SimCenter NHERI
Center for Computational Modeling and Simulation

Programming Bootcamp

C,C++ And Parallel Procesing

Frank McKenna
University of California at Berkeley

NSF award: CMMI 1612843

Why Another Language?

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

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Computers & Computer Programs

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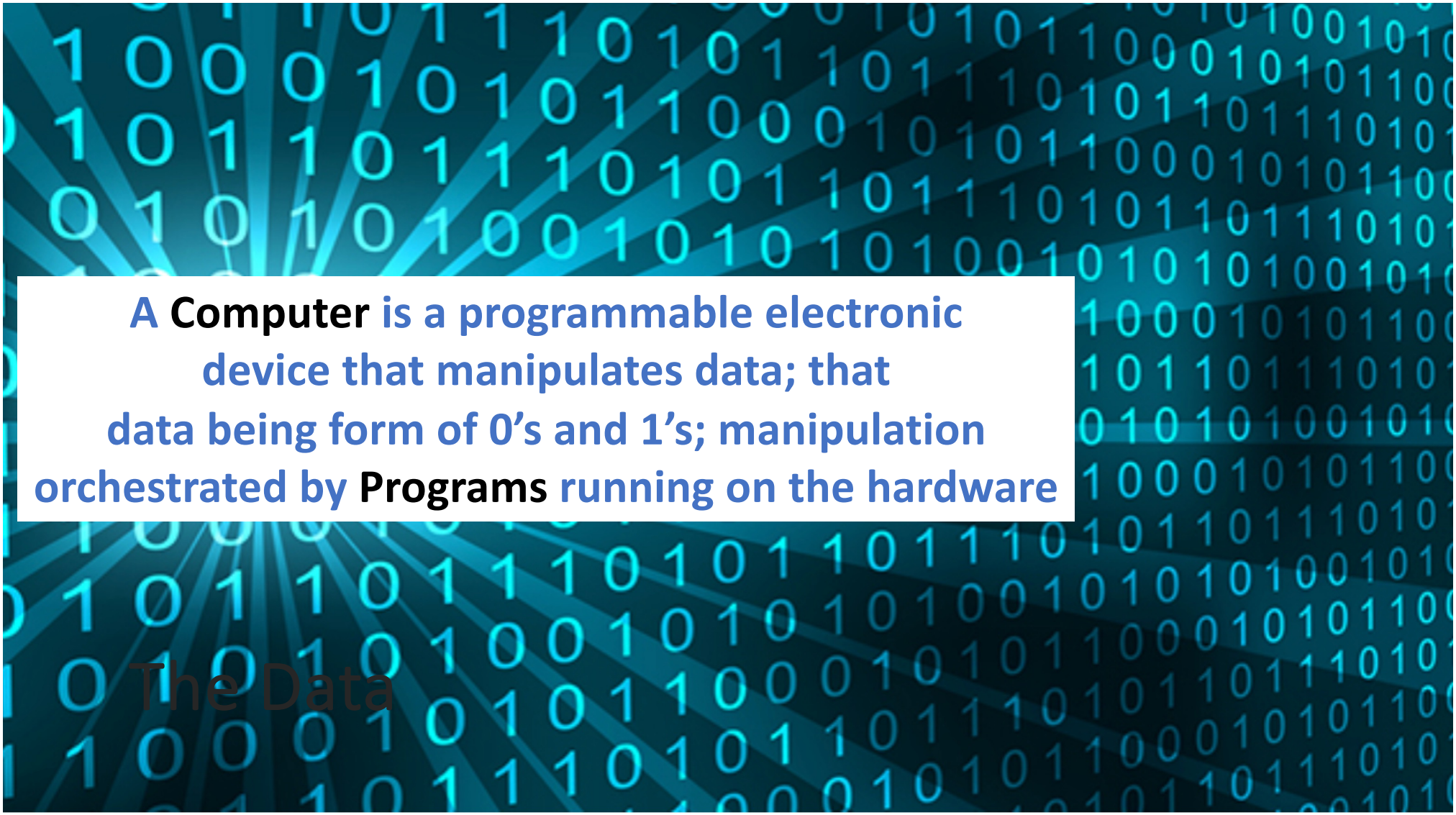
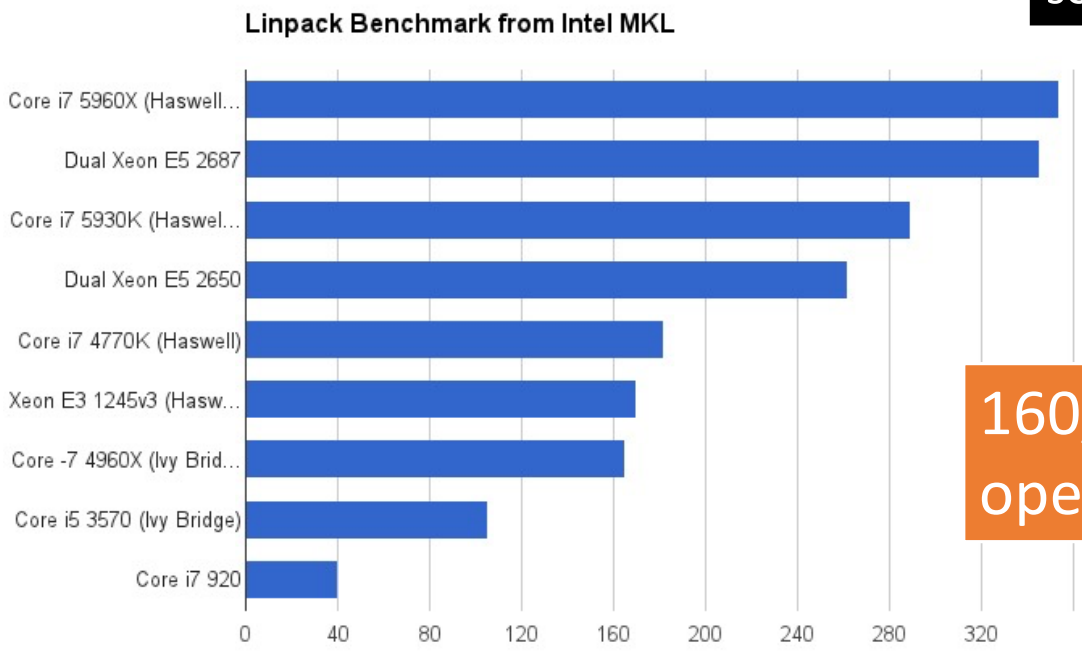

A Computer is a programmable electronic
device that manipulates data; that
data being form of 0's and 1's; manipulation
orchestrated by Programs running on the hardware
The Data

Computers Are Greatly Limited in What they can do!

They Just Do What They Can do Incredibly Fast

How Fast?

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



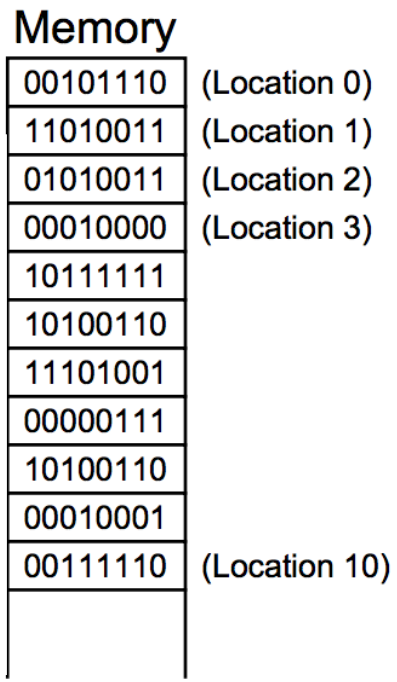
160/8 = 20 floating point operations per person per second!

GFLOPS = 1 billion floating point operations per second

What is a Computer Application?

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.



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

```
if a > 0 then
  writeln("yes")
else
  writeln("no");
```

ADA:

```
if a > 0 then
   Put_Line("yes");
else
   Put_Line("no");
end if;
```

C:

```
if (a > 0) {
   printf("yes");
} else {
   printf("no");
}
```

SHELL SCRIPT:

```
if [ $a -gt 0 ]; then
   echo "yes"
else
   echo "no"
fi
```

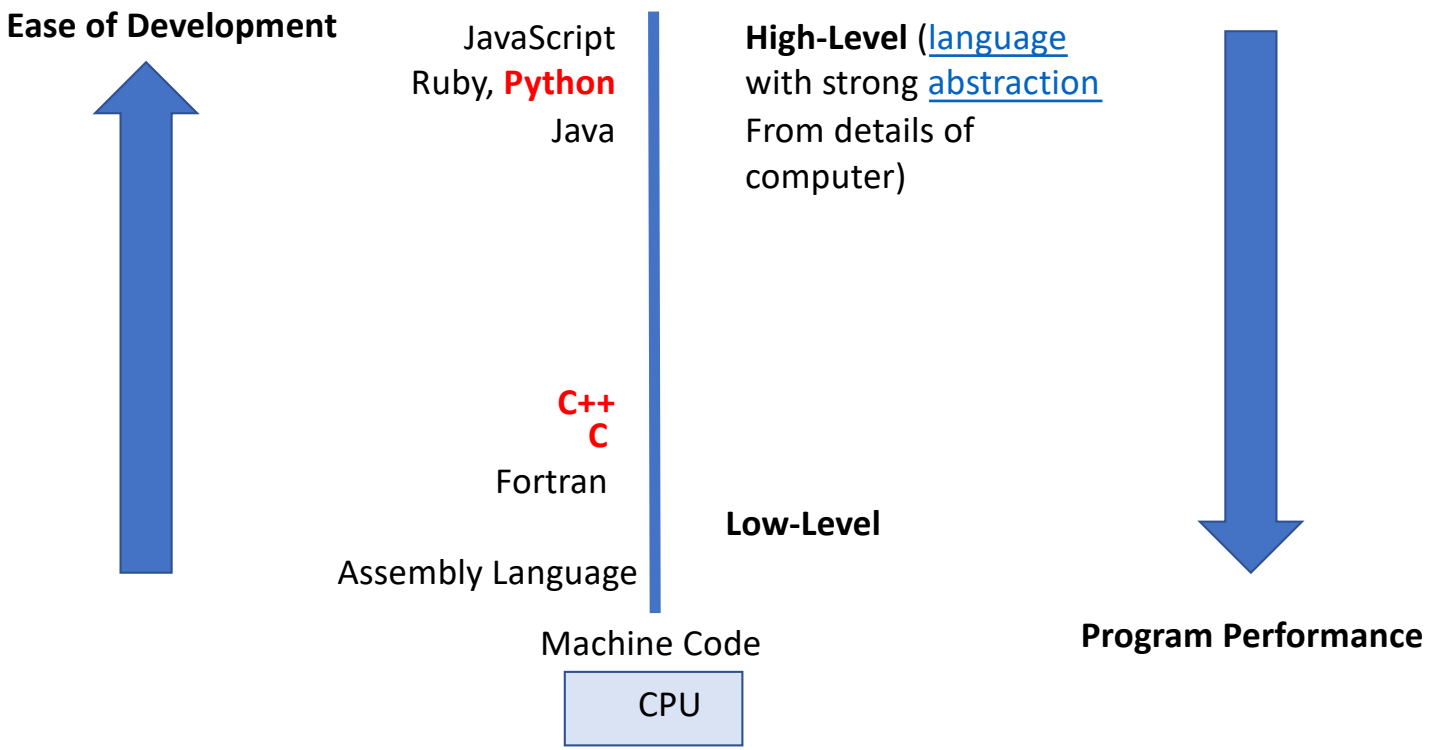
PYTHON:

```
if a > 0:
   print "yes"
else:
   print "no"
```

TCL

```
If ($a > 0} {
   puts “yes”
} else {
   puts “no”
}
```

Programming Language Hierarchy



Speed Comparison

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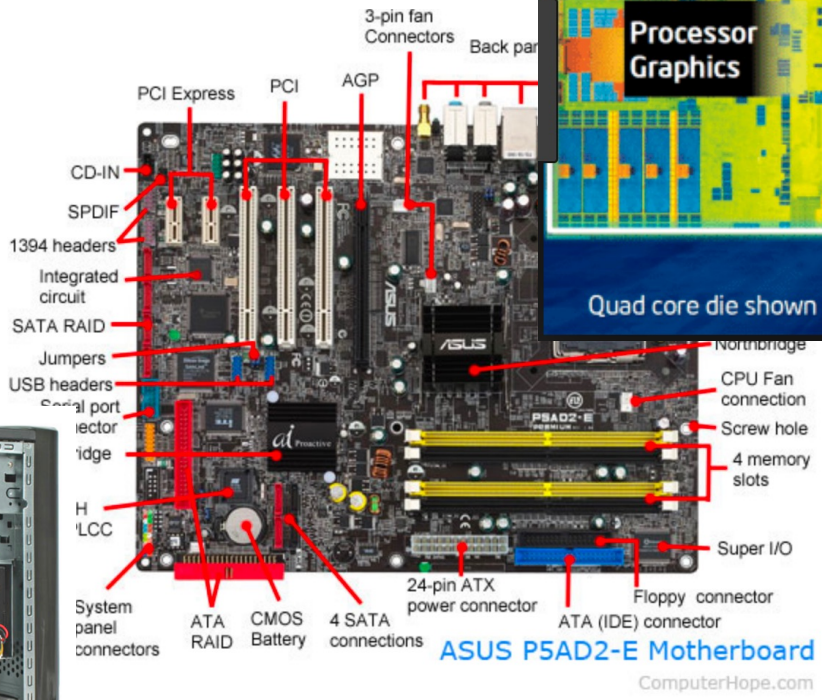
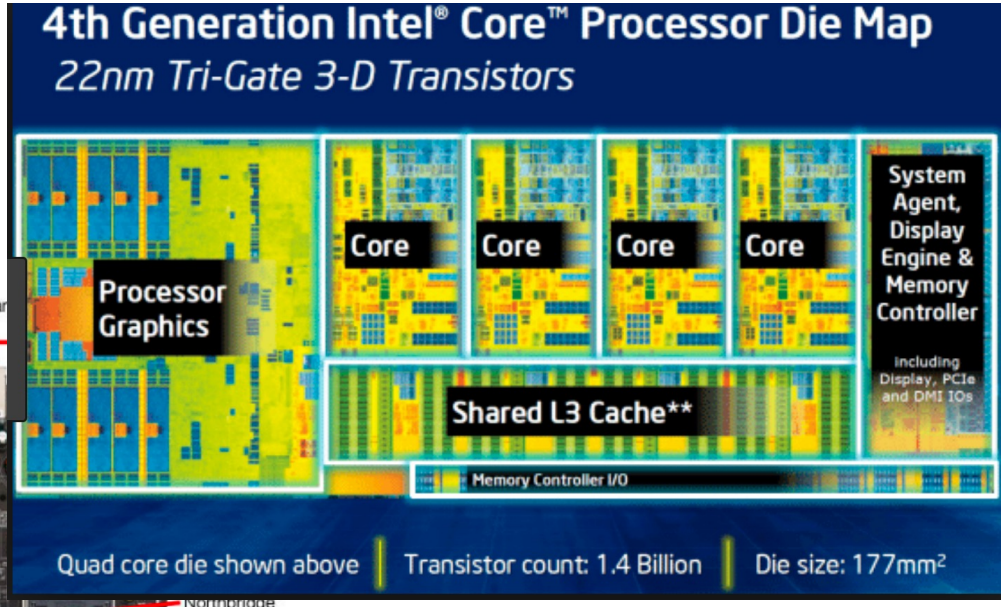
PYTHON Performance: original 160 GFLOP/60000 = 2.5 Million FLOPS or each person in the 193rd most populous city, Lubumbashi Dr Congo (pop 2,478,262) doing 1 floating point operation a second!

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


3-pin fan Connectors
Back par
PCI Express
PCI
AGP
CD-IN
SPDIF
1394 headers
Integrated circuit
SATA RAID
Jumpers
USB headers
Northbridge
CPU Fan connection
Screw hole
4 memory slots
Super I/O
Floppy connector
ATA (IDE) connector
24-pin ATX power connector
System panel connectors
ATA RAID
CMOS Battery
4 SATA connections
ASUS P5AD2-E Motherboard
ComputerHope.com


4th Generation Intel® Core™ Processor Die Map
22nm Tri-Gate 3-D Transistors
Processor Graphics
Core
Core
Core
Core
System Agent, Display Engine & Memory Controller
including Display, PCIe and DMI IOs
Shared L3 Cache**
Memory Controller I/O
Quad core die shown above
Transistor count: 1.4 Billion
Die size: 177mm²

Cores only Work on Data in Registers

Which is Why Understanding Memory Hierarchy is Crucial

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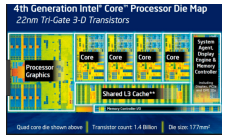
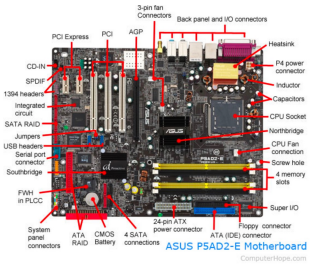
Memory Hierarchy

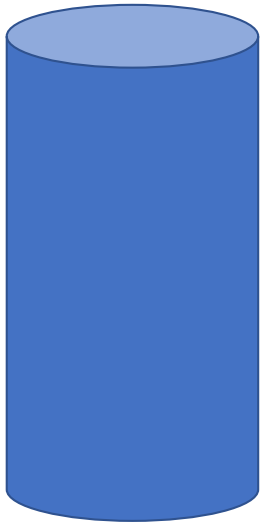


Core Processor



Disk

	Control	L1 Cache	L2 Cache	L3 Cache	Memory(RAM)	Hard Drive	SSD
Size	1000 Bytes	64 KB	256 KB	2-4 MB	4-32 GB	4-16 TB	.25-1TB
Latency	0.3 ns	1 ns	3-10 ns	20-30 ns	50-100 ns	5-10e6 ns	25-50e3 ns
	Compiler	HW	HW	HW	Operating System	Operating System	

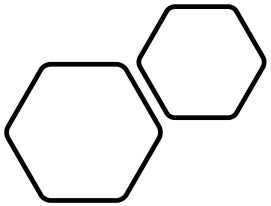


Why Do Caches Work?

- **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

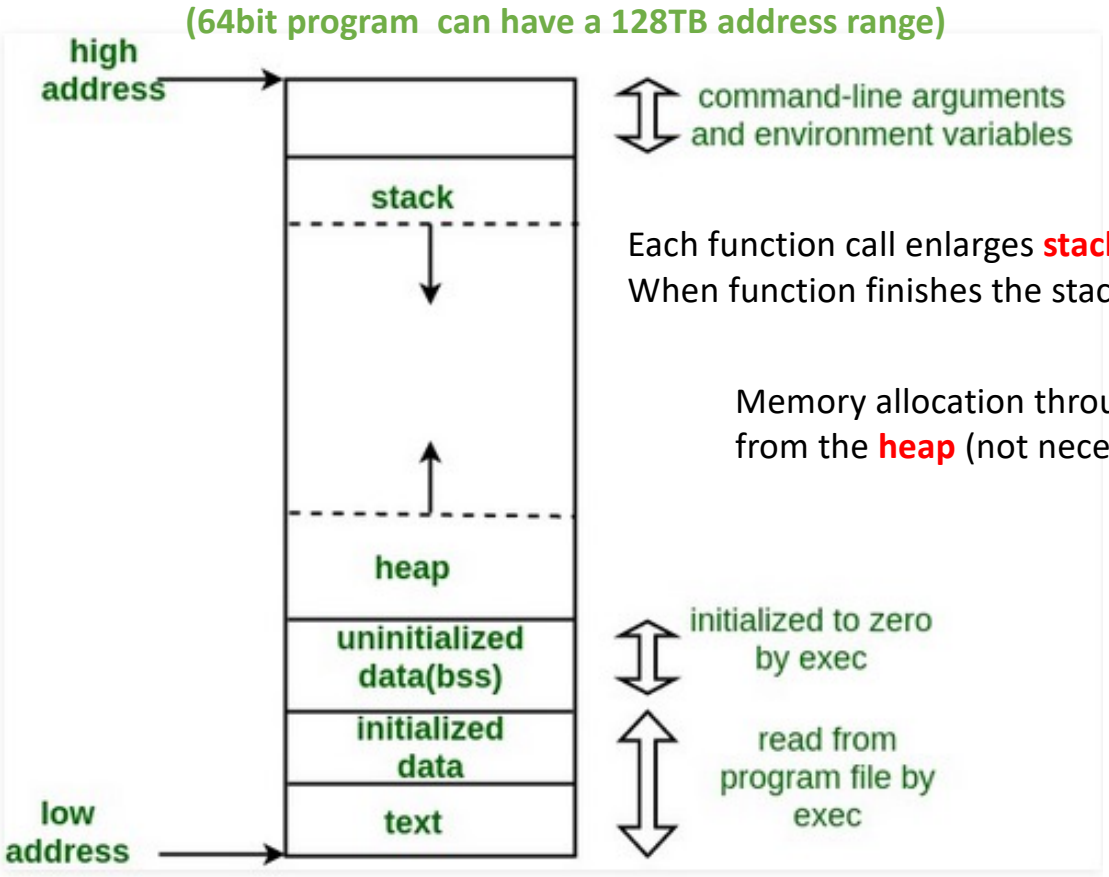
```
int main(int argc, char **argv) {
   …
  double dotProduct = 0
   for (int i=0, i<vectorSize; i++)
      dotProduct += x[i] * y[i];
   …
}
```

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

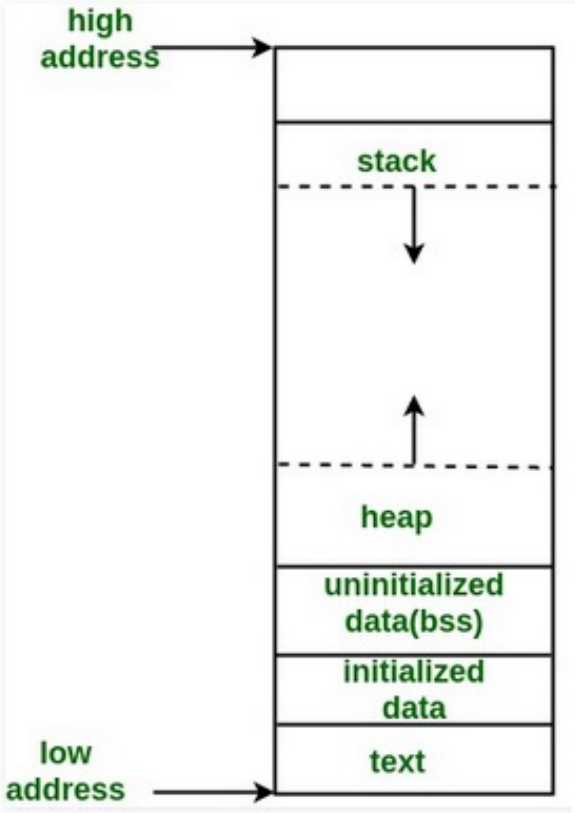


Each function call enlarges **stack** with the function variables
When function finishes the stack is popped

Memory allocation through malloc() and new[] is allocated memory from the **heap** (not necessarily one chunk after another)

Memory of a RUNNING Program versus RAM

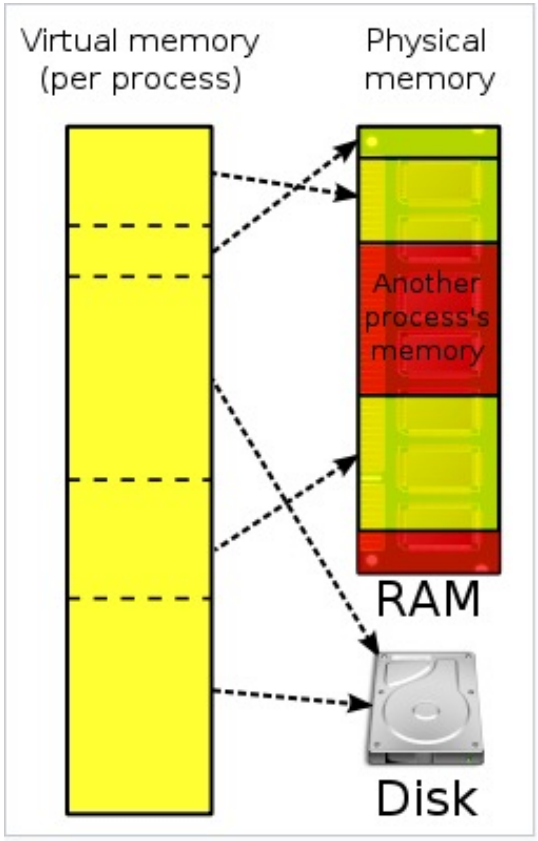
(64bit program can have a 128TB address range)



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

RAM 32GB

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 Boatload 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

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Introduction to C & Compilation

Frank McKenna
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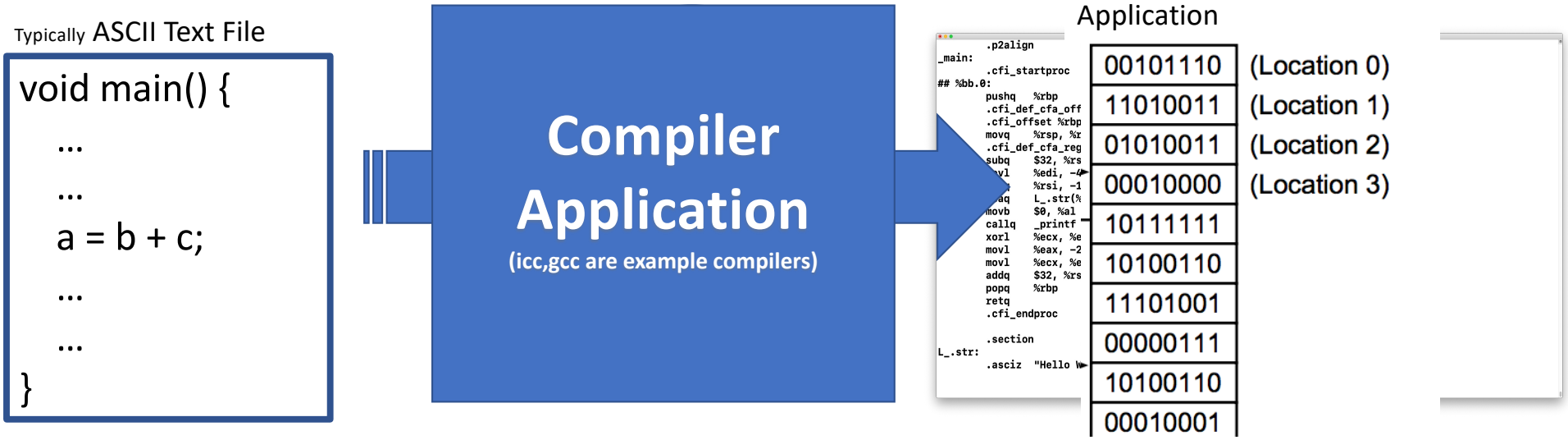
NSF award: CMMI 1612843

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!)
- No Automatic Garbage Collection
- 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,



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.

Python (weakly typed)

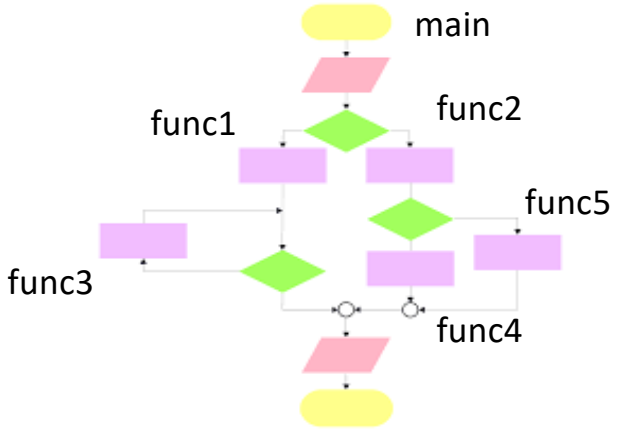
```
..
a=3.0
..
```

C (strongly typed)

```
..
double a=3.0;
..
```

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

hello1.c

```
#include <stdio.h>

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. It's implementation in the standard C library.
- The next statement **return 0;** terminates the main() function and returns the value 0.

BREAK

Exercise: git setup, compile & Run Hello World on Frontera

1. fork the SimCenterBootcamp2024 github repo
2. ssh yourname@frontera.tacc.utexas.edu
3. git clone https://github.com/YOUR GIT LOGIN/SimCenterBootcamp2024.git
4. cd SimCentercBootcamp2024
5. git remote add upstream https://github.com/NHERI-SimCenter/SimCenterBootcamp2024.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;
}
```

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C: Variable Types & Variable Names

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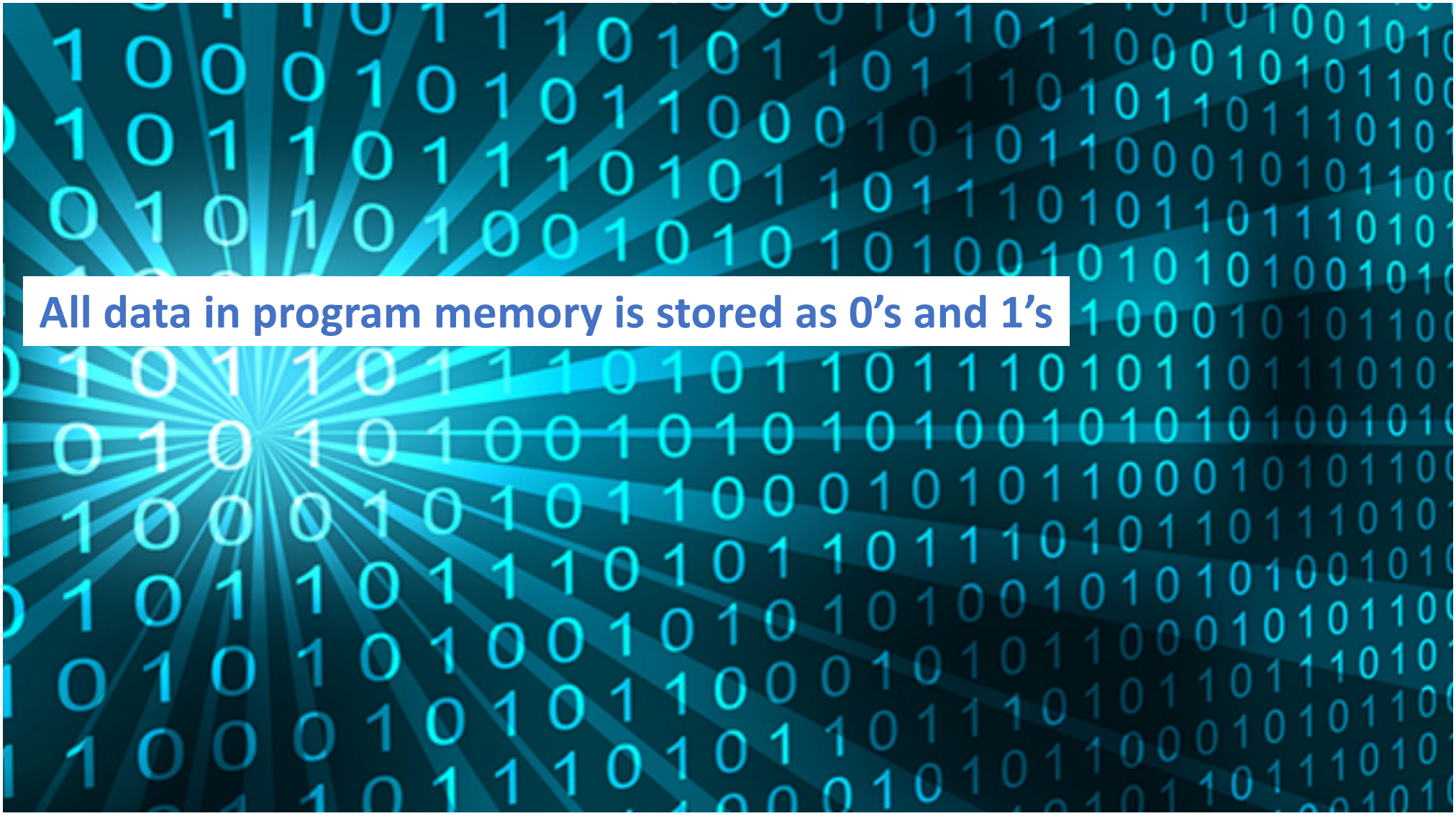

All data in program memory is stored as 0’s and 1’s

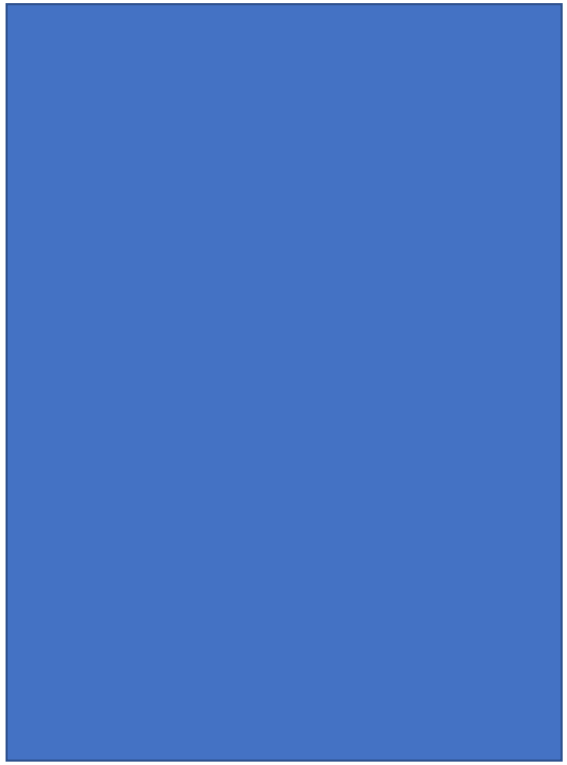
Computers Work in Binary

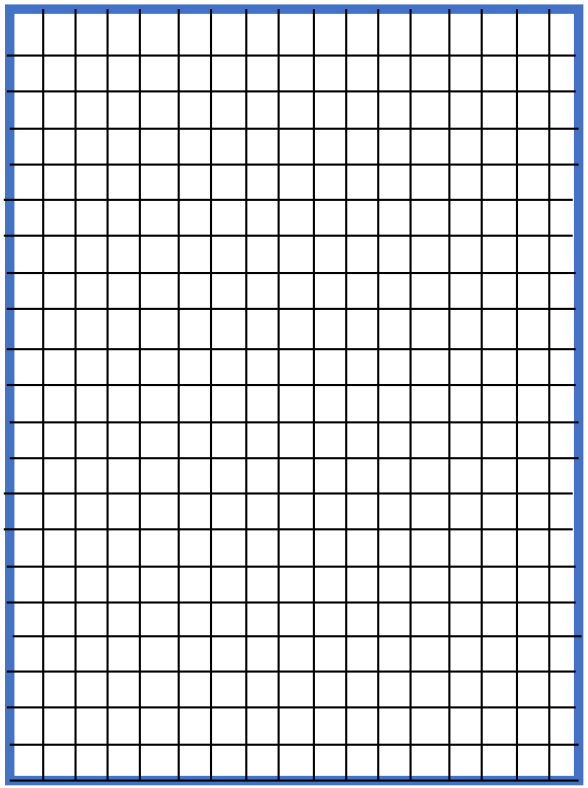
- The smallest unit of data (each individual 0 or 1 in program memory) is called a **BIT**
- Trick Programmers have used is to group bits together to represent more data, e.g. Possibilities for 3 bits (2^3 combinations)

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

C breaks program memory into byte sized units

1 Byte = 8 bits





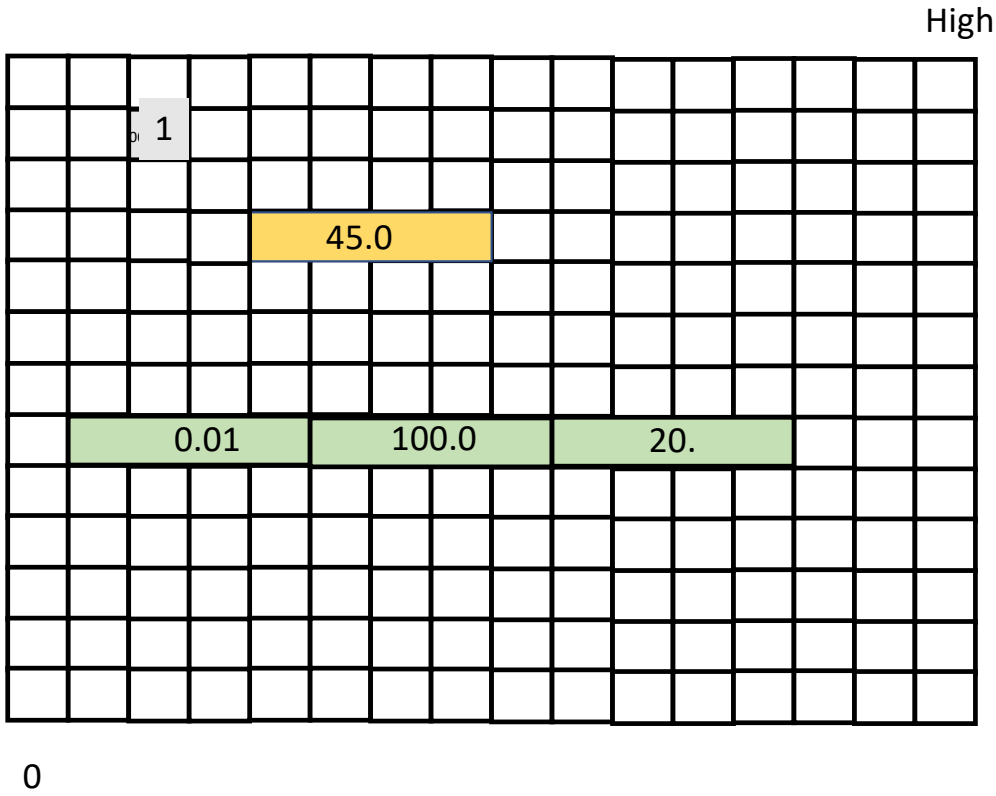
To a single Byte or Contiguous Array of Bytes the Programmer can associate the byte(s) with a variable name, and then use thar name in the program to set and use the values stored in those bytes.

```
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

C KEYWORDS OR RESERVED WORDS

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

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	00001000	010	08	BS	40	00101000	050	28	(	72	01001000	110	48	H	104	01101000	150	68	h
9	00001001	011	09	HT	41	00101001	051	29	)	73	01001001	111	49	I	105	01101001	151	69	i
10	00001010	012	0A	LF	42	00101010	052	2A	*	74	01001010	112	4A	J	106	01101010	152	6A	j
11	00001011	013	0B	VT	43	00101011	053	2B	+	75	01001011	113	4B	K	107	01101011	153	6B	k
12	00001100	014	0C	FF	44	00101100	054	2C	,	76	01001100	114	4C	L	108	01101100	154	6C	l
13	00001101	015	0D	CR	45	00101101	055	2D	-	77	01001101	115	4D	M	109	01101101	155	6D	m
14	00001110	016	0E	SO	46	00101110	056	2E	.	78	01001110	116	4E	N	110	01101110	156	6E	n
15	00001111	017	0F	SI	47	00101111	057	2F	/	79	01001111	117	4F	O	111	01101111	157	6F	o
16	00010000	020	10	DLE	48	00110000	060	30	0	80	01010000	120	50	P	112	01110000	160	70	p
17	00010001	021	11	DC1	49	00110001	061	31	1	81	01010001	121	51	Q	113	01110001	161	71	q
18	00010010	022	12	DC2	50	00110010	062	32	2	82	01010010	122	52	R	114	01110010	162	72	r
19	00010011	023	13	DC3	51	00110011	063	33	3	83	01010011	123	53	S	115	01110011	163	73	s
20	00010100	024	14	DC4	52	00110100	064	34	4	84	01010100	124	54	T	116	01110100	164	74	t
21	00010101	025	15	NAK	53	00110101	065	35	5	85	01010101	125	55	U	117	01110101	165	75	u
22	00010110	026	16	SYN	54	00110110	066	36	6	86	0101011								
23	00010111	027	17	ETB	55	00110111	067	37	7	87	0101011								
24	00011000	030	18	CAN	56	00111000	070	38	8	88	0101100								
25	00011001	031	19	EM	57	00111001	071	39	9	89	0101100								
26	00011010	032	1A	SUB	58	00111010	072	3A	:	90	0101101								
27	00011011	033	1B	ESC	59	00111011	073	3B	;	91	0101101								
28	00011100	034	1C	FS	60	00111100	074	3C	<	92	01011100	134	5C	\	124	01111100	174	7C	|
29	00011101	035	1D	GS	61	00111101	075	3D	=	93	01011101	135	5D	]	125	01111101	175	7D	}
30	00011110	036	1E	RS	62	00111110	076	3E	>	94	01011110	136	5E	^	126	01111110	176	7E	~
31	00011111	037	1F	US	63	00111111	077	3F	?	95	01011111	137	5F	_	127	01111111	177	7F	DEL

```
char one = '1';
char yes = 'Y';
```

int – size 4 Byte (2^32 possibilities)

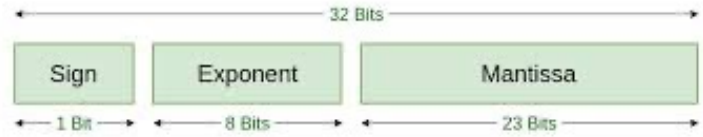
any int in range: -2,147,483,648 to 2,147,483,647

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	$\pm 1.18\times10^{-38}$	to $\pm 3.4\times10^{38}$	Approx. 7 decimal digits
double	64 bits	$\pm 2.23\times10^{-308}$	to $\pm 1.80\times10^{308}$.	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(base 10) = 1 + 7/10 + 2/100

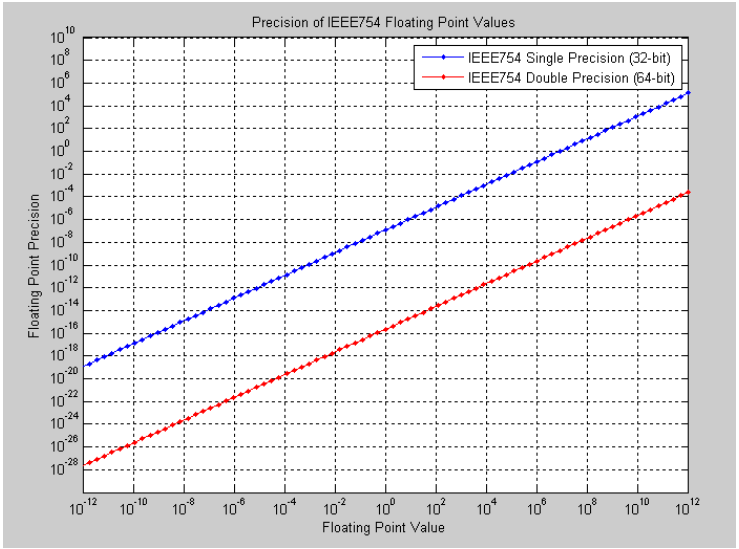
What is number in base 2 using 10 bit mantissa?

1.72 = 1 + 1/2 + 0/4 + 1/8 + 1/16 + 1/32 + 0/64 + 0/128 + 0/256 + 0/512 + 1/1024 + ... Ignored due to limit on # bits allowed

1.1011100001(base 2) => 1.71972656(base 10)

!= 1.72.

Some ERROR associated with # depends on #

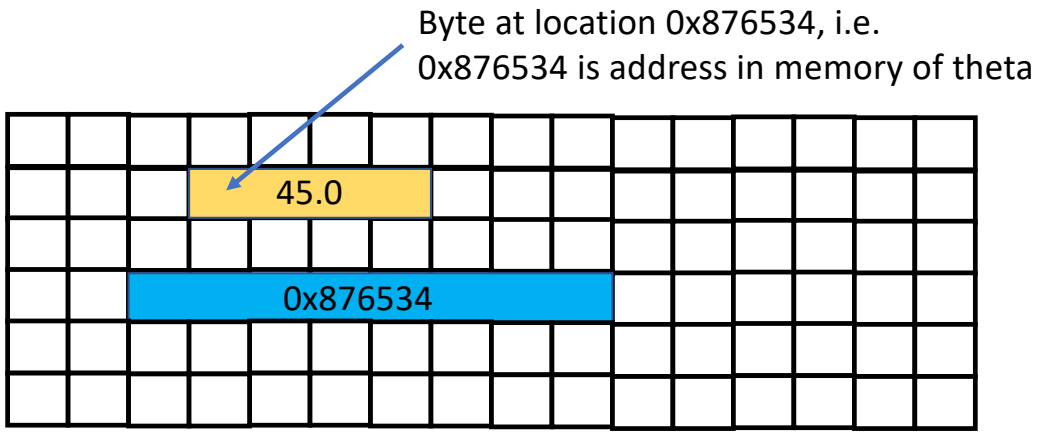


Question: Can 0.1 be represented exactly on a computer using IEEE?

POINTERS .. WE WILL REVIST TOMORROW

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

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



Pointer Variables

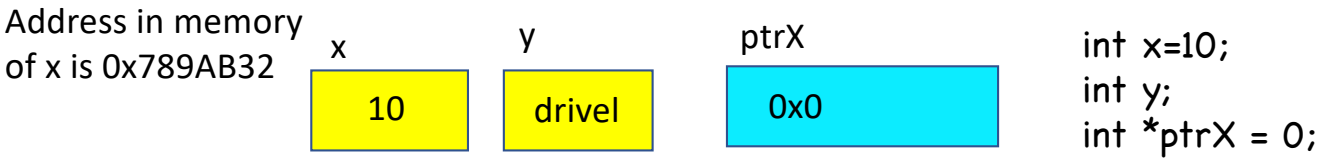
A **Pointer Variable** is a named memory location that can holds an address**.**

1. The unary * in a declaration indicates that the object is a pointer to an object of a specific type

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

pointer1.c

1.



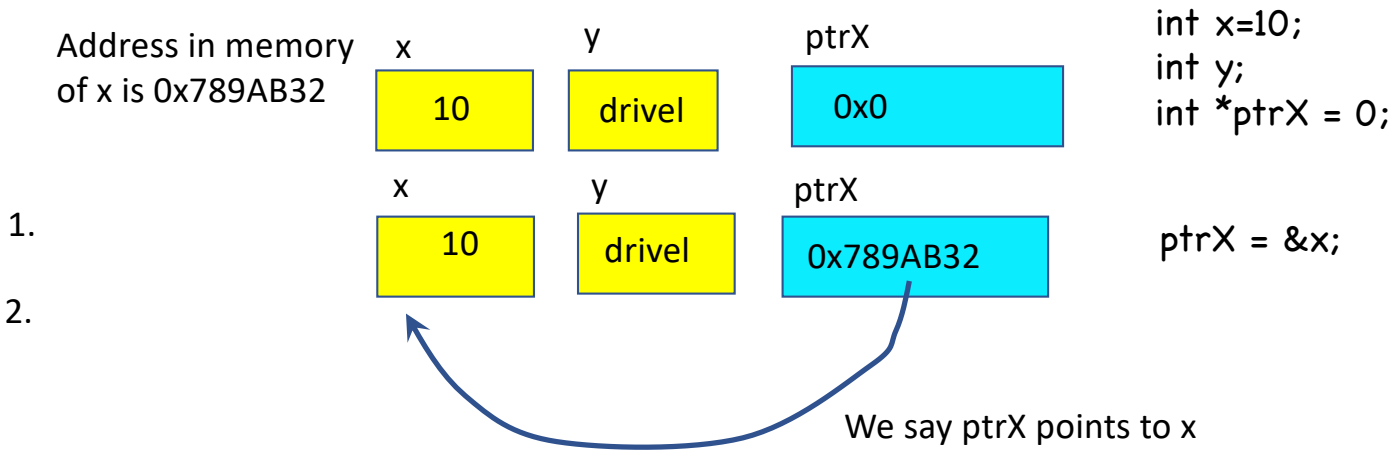
Pointer Variables

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

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

pointer1.c



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 dereferences it, which depending on which side of operand is does one of two things:

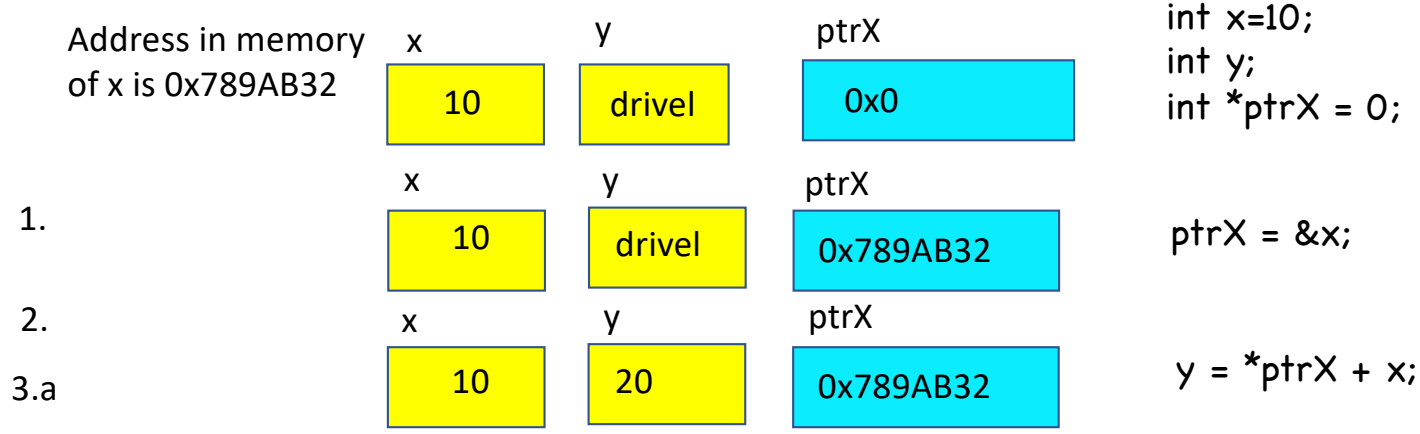
    a. fetches the contents for use in an expression

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

}
```

pointer1.c

Address in memory of x is 0x789AB32



Pointer Variables

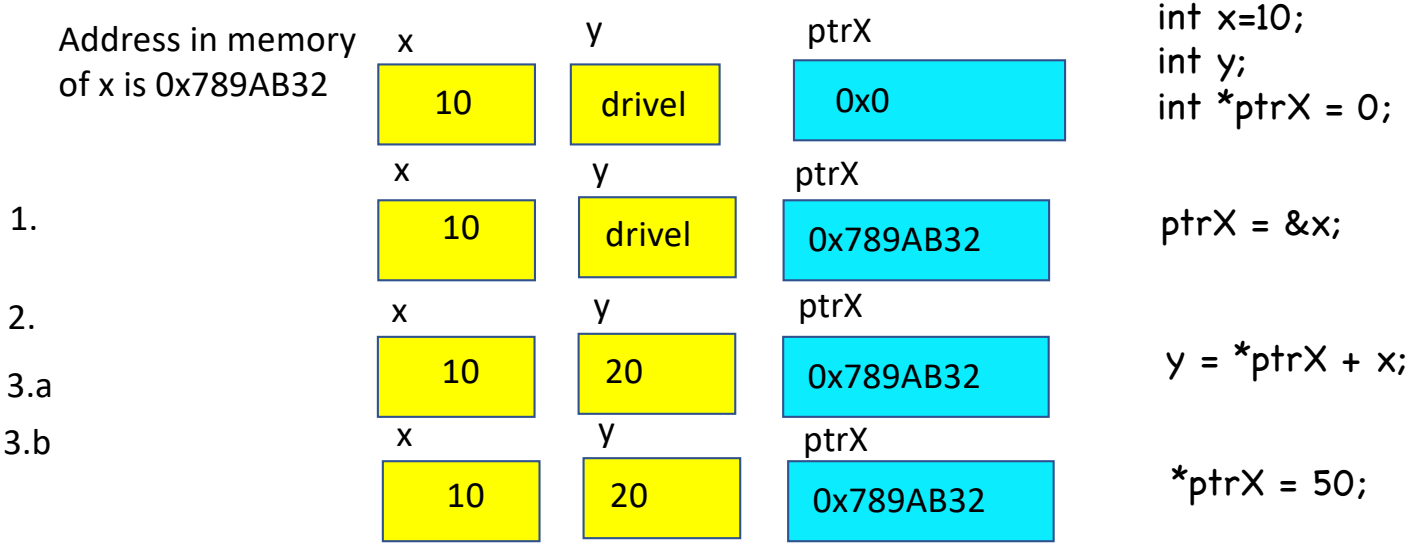
A **Pointer Variable** is a named memory location that can holds an address**.**

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 dereferences it, which depending on which side of operand is does one of two things:
   a. fetches the contents for use in an expression
   b. Sets the memory location to which it points to some value.

```
#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



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

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

Variable Example

var1.c

```
#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;
}
```

Uninitialized Variable

var2.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;
}
```

Initialized Variable

Some Allowable Variable Types in C

char
int
float
double

var3.c

```
#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;
}
```

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];

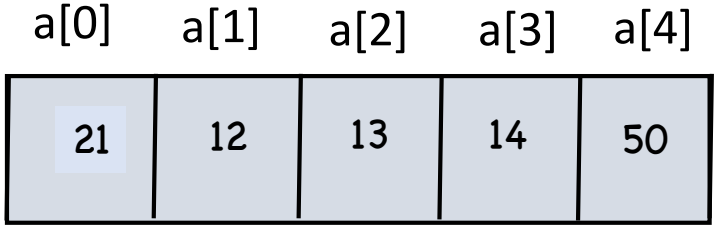
  type arrayName [size] = {size comma separated values}

array1.c

```
#include <stdio.h>

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

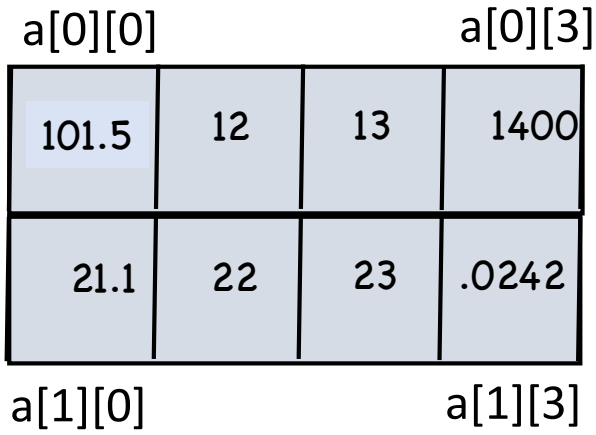
- A fixed size sequential collection of elements laid out in memory of the *same* type
  We access using an index inside a square brackets, indexing start at 0 var1.c
- to declare: type arrayName [l1][l2][l3]…;

  type arrayName [l1][l2][l3] = {l1*l2*… comma separated values

array2.c

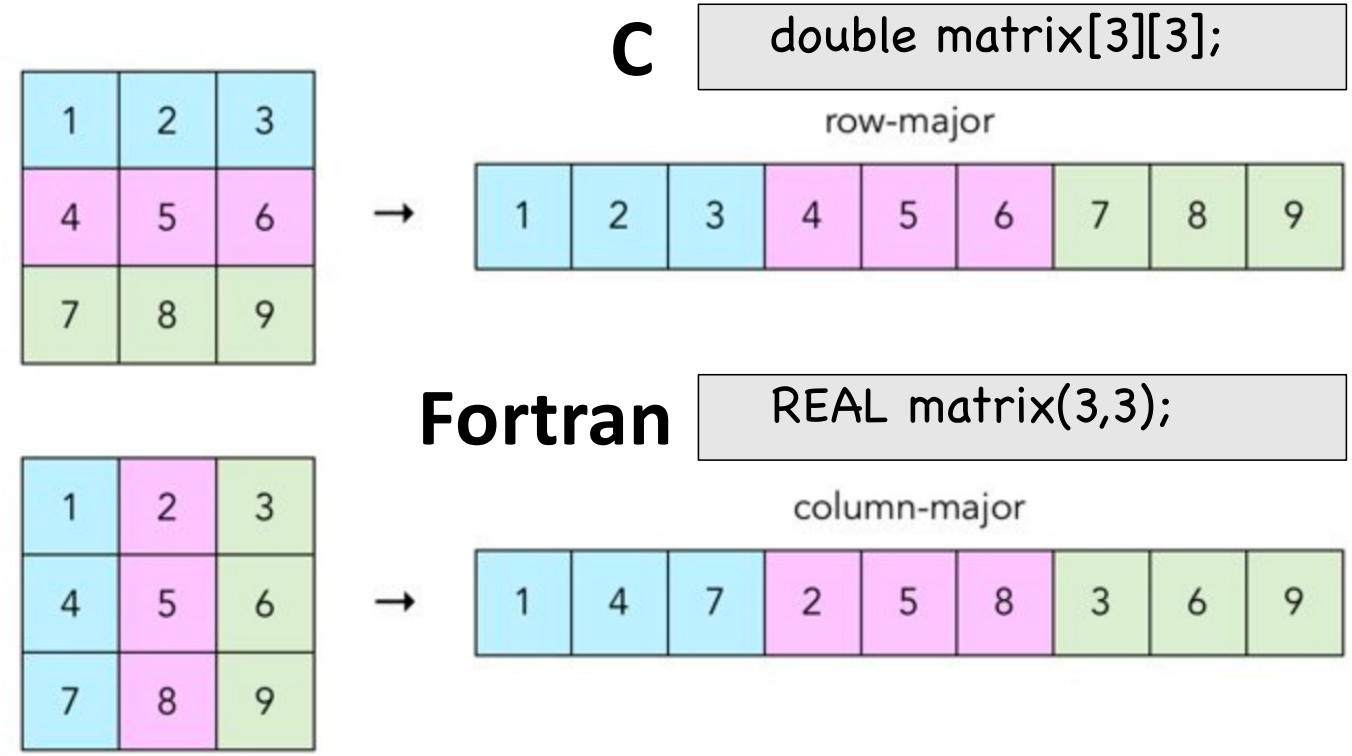
```
#include <stdio.h>

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);
 }
```



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

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Programming Bootcamp

C: Operations, Conditionals & Loops

Frank McKenna
University of California at Berkeley

NSF award: CMMI 1612843

Operations

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

+, -, *, /, %

op1.c

```
#include <stdio.h>

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 –

op2.c

```
#include <stdio.h>
int main(int argc, char **argv) {
  int a = 5;
  int b = 2;
  int c = a + b * 2;
  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;
  printf("((%d * 2) + %d ) * 2; is %d  \n",a,b,c);
  return(0);
}
```

What is c? Operator precedence!

USE PARENTHESES

```
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	left-to-right
+ -	Addition/subtraction	left-to-right
<< >>	Bitwise shift left, Bitwise shift right	left-to-right
< <= > >=	Relational less than/less than or equal to 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

if1.c

```
#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);
}
```

Conditional Operators

<
<=
>
>=
==
!=

If-else

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

if2.c

```
#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);
}
```

else-if

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

if3.c

```
#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);
}
```

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,…

while1.c

```
#include <stdio.h>

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

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

for1.c

```
#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
}
```

for loop – multiple init & increment

for2.c

```
#include <stdio.h>

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);
 }
```

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C: Functions

Frank McKenna
University of California at Berkeley

NSF award: CMMI 1612843

Functions

- **Art of Programming**: *"To take a problem, and recursivily 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 the 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.

function1.c

```
#include <stdio.h>

// 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);
 }
```

function2.c

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

function3.c

```
#include <stdio.h>
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 (vec*tor.c)*, matrix operations in another (matrix.c).
3. Put prototypes for all functions in another file, a .h file, e.g. vector.h
4. Get into a system of documenting inputs and outputs.

Example: application that requires use of vectors

myVector.h

```
#ifndef  _MY_VECTOR_H
#define _MY_VECTOR_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);

#endif
```

myVector.c

```
/* function to return component sum of two vectors */
void normMyVector(double *v1,  double *v2, double *res , int size) {
    for (int i = 0; i < size; i++) {
        res[i] = vector1[i] + vector2[i];
    }
}
```

vector1.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;
}
```

Scope of Variables

scope1.c

```
#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;
}
```

```
[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.

function4.c

```
#include <stdio.h>
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*(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(x,p)`	returns fractional part of *x* and stores integral part where pointer *p* points to
`pow(x,y)`	raise *x* to the power of *y*, 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(34.000000) 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?

recursion1.c

```
#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);
}
```

EXERCISES

https://nheri-simcenter.github.io/SimCenterBootcamp2024/source/assignment_C1.html