Programming in C

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

University of Bristol

October 4, 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

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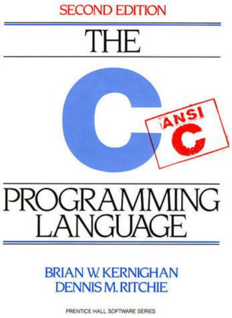
- Whatever you use, make sure it's **C99** that's being taught, not something else e.g. C11 or C++.
- If you fall in love with C and know you're going to use it for the rest of your life, the reference 'bible' is K&R 2nd edition. It's not a textbook for those new to programming, though.



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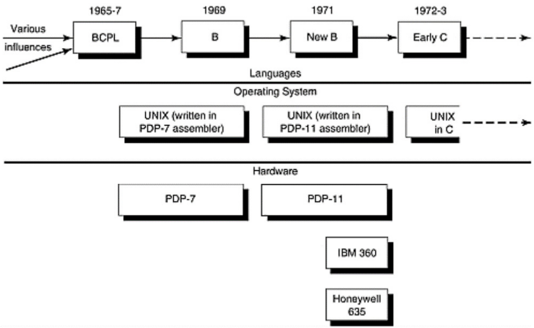
- Don't place your code on publicly accessible sites e.g. github - other students may have extensions etc.

History of C



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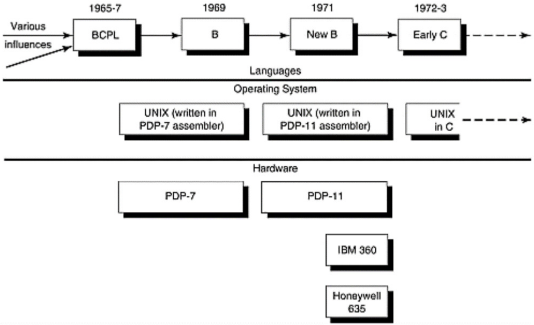

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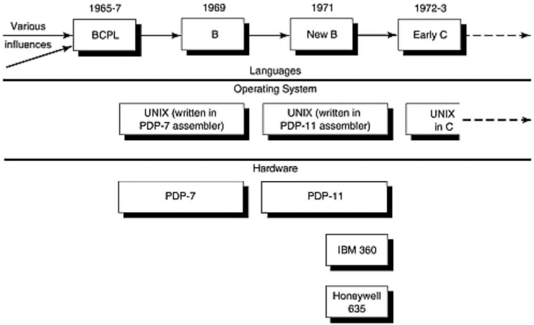

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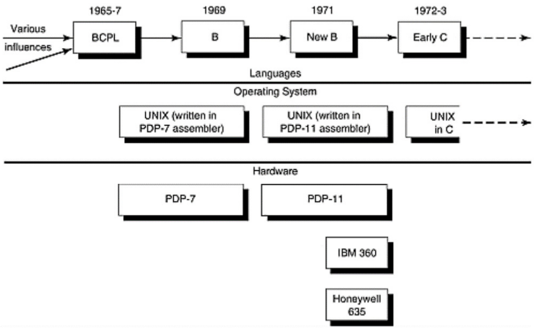

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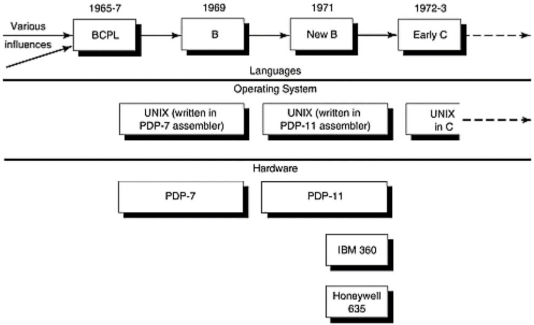

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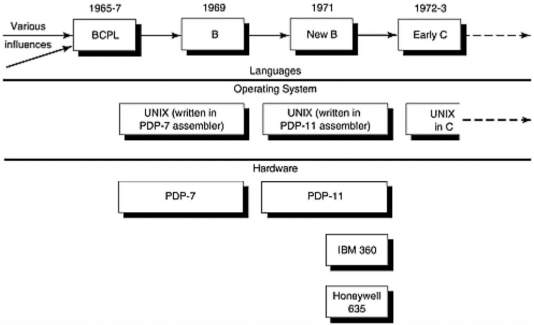

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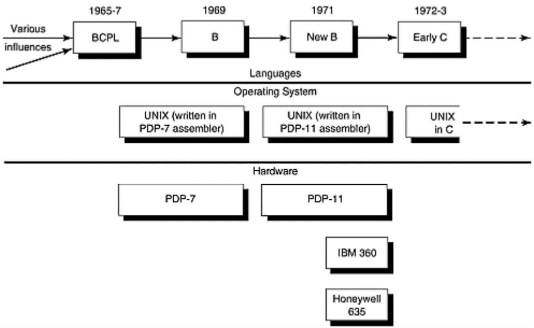

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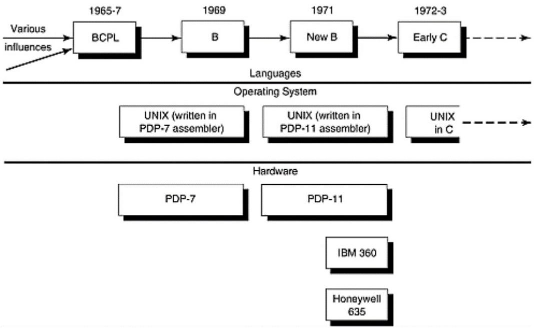

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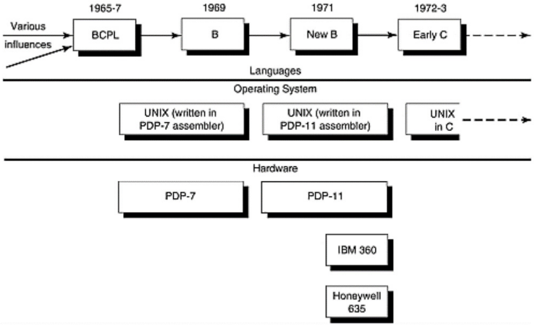

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- C++ - Object Oriented Programming (OOP)
- Java (Subset of C++, WWW enabled).

Why C ?

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

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

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

Help with Computers

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

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

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

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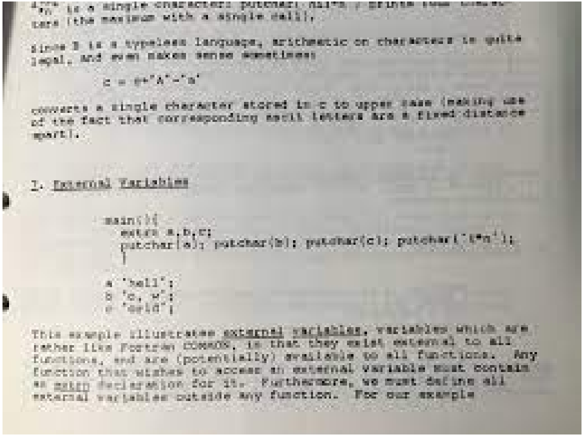
Hello World!



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

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

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

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

7. External Variables

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

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

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

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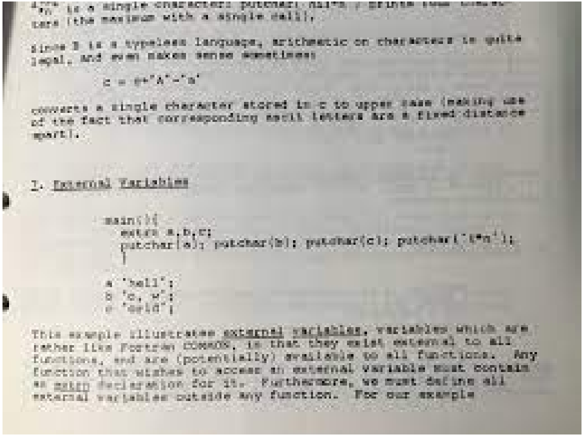

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```c
/* The traditional first program
in honour of Dennis Ritchie
who invented C at Bell Labs
in 1972 */

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

Execution :

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

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preprocessing directives

int main(void)
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    declarations

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  7%4 is 3, 12%6 is 0.
- Only available for integer arithmetic.

The Character Type

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

int main(void)
{
   char   c;

   c = 'A';
   printf("%c ", c);
   printf("%c\n", c+1);
   return 0;
}
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- Note the %c conversion format.

Floating Types

```c
#include <stdio.h>

int main(void)
{

    double x, y;

    x = 1.0;
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    printf("Sum of x & y is %f.\n", x + y);

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Execution :

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Sum of x & y is 3.000000.
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- `#define PI 3.14159265358979` Replaces all occurrences of `PI` with `3.14159265358979`.

The Preprocessor

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- Include files generally contain other `#define`'s and `#include`'s (amongst other tings).

Using printf()

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

%c	Characters
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  F: 3.0001

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

Using scanf()

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

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- Note doubles handled differently than floats.

While Loops

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

While Loops

```
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    statement 1;
        ...
    statement n;
}
```

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

int main(void)
{

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

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

Execution :

```
Input some numbers: 1 5 9 10

Count:    4
Sum:  25.000000
```

Common Mistakes

- Missing "

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

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```
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```
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scanf("%d", a);
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Table of Contents

Grammar

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  17 (decimal), `017` (octal), `0x17` (hexadecimal).
- String Constant enclosed in double-quotes :
  `"I am a string"`

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- Increment and decrement operators : i++; is equivalent to i = i + 1;
- May also be prefixed --i;

```
#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 ?

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

Execution :

```
    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;
}
```

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
```

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

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

Table of Contents

Comparisons

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

Execution :

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

The while() Statement

```
while(expr)
   statement
```

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

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

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

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        .
        .
   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;
}
```

Execution :

```
9 8 7 6 5 4 3 2 1
```

The for() Loop

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

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

and may be thought of as :

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

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In the for() loop, note :

- Semi-colons separate the three parts.

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```

In the for() loop, note :

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

A Triply-Nested Loop

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

#define N 7

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

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

Output :

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

etc.

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

Count: 36
```

The Comma Operator

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

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

Hence, the for loop may become quite complex :

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

An equivalent, but more difficult to read expression :

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

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

The do-while() Loop

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

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

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

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```
// Simple do-while countdown

#include <stdio.h>

int main(void)
{

    int n = 9;

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

Execution :

9 8 7 6 5 4 3 2 1

The switch() Statement

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

- The `val` must be an integer.

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    case 1 :
        a++;
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    case 3 :
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        break;
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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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    default :
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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.
- The `default` label is a catch-all.

The switch() Statement

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

#include <stdio.h>

int main(void)
{

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

Execution :

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

The Conditional (?) Operator

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

```
expr1 ? expr2 : expr3
```

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

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

```
expr1 ? expr2 : expr3
```

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

```
#include <stdio.h>

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

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

Table of Contents

Simple Functions

```c
#include <stdio.h>

int min(int a, int b);

int main(void)
{

    int j, k, m;

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

}

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

Execution :

```
Input two integers: 5 2

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

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- The function *prototype is shown* at the top of the file. This allows the compiler to check the code more thoroughly.

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- The function `min()` returns an `int` and takes two `int`'s as arguments. These are copies of `j` and `k`.

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- The function is defined between two braces.
- The function `min()` returns an `int` and takes two `int`'s as arguments. These are copies of j and `k`.
- The `return` statement is used to return a value to the calling statement.

Call-by-Value

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

```c
#include <stdio.h>

void fnc1(int x);

int main(void)
{
    int x = 1;

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

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

Execution :

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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 %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;
}
```

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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

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- We need something more automated.

Pre- and Post-Conditions

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#include <assert.h>

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   int count = 0;

   assert(k >= 1); // Avoid trying zero
   for(int i=1; i<=k; i++){
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      }
   }
   assert(count <= k);
   return count;
}
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- Pre-conditions check the inputs to functions, typically their arguments.

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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);
   assert(numfactors(12) == 6);
   assert(numfactors(6) == 4);
   assert(numfactors(0) == 0); // ?
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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()`.

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

Self-test : Multiply

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

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

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

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

int main(void)
{
   test();

   return 0;
}

int mult( int a,  int b)
{

// To be completed

}

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

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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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.

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Self-test : Multiply

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

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   any maths cleverer than addition.     */

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int mult(int a, int b);
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Program Layout

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

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

list of function prototypes

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

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

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

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

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

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

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

int main(void)
{

    . . . . .

}
```

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

Replacing Functions with Macros

```c
#include <stdio.h>

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

int main(void)
{

    int j, k, m;

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

}
```

Execution :

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

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

Execution :

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

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

Replacing Functions with Macros

```c
#include <stdio.h>

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

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- Historically, for small functions that needed to be fast, programmers might have #define a macro.
- There's a problem though - what happens if we used m = MIN(i++, j++); ?
- This is expanded to ((i++)<(j++)?(i++):(j++)) which is **not** what was intended.

The inline modifier

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

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

```c
#include <stdio.h>

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

int main(void)
{

    int j, k, m;

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

}

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

Execution :

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Factorials via Iteration

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

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```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.

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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);
   assert(mult(1,8) == 8);
   assert(mult(8,1) == 8);
}
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- Use assert() calls to test it thoroughly.

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Table of Contents

Fundamental Data types

- **[** unsigned | signed **]**

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

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

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Binary Storage of Numbers

In an unsigned char :

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

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

- Floating operations need not be exact.

```c
#include <stdio.h>

int main(void)
{

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

Execution :

```
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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:

```
#include <stdio.h>

int main(void)
{

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

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

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- Functions include :

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

Casting

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

#define PI 3.14159265358979323846

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

```
Enter a radius : 7.75
Area of your ball = 1949.816390
Area of your ball = 1949.82
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- *If it moves - cast it*. Don't trust the compiler to do it for you !

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- Use enumerated types as constants to aid readability - they are self-documenting.

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- The default numbering may be changed as well:

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

- Use enumerated types as constants to aid readability - they are self-documenting.
- Declare them in a header (`.h`) file.

Enumerated Types

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

- This creates a user-defined **type** `enum day`.
- The enumerators are constants of type `int`.
- By default the first (`sun`) has the value 0, the second has the value 1 and so on.

- An example of their use:

```
enum day d1;
  . . .
d1 = fri;
```

- The default numbering may be changed as well:

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

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

Typedefs

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

  `typedef int colour;`

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  `typedef int colour;`

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

Combining typedefs and enums

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

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

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

day find_next_day(day d);

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

```c
day find_next_day(day d)
{
   day next_day;
   switch(d){
      case sun:
         next_day = mon;
         break;
      case mon:
         next_day = tue;
         break;
      case tue:
         next_day = wed;
         break;
      case wed:
         next_day = thu;
         break;
      case thu:
         next_day = fri;
         break;
      case fri:
         next_day = tue;
         break;
      case sat:
         next_day = sun;
         break;
      default:
         printf("I wasn't expecting that!\n");
   }
   return next_day;
}
```

Style

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

- We can combine the two operations into one:

  ```
  typedef enum veg {beet,carrot,pea} veg;
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  ```
  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!
```

Fever

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

```
#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)
{
}
```

Table of Contents

1D Arrays

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

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  float x[10];
  int k[ARRAY_SIZE];
  ```

  The following, however, is not valid:

  ```
  float y[i*2];
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  int a[5];
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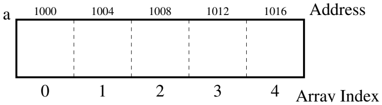

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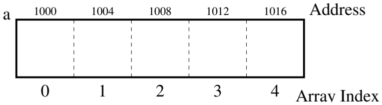

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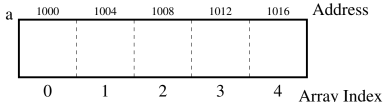

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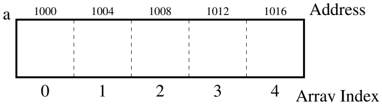

- Arrays are indexed **0** to **n-1**.

```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[%d]=%d ", i, a[i]);
    }
    /* sum elements */
    for (i = 0; i < N; ++i){
       sum += a[i];
    }
    /* print sum */
    printf("\nsum=%d\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;`

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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   set_array(x, 5, 4); assert(x[2] == 4);
   set_array(x, 1, 0); assert(x[0] == 0);
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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.

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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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- ```
  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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   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("%2d", d[i].pips);
        }
        switch(d[i].st){
            case hearts :
                printf(" of Hearts\n");
                break;
            case diamonds :
                printf(" of Diamonds\n");
                break;
            case spades:
                printf(" of Spades\n");
                break;
            default :
                printf(" of Clubs\n");
        }
    }
    printf("\n");
}
```

Execution :

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

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

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

Testing

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

- Note the direct ability to copy a structure.

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

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

Testing

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

- Note the direct ability to copy a structure.
- You can't compare them using == though.
- Tricky to think of a good test for shuffle_deck.
- You could also typedef away the array, e.g.:

  ```
  typedef card deck[DECK];

  void shuffle_deck(deck d);
  ```

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

Table of Contents

Storage of Characters

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char c;

c = 'A';
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or :

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

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

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

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

Using Characters

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

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

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

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

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

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\"	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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```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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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;
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            putchar(c);
        }
    }
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    return 0;
}
```

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

int main(void)
{

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

Execution :

```
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Strings

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Initialising Strings :

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Initialising Strings :

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

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

Unused Letters and string.h

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

#define ALPHASIZE 26

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

Execution :

```
j has not been used.
m has not been used.
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In #include <string.h> :

char *strcat(char dest[], const char src[]);
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- strcat() appends a copy of string src, including the terminating null character, to the end of string dst.

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

More string.h

In #include <string.h> :

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

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

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- 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 sprintf() Function

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

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

For example:

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

Outputs : 7 17.041000

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

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```

Outputs : 7 17.041000

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

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

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

sprintf() and sscanf()

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

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   for(int i=0; i<1000; i++){
      shuffle_deck(d);
      print_card(str, d[0]);
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      if(strcmp(str, FIRSTCARD)==0){
         n++;
      }
   }
   // Is this a reasonable test ?
   assert((n > 10) && (n < 30));
}
```

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

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

#include <stdio.h>

int main(void)
{


   printf("Please type your first name and your age\n");
   char bigstr[BIGSTR];
   fgets(bigstr, BIGSTR, stdin);
   char name[SMLSTR];
   int age;
   // Note no "&" before name : passed by reference already
   assert(sscanf(bigstr, "%s %d\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}};
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```
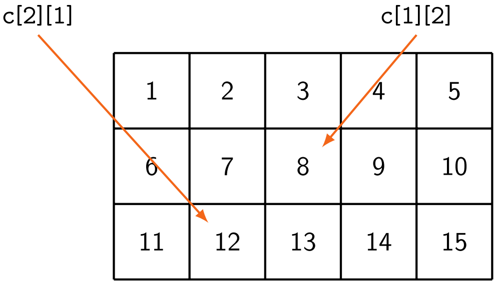

Although 2D arrays are stored in a contiguous block of memory, we may think of them as a 2D rectangle of data.

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



2D Distance

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

#define  M  7
#define  N  9

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

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

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

   return 0;
}
```

Execution :

```
544333445
443222344
432111234
432101234
432111234
443222344
544333445
```

Cards (again!)

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

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

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

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

Storage Classes

- **auto**

  ```
  auto int a, b, c;
  auto float f;
  ```

  Because this is the default, it is seldom used.

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

```c
#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 %d 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("%d\n", x);
}

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

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.
- 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("%d", &v);`

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

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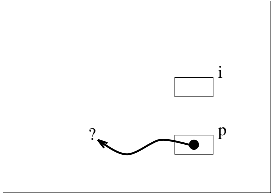

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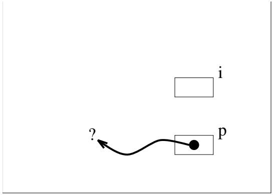

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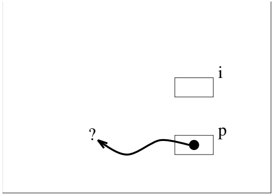
- `int i, *p;`
- Here `i` is an `int` and `p` is of type *pointer to int*.
- Pointers have a legal range which includes the special address 0 and a set of positive integers which are the machine addresses of a particular system.



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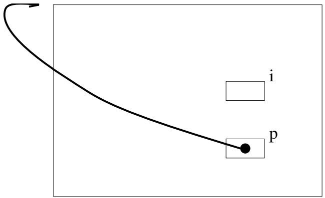
- `p = NULL;`



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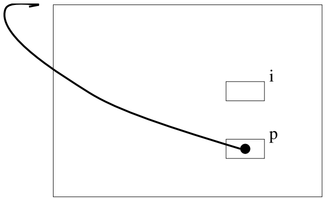

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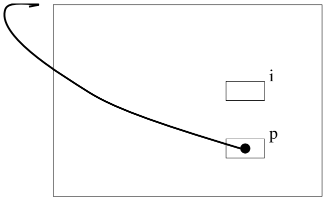
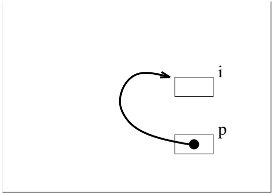
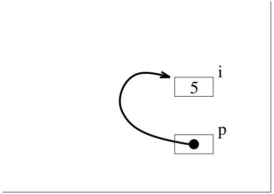


- p = &i;



Equivalence of i and $*p$

- i = 5;



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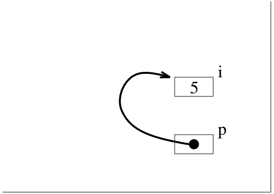

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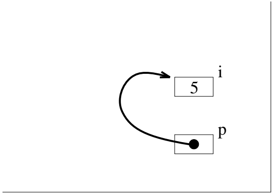


```c
#include <stdio.h>

int main(void)
{

    int i, *p;

    p = &i;
    i = 5;
    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, *p;

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

    return 0;

}
```

Execution :

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

scanf Again

```c
#include <stdio.h>

int main(void)
{

    int i, *p;

    p = &i;
    printf("Please Type a number : ");
    scanf("%i", &i);
    printf("%i\n", i);
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    return 0;

}
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Please Type a number : 70
70
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- In many ways the dereference operator * is the inverse of the address operator &.

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

scanf Again

```
#include <stdio.h>

int main(void)
{

    int i, *p;

    p = &i;
    printf("Please Type a number : ");
    scanf("%i", &i);
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    return 0;

}
```

Execution :

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

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

- What is this equivalent to ?

The *swap* Function

```
#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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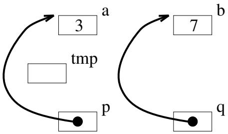

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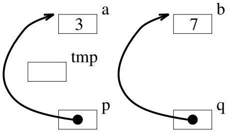

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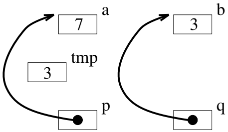

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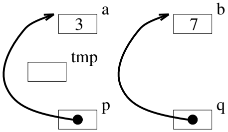

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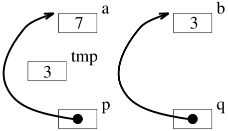
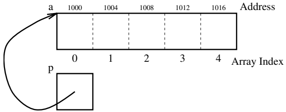


- Remeber that the variables *a* and *b* are not in the scope of *swap()*.

Arrays are Pointer?

- An array name by itself is simply an address.



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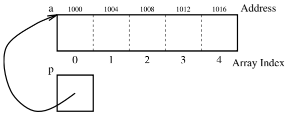
  declares an array of 5 elements, and a is the address of the start of the array.



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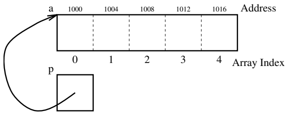
  p = a;

  is completely valid and the same as:

  p = &a[0];



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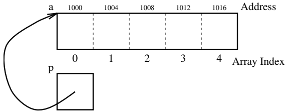

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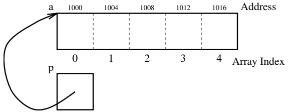

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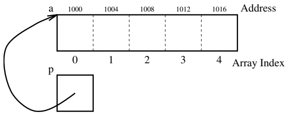

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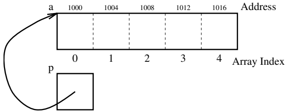

- To assign `p` to point to the next element, we could either :

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

  `*p = 5;`

Summing an Array

```c
#include <stdio.h>

#define NUM 5

int sum(int a[]);

int main(void)
{

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

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

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

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

Execution :

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

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Pointers to Structures

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

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- But, like any other type, we could pass a pointer instead.
- The complication is that to access the elements of a structure via a pointer, we use the “->” operator, and not the “.”.

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 “.”.

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 ".".

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

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