COMSM1201 : Programming in C

Dr. Neill Campbell

Neill.Campbell@bristol.ac.uk

University of Bristol

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Table of Contents

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

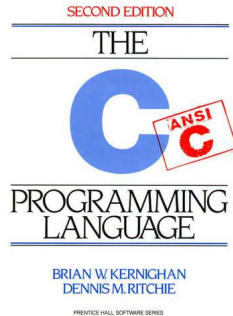- Free : https://en.wikibooks.org/wiki/C_Programming

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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.

SECOND EDITION
THE
C
ANSI C
PROGRAMMING LANGUAGE
BRIAN W. KERNIGHAN
DENNIS M. RITCHIE
PRENTICE HALL SOFTWARE SERIES

Computer Science Ethos

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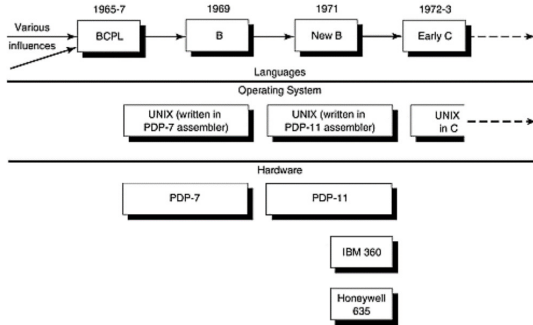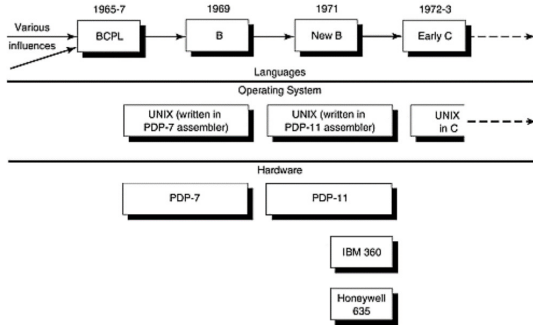
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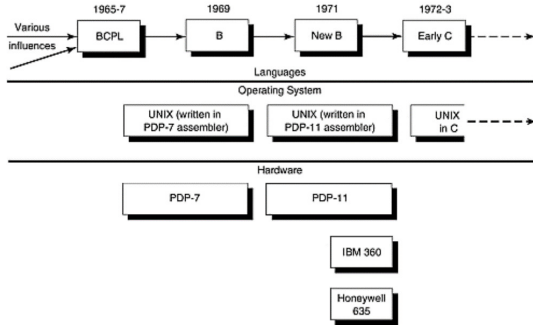From **Deep C Secrets** by *Peter Van Der Linden*

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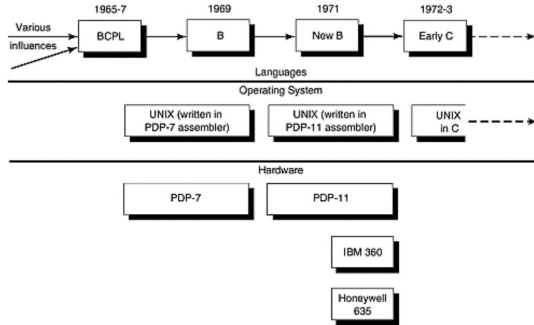- K&R C (Kernighan and Ritchie) 1978

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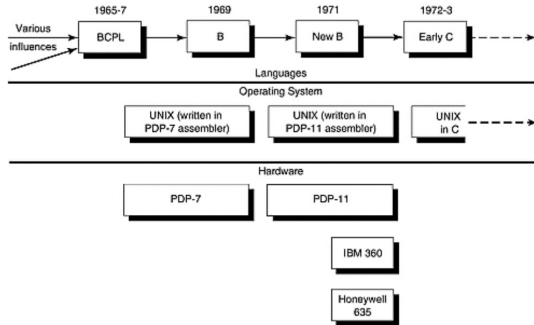- K&R C (Kernighan and Ritchie) 1978
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- C99 (COMSM1201)

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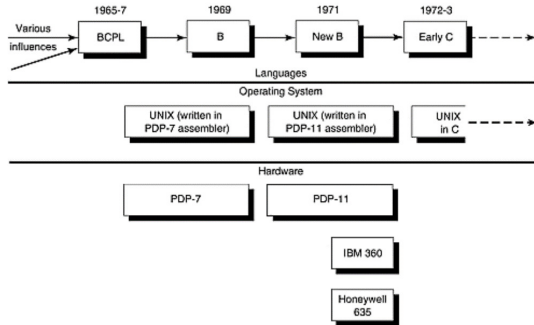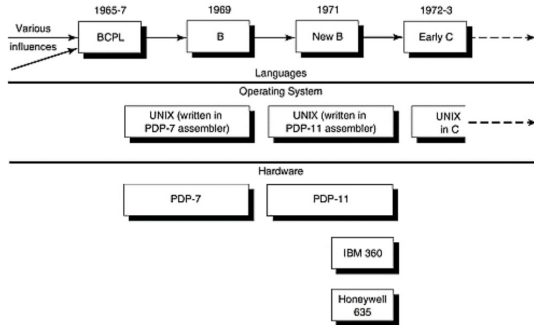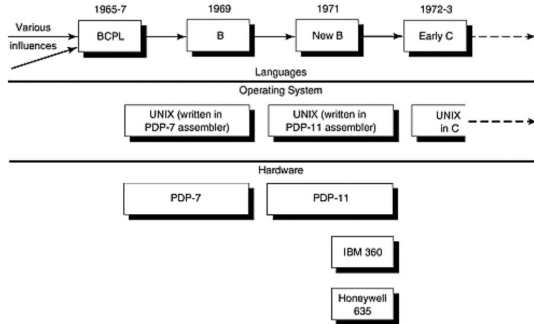- C++ - Object Oriented Programming (OOP)

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- ANSI C
- 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	▼		Java
4	4			C++
5	5			C#
6	6			Visual Basic
7	7			JavaScript

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- Programming (C), data structures, algorithms - searching, sorting, string processing, trees etc.

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- 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.

Table of Contents

'\n' is a single character: putchar('\n') prints that character 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

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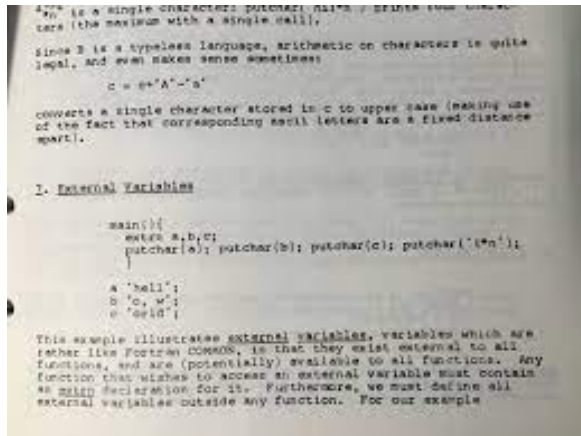
```
1    /* The traditional first program
2    in honour of Dennis Ritchie
3    who invented C at Bell Labs
4    in 1972 */
5
6    #include <stdio.h>
7
8    int main(void)
9    {
10
11       printf("Hello, world!\n");
12       return 0;
13
14   }
```

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
1   #include <stdio.h>
2
3   int main(void)
4   {
5       // Compute the area of a rectangle
6       int side1, side2, area;
7       side1 = 7;
8       side2 = 8;
9       area = side1 * side2;
10
11      printf("Length of side  1 = %i metres\n", side1);
12      printf("Length of side  2 = %i metres\n", side2);
13      printf("Area of rectangle = %i metres squared\n", area);
14      return 0;
15  }
```

Execution :

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

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2
3    int main(void)
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5        declarations
6
7        statements
8    }
```

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- Integer arithmetic discards remainder i.e. 1/2 is 0 , 7/2 is 3.
- Modulus (Remainder) Arithmetic. 7%4 is 3, 12%6 is 0.
- Only available for integer arithmetic.

The Character Type

```
1    // Demonstration of character arithmetic
2    #include <stdio.h>
3
4    int main(void)
5    {
6        char    c;
7
8        c = 'A';
9        printf("%c ", c);
10       printf("%c\n", c+1);
11       return 0;
12   }
```

Execution :

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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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  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
%i	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*.

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%i	Integers
%f	Floats
%lf	Doubles
%s	Strings

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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- Note that the *address* of the argument is required.

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%i	Integers
%f	Floats
%lf	Doubles
%s	Strings

- Note doubles handled differently than floats.

While Loops

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

```
1    // Sums are computed.
2    #include <stdio.h>
3
4    int main(void)
5    {
6
7        int cnt = 0;
8        float sum = 0.0, x;
9        printf("Input some numbers: ");
10       while (scanf("%f", &x) == 1) {
11           cnt = cnt + 1;
12           sum = sum + x;
13       }
14
15       printf("\n%s%5i\n%s%5f\n\n",
16              "Count:", cnt, "Sum: ", sum);
17       return 0;
18   }
```

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

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("%i", a);
  ```

Table of Contents

Grammar

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- **Invalid** Identifiers :
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- 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*.

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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 $+$.
- 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;
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- 1 + 2 * 3 is the same as 1 + (2 * 3) because * has a higher precedence than +.
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- 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("%i %i %i\n", a, b, ++c);
    return 0;
}
```

Question : What is the output ?

Assignment

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

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- a = b = c = 0; is valid and equivalent to :
  = (b = (c = 0));

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- 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;

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- a $=$ b $=$ c $=$ 0; is valid and equivalent to :
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- i $=$ i $+$ 3; is the same as i $+=$ 3;
- Many other operators are possible e.g.
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- Many other operators are possible e.g. -=, *=, /=.

```
1   // 1st few powers of 2 are printed.
2
3   #include <stdio.h>
4
5   int main(void)
6   {
7       int   i = 0, power = 1;
8
9       while (++i <= 10){
10          printf("%5i", power *= 2);
11      }
12      printf("\n");
13      return 0;
14  }
```

Execution :

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

The Standard Library

```c
 1    #include <stdio.h>
 2    #include <stdlib.h>
 3
 4    int main(void)
 5    {
 6        int    i, n;
 7        printf("Randomly distributed integers are printed.\n"
 8               "How many do you want to see?  ");
 9        do{
10            i = scanf("%i", &n);
11        }while(i != 1);
12        for (i = 0; i < n; ++i) {
13            if (i % 4 == 0)
14                printf("\n");
15            printf("%12i", rand());
16        }
17        printf("\n");
18        return 0;
19    }
```

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
```

```c
1   #include <stdio.h>
2   #include <stdlib.h>
3
4   int main(void)
5   {
6       int   i, n;
7       printf("Randomly distributed integers are printed.\n"
8              "How many do you want to see?  ");
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11      }while(i != 1);
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13          if (i % 4 == 0)
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- Definitions required for the proper use of many functions such as rand() are found in stdlib.h.

Execution :

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Randomly distributed integers are printed.
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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 !

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Comparisons

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&&	logical AND
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- (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

```
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.

The if() Statement

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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
1    #include <stdio.h>
2
3    int main(void)
4    {
5        int   x, y, z;
6
7        printf("Input three integers:  ");
8        if(scanf("%i%i%i", &x, &y, &z) != 3){
9            printf("Didn't get 3 numbers?\n");
10           return 1;
11       }
12       int min;
13       if (x < y){
14           min = x;
15       }
16       // Nasty, dropped braces:
17       else
18           min = y;
19       if (z < min){
20           min = z;
21       }
22       printf("The minimum value is %i\n", min);
23       return 0;
24   }
```

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.

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.

```
1    // Simple while countdown
2
3    #include <stdio.h>
4
5    int main(void)
6    {
7
8        int n = 9;
9
10       while(n > 0){
11           printf("%i ", n);
12           n--;
13       }
14       printf("\n");
15       return 0;
16   }
```

Execution :

9 8 7 6 5 4 3 2 1

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 ;
}
```

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

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and may be thought of as :

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

In the for() loop, note :

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

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        .
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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*.

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

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

```
1    // Triples of integers that sum to N
2    #include <stdio.h>
3
4    #define N 7
5
6    int main(void)
7    {
8        int   cnt = 0, i, j, k;
9
10       for(i = 0; i <= N; i++){
11           for(j = 0; j <= N; j++){
12               for(k = 0; k <= N; k++){
13                   if(i + j + k == N){
14                       ++cnt;
15                       printf("%3i%3i%3i\n", i, j, k);
16                   }
17               }
18           }
19       }
20       printf("\nCount: %i\n", cnt);
21       return 0;
22   }
```

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.

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
1   // Simple do-while countdown
2
3   #include <stdio.h>
4
5   int main(void)
6   {
7
8       int n = 9;
9
10      /* This program always prints at least one
11         number, even if n initialised to 0 */
12      do{
13          printf("%i ", n);
14          n--;
15      }while(n > 0);
16      printf("\n");
17      return 0;
18  }
```

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.

```
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("%i", &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 0 10 3
Enter a number from 2 - 9 : Enter a number

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.

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

```c
1   #include <stdio.h>
2
3   int main(void)
4   {
5       int   x, y, z;
6
7       printf("Input three integers:  ");
8       if(scanf("%i%i%i", &x, &y, &z) != 3){
9           printf("Didn't get 3 numbers?\n");
10          return 1;
11      }
12      int min;
13      min = (x < y) ? x : y;
14      min = (z < min) ? z : min;
15      printf("The minimum value is %i\n", min);
16      return 0;
17  }
```

Table of Contents

Simple Functions

```c
1    #include <stdio.h>
2
3    int min(int a, int b);
4
5    int main(void)
6    {
7
8        int j, k, m;
9
10       printf("Input two integers: ");
11       scanf("%i%i", &j, &k);
12       m = min(j, k);
13       printf("\nOf the two values %i and %i, " \
14       "the minimum is %i.\n\n", j, k, m);
15       return 0;
16
17   }
18
19   int min(int a, int b)
20   {
21       if (a < b)
22           return a;
23       else
24           return b;
25   }
```

Execution :

Input two integers: 5 2

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

Simple Functions

```c
#include <stdio.h>

int min(int a, int b);

int main(void)
{
    int j, k, m;

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

}

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

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

Execution :

```
Input two integers: 5 2

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

Simple Functions

```c
#include <stdio.h>

int min(int a, int b);

int main(void)
{

    int j, k, m;

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

}

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

- 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.

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Input two integers: 5 2

Of the two values 5 and 2, the minimum is 2.
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int min(int a, int b);

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    int j, k, m;

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    m = min(j, k);
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    "the minimum is %i.\n\n", j, k, m);
    return 0;

}

int min(int a, int b)
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- 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.

Execution :

```
Input two integers: 5 2

Of the two values 5 and 2, the minimum is 2.
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Simple Functions

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int min(int a, int b);

int main(void)
{

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    printf("Input two integers: ");
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    printf("\nOf the two values %i and %i, " \
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    return 0;

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

- 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.

Execution :

```
Input two integers: 5 2

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

Simple Functions

```c
1    #include <stdio.h>
2
3    int min(int a, int b);
4
5    int main(void)
6    {
7
8        int j, k, m;
9
10       printf("Input two integers: ");
11       scanf("%i%i", &j, &k);
12       m = min(j, k);
13       printf("\nOf the two values %i and %i, " \
14       "the minimum is %i.\n\n", j, k, m);
15       return 0;
16
17   }
18
19   int min(int a, int b)
20   {
21       if (a < b)
22           return a;
23       else
24           return b;
25   }
```

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 x);

int main(void)
{
    int x = 1;

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

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

Execution :

1

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

```
1    #include <stdio.h>
2
3    void fnc1(int x);
4
5    int main(void)
6    {
7        int x = 1;
8
9        fnc1(x);
10       printf("%i\n", x);
11   }
12
13   void fnc1(int x)
14   {
15       x = x + 1;
16   }
```

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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1    #include <stdio.h>
2
3    void fnc1(int x);
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5    int main(void)
6    {
7        int x = 1;
8
9        fnc1(x);
10       printf("%i\n", x);
11   }
12
13   void fnc1(int x)
14   {
15       x = x + 1;
16   }
```

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.
- 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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1    #include <stdio.h>
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3    void fnc1(int x);
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9        fnc1(x);
10       printf("%i\n", x);
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13   void fnc1(int x)
14   {
15       x = x + 1;
16   }
```

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.
- 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 %i is %i\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;
}
```

Testing

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int main(void)
{

    int n = 12;
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    int count = 0;

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        }
    }
    return count;
}
```

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

```
1   #include <stdio.h>
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3   int numfactors(int f);
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8       int n = 12;
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10              n, numfactors(n));
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17      int count = 0;
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19      for(int i=1; i<=k; i++){
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21              count++;
22          }
23      }
24      return count;
25  }
```

- 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.

```
1   #include <stdio.h>
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3   int numfactors(int f);
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5   int main(void)
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9       printf("Number of factors in %i is %i\n", \
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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.
- 12 has 6 factors: $1, 2, 3, 4, 6$ and 12 itself.

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3    int numfactors(int f);
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5    int main(void)
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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.
- 12 has 6 factors: $1, 2, 3, 4, 6$ and 12 itself.
- How do we know the program works though ?

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int numfactors(int f);

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}

int numfactors(int k)
{

    int count = 0;

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

- This is a (not very good) function to compute the number of factors a number has.
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- 12 has 6 factors: $1, 2, 3, 4, 6$ and 12 itself.
- How do we know the program works though ?
- Running it ?
  Number of factors in 12 is 6

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23       }
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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.
- 12 has 6 factors: $1, 2, 3, 4, 6$ and 12 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 %i is %i\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- and Post-Conditions

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1   #include <stdio.h>
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```

- 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.
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- An assert simple states some test that **ought** to be true. If not, the program aborts with an error.

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28   }
```

- 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)
{

    int count = 0;

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

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

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

Assert Testing

```c
#include <stdio.h>
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int numfactors(int f);

int main(void)
{
    assert(numfactors(17) == 2);
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    return 0;
}

int numfactors(int k)
{

    int count = 0;

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

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

- These tests tend to get quite long, so we generally collect them in a function called test() which itself is called from main().

```
1    #include <stdio.h>
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4    int numfactors(int f);
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8        assert(numfactors(17) == 2);
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23           }
24       }
25       return count;
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```

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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.

```c
#include <stdio.h>
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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)
{

    int count = 0;

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

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

- 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);
}
```

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.

```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);
}
```

- 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.

```c
1   /* Try to write mult(a,b) without using
2      any maths cleverer than addition.      */
3
4   #include <stdio.h>
5   #include <assert.h>
6
7   int mult( int a,  int b);
8   void test(void);
9
10  int main(void)
11  {
12      test();
13
14      return 0;
15  }
16
17  int mult( int a,  int b)
18  {
19
20  // To be completed
21
22  }
23
24  void test(void)
25  {
26      assert(mult(5,3) == 15);
27      assert(mult(3,5) == 15);
28      assert(mult(0,3) == 0);
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31      assert(mult(8,1) == 8);
32  }
```

- 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.

```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);
}
```

Program Layout

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

```c
#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)
{
   . . . . .
}
```

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

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int main(void)
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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.

```
1    #include <stdio.h>
2
3    #define MIN(A, B)  ((A)<(B)?(A):(B))
4
5    int main(void)
6    {
7
8        int j, k, m;
9
10       printf("Input two integers: ");
11       scanf("%i%i", &j, &k);
12       m = MIN(j, k);
13       printf("Minimum is %i\n", m);
14       return 0;
15
16   }
```

Execution :

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

Replacing Functions with Macros

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

```c
#include <stdio.h>

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

int main(void)
{

    int j, k, m;

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

}
```

Execution :

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

Replacing Functions with Macros

```c
1   #include <stdio.h>
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3   #define MIN(A, B) ((A)<(B)?(A):(B))
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5   int main(void)
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- There's sometimes a (tiny) time penalty for using functions.
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- 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("%i%i", &j, &k);
    m = min(j, k);
    printf("Minimum is %i\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
```

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Factorials via Iteration

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- Obviously, we'd do more assert tests in the full version.

```c
1   #include <stdio.h>
2   #include <assert.h>
3
4   int fact(int a);
5
6   int main(void)
7   {
8       assert(fact(4) == 24);
9       assert(fact(1) == 1);
10      assert(fact(0) == 1);
11      assert(fact(10) == 3628800);
12      return(0);
13
14  }
15
16  int fact(int a)
17  {
18
19      int i;
20      int tot = 1;
21
22      for(i=1; i<=a; i++){
23          tot *= i;
24      }
25      return tot;
26
27  }
```

Factorials via Recursion (Advanced)

- We could achieve the same result using recursion.

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1   #include <stdio.h>
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12      return(0);
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14  }
15
16  int fact(int a)
17  {
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19      if(a > 0)
20          return ( a * fact(a - 1) );
21      else
22          return 1;
23
24  }
```

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

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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.

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1   #include <stdio.h>
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4   int fact(int a);
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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 ∗)

```c
1   /* Try to write mult(a,b) without using
2      any maths cleverer than addition.    */
3
4   #include <stdio.h>
5   #include <assert.h>
6
7   int mult( int a,  int b);
8   void test(void);
9
10  int main(void)
11  {
12      test();
13
14      return 0;
15  }
16
17  int mult( int a,  int b)
18  {
19
20  // To be completed
21
22  }
23
24  void test(void)
25  {
26      assert(mult(5,3) == 15);
27      assert(mult(3,5) == 15);
28      assert(mult(0,3) == 0);
29      assert(mult(3,0) == 0);
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- Use assert() calls to test it thoroughly.

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```

Table of Contents

Fundamental Data types

- **[unsigned | signed]**

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 %hi
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	%ld or %li
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

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- **[unsigned | signed]**
- **[long | short]**

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unsigned unsigned int	16	%u
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- Likewise unsigned short means unsigned short int.

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

    return 0;
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14       printf("\n");
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Execution :

```
char      :   1
short     :   2
long      :   8
unsigned  :   4
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Mathematical Functions

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- Functions include :

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  fabs() exp() log()
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- Most take doubles as arguments and return doubles.

Casting

```
1    /* Compute the Area of a Sphere
2       to the nearest integer        */
3    #include <stdio.h>
4    #include <math.h>
5
6    #define PI 3.14159265358979323846
7
8    int main(void)
9    {
10       double r;
11       printf("Enter a radius : ");
12       scanf("%lf", &r);
13       // Make sure radius is positive
14       r = fabs(r);
15       double a = 4.0 / 3.0 * PI * pow(r, (double) 3);
16       printf("Area of your ball = %f\n", a);
17       printf("Area of your ball = %.2f\n", a);
18       printf("Area of your ball = %i\n", (int)a);
19       printf("Area of your ball = %.0f\n", round(a));
20       return 0;
21   }
```

- An explicit type conversion is called a *cast*.

Execution :

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

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

Execution :

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Enter a radius : 7.75
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Area of your ball = 1949.82
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- By default the first (sun) has the value 0,
  the second has the value 1 and so on.

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Enumerated Types

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

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- 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.:

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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 later).

Combining `typedefs` and `enums`

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

```c
#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;
}
```

```c
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 wasn't 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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- We can combine the two operations into one:
  ```
  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:

```
1   #include <stdio.h>
2   #include <assert.h>
3
4   typedef enum bool {false, true} bool;
5
6   int main(void)
7   {
8
9       bool b = true;
10      if (b){
11          printf("It's true!\n");
12      }
13      else{
14          printf("It's false!\n");
15      }
16      return 0;
17  }
```

Execution :

It's true!

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    else{
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    }
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}
```

Execution :

It's true!

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

```c
#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");
    }
    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
1    #include <stdio.h>
2    #include <assert.h>
3
4    // Argument 1 is temperature
5    // Argument 2 is scale (0=>Celsius, 1=>Farenheit)
6    int fvr(double t, int s);
7
8    int main(void)
9    {
10       assert(fvr(37.5, 0)==1);
11       assert(fvr(36.5, 0)==0);
12       assert(fvr(96.5, 1)==0);
13       assert(fvr(99.5, 1)==1);
14       return 0;
15   }
16
17   int fvr(double t, int s)
18   {
19   }
```

Table of Contents

1D Arrays

- One-Dimensional arrays are declared by a type followed by an identifier with a bracketed constant expression:

  float x[10];

  int k[ARRAY_SIZE];

  The following, however, is not valid:

  float y[i*2];

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- Arrays are indexed **0** to **n-1**.

```c
#include <stdio.h>

#define N 500

int main(void)
{

    /* allocate space a[0]...a[N-1] */
    int a[N];
    int i, sum = 0;
    /* fill array */
    for (i = 0; i < N; ++i){
        a[i] = 7 + i * i;
    }
    /* print array */
    for (i = 0; i < N; ++i){
        printf("a[%i]=%i ", i, a[i]);
    }
    /* sum elements */
    for (i = 0; i < N; ++i){
        sum += a[i];
    }
    /* print sum */
    printf("\nsum=%i\n", sum);
    return 0;
}
```

1D Arrays : Initialisation

By default, arrays are uninitialised. When they are declared, they may be assigned a value:

float x[7] = {-1.1,0.2,2.0,4.4,6.5,0.0,7.7};

or,

float x[7] = {-1.1, 0.2};

the elements 2 ... 6 are set to zero.
Also:

int a[] = {3, 8, 9, 1};

is valid, the compiler assumes the array size to be 4.

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- a[5] = a[4] + 1;
- k[9]++;
- n[12+i] = 0;

1D Arrays : Call by Reference

```c
1    #include <stdio.h>
2    #include <math.h>
3    #include <assert.h>
4    #define MAX 5
5
6    // Pass array, AND number of elements
7    void set_array(int a[MAX], unsigned int len, int n);
8
9    int main(void)
10   {
11       int x[MAX] = {2, 3, 3, 3, 3};
12       set_array(x, 5, 3); assert(x[0] == 3);
13       x[0] = 5; x[1] = 5; x[2] = 5; x[3] = 5; x[4] = 5;
14       set_array(x, 5, 4); assert(x[2] == 4);
15       set_array(x, 1, 0); assert(x[0] == 0);
16       x[0] = 1; x[1] = 2; x[2] = 3;
17       set_array(x, 3, 2);
18       assert(x[2] == 2); assert(x[3] == 4);
19   }
20
21   // Set all values of array (size len) to n
22   void set_array(int a[MAX], unsigned int len, int n)
23   {
24       if(len == 0){
25           return;
26       }
27       for(unsigned int i=0; i<len; i++){
28           a[i] = n;
29       }
30   }
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14      set_array(x, 5, 4); assert(x[2] == 4);
15      set_array(x, 1, 0); assert(x[0] == 0);
16      x[0] = 1; x[1] = 2; x[2] = 3;
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    x[0] = 5; x[1] = 5; x[2] = 5; x[3] = 5; x[4] = 5;
    set_array(x, 5, 4); assert(x[2] == 4);
    set_array(x, 1, 0); assert(x[0] == 0);
    x[0] = 1; x[1] = 2; x[2] = 3;
    set_array(x, 3, 2);
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- All arrays are passed like this in C - we'll see later when we look at *pointers* why this is the case.

Structures

- A structure type allows the programmer to aggregate components into a single, named variable. Other languages call these *Records* or *Tuples*.

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- ```
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- The member name must be unique within the same structure.

- Arrays of structures are possible, i.e.:
  struct employee team[400];

Arrays of Structures

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

#define SUITS 4
#define PERSUIT 13
#define DECK (SUITS*PERSUIT)
#define SHUFFLE 3

typedef enum {hearts, diamonds, spades, clubs} suit;

struct card {
    suit st;
    int pips;
};
typedef struct card card;

void shuffle_deck(card d[DECK]);
void init_deck(card d[DECK]);
void print_deck(card d[DECK], int n);
void test(void);

int main(void)
{
    card d[DECK];

    test();
    init_deck(d);
    print_deck(d, 7);
    shuffle_deck(d);
    print_deck(d, 7);
    return 0;
}
```

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int main(void)
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    card d[DECK];

    test();
    init_deck(d);
    print_deck(d, 7);
    shuffle_deck(d);
    print_deck(d, 7);
    return 0;
}
```

```c
void init_deck(card d[DECK])
{
    for(int i=0; i<DECK; i++){
        // Number 1 .. 13
        d[i].pips = (i%PERSUIT) + 1;
        switch (i/PERSUIT) {
            case hearts: d[i].st = hearts; break;
            case diamonds: d[i].st = diamonds; break;
            case spades: d[i].st = spades; break;
            case clubs: d[i].st = clubs; break;
            // Force an abort ?
            default : assert(false);
        }
    }
}

void shuffle_deck(card d[DECK])
{
    for(int i=0; i<SHUFFLE*DECK; i++){
        int n1 = rand()%DECK;
        int n2 = rand()%DECK;
        card c = d[n1]; d[n1] = d[n2]; d[n2] = c;
    }
}
```

Arrays of Structures

```c
void print_deck(card d[DECK], int n)
{
    for(int i=0; i<n; i++){
        switch(d[i].pips){
            case 11:
                printf("Jack");
                break;
            case 12:
                printf("Queen");
                break;
            case 13:
                printf("King");
                break;
            default:
                printf("%2i", d[i].pips);
        }
        switch(d[i].st){
            case hearts :
                printf(" of Hearts\n");
                break;
            case diamonds :
                printf(" of Diamonds\n");
                break;
            case spades:
                printf(" of Spades\n");
                break;
            default :
                printf(" of Clubs\n");
        }
    }
    printf("\n");
}
```

Execution :

```
 1 of Hearts
 2 of Hearts
 3 of Hearts
 4 of Hearts
 5 of Hearts
 6 of Hearts
 7 of Hearts

 4 of Spades
Jack of Spades
 7 of Clubs
 9 of Spades
10 of Spades
 7 of Hearts
 2 of Spades
```

- The print_deck() function is clearly messy ! We can simplify this a little when we understand strings.

Testing

```
void test(void)
{
    int n = 0;
    card d[DECK];
    init_deck(d);
    // Direct assignment
    card c = {hearts, 10};
    // 1st element initialised correctly
    assert(d[9].pips == c.pips);
    assert(d[9].st == c.st);
    for(int i=0; i<1000; i++){
        shuffle_deck(d);
        // Happens 1 time in 52 ?
        if((d[0].st == c.st) && (d[0].pips == c.pips)){
            n++;
        }
    }
    // Is this a reasonable test ?
    assert((n > 10) && (n < 30));
}
```

- Note the direct ability to copy a structure.

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    assert(d[9].st == c.st);
    for(int i=0; i<1000; i++){
        shuffle_deck(d);
        // Happens 1 time in 52 ?
        if((d[0].st == c.st) && (d[0].pips == c.pips)){
            n++;
        }
    }
    // Is this a reasonable test ?
    assert((n > 10) && (n < 30));
}
```

- Note the direct ability to copy a structure.
- You can't compare them using ==
  though.

```
void test(void)
{
    int n = 0;
    card d[DECK];
    init_deck(d);
    // Direct assignment
    card c = {hearts, 10};
    // 1st element initialised correctly
    assert(d[9].pips == c.pips);
    assert(d[9].st == c.st);
    for(int i=0; i<1000; i++){
        shuffle_deck(d);
        // Happens 1 time in 52 ?
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- Note the direct ability to copy a structure.
- You can't compare them using ==
  though.
- Tricky to think of a good test for
  shuffle_deck.
- You could also typedef away the array,
  e.g.:
  typedef card deck[DECK];

  void shuffle_deck(deck d);
  But this hides the fact it's an array
  (which seems odd?)

Table of Contents

Storage of Characters

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  or :
  ```
  char c1 = 'A', c2 = '*', c3 = ';' ;
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- Declaration:

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  or :

  char c1 = 'A', c2 = '*', c3 = ';' ;

- The particular integer used to represent a character is dependent on the encoding used. The most common of these, used on most UNIX and PC platforms, is ASCII.

lowercase	'a'	'b'	'c'	...	'z'
ASCII value	97	98	99	...	112
uppercase	'A'	'B'	'C'	...	'Z'
ASCII value	65	66	67	...	90
digit	'0'	'1'	'2'	...	'9'
ASCII value	48	49	50	...	57
other	'&'	'*'	'+'	...	
ASCII value	38	42	43	...	

Using Characters

- When using printf() and scanf() the formats %c and %i do very different things :

  char c = 'a'
  printf("%c\n", c); /* prints : a */
  printf("%i\n", c); /* prints : 97 */

Escape sequence	Hex value	Character
\a	07	Alert (Beep, Bell)
\b	08	Backspace
\e	1B	Escape character
\f	0C	Formfeed Page Break
\n	0A	Newline (Line Feed)
\r	0D	Carriage Return
\t	09	Horizontal Tab
\v	0B	Vertical Tab
\\	5C	Backslash
\'	27	Apostrophe
\"	22	Double quote
\?	3F	Question mark

Using Characters

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  char c = 'a'
  printf("%c\n", c); /* prints : a */
  printf("%i\n", c); /* prints : 97 */

- Hard-to-print characters have an escape sequence i.e. to print a newline, the 2 character escape '\n' is used.

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\?	3F	Question mark

Using getchar() and putchar()

```c
// Outputs characters twice

#include <stdio.h>

int main(void)
{

    char c;

    do{
        c = getchar();
        putchar(c);
        putchar(c);
    }while(c != '!');
    putchar('\n');

    return 0;
}
```

Execution :

```
abc123!
aabbcc112233!!
```

This has the unfortunate problem of requiring a
'special' character to terminate. More aggressively, the
user could terminate by pressing CTRL-C.

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This has the unfortunate problem of requiring a 'special' character to terminate. More aggressively, the user could terminate by pressing CTRL-C.

```c
// Outputs characters twice

#include <stdio.h>

int main(void)
{

    char c; // char or int ?

    while ((c = getchar()) != EOF) {
        putchar(c);
        putchar(c);
    }
    putchar('\n');

    return 0;
}
```

Execution :

```
abc123
aabbcc112233
```

The end-of-file constant is defined in stdio.h.
Although system dependent, -1 is often used. On the UNIX system this is generated when the end of a file being piped is reached, or when CTRL-D is pressed.

Capitalization

```c
// Outputs characters twice

#include <stdio.h>

#define CAPS ('A' - 'a')

int main(void)
{
    int   c;
    while ((c = getchar()) != '!'){
        if (c >= 'a' && c <= 'z'){
            putchar(c + CAPS);
        }
        else{
            putchar(c);
        }
    }
    putchar('\n');

    return 0;
}
```

Execution :

Hello World!
HELLO WORLD

This is more easily achieved by using some of the definitions found in ctype.h.

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    }
    putchar('\n');

    return 0;
}
```

Macro	true returned if:
isalnum(int c)	Letter or digit
isalpha(int c)	Letter
iscntrl(int c)	Control character
isdigit(int c)	Digit
isgraph(int c)	Printable (not space)
islower(int c)	Lowercase
isprint(int c)	Printable
ispunct(int c)	Punctuation
isspace(int c)	White Space
isupper(int c)	Uppercase
isxdigit(int c)	Hexadecimal
isascii(int c)	ASCII code

Execution :

```
Hello World!
HELLO WORLD
```

This is more easily achieved by using some of the definitions found in `ctype.h`.

ctype.h

Some useful functions are :

Function/Macro	Returns:
int tolower(int c)	Lowercase c
int toupper(int c)	Uppercase c
int toascii(int c)	ASCII code for c

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

int main(void)
{

    int c;
    while ((c = getchar()) != EOF){
        if (islower(c)){
            putchar(toupper(c));
        }
        else{
            putchar(c);
        }
    }
    putchar('\n');
    return 0;
}
```

ctype.h

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int main(void)
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            putchar(toupper(c));
        }
        else{
            putchar(c);
        }
    }
    putchar('\n');
    return 0;
}
```

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

int main(void)
{

    int c;
    while ((c = getchar()) != EOF){
        /* toupper() returns non-lowercae
           chars unaltered */
        putchar(toupper(c));
    }
    putchar('\n');
    return 0;
}
```

Execution :

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HELLO WORLD!

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Initialising Strings :

- `char w[6] = "Hello";`

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Initialising Strings :

- `char w[6] = "Hello";`
- `char w[250];`
  `w[0] = 'a';`
  `w[1] = 'b';`
  `w[2] = 'c';`
  `w[3] = '\0';`

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- `char w[250];`
  `w[0] = 'a';`
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  `w[2] = 'c';`
  `w[3] = '\0';`
- `scanf("%s", w);`
  Removes leading spaces, reads a string (terminated by a space or EOF). Adds a null character to the end of the string.

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- `char w[6] = "Hello";`
- ```
  char w[250];
  w[0] = 'a';
  w[1] = 'b';
  w[2] = 'c';
  w[3] = '\0';
  ```
- `scanf("%s", w);`
  Removes leading spaces, reads a string (terminated by a space or EOF). Adds a null character to the end of the string.
- `char w[250] = {'a', 'b', 'c', '\0'};`

Unused Letters and `string.h`

```c
#include <stdio.h>
#include <stdbool.h>
#include <ctype.h>

#define ALPHASIZE 26

int main(void)
{
    char s[100] = "The Quick Brown Fox Leaps" \
                  "Over the Lazy Dog";
    bool used[ALPHASIZE] = {false};
    int i = 0;
    while(s[i]){
        char c = tolower(s[i]);
        if(islower(c)){
            used[c - 'a'] = true;
        }
        i++;
    }
    for(i=0; i<ALPHASIZE; i++){
        if(!used[i]){
            printf("%c has not been used.\n", i+'a');
        }
    }
    return 0;
}
```

Execution :

j has not been used.
m has not been used.

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9      char s[100] = "The Quick Brown Fox Leaps" \
10                    "Over the Lazy Dog";
11     bool used[ALPHASIZE] = {false};
12     int i = 0;
13     while(s[i]){
14         char c = tolower(s[i]);
15         if(islower(c)){
16             used[c - 'a'] = true;
17         }
18         i++;
19     }
20     for(i=0; i<ALPHASIZE; i++){
21         if(!used[i]){
22             printf("%c has not been used.\n", i+'a');
23         }
24     }
25     return 0;
26 }
```

In `#include <string.h>` :

`char *strcat(char dest[], const char src[]);`
`int strcmp(const char s1[], const char s2[]);`

- strcat() appends a copy of string src, including the terminating null character, to the end of string dst.

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Execution :

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`int strcmp(const char s1[], const char s2[]);`

- strcat() appends a copy of string src, including the terminating null character, to the end of string dst.

- strcmp() compares two strings byte-by-byte, according to the ordering of your machine's character set. The function returns an integer greater than, equal to, or less than 0, if the string pointed to by s1 is greater than, equal to, or less than the string pointed to by s2 respectively.

More string.h

In #include <string.h> :

```
char *strcpy(char dst[], const char src[]);
unsigned strlen(const char s[]);
```

- strcpy() copies string src to dst including
  the terminating null character, stopping
  after the null character has been copied.

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- `strcpy()` copies string src to dst including the terminating null character, stopping after the null character has been copied.
- `strlen()` returns the number of bytes in s, not including the terminating null character.

One way to write the function `strlen()`

```
1    #include <stdio.h>
2    #include <assert.h>
3
4    unsigned nstrlen(const char s[]);
5
6    int main(void)
7    {
8        assert(nstrlen("Neill")==5);
9        assert(nstrlen("")==0);
10       assert(nstrlen("\n")==1);
11       assert(nstrlen("abcdef")==nstrlen("fedcba"));
12       return 0;
13   }
14
15   unsigned nstrlen(const char s[])
16   {
17       register unsigned n = 0;
18
19       while(s[n] != '\0'){
20           ++n;
21       }
22       return n;
23   }
```

The sprintf() Function

In #include <string.h> : This is very similar to the function printf(), except that the output is stored in a string rather than written to the output. It is defined as:

```
int sprintf(string, control-arg, other args);
```

For example:

```
int i = 7;
float f = 17.041;
char str[100];
sprintf(str, "%i %f", i, f);
printf("%s\n", str);
```

Outputs : 7 17.041000
This is useful if you need to create a string for passing to another function for further processing.

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Outputs : 7 17.041000
This is useful if you need to create a string for
passing to another function for further
processing.

```c
#define SMALLSTR 20
void print_card(char s[], card c)
{

    char pipstr[SMALLSTR];
    char suitstr[SMALLSTR];
    switch(c.pips){
        case 11:
            strcpy(pipstr, "Jack");
            break;
        case 12:
            strcpy(pipstr, "Queen");
            break;
        case 13:
            strcpy(pipstr, "King");
            break;
        default:
            sprintf(pipstr, "%2i", c.pips);
    }
    switch(c.st){
        case hearts :
            strcpy(suitstr, "Hearts");
            break;
        case diamonds :
            strcpy(suitstr, "Diamonds");
            break;
        case spades:
            strcpy(suitstr, "Spades");
            break;
        default :
            strcpy(suitstr, "Clubs");
    }
    sprintf(s, "%s of %s", pipstr, suitstr);
}
```

sprintf() and sscanf()

```c
#define FIRSTCARD " 1 of Hearts"
void test(void)
{
    int n = 0;
    char str[BIGSTR];
    card d[DECK];
    init_deck(d);
    // Direct assignment
    print_card(str, d[0]);
    // 1st element initialised correctly
    assert(strcmp(str, FIRSTCARD)==0);
    for(int i=0; i<1000; i++){
        shuffle_deck(d);
        print_card(str, d[0]);
        // Happens 1 time in 52 ?
        if(strcmp(str, FIRSTCARD)==0){
            n++;
        }
    }
    // Is this a reasonable test ?
    assert((n > 10) && (n < 30));
}
```

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        if(strcmp(str, FIRSTCARD)==0){
            n++;
        }
    }
    // Is this a reasonable test ?
    assert((n > 10) && (n < 30));
}
```

```c
// Simple demo of sscanf (and fgets in passing)
#include <stdio.h>
#include <assert.h>

#define BIGSTR 1000
#define SMLSTR 100
#define DAYSINYEAR 365.2425

#include <stdio.h>

int main(void)
{

    printf("Please type your first name and your age\n");
    char bigstr[BIGSTR];
    fgets(bigstr, BIGSTR, stdin);
    char name[SMLSTR];
    int age;
    // Note no "&" before name : passed by reference already
    assert(sscanf(bigstr, "%s %i\n", name, &age)==2);
    printf("%s, you've lived approximately %.0f days\n",
            name, ((double)(age)+0.5)*DAYSINYEAR);
    return 0;

}
```

Execution :

```
Please type your first name and your age
Joe 25
Joe, you've lived approximately 9314 days
```

Table of Contents

Initializing 2D Arrays

A 2D array is declared as follows:

```
#define ROWS 3
#define COLS 5
int a[ROWS][COLS];
```

2D array initialisation :

```
int b[2][3] = {1, 2, 3, 4, 5, 6};
int b[2][3] = {{1, 2, 3}, {4, 5, 6}};
int b[ ][3] = {{1, 2, 3}, {4, 5, 6}};
```

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Although 2D arrays are stored in a contiguous block of memory, we may think of them as a 2D rectangle of data.

int c[3][5] = {{1,2,3,4,5}, {6,7,8,9,10},
               {11,12,13,14,15}};
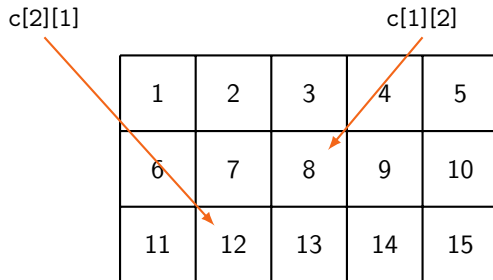
c[2][1]   c[1][2]

1	2	3	4	5
6	7	8	9	10
11	12	13	14	15

2D Distance

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

#define    M    7
#define    N    9

void fillarray(int a[M][N]);

int main(void)
{
    int    a[M][N];

    fillarray(a);
    // Print Array
    for (int j = 0; j < M; j++){
        for(int i = 0; i < N; i++){
            printf("%i", a[j][i]);
        }
        printf("\n");
    }
    printf("\n");
    return 0;
}

void fillarray(int a[M][N])
{
    for (int j = 0; j < M; ++j){
        double y = ((double)j - ((double)(M-1)/2.0));
        for(int i = 0; i < N; ++i){ // Column-first
            double x = ((double)i - ((double)(N-1)/2.0));
            a[j][i] = round(sqrt(x*x + y*y));
        }
    }
}
```

Execution :

544333445
443222344
432111234
432101234
432111234
443222344
544333445

Cards (again!)

```c
#define SMALLSTR 20
void print_card(char s[], card c)
{
    // Note the +1 below : zero pips not used, but makes easier coding ?
    char pipnames[PERSUIT+1][SMALLSTR] = {"Zero", "One", "Two", "Three",
                                          "Four", "Five", "Six", "Seven",
                                          "Eight", "Nine", "Ten", "Jack",
                                          "Queen", "King"};
    char suitnames[SUITS][SMALLSTR] = {"Hearts", "Diamonds", "Spades", "Clubs"};
    sprintf(s, "%s of %s", pipnames[c.pips], suitnames[c.st]);
}
```

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}
```

- The 2D arrays of characters here have one string per row.

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    sprintf(s, "%s of %s", pipnames[c.pips], suitnames[c.st]);
}
```

- The 2D arrays of characters here have one string per row.
- They are of a fixed-width, sometime called *ragged-right* or *jagged-right* arrays.

Storage Classes

- **auto**

  auto int a, b, c;

  auto float f;

  Because this is the default, it is seldom
  used.

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- **register**

  Informs the compiler to place the variable in a high-speed memory register if possible, i.e. if there are enough such registers available & the hardware supports this.

```c
1   #include <stdio.h>
2   #include <stdlib.h>
3
4   void printstuff(void);
5
6   #define MAXLOOP 20
7
8   int main(void)
9   {
10      int r = rand() % MAXLOOP;
11      for(int i=0; i<r; i++){
12          printstuff();
13      }
14      return 0;
15  }
16
17  void printstuff(void)
18  {
19      static int cnt = 0;
20      printf("You've been here %i times\n", ++cnt);
21  }
```

Execution :

```
You've been here 1 times
You've been here 2 times
You've been here 3 times
```

Table of Contents

Call-by-Value

```c
#include <stdio.h>

void changex(int x);

int main(void)
{
    int x = 1;

    changex(x);
    printf("%i\n", x);
    return 0;
}

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

Execution :

1

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1

- In the program, the function cannot change the value of v as defined in main() since a **copy** is made of it.

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int main(void)
{
    int x = 1;

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}

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{
    x = x + 1;
}
```

Execution :

1

- In the program, the function cannot change the value of v as defined in main() since a **copy** is made of it.
- To allow a function to modify the value of a variable passed to it we need a mechanism known as **call-by-reference**, which uses the **address** of variables (pointers).

Call-by-Reference

- We have already seen addresses used with
  scanf(). The function call:

  scanf("%i", &v);

  causes the appropriate value to be stored
  at a particular address in memory.

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- int i, *p;
- Here i is an int and p is of type *pointer to int*.
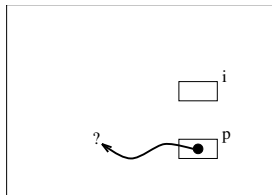
Call-by-Reference

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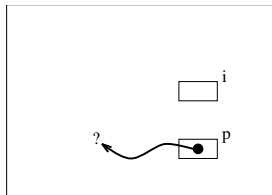 causes the appropriate value to be stored at a particular address in memory.

- If v is a variable, then &v is its address, or location, in memory.

- int i, *p;

- Here i is an int and p is of type *pointer to int.*

- Pointers have a legal range which includes the special address 0 and a set of positive integers which are the machine addresses of a particular system.
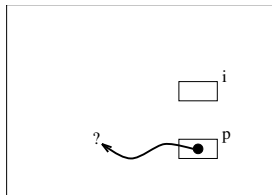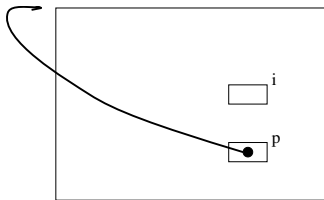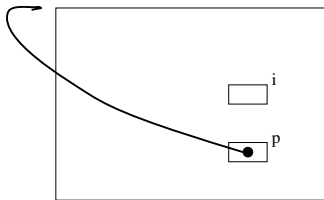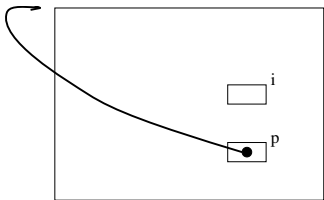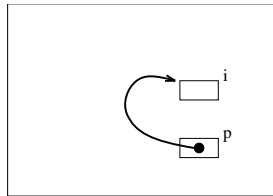
- `p = NULL;`

- `p = NULL;`

- `p = NULL;`

- `p = &i;`

- `i = 5;`

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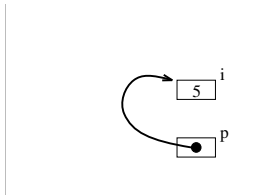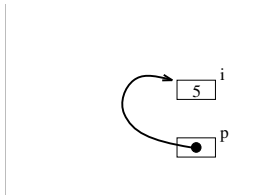

```c
1    #include <stdio.h>
2
3    int main(void)
4    {
5
6        int i = 5;
7        int* p = &i;
8        printf("%i\n", *p);
9        i = 17;
10       printf("%i\n", *p);
11       *p = 99;
12       printf("%i\n", i);
13
14       return 0;
15
16   }
```

Execution :

5
17
99

scanf Again

```c
#include <stdio.h>

int main(void)
{

    int i;
    int* p;

    p = &i;
    printf("Please Type a number : ");
    scanf("%i", &i);
    printf("%i\n", i);
    printf("Please Type a number : ");
    scanf("%i", p);
    printf("%i\n", i);

    return 0;

}
```

Execution :

```
Please Type a number : 70
70
Please Type a number : 3
3
```

scanf Again

```
1   #include <stdio.h>
2
3   int main(void)
4   {
5
6       int i;
7       int* p;
8
9       p = &i;
10      printf("Please Type a number : ");
11      scanf("%i", &i);
12      printf("%i\n", i);
13      printf("Please Type a number : ");
14      scanf("%i", p);
15      printf("%i\n", i);
16
17      return 0;
18
19  }
```

Execution :

```
Please Type a number : 70
70
Please Type a number : 3
3
```

- In many ways the dereference operator *
  is the inverse of the address operator &.

```
float x = 5, y = 8, *p;
p = &x;
y = *p;
```

scanf Again

```c
#include <stdio.h>

int main(void)
{

    int i;
    int* p;

    p = &i;
    printf("Please Type a number : ");
    scanf("%i", &i);
    printf("%i\n", i);
    printf("Please Type a number : ");
    scanf("%i", p);
    printf("%i\n", i);

    return 0;

}
```

Execution :

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Please Type a number : 70
70
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```

- In many ways the dereference operator * is the inverse of the address operator &.

```c
float x = 5, y = 8, *p;
p = &x;
y = *p;
```

- What is this equivalent to ?

The *swap* Function

```c
#include <stdio.h>

void swap(int* p, int* q);

int main(void)
{
    int     a = 3, b = 7;

    // 3 7 printed
    printf("%i %i\n", a, b);
    swap(&a, &b);
    // 7 3 printed
    printf("%i %i\n", a, b);
    return 0;
}

void swap(int* p, int* q)
{
    int     tmp;

    tmp = *p;
    *p = *q;
    *q = tmp;
}
```

Execution :

3 7
7 3

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3 7
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- At beginning of function:

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    *q = tmp;
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Execution :

3 7
7 3

- At beginning of function:

- At end of function:

- Remeber that the variables *a* and *b* are not in the scope of *swap()*.

Arrays are Pointers ?

- An array name by itself is simply an address (**Array Decay**).

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  int a[5];
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- To assign p to point to the next element, we could either :

  p = a + 1;

  p = &a[1];
- Notice that p = a + 1 advances the pointer **4** bytes and not 1 byte. This is because an integer is 4 bytes long and p is a pointer to an int.
- we can use the pointer p is exactly the same way as normal, i.e.:

  *p = 5;

Summing an Array

```c
#include <stdio.h>

#define NUM 5

int sum(int a[]);

int main(void)
{

    int n[NUM] = {10, 12, 6, 7, 2};

    printf("%i\n", sum(n));
    return 0;
}

int sum(int a[])
{
    int sum = 0;

    for(int i=0; i<NUM; i++){
        sum += a[i];
    }
    return sum;
}
```

Execution :

37

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    printf("%i\n", sum(n));
    return 0;
}

int sum(int a[])
{
    int sum = 0;

    for(int i=0; i<NUM; i++){
        sum += *(a + i);
    }
    return sum;
}
```

Execution :

37

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37

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#define NUM 5

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    printf("%i\n", sum(n));
    return 0;
}

int sum(int a[])
{
    int sum = 0;

    for(int i=0; i<NUM; i++){
        sum += a[i];
    }
    return sum;
}
```

Execution :

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#define NUM 5

int sum(int a[]);

int main(void)
{

    int n[NUM] = {10, 12, 6, 7, 2};

    printf("%i\n", sum(n));
    return 0;
}

int sum(int a[])
{
    int sum = 0;

    for(int i=0; i<NUM; i++){
        sum += *(a + i);
    }
    return sum;
}
```

Execution :

37

```c
#include <stdio.h>

#define NUM 5

int sum(int* p );

int main(void)
{

    int n[NUM] = {10, 12, 6, 7, 2};

    printf("%i\n", sum(n));
    return 0;
}

int sum(int* p )
{
    int sum = 0;

    for(int i=0; i<NUM; i++){
        sum += *p;
        p++;
    }
    return sum;
}
```

Execution :

37

Pointers to Structures

- By default, structures are passed by value (copied) when used as a parameter to a function.

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- But, like any other type, we could pass a pointer instead.

- The complication is that to access the elements of a structure via a pointer, we use the "->" operator, and not the ".".

```c
void print_deck(card d[DECK], int n)
{
    char str[BIGSTR];
    for(int i=0; i<n; i++){
        print_card(str, &d[i]);
        printf("%s\n", str);
    }
    printf("\n");
}

#define SMALLSTR 20
void print_card(char s[], const card* p)
{
    // Note the +1 below : zero pips not used, but makes easier coding ?
    char pipnames[PERSUIT+1][SMALLSTR] = {"Zero", "One", "Two", "Three",
                                          "Four", "Five", "Six", "Seven",
                                          "Eight", "Nine", "Ten", "Jack",
                                          "Queen", "King"};
    char suitnames[SUITS][SMALLSTR] = {"Hearts", "Diamonds", "Spades", "Clubs"};
    sprintf(s, "%s of %s", pipnames[p->pips], suitnames[p->st]);
}
```

Nested Structures

```c
#include <stdio.h>

struct dateofbirth {
    unsigned char day;
    unsigned short month;
    unsigned short year;
};
typedef struct dateofbirth dob;

typedef struct {
    char* name;
    dob date;
} person;

void print_byval(person b);
void print_byref(const person* p);

int main(void)
{
    person a = {"Gary", {17, 5, 1999}};
    print_byval(a);
    print_byref(&a);
}

void print_byval(person b)
{
    printf("%s %hhu/%hi/%hi\n", b.name, b.date.day, b.date.month, b.date.year);
}

void print_byref(const person* p)
{
    printf("%s %hhu/%hi/%hi\n", p->name, p->date.day, p->date.month, p->date.year);
}
```

Execution :

Gary 17/5/1999
Gary 17/5/1999

Table of Contents

String Constants

```c
// A FAILED attempt to
// convert all 'n' chars to 'N'
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <assert.h>

void nify(char s[]);

int main(void)
{

    nify("neill");
    return 0;

}

// In-Place : Swaps all 'n' -> 'N'
void nify(char s[])
{
    for(int i=0; s[i]; i++){
        if(s[i] == 'n'){
            s[i] = 'N';
        }
    }
}
```

String Constants

```
1    // A FAILED attempt to
2    // convert all 'n' chars to 'N'
3    #include <stdio.h>
4    #include <stdlib.h>
5    #include <string.h>
6    #include <assert.h>
7
8    void nify(char s[]);
9
10   int main(void)
11   {
12
13       nify("neill");
14       return 0;
15
16   }
17
18   // In-Place : Swaps all 'n' -> 'N'
19   void nify(char s[])
20   {
21       for(int i=0; s[i]; i++){
22           if(s[i] == 'n'){
23               s[i] = 'N';
24           }
25       }
26   }
```

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8   void nify(char s[]);
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- It turns out that in `main()` we have passed a **constant** string to the function. This is in a part of memory that we have read-only permission.

Local Variables

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// A FAILED attempt to
// convert all 'n' chars to 'N'
#include <stdio.h>
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#define LINE 500

char* nify(char s[]);

int main(void)
{
    char* s1 = nify("inconveniencing");
    char* s2 = nify("neill");
    assert(strcmp(s2, "Neill")==0);
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    char t[LINE];
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- The string t is local to nify().
- What happens in this memory when outside the scope of this function is completely undefined.

Static Variables

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char* nify(char s[]);

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- We could just make the local string a static and return it's address couldn't we?

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- This only works if we're very careful with the order in which we use the strings.

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- The pointers s1 and s2 are the same.

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18  // malloc : Swaps all 'n' -> 'N'
19  char* nify(char s[])
20  {
21      int l = strlen(s);
22      char* t  = (char*)malloc(l+1);
23      if(t==NULL){
24          exit( EXIT_FAILURE );
25      }
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Variable Length Arrays

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#define WORD 500

int main(void)
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    char s[WORD];
    assert(scanf("%s", s)==1);
    int n = strlen(s) + 1;
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13       char s[WORD];
14       assert(scanf("%s", s)==1);
15       int n = strlen(s) + 1;
16       char t[n];
17       // Deep copy: character by character
18       strcpy(t, s);
19       printf("%s %s\n", s, t);
20       return 0;
21
22   }
```

- Here we duplicate a string into *t*.

- This is known as a variable length array.

- However, we will always use the -Wvla with the compiler to prevent them.

- There are a number of reasons for this:
  - Some C++ compilers don't accept it.
  - The memory comes off the stack not the heap, and you have no idea if the allocation has worked (it'll just crash if not)
  - https://nullprogram.com/blog/2019/10/27/

- None of these is a problem if we use malloc().

Memory Leaks

```
1    // This leaks - but it's not obvious
2    #include <stdio.h>
3    #include <stdlib.h>
4    #include <string.h>
5    #include <assert.h>
6
7    #define WORD 500
8
9    int main(void)
10   {
11
12       printf("Please type a string :\n");
13       char s[WORD];
14       assert(scanf("%s", s)==1);
15       int n = strlen(s);
16       /* malloc() returns a pointer to memory that
17          you have access to. Note forcing cast. */
18       char* t = (char*) malloc(n+1);
19       // If no space, returns NULL
20       assert(t != NULL);
21       // Deep copy: character by character
22       strcpy(t, s);
23       printf("%s %s\n", s, t);
24       return 0;
25
26   }
```

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#include <stdlib.h>
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#define WORD 500

int main(void)
{

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    char s[WORD];
    assert(scanf("%s", s)==1);
    int n = strlen(s);
    /* malloc() returns a pointer to memory that
       you have access to. Note forcing cast. */
    char* t = (char*) malloc(n+1);
    // If no space, returns NULL
    assert(t != NULL);
    // Deep copy: character by character
    strcpy(t, s);
    printf("%s %s\n", s, t);
    return 0;

}
```

- This code appears to work correctly.

Memory Leaks

```c
// This leaks - but it's not obvious
#include <stdio.h>
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#include <string.h>
#include <assert.h>

#define WORD 500

int main(void)
{

    printf("Please type a string :\n");
    char s[WORD];
    assert(scanf("%s", s)==1);
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    /* malloc() returns a pointer to memory that
       you have access to. Note forcing cast. */
    char* t = (char*) malloc(n+1);
    // If no space, returns NULL
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    // Deep copy: character by character
    strcpy(t, s);
    printf("%s %s\n", s, t);
    return 0;

}
```

- This code appears to work correctly.
- However, it actually **leaks**. The memory allocated was never free()'d.

Memory Leaks

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23      printf("%s %s\n", s, t);
24      return 0;
25
26  }
```

- This code appears to work correctly.
- However, it actually **leaks**. The memory allocated was never free()'d.
- This is best found by running the program valgrind.

```
String String
==474==
==474== HEAP SUMMARY:
==474==     in use at exit: 7 bytes in 1 blocks
==474==   total heap usage: 2 allocs, 1 frees, 1,031 bytes allocated
==474==
==474== LEAK SUMMARY:
==474==    definitely lost: 7 bytes in 1 blocks
```

free()

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

#define WORD 500

int main(void)
{

    char s[WORD] = "String";
    int n = strlen(s);
    /* malloc() returns a pointer to memory that
        you have access to. Note forcing cast. */
    char* t = (char*) malloc(n+1);
    /* If no space, returns NULL */
    assert(t != NULL);
    /* Deep copy: character by character */
    strcpy(t, s);
    printf("%s %s\n", s, t);
    /* All malloc'd memory must be freed
        to prevent memory leaks */
    free(t);
    return 0;

}
```

free()

```
1   #include <stdio.h>
2   #include <stdlib.h>
3   #include <string.h>
4   #include <assert.h>
5
6   #define WORD 500
7
8   int main(void)
9   {
10
11      char s[WORD] = "String";
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13      /* malloc() returns a pointer to memory that
14         you have access to. Note forcing cast. */
15      char* t = (char*) malloc(n+1);
16      /* If no space, returns NULL */
17      assert(t != NULL);
18      /* Deep copy: character by character */
19      strcpy(t, s);
20      printf("%s %s\n", s, t);
21      /* All malloc'd memory must be freed
22         to prevent memory leaks */
23      free(t);
24      return 0;
25
26   }
```

- This code is now correct.

```
String String
==475==
==475== HEAP SUMMARY:
==475==     in use at exit: 0 bytes in 0 blocks
==475==   total heap usage: 2 allocs, 2 frees, 1,031 bytes allocated
==475==
==475== All heap blocks were freed -- no leaks are possible
```

Structures with Self-Referential Pointers

```c
1   // Store a list of numbers
2   #include <stdio.h>
3   #include <stdlib.h>
4   #include <assert.h>
5
6   struct data {
7       int num;
8       struct data* next;
9   };
10  typedef struct data data;
11
12  int main(void)
13  {
14  //          a         b         c
15
16  //      |11 -->|17 -->| 5 . |
17      data c = {5 , NULL};
18      data b = {17, &c};
19      data a = {11, &b};
20
21      // print first number
22      printf("%i\n", a.num);
23      data* p = &a;
24      // Can also get to it via p
25      printf("%i\n", p->num);
26      // Pointer chasing : The Key concept
27      p = p->next;
28      // We're accessing b, without using it's name
29      printf("%i\n", p->num);
30      p = p->next;
31      // And c
32      printf("%i\n", p->num);
33      return 0;
34  }
```

Structures with Self-Referential Pointers

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// Store a list of numbers
#include <stdio.h>
#include <stdlib.h>
#include <assert.h>

struct data {
    int num;
    struct data* next;
};
typedef struct data data;

int main(void)
{
//        a        b        c

//    |11 -->|17 -->| 5 . |
    data c = {5 , NULL};
    data b = {17, &c};
    data a = {11, &b};

    // print first number
    printf("%i\n", a.num);
    data* p = &a;
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    printf("%i\n", p->num);
    // Pointer chasing : The Key concept
    p = p->next;
    // We're accessing b, without using it's name
    printf("%i\n", p->num);
    p = p->next;
    // And c
    printf("%i\n", p->num);
    return 0;
}
```

- The structure contains a pointer to a something of it's own type (even before we've fully defined the struture itself).

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    data* p = &a;
    // Can also get to it via p
    printf("%i\n", p->num);
    // Pointer chasing : The Key concept
    p = p->next;
    // We're accessing b, without using it's name
    printf("%i\n", p->num);
    p = p->next;
    // And c
    printf("%i\n", p->num);
    return 0;
}
```

- The structure contains a pointer to a something of it's own type (even before we've fully defined the struture itself).

- Here, if p points to a, then p->next->next points to c.

Linked Lists

```c
// Store a list of numbers (length unknown)
#include <stdio.h>
#include <stdlib.h>
#include <assert.h>

#define MAXNUM 20
#define ENDNUM 10

struct data {
    int num;
    struct data* next;
};
typedef struct data data;

void addtolist(data* tail);
void printlist(data* st);

int main(void)
{
    data *p, *start;
    start = p = calloc(1, sizeof(data));
    assert(p);
    p->num = rand()%MAXNUM;
    // Add other numbers to the list
    do{
        addtolist(p);
        p = p->next;
    }while(p->num != ENDNUM);
    printlist(start);
    // Need to free up list - not shown here ...
    return 0;
}
```

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#include <stdio.h>
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int main(void)
{
    data *p, *start;
    start = p = calloc(1, sizeof(data));
    assert(p);
    p->num = rand()%MAXNUM;
    // Add other numbers to the list
    do{
        addtolist(p);
        p = p->next;
    }while(p->num != ENDNUM);
    printlist(start);
    // Need to free up list - not shown here ...
    return 0;
}
```

```c
// Create some new space and store number in it
void addtolist(data* tail)
{
    tail->next = calloc(1, sizeof(data));
    assert(tail);
    tail = tail->next;
    tail->num = rand()%MAXNUM;
}

void printlist(data* st)
{
    while(st != NULL){
        printf("%i ", st->num);
        st = st->next;
    };
    printf("\n");
}
```

Execution :

3 6 17 15 13 15 6 12 9 1 2 7 10

- calloc() is similar to malloc(), but *clears* the memory is reserves for you.

Linked Lists

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// Store a list of numbers (length unknown)
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int main(void)
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    data *p, *start;
    start = p = calloc(1, sizeof(data));
    assert(p);
    p->num = rand()%MAXNUM;
    // Add other numbers to the list
    do{
        addtolist(p);
        p = p->next;
    }while(p->num != ENDNUM);
    printlist(start);
    // Need to free up list - not shown here ...
    return 0;
}
```

```c
// Create some new space and store number in it
void addtolist(data* tail)
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    tail->next = calloc(1, sizeof(data));
    assert(tail);
    tail = tail->next;
    tail->num = rand()%MAXNUM;
}

void printlist(data* st)
{
    while(st != NULL){
        printf("%i ", st->num);
        st = st->next;
    };
    printf("\n");
}
```

Execution :

3 6 17 15 13 15 6 12 9 1 2 7 10

- calloc() is similar to malloc(), but *clears* the memory is reserves for you.
- It's passed the number of array cells you wish to create, and the size of each of them.

Table of Contents

- They have a name.

File Properties

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- Until a file is opened nothing can be done with it.

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- Until a file is opened nothing can be done with it.
- After use a file must be closed.
- Files may be read, written or appended.
- Conceptually a file may be thought of as a stream of characters.

```c
1   /* Creates a file called helloworld.txt
2   in the current filespace and writes to it */
3   #include <stdio.h>
4   #include <stdlib.h>
5
6   int main(void)
7   {
8       // Clobber the file if it exists already
9       FILE* fp = fopen("helloworld.txt", "w");
10      if(fp == NULL){
11          fprintf(stderr, "Cannot open file?\n");
12          exit(EXIT_FAILURE);
13      }
14      fprintf(fp, "Hello World!\n");
15      // fscanf() is also available to read in
16      fclose(fp);
17      return EXIT_SUCCESS;
18  }
```

Reading and Writing

```c
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#define BIGSTR 500
#define FNAME "helloworld.txt"

int main(void)
{
    FILE* fp = fopen(FNAME, "w");
    if(fp == NULL){
        fprintf(stderr, "Cannot open file %s ?\n", FNAME);
        exit(EXIT_FAILURE);
    }
    fprintf(fp, "Hello World!\n");
    fclose(fp);

    fp = fopen(FNAME, "r");
    if(fp == NULL){
        fprintf(stderr, "Cannot read file %s ?\n", FNAME);
        exit(EXIT_FAILURE);
    }
    char str[BIGSTR];
    if(fgets(str, BIGSTR, fp) == NULL){
        fprintf(stderr, "Cannot read 1st line of %s ?\n", FNAME);
        exit(EXIT_FAILURE);
    }
    fclose(fp);
    // Newline is read too
    if(strcmp(str, "Hello World!\n")){
        fprintf(stderr, "1st line of %s not correct?\n", FNAME);
        exit(EXIT_FAILURE);
    }
    return EXIT_SUCCESS;
}
```

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#define BIGSTR 500
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int main(void)
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    FILE* fp = fopen(FNAME, "w");
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```

- If you write a file, it overwrites it from the beginning.

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    fclose(fp);

    fp = fopen(FNAME, "r");
    if(fp == NULL){
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    if(fgets(str, BIGSTR, fp) == NULL){
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```

- If you write a file, it overwrites it from the beginning.
- You must fclose() your file pointers otherwise there is a memory leak.

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- If you write a file, it overwrites it from the beginning.
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- The statement exit() allows you to exit the code **anywhere**, not just in main.

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int main(void)
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- If you write a file, it overwrites it from the beginning.

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- There are three files already open for you: stdin, stdout and stderr.

```
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15      fclose(fp);
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17      fp = fopen(FNAME, "r");
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19          fprintf(stderr, "Cannot read file %s ?\n", FNAME);
20          exit(EXIT_FAILURE);
21      }
22      char str[BIGSTR];
23      if(fgets(str, BIGSTR, fp) == NULL){
24          fprintf(stderr, "Cannot read 1st line of %s ?\n", FNAME);
25          exit(EXIT_FAILURE);
26      }
27      fclose(fp);
28      // Newline is read too
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- If you write a file, it overwrites it from the beginning.
- You must fclose() your file pointers otherwise there is a memory leak.
- The statement exit() allows you to exit the code **anywhere**, not just in main.
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- Therefore printf(...) is just a shorthand for fprintf(stdout, ...)

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```

- If you write a file, it overwrites it from the beginning.
- You must fclose() your file pointers otherwise there is a memory leak.
- The statement exit() allows you to exit the code **anywhere**, not just in main.
- There are three files already open for you: stdin, stdout and stderr.
- Therefore printf(...) is just a shorthand for fprintf(stdout, ...)
- fscanf() could be used instead of fgets().

- To write to screen you'd generally use stdout, so why is there stderr ?

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- It's fairly common, when running a program, to want to redirect the output to a file.

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  $ ls > myfiles.txt

  this will list all your files into myfiles.txt

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  this will list all your files into myfiles.txt
- The ">" at the prompt redirects the output (or "<" input) to file rather than screen.

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  this will list all your files into myfiles.txt
- The ">" at the prompt redirects the output (or "<" input) to file rather than screen.
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- For instance, if you were to type:

  $ ls > myfiles.txt

  this will list all your files into myfiles.txt
- The ">" at the prompt redirects the output (or "<" input) to file rather than screen.
- If something went wrong though, the user would never see the message.
- Therefore, stderr exists so that there is a stream to display warnings/errors to the user.

One Character at a Time

```c
// Some of the functionality of cp
#include <stdio.h>
#include <stdlib.h>

int main(int argc, char* argv[])
{
    if(argc != 3){
        fprintf(stderr, "Usage : %s <filein> <fileout>\n", argv[0]);
        exit(EXIT_FAILURE);
    }
    FILE* fpin = fopen(argv[1], "r");
    if(!fpin){
        fprintf(stderr, "Cannot read from %s\n", argv[1]);
        exit(EXIT_FAILURE);
    }
    FILE* fpout = fopen(argv[2], "w");
    if(!fpout){
        fprintf(stderr, "Cannot write to %s\n", argv[2]);
        exit(EXIT_FAILURE);
    }

    char c;
    while((c = fgetc(fpin)) != EOF){
        fputc(c, fpout);
    }
    fclose(fpin);
    fclose(fpout);
    return EXIT_SUCCESS;
}
```

One Character at a Time

```c
// Some of the functionality of cp
#include <stdio.h>
#include <stdlib.h>

int main(int argc, char* argv[])
{
    if(argc != 3){
        fprintf(stderr, "Usage : %s <filein> <fileout>\n", argv[0]);
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    FILE* fpin = fopen(argv[1], "r");
    if(!fpin){
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    if(!fpout){
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    char c;
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- This is a very basic version of the Linux command cp.

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26      fclose(fpin);
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29  }
```

- This is a very basic version of the Linux command cp.
- fgetc() and fputc() are the file equivalents of getchar and putchar.

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```c
/* Compute some factorials and save them
   for another program to read back later. */
#include <stdio.h>
#include <stdlib.h>

#define FACTS 20

typedef unsigned long facttype;

int main(int argc, char* argv[])
{
    if(argc != 2){
        fprintf(stderr, "Usage : %s <fileout>\n", argv[0]);
        exit(EXIT_FAILURE);
    }
    FILE* fpout = fopen(argv[1], "wb");
    if(!fpout){
        fprintf(stderr, "Cannot write to %s\n", argv[1]);
        exit(EXIT_FAILURE);
    }
    facttype facts[FACTS] = {1};
    for(facttype i=1; i<FACTS; i++){
        facts[i] = facts[i-1]*i;
    }

    int n = fwrite(facts, sizeof(facttype), FACTS, fpout);
    if(n != FACTS){
        fprintf(stderr, "Cannot write to %s\n", argv[1]);
        exit(EXIT_FAILURE);
    }
    fclose(fpout);
    return EXIT_SUCCESS;
}
```

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

#define BIGSTR 10000

int main(int argc, char* argv[])
{
    if(argc != 2){
        fprintf(stderr, "Usage : %s <file>\n", argv[0]);
        exit(EXIT_FAILURE);
    }
    FILE* fpin = fopen(argv[1], "rb");
    if(!fpin){
        fprintf(stderr, "Cannot read %s\n", argv[1]);
        exit(EXIT_FAILURE);
    }
    char str[BIGSTR];
    if(fgets(str, BIGSTR, fpin)==NULL){
        fprintf(stderr, "Cannot read %s\n", argv[1]);
        exit(EXIT_FAILURE);
    }
    int n = strlen(str);
    if(n > 1){
        if((str[n-1] == '\n') && (str[n-2] == '\r')){
            printf("Looks like a DOS file?\n");
        }
        else{
            printf("Looks like a Unix file?\n");
        }
    }
    fclose(fpin);
    return EXIT_SUCCESS;
}
```