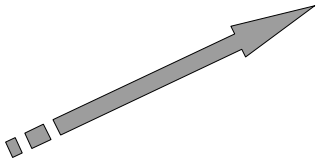
Lecture 4



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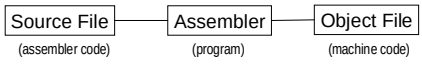
Machine Code

- As we have seen, programs exist as binary machine code. This is inconvenient for humans as we can not naturally interpret the code.
- To overcome this, assembly language was invented, e.g.

```
LDA 1BC9    - load accumulator from address 1BC9
ADD 05      - add 5 to accumulator
STA 1AF7    - store the result at address 1AF7
```

- This is translated more or less directly into machine code by a program called an assembler

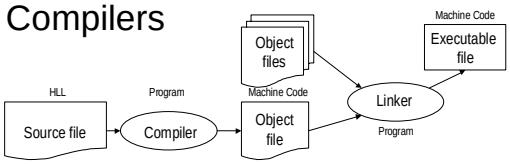
Assembler



- For complex programs we need a greater level of abstraction which is offered by high level languages such as c

e.g.
```
x=newWindow(200,300,x_pos,y_pos);
y=1+sin(theta)-cos(phi)/2;
```

Compilers



- A compiler is used to convert the HLL source code into an object file, which is then possibly combined with others to produce an executable program.
- Other object files can come from other programmers, libraries (e.g. maths, graphics), assembler or other HLLs

Errors

- Several types of error can occur when developing programs. *They are all introduced by the programmer, not the computer!*
  - Compile time errors (reported by the compiler)
    a) Syntax errors, e.g. missing semicolon at end of statement
    b) Semantic errors, e.g. forgetting to #include <stdio.h>, then using printf (which therefore doesn't mean anything)
  - Run time errors
    the program compiles ok but crashes when it is ran, e.g. z=x/y; where y=0
  - Algorithmic errors
    the program compiles and runs ok, but doesn't do what is intended.

Anatomy of a Simple C Program

```
/* Example: anatomy of a simple C program. */

/* It's useful to put comments in your programs to explain
what you're doing. Not too few, not too many: one helpful
comment every 10 to 20 lines of code is probably about
right. This program has far too many! */

/* Note: C doesn't allow nested comments: you can't put one
comment inside another! */

#include <stdio.h>
/* This is a preprocessor directive.
Most C programs need to include the standard header file
<stdio.h> which tells the compiler about input and output facilities,
it declares the function printf, for formatted printing. */

#define ANSWER 42
/* This is another preprocessor directive.
The symbol ANSWER will be replaced by 42. It's useful for
defining constants. */

int a, b;
/* Declared outside any function, these are external
(global) variables, accessible to all functions in this
file. There are good reasons for minimising the use of
globals! */

int mult_and_print(float f, float g);
void add(void);
/* Function prototypes. Their actual definitions follow
main. */

main()
{
  /* This is a function definition. Every C program needs a
     main function, where execution starts. */

  float x, y = 13.7;
  /* Declaring two local variables, visible only within the
     main function */
```

Anatomy of a Simple C Program cont……

```
    x = y * ANSWER + a;  /* This is a statement */

    add();
    b = mult_and_print(x, y);  /* These are function calls */

    return;  /* End of the main function */
}

void add(void)  /* Definition of a function */
{
    a = a + b;
    return;
}

int mult_and_print(float f, float g)
/* definition of a function */
{
    int r;  /* Declaring a local variable */

    r = (int) (f * g);  /* A statement */

    printf("Yesterday I saw %i penguins!\n", r);
    /* A function call; the prototype for printf is in
    <stdio.h> */

    return r;  /* Returning a value to the calling
                  function */
}
```

Simple Data types in C

- C has only a few simple data types:
  - Integer types
    `int, short, long`
  - Floating point types:
    `float, double, long double`
  - Character types
    `char`
- The integer and character types can be either signed or unsigned
- NB. C does not define how many bytes each type uses. The compiler does !!!

Integers

- Consider an `unsigned int` variable. Suppose the compiler uses 2 bytes for this data type.
  It can vary from 0000 to FFFF (hex), i.e. 0 to 65535 (decimal)

  e.g.
  ```
  unsigned int x=65535;
  x=x+1;
  ```
- Whats the value of x now ?
  Its 0000 (hex) - overflow has occurred.

One and Two'2 Complement

- Negative integers are stored in a form known as one and two's complement
- Standard Binary number

128	64	32	16	8	4	2	1
0	0	0	0	1	0	0	1 = 9

- One's Complement, Invert the number

-127	64	32	16	8	4	2	1
1	1	1	1	0	1	1	0 = -9

- Two's Complement, Invert the number and add 1

-128	64	32	16	8	4	2	1
1	1	1	1	0	1	1	1 = -9

Two'2 Complement

- So when overflow occurs +127+1 gives??
- 127=

-128	64	32	16	8	4	2	1
0	1	1	1	1	1	1	1 = 127

- +1

-128	64	32	16	8	4	2	1
1	0	0	0	0	0	0	0 = -128

overflow.c

```
/* Example: demonstrates overflow
of integer variables */

/* Don't worry about how the program works, just
appreciate what happens! */

#include <stdio.h>
#include <limits.h>

void main(void)
{
    unsigned int x = UINT_MAX - 1;
    signed int y = INT_MAX - 1;

    printf("x is an unsigned int, occupying %i bytes.\n\n", sizeof(x));

    printf("The initial value of x is %u\n", x);
    x++;
    printf("Add 1; the new value of x is %u\n", x);
    x++;
    printf("Add 1; the new value of x is %u\n", x);
    x++;
    printf("Add 1; the new value of x is %u\n", x);

    printf("\ny is a signed int, occupying %i bytes.\n\n", sizeof(y));

    printf("The initial value of y is %i\n", y);
    y++;
    printf("Add 1; the new value of y is %i\n", y);
    y++;
    printf("Add 1; the new value of y is %i\n", y);
    y++;
    printf("Add 1; the new value of y is %i\n", y);

    return;
}
```

```
x is an unsigned int, occupying 4 bytes.

The initial value of x is 4294967294
Add 1; the new value of x is 4294967295
Add 1; the new value of x is 0
Add 1; the new value of x is 1

y is a signed int, occupying 4 bytes.

The initial value of y is 2147483646
Add 1; the new value of y is 2147483647
Add 1; the new value of y is -2147483648
Add 1; the new value of y is -2147483647
```

sizes.c

```
/* Example, compile and run this program to find out how your C compiler
treats different data types. The result will depend on the computer and
compiler you use, and possibly on the compiler settings.

*/
#include <stdio.h>
#include <limits.h>
#include <float.h>

void main(void)
{
  puts("With this computer and compiler, the simple C");
  puts("data types have the following characteristics:\n");

  puts("signed char:");
  printf("\tOccupies %i byte (%i bits)\n", sizeof(signed char), CHAR_BIT);
  printf("\tRanges from %i to %i\n\n", CHAR_MIN, CHAR_MAX);

  puts("unsigned char:");
  printf("\tOccupies %i bytes (%i bits)\n", sizeof(unsigned char), CHAR_BIT);
  printf("\tRanges from %i to %i\n\n", 0, UCHAR_MAX);

  puts("signed short:");
  printf("\tOccupies %i bytes\n", sizeof(signed short));
  printf("\tRanges from %i to %i\n\n", SHRT_MIN, SHRT_MAX);

  puts("unsigned short:");
  printf("\tOccupies %i bytes\n", sizeof(unsigned short));
  printf("\tRanges from %i to %i\n\n", 0, USHRT_MAX);

  puts("signed int:");
  printf("\tOccupies %i bytes\n", sizeof(signed int));
  printf("\tRanges from %i to %i\n\n", INT_MIN, INT_MAX);

  puts("unsigned int:");
  printf("\tOccupies %i bytes\n", sizeof(unsigned int));
  printf("\tRanges from %i to %u\n\n", 0, UINT_MAX);

  puts("signed long:");
  printf("\tOccupies %i bytes\n", sizeof(signed long));
  printf("\tRanges from %li to %li\n\n", LONG_MIN, LONG_MAX);

  puts("unsigned long:");
  printf("\tOccupies %i bytes\n", sizeof(unsigned long));
  printf("\tRanges from %i to %lu\n\n", 0, ULONG_MAX);

  puts("float:");
  printf("\tOccupies %i bytes\n", sizeof(float));
  printf("\tRanges from +/-(10e-1 to 10e1) approx.\n", FLT_MIN_10_EXP, FLT_MAX_10_EXP);
  printf("\tPrecision is %i decimal digits approx.\n\n", FLT_DIG);

  puts("double:");
  printf("\tOccupies %i bytes\n", sizeof(double));
  printf("\tRanges from +/-(10e-1 to 10e1) approx.\n", DBL_MIN_10_EXP, DBL_MAX_10_EXP);
  printf("\tPrecision is %i decimal digits approx.\n\n", DBL_DIG);

  puts("long double:");
  printf("\tOccupies %i bytes\n", sizeof(long double));
  printf("\tRanges from +/-(10e-1 to 10e1) approx.\n", LDBL_MIN_10_EXP, LDBL_MAX_10_EXP);
  printf("\tPrecision is %i decimal digits approx.\n\n", LDBL_DIG);

  puts("pointer:");
  printf("\tOccupies %i bytes\n", sizeof(void *));
  puts("");
  return;
}
```

```
With this computer and compiler, the simple C
data types have the following characteristics:

signed char:
        Occupies 1 byte (8 bits)
        Ranges from -128 to 127

unsigned char:
        Occupies 1 bytes (8 bits)
        Ranges from 0 to 255

signed short:
        Occupies 2 bytes
        Ranges from -32768 to 32767

unsigned short:
        Occupies 2 bytes
        Ranges from 0 to 65535

signed int:
        Occupies 4 bytes
        Ranges from -2147483648 to 2147483647

unsigned int:
        Occupies 4 bytes
        Ranges from 0 to 4294967295

signed long:
        Occupies 4 bytes
        Ranges from -2147483648 to 2147483647

unsigned long:
        Occupies 4 bytes
        Ranges from 0 to 4294967295

float:
        Occupies 4 bytes
        Ranges from +/-(1E-37 to 3E+38) approx.
        Precision is 6 decimal digits approx.

double:
        Occupies 8 bytes
        Ranges from +/-(1E-307 to 1E+308) approx.
        Precision is 15 decimal digits approx.

long double:
        Occupies 8 bytes
        Ranges from +/-(1E-307 to 1E+308) approx.
        Precision is 15 decimal digits approx.

pointer:
        Occupies 4 bytes
```

Integer types

- In the examples we used the `sizeof` keyword to determine how many bytes are used to store each type.

  `sizeof(unsigned int)` or `sizeof(x)`

  data type — variable
- The names `short` and `long` can be misleading, on in the last example `int` and `long` were the same size.

  `sizeof(short)` ≤ `sizeof(int)` ≤ `sizeof(long)`

Floating Point Numbers

- Numbers like 1234.567 can be expressed in "scientific notation" as 1.234567×10^3, or +.1234567 e+4

  mantissa — exponent
- We let the decimal point *float* to the LH end of the mantissa
  - Such as representation is called *floating point*
- We can use a similar method to generate a binary code, typically 4 bytes are used to store floating point N's
  - The majority of bits are used for the mantissa and a few for the exponent.
  - Both parts are stored as 2's complement
- The float type is often poor precision (6 sig figs) far worse than a calculator
  - C also has a *double* precision floating point type , `double`, which typically uses 8 bytes

Characters

- There is only one character type, `char`
- This is defined (in ANSI C) to be a single byte.
- Depending upon the context it can be treated as an integer, so there are signed and unsigned versions
  - `char` (-128 to +127) and
  - `unsigned char` (0 to 255)
- A char variable holds ASCII codes as well as some escape characters
  - `'\n'` = new line, `'\t'` = tab, `'\a'` = alert (beep), `'\0'` = null
- The `null` character has the code 0000000 (binary) and has a special role in strings.

Names rules

- If we wish to create a new variable, say a floating point variable called x, this is done by

  `float x;`
- However there are restrictions on the names that we can use.
  - Can only include letters, digits or underscores '_'
  - First character cannot be a digit
  - Upper and lower case are distinct (All upper used for #define)
  - Must not be the same as any of C's 32 keywords
    - `auto, break, case, char, const, continue, default, do, double, else, enum, extern, float, for, goto, if, int, long, register, return, short, signed, sizeof, static, struct, switch, typedef, union, unsigned, void, volatile, while`
  - Is is also sensible not to use other common C identifiers, e.g. printf

Declaring Variables

- In C, all variables must be declared before they can be used. Typical declarations :
  - `int i,j,k;`
  - `unsigned long very_big_thing=1000000;`
  - `char c;`
  - `char ch='a',NL='\n';`
  - `float x,y=4E-6,z=0.0015f;`
- Note that variables can be initialised (given a value) at their declaration, if desired.

Constants

- It makes sense to use symbols for constants, e.g. π instead of 3.14159…, to save typing, avoid errors and improve readability
- We could define a variable
  `float pi=3.14159;`
  but it is better C style to use a `#define`
  `#define PI 3.14159`
- This means that where ever "PI" appears in the program, the pre-processor substitutes "3.14159"
  - The pre-processor is a program that processes the source file just before the compiler proper starts
- Conventionally such constants are in CAPITALS

define.c

```
/* Example: constant definition using #define */

#include <stdio.h>

#define PI 3.142

/* To change this to a more accurate value,
(e.g. 3.14159265358979323846) throughout the program,
only one line needs to be edited.
*/

main()
{
  double r, c, ac, as, v;

  r = 5.678;
  printf("Radius = %f\n", r);

  c = 2.0 * PI * r;
  printf("Circle's circumference = %f\n", c);

  ac = PI * r * r;
  printf("Circle's area = %f\n", ac);

  as = 4.0 * PI * r * r;
  printf("Sphere's area = %f\n", as);

  v = 4.0/3.0 * PI * r * r * r;
  printf("Sphere's volume = %f\n", v);
}
```