last update: 31st January 2023

Session: 2023-24

# COMP281 Lecture 2

# Principles of C and Memory Management

Phil Jimmieson

UNIVERSITY OF LIVERPOOL

Department of Computer Science

# Last Lecture

- Principles of C and Memory Management?

  what this module is about
- General module information.

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- Principles of C and Memory Management?
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Recap

Last Lecture

**hello.c**

```c
#include <stdio.h>
int main(void)
{
    printf("Hello, World!\n");
    return 0;
}
```

==========

**Compile via the terminal**

```
% gcc hello.c
% ./a.out
Hello, world!
%
```

On Windows, the default executable program name is a.exe
(Windows program names must end with .exe )

# Last Lecture

code

```
#include <stdio.h>
int main(void)
{
    printf("Hello, World!\n");
    return 0;
}
```

compile

output

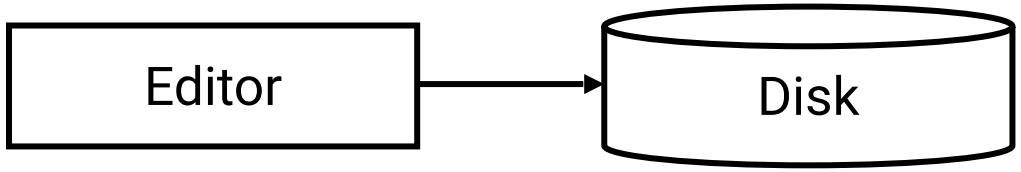
Executable
**Program**

This time:

- Compiling and Running C Programs
- C Language Basics

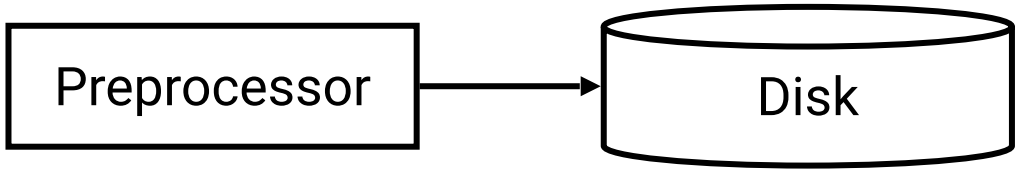
# Compiling and Running C Programs

Phase 1



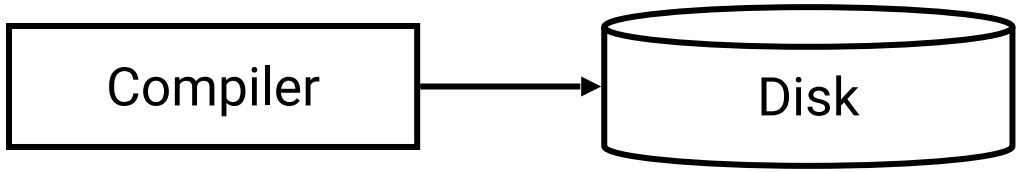

Program is created using the **Editor** and stored on Disk

Phase 2



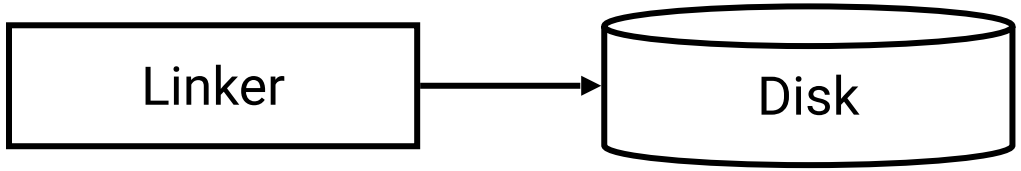

**Preprocessor** program processes the code

Phase 3



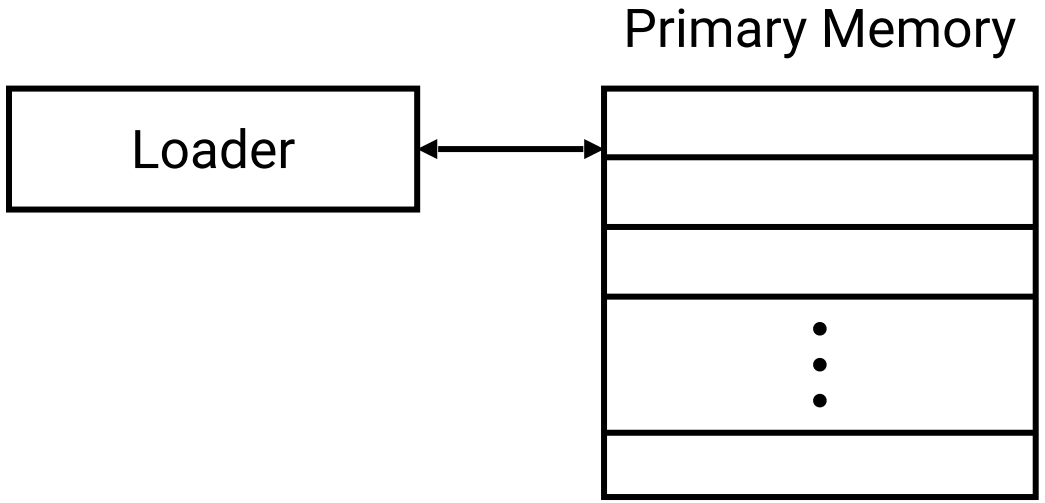

**Compiler** creates object code and stores it on Disk

Phase 4



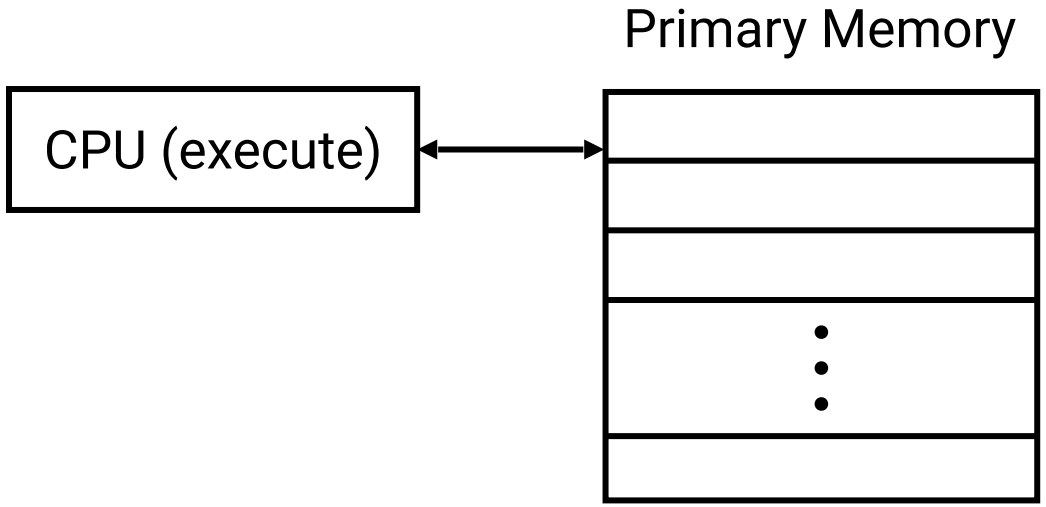

**Linker** links object code with libraries, create .out and stores on Disk

Phase 5




**Loader** puts Program in Memory

Phase 6




**CPU** takes each instruction and executes it, storing new data values as the program executes

# Compiling C Programs

- 4 kinds of files to work with
- The Preprocessor
- The Compiler
- The Linker

# Compiling C Programs

- **4 kinds of files to work with**
- The Preprocessor
- The Compiler
- The Linker

4 kinds of files
to work with

## 1. **Source Code** files

- *.c files
- Contain function ***definitions***

4 kinds of files to work with

## 2. **Header** files

- *.h files
- Contain function ***declarations*** (function prototypes)
- Contain various preprocessor statements
- Allow source code files to access externally-defined functions

4 kinds of files
to work with

## 3. **Object** files

- *.o files (or *.obj on Windows)
- The *output* of the **compiler**
- Contain function ***definitions in binary form***
- Not executable by themselves

4 kinds of files
to work with

## 4. **Binary executables**

- No suffix on macOS or Unix OS (*.exe on Windows)
- The *output* of the **Linker**
- Made from (a few) object files
- Can be directly executed

# Compiling C Programs

- 4 kinds of files to work with
- **The Preprocessor**
- The Compiler
- The Linker

# Compiling C Programs – The Preprocessor

**Before** the C compiler starts compiling a source code file, the file is processed by the preprocessor.

- It is a separate program, normally called “cpp” for “c preprocessor”.
- It **is invoked automatically** by the compiler **before compilation** proper begins.
- It **converts** source code (*.c) files, which may exist as a real file or be stored in memory for a short time before being sent to the Compiler.
- Preprocessor commands start with “#”. There are several preprocessor commands; the most important ones are:

```
#include #define
```

# `#include`

To access function definitions defined outside of a source code file, e.g.,

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

=====================
```

causes the preprocessor to paste the contents of `<stdio.h>` into the source code at the location of the `#include` statement before it get compiled.

- C compilers do not allow using a function unless it has previously been **declared** or **defined** in the file.

  #include statements are thus the way to *re-use previously-written code* in C programs.

- To include **header** files, which mainly contain **function declarations** and `#define` statements, e.g.,

  `#include <stdio.h>` for using functions such as `printf`, whose declarations are located in the file `stdio.h`.

# #define

Mainly to define constants, e.g.,

```
#define MAXNUM 999999
```

specifies wherever the character string MAXNUM is found in the rest of the program, 999999 should be substituted for it, e.g.,

```
int i = MAXNUM;
```

becomes

```
int i = 999999;
```

# `#define`

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becomes

```
int i = 999999;
```

**Why is it useful?**

- To avoid having to explicitly write out some constant value in many different places in a source code file.
- This is important if the constant value needs to be changed later; it's much less bug-prone to change it once, in the `#define`, than to have to change it in multiple places scattered all over the source code.

Some preprocessors commands

```
#define
#include
#undef
#ifdef
#ifundef
#error
```

```
#if
#else
#elif
#endif
#pragma
```

# Compiling C Programs

- 4 kinds of files to work with
- The Preprocessor
- **The Compiler**
- The Linker

# Compiling C Programs – The Compiler

- After the Preprocessor has included all header files and expanded out all the `#define` and `#include` statements (and any other preprocessor commands that may be in the original file), the compiler compiles the program.
- It turns the source code into an **object code** file, which contains the binary version of the source code (not *executable* yet).

# Compiling C Programs – The Compiler

- The **Compiler** may be invoked as:

  % `gcc foo.c` or

  % `gcc -c foo.c`

  This tells the compiler to run the preprocessor on the file `foo.c`, and then compile it into the **object** file `foo.o`. In the second example, the **–c** option means to compile the source code file into an **object** file but <u>NOT</u> to invoke the Linker.

# Compiling C Programs – The Compiler

- If the program is in one **source code** file

```
% gcc foo.c -o foo
```

This tells the Compiler to run the Preprocessor on the file `foo.c`, *compile* it and then *link* it to create an **executable** called `foo`.

The **–o** option states the <u>name</u> of the *output* binary **executable** file

foo.exe on Windows

# Compiling C Programs

- 4 kinds of files to work with
- The Preprocessor
- The Compiler
- **The Linker**

# Compiling C Programs – The Linker

- It links together **object** files (.o files) into a binary **executable**.
- It is a separate program called `ld`.
- It is invoked *automatically* when using the **Compiler**.
- The normal way of using the linker is as follows:

```
% gcc foo.o bar.o baz.o -o myprogram
```

This tells the compiler to link together 3 **object** files (`foo.o`, `bar.o` and `baz.o`) into a binary **executable** file named `myprogram`.

```
% gcc foo.c
```
→ a.out

compile & link to generate standard app

Effectively is equivalent to

```
% gcc -c foo.c
```
→ foo.o

generate object file

```
% gcc foo.o
```
→ a.out

link object file

```
% gcc foo.c -o foo
```
→ foo

compile and link to create named app

Effectively is equivalent to

```
% gcc -c foo.c
```
→ foo.o

generate object file

```
% gcc foo.o -o foo
```
→ foo

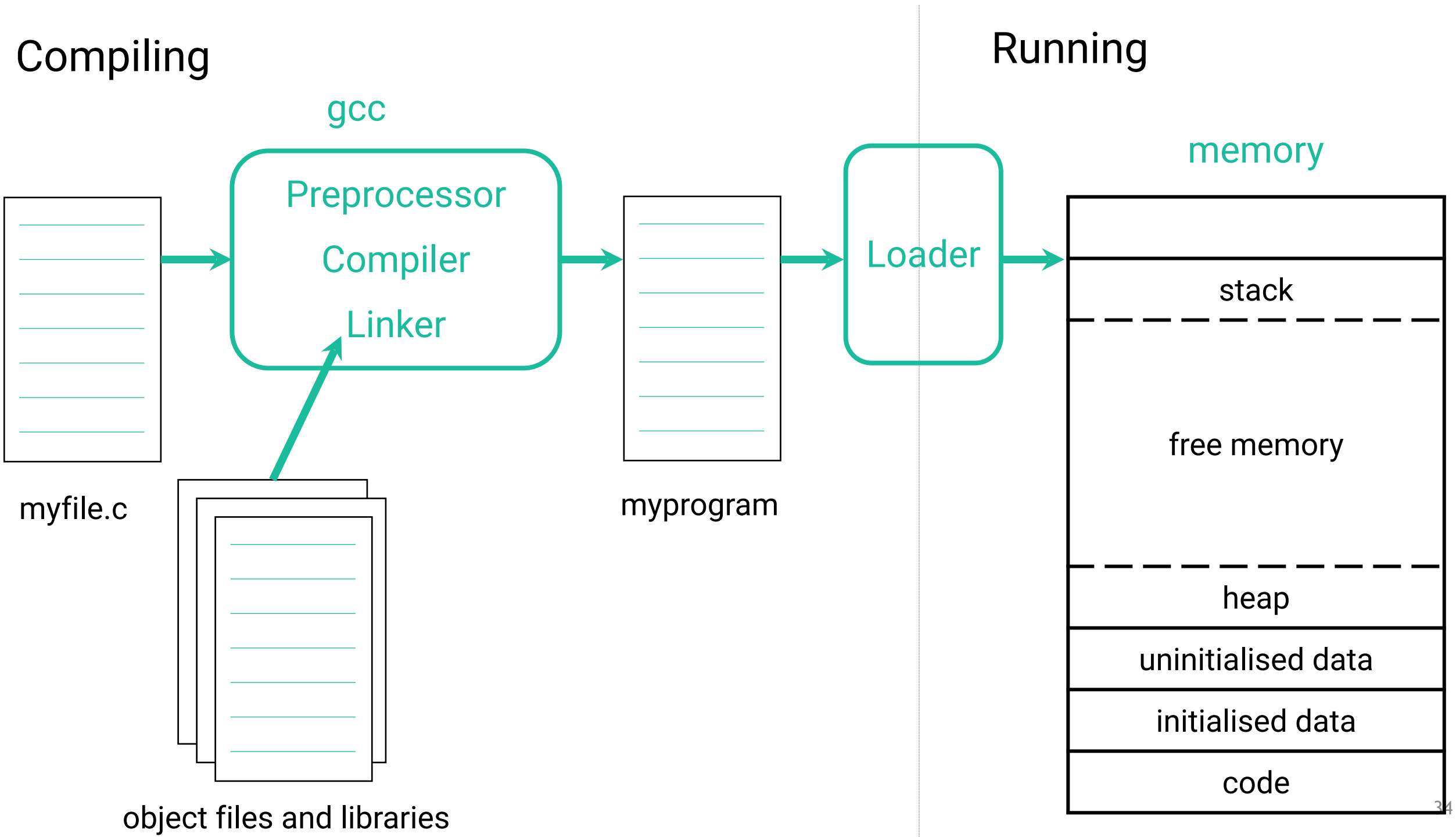
link object file

Remember: on Windows, executable programs have file names ending in .exe

Now you have a file called `myprogram` that you can **run**

and which will hopefully do something cool and/or useful.

```
% ./myprogram
```


Compiling
Running
gcc
Preprocessor
Compiler
Linker
myfile.c
object files and libraries
myprogram
Loader
memory
stack
free memory
heap
uninitialised data
initialised data
code

# C Language Basics

```c
#include <stdio.h>

int main(void)

{

    printf("Hello, World!\n");

    return 0;

}
```

- The main ( ) function
- Statements
- C Skeleton
- Identifiers
- Keywords
- Basic data variables and types
- Constants

# The `main()` Function

- Identify the start of the program
- Every C program has a `main()`
- “main” is a *C* ***keyword***. We **must not** use it for any other variable.
- Good programming practice tells us that we should not ourselves call Main() in our code.

# Statements

- “A specification of an action to be taken by the machine as the program executes.”
- Each statement in C needs to be terminated with semicolon (`;`).

# Statements

- A specification of an action to be taken by the machine as the program executes.
- Each statement in C needs to be terminated with semicolon (`;`).

```
#include <stdio.h>
int main(void)
{
    printf("Hello, World!\n");
    return 0;
}
```

a statement

another statement

# C Program Skeleton

In short, the basic skeleton of a C program looks like this:

```
#include <stdio.h>

int main(void)

{

    printf("Hello, World!\n");

    return 0;

}
```

# C Program Skeleton

In short, the basic skeleton of a C program looks like this:

```
#include <stdio.h>

int main(void)

{

    printf("Hello, World!\n");

    return 0;

}
```

preprocessor directives

function main

start of block

statement(s)

end of block

# Identifiers

Words used to represent certain program entities

(variables, function names, etc.)

E.g.,

- `int my_int;`
  - `my_int` is an identifier used as a program variable.
- `Void CalculateArea (int radius)`
  - `CalculateArea` is an identifier used as a function name

# Identifiers

Rules for naming identifiers:

| **Rule** | **Example** |
|---|---|
| Can contain a mix of characters and numbers | W3c |
| Cannot start with a number | 2assignments |
| Must start with a letter or underscore | Number1 _area |
| Can be of mixed cases | whoAmI |
| Cannot contain any arithmetic operators | Sm*il |
| Cannot be any other punctuation marks (separators) | !@#$%^&*(){} |
| Cannot be a C **keyword/reserved** word | main printf |
| Cannot contain a space | Oh yay |
| Identifiers are case sensitive | Happy ≠ happy |

# Keywords

These are reserved words in C. They may not be used as constants or variables or any other identifier names.

| | | | |
|---|---|---|---|
| auto | else | long | switch |
| break | enum | register | typedef |
| case | extern | return | union |
| char | float | short | unsigned |
| const | for | signed | void |
| continue | goto | sizeof | volatile |
| default | if | static | while |
| do | int | struct | _Packed |
| double | | | |

# Basic Data Variables and Types

- All data in C has to have a specified type
- C has several types of variables, but there are a few basic types:
  - Integers
  - Unsigned integers
  - Floating point numbers
  - Chars
- Variables hold data of a particular type only
- Variables must be declared before use

# Integers

Whole numbers which can be both ***positive*** and ***negative***.

Defined using:

- `char`
- `int`
- `short`
- `long`
- `long long`

## Examples 1a & 1b

```c
#include <stdio.h>
int main(void)
{
    int i, j = 1;
    printf("%d %d", i, j);
    return 0;
}
```

```
50289792 1
```

```c
#include <stdio.h>
int main(void)
{
    int i = 1, j = 1;
    printf("%d %d", i, j);
    return 0;
}
```

```
1 1
```

# Unsigned integers

Whole numbers which can only be ***positive***.

Defined using:

- `unsigned char`
- `unsigned int`
- `unsigned short`
- `unsigned long`
- `unsigned long long`

# Floating point numbers

Real numbers (numbers with a decimal part)

Defined using:

- `float`
- `double`

# Chars

Equivalent to ‘letters’ in English.

Examples:

- Numeric digits: 0 – 9
- Letters: a – z and A – Z
- Space (blank)
- Special characters: !@£$%^&*()

Single character

e.g., `char my_letter = 'E';`

***(the declared character must be enclosed within single quotes!)***

# Constants

- Entities that appear in the program code as fixed values.
- Any attempt to modify a CONSTANT will result in error.
- There are 4 types of constants:
  - Integer constants, e.g., `const int MAX_NUM = 9999;`
  - Floating point constants, e.g., `const double VAL = 1.23e4;` ($1.23 \times 10^4$)
  - Character constants, e.g., `const char letter = 'l';`
  - Enumeration, e.g., `enum City { Manchester, Liverpool, Leeds };`
- **The other way to define "constants is to use"** `#define`

# Constants

## Example 1

```
#include <stdio.h>
int main(void)
{
    int i = 1;
    const int x = 2;
    i = 3;
    x = 4;
    printf("i = %d\nx = %d", i, x);
    return 0;
}
```

This generates an error

## Example 2

```
#include <stdio.h>
#define PI 3.14
int main(void)
{
    int r = 2, area ;
    printf("The radius of circle is %d.\n",r) ;
    area = PI * (r * r) ;
    printf("Area of the circle = %d.\n", area) ;
    return 0;
}
```

Define a constant using `#define` preprocessor directive

# Summary

# Today

- Compiling C Programs
  - 4 kinds of files to work with: **source code** files, **header** files, **object** files, and binary **executables**
  - The Preprocessor -> `#define`, `#include`
  - The Compiler -> `% gcc foo.c –o foo`
  - The Linker -> `% gcc foo.o bar.o baz.o -o myprogram`

Today

- C Language Basics
  - The `main()` function ( returns an int result - usually 0 )
  - C Program Skeleton -> segments
  - Identifiers -> naming variables, functions, etc.
  - Keywords -> reserved words, may not be used as identifier names
  - Basic Data Variables and Types
    - Integers, unsigned integers, floating point numbers, chars
  - Constants (fixed values) -> `const int x = 2;` `#define PI 3.14;`

# Next

- C Language Basics
  - …
  - Basic I/O
  - Operators
  - Decision Making