COMSM1201 : Programming in C

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University of Bristol

Built : September 23, 2024

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 over the years.

Resources

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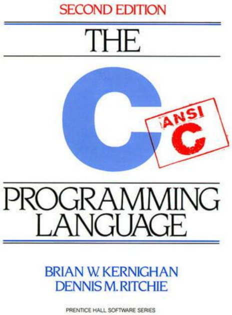
- Whatever you use, make sure it's **C99** that's being taught, not something else e.g. C11 or C++.
- If you fall in love with C and know you're going to use it for the rest of your life, the reference 'bible' is K&R 2nd edition. It's not a textbook for those new to programming, though.



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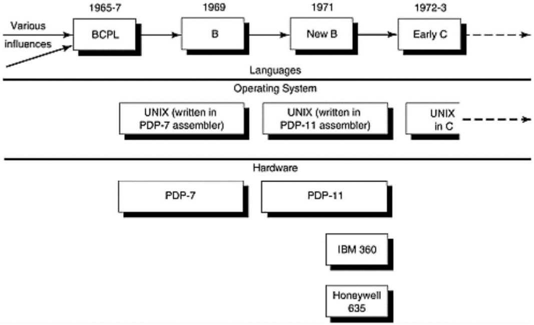
History of C



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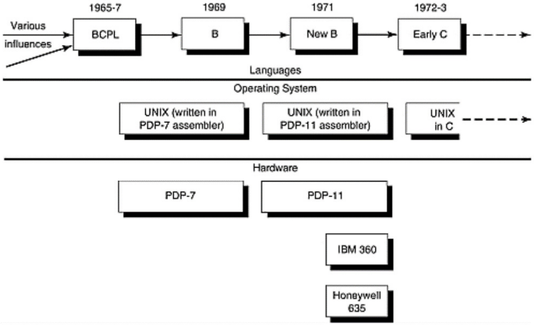

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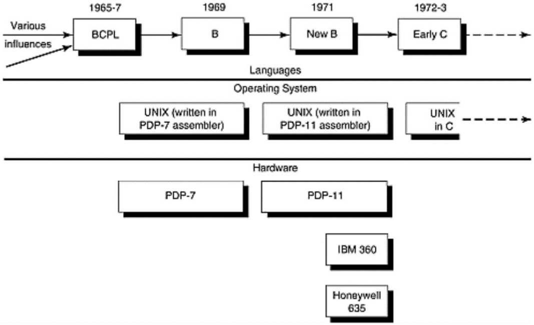

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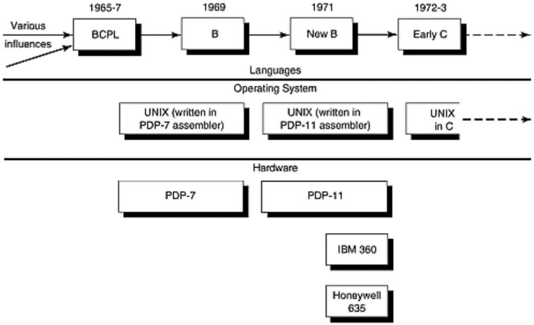

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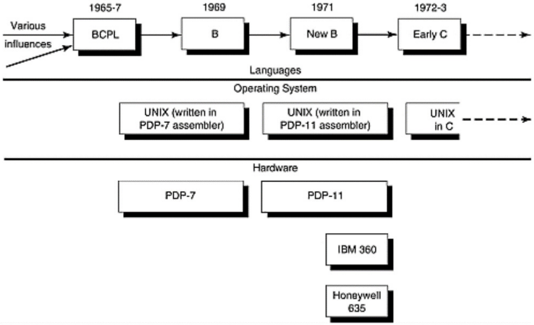

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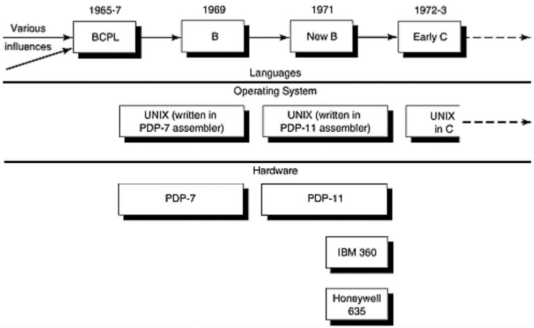

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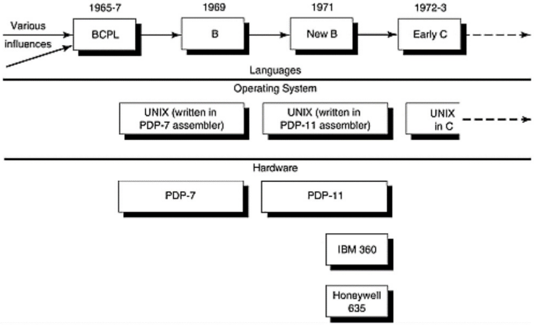

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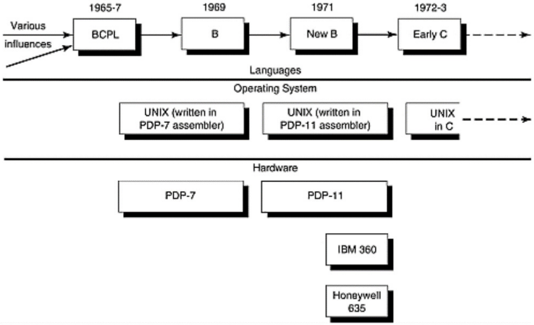

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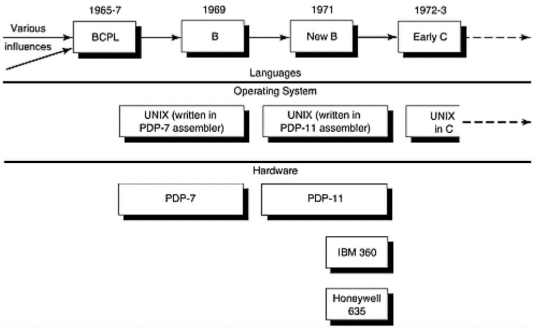

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- C++ Object Oriented Programming (OOP)
- Java (Subset of C++, WWW enabled).

Why C ?

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2	3			C++	10.75%	+0.09%
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7	7		VB	Visual Basic	2.70%	+0.48%
8	12		GO	Go	2.35%	+1.16%
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- Large parts common to Java

- Lectured 4 hours per week (Neill & Kira) for weeks 1-12 (barring week 6)

Programming and Software Engineering

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

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- Four assignments and final exam.
- 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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- TAs are not allowed to write pieces of code for you, nor undertake detailed bug-fixing of your program.

Table of Contents

Hello World!

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

a 'hell';
b 'o, w';
c 'orld';
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Hello World first seen in: Brian Kernighan, *A Tutorial Introduction to the Language B*, 1972

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

#include <stdio.h>

int main(void)
{

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

}
```

Execution :

```
Hello, world!
```

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

Area of a Rectangle

```c
#include <stdio.h>

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

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

Execution :

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

Dissecting the Area Program

- // One line comment.

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```
preprocessing directives

int main(void)
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    declarations

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

The Character Type

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

int main(void)
{
    char   c;

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

Execution :

A B

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- 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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- The *Working Type* is doubles.

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- `#define PI 3.14159265358979` Replaces all occurrences of `PI` with `3.14159265358979`.

The Preprocessor

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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 things).

Using printf()

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

%c	Characters
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%e	Floats/Doubles (Engineering Notation)
%f	Floats/Doubles
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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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- Note doubles handled differently than floats.

While Loops

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

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        ...
    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%5i\n%s%5f\n\n",
           "Count:", cnt, "Sum: ", sum);
    return 0;
}
```

Execution :

```
Input some numbers: 1 5 9 10

Count:    4
Sum: 25.000000
```

Common Mistakes

- Missing "

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

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printf("%c\n, ch);
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Table of Contents

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- String Constant enclosed in double-quotes :
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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

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- 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("%5i", power *= 2);
    }
    printf("\n");
    return 0;
}
```

Execution :

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

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

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

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
```

The Standard Library

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

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

Execution :

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

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

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

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Randomly distributed integers are printed.
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- Do not mistake these header files for the libraries themselves !

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- 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.

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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("%i%i%i", &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 %i\n", min);
   return 0;
}
```

Execution :

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

The while() Statement

```
while(expr)
   statement
```

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

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

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       .
       .
   statement-n
}
```

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

```c
// Simple while countdown

#include <stdio.h>

int main(void)
{

   int n = 9;

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

Execution :

9 8 7 6 5 4 3 2 1

The for() Loop

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

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

and may be thought of as :

```
init;
while(test){
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       .
       .
       .
   statement-n
   loop;
}
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        .
   statement-n
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In the for() loop, note :

- Semi-colons separate the three parts.

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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.
- 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("%3i%3i%3i\n", i, j, k);
            }
         }
      }
   }
   printf("\nCount: %i\n", cnt);
   return 0;
}
```

Output :

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

etc.

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

Count: 36
```

The Comma Operator

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

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

Hence, the for loop may become quite complex :

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

An equivalent, but more difficult to read expression :

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

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         .
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} while ( test );
```

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```c
// Simple do-while countdown

#include <stdio.h>

int main(void)
{

   int n = 9;

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

Execution :

9 8 7 6 5 4 3 2 1

The switch() Statement

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

- The val must be an integer.

The switch() Statement

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switch (val) {
    case 1 :
        a++;
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- 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.

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switch (val) {
    case 1 :
        a++;
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    case 3 :
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        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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As we have seen, C programers have a range of techniques available to reduce the amount of typing :

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

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   int   x, y, z;

   printf("Input three integers:  ");
   if(scanf("%i%i%i", &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 %i\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("%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;

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int min(int a, int b)
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   else
      return b;
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Execution :

```
Input two integers: 5 2

Of the two values 5 and 2, the minimum is 2.
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- 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);
}

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    x = x + 1;
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- 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;
}
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- This is a (not very good) function to compute the number of factors a number has.

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- A factor is a number by which a larger (whole/integer) number can be divided.

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- 12 has 6 factors: $1, 2, 3, 4, 6$ and 12 itself.

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

Pre- and Post-Conditions

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#include <stdio.h>
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   assert(k >= 1); // Avoid trying zero
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      }
   }
   assert(count <= k);
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- Pre-conditions check the inputs to functions, typically their arguments.
- Post-conditions check the returns from functions.
- An `assert` simple states some test that **ought** to be true. If not, the program aborts with an error.
- There's a sense that this is somehow *safer*, but we haven't exactly done much testing on it to ensure the correct answers are returned.

Assert Testing

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

int numfactors(int f);

int main(void)
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   assert(numfactors(17) == 2);
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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.
- If you #define 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.

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- 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 $*$)
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- 7×8 is computed by adding 7, eight times.

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- Use iteration (a loop) to achieve this.
- 7×8 is computed by adding 7, eight times.
- Use assert() calls to test it thoroughly - I've given you some to get you started.

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Program Layout

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

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

 list of function prototypes

 int main(void)
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However, it is theoretically possible to avoid the need for function prototypes by defining a function before it is used :

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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("%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
#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
```

- 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 "double evaluation" problem though - what happens if we used `m = MIN(j++, k++);` ?
- This is expanded to `((j++)<(k++)?(j++):(k++))` 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;
}
```

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Factorials via Iteration

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

}
```

Factorials via Recursion (Advanced)

- We could achieve the same result using recursion.

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        return ( a * fact(a - 1) );
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- The factorial of 4 can be thought of as $4 \times 3!$

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Factorials via Recursion (Advanced)

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- 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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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
/* 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);
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- Use assert() calls to test it thoroughly.

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Table of Contents

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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	Identical for printf : %i or %d For scanf, %d input decimal only For scanf, %i auto-detects format (octal,decimal,hex)
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

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)
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    float d = 0.1;
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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));
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```
char        :  1
short       :  2
long        :  8
unsigned    :  4
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long dbl    : 16
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- Most take `doubles` as arguments and return `doubles`.

Casting

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

#define PI 3.14159265358979323846

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

Execution :

```
Enter a radius : 7.75
Volume of your ball = 1949.816390
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- An explicit type conversion is called a *cast*.

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- *If it moves - cast it*. Don't trust the compiler to do it for you !

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char c1 = 'A', c2 = '*', c3 = ';' ;
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lowercase	'a'	'b'	'c'	...	'z'
ASCII value	97	98	99	...	112
uppercase	'A'	'B'	'C'	...	'Z'
ASCII value	65	66	67	...	90
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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

- 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 */
  ```

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

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 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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Execution :

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

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

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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        }
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            putchar(c);
        }
    }
    putchar('\n');
    return 0;
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```

```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');
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Execution :

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enum day { sun, mon, tue, wed, thu, fri, sat};
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enum day d1;
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enum fruit{apple=7, pear, orange=3, lemon};
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  ```
- Use enumerated types as constants to aid readability - they are self-documenting.

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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.:

```
typedef int colour;
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  ```
  typedef int colour;
  ```

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

Combining typedefs and enums

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

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

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

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

typedef enum bool {false, true} bool;

int main(void)
{

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

Execution :

```
It's true!
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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!
```

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

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

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

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

int fvr(double t, int s)
{
}
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1D Arrays

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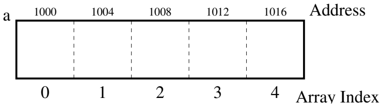

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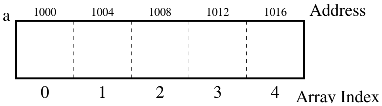

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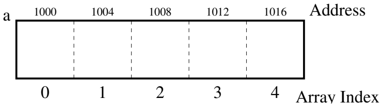

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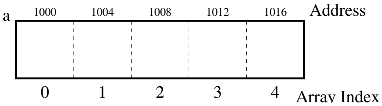

- Arrays are indexed **0** to **n-1**.

```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};
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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;`
- Accessing an array out of bounds will not be identified by the compiler. It may cause an error at run-time. One frequent result is that an entirely unrelated variable is altered.

1D Arrays : Call by Reference

```c
#include <stdio.h>
#include <math.h>
#include <assert.h>
#define MAX 5

// Pass array, AND number of elements
void set_array(int a[MAX], unsigned int len, int n);

int main(void)
{
   int x[MAX] = {2, 3, 3, 3, 3};
   set_array(x, 5, 3); assert(x[0] == 3);
   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);
   assert(x[2] == 2); assert(x[3] == 4);
}

// Set all values of array (size len) to n
void set_array(int a[MAX], unsigned int len, int n)
{
   if(len == 0){
      return;
   }
   for(unsigned int i=0; i<len; i++){
     a[i] = n;
   }
}
```

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- Here, the array is passed by *Reference* - no copy of the array is made - the function processes the array that was created inside `main()`, despite it apparently having a 'different' name.
- All arrays are passed like this in C - we'll see later when we look at *pointers* why this is the case.

Structures

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  actually creates storage for the variables.
- A member is accessed using the member operator "."
- `e1.salary = 35000.2;`
  `e2.age = 29;`
- 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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{
   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

```c
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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- 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.:

  ```c
  typedef card deck[DECK];

  void shuffle_deck(deck d);
  ```

  But this hides the fact it's an array (which seems odd?)

Table of Contents

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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 :

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- 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> :

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- strlen() returns the number of bytes in s, not including the terminating null character.

One way to write the function strlen() :

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

unsigned nstrlen(const char s[]);

int main(void)
{
   assert(nstrlen("Neill")==5);
   assert(nstrlen("")==0);
   assert(nstrlen("\n")==1);
   assert(nstrlen("abcdef")==nstrlen("fedcba"));
   return 0;
}

unsigned nstrlen(const char s[])
{
   register unsigned n = 0;

   while(s[n] != '\0'){
      ++n;
   }
   return n;
}
```

The snprintf() 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 snprintf(string, str-size, control-arg, other args);

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```
int snprintf(string, str-size, control-arg, other args);
```

For example:

```
int i = 7;
float f = 17.041;
char str[100];
snprintf(str, 100, "%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[BIGSTR], 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:
         snprintf(pipstr, SMALLSTR, "%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");
   }
   snprintf(s, BIGSTR, "%s of %s", pipstr, suitstr);
}
```

snprintf() 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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    // Is this a reasonable test ?
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}
```

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

2D array initialisation :

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

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));
      }
   }
}
```

2D Distance

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

#define  M  7
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void fillarray(int a[M][N]);

int main(void)
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   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])
{
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         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!)

```
#define SMALLSTR 20
void print_card(char s[BIGSTR], 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"};
   snprintf(s, BIGSTR, "%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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}
```

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

void printstuff(void);

#define MAXLOOP 20

int main(void)
{
   int r = rand() % MAXLOOP;
   for(int i=0; i<r; i++){
      printstuff();
   }
   return 0;
}

void printstuff(void)
{
   static int cnt = 0;
   printf("You've been here %i times\n", ++cnt);
}
```

Storage Classes

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void printstuff(void);

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int main(void)
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    int r = rand() % MAXLOOP;
    for(int i=0; i<r; i++){
       printstuff();
    }
    return 0;
}

void printstuff(void)
{
    static int cnt = 0;
    printf("You've been here %i times\n", ++cnt);
}
```

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;
}
```

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Execution :

1

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

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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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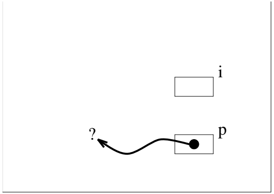
- `int i, *p;`



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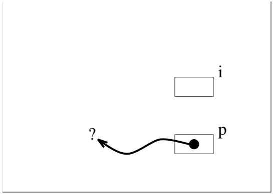
- Here `i` is an `int` and `p` is of type *pointer to int*.



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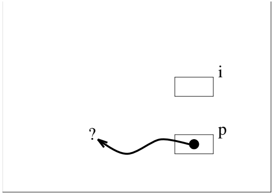
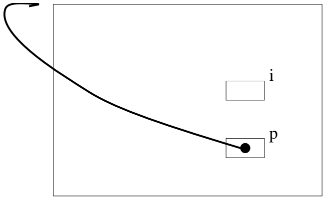
  causes the appropriate value to be stored at a particular address in memory.
- If `v` is a variable, then `&v` is its address, or location, in memory.
- `int i, *p;`
- Here `i` is an `int` and `p` is of type *pointer to int*.
- Pointers have a legal range which includes the special address 0 and a set of positive integers which are the machine addresses of a particular system.



The *NULL* Pointer

- `p = NULL;`



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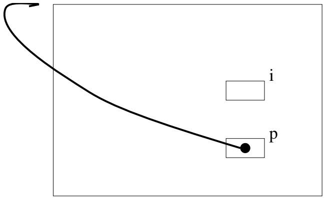

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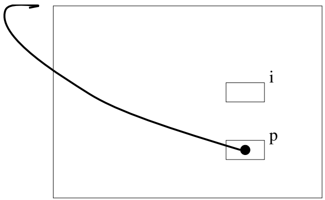
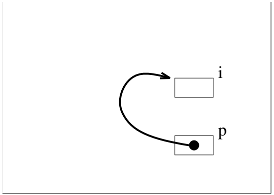
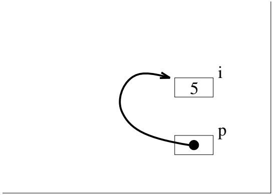


- p = &i;



Equivalence of i and $*p$

- i = 5;



Equivalence of *i* and **p*

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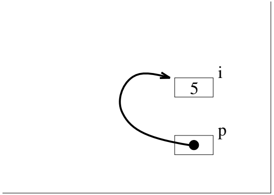

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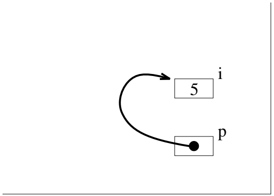


```c
#include <stdio.h>

int main(void)
{

    int i = 5;
    int* p = &i;
    printf("%i\n", *p);
    i = 17;
    printf("%i\n", *p);
    *p = 99;
    printf("%i\n", i);

    return 0;

}
```

Execution :

5
17
99

scanf Again

```c
#include <stdio.h>

int main(void)
{

    int i;
    int* 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

```c
#include <stdio.h>

int main(void)
{

    int i;
    int* 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
```

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

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

scanf Again

```c
#include <stdio.h>

int main(void)
{

    int i;
    int* 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
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3
```

- 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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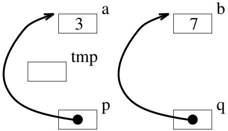
Execution :

3 7
7 3

- At beginning of function:



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3 7
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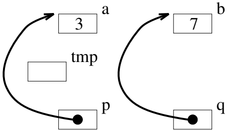

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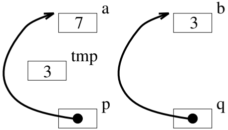

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Execution :

3 7
7 3

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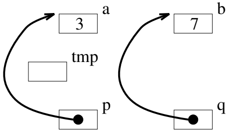

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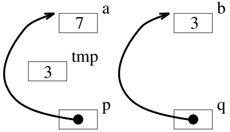
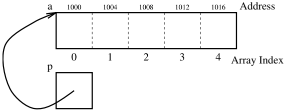


- Remember that the variables *a* and *b* are not in the scope of *swap()*.

Arrays are Pointers ?

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



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```
int a[5];
int *p;
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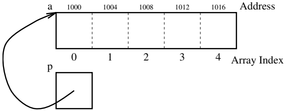
declares an array of 5 elements, and a is the address of the start of the array.



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  `p = a;`

  is completely valid and the same as:

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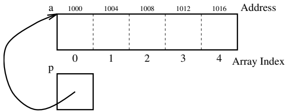

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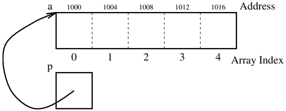

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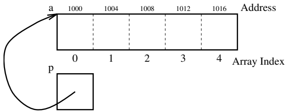

- To assign p to point to the next element, we could either :

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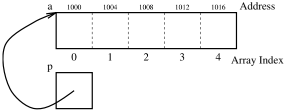

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- Notice that p = a + 1 advances the pointer **4** bytes and not 1 byte. This is because an integer is 4 bytes long and p is a pointer to an int.

Arrays are Pointers ?

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

```
int a[5];
int *p;
```

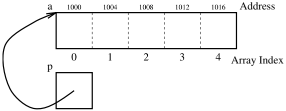
declares an array of 5 elements, and a is the address of the start of the array.

- Assigning:

```
p = a;
```

is completely valid and the same as:

```
p = &a[0];
```



- 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 tot = 0;

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

Execution :

37

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#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;
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    int tot= 0;

    for(int i=0; i<NUM; i++){
        tot += *p;
        p++;
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    return tot;
}
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Execution :

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Pointers to Structures

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Pointers to Structures

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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 ".".

```
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[BIGSTR], 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"};
   snprintf(s, BIGSTR, "%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

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// 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[])
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   for(int i=0; s[i]; i++){
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  is the culprit.
- 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

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

#define LINE 500

char* nify(char s[]);

int main(void)
{

   char* s1 = nify("inconveniencing");
   char* s2 = nify("neill");
   assert(strcmp(s2, "Neill")==0);
   assert(strcmp(s1, "iNcoNveNieNciNg")==0);
   return 0;

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// Local copy : Swaps all 'n' -> 'N'
char* nify(char s[])
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   char t[LINE];
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- Now we try to create a copy of the string, and return a pointer to it.

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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.

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- This only works if we're very careful with the order in which we use the strings.
- This code fails because, in `main()`, by the time we `strcmp(s1, "iNcoNveNieNciNg")` the contents of `s1` have been overwritten by `"Neill"`.
- The pointers `s1` and `s2` are the same.

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#include <string.h>
#include <assert.h>

char* nify(char s[]);

int main(void)
{
   char* s1 = nify("inconveniencing");
   char* s2 = nify("neill");
   assert(strcmp(s2, "Neill")==0);
   assert(strcmp(s1, "iNcoNveNieNciNg")==0);
   free(s1);
   free(s2);
   return 0;
}

// malloc : Swaps all 'n' -> 'N'
char* nify(char s[])
{
   int l = strlen(s);
   char* t  = (char*)malloc(l+1);
   if(t==NULL){
      exit( EXIT_FAILURE );
   }
   strcpy(t, s);
   for(int i=0; t[i]; i++){
      if(t[i] == 'n'){
         t[i] = 'N';
      }
   }
   return t;
}
```

Variable Length Arrays

```
// This code is not allowed by the -Wvla flag
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#define WORD 500

int main(void)
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    printf("Please type a string :\n");
    char s[WORD];
    assert(scanf("%s", s)==1);
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- None of these is a problem if we use malloc().

Memory Leaks

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// This leaks - but it's not obvious
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    /* malloc() returns a pointer to memory that
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    char* t = (char*) malloc(n+1);
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- 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()

```
#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);
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    /* 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);
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    /* Deep copy: character by character */
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    printf("%s %s\n", s, t);
    /* All malloc'd memory must be freed
       to prevent memory leaks */
    free(t);
    return 0;

}
```

- 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
// 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;
   // 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;
}
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- 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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   printf("%i\n", p->num);
   return 0;
}
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- 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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int main(void)
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   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->next);
   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

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- Files may be read, written or appended.
- Conceptually a file may be thought of as a stream of characters.

```c
/* Creates a file called helloworld.txt
in the current filespace and writes to it */
#include <stdio.h>
#include <stdlib.h>

int main(void)
{
   // Clobber the file if it exists already
   FILE* fp = fopen("helloworld.txt", "w");
   if(fp == NULL){
      fprintf(stderr, "Cannot open file?\n");
      exit(EXIT_FAILURE);
   }
   fprintf(fp, "Hello World!\n");
   // fscanf() is also available to read in
   fclose(fp);
   return EXIT_SUCCESS;
}
```

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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- 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.

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      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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- 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, ...)

```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);
   }
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- fscanf() could be used instead of fgets().

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  this will list all your files into myfiles.txt

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- Therefore, `stderr` exists so that there is a stream to display warnings/errors to the user.

Interlude : argc/v

- A traditional C program has
  int main(int argc, char* argv[]);

```c
#include <stdio.h>

int main(int argc, char* argv[])
{

    printf("You typed %i arguments\n", argc);
    printf("The name of your executable is : %s\n", argv[0]);
    for(int i=1; i<argc; i++){
        printf("Argument %d is : %s\n", i, argv[i]);
    }

    return 0;
}
```

Execution :

```
$ ./usingargs -c doof groob
You typed 4 arguments
The name of your executable is : ./usingargs
Argument 1 is : -c
Argument 2 is : doof
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- This is sometimes known as a ragged-right or jagged array.

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Back to Files : 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);
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  `$ cp oldfile.txt newfile.txt`

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- This is a very basic version of the Linux command cp :

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- Almost all Linux programs access arguments typed on the command line.
- fgetc() and fputc() are the file equivalents of getchar and putchar.

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- Here we save an entire array to a binary file - another program could read this in later.

```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;
}
```