int's:
    - 40000 * 40000 → 1600000000
    - 50000 * 50000 → ??
- **Example 2: Is (x + y) + z = x + (y + z)?**
  - Unsigned & Signed Int's: Yes!
  - Float's:
    - (1e20 + -1e20) + 3.14 --> 3.14
    - 1e20 + (-1e20 + 3.14) --> ??

Source: xkcd.com/571

Computer Arithmetic

- **Does not generate random values**
  - Arithmetic operations have important mathematical properties
- **Cannot assume all “usual” mathematical properties**
  - Due to finiteness of representations
  - Integer operations satisfy “ring” properties
    - Commutativity, associativity, distributivity
  - Floating point operations satisfy “ordering” properties
    - Monotonicity, values of signs
- **Observation**
  - Need to understand which abstractions apply in which contexts
  - Important issues for compiler writers and serious application programmers

Performance

```
void copyij(int src[2048][2048],
            int dst[2048][2048])
{
  int i,j;
  for (i = 0; i < 2048; i++)
    for (j = 0; j < 2048; j++)
      dst[i][j] = src[i][j];
}
```

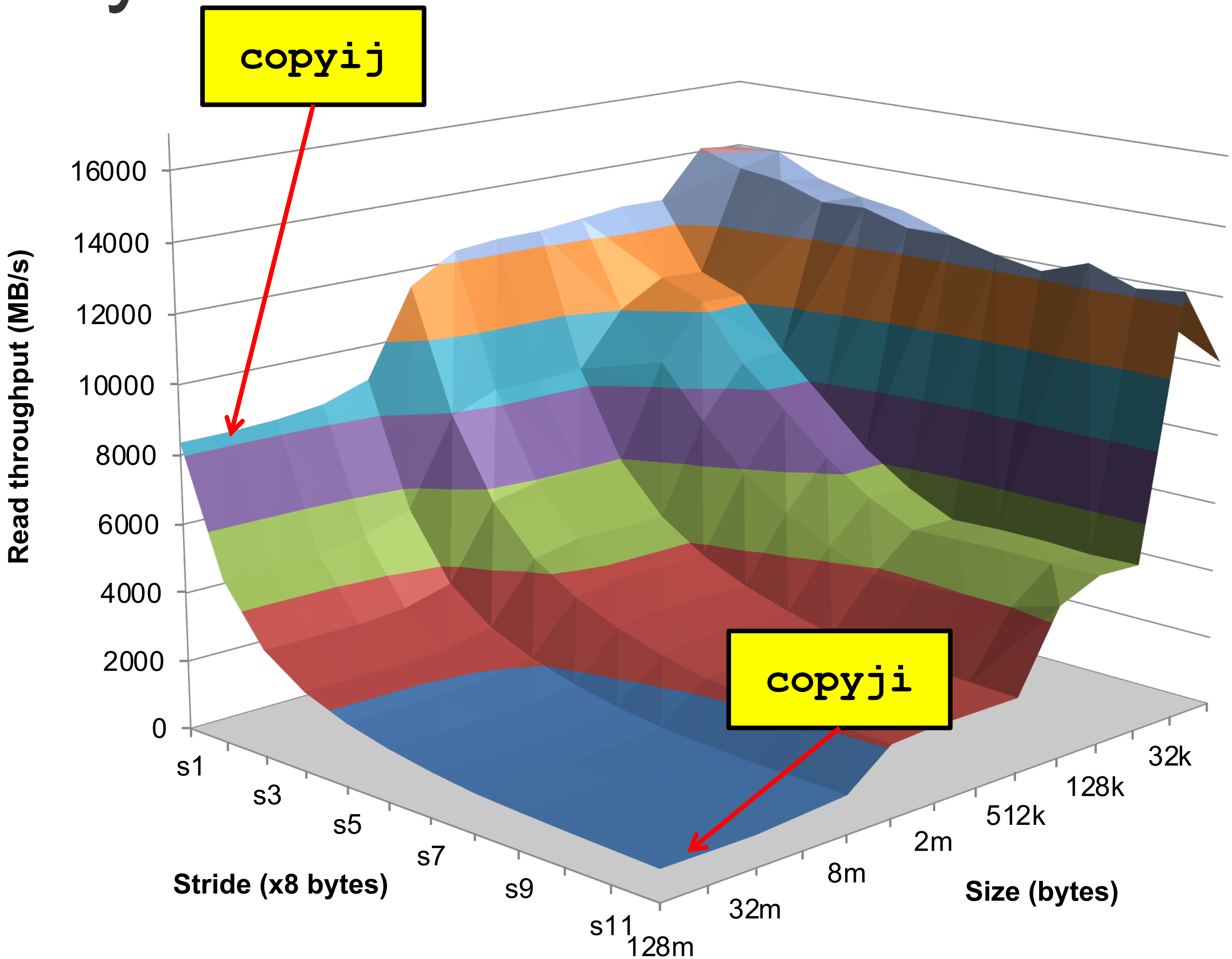
```
void copyji(int src[2048][2048],
            int dst[2048][2048])
{
  int i,j;
  for (j = 0; j < 2048; j++)
    for (i = 0; i < 2048; i++)
      dst[i][j] = src[i][j];
}
```

4.3ms 81.8ms

2.0 GHz Intel Core i7 Haswell

- Hierarchical memory organization
- Performance depends on access patterns
  - Including how step through multi-dimensional array

Why The Performance Differs



Real-World Performance

- **Constant factors matter too!**
- **And even exact op count does not predict performance**
  - Easily see 10:1 performance range depending on how code written
  - Must optimize at multiple levels: algorithm, data representations, procedures, and loops
- **Must understand system to optimize performance**
  - How programs compiled and executed
  - How to measure program performance and identify bottlenecks
  - How to improve performance without destroying code modularity and generality

Security

```
void admin_stuff(int authenticated){
  if(authenticated){
    // do admin stuff
  }
}

int dontTryThisAtHome(char * user_input, int size) {
  char data[size];
  int ret = memcpy(*user_input, data);
  return ret;
}
```

Bits

- a **bit** is a binary digit that can have two possible values

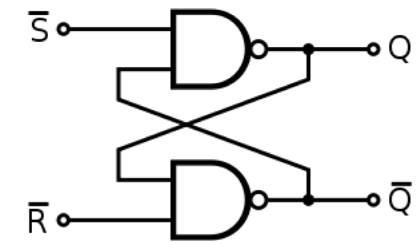
- can be physically represented with a two state device

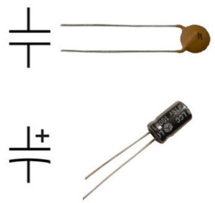
Bits


A'LA'IH, DO'NEH'LINI, DO'NEH'LINI, A'LA'IH, A'LA'IH, DO'NEH'LINI, DO'NEH'LINI, DO'NEH'LINI, A'LA'IH, A'LA'IH, DO'NEH'LINI, A'LA'IH, DO'NEH'LINI, DO'NEH'LINI, DO'NEH'LINI . . .
FOR ADDED SECURITY, AFTER WE ENCRYPT THE DATA STREAM, WE SEND IT THROUGH OUR NAVAJO CODE TALKER.
...IS HE JUST USING NAVAJO WORDS FOR "ZERO" AND "ONE"?
WHOA, HEY, KEEP YOUR VOICE DOWN!

Storing bits

- Static random access memory (SRAM): stores each bit of data in a flip-flop, a circuit with two stable states
- Dynamic Memory (DRAM): stores each bit of data in a capacitor, which stores energy in an electric field (or not)
- Magnetic Disk: regions of the platter are magnetized with either N-S polarity or S-N polarity
- Optical Disk: stores bits as tiny indentations (pits) or not (lands) that reflect light differently
- Flash Disk: electrons are stored in one of two gates separated by oxide layers





Bytes and Memory

- A **byte** is a unit of eight bits
- **Memory** is an array of bytes
- An index into the array is an *address*, *location*, or *pointer*
  - Often expressed in hexadecimal
- We speak of the *value* in memory at an address
  - The value may be a single byte …
  - … or a multi-byte quantity starting at that address

Binary Numbers

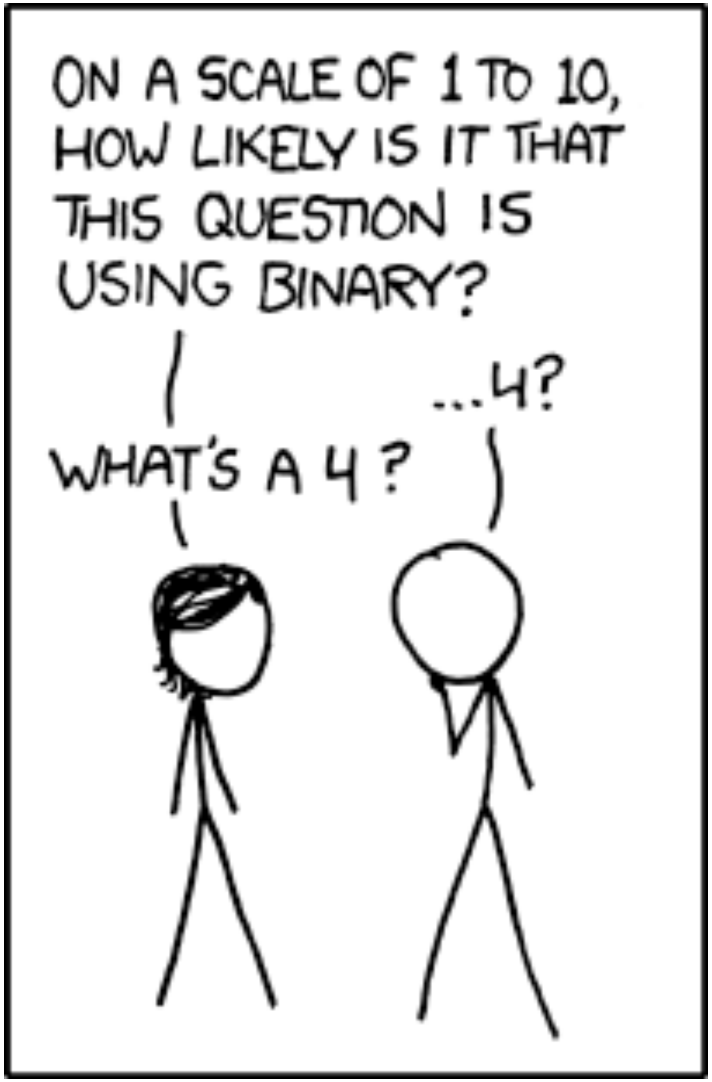
4211

$$= 4 \cdot 10^3 + 2 \cdot 10^2 + 1 \cdot 10^1 + 1 \cdot 10^0$$
$$= 4211$$

1011

$$= 1 \cdot 2^3 + 0 \cdot 2^2 + 1 \cdot 2^1 + 1 \cdot 2^0$$
$$= 11$$

Binary Numbers



Hexidecimal Numbers

- Use digits 0,1,2,3,4,5,6,7,8,9,A,B,C,D,E,F
- Compute numbers base 16

1011

$$= 1 \cdot 2^3 + 0 \cdot 2^2 + 1 \cdot 2^1 + 1 \cdot 2^0$$
$$= 11$$

$$= 1 \cdot 10^3 + 0 \cdot 10^2 + 1 \cdot 10^1 + 1 \cdot 10^0$$
$$= 1011$$

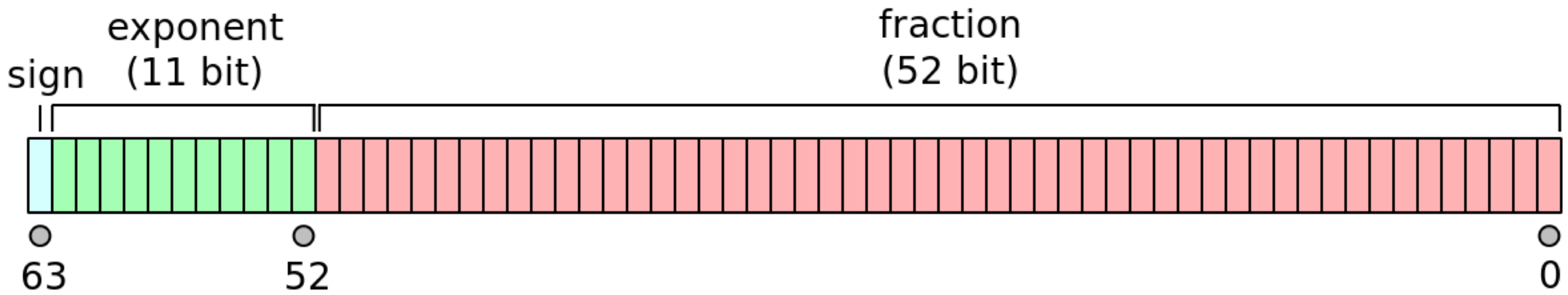
$$= 1 \cdot 16^3 + 0 \cdot 16^2 + 1 \cdot 16^1 + 1 \cdot 16^0$$
$$= 4113$$

- one byte is two digits in hex

ASCII characters

Char	Dec	Oct	Hex	Char	Dec	Oct	Hex	Char	Dec	Oct	Hex
(sp)	32	0040	0x20	@	64	0100	0x40	`	96	0140	0x60
!	33	0041	0x21	A	65	0101	0x41	a	97	0141	0x61
"	34	0042	0x22	B	66	0102	0x42	b	98	0142	0x62
#	35	0043	0x23	C	67	0103	0x43	c	99	0143	0x63
$	36	0044	0x24	D	68	0104	0x44	d	100	0144	0x64
%	37	0045	0x25	E	69	0105	0x45	e	101	0145	0x65
&	38	0046	0x26	F	70	0106	0x46	f	102	0146	0x66
'	39	0047	0x27	G	71	0107	0x47	g	103	0147	0x67
(	40	0050	0x28	H	72	0110	0x48	h	104	0150	0x68
)	41	0051	0x29	I	73	0111	0x49	i	105	0151	0x69
*	42	0052	0x2a	J	74	0112	0x4a	j	106	0152	0x6a
+	43	0053	0x2b	K	75	0113	0x4b	k	107	0153	0x6b
,	44	0054	0x2c	L	76	0114	0x4c	l	108	0154	0x6c
-	45	0055	0x2d	M	77	0115	0x4d	m	109	0155	0x6d
.	46	0056	0x2e	N	78	0116	0x4e	n	110	0156	0x6e
/	47	0057	0x2f	O	79	0117	0x4f	o	111	0157	0x6f
0	48	0060	0x30	P	80	0120	0x50	p	112	0160	0x70
1	49	0061	0x31	Q	81	0121	0x51	q	113	0161	0x71
2	50	0062	0x32	R	82	0122	0x52	r	114	0162	0x72
3	51	0063	0x33	S	83	0123	0x53	s	115	0163	0x73
4	52	0064	0x34	T	84	0124	0x54	t	116	0164	0x74
5	53	0065	0x35	U	85	0125	0x55	u	117	0165	0x75
6	54	0066	0x36	V	86	0126	0x56	v	118	0166	0x76
7	55	0067	0x37	W	87	0127	0x57	w	119	0167	0x77
8	56	0070	0x38	X	88	0130	0x58	x	120	0170	0x78
9	57	0071	0x39	Y	89	0131	0x59	y	121	0171	0x79
:	58	0072	0x3a	Z	90	0132	0x5a	z	122	0172	0x7a
;	59	0073	0x3b	[	91	0133	0x5b	{	123	0173	0x7b
<	60	0074	0x3c	\	92	0134	0x5c	|	124	0174	0x7c
=	61	0075	0x3d	]	93	0135	0x5d	}	125	0175	0x7d
>	62	0076	0x3e	^	94	0136	0x5e	~	126	0176	0x7e
?	63	0077	0x3f	_	95	0137	0x5f				

Doubles



$$(-1)^{sign} \cdot \left(1 + \sum_{1}^{52} fraction[52 - i] \cdot 2^{i}\right) \cdot 2^{exponent\ -1023}$$

x86 instructions

Machine code bytes	Assembly
	foo:
B8 22 11 00 FF	movl $0xFF001122, %eax
01 CA	addl %ecx, %edx
31 F6	xorl %es1, %es1
53	pushl %ebx
8B 5C 24 04	movl 4(%esp), %ebx
8D 34 48	leal (%eax,%ecx,2), %exi
39 C3	cmpl %eax, %ebx
72 EB	jnae foo
C3	retl

Bits and Bytes Require Interpretation

00000000 00110101 00110000 00110001 (or 0x00353031)

might be interpreted as

- The integer $3{,}485{,}745_{10}$
- A floating point number close to 4.884569×10^{-39}
- The string "105"
- A portion of an image or video
- An address in memory

Information is Bits + Context

C

code/intro/hello.c

```
#include<stdio.h>

int main(int argc, char ** argv){
  printf("Hello world!\n");
  return 0;
}
```

Preprocessor Directives

- **`#include <filename>`**
- **`#include "filename"`**
  - Usually include header files, with extension **`.h`**

- **`#define PI 3.14`**
- **`#define TIMESFOUR(j) ((j)<<2)`**
  - Textual substitution--parentheses are important!

- **`#if #elif #else #endif`**

```
#ifndef _STDIO_H_
#define _STDIO_H_

    All of the code

#endif /* _STDIO_H_ */
```

Example Data Representations

C Data Type	Typical 32-bit	Typical 64-bit	x86-64
`char`	1	1	1
`short`	2	2	2
`int`	4	4	4
`long`	4	8	8
`long long`	8	8	8
`float`	4	4	4
`double`	8	8	8
pointer	4	8	8

Typedefs

- Abbreviation for complex types

```
int b[6][8];  // b is a two-dim array
              // variable

typedef int b_type[6][8];
b_type b_var; // b_var is a two-dim array
```

Structs

- Heterogeneous records, like Java objects
- Typical linked list declaration:

```
typedef struct cell {
  int value;
  struct cell *next;
} cell_t;
```

- Usage:

```
cell_t c;
c.value = 42;
c.next = NULL;
```

How many bytes are allocated for **c**? for **p**?

- Usage with pointers:

Find the error →

```
cell_t *p;
p->value = 42;
p->next = NULL;
```

p->next is an bbreviation for **(*p).next**

Memory Access in C

```
int x;    // an integer
int *p    // a pointer to an integer

// normal initialization:
x = 0;

// silly, but illustrative:
p = &x;   // & means "address of"
*p = 0;   // * means "memory at address"
```

- & and * are inverses of one another
- prefix vs infix operators
- **`x`** occupies 4 bytes in memory; **`p`** occupies 8

Arrays

- Contiguous block of memory
- Pointer to start, then indexed by element size
  - Indices start at zero

- **`ary[k]`** is the same as **`*(ary+k)`**
  - Location of **`ary+k`** depends on the type of array elements

Two-dimensional Arrays

- Same storage layout:

```
int a[48];       // 48 integers
int b[6][8];     // 6 rows, 8 columns
```

- **`b[i][j]`** is the same as **`b[8*i+j]`**

Arrays and Pointers Combined

```
int *p[47];
```

- Array of pointers … or … pointer to an array??
- It's an array of **`47`** pointers
  - **`p[3]`** is the fourth pointer in the array **`p`**
  - **`p[3]`** is the base of an array
  - **`p[3][6]`** is the integer at position **`6`** in the array **`p[3]`**

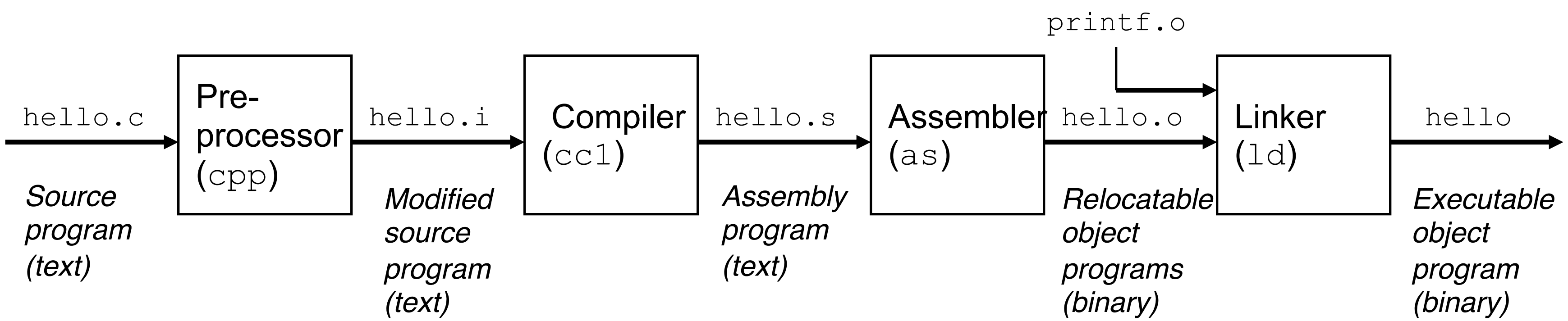
What is printed?

```
int a[100];
int *p[47];

p[3] = a+12;
for (int i = 0; i < 100; i++)
    a[i] = i;

printf("%d\n", p[3][4]);
```

Compilation



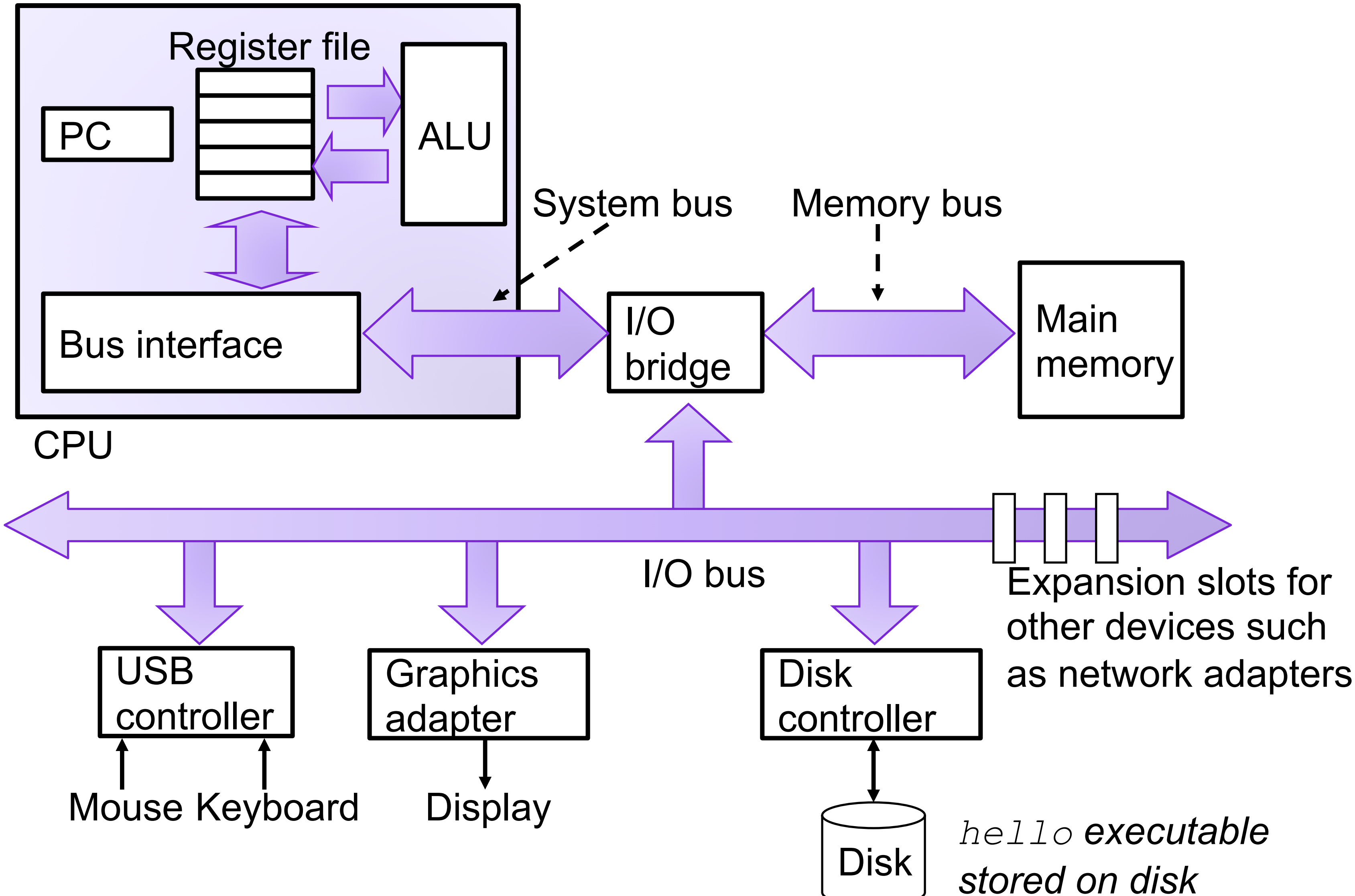

```
#include<stdio.h>

int main(int argc,
         char ** argv){
  printf("Hello world!\n");
  return 0;
}
```

Running a Program

- ./hello

A Computer System



LOGISTICS

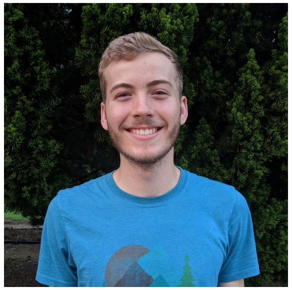
Prerequisites and Assumptions

- Proficiency with:
  - Representing numbers in different bases
  - Writing reasonably complex programs in Java/C/C++
  - Data structures such as: linked lists, arrays, stacks, trees
  - Debugging
- Experience with:
  - Terminal window and command line
  - Learning new languages and applications
  - Experimenting and being confused
  - Searching for and reading documentation

Course staff

Prof. Eleanor Birrell
Edmunds 221

Research in security and privacy
OH: M 8-10pm, T 5:30-7pm



Greg Cannon

Gabriel de Motta de Fontnouvelle

Victor

Wentao Guo

Harini Salgado

The Course in a Nutshell

- Textbooks
  - Required:
    - Bryant and O'Halloran, *Computer Systems: A Programmer's Perspective*, **third edition**, Pearson, 2016
  - Optional: some reference for the C language
    - Kernighan and Ritchie, *The C Programming Language,* second edition, Prentice Hall, 1988
    - Miller and Quilici, *The Joy of C,* third edition, Wiley, 1997
    - **Be cautious about web resources!**

- Classes
  - Monday and Wednesday, 2:45-4pm in Edmunds 101
  - Come prepared—do the reading first!

Nutshell, continued

- Participation
  - 5% of the grade
- Labs
  - Wednesday 7-8:15 in Edmunds 229
  - **Start tonight**! Be sure to have an account and password
- Assignments
  - Introduced during labs, Due Tuesdays at 11:59pm
  - Tremendous fun, work in pairs
  - 45% of the grade
- Midterm exam
  - March 13
  - 20% of the grade each
- Final exam
  - Friday, May 17, 2:00—5:00 pm
  - 30% of the grade
  - **Important:** The exam is late in finals week; make travel plans accordingly

Course website

http://www.cs.pomona.edu/classes/cs105/2019sp/

- All information is on the course website
- Links from the course page:
  - Piazza, for questions and discussion
  - Lab assistants and mentors, schedule
  - Submission site
- Sakai, for recording lab grades only

PERMs

- If you are already registered in the class, welcome!
- If you are not registered:
  - Make sure you have submitted a PERM request
  - Put your name on the sign-up sheet

Things to Do Right Away

- For lab tonight
  - Be sure you have an account on the Pomona CS system

- For class on Monday
  - Begin the reading: Chapters 1 and 2.1-2.3

- This week
  - Accept the invitation to our course’s Piazza site
  - Enroll in CS 105 on **`submit.cs.pomona.edu`**