Programming in C

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University of Bristol

September 20, 2021

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About the Course

These course notes were originally based on :

C By Dissection (3rd edition)
Al Kelley and Ira Pohl

because I liked arrays being taught late(r). I've since changed my mind a little & have re-jigged the notes quite heavily for this year.

Resources

- Free : https://en.wikibooks.org/wiki/C_Programming

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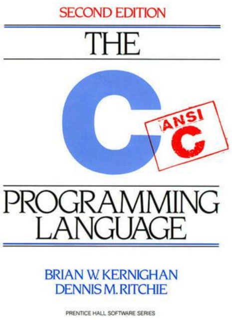
- Whatever you use, make sure it's **C99** that's being taught, not something else e.g. C11 or C++.
- If you fall in love with C and know you're going to use it for the rest of your life, the reference 'bible' is K&R 2nd edition. It's not a textbook for those new to programming, though.



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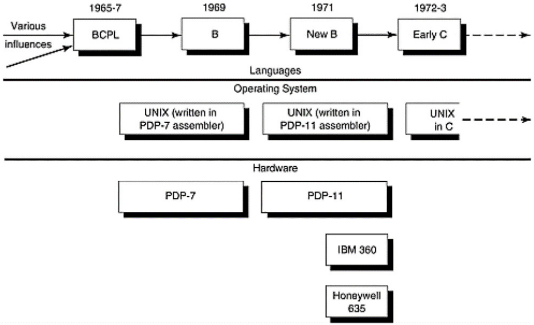
- Don't place your code on publicly accessible sites e.g. github - other students may have extensions etc.

History of C



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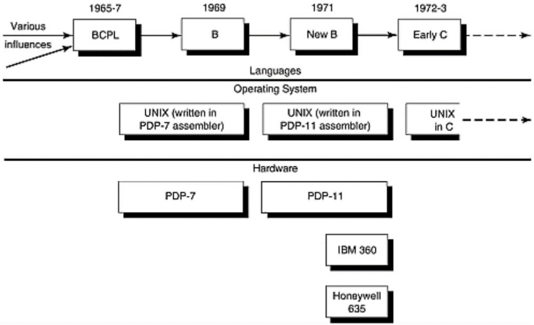

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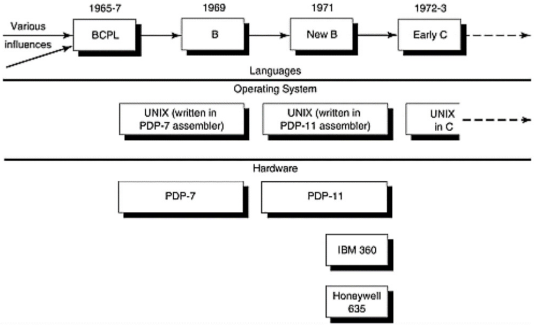

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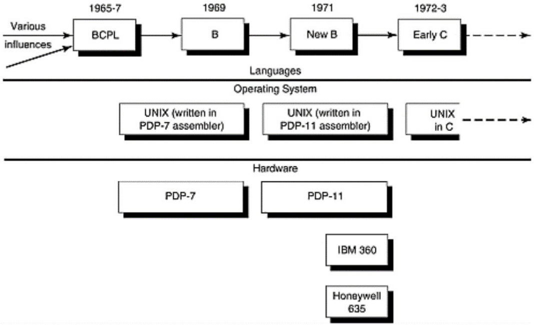

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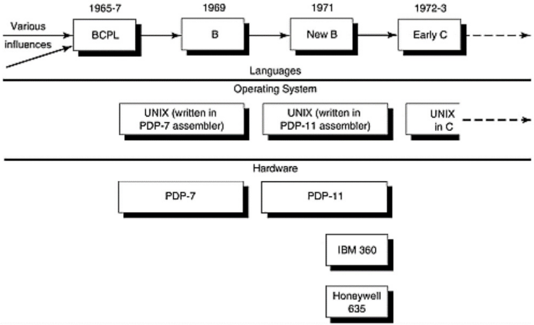

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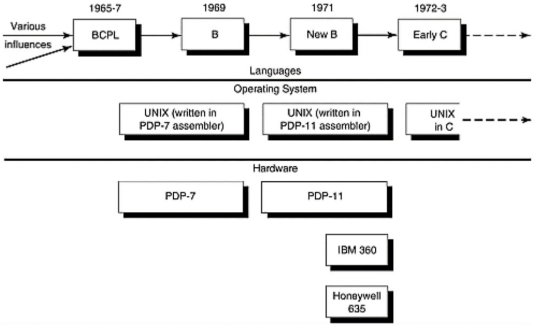

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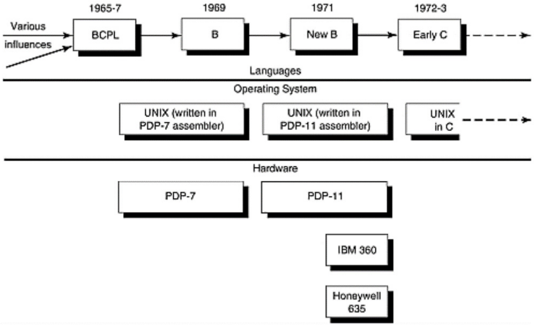

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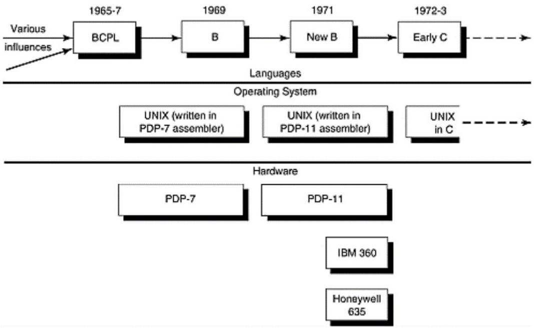

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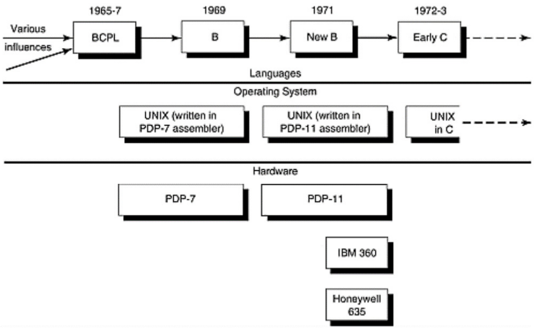

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- C99 (COMSM1201)
- C++ - Object Oriented Programming (OOP)
- Java (Subset of C++, WWW enabled).

Why C ?

Jun 2021	Jun 2020	Change	Programming Language
1	1		C
2	3	^	Python
3	2	v	Java
4	4		C++
5	5		C#
6	6		Visual Basic
7	7		JavaScript

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- In the blended world, I'll post the equivalent online, broken into manageable chunks
- Programming (C), data structures, algorithms - searching, sorting, string processing, trees etc.

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- Approximately three/four assignments and one lab test.
- One major project due in early TB2 (35%).
- Hard to gauge timings, so don't make any plans in advance - I'll change it if we're going too fast.

Help with Computers

- Any problems with the computers e.g. installing the correct S/W, accessing lab machines : http://www.bris.ac.uk/it-services/

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- This page also links to the rather useful Laptop & Mobile Clinic.

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- Online will mainly be via myself giving ‘live’ Q&A session, the associated MS Teams group with Forum, and Teaching Assistants in our on-campus / face-to-face labs.
- TAs are not allowed to write pieces of code for you, nor undertake detailed bug-fixing of your program.

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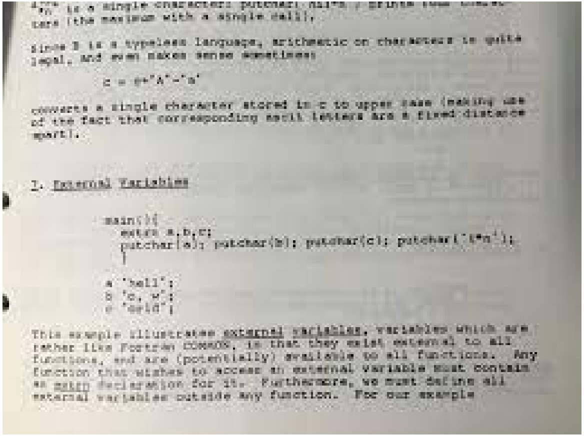
Hello World!



'*n' is a single character: putchar('hi*n') prints four characters (the maximum with a single call).

Since B is a typeless language, arithmetic on characters is quite legal, and even makes sense sometimes:

c = c+'A'-'a'

converts a single character stored in c to upper case (making use of the fact that corresponding ascii letters are a fixed distance apart).

7. External Variables

```
main( ) {
  extrn a,b,c;
  putchar(a); putchar(b); putchar(c); putchar('!*n');
  }

a 'hell';
b 'o, w';
c 'orld';
```

This example illustrates external variables, variables which are rather like Fortran COMMON, in that they exist external to all functions, and are (potentially) available to all functions. Any function that wishes to access an external variable must contain an extrn declaration for it. Furthermore, we must define all external variables outside any function. For our example

Hello World first seen in: Brian Kernighan, *A Tutorial Introduction to the Language B*, 1972

```c
/* The traditional first program
in honour of Dennis Ritchie
who invented C at Bell Labs
in 1972 */

#include <stdio.h>

int main(void)
{

    printf("Hello, world!\n");
    return 0;

}
```

Execution:

```
Hello, world!
```

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- Notice all declarations and statements are terminated with a semi-colon.
- return(0) Instruct the Operating System that the function main() has completed successfully.

Area of a Rectangle

```c
#include <stdio.h>

int main(void)
{
   // Compute the area of a rectangle
   int side1, side2, area;
   side1 = 7;
   side2 = 8;
   area = side1 * side2;

   printf("Length of side  1 = %d metres\n", side1);
   printf("Length of side  2 = %d metres\n", side2);
   printf("Area of rectangle = %d metres squared\n", area);
   return 0;
}
```

Execution :

```
Length of side  1 = 7 metres
Length of side  2 = 8 metres
Area of rectangle = 56 metres squared
```

Dissecting the Area Program

- // One line comment.

```
preprocessing directives

int main(void)
{
   declarations

   statements
}
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- #include <stdio.h> Always required when using I/O.
- int side1, side2, area; *Declaration*
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- printf() has 2 Arguments. The *control string* contains a %d to indicate an integer is to be printed.

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Arithmetic Operators

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- Modulus (Remainder) Arithmetic.
  7%4 is 3, 12%6 is 0.
- Only available for integer arithmetic.

The Character Type

```c
// Demonstration of character arithmetic
#include <stdio.h>

int main(void)
{
   char   c;

   c = 'A';
   printf("%c ", c);
   printf("%c\n", c+1);
   return 0;
}
```

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A B

- The keyword char stands for character.

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- Some keyboards have a second single quote the **back quote** ‘
- Note the %c conversion format.

Floating Types

```c
#include <stdio.h>

int main(void)
{

   double x, y;

   x = 1.0;
   y = 2.0;

   printf("Sum of x & y is %f.\n", x + y);

   return 0;

}
```

Execution :

```
Sum of x & y is 3.000000.
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- In C there are three common floating types :

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  2. double
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  1. float
  2. double
  3. long double
- The *Working Type* is doubles.

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- #define PI 3.14159265358979 Replaces all occurrences of PI with 3.14159265358979.
- Include files generally contain other #define's and #include's (amongst other tings).

Using printf()

- printf(fmt-str, arg1, arg2, ...);

%c	Characters
%d	Integers
%e	Floats/Doubles (Engineering Notation)
%f	Floats/Doubles
%s	Strings

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- Fixed-width fields: `printf("F:%7f\n", f);`
  F: 3.0001

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- Fixed-width fields: `printf("F:%7f\n", f);`
  F: 3.0001
- Fixed Precision: `printf("F:%.2f\n", f);`
  F:3.00

Using scanf()

- Similar to `printf()` but deals with *input* rather than *output*.

%c	Characters
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- scanf(fmt-str, &arg1, &arg2, ...);

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Using scanf()

- Similar to `printf()` but deals with *input* rather than *output*.
- `scanf(fmt-str, &arg1, &arg2, ...);`
- Note that the *address* of the argument is required.

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Using scanf()

- Similar to printf() but deals with *input* rather than *output*.
- scanf(fmt-str, &arg1, &arg2, ...);
- Note that the *address* of the argument is required.

%c	Characters
%d	Integers
%f	Floats
%lf	Doubles
%s	Strings

- Note doubles handled differently than floats.

While Loops

```
while (test is true) {
    statement 1;
        ...
    statement n;
}
```

```c
// Sums are computed.
#include <stdio.h>

int main(void)
{

   int cnt = 0;
   float sum = 0.0, x;
   printf("Input some numbers: ");
   while (scanf("%f", &x) == 1) {
      cnt = cnt + 1;
      sum = sum + x;
   }

   printf("\n%s%5d\n%s%5f\n\n",
          "Count:", cnt, "Sum: ", sum);
   return 0;
}
```

Execution :

```
Input some numbers: 1 5 9 10

Count:    4
Sum: 25.000000
```

Common Mistakes

- Missing "

```
printf("%c\n, ch);
```

Common Mistakes

- Missing "

```
printf("%c\n, ch);
```

- Missing ;

```
a = a + 1
```

Common Mistakes

- Missing "

```
printf("%c\n, ch);
```

- Missing ;

```
a = a + 1
```

- Missing Address in scanf()

```
scanf("%d", a);
```

Table of Contents

Grammar

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- Constants :
  17 (decimal), 017 (octal), 0x17 (hexadecimal).

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- Valid Identifiers :
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- **Invalid** Identifiers :
  not#me, 101_south, -plus.
- Constants :
  17 (decimal), 017 (octal), 0x17 (hexadecimal).
- String Constant enclosed in double-quotes :
  "I am a string"

Operators

- All operators have rules of both *precedence* and *associativity*.

```c
#include <stdio.h>

int main(void)
{
    int a, c = 0;
    a = ++c;
    int b = c++;
    printf("%d %d %d\n", a, b, ++c);
    return 0;
}
```

Question : What is the output ?

Operators

- All operators have rules of both *precedence* and *associativity*.
- $1 + 2 * 3$ is the same as $1 + (2 * 3)$ because $*$ has a higher precedence than $+$.

```c
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int main(void)
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Question : What is the output ?

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- All operators have rules of both *precedence* and *associativity*.
- $1 + 2 * 3$ is the same as $1 + (2 * 3)$ because $*$ has a higher precedence than $+$.
- The associativity of $+$ is left-to-right, thus $1 + 2 + 3$ is equivalent to $(1 + 2) + 3$.

```c
#include <stdio.h>

int main(void)
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}
```

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- Increment and decrement operators : i++; is equivalent to $i = i + 1$;

```c
#include <stdio.h>

int main(void)
{
    int a, c = 0;
    a = ++c;
    int b = c++;
    printf("%d %d %d\n", a, b, ++c);
    return 0;
}
```

Question : What is the output ?

Operators

- All operators have rules of both *precedence* and *associativity*.
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- The associativity of $+$ is left-to-right, thus $1 + 2 + 3$ is equivalent to $(1 + 2) + 3$.
- Increment and decrement operators : i++; is equivalent to i = i + 1;
- May also be prefixed --i;

```c
#include <stdio.h>

int main(void)
{
    int a, c = 0;
    a = ++c;
    int b = c++;
    printf("%d %d %d\n", a, b, ++c);
    return 0;
}
```

Question : What is the output ?

Assignment

- The $=$ operator has a low precedence and a right-to-left associativity.

```c
// 1st few powers of 2 are printed.

#include <stdio.h>

int main(void)
{
   int   i = 0, power = 1;

   while (++i <= 10){
      printf("%5d", power *= 2);
   }
   printf("\n");
   return 0;
}
```

Execution :

```
    2    4    8   16   32   64  128  256
  512 1024
```

Assignment

- The = operator has a low precedence and a right-to-left associativity.
- a = b = c = 0; is valid and equivalent to :
  = (b = (c = 0));

```c
// 1st few powers of 2 are printed.

#include <stdio.h>

int main(void)
{
    int   i = 0, power = 1;

    while (++i <= 10){
        printf("%5d", power *= 2);
    }
    printf("\n");
    return 0;
}
```

Execution :

```
    2     4     8    16    32    64   128   256
512  1024
```

Assignment

- The = operator has a low precedence and a right-to-left associativity.
- a = b = c = 0; is valid and equivalent to : = (b = (c = 0));
- i = i + 3; is the same as i += 3;

```c
// 1st few powers of 2 are printed.

#include <stdio.h>

int main(void)
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    }
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    return 0;
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Assignment

- The = operator has a low precedence and a right-to-left associativity.
- a = b = c = 0; is valid and equivalent to : = (b = (c = 0));
- i = i + 3; is the same as i += 3;
- Many other operators are possible e.g. -=, *=, /=.

```c
// 1st few powers of 2 are printed.

#include <stdio.h>

int main(void)
{
   int   i = 0, power = 1;

   while (++i <= 10){
      printf("%5d", power *= 2);
   }
   printf("\n");
   return 0;
}
```

Execution :

```
    2    4    8   16   32   64  128  256
512 1024
```

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

int main(void)
{
   int   i, n;
   printf("Randomly distributed integers are printed.\n"
          "How many do you want to see?  ");
   do{
      i = scanf("%d", &n);
   }while(i != 1);
   for (i = 0; i < n; ++i) {
      if (i % 4 == 0)
         printf("\n");
      printf("%12d", rand());
   }
   printf("\n");
   return 0;
}
```

Execution :

```
Randomly distributed integers are printed.
How many do you want to see?  11

  1804289383   846930886  1681692777  1714636915
  1957747793   424238335   719885386  1649760492
   596516649  1189641421  1025202362
```

- Definitions required for the proper use of many functions such as `rand()` are found in `stdlib.h`.

The Standard Library

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

int main(void)
{
   int   i, n;
   printf("Randomly distributed integers are printed.\n"
          "How many do you want to see?  ");
   do{
      i = scanf("%d", &n);
   }while(i != 1);
   for (i = 0; i < n; ++i) {
      if (i % 4 == 0)
         printf("\n");
      printf("%12d", rand());
   }
   printf("\n");
   return 0;
}
```

Execution :

```
Randomly distributed integers are printed.
How many do you want to see?  11

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```

- Definitions required for the proper use of many functions such as `rand()` are found in `stdlib.h`.
- Do not mistake these header files for the libraries themselves !

Table of Contents

Comparisons

<	less than
>	greater than
<=	less than or equal to
>=	greater than or equal to
==	**equal to**
!=	not equal to
!	not
&&	logical AND
||	logical OR

- Any relation is either *true* or *false*.

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- Any non-zero value is *true*.

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- Any relation is either *true* or *false*.
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- `(i == 5)` is a **test** not an **assignment**.

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- `(a < b)` returns the value *0* or *1*.
- `(i == 5)` is a **test** not an **assignment**.
- `(!a)` is either *true (1)* or *false (0)*.
- `(a && b)` is *true* if both `a` and `b` are *true*.

Comparisons

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- Any relation is either *true* or *false*.
- Any non-zero value is *true*.
- `(a < b)` returns the value *0* or *1*.
- `(i == 5)` is a **test** not an **assignment**.
- `(!a)` is either *true (1)* or *false (0)*.
- `(a && b)` is *true* if both `a` and `b` are *true*.
- Single & and | are *bitwise* operators not comparisons - more on this later.

Short-Circuit Evaluation

```c
if(x >= 0.0 && sqrt(x) < 10.0){
..... /* Do Something */
}
```

It's not possible to take the sqrt() of a negative number. Here, the sqrt() statement is never reached if the first test is *false*. In a logical AND, once any expression is *false*, the whole must be *false*.

The if() Statement

Strictly, you don't need braces if there is only one statement as part of the if :

```
if (expr)
   statement
```

If more than one statement is required :

```
if (expr) {
   statement-1
         .
         .
         .
   statement-n
}
```

However, we will **always** brace them, even if it's not necessary.

Adding an else statement :

```
if (expr) {
   statement-1
         .
         .
         .
   statement-n
}
else{
   statement-a
         .
         .
         .
   statement-e
}
```

A Practical Example of if:

```c
#include <stdio.h>

int main(void)
{
   int   x, y, z;

   printf("Input three integers:  ");
   if(scanf("%d%d%d", &x, &y, &z) != 3){
      printf("Didn't get 3 numbers?\n");
      return 1;
   }
   int min;
   if (x < y){
      min = x;
   }
   // Nasty, dropped braces:
   else
      min = y;
   if (z < min){
      min = z;
   }
   printf("The minimum value is %d\n", min);
   return 0;
}
```

Execution :

```
Input three integers:  5 7 -4
The minimum value is -4
```

The while() Statement

```
while(expr)
   statement
```

This, as with the for loop, may execute compound statements :

```
while(expr){
   statement-1
      .
      .
      .
   statement-n
}
```

However, we will **always** brace them, even if it's not necessary.

```c
// Simple while countdown

#include <stdio.h>

int main(void)
{

   int n = 9;

   while(n > 0){
      printf("%d ", n);
      n--;
   }
   printf("\n");
   return 0;
}
```

Execution :

9 8 7 6 5 4 3 2 1

The for() Loop

This is one of the more complex and heavily used means for controlling execution flow.

```
for( init ; test; loop){
   statement-1
       .
       .
       .
   statement-n
}
```

and may be thought of as :

```
init;
while(test){
   statement-1
       .
       .
       .
   statement-n
   loop;
}
```

In the for() loop, note :

- Semi-colons separate the three parts.

The for() Loop

This is one of the more complex and heavily used means for controlling execution flow.

```
for( init ; test; loop){
   statement-1
        .
        .
        .
   statement-n
}
```

and may be thought of as :

```
init;
while(test){
   statement-1
        .
        .
        .
   statement-n
   loop;
}
```

In the for() loop, note :

- Semi-colons separate the three parts.
- Any (or all) of the three parts could be empty.

The for() Loop

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for( init ; test; loop){
   statement-1
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       .
       .
   statement-n
}
```

and may be thought of as :

```
init;
while(test){
   statement-1
       .
       .
       .
   statement-n
   loop;
}
```

In the for() loop, note :

- Semi-colons separate the three parts.
- Any (or all) of the three parts could be empty.
- If the test part is empty, it evaluates to *true*.

The for() Loop

This is one of the more complex and heavily used means for controlling execution flow.

```
for( init ; test; loop){
   statement-1
        .
        .
        .
   statement-n
}
```

and may be thought of as :

```
init;
while(test){
   statement-1
        .
        .
        .
   statement-n
   loop;
}
```

In the for() loop, note :

- Semi-colons separate the three parts.
- Any (or all) of the three parts could be empty.
- If the test part is empty, it evaluates to *true*.
- for(;;){ a+=1; } is an infinite loop.

A Triply-Nested Loop

```c
// Triples of integers that sum to N
#include <stdio.h>

#define N 7

int main(void)
{
   int   cnt = 0, i, j, k;

   for(i = 0; i <= N; i++){
      for(j = 0; j <= N; j++){
         for(k = 0; k <= N; k++){
            if(i + j + k == N){
               ++cnt;
               printf("%3d%3d%3d\n", i, j, k);
            }
         }
      }
   }
   printf("\nCount: %d\n", cnt);
   return 0;
}
```

Output :

```
  0  0  7
  0  1  6
  0  2  5
  0  3  4
  0  4  3
  0  5  2
  0  6  1
  0  7  0
```

etc.

```
  4  3  0
  5  0  2
  5  1  1
  5  2  0
  6  0  1
  6  1  0
  7  0  0

Count: 36
```

The Comma Operator

This has the lowest precedence of all the operators in C and associates left-to-right.

```
a = 0 , b = 1;
```

Hence, the for loop may become quite complex :

```
for(sum = 0, i = 1; i <= n; ++i){
   sum += i;
}
```

An equivalent, but more difficult to read expression :

```
for(sum = 0 , i = 1; i <= n; ++i , sum += i);
```

Notice the loop has an empty body, hence the semicolon.

The do-while() Loop

```
do {
    statement-1
         .
         .
         .
    statement-n
} while ( test );
```

Unlike the while() loop, the do-while() will always be executed at least once.

```c
// Simple do-while countdown

#include <stdio.h>

int main(void)
{

   int n = 9;

   /* This program always prints at least one
      number, even if n initialised to 0 */
   do{
      printf("%d ", n);
      n--;
   }while(n > 0);
   printf("\n");
   return 0;
}
```

Execution :

9 8 7 6 5 4 3 2 1

The switch() Statement

```
switch (val) {
   case 1 :
      a++;
      break;
   case 2 :
   case 3 :
      b++;
      break;
   default :
      c++;
}
```

- The val must be an integer.

The switch() Statement

```
switch (val) {
   case 1 :
      a++;
      break;
   case 2 :
   case 3 :
      b++;
      break;
   default :
      c++;
}
```

- The val must be an integer.
- The break statement causes execution to jump out of the loop. No break statement causes execution to 'fall through' to the next line.

The switch() Statement

```c
switch (val) {
   case 1 :
      a++;
      break;
   case 2 :
   case 3 :
      b++;
      break;
   default :
      c++;
}
```

- The `val` must be an integer.
- The `break` statement causes execution to jump out of the loop. No `break` statement causes execution to ‘fall through’ to the next line.
- The `default` label is a catch-all.

The switch() Statement

```c
/* A Prime number can only be divided
   exactly by 1 and itself */

#include <stdio.h>

int main(void)
{

   int i, n;
   do{
      printf("Enter a number from 2 - 9 : ");
      n = scanf("%d", &i);
   }while( (n!=1) || (i<2) || (i>9) );
   switch(i){
      case 2:
      case 3:
      case 5:
      case 7:
         printf("That's a prime!\n");
         break;
      default:
         printf("That is not a prime!\n");
   }
   return 0;
}
```

Execution :

```
Enter a number from 2 - 9 : 1
Enter a number from 2 - 9 : 0
Enter a number from 2 - 9 : 10
Enter a number from 2 - 9 : 3
That's a prime!
```

The Conditional (?) Operator

As we have seen, C programers have a range of techniques available to reduce the amount of typing :

```
expr1 ? expr2 : expr3
```

If expr1 is *true* then expr2 is executed, else expr3 is evaluated.

```
#include <stdio.h>

int main(void)
{
   int   x, y, z;

   printf("Input three integers:  ");
   if(scanf("%d%d%d", &x, &y, &z) != 3){
      printf("Didn't get 3 numbers?\n");
      return 1;
   }
   int min;
   min = (x < y) ? x : y;
   min = (z < min) ? z : min;
   printf("The minimum value is %d\n", min);
   return 0;
}
```

Table of Contents

Simple Functions

```c
#include <stdio.h>

int min(int a, int b);

int main(void)
{

   int j, k, m;

   printf("Input two integers: ");
   scanf("%d%d", &j, &k);
  m = min(j, k);
   printf("\nOf the two values %d and %d, " \
   "the minimum is %d.\n\n", j, k, m);
   return 0;

}

int min(int a, int b)
{
   if (a < b)
      return a;
   else
      return b;
}
```

Execution :

```
Input two integers: 5 2

Of the two values 5 and 2, the minimum is 2.
```

- Execution begins, as normal, in the main() function.

Simple Functions

```c
#include <stdio.h>

int min(int a, int b);

int main(void)
{

   int j, k, m;

   printf("Input two integers: ");
   scanf("%d%d", &j, &k);
   m = min(j, k);
   printf("\nOf the two values %d and %d, " \
   "the minimum is %d.\n\n", j, k, m);
   return 0;

}

int min(int a, int b)
{
   if (a < b)
      return a;
   else
      return b;
}
```

Execution :

```
Input two integers: 5 2

Of the two values 5 and 2, the minimum is 2.
```

- Execution begins, as normal, in the `main()` function.
- The function *prototype is shown* at the top of the file. This allows the compiler to check the code more thoroughly.

```c
#include <stdio.h>

int min(int a, int b);

int main(void)
{

   int j, k, m;

   printf("Input two integers: ");
   scanf("%d%d", &j, &k);
   m = min(j, k);
   printf("\nOf the two values %d and %d, " \
   "the minimum is %d.\n\n", j, k, m);
   return 0;

}

int min(int a, int b)
{
   if (a < b)
      return a;
   else
      return b;
}
```

Execution :

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Input two integers: 5 2

Of the two values 5 and 2, the minimum is 2.
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- Execution begins, as normal, in the `main()` function.
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- The function is defined between two braces.

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   printf("Input two integers: ");
   scanf("%d%d", &j, &k);
   m = min(j, k);
   printf("\nOf the two values %d and %d, " \
   "the minimum is %d.\n\n", j, k, m);
   return 0;

}

int min(int a, int b)
{
   if (a < b)
      return a;
   else
      return b;
}
```

Execution :

```
Input two integers: 5 2

Of the two values 5 and 2, the minimum is 2.
```

- Execution begins, as normal, in the `main()` function.
- The function *prototype is shown* at the top of the file. This allows the compiler to check the code more thoroughly.
- The function is defined between two braces.
- The function `min()` returns an `int` and takes two `int`'s as arguments. These are copies of `j` and `k`.

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{

   int j, k, m;

   printf("Input two integers: ");
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  m = min(j, k);
   printf("\nOf the two values %d and %d, " \
   "the minimum is %d.\n\n", j, k, m);
   return 0;

}

int min(int a, int b)
{
   if (a < b)
      return a;
   else
      return b;
}
```

Execution :

```
Input two integers: 5 2

Of the two values 5 and 2, the minimum is 2.
```

- Execution begins, as normal, in the `main()` function.
- The function *prototype is shown* at the top of the file. This allows the compiler to check the code more thoroughly.
- The function is defined between two braces.
- The function `min()` returns an `int` and takes two `int`'s as arguments. These are copies of `j` and `k`.
- The `return` statement is used to return a value to the calling statement.

Call-by-Value

In the following example, a function is passed an integer using call by value:

```c
#include <stdio.h>

void fnc1(int a);

int main(void)
{

   int x = 1;

   fnc1(x);
   printf("%d\n", x);
}

void fnc1(int x)
{
   x = x + 1;
}
```

Execution :

1

- The function does not change the value of `x` in `main()`, since a in the function is effectively only a **copy** of the variable.

Call-by-Value

In the following example, a function is passed an integer using call by value:

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void fnc1(int a);

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    printf("%d\n", x);
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```

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- The function does not change the value of `x` in `main()`, since a in the function is effectively only a **copy** of the variable.
- A function which has no return value, is declared `void` and, in other languages, might be termed a *procedure*.

Call-by-Value

In the following example, a function is passed an integer using call by value:

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#include <stdio.h>

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int main(void)
{

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   fnc1(x);
   printf("%d\n", x);
}

void fnc1(int x)
{
   x = x + 1;
}
```

Execution :

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- The function does not change the value of `x` in `main()`, since a in the function is effectively only a **copy** of the variable.
- A function which has no return value, is declared `void` and, in other languages, might be termed a *procedure*.
- Most parameters used as arguments to functions in C are copied - this is known as *call-by-value*. We'll see the alternative, *call-by-reference*, later.

Testing

```c
#include <stdio.h>

int numfactors(int f);

int main(void)
{

   int n = 12;
   printf("Number of factors in %d is %d\n", \
          n, numfactors(n));
   return 0;
}

int numfactors(int k)
{

   int count = 0;

   for(int i=1; i<=k; i++){
      if( (k%i)==0) {
         count++;
      }
   }
   return count;
}
```

- This is a (not very good) function to compute the number of factors a number has.

Testing

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- This is a (not very good) function to compute the number of factors a number has.
- A factor is a number by which a larger (whole/integer) number can be divided.

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- This is a (not very good) function to compute the number of factors a number has.
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- 36 has 6 factors: $1, 2, 3, 4, 6, 12$ and 36 itself.

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   }
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- How do we know the program works though ?

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- Running it ?

  Number of factors in 12 is 6

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```

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- A factor is a number by which a larger (whole/integer) number can be divided.
- 36 has 6 factors: $1, 2, 3, 4, 6, 12$ and 36 itself.
- How do we know the program works though ?
- Running it ?

  `Number of factors in 12 is 6`
- We need something more automated.

Pre- and Post-Conditions

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

int numfactors(int f);

int main(void)
{

   int n = 12;
   printf("Number of factors in %d is %d\n", \
          n, numfactors(n));
   return 0;
}

int numfactors(int k)
{

   int count = 0;

   assert(k >= 1); // Avoid trying zero
   for(int i=1; i<=k; i++){
      if( (k%i)==0) {
         count++;
      }
   }
   assert(count <= k);
   return count;
}
```

- Pre-conditions check the inputs to functions, typically their arguments.

Pre- and Post-Conditions

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}
```

- Pre-conditions check the inputs to functions, typically their arguments.
- Post-conditions check the returns from functions.
- An assert simple states some test that **ought** to be true. If not, the program aborts with an error.
- There's a sense that this is somehow *safer*, but we haven't exactly done much testing on it to ensure the correct answers are returned.

Assert Testing

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

int numfactors(int f);

int main(void)
{
   assert(numfactors(17) == 2);
   assert(numfactors(12) == 6);
   assert(numfactors(6) == 4);
   assert(numfactors(0) == 0); // ?
   return 0;
}

int numfactors(int k)
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   for(int i=1; i<=k; i++){
      if( (k%i)==0) {
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      }
   }
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}
```

- We will use assert testing in this style **every** time we write a function.

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- These tests tend to get quite long, so we generally collect them in a function called test() which itself is called from main().
- If there is no error, there is no output from this program.
- By #define'ing NDEBUG before the #include <assert.h>, all assertions are ignored, allowing them to be used during development and switched off later.

Self-test : Multiply

- Write a simple function `int mul(int a, int b)` which multiples two integers together **without** the use of the multiply symbol in C (i.e. the $*$)

```c
/* Try to write mult(a,b) without using
   any maths cleverer than addition.     */

#include <stdio.h>
#include <assert.h>

int mult( int a,  int b);
void test(void);

int main(void)
{
   test();

   return 0;
}

int mult( int a,  int b)
{

// To be completed

}

void test(void)
{
   assert(mult(5,3) == 15);
   assert(mult(3,5) == 15);
   assert(mult(0,3) == 0);
   assert(mult(3,0) == 0);
   assert(mult(1,8) == 8);
   assert(mult(8,1) == 8);
}
```

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- 7×8 is computed by adding up 7 eight times.

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Self-test : Multiply

- Write a simple function `int mul(int a, int b)` which multiples two integers together **without** the use of the multiply symbol in C (i.e. the $*$)
- Use iteration (a loop) to achieve this.
- 7×8 is computed by adding up 7 eight times.
- Use `assert()` calls to test it thoroughly - I've given you some to get you started.

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```

Program Layout

It is normal for the main() function to come first in a program :

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

list of function prototypes

int main(void)
{
   . . . . .
}

int f1(int a, int b)
{
   . . . . .
}

int f2(int a, int b)
{
   . . . . .
}
```

However, it is theoretically possible to avoid the need for function prototypes by defining a function before it is used :

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

int f1(int a, int b)
{
   . . . . .
}

int f2(int a, int b)
{
   . . . . .
}

int main(void)
{

   . . . . .

}
```

We will **never** use this second approach - put main() first with the prototypes above it.

Replacing Functions with Macros

```c
#include <stdio.h>

#define MIN(A, B) ((A)<(B)?(A):(B))

int main(void)
{

   int j, k, m;

   printf("Input two integers: ");
   scanf("%d%d", &j, &k);
   m = MIN(j, k);
   printf("Minimum is %d\n", m);
   return 0;

}
```

Execution :

```
Input two integers: 5 2
Minimum is 2
```

- There's sometimes a (tiny) time penalty for using functions.

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- The contents of the functions are saved onto a special stack, so that when you return to the function, its variables and state can be restored.

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   m = MIN(j, k);
    printf("Minimum is %d\n", m);
    return 0;

}
```

Execution :

```
Input two integers: 5 2
Minimum is 2
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- https://en.wikipedia.org/wiki/Call_stack
- Historically, for small functions that needed to be fast, programmers might have #define a macro.
- There's a problem though - what happens if we used m = MIN(i++, j++); ?
- This is expanded to ((i++)<(j++)?(i++):(j++)) which is **not** what was intended.

The inline modifier

- In C99 the inline modifier was introduced https://en.wikipedia.org/wiki/Inline_function

  ... serves as a compiler directive that suggests (but does not require) that the compiler substitute the body of the function inline by performing inline expansion, i.e. by inserting the function code at the address of each function call, thereby saving the overhead of a function call.

```c
#include <stdio.h>

static inline int min(int a, int b);

int main(void)
{

   int j, k, m;

   printf("Input two integers: ");
   scanf("%d%d", &j, &k);
   m = min(j, k);
   printf("Minimum is %d\n", m);
   return 0;

}

inline int min(int a, int b)
{
   if (a < b)
      return a;
   else
      return b;
}
```

Execution :

```
Input two integers: 5 2
Minimum is 2
```

Factorials via Iteration

- A repeated computation computation is normally achieved via *iteration*, e.g. using for():

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

int fact(int a);

int main(void)
{
    assert(fact(4) == 24);
    assert(fact(1) == 1);
    assert(fact(0) == 1);
    assert(fact(10) == 3628800);
    return(0);

}

int fact(int a)
{

    int i;
    int tot = 1;

    for(i=1; i<=a; i++){
        tot *= i;
    }
    return tot;

}
```

Factorials via Iteration

- A repeated computation computation is normally achieved via *iteration*, e.g. using for():
- Here we compute the factorial of a number - the factorial of 4, written as 4!, is simply $4 \times 3 \times 2 \times 1$.

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

int fact(int a);

int main(void)
{
    assert(fact(4) == 24);
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Factorials via Iteration

- A repeated computation computation is normally achieved via *iteration*, e.g. using for():
- Here we compute the factorial of a number - the factorial of 4, written as 4!, is simply $4 \times 3 \times 2 \times 1$.
- Obviously, we'd do more assert tests in the full verson.

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

int fact(int a);

int main(void)
{
   assert(fact(4) == 24);
   assert(fact(1) == 1);
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   }
   return tot;

}
```

Factorials via Recursion (Advanced)

- We could achieve the same result using recursion.

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

int fact(int a);

int main(void)
{
   assert(fact(4) == 24);
   assert(fact(1) == 1);
   assert(fact(0) == 1);
   assert(fact(10) == 3628800);
   return(0);

}

int fact(int a)
{

   if(a > 0)
      return ( a * fact(a - 1) );
   else
      return 1;

}
```

Factorials via Recursion (Advanced)

- We could achieve the same result using recursion.
- The factorial of 4 can be thought of as $4 \times 3!$

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

int fact(int a);

int main(void)
{
    assert(fact(4) == 24);
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    assert(fact(10) == 3628800);
    return(0);

}

int fact(int a)
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    if(a > 0)
       return ( a * fact(a - 1) );
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}
```

Factorials via Recursion (Advanced)

- We could achieve the same result using recursion.
- The factorial of 4 can be thought of as $4 \times 3!$
- A recursive function calls *itself* - there may be many versions of the same function 'alive' at the same time during execution.

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

int fact(int a);

int main(void)
{
   assert(fact(4) == 24);
   assert(fact(1) == 1);
   assert(fact(0) == 1);
   assert(fact(10) == 3628800);
   return(0);

}

int fact(int a)
{

   if(a > 0)
      return ( a * fact(a - 1) );
   else
      return 1;

}
```

- Write a simple function int mul(int a, int b) which multiples two integers together **without** the use of the multiply symbol in C (i.e. the *)

```c
/* Try to write mult(a,b) without using
   any maths cleverer than addition.     */

#include <stdio.h>
#include <assert.h>

int mult( int a,  int b);
void test(void);

int main(void)
{
   test();

   return 0;
}

int mult( int a,  int b)
{

// To be completed

}

void test(void)
{
   assert(mult(5,3) == 15);
   assert(mult(3,5) == 15);
   assert(mult(0,3) == 0);
   assert(mult(3,0) == 0);
   assert(mult(1,8) == 8);
   assert(mult(8,1) == 8);
}
```

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Self-test : Multiply (Advanced)

- Write a simple function int mul(int a, int b) which multiples two integers together **without** the use of the multiply symbol in C (i.e. the *)
- Use recursion to achieve this.
- Use assert() calls to test it thoroughly.

```c
/* Try to write mult(a,b) without using
   any maths cleverer than addition.     */

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int mult( int a,  int b);
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Table of Contents

Fundamental Data types

- [unsigned | signed]
- [long | short]
- [char | int | float | double]
- The use of int implies signed int without the need to state it.
- Likewise unsigned short means unsigned short int.

Type	Minimum size (bits)	Format specifier
char	8	%c
signed char	8	%c (or %hhi for numerical output)
unsigned char	8	%c (or %hhu for numerical output)
short short int signed short signed short int	16	%hi or %hd
unsigned short unsigned short int	16	%hu
int signed signed int	16	%i or %d
unsigned unsigned int	16	%u
long long int signed long signed long int	32	%li or %ld
unsigned long unsigned long int	32	%lu
long long long long int signed long long signed long long int	64	%lli or %lld
unsigned long long unsigned long long int	64	%llu
float		scanf(): %f, %g, %e, %a
double		%lf, %lg, %le, %la
long double		%Lf, %Lg, %Le, %La

Binary Storage of Numbers

In an unsigned char :

2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
0	1	0	0	1	1	0	0

The above represents :
$1 * 64 + 1 * 8 + 1 * 4 = 76.$

- Floating operations need not be exact.

```c
#include <stdio.h>

int main(void)
{

   float d = 0.1;
   printf("%.12f\n", 3.0*d);
   return 0;
}
```

Execution :

```
0.300000004470
```

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if ( d == 0.3 )
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```

- Therefore, we don't allow this by explicitly using the compiler warning flag: -Wfloat-equal

sizeof()

To find the exact size in bytes of a type on a particular machine, use sizeof(). On a Dell Windows 10 laptop running WSL:

```c
#include <stdio.h>

int main(void)
{

    printf("char        :%3ld\n", sizeof(char));
    printf("short       :%3ld\n", sizeof(short));
    printf("long        :%3ld\n", sizeof(long));
    printf("unsigned    :%3ld\n", sizeof(unsigned));
    printf("long long   :%3ld\n", sizeof(long long));
    printf("float       :%3ld\n", sizeof(float));
    printf("dbl         :%3ld\n", sizeof(double));
    printf("long dbl    :%3ld\n", sizeof(long double));
    printf("\n");

    return 0;
}
```

Execution :

```
char        :  1
short       :  2
long        :  8
unsigned    :  4
long long   :  8
float       :  4
dbl         :  8
long dbl    : 16
```

Mathematical Functions

- There are no mathematical functions built into the C language.
- However, there are many functions in the maths library which may linked in using the **-lm** option with the compiler.
- Functions include :

  `sqrt()` `pow()` `round()`
  `fabs()` `exp()` `log()`
  `sin()` `cos()` `tan()`
- Most take `doubles` as arguments and return `doubles`.

Casting

```c
/* Compute the Area of a Sphere
   to the nearest integer        */
#include <stdio.h>
#include <math.h>

#define PI 3.14159265358979323846

int main(void)
{
   double r;
   printf("Enter a radius : ");
   scanf("%lf", &r);
   // Make sure radius is positive
   r = fabs(r);
   double a = 4.0 / 3.0 * PI * pow(r, (double) 3);
   printf("Area of your ball = %f\n", a);
   printf("Area of your ball = %.2f\n", a);
   printf("Area of your ball = %d\n", (int)a);
   printf("Area of your ball = %.0f\n", round(a));
   return 0;
}
```

Execution :

```
Enter a radius : 7.75
Area of your ball = 1949.816390
Area of your ball = 1949.82
Area of your ball = 1949
Area of your ball = 1950
```

- An explicit type conversion is called a *cast*.
- *If it moves - cast it*. Don't trust the compiler to do it for you !

Table of Contents

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enum day { sun, mon, tue, wed, thu, fri, sat};
```

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enum day d1;
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- Use enumerated types as constants to aid readability - they are self-documenting.

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- Declare them in a header (`.h`) file.

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- The default numbering may be changed as well:

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enum fruit{apple=7, pear, orange=3, lemon};
```

- Use enumerated types as constants to aid readability - they are self-documenting.
- Declare them in a header (`.h`) file.
- Note that the type is `enum day`; the keyword `enum` is not enough.

Typedefs

- Sometimes it is useful to associate a particular name with a certain type, e.g.:

  ```
  typedef int colour;
  ```

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  `typedef int colour;`
- Now the type `colour` is synonymous with the type `int`.
- Makes code self-documenting.
- Helps to control complexity when programmers are building complicated or lengthy user-defined types (See Structures **??**).

Combining typedefs and enums

- Often typedef's are used in conjunction with enumerated types:

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

enum day {sun,mon,tue,wed,thu,fri,sat};
typedef enum day day;

day find_next_day(day d);

int main(void)
{
   assert(find_next_day(mon)==tue);
   assert(find_next_day(sat)==sun);
   assert(find_next_day(sun)==mon);
   return 0;
}
```

```
day find_next_day(day d)
{
   day next_day;
   switch(d){
      case sun:
         next_day = mon;
         break;
      case mon:
         next_day = tue;
         break;
      case tue:
         next_day = wed;
         break;
      case wed:
         next_day = thu;
         break;
      case thu:
         next_day = fri;
         break;
      case fri:
         next_day = tue;
         break;
      case sat:
         next_day = sun;
         break;
      default:
         printf("I wasnâĂŹt expecting that!\n");
   }
   return next_day;
}
```

Style

```
enum veg {beet, carrot, pea};
typedef enum veg veg;
veg v1, v2;
v1 = carrot;
```

- We can combine the two operations into one:

  ```
  typedef enum veg {beet,carrot,pea} veg;
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  ```
  typedef enum veg {beet,carrot,pea} veg;
  veg v1, v2;
  v1 = carrot;
  ```

- Assigning:

  ```
  v1 = 10;
  ```

  is very poor programming style !

Booleans

- Before C99 you might have been tempted to define your own Boolean type:

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

typedef enum bool {false, true} bool;

int main(void)
{

    bool b = true;
    if (b){
        printf("It's true!\n");
    }
    else{
        printf("It's false!\n");
    }
    return 0;
}
```

Execution :

```
It's true!
```

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

int main(void)
{

    bool b = true;
    if (b){
        printf("It's true!\n");
    }
    else{
        printf("It's false!\n");
    }
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}
```

Execution :

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It's true!
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        printf("It's false!\n");
    }
    return 0;
}
```

Execution :

```
It's true!
```

- However, we can just use `#include <stdbool.h>`

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    }
    return 0;
}
```

Execution :

```
It's true!
```

Fever

Rewrite/complete this code using typedefs and enums to create self-documenting code in any manner you wish.

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

// Argument 1 is temperature
// Argument 2 is scale (0=>Celsius, 1=>Farenheit)
int fvr(double t, int s);

int main(void)
{
   assert(fvr(37.5, 0)==1);
   assert(fvr(36.5, 0)==0);
   assert(fvr(96.5, 1)==0);
   assert(fvr(99.5, 1)==1);
   return 0;
}

int fvr(double t, int s)
{
}
```