Winter Workshop

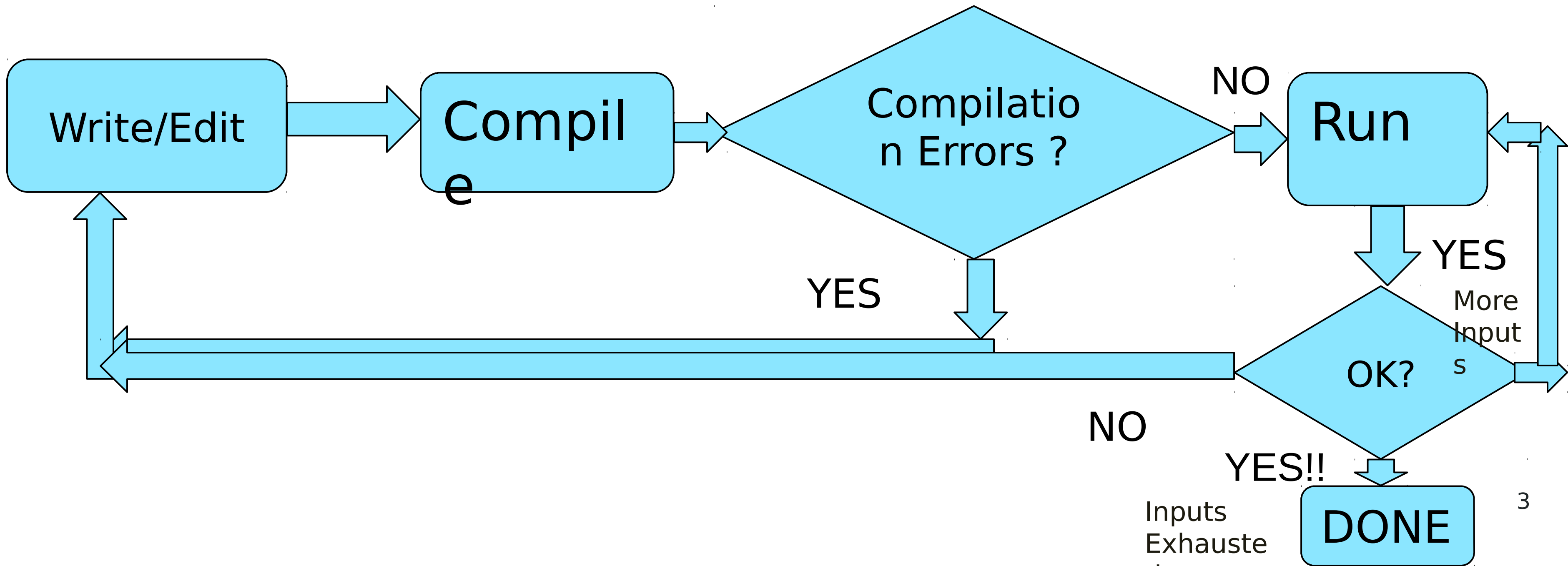
General Programming

What is Programming?

Computer programming is the process of designing and building an executable computer program for accomplishing a specific computing task.

The Programming Cycle

1. Write your program or edit (i.e., change or modify) your program
2. Compile your program. If compilation fails, return to editing step
3. Run your program on an input. If output is not correct, return to editing step
   a. Repeat step 3 for other inputs, if any



Simple Program

In the first week, we practice the simplest C programs.

```
# include <stdio.h>
int main ()  {
   printf(“Welcome to Robotics
Workshop”);
   return 0;
}
```

The program prints the message “Welcome to Robotics Workshop”

Program Components

```
# include <stdi
int main ()
{
    printf(“W elcome to
ESC101”);
    eturn 0;
}
```

1. This tells the C compiler to include the standard input output library.

2. Include this line routinely as

printf is the function called to output from a C program. To print a string, enclose it in “ ” and it gets printed.

“return” returns the control to the caller (program finishes in this case.)

main() is a function. All C programs start by executing from the first statement of the main function.

printf(“Welcome to ESC101”); is a statement in C. Statements in C end in semicolon ;

printf

- printf is the “voice” of the C program
  - Used to interact with the users
- printf prints its arguments in a certain format
  - Format provided by user

Understand this program?

Program to add two integers (17 and 23)

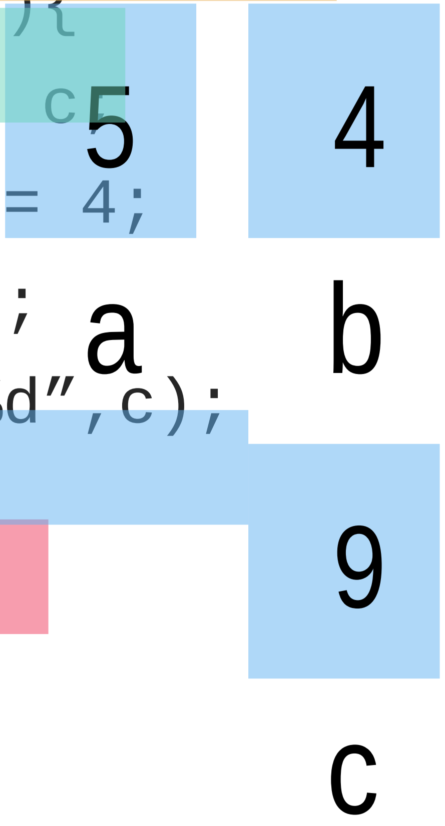
```
# include <stdio.h>
int main ()  {
   int a = 17;
   int b = 23;
   int c;
   c = a + b;
   printf("Result is %d", c);
   return 0;
}
```

The program prints the message: **Result is 40**

Printing the sum of two numbers

HOW WE MUST SPEAK TO THE C COMPILER

```
#include<stdio.h>
int main(){
int a, b, c;
a = 5, b = 4;
c = a + b;
printf(“%d”,c);
return 0;
}
```



HOW WE USUALLY SPEAK TO A HUMAN

I’m speaking English

Hello

a,b,c are variables.

a = 5 and b = 4.

Please add them and put the result in variable c.

Please tell me value of c.

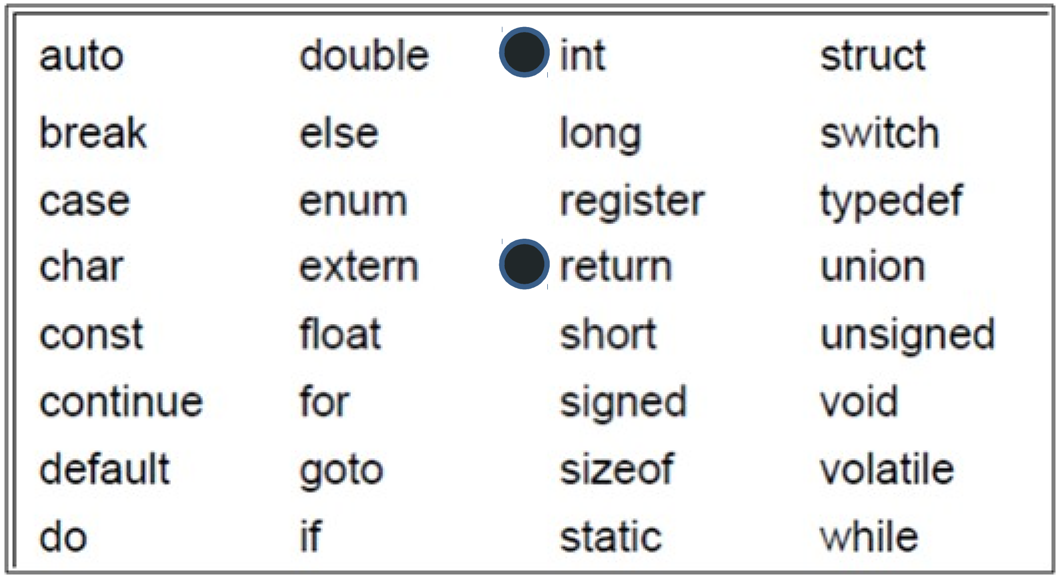
Goodbye

Words

- Made of alphabets
- Used to convey meaning
- English words have fixed meanings
- C *keywords* have fixed meanings
- All other C words (identifiers) have variable meanings
    - They take the meaning you want to give them

C Keywords

● Seen already



auto	double	● int	struct
break	else	long	switch
case	enum	register	typedef
char	extern	● return	union
const	float	short	unsigned
continue	for	signed	void
default	goto	sizeof	volatile
do	if	static	while

These 32 keywords mean the same across every C compiler
Some compilers reserve a few extra keywords, but those are less important

int

- Computers store data in binary code
  - A 0 or 1 is a bit
  - 8 bits make a byte
  - 2/4/8 bytes make a word (depending on architecture)
- The keyword *int* asks the computer to assign one *word* of memory to store an integer value
  - int a = 34;
  - `0000 0000 | 0010 0010`
- How many integers can you store using N bits?
- Can only use *int* to store integers in a limited range
  - If you exceed the range, you will get a compilation error

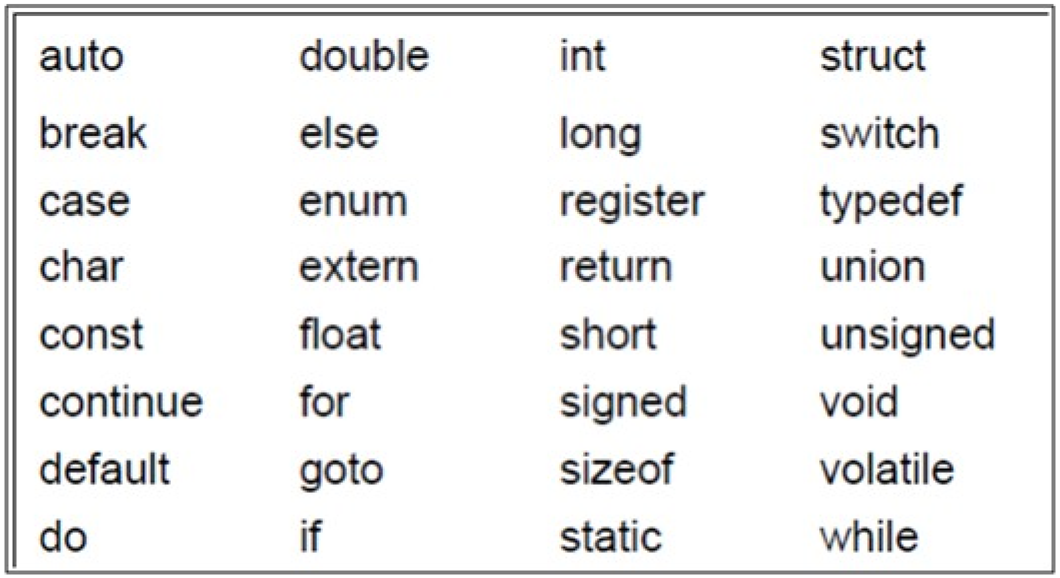
C Identifier/Variable Syntax

- Can use
  - A – Z
  - a – z
  - 0 – 9
  - The underscore character
- Cannot begin with a number
- A_3, abcDS2, this_variable are fine
- 321, 5_r, dfd@dhr, this variable, no-entry are not

Keyword Usage

```
#include <stdio.h>
int main(){
   int else = 3;
   printf("%d", else);
   return 0;
}
```

This won’t work



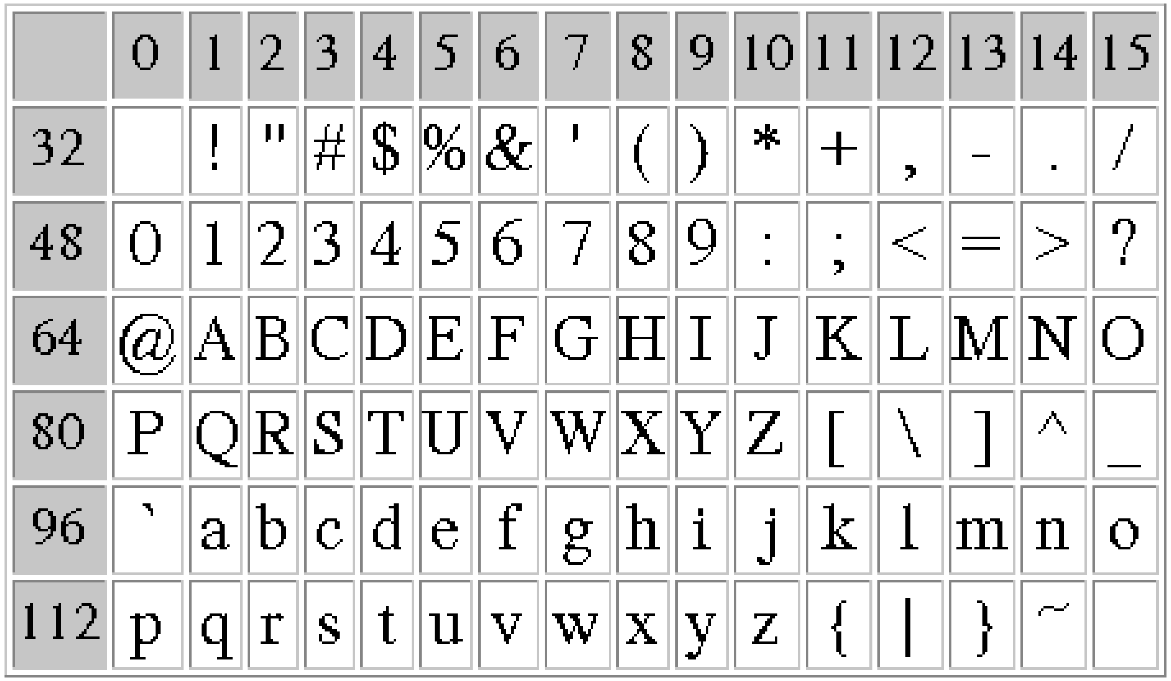
auto	double	int	struct
break	else	long	switch
case	enum	register	typedef
char	extern	return	union
const	float	short	unsigned
continue	for	signed	void
default	goto	sizeof	volatile
do	if	static	while

C character constants

```
#include <stdio.h>
int main(){
    int a = 'B';
    printf("%d\n", a);
    return 0;
}
```

What do you think the output will be?

ASCII character set



	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
32		!	"	#	$	%	&	'	(	)	*	+	,	-	.	/
48	0	1	2	3	4	5	6	7	8	9	:	;	<	=	>	?
64	@	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
80	P	Q	R	S	T	U	V	W	X	Y	Z	[	\	]	^	_
96	`	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
112	p	q	r	s	t	u	v	w	x	y	z	{	|	}	~	

Translates letters to numbers for the computer to understand

Character Constant Operations

```
#include <stdio.h>
int main(){
  int a = ‘C’ – ‘3’;
  printf("%d\n", a);
  return 0;
}
```

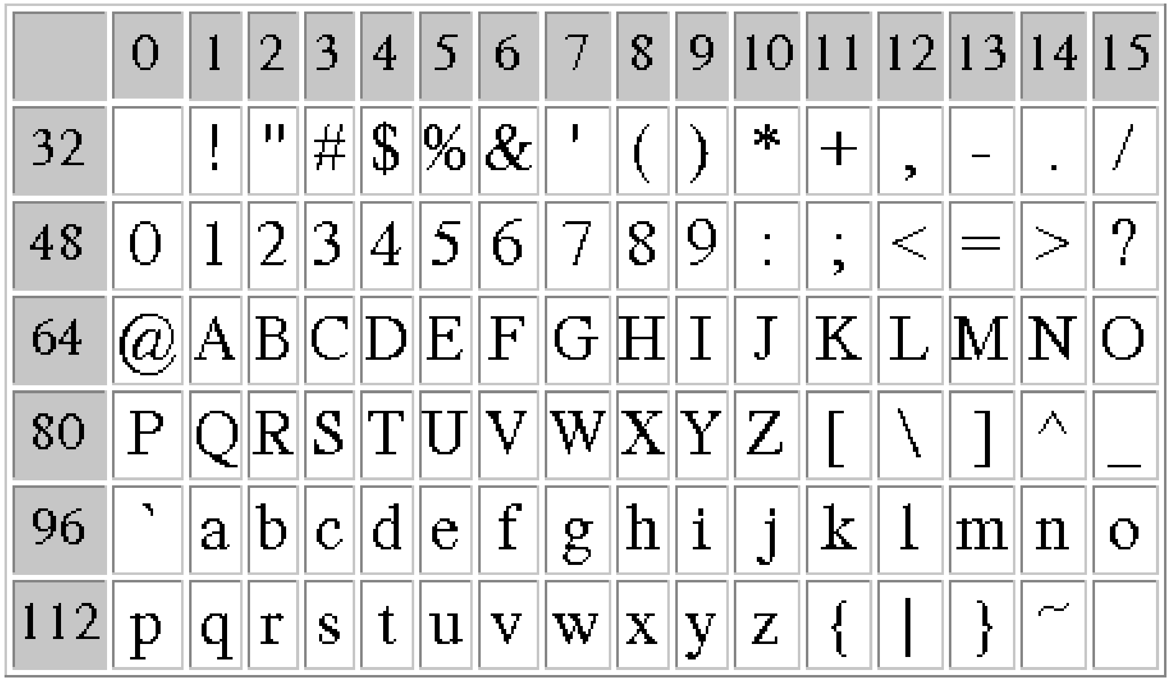
```
#include <stdio.h>
int main(){
  int a = ‘c’ – ‘3’;
  printf("%d\n", a);
  return 0;
}
```

Another Example: Playing with ASCII

A program that converts Capital to small characters

```
# include <stdio.h>
int main(){
   char first = ‘D’;
   char second =_______;
   printf(“__ is now __\n”, first, second);
   return 0;
}
```

ASCII Table



	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
32		!	"	#	$	%	&	'	(	)	*	+	,	-	.	/
48	0	1	2	3	4	5	6	7	8	9	:	;	<	=	>	?
64	@	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
80	P	Q	R	S	T	U	V	W	X	Y	Z	[	\	]	^	_
96	`	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
112	p	q	r	s	t	u	v	w	x	y	z	{	|	}	~	

Playing with ASCII

A program that converts Capital to small characters

```
# include <stdio.h>
int main(){
   char first = ‘D’;
   char second = first + ‘a’ - ‘A’;
   printf(“%c is now %c\n”, first, second);
   return 0;
}
```

Another Simple Program

A program that uses multiple types

```
# include <stdio.h>
int main(){
   char letter = ‘3’;
   int number = ________
   printf(“letter __ as a number is __\n”,
letter, number);
   return 0;
}
```

Another Simple Program

A program that uses multiple types

```
# include <stdio.h>
int main(){
   char letter = ‘3’;
   int number = letter - ‘0’;
   printf(“letter __ as a number is __\n”,
letter, number);
   return 0;
}
```

Another Simple Program

A program that uses multiple types

```
# include <stdio.h>
int main(){
   char letter = ‘3’;
   int number = letter - ‘0’;
   printf(“letter %c as a number is %d\n”,
letter, number);
   return 0;
}
```

Tracing the Execution

```
1  # include <stdio.h>
2  int main()
3  {
4          printf(“Welcome to ”);
5          printf(“C Programming”);
6          return 0;
   }
```

After lines 3,4

After lines 5,6

Output:

```
Welcome to  C Programming
```

- Line numbers of C program are given for clarity
- Program counter (reader part of C Compiler) starts at the first executable statement of main
- Program terminates gracefully when main “returns”

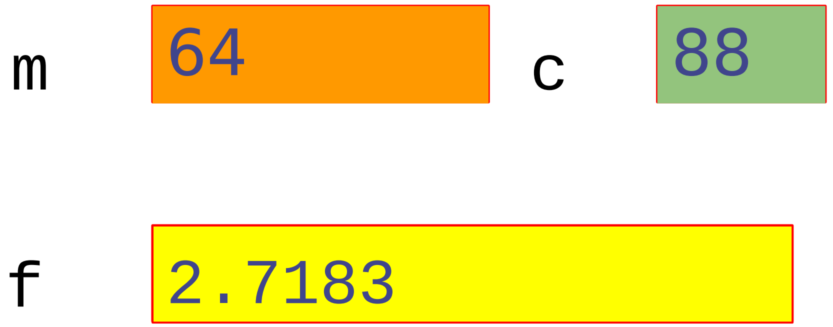
Variables

- A name associated with memory cells (boxes) that store data
- Type of variable determines the size of the box.

  int m = 64;

  char c = ‘X’;

  float f = 3.1416;



- Variables can change their value during program

  f = 2.7183;

Variable Declaration

- To communicate to compiler the names and types of the variables used by the program
  - Type tells size of the box to store value
  - Variable must be declared before used
  - Optionally, declaration can be combined with definition (initialization)

```
int count;
int min = 5;
```

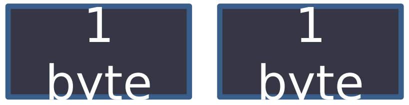
Declaration without initialization

Declaration with initialization

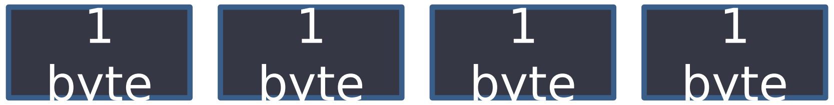
Data Types in C

- int

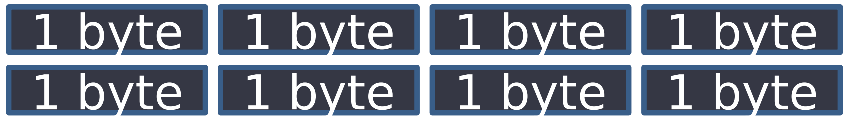
  Some modern compilers use 4 bytes for int



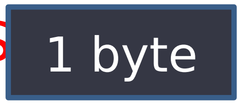
  - Bounded integers, e.g. 732 or -5
- float



  - Real numbers, e.g. 3.14 or 2.0
- double



  - Real numbers with more precision
- char
  - Single character, e.g. a or C or 6 or $



Assignment Statement

- A simple assignment statement

    variable = expression / value to be assigned;

- Computes the value of the expression on the right hand side (RHS), and stores it in the “box” of the variable on the left hand side (LHS)
- = is known as the assignment operator
- Examples

```
x = 10;
ch = ‘c’;
disc_2 = b*b – 4*a*c;
count = count + 1;
```

Input/Output

- Input: receive data from external sources (keyboard, mouse, sensors)
- Output: produce data (results of computations) (to monitor, printer, projector, ...)

Input/Output

- `printf` function is used to display results to the user. (output) - **voice** of C compiler
- `scanf` function is used to read data from the user. (input) - **ear** of C compiler
- Both of these are provided as library functions.
  - `#include <stdio.h>` tells compiler that these (and some other) functions may be used by the programmer.

Output - printf

string to be displayed, with placeholders

\n is the newline character.

```
printf("%d kms is equal\nto %f miles.\n", km, mi);
```

The string contains placeholders (%d and %f). Exactly one for each expression in the list of expressions

Placeholder and the corresponding variable have compatible type.

While displaying the string, the placeholders are replaced with the value of the corresponding expression: first placeholder by value of first expression, second placeholder by value of second expression, and so on.

Input - scanf

Similar to printf: string with placeholders, followed by list of variables to read

& is the *addressof* operator. To be covered later.

```
scanf("%d", &km);
```

Note the & before the variable name. DO NOT FORGET IT.

- String in " " contains only the placeholders corresponding to the list of variables after it.
- Best to use one scanf statement at a time to input value into one variable.

Some Placeholders

Placeholder	Type
`%d`	**int**
`%f`	**float**
`%lf`	**double**
`%c`	**char**
`%%`	**literal percent sign (%)**

If placeholder and expression/variable type do
not match, you may get unexpected

Special Characters

Escape Sequence	**Character**	ASCII Value
\0	null	000
\t	horizontal tab	009
\n	new line (line feed)	010
\v	vertical Tab	011
\”	quotation mark	034
\ \	backslash	092

Composite data types

- signed short int = signed short = short (%hi)
- signed long int = signed long = long (%li)
- unsigned int (%u)
- float (%f)
- double (%lf)
- long double (%Lf)

Comments in C

- Anything written between /* and */ is considered a comment.

```
diameter = 2*radius; /* diameter of a circle */
```

- Comments cannot be nested.

```
/* I am /* a comment */ but I am not */
```

First */ ends the effect of all unmatched start-of-comments (/*).

Comments in C

- Anything written after // up to the end of that line

```
diameter = 2*radius; // diameter of a circle
area = pi*radius*radius; // and its area
```

- Not all C compilers support this style of comments.
    - Our lab compiler **does** support it.

Relational Operators

- Compare two quantities
- Work on int, char, float, double…

Operator	Function
>	Strictly greater than
>=	Greater than or equal to
<	Strictly less than
<=	Less than or equal to
==	Equal to
!=	Not equal to

Examples

Rel. Expr.	**Result**	Remark
3>2	1	
3>3	0	
‘z’ > ‘a’	1	ASCII values used for char
2 == 3	0	
‘A’ <= 65	1	'A' has ASCII value 65
‘A’ == ‘a’	0	Different ASCII values
(‘a’ – 32) == ‘A’	1	
5 != 10	1	
1.0 == 1	AVOID	May give unexpected result due to approximation

Avoid mixing int and float values while comparing.
Comparison with floats is not exact!

Example

- Problem: Input 3 positive integers. Print the count of inputs that are even and odd.
  - Do not use if-then-else

INPUT
10
5
3

OUTPUT
Even=1
Odd=2

```
int a; int b; int c;
int cEven; // count of even inputs
scanf(“%d%d%d”, &a,&b,&c); // input a,b,c

// (x%2 == 0) evaluates to 1 if x is Even,
// 0 if x is Odd

cEven = (a%2 == 0) + (b%2 == 0) + (c%2 == 0);
printf(“Even=%d\nOdd=%d”, cEven, 3-cEven);
```

Logical Operators

Logical Op	**Function**	Allowed Types
&&	Logical AND	char, int, float, double
||	Logical OR	char, int, float, double
!	Logical NOT	char, int, float, double

Remember

- value 0 represents false.
- any other value represents true. Compiler returns 1 by default

Examples

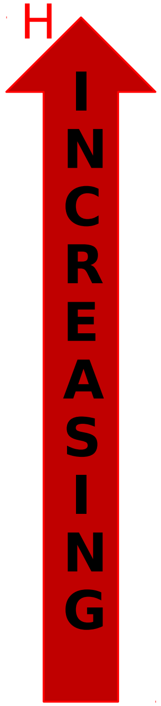
Expr	**Result**	Remark
2 && 3	1	
2 || 0	1	
‘A’ && ‘0’	1	ASCII value of ‘0’≠0
‘A’ && 0	0	
‘A’ && ‘b’	1	
! 0.0	1	0.0 == 0 is **guaranteed**
! 10.05	0	Any real ≠ 0.0
(2<5) && (6>5)	1	Compound expr

Precedence and Associativity

- NOT has same precedence as equality operator
- AND and OR are lower than relational operators
- OR has lower precedence than AND
- Associativity goes left to right
- 2 == 2 && 3 == 1 || 1 == 1 || 5 == 4 is true
- Recommended: use brackets

Operator Precedence

HIGH

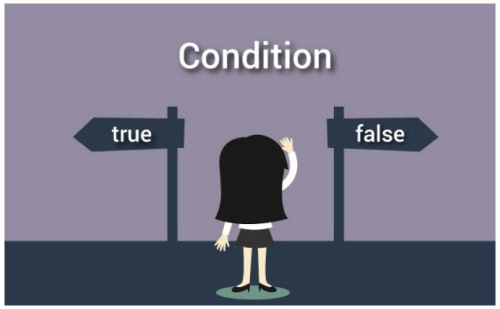


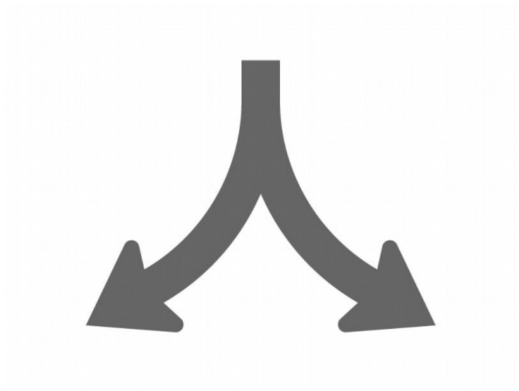
Operators	**Description**	Associativity
< > >= <=	Relational operators	Left to right
== !=	Equal, not equal	Left to right
&&	And	Left to right
||	Or	Left to right
=	Assignment	Right to left

LOW

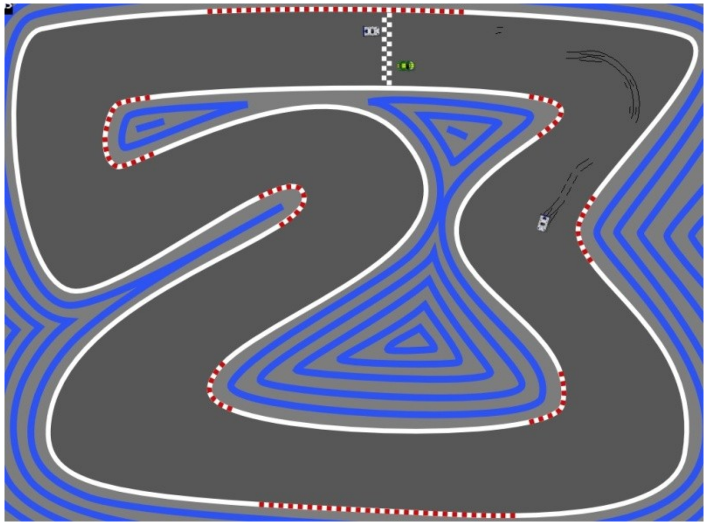
Control Statements

- Branching





- Looping



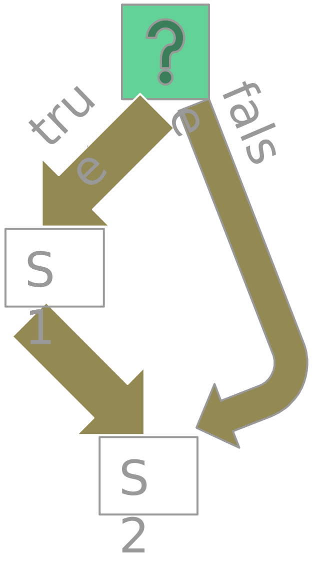
Branching Statements in C

- 3 types of conditional statements in C
  - if (cond) action
  - if (cond) action
    else some-other-action
  - switch-case
- Each action is a sequence of one or more statements!

if Statement

- General form of the if statement

```
if (expression)
                statement S1
statement S2
```

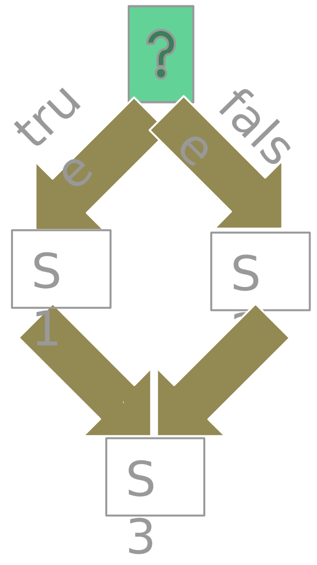


- Execution of if statement
  - First the expression is evaluated.
  - If it evaluates to a non-zero value, then S1 is executed and then control (program counter) moves to the statement S2.
  - If expression evaluates to 0, then S2 is executed.

`if-else` Statement

- General form of the if-else statement

```
if (expression)
            statement S1
else
            statement S2
statement S3
```



- Execution of if-else statement
    - First the expression is evaluated.
    - If it evaluates to a non-zero value, then S1 is executed and then control (program counter) moves to S3.
    - If expression evaluates to 0, then S2 is executed and then control moves to S3.
    - S1/S2 can be a **block** of statements!

Example

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

int main() {
  int n;
  double m;
  printf(“Please enter a positive number: ”);
  scanf(“%d”,&n);
  if (n>0){
   m = log(n);         // natural log
   printf("%f\n", m);
  }
  else
   printf(“Why can’t you follow instructions?");
  return 0;
}
```

Nested if, if-else

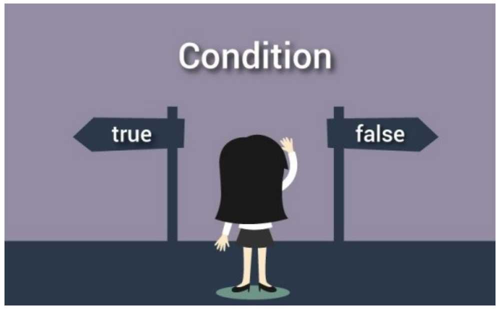
- Earlier examples showed us *nested* if-else stat

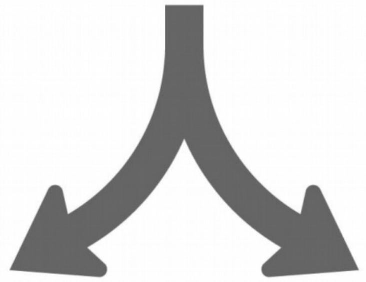
```
if (a <= b) {
       if (a <= c) { … }  else {…}
} else {
        if (b <= c)  { … } else { … }
}
```

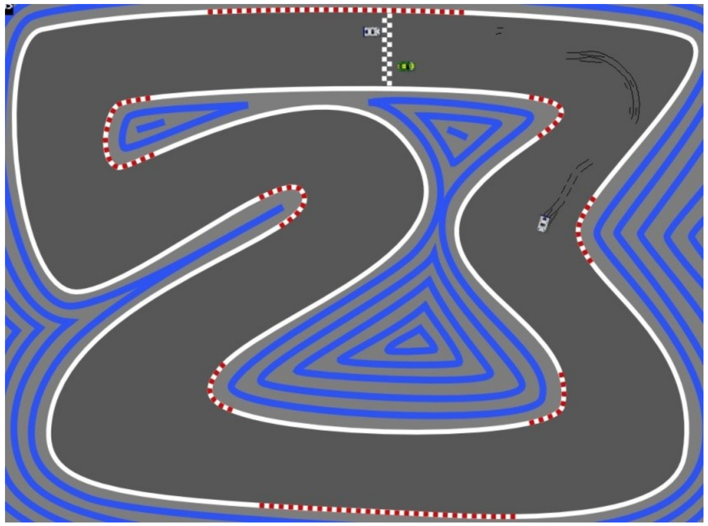
- Because if and if-else are also statements, they can be used anywhere a statement or block can be used.

Control Statements

- Branching ✔
- Looping







The for loop

Brackets essential if you want to do many things while looping

General form of a for loop

```
for(init_expr; stopping_expr; update_expr){
    statement1;
    statement2;
    ...
}
statement3;
statement4;
...
```

How we usually speak to a human

1. Do what is told in initialization expression
2. Then check the stopping expression
3. If stopping expression is true
    Execute all statements inside braces
    Execute update expression
    Go back to step 2
  Else stop looping and execute rest of the code

The for loop

```
for(init_expr; stopping_expr; update_expr){
    statement1;
    statement2;
 }
```

The entire for loop is considered one statement

Can put inside for loops: printf statements, if-else/switch statements, even for loop statement (nested for loop)

Usually init_expr, stopping_expr, update_expr involve the same variable, e.g. b in multiplication table example

Lovingly called variable of the loop/counter variable

Some common errors in loops

Initialization: forget to do it or else wrong initialization

Statements: Note, update_expr executed **after** statements

Update: Forget to do update step or wrong update step

Termination: wrong or missing termination

for(b=1;**b<10**;b++){…} not same as for(b=1;**b<=10**;b++){…}

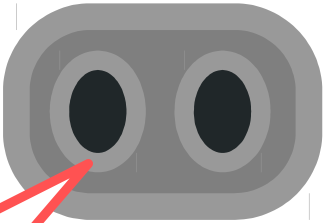
Infinite loop: The loop goes on forever. Never terminates.

for(b=2;b>=1,b++){…}

Print sum of reciprocals of 1, 2, ..., n

Take n >= 1 from the user and give as output

$$\frac{1}{1} + \frac{1}{2} + \frac{1}{3} + \ldots + \frac{1}{n}$$



Oops! Integer division!

The repeating task can be

*Given the sum of first i-1 reciprocals and add **`1/i`** to it*

Define a variable (let's call it **`sum`**) to store partial sums

Also called *partial sums* or *running sums*

The above task is accomplished by the code

```
sum = sum + 1/i;
sum = sum + 1.0/i;
sum = sum + (double)1/i;
```

Loop Invariant

Notice that in prev

At the beginning of i-th iterat

$$\frac{1}{1} + \frac{1}{2} + \frac{1}{3} + \ldots + \frac{1}{i-1}$$

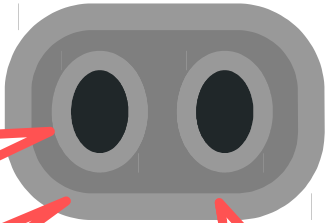
Except for the special case for the iteration with i = 1, where sum stored 0

After the i-th iteration is over, **`sum`** stored the value

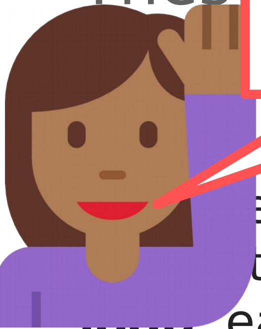
$$\frac{1}{1} + \frac{1}{2} + \frac{1}{3} + \ldots + \frac{1}{i}$$

These *op invariants* – few nice r all iterations of a loop

nvariant is a formal statement about the relationship between es in your program which holds true just before the **loop** is ever tablishing the **invariant**) and is true again at the bottom of the **loop**, each time through the **loop**(maintaining the **invariant**).



Very important once loops get more complicated
Loop invariants are powerful ways to ensure that your loop code is correct!
Very Good!



Exercise 1: sum of reciprocals of the first n even numbers
Exercise 2: find if a number is prime or not
Exercise 3*: sum of reciprocals of the first n prime numbers

Interesting Exercise

Euler series

$$1 + \frac{1}{2^2} + \frac{1}{3^2} + \frac{1}{4^2} + \ldots + \infty$$

We know the solution $\frac{\pi^2}{6}$

How should we compute it numerically?