Programming in C

Dr. Neill Campbell
Neill.Campbell@bristol.ac.uk

University of Bristol

June 24, 2021

Table of Contents

About the Course

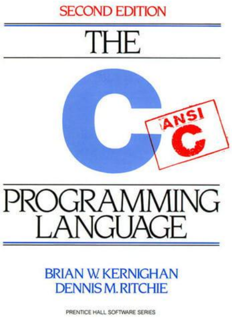
These course notes were originally based on :

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

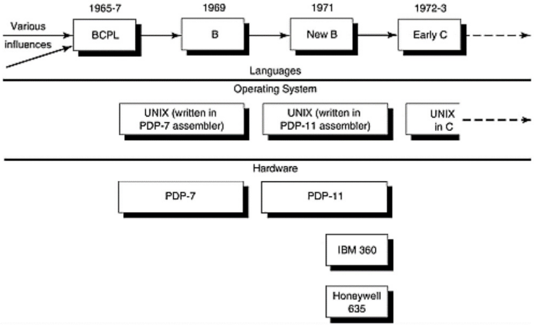
- Free : `https://en.wikibooks.org/wiki/C_Programming`
- A list of more : `https://www.linuxlinks.com/excellent-free-books-learn-c/`
- Whatever you use, make sure it's **ANSI C** or **C99** that's being taught, not something else e.g. C11 or C++.
- If you fall in love with C and know you're going to 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.



Computer Science Ethos

- Talk to your friends, ask for help, work together.
- Never pass off another persons work as your own.
- Do not pass work to others - either on paper or electronically - even after the submission deadline.
- If someone takes your code and submits it, we need to investigate where it originated - all students involved will be part of this.
- Don't place your code on publicly accessible sites e.g. github - other students may have extensions etc.

History of C



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

- BCPL - Martin Richards
- B - Ken Thomson 1970
- Both of above are *typeless*.
- C - Dennis Ritchie 1972 designed for (& implemented on) a UNIX system.
- K&R C (Kernighan and Ritchie) 1978
- 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	v	Java
4	4		C++
5	5		C#
6	6		Visual Basic
7	7		JavaScript

https://www.tiobe.com/tiobe-index/

- One of the most commonly used programming languages according to tiobe.com
- Low-level (c.f. Java)
- Doesn't hide nitty-gritty
- Fast ?
- Large parts common to Java

Programming and Software Engineering

- Was traditionally Lectured 2(or 3) hours a week for weeks 1-12
- In the blended world, I'll post the equivalent online, broken into manageable chunks
- Programming (C), data structures, algorithms - searching, sorting, string processing, trees etc.

Assessment

- Weekly (unmarked) exercises that, if completed, should ensure you are able to pass the unit.
- Approximately three/four assignments and one lab test.
- One major project due in early TB2 (35%).
- Hard to gauge timings, so don't make any plans in advance - I'll change it if we're going too fast.

Help with Computers

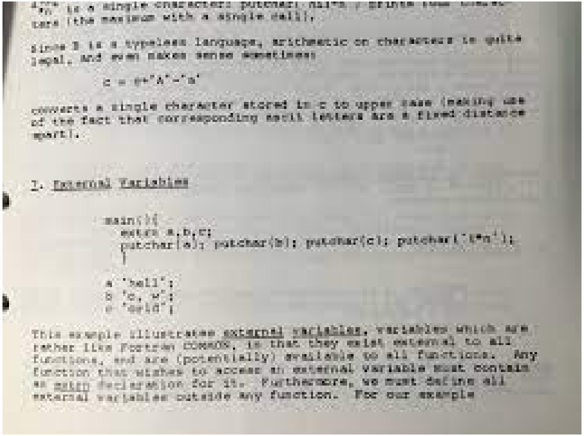
- Any problems with the computers e.g. installing the correct S/W, accessing lab machines : `http://www.bris.ac.uk/it-services/`.
- They are also the people to see about passwords etc.
- This page also links to the rather useful Laptop & Mobile Clinic.

Help with the Unit

- Further information is available via the Blackboard site.
- Help will mainly be via myself giving ‘live’ Q&A session, the associated MS Teams group and the corresponding Forum.
- You will often work in a peer group (approx 15 people).
- There will be a group of Teaching Assistants to help each of these groups.
- TAs are not allowed to write pieces of code for you, nor undertake detailed bug-fixing of your program.

Table of Contents

Hello World!



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

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

```
c = c+'A'-'a'
```

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

7. External Variables

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

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

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

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

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

#include <stdio.h>

int main(void)
{

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

}
```

Dissecting the 1st Program

- Comments are bracketed by the `/*` and `*/` pair.
- `#include <stdio.h>`
  Lines that begin with a # are called preprocessing directives.
- `int main(void)`
  Every program has a function called
  `main()`
- Statements are grouped using braces,
  `{ ... }`
- `printf()` One of the pre-defined library functions being called (invoked) using a single argument the string :
  `"Hello, world!\n"`
- The `\n` means print the single character *newline*.
- Notice all declarations and statements are terminated with a semi-colon.
- `return(0)` Instruct the Operating System that the function `main()` has completed successfully.

Area of a Rectangle

```c
#include <stdio.h>

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

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

Output :

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

Dissecting the Area Program

- // One line comment.
- #include <stdio.h> Always required when using I/O.
- int side1, side2, area; *Declaration*
- side2 = 8; *Assignment*
- printf() has 2 Arguments. The *control string* contains a %d to indicate an integer is to be printed.

```
preprocessing directives

int main(void)
{
    declarations

    statements
}
```

Arithmetic Operators

- + , - , / , *, %
- Addition, Subtraction, Division, Multiplication, Modulus.
- 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

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

int main(void)
{
   char   c;

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

- The keyword `char` stands for character.
- Used with single quotes i.e. 'A', or '+'.
- Some keyboards have a second single quote the **back quote** `
- Note the %c conversion format.
- Output :

  A B

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;

}
```

Output :

Sum of x & y is 3.000000.

- In C there are three common floating types :
  1. float
  2. double
  3. long double
- The *Working Type* is doubles.

The Preprocessor

- A # in the first column signifies a preprocessor statement.
- `#include <file.h>` Exchange this line for the entire contents of `file.h`, which is to be found in a standard place.
- `#define PI 3.14159265358979` Replaces all occurrences of `PI` with `3.14159265358979`.
- Include files generally contain other `#define`'s and `#include`'s (amongst other tings).

Using printf()

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

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

- 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*.
- `scanf(fmt-str, &arg1, &arg2, ...);`
- Note that the *address* of the argument is required.

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

- Note doubles handled differently than floats.

While Loops

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

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

int main(void)
{

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

   printf("\n%s%5d\n%s%12f\n\n",
          "Count:", cnt, " Sum:", sum);
   return 0;
}
```

Common Mistakes

- Missing "

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

- Missing ;

```
a = a + 1
```

- Missing Address in scanf()

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

Table of Contents

Grammar

- C has a grammar/syntax like every other language.
- It has *Keywords*, *Identifiers*, *Constants*, *String Constants*, *Operators* and *Punctuators*.
- Valid Identifiers :
  k, _id, iamanidentifier2, so_am_i.
- **Invalid** Identifiers :
  not#me, 101_south, -plus.
- Constants :
  17 (decimal), `017` (octal), `0x17` (hexadecimal).
- String Constant enclosed in double-quotes :
  "I am a string"

Operators

- All operators have rules of both *precedence* and *associativity*.
- $1 + 2 * 3$ 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 $i = i + 1$;
- May also be prefixed --i;

```c
#include <stdio.h>

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

Question : What is the output ?

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

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

#include <stdio.h>

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

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

Output :

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

The Standard Library

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

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

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

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

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

Table of Contents

Comparisons

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

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

Short-Circuit Evaluation

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

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

The if() Statement

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

```
if (expr)
   statement
```

If more than one statement is required :

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

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

Adding an else statement :

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

A Practical Example of if:

```c
#include <stdio.h>

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

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

Output:

```
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.

```
// Simple while countdown

#include <stdio.h>

int main(void)
{

   int n = 9;

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

Output :

9 8 7 6 5 4 3 2 1

The for() Loop

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

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

and may be thought of as :

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

In the for() loop, note :

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

A Triply-Nested Loop

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

#define N 7

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

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

Output :

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

... etc ...

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.

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

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

```
// Simple do-while countdown

#include <stdio.h>

int main(void)
{

   int n = 9;

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

Output :

9 8 7 6 5 4 3 2 1

The switch() Statement

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

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

The switch() Statement

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

#include <stdio.h>

int main(void)
{

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

Output :

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

The Conditional (?) Operator

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

```
expr1 ? expr2 : expr3
```

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

```c
#include <stdio.h>

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

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

Table of Contents

Simple Functions

```c
#include <stdio.h>

int min(int a, int b);

int main(void)
{

    int j, k, m;

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

}

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

Output :

Input two integers: 5 2

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

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

Call-by-Value

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

```c
#include <stdio.h>

void fnc1(int a);

int main(void)
{

    int x = 1;

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

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

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

Testing

```c
#include <stdio.h>

int numfactors(int f);

int main(void)
{

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

int numfactors(int k)
{

   int count = 0;

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

- This is a (not very good) function to compute the number of factors a number has.
- A factor is a number by which a larger (whole/integer) number can be divided.
- 36 has 6 factors: $1, 2, 3, 4, 6, 12$ and 36 itself.
- How do we know the program works though ?
- Running it ?

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

Pre- and Post-Conditions

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

int numfactors(int f);

int main(void)
{

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

int numfactors(int k)
{

   int count = 0;

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

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

- If there is no error, there is no output from this program.
- 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().
- By #define'ing NDEBUG before the #include <assert.h>, all assertions are ignored, allowing them to be used during development and switched off later.

Self-test : Multiply

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

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

 list of function prototypes

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

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

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

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

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

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

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

 int main(void)
 {

     . . . . .

 }
```

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

Replacing Functions with Macros

```c
#include <stdio.h>

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

int main(void)
{

    int j, k, m;

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

}
```

Output :

Input two integers: 5 2
Minimum is 2

- There's sometimes a (tiny) time penalty for using functions.
- The contents of the functions are saved onto a special stack, so that when you return to the function, its variables and state can be restored.
- https://en.wikipedia.org/wiki/Call_stack
- Historically, for small functions that needed to be fast, programmers might have #define a macro.
- There's a problem though - what happens if we used m = MIN(i++, j++); ?
- This is expanded to ((i++)<(j++)?(i++):(j++)) which is **not** what was intended.

The inline modifier

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

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

```c
#include <stdio.h>

inline int min(int a, int b);

int main(void)
{

   int j, k, m;

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

}

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

Output :

Input two integers: 5 2
Minimum is 2

Factorials via Iteration

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

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

int fact(int a);

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

}

int fact(int a)
{

   int i;
   int tot = 1;

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

}
```

Factorials via Recursion (Advanced)

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

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

int fact(int a);

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

}

int fact(int a)
{

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

}
```

Self-test : Multiply (Advanced)

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

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

int fact(int a);

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

}

int fact(int a)
{

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

}
```