



Programming Bootcamp

# Setup Instructions for C Programming Days

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NSF award: CMMI 1612843

# Exercise: git setup, Compile & Run Hello World on Frontera

1. fork the SimCenterBootcamp2020 github repo
2. ssh [yourname@frontera.tacc.utexas.edu](mailto:yourname@frontera.tacc.utexas.edu)
3. git clone <https://github.com/YOUR GIT LOGIN/SimCenterBootcamp2020.git>
4. cd SimCenterBootcamp2020
5. git remote add upstream <https://github.com/NHERI-SimCenter/SimCenterBootcamp2020.git>
6. cd ~
7. mkdir hello
8. cd hello
9. emacs hello.c
10. enter the text shown on right →
11. <Control> x <Control> s
12. <Control> x <Control> c
13. icc hello.c
14. idev
15. ./a.out
16. exit
17. exit

```
#include <stdio.h>

int main(int argc, char **argv) {
    // my first program in C
    printf("Hello World! \n");
    return 0;
}
```

<https://nheri-simcenter.github.io/SimCenterBootcamp2020/source/assignmentPreC.html>



## Programming Bootcamp

# Computers & Computer Programs

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**A Computer is a programmable electronic device that manipulates data; that data being form of 0's and 1's; manipulation orchestrated by Programs running on the hardware**

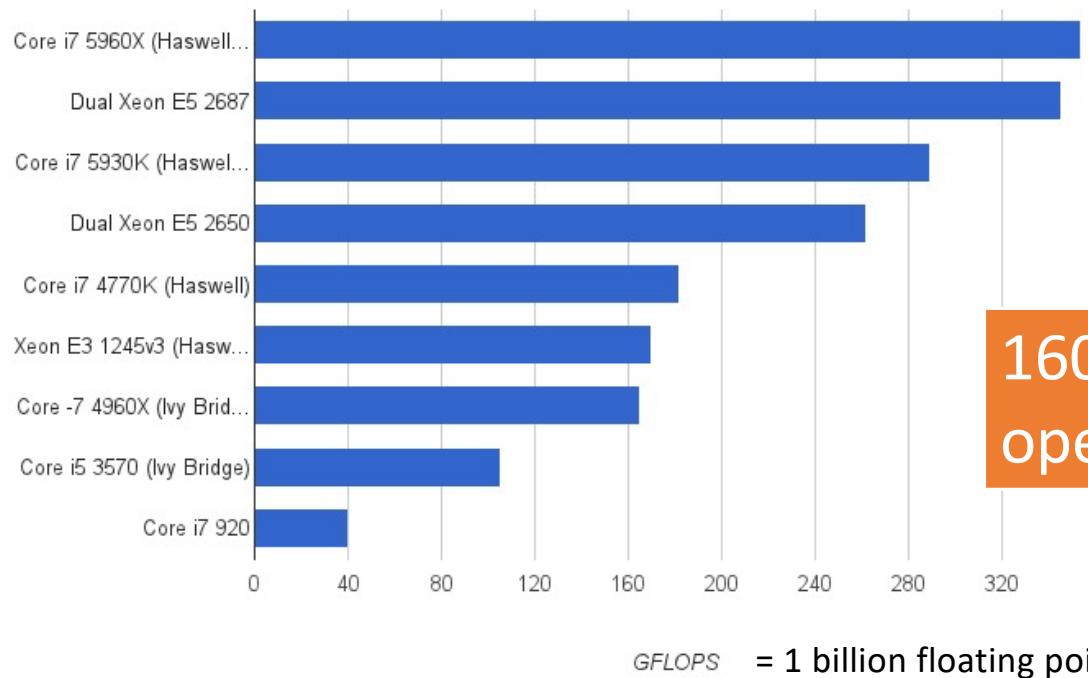
The Data

**Computers** Are Greatly Limited in What they can do!

They Just Do What They Can do Incredibly **Fast**

# How Fast?

Linpack Benchmark from Intel MKL

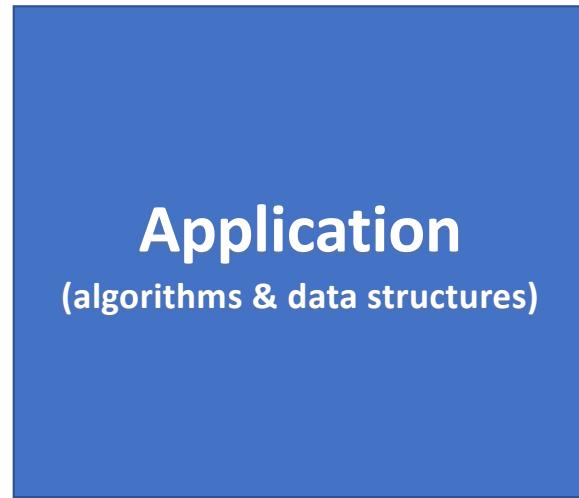


World population Dec 2020 = 7.8billion  
source: <https://www.worldometers.info/>

160/8 = 20 floating point operations per person per second!

# What is a Computer Application?

Input(  )



Output (  )



# Internally a Computer Application is

- A sequence of separate instructions one after another that start at location 0
- Each instruction tells CPU to do 1 small specific task
- When the instructions are completed the computer has done something we wanted done.

Memory	
00101110	(Location 0)
11010011	(Location 1)
01010011	(Location 2)
00010000	(Location 3)
10111111	
10100110	
11101001	
00000111	
10100110	
00010001	
00111110	(Location 10)

# How Do We Input the Instructions?

Memory	
00101110	(Location 0)
11010011	(Location 1)
01010011	(Location 2)
00010000	(Location 3)
·	·
10111111	
10100110	
11101001	
00000111	
·	·
10100110	
00010001	
00111110	(Location 10)

MITS Altair 8800	
<b>Introduced:</b>	January 1975
<b>Available:</b>	February 1975
<b>Prices:</b>	US \$395 as a kit (prior to March) US \$650 assembled
<b>How many:</b>	estimated 2000+
<b>CPU:</b>	Intel 8080, 2.0 MHz
<b>RAM:</b>	256 bytes, 64K max
<b>Display:</b>	front panel LEDs
<b>Controls:</b>	front panel switches
<b>Expansion:</b>	Altair-bus card-cage
<b>Storage:</b>	paper tape, cassette or floppy drive
<b>OS:</b>	CP/M, BASIC



We No longer write applications in 0's and 1's

We No longer write them in Assembly Language

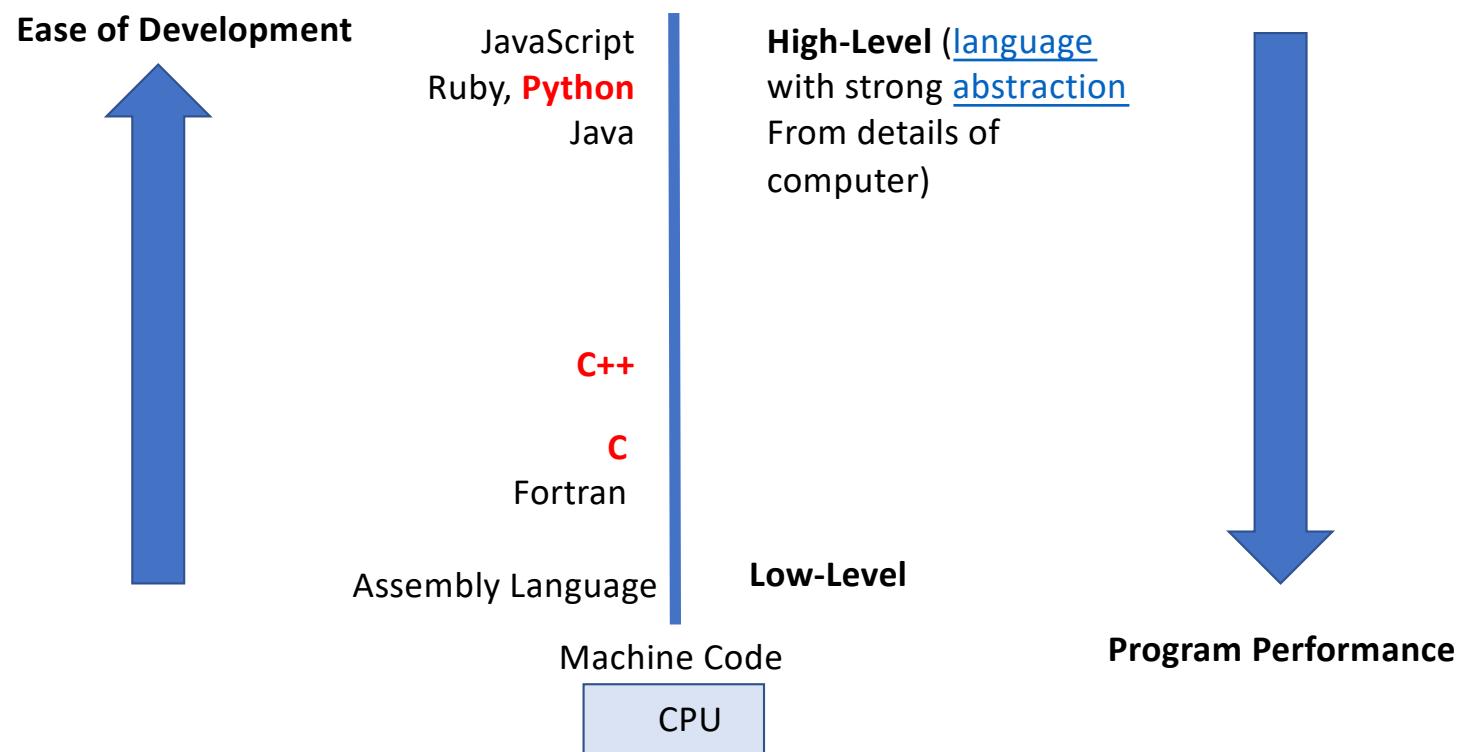
We of Course now write in a Programming language

# What Programming Language?

- Hundreds of languages ....
- Only a dozen or so are popular at any time
- We will be looking at C, C++ and Python

PASCAL:	ADA:	C:	SHELL SCRIPT:	PYTHON:	TCL
<pre>if a &gt; 0 then   writeln("yes") else   writeln("no"); end if;</pre>	<pre>if a &gt; 0 then   Put_Line("yes"); else   Put_Line("no"); end if;</pre>	<pre>if (a &gt; 0) {   printf("yes"); } else {   printf("no"); }</pre>	<pre>if [ \$a -gt 0 ]; then   echo "yes" else   echo "no" fi</pre>	<pre>if a &gt; 0:   print "yes" else:   print "no"</pre>	<pre>If (\$a &gt; 0) {   puts "yes" } else {   puts "no" }</pre>

# Programming Language Hierarchy



# Speed Comparison

## There's plenty of room at the Top: What will drive computer performance after Moore's law?

Charles E. Leiserson, Neil C. Thompson\*, Joel S. Emer, Bradley C. Kuszmaul, Butler W. Lampson,  
Daniel Sanchez, Tao B. Schardl

**Table 1. Speedups from performance engineering a program that multiplies two 4096-by-4096 matrices.** Each version represents a successive refinement of the original Python code. “Running time” is the running time of the version. “GFLOPS” is the billions of 64-bit floating-point operations per second that the version executes. “Absolute speedup” is time relative to Python, and “relative speedup,” which we show with an additional digit of precision, is time relative to the preceding line. “Fraction of peak” is GFLOPS relative to the computer’s peak 835 GFLOPS. See Methods for more details.

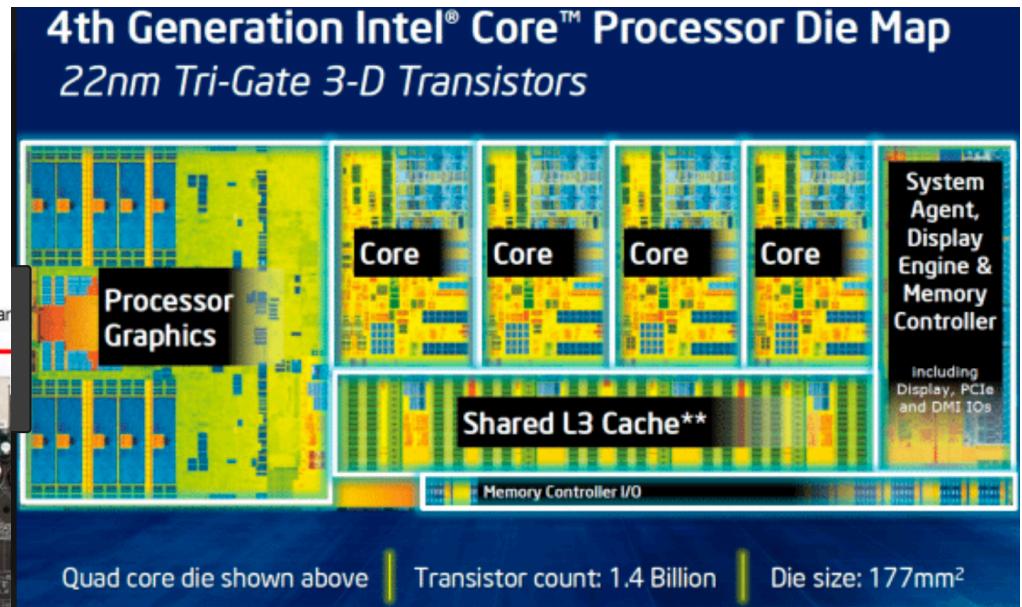
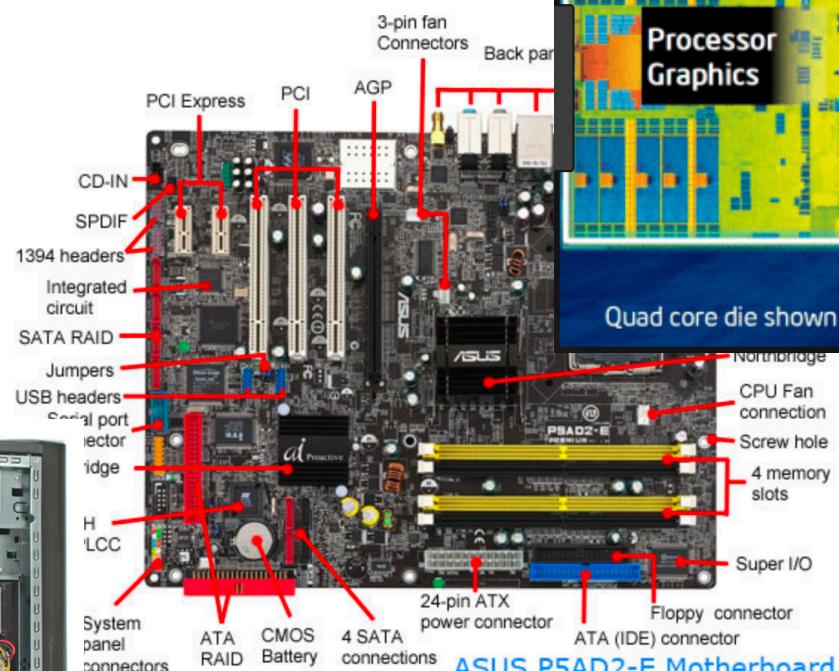
Version	Implementation	Running time (s)	GFLOPS	Absolute speedup	Relative speedup	Fraction of peak (%)
1	Python	25,552.48	0.005	1	—	0.00
2	Java	2,372.68	0.058	11	10.8	0.01
3	C	542.67	0.253	47	4.4	0.03
4	Parallel loops	69.80	1.969	366	7.8	0.24
5	Parallel divide and conquer	3.80	36.180	6,727	18.4	4.33
6	plus vectorization	1.10	124.914	23,224	3.5	14.96
7	plus AVX intrinsics	0.41	337.812	62,806	2.7	40.45

PYTHON: original  $160 \text{ GFLOP} / 60000 = 2.5 \text{ Million FLOPS}$  or each person in the 193rd most populous city, Lubumbashi Dr Congo (pop 2,478,262) doing 1 floating point operation a second!

**Ultimate Performance Comes  
from writing code that takes  
advantage of Hardware**

(C and Fortran are as close to hardware as you get in a human readable form)

# Hardware



ComputerHope.com

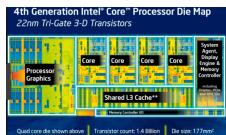
# Cores only Work on Data in Registers

Which is Why Understanding  
Memory Hierarchy is Crucial

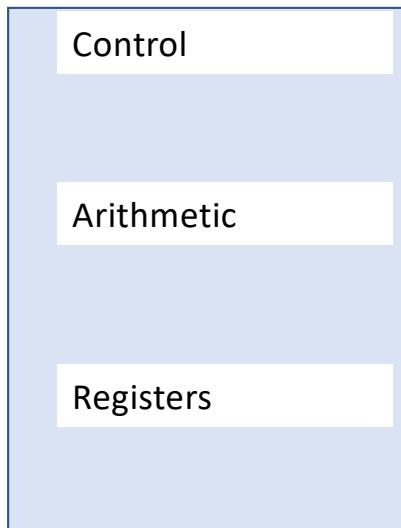
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# Memory Hierarchy



Core Processor



L1 Cache



L2 Cache



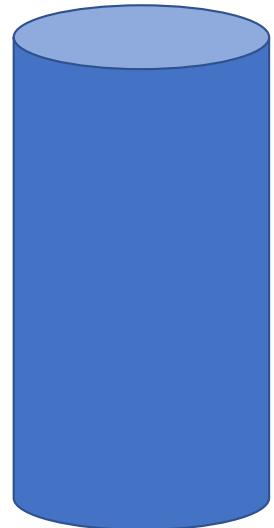
L3 Cache



Memory(RAM)



Disk



	Hard Drive	SSD
Size	1000 Bytes	.25-1TB
Latency	0.3 ns	5-10e6 ns
Compiler	HW	25-50e3 ns
	Operating System	Operating System
	20-30 ns	
	4-32 GB	
	50-100 ns	

# What is Cache?

- Small, Fast Memory
- Placed Between Registers and Main Memory
- It keeps a copy of data in memory
- It is hidden from software (neither compiler or OS can say what gets loaded)

- Cache-hit: data in cache (b in cache)

- Cache-miss: data not in cache, have to go get from memory (b in memory)

- Cache-line-length: number of bytes of data loaded into cache with missing data (32 to 128bytes)

- Cores have own L1 & L2, but share L3

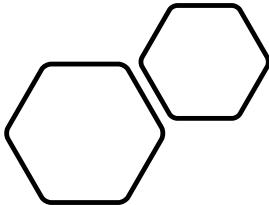
```
void main() {  
    ...  
    a = b*c  
    ...  
}
```

# Why Do Caches Work?

- **Temporal Locality** – probability is high that if program is accessing some memory location it will access same location again soon.
- **Spatial Locality** – probability is high that if program is accessing some memory on 1 instruction, it is going to access a nearby one soon

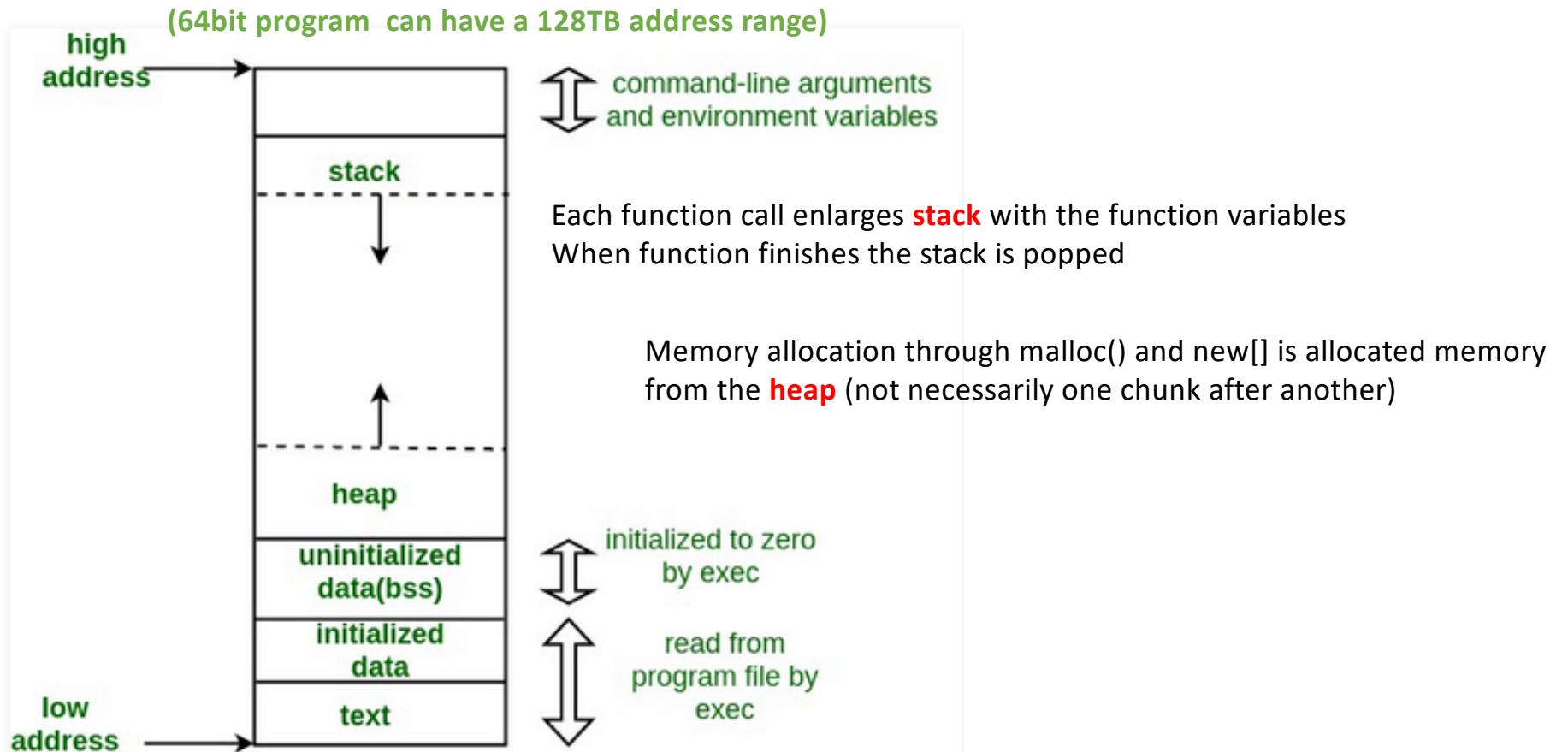
```
int main() {  
    ...  
    double dotProduct = 0  
    for (int i=0, i<vectorSize; i++)  
        dotProduct += x[i] * y[i];  
    ...  
}
```

# So Why Do I Bring Cache Up If You Have No Control Over It?



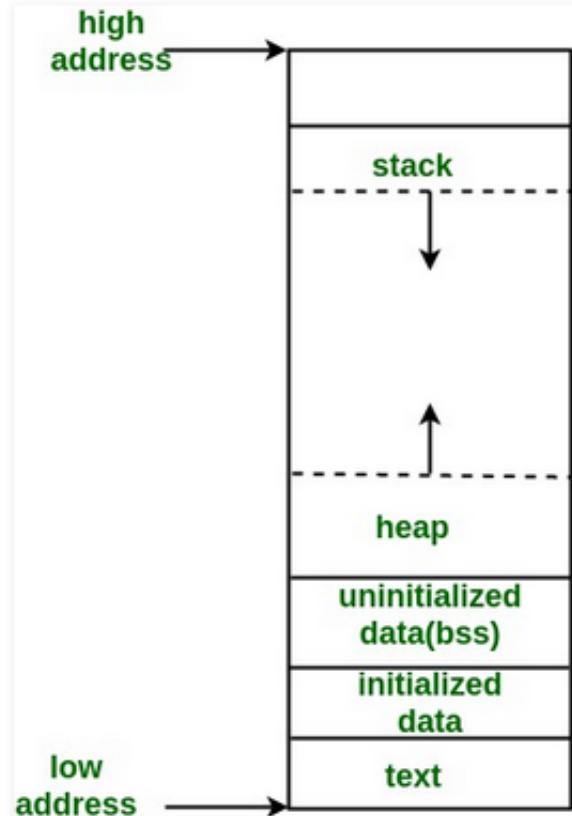
- Knowing caches exist, understanding how they work, allows you as a programmer to take advantage of them when you write the program to greatly speed it up, i.e. Allocate chunks of memory, consider cache line sizes, think about where you store your variables. (we will demonstrate when we do parallel programming exercises)

# Memory Layout of a RUNNING Program



# Memory of a RUNNING Program versus RAM

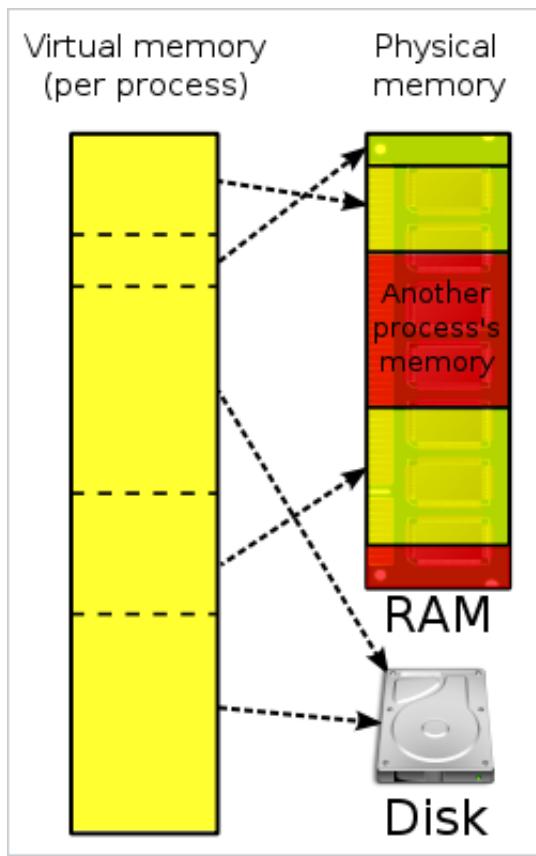
(64bit program can have a 128TB address range)



A 128TB PROGRAM DOES  
NOT FIT INTO 32GB RAM!



# Operating System & Virtual Memory



- Virtual Memory is a [memory management](#) technique that provides an "idealized abstraction of the storage resources that are actually available on a given machine" wikipedia.
- Program Memory is broken into a number of pages. Some of these are in memory, some on disk, some may not exist at all (segmentation fault)
- CPU issues virtual addresses (load b into R1) which are translated to physical addresses. If page in memory, HW determines the physical memory address. If not, page fault, OS must get page from Disk.
- Page Table: table of pages in memory.
- Page Table Lookup – relatively expensive.
- Page Fault (page not in memory) very expensive as page must be brought from disk by OS
- Page Size: size of pages
- TLB Translation Look-Aside Buffer HW cache of virtual to physical mappings.
- Allows multiple programs to be running at once in memory.

# Major page fault

- Major => need to retrieve page from disk
    1. CPU detects the situation (valid bit = 0)
      - It cannot remedy the situation on its own;
      - It doesn't communicate with disks (nor even knows that it should)
    2. CPU generates interrupt and transfers control to the OS
      - Invoking the OS page-fault handler
    3. OS regains control, realizes page is on disk, initiates I/O read ops
      - To read missing page from disk to DRAM
      - Possibly need to write victim page(s) to disk (if no room & dirty)
    4. OS suspends process & context switches to another process
      - It might take a few milliseconds for I/O ops to complete
    5. Upon read completion, OS makes suspended process runnable again
      - It'll soon be chosen for execution
    6. When process is resumed, faulting operation is re-executed
      - Now it will succeed because the page is there
- Page Fault Takes a Bootload of Time*

## In Conclusion

- Computer just performs simple operations BUT does so very fast
- Data on a computer is a sequence of 0's and 1's
- A program is just a sequence of instructions.
- Each running program has it's own program memory space
- Operations can only occur on data that exists in the registers of a core
- To move data from RAM to the registers is expensive, from disk to registers extremely so as it results in page faults



Center for Computational Modeling and Simulation

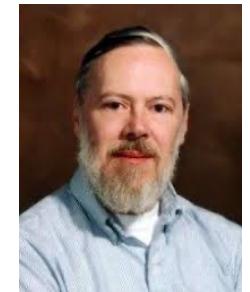
## Programming Bootcamp

# Introduction to C & Compilation

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University of California at Berkeley



NSF award: CMMI 1612843



# The C Programming Language

- Originally Developed by Dennis Ritchie at Bell Labs in 1969 to implement the Unix operating system.
- It is a **compiled** language. (Python is an interpreted language)
- It is a **structured** (PROCEDURAL) language. (Python is ‘object-oriented’ if you use classes, Fortran is procedural)
- It is a **strongly typed** language (Python is also strongly typed, but interpreter figures out current type!)
- The most widely used languages of all time (Python is language du jour)
- It's been #1 or #2 most popular language since mid 80's
  - It works with nearly all systems
  - As close to assembly as you can get
  - Small runtime (embedded devices)
- It can produce **FAST** code by maximizing your hardware resources.

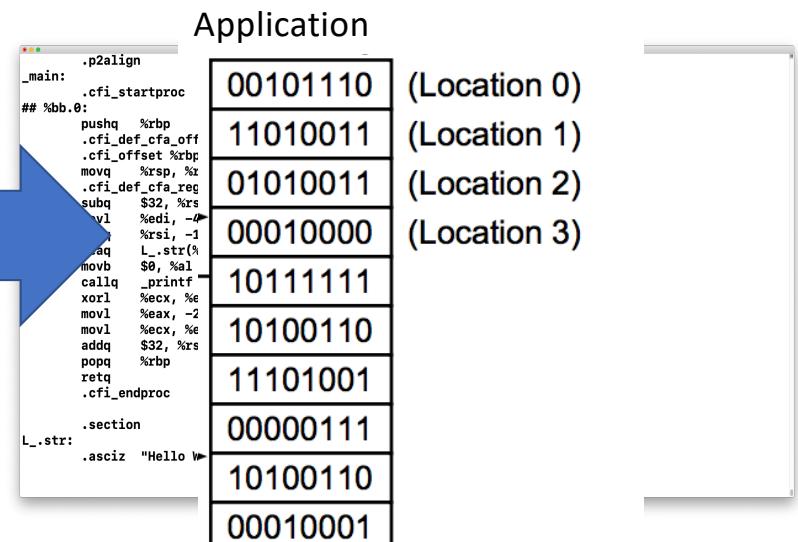
# Compiled Language:

- A language that uses an application, the compiler, to turn the program into a runnable application.
- The purpose of a compiler:
  - Translate a program into lower level language (assembly, machine instruction)
  - Check a program is legal, i.e. follows the syntax
  - Optimize the output for performance, e.g. order of instructions,

Typically ASCII Text File

```
void main() {  
    ...  
    ...  
    a = b + c;  
    ...  
    ...  
}
```

Compiler  
Application  
(icc is an example compiler)



# Strongly Typed

- **Strongly typed language** refers to a programming language that typically requires the programmer to specify the type of a variable so that strict enforcement of restrictions on intermixing of values with differing data types can be performed.

# Structured Programming Language

- In this type of language, large programs are divided into smaller units called **functions**.
- Data is passed from one function to another through function arguments and function return types.
- The main focus in program design is on identifying functions and the defining the function interfaces, i.e. identifying the data types passed in the function arguments.

# C Program Structure

A C Program consists of the following parts:

- Preprocessor Commands
- Functions
- Variables
- Statements & Expressions
- Comments
- Pragmas

# Everyone's First C Program

no space between # and include

```
#include <stdio.h>
```

hello1.c

```
int main(int argc, char **argv) {
    /* my first program in C */
    printf("Hello World! \n");
    return 0;      statements end with ;
}
```

Function that indicates they will return  
an integer, MUST return an integer

- The first line of the program **#include <stdio.h>** is a preprocessor command, which tells a C compiler to include the stdio.h file before starting compilation.
- The next line **int main()** is the main function. Every program must have a main function as that is where the program execution will begin.
- The next line **/\* ... \*/** will be ignored by the compiler. It is there for the programmer benefit. It is a comment.
- The next line is a statement to invoke the **printf(...)** function which causes the message "Hello, World!" to be displayed on the screen. The prototype for the function is in the stdio.h file. Its implementation in the standard C library.
- The next statement **return 0;** terminates the main() function and returns the value 0.



## Programming Bootcamp

# C: Variable Types & Variable Names

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NSF award: CMMI 1612843

All data in program memory is stored as 0's and 1's

# Computers Work in Binary

- The smallest unit of data (each individual 0 or 1 in program memory) is called a **BIT**
- Trick Programmers have used is to group bits together to represent more data, e.g. Possibilities for 3 bits ( $2^3$  combinations)

0 0 0	0	A	France
0 0 1	1	B	Germany
0 1 0	2	C	UK
0 1 1	3	D	Italy
1 0 0	4	E	Japan
1 0 1	5	F	USA
1 1 0	6	G	Canada
1 1 1	7	H	Russia

# Allowable Variable Types in C – II

## qualifiers: unsigned, short, long

### 1. Integer Types

char	1 byte	-128 to 127 or 0 to 255
unsigned char	1 byte	0 to 255
signed char	1 byte	-128 to 127
int	2 or 4 bytes	-32,768 to 32,767 or -2,147,483,648 to 2,147,483,647
unsigned int	2 or 4 bytes	0 to 65,535 or 0 to 4,294,967,295
short	2 bytes	-32,768 to 32,767
unsigned short	2 bytes	0 to 65,535
long	4 bytes	-2,147,483,648 to 2,147,483,647
unsigned long	4 bytes	0 to 4,294,967,295

### 2. Floating Point Types

float	4 byte	1.2E-38 to 3.4E+38	6 decimal places
double	8 byte	2.3E-308 to 1.7E+308	15 decimal places
long double	10 byte	3.4E-4932 to 1.1E+4932	19 decimal places

### 3. Enumerated Types

### 4. **void** Type

### 5. Derived Types

Structures,  
Unions,  
**Arrays**

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### 2. Floating Point Types

float	4 byte	1.2E-38 to 3.4E+38	6 decimal places
double	8 byte	2.3E-308 to 1.7E+308	15 decimal places
long double	10 byte	3.4E-4932 to 1.1E+4932	19 decimal places

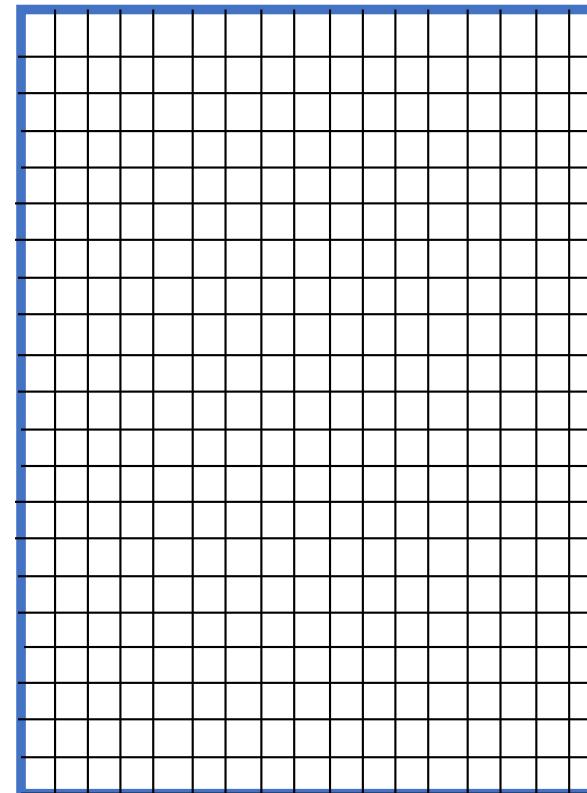
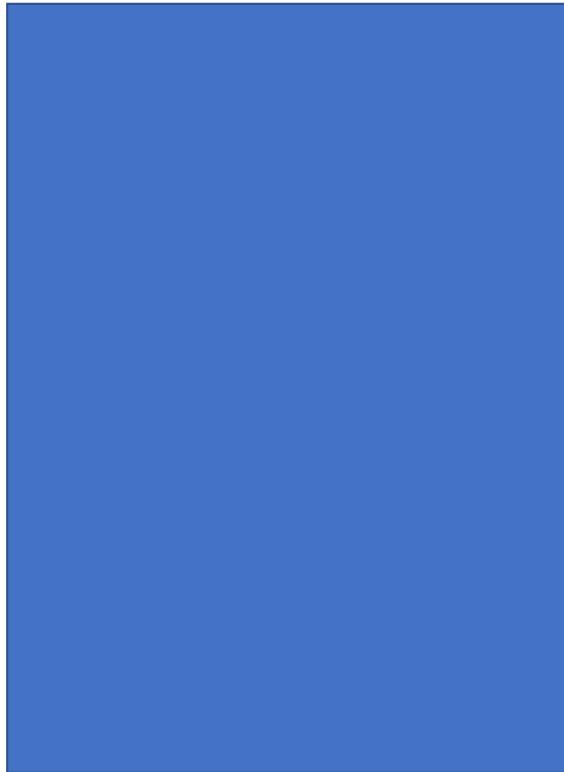
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### 5. Derived Types

Structures,  
Unions,  
**Arrays**

C breaks program memory into byte sized units  
1 Byte = 8 bits



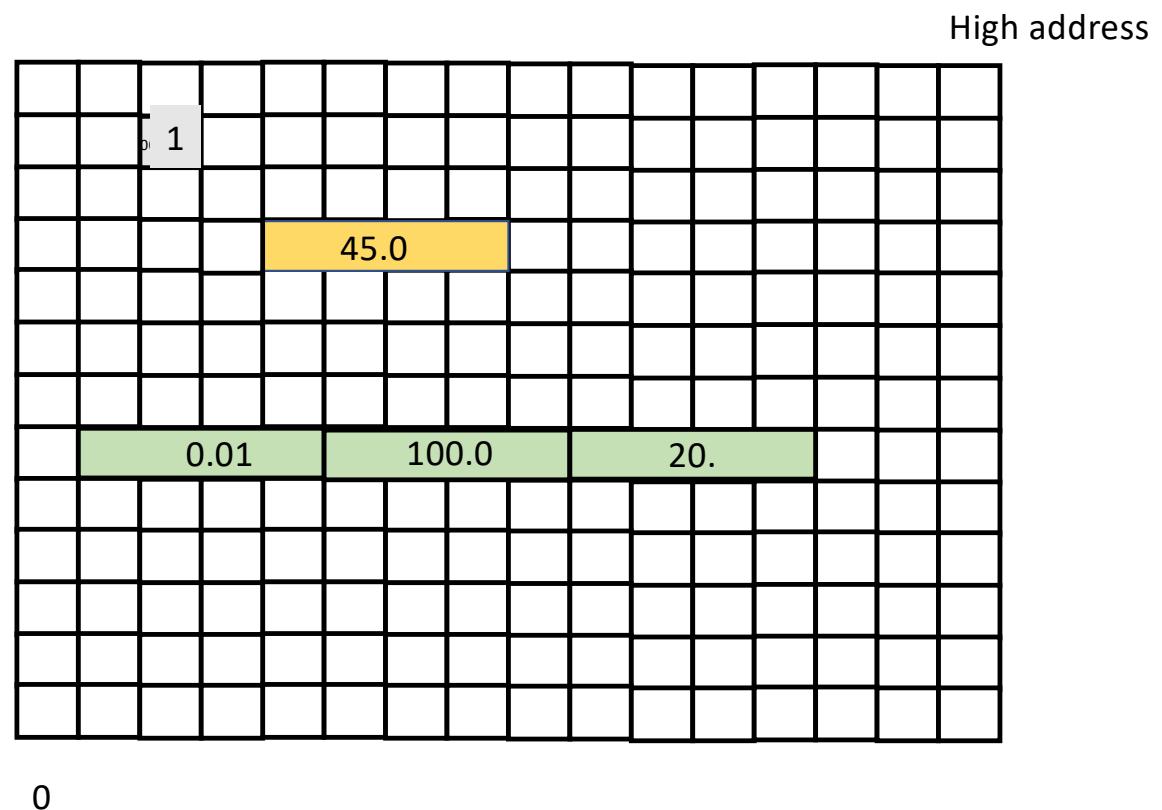
To a single Byte or Contiguous Array of Bytes the Programmer can associate the byte(s) with a variable name, and then use that name in the program to set and use the values stored in those bytes.

```
char a = '1';
```

```
float theta = 45.0;
```

```
float stress[3] = {0.01, 100. 20.};
```

NOTE: each of these byte has a memory location which can be obtained with the location varying from 0 to high address value..



# Variable Name

- A **Variable** is a named memory location that can hold various values.
- Because C is a **strongly typed language**, the programmer **must specify the data type associated with the variable**. The compiler will issue warnings if variable type is misused.
- The size of the memory associated with the variable depends on the data type.
- Names are **made up of letters and digits**; they are **case sensitive**; names must **start with a character**, for variable names ‘\_’ counts as a character
- **Certain keywords are reserved**, i.e. cannot be used as variable names

# Reserved Keywords in C cannot be used as variable names

<b>C KEYWORDS OR RESERVED WORDS</b>			
auto	break	case	char
const	continue	default	do
int	long	register	return
short	signed	sizeof	static
struct	switch	typedef	union
unsigned	void	volatile	while
double	else	enum	extern
float	for	goto	if

BeginnersBook.com

# char – size 1 byte ( $2^8 = 256$ (0-255) possibilities)

ASCII Character set (only uses 128 possibilities) – note '1' is 49 which corresponds to bit pattern 00110001

Decimal	Binary	Octal	Hex	ASCII	Decimal	Binary	Octal	Hex	ASCII	Decimal	Binary	Octal	Hex	ASCII	Decimal	Binary	Octal	Hex	ASCII
0	00000000	000	00	NUL	32	00100000	040	20	SP	64	01000000	100	40	@	96	01100000	140	60	'
1	00000001	001	01	SOH	33	00100001	041	21	!	65	01000001	101	41	A	97	01100001	141	61	a
2	00000010	002	02	STX	34	00100010	042	22	"	66	01000010	102	42	B	98	01100010	142	62	b
3	00000011	003	03	ETX	35	00100011	043	23	#	67	01000011	103	43	C	99	01100011	143	63	c
4	00000100	004	04	EOT	36	00100100	044	24	\$	68	01000100	104	44	D	100	01100100	144	64	d
5	00000101	005	05	ENQ	37	00100101	045	25	%	69	01000101	105	45	E	101	01100101	145	65	e
6	00000110	006	06	ACK	38	00100110	046	26	&	70	01000110	106	46	F	102	01100110	146	66	f
7	00000111	007	07	BEL	39	00100111	047	27	'	71	01000111	107	47	G	103	01100111	147	67	g
8	000001000	010	08	BS	40	00101000	050	28	(	72	01001000	110	48	H	104	01101000	150	68	h
9	000001001	011	09	HT	41	00101001	051	29	)	73	01001001	111	49	I	105	01101001	151	69	i
10	000001010	012	0A	LF	42	00101010	052	2A	*	74	01001010	112	4A	J	106	01101010	152	6A	j
11	000001011	013	0B	VT	43	00101011	053	2B	+	75	01001011	113	4B	K	107	01101011	153	6B	k
12	000001100	014	0C	FF	44	00101100	054	2C	,	76	01001100	114	4C	L	108	01101100	154	6C	l
13	000001101	015	0D	CR	45	00101101	055	2D	-	77	01001101	115	4D	M	109	01101101	155	6D	m
14	000001110	016	0E	SO	46	00101110	056	2E	.	78	01001110	116	4E	N	110	01101110	156	6E	n
15	000001111	017	0F	SI	47	00101111	057	2F	/	79	01001111	117	4F	O	111	01101111	157	6F	o
16	000010000	020	10	DLE	48	00110000	060	30	0	80	01010000	120	50	P	112	01110000	160	70	p
17	000010001	021	11	DC1	49	00110001	061	31	1	81	01010001	121	51	Q	113	01110001	161	71	q
18	000010010	022	12	DC2	50	00110010	062	32	2	82	01010010	122	52	R	114	01110010	162	72	r
19	000010011	023	13	DC3	51	00110011	063	33	3	83	01010011	123	53	S	115	01110011	163	73	s
20	000010100	024	14	DC4	52	00110100	064	34	4	84	01010100	124	54	T	116	01110100	164	74	t
21	000010101	025	15	NAK	53	00110101	065	35	5	85	01010101	125	55	U	117	01110101	165	75	u
22	000010110	026	16	SYN	54	00110110	066	36	6	86	01010110	126	56	V	char one = '1'; char yes = 'Y';				
23	000010111	027	17	ETB	55	00110111	067	37	7	87	01010111	127	57	W					
24	000011000	030	18	CAN	56	00111000	070	38	8	88	01011000	130	58	X					
25	000011001	031	19	EM	57	00111001	071	39	9	89	01011001	131	59	Y					
26	000011010	032	1A	SUB	58	00111010	072	3A	:	90	01011010	132	5A	Z					
27	000011011	033	1B	ESC	59	00111011	073	3B	;	91	01011011	133	5B	\					
28	000011100	034	1C	FS	60	00111100	074	3C	<	92	01011100	134	5C	\\	124	01111100	174	7C	
29	000011101	035	1D	GS	61	00111101	075	3D	=	93	01011101	135	5D	]	125	01111101	175	7D	}
30	000011110	036	1E	RS	62	00111110	076	3E	>	94	01011110	136	5E	^	126	01111110	176	7E	~
31	000011111	037	1F	US	63	00111111	077	3F	?	95	01011111	137	5F	_	127	01111111	177	7F	DEL

**int** – size 4 Byte ( $2^{32}$  possibilities)

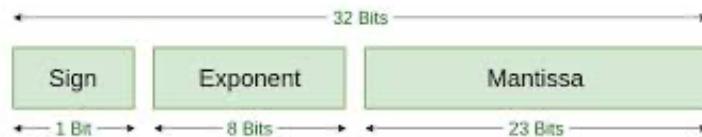
any int in range: -2,147,483,648 to 2,147,483,647

**unsigned int** – size 4 Byte ( $2^{32}$  possibilities)

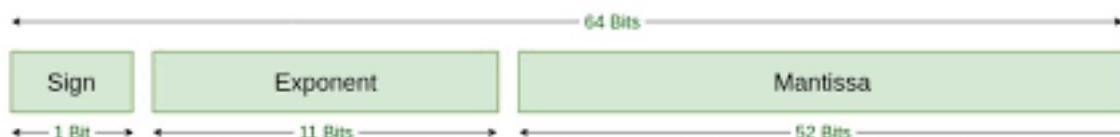
any non negative int in range: 0 to 4,294,967,295

```
int a = 1;  
unsigned int b = 2;
```

# float (4 Byte) and double (8 Byte) numbers



Single Precision  
IEEE 754 Floating-Point Standard



Double Precision  
IEEE 754 Floating-Point Standard

**float** 32 bits  $\pm 1.18 \times 10^{-38}$  to  $\pm 3.4 \times 10^{38}$  Approx. 7 decimal digits

**double** 64 bits  $\pm 2.23 \times 10^{-308}$  to  $\pm 1.80 \times 10^{308}$ . Approx. 16 decimal digits

```
float theta = 45.0;  
double force = stress * Area;
```

Not all numbers in base 2 can be represented in a limited set of bits just like not all numbers in base 10 can be represented in a limited set of decimal digits, e.g.  $1/3$

$$1.72(\text{base 10}) = 1 + 7/10 + 2/100$$

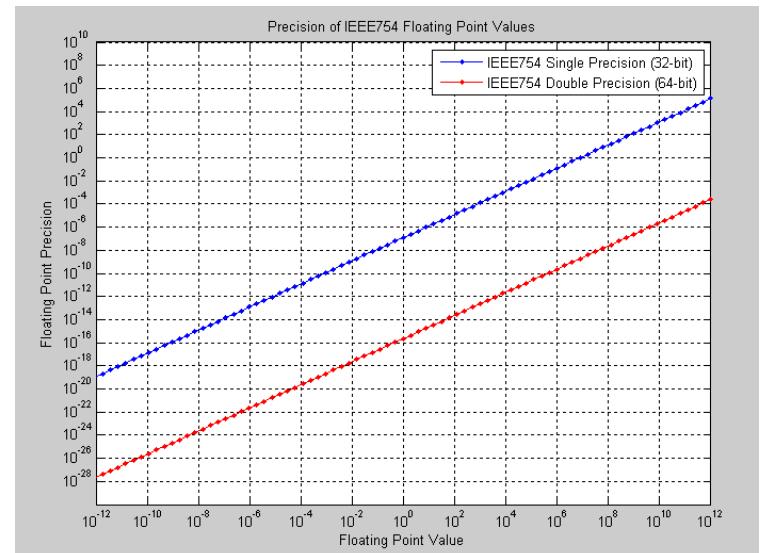
What is number in base 2 using 10 bit mantissa?

$$\begin{aligned} 1.72 &= 1 + 1/2 + 0/4 + 1/8 + 1/16 + 1/32 + 0/64 + \\ &0/128 + 0/256 + 0/512 + 1/1024 + \dots \text{Ignored due to} \\ &\text{limit on \# bits allowed} \end{aligned}$$

$$1.1011100001(\text{base 2}) \Rightarrow 1.71972656(\text{base 10})$$

$$!= 1.72.$$

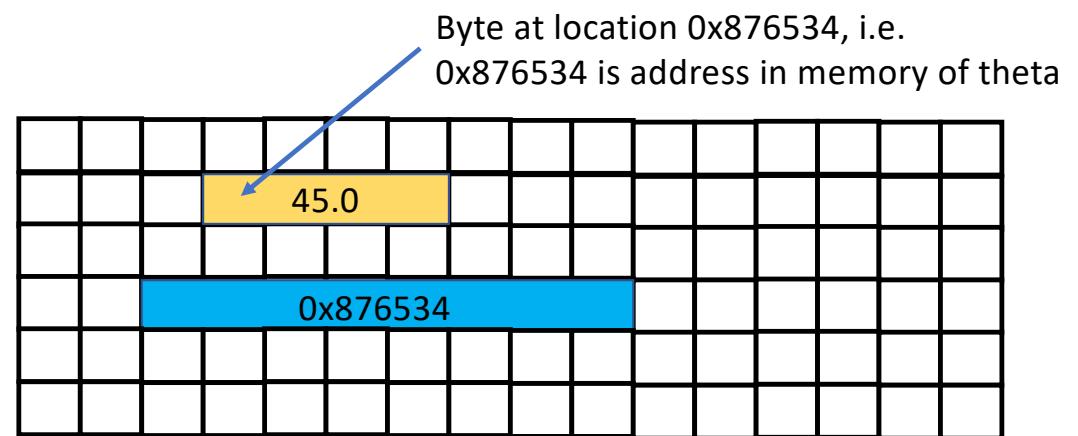
Some ERROR associated with # depends on #



Question: Can 0.1 be represented exactly on a computer using IEEE?

**pointer** – size 8 Byte (x64 – 64bit application) or 4 Byte (x86 = 32 bit application)

```
float theta = 45.0;  
float *thetaPtr= &theta;
```



# Pointer Variables

A **Pointer Variable** is a named memory location that can holds an address.

1. The unary **\*** in a declaration indicates that the object is a pointer to an object of a specific type
2. The unary **&** gives the “**address**” of an object in memory, e.g. **&x** is location of variable x
3. The unary **\*** elsewhere treats the operand as an address, and depending on which side of operand either sets the contents at that address or fetches the contents. It is said to dereference the pointer

```
#include <stdio.h>
int main() {
    int x = 10, y;
    int *ptrX = 0;

    ptrX = &x;
    y = *ptrX + x;
    *ptrX = 50.
}
```

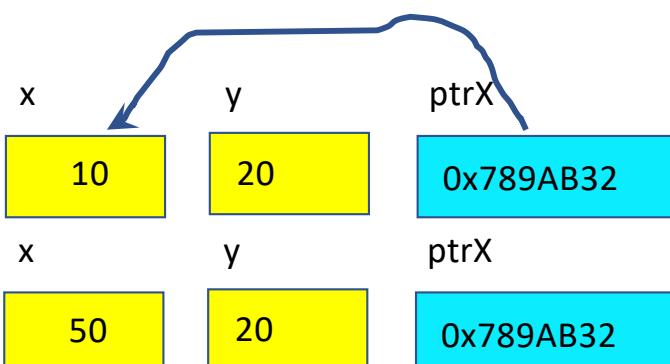
pointer1.c

Address in memory of x is 0x789AB32



```
int x=10;
int y;
int *ptrX = 0;
```

- 1.
- 2.
- 3.



```
ptrX = &x;
y = *ptrX + x;
```

```
*ptrX = 50.
```

**bool\***: size 1Byte – true or false == 1 or 0  
(actually anything or 0)

```
#include <stdbool.h>
bool result = true;
```

# Variable Example

```
#include <stdio.h>
// define and then set variable
int main(int argc, char **argv) {
    int a;
    a = 1;
    printf("Value of a is %d \n", a);
    return 0;
}
```

var1.c

```
#include <stdio.h>
// define & set in 1 statement
int main(int argc, char **argv) {
    int a = 1;
    printf("Value of a is %d \n", a);
    return 0;
}
```

var2.c

Uninitialized Variable

Initialized Variable

# Allowable Variable Types in C

char  
int  
float  
double

```
#include <stdio.h>
#include <stdlib.h>

int main(int argc, char **argv) {
    int    i1 = 5;
    float  f1 = 1.2;
    double d1 = 1.0e6;
    char   c1 = 'A';
    printf("int %d, float %f, double %lf, char %c \n", i1, f1, d1, c1);
    printf("int %d, float %e, double %le, char %c \n", i1, f1, d1, c1);
    printf("int %3d, float %16.3e, double %23.8le, char %2c \n", i1, f1, d1,
    return 0;
}
```

var3.c

# Arrays - I

- A fixed size sequential collection of elements laid out in memory of the *same* type. We access using an index inside a square brackets, indexing start at 0
- to declare: `type arrayName [size];`  
`type arrayName [size] = {size comma separated values}`

```
#include <stdio.h>
```

array1.c

```
int main(int argc, char **argv) {
    int intArray[5] = {19, 12, 13, 14, 50};
    intArray[0] = 21;
    int first = intArray[0];
    int last = intArray[4];
    printf("First %d, last %d \n", first, last);
    return 0 ;
}
```

**WARNING: indexing starts at 0**



# Multidimensional Arrays- I

- A fixed size sequential collection of elements laid out in memory of the *same type*.  
We access using an index inside a square brackets, indexing start at 0 var1.c
- to declare: `type arrayName [l1][l2][l3]...;`  
`type arrayName [l1][l2][l3] = {l1*l2*... comma separated values}`

```
#include <stdio.h>
```

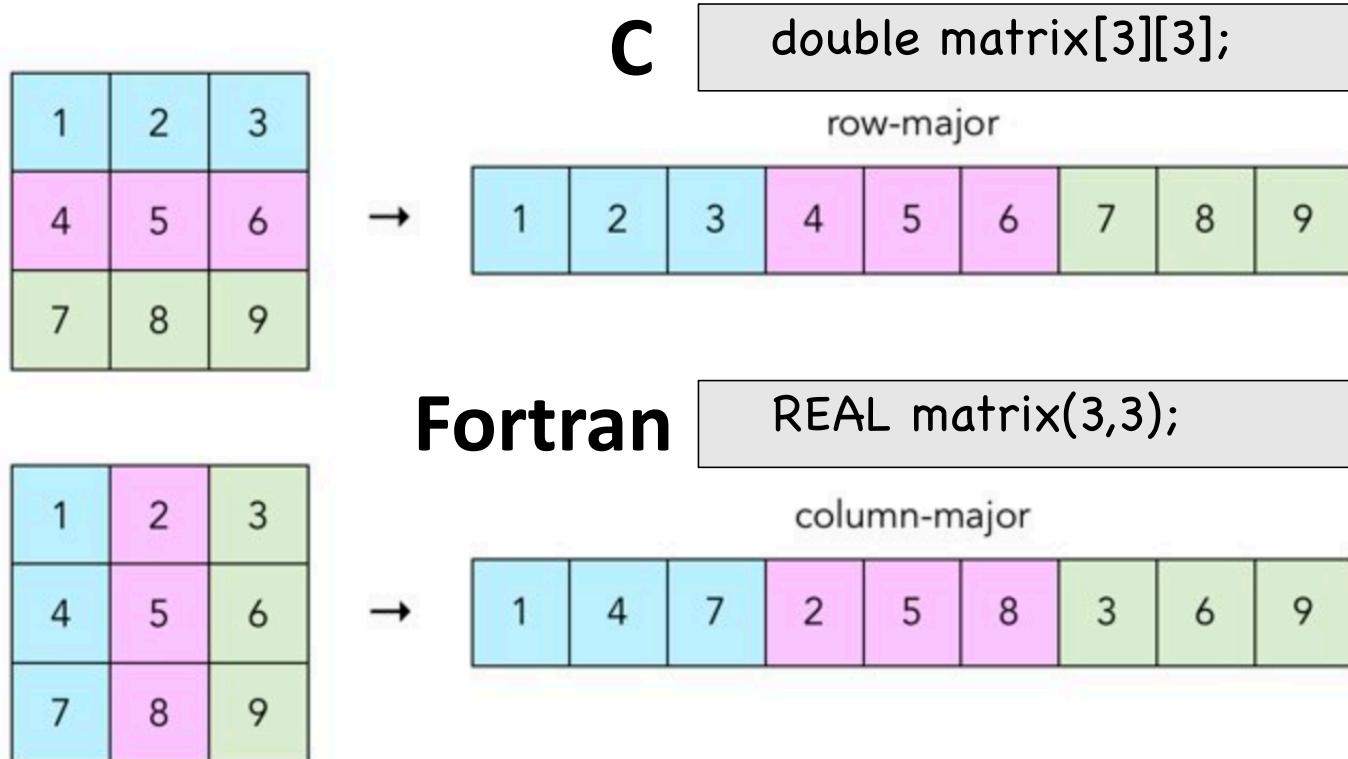
```
int main(int argc, char **argv) {
    double dArray[2][4]= {{19.1, 12, 13, 14e2},
                          {21.1, 22, 23, 24.2e-3}};
    dArray[0][0] = 101.5;
    int first = dArray[0][0];
    int last = dArray[1][3];
    printf("First %f, last %f \n", first, last);
    return(0);
}
```

array2.c

a[0][0]	a[0][1]	a[0][2]	a[0][3]
101.5	12	13	1400
21.1	22	23	.0242
a[1][0]	a[1][1]	a[1][2]	a[1][3]

*NOT USED A LOT*

# Memory Layout of Arrays in C and Fortran



2 reasons to bring it up:

1. can use a 1 dimensional array
2. when calling Fortran from c, you need to think about matrix (i.e. store in Fortran format)

# Allowable Variable Types in C – II

## qualifiers: unsigned, short, long

### 1. Integer Types

char	1 byte	-128 to 127 or 0 to 255
unsigned char	1 byte	0 to 255
signed char	1 byte	-128 to 127
int	2 or 4 bytes	-32,768 to 32,767 or -2,147,483,648 to 2,147,483,647
unsigned int	2 or 4 bytes	0 to 65,535 or 0 to 4,294,967,295
short	2 bytes	-32,768 to 32,767
unsigned short	2 bytes	0 to 65,535
long	4 bytes	-2,147,483,648 to 2,147,483,647
unsigned long	4 bytes	0 to 4,294,967,295

### 2. Floating Point Types

float	4 byte	1.2E-38 to 3.4E+38	6 decimal places
double	8 byte	2.3E-308 to 1.7E+308	15 decimal places
long double	10 byte	3.4E-4932 to 1.1E+4932	19 decimal places

### 3. Enumerated Types

### 4. **void** Type

### 5. Pointers

### 6. Derived Types

Structures,  
Unions,  
**Arrays**



## Programming Bootcamp

# C: Operations, Conditionals & Loops

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NSF award: CMMI 1612843

# Operations

- We want to do stuff with the data, to operate on it
- Basic Arithmetic Operations

+ , - , \* , / , %

```
#include <stdio.h>
op1.c

int main(int argc, const char **argv) {
    int a = 1;
    int b = 2;
    int c = a+b;
    printf("Sum of %d and %d is %d \n",a,b,c);
    return(0);
}
```

# You Can String Operations Together –

```
#include <stdio.h>
```

op2.c

```
int main(int argc, char **argv) {
```

```
    int a = 5;
```

```
    int b = 2;
```

```
    int c = a + b * 2;
```

**What is c? Operator precedence!**

```
    printf("%d + %d * 2 is %d \n",a,b,c);
```

```
    c = a * 2 + b * 2;
```

```
    printf("%d * 2 + %d * 2 is %d \n",a,b,c);
```

```
// use parentheses
```

```
c = ((a * 2) + b ) * 2;
```

**USE PARENTHESSES**

```
    printf("((%d * 2) + %d ) * 2; is %d \n",a,b,c);
```

```
    return(0);
```

```
}
```

```
[c >gcc oper3.c; ./a.out
5 + 2 * 2 is 9
5 * 2 + 2 * 2 is 14
((5 * 2) + 2 ) * 2; is 24
c >]
```

# C Operator Precedence Table

This page lists C operators in order of *precedence* (highest to lowest). Their *associativity* indicates in what order operators of equal precedence in an expression are applied.

Operator	Description	Associativity
( ) [ ] . -> ++ --	Parentheses (function call) (see Note 1) Brackets (array subscript) Member selection via object name Member selection via pointer Postfix increment/decrement (see Note 2)	left-to-right
++ -- + - ! ~ (type) * & sizeof	Prefix increment/decrement Unary plus/minus Logical negation/bitwise complement Cast (convert value to temporary value of type) Dereference Address (of operand) Determine size in bytes on this implementation	right-to-left
* / % + - << >> < <=	Multiplication/division/modulus Addition/subtraction Bitwise shift left, Bitwise shift right Relational less than/less than or equal to	left-to-right
> >=	Relational greater than/greater than or equal to	left-to-right
== !=	Relational is equal to/is not equal to	left-to-right
&	Bitwise AND	left-to-right
^	Bitwise exclusive OR	left-to-right
	Bitwise inclusive OR	left-to-right
&&	Logical AND	left-to-right
	Logical OR	left-to-right
? :	Ternary conditional	right-to-left
= += -= *= /= %= &= ^=  = <<= >>=	Assignment Addition/subtraction assignment Multiplication/division assignment Modulus/bitwise AND assignment Bitwise exclusive/inclusive OR assignment Bitwise shift left/right assignment	right-to-left
,	Comma (separate expressions)	left-to-right

# Some Operations are so Common there are special operators

```
#include <stdio.h>
int main() {
    ...
    a = a + 1;
    ...
}
```

**+ =**

a += 1;

**- =**

**\* =**

**/ =**

**++**

a ++;

**--**

# Conditional Code – if statement

```
if (condition) {  
    // code block  
}
```

- So far instruction sequence has been sequential, one instruction after the next .. Beyond simple programs we need to start doing something, if balance is less than 0 don't withdraw money

```
#include <stdio.h>  
int main(int argc, char **argv) {  
    int a = 15;  
    if (a < 10) {  
        printf("%d is less than 10 \n", a);  
    }  
    if (a == 10) {  
        printf("%d is equal to 10 \n", a);  
    }  
    if (a > 10) {  
        printf("%d is greater than 10 \n", a);  
    }  
    return(0);  
}
```

if1.c

Conditional  
Operators

<  
≤  
>  
≥  
==  
!=

# If-else

```
if (condition) {  
    // code block  
} else {  
    // other code  
}
```

```
#include <stdio.h>  
int main(int argc, char **argv) {  
    int a = 15;  
    if (a <= 10) {  
        if (a != 10) {  
            printf("%d is less than 10 \n", a);  
        } else {  
            printf("%d is equal to 10 \n", a);  
        }  
    } else {  
        printf("%d is greater than 10 \n", a);  
    }  
    return(0);  
}
```

if2.c

# else-if

```
if (condition) {  
    // code block  
} else if (condition) {  
    // another code block  
} else {  
    // and another  
}
```

```
#include <stdio.h>  
int main(int argc, char **argv) {  
    int a = 15;  
    if (a < 10) {  
        printf("%d is less than 10 \n", a);  
    } else if ( a == 10) {  
        printf("%d is equal to 10 \n", a);  
    } else {  
        printf("%d is greater than 10 \n", a);  
    }  
    return(0);  
}
```

if3.c

Can have multiple else if in if statement

# Logical Operators: and/or/not

```
#include <stdio.h>
int main(int argc, char **argv) {
    int a = 15;
    if ((a < 10) && (a == 10)) {
        if !(a == 10) {
            printf("%d is less than 10 \n", a);
        } else {
            printf("%d is equal to 10 \n", a);
        }
    } else {
        printf("%d is greater than 10 \n", a);
    }
    return(0);
}
```

&&  
||  
!

# Conditional Code – switch statement

- Special multi-way decision maker that tests if an expression matches one of a number of **constant** values

```
switch(expression) {  
    case constant-expression :  
        statement(s);  
        break; /* optional */  
    case constant-expression :  
        statement(s);  
        break; /* optional */  
    ....  
    default : /* Optional */  
        statement(s);  
}
```

```
#include <stdio.h>  
int main(int argc, char **argv) {  
    char c='Y';  
    switch (c) {  
        case 'Y':  
        case 'y':  
            c = 'y';  
            break;  
        default:  
            printf("unknown character %c \n",c);  
    }  
    return(0);  
}
```

# Iteration/loops - while

```
while (condition) {  
    // code block  
}
```

- Common task is to loop over a number of things, e.g. look at all files in a folder, loop over all values in an array,...

```
#include <stdio.h>
```

while1.c

```
int main(int argc, char **argv) {  
    int intArray[5] = {19, 12, 13, 14, 50};  
    int sum = 0, count = 0;  
    while (count < 5) {  
        sum += intArray[count];  
        count++; // If left out => infinite loop ..  
    }           // Something must happen in while to break out of loop  
    printf("sum is: %d \n", sum);  
}
```

If you do enough while loops you will recognize a pattern

- 1) Initialization of some variables,
- 2) condition,
- 3) increment of some value

Hence the for loop

# for loop

```
#include <stdio.h>
```

```
int main(int argc, char **argv) {
    int intArray[5] = {19, 12, 13, 14, 50};
    int sum = 0;
    for (int count = 0; count < 5; count++) {
        sum += intArray[count];
    }
    printf("sum is: %d \n", sum);
}
```

```
for (init; condition; increment) {
    // code block
}
```

for1.c

```
for (init; condition; increment) {  
    // code block  
}
```

## for loop – multiple init & increment

```
#include <stdio.h>
```

for2.c

```
int main(int argc, char **argv) {  
    int intArray[6] = {19, 12, 13, 14, 50, 0};  
    int sum = 0;  
    for (int i = 0, j=1; i < 5; i+=2, j+=2) {  
        sum += intArray[i] + intArray[j];  
    }  
    printf("sum is: %d \n", sum);  
}
```

Exercise: Code to count number of digits [0,9], white spaces (' ', '\n','\t') and other char in a file. Write info out.

```
#include <stdio.h>
int main(int argc, char **argv) {
    char c;
    int nDigit =0, nWhite =0, nOther = 0;
    while ((c = getchar()) != EOF) {
        // your code
    }
    // some more code here
}
```

1. emacs count.c
2. gcc count.c
3. ./a.out < count.c

**Exercise Advanced:** There is a text file file elCentro.dat in SimCenterBootcamp2020/code. Write program to create another file with same information but reduced in size and you can't open file of type binary, i.e. no open file of type 'wb' for those who know c

```
#include <stdio.h>
int main(int argc, char **argv) {
    // your code here
}
```

1. emacs count.c
2. icc count.c
3. ./a.out < count.c



## Programming Bootcamp

# C: Functions

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# Functions

- **Art of Programming:** *“To take a problem, and recursively break it down into a series of smaller tasks until ultimately these tasks become a series of small specific individual instructions.”*
- For large code projects we do not put all the code inside a single main block
- We break it up into logical/meaningful blocks of code. In object-oriented programming we call these blocks **classes**, in procedural programming we call these blocks **procedures or functions**.
- Functions make large programs manageable: easier to understand, allow for code re-use, allow it to be developed by teams of programmers,..

## C Function

```
returnType funcName (funcArgs) {  
    codeBlock  
}
```

- **returnType** <optional>: what data type the function will return, if no return is specified returnType is **int**. If want function to return nothing the return to specify is **void**.
- **funcName**: the name of the function, you use this name when “invoking” the function in your code.
- **funcArgs**: comma seperated list of args to the function.
- **codeBlock**: contains the statements to be executed when procedure runs. These are only ever run if procedure is called.

```
#include <stdio.h>
```

function1.c

```
// function to evaluate vector sum
int sumArray(int *data, int size) {
    int sum = 0;
    for (int i = 0; i < size; i++) {
        sum += data[i];
    }
    return sum;
}
```

```
int main(int argc, char **argv) {
    int intArray[6] = {19, 12, 13, 14, 50, 0};
    int sum = sumArray(intArray, 6);
    printf("sum is: %d \n", sum);
    return(0);
}
```

```
#include <stdio.h>
```

function2.c

```
// function to evaluate vector sum
int sumArray(int *data, int size) {
    int sum = 0;
    for (int i = 0; i < size; i++) {
        sum += *data++;
    }
    return sum;
}
```

```
int main(int argc, char **argv) {
    int intArray1[6] = {19, 12, 13, 14, 50, 0};
    int intArray2[3] = {21, 22, 23};
    int sum1 = sumArray(intArray1, 6);
    int sum2 = sumArray(intArray2, 3);
    printf("sums: %d and %d\n", sum1, sum2);
    return(0);
}
```

# Function Prototype

```
#include <stdio.h>                                         function3.c
int sumArray(int *arrayData, int size);
int main(int argc, char **argv) {
    int intArray1[6] = {19, 12, 13, 14, 50, 0};
    int intArray2[3] = {21, 22, 23};
    int sum1 = sumArray(intArray1, 6);
    int sum2 = sumArray(intArray2, 3);
    printf("sums: %d and %d\n", sum1, sum2);
    return(0);
}
// function to evaluate vector sum
int sumArray(int *data, int size) {
    int sum = 0;
    for (int i = 0; i < size; i++) {
        sum += *data++;
    }
    return sum;
}
```

Good practice to give the args names. Names are not actually needed (but they remind you and show others the purpose of each arg)

## Good Practice:

1. For large programs it is a good idea to put functions into different files (many different people can be working on different parts of the code)
2. If not too large, put them in logical units, i.e. all functions dealing with vector operations in 1 file, matrix operations in another.
3. Put prototypes for all functions in another file, a .h file.
4. Get into a system of documenting inputs and outputs.

## main.c

```
#include <stdlib.h>
#include <stdio.h>
#include <time.h>
#include "myVector.h"

int main(int argc, char **argv) {
    if (argc != 3) {
        fprintf(stderr,"Need 3 args: appName n maxVal\n");
        return -1;
    }
    int n = atoi(argv[1]);
    double maxVal = atof(argv[2]);

    double *data1 = createMyVector(n);
    double *data2 = createMyVector(n);
    double *data3 = createMyVector(n);
    // fill in vectors with random values
    srand(100); //srand((unsigned int)time(0));
    for (int i=0; i<n; i++) {
        data1[i] = ((float)rand()/(float)RAND_MAX) * maxVal;
        data2[i] = ((float)rand()/(float)RAND_MAX) * maxVal;;
    }
    printMyVector(data1, n, "vector 1");
    printMyVector(data2, n, "vector 2");

    // dotSum the vectors & print result;
    dotSumMyVector(data1, data2, data3, n);
    printMyVector(data3, n, "dotSum");
    return 0;
}
```

## myVector.h

```
double *createMyVector(int size);
double normMyVector(double *data, int size);
double dotMyVector(double *data1, double *data2, int size);
void dotSumMyVector(double *data1, double *data2, double *result, int size);
void printMyVector(double *data, int size, char *name);
```

## myVector.c

```
double normMyVector(double *data, int size) {

    double dot = 0;

    for (int i = 0; i < size; i++) {

        dot += data[i]*data[i];
    }

    return sqrt(dot);
}
```

# Scope of Variables

```
#include <stdio.h>
int sum(int, int);
int x = 20; // global variable
int main(int argc, char **argv) {
    printf("LINE 5: x = %d\n",x);

    int x = 5;
    printf("LINE 8: x = %d\n",x);

    if (2 > 1) {
        int x = 10;
        printf("LINE 12: x = %d\n",x);
    }
    printf("LINE 14: x = %d\n",x);

    x = sum(x,x);
    printf("LINE 17: x = %d\n",x);
}

int sum(int a, int b) {
    printf("LINE 21: x = %d\n",x);
    return a+b;
}
```

scope1.c

```
[c >gcc scope1.c; ./a.out
LINE 5: x = 20
LINE 8: x = 5
LINE 12: x = 10
LINE 14: x = 5
LINE 21: x = 20
LINE 17: x = 10
c >]
```

# Pass By Value, Pass by Reference

- C (unlike some languages) all args are passed by value

**to change the function argument in the callers “memory” we can pass pointer to it, i.e it’s address in memory.**

**This is Useful if you want multiple variables changed, or want to return an error code with the function.**

```
#include <stdio.h>                                         function4.c

sumInt(int1, int2, int *sum);

int main() {
    int int1, int2, sum=0;
    printf("Enter first integer: ");
    scanf("%d", &int1);
    printf("Enter second integer: ");
    scanf("%d", &int2);
    sumInt(int1, int2, &sum);
    print("%d + %d = %d \n", int1, int2, sum)
}

void sumInt(int a, int b, int *sum) {
    *sum = a+b;
}
```

# Math Functions in <math.h>, link with -lm

Pre-C99 functions [\[edit\]](#)

Name	Description
acos	inverse cosine
asin	inverse sine
atan	one-parameter inverse tangent
atan2	two-parameter inverse tangent
ceil	ceiling, the smallest integer not less than parameter
cos	cosine
cosh	hyperbolic cosine
exp	exponential function
fabs	absolute value (of a floating-point number)
floor	floor, the largest integer not greater than parameter
fmod	floating-point remainder: $x - y * (\text{int})(x/y)$
frexp	break floating-point number down into mantissa and exponent
ldexp	scale floating-point number by exponent (see article)
log	natural logarithm
log10	base-10 logarithm
modf( <i>x, p</i> )	returns fractional part of <i>x</i> and stores integral part where pointer <i>p</i> points to
pow( <i>x, y</i> )	raise <i>x</i> to the power of <i>y</i> , $x^y$
sin	sine
sinh	hyperbolic sine
sqrt	square root
tan	tangent
tanh	hyperbolic tangent]]

```
#include <stdio.h>
#include <math.h>
int main() {
    double a = 34.0;
    double b = sqrt(a);
    print("%f + %f = %f \n", a, b)
    return 0;
}
```

```
[c >]gcc math1.c -lm; ./a.out
sqrt(34.00000) is 5.830952
c >]
```

# Recursion

- Recursion is a powerful programming technique commonly used in divide-and-conquer situations.

```
[c >gcc recursion.c -o factorial;  
[c >./factorial 3  
factorial(3) is 6  
[c >./factorial 4  
factorial(4) is 24  
[c >./factorial 10  
factorial(10) is 3628800  
c >]
```

Can you think how this program can go into an infinite loop?

```
#include <stdio.h>  
#include <stdlib.h>  
int factorial(int n);  
int main(int argc, char **argv) {  
    if (argc < 2) {  
        printf("Program needs an integer argument\n");  
        return(-1);  
    }  
    int n = atoi(argv[1]);  
    int fact = factorial(n);  
    printf("factorial(%d) is %d\n",n, fact);  
    return 0;  
}  
int factorial(int n) {  
    if (n == 1)  
        return 1;  
    else  
        return n*factorial(n-1);  
}
```

recursion1.c

i

# Exercise: Write a function to sum two values

```
#include <stdio.h>
int sumInt(int a, int b);
int main() {
    int integer1, integer2, sum;
    printf("Enter two integers (space separated): ");
    scanf("%d %d", &integer1, &integer2); // read input to integer 1
    sum = sumInt(integer1, integer2);
    printf("sum %d + %d = %d\n", integer1, integer2, sum);
    return(0);
}
// your code here
int sumInt(int a, int b) {
    // your code here
}
```

**&integer1: memory address of integer1**

1. emacs sumc
2. icc sum.c
3. ./a.out