COMP26120: Algorithms and Imperative Programming

Lecture 3:

Control flow

Information representation (part I)

Lecture outline

- Control flow
  - Sequencing;
  - Selection (if, nested if, chained if, switch);
  - Iteration (for loops, while and do while loops);
- Information representation
  - Introduction to memory and types;
  - Type conversion and casting;
  - Pointers;
  - Memory management and allocation;

Control flow
Sequencing

- Performing an activity frequently consists of a number of sub-activities, which need to be performed correctly and in a correct sequence.
- Dijkstra identified sequencing in computer programming as one of the three control constructs. An important feature of a sequence of instructions is that, for the same input parameters, the sequence will always yield the same result.
- Example:

```
#input <stdio.h>
main()
{
    scanf(…);
    fprintf(…);
    return 0;
}
```

Control flow
Selection

- The second control construct identified by Dijkstra is the selection.
- Example: If I wake up, I will go to the COMP26120 lecture, else I will stay in bed.

```
if <condition> then
   {do something}
else
   {do something else}
```

- Conditions are formed using relational operators. These compare two values and return a true/false answer which controls futher flow of execution.
- Some examples of relational operators include: < (less than), > (greater than), == (equal to), <= (less or equal), >= (greater or equal), and != (not equal to).

Control flow
Multiple selection

- If within the body of then or else branch another if statement(s) exist, we have a nested if structure.
- Example:

```
 if (condition) then
{
   if (condition) then
   { do something }
   else
   { do something else }
}
else
{ do this };
```

Control flow
Multiple selection

- A multiple choice construct can be created using multiple elseif constructs.
- Example:

```
if (condition1) then
   {do this 1}
else if (condition2) then
   {do this 2}
else if (condition3) then …
    …
else
    {do this n}
```

- Not recommended to have too many branches (affects the performance of execution).

Control flow
Multiple selection

- An cleaner and more effective alternative to the chained if … then … else … construct is available in many programming languages.
- In C this is a switch construct.
- Example:

```
  switch (integer expression)
  {
  case constant1:
     {do this 1};
  case constant2:
     {do this 2};
   …
   default:
      {do this default};
    }
```

Control flow
Iteration

- This makes the third form of program control (Dijkstra).
- It is used when a certain number of statements need to be repeated fixed or variable number of times (i.e. until a certain condition is satisfied).
- C has three different types of loops: for loop, while loop and do-while loop.

```
for (initialisation,exit criterion, update)
{ do this }
```

```
for (int i=0, i<10, i++) {printf('%3u',i);}
```

```
while (condition)
{ do this }
```

```
i=0;
while(i<10) {printf('%3u',i); i++}
```

```
do
{ this }
while (this condition is true);
```

```
i=0;
do
{printf('%3u',i); i++}
while (i<10);
```

Control flow
Recursion

- There is an alternative way to explicit loop constructs to execute repeatedly some part of the code. This method is based on functions that call themselves.
- Homework: Read on functions in C (important for program structuring !)

  http://moodle.cs.man.ac.uk/file.php/28/coursedata/c_cbt/program_structure/functions/step01.html
- In order to understand recursion, you must first understand recursion.
- Example: Fibonacci sequence $a_0 = 0,\ a_1 = 1,\ a_n = a_{n-1} + a_{n-2},\ n \geq 2$

```
 unsigned int fib(unsigned int n)
 {
 /* Base case 1: n = 0, so return 0 */
 if(n == 0)  return 0;
/* Base case 2: n = 1, so return 1 */
else if(n == 1)  return 1;
/* Recursive case: n >= 2, return the result of previous fib()s */
```

Control flow
Exiting the loop

- In some cases it is necessary to escape from the current block of code either completely, or to move directly to the next iteration within a loop.
- In the C language, the break statement to make an early exit from for, while, do...while loops.
- The continue statement, used in conjunction with for, while and do...while causes the next iteration of the loop to begin, skipping any remaining code within the loop.

```
main( )
{
   int num, i;
   printf("Enter a number");
   scanf("%d", &num); i = 2
   while (i < = num −1)
   {
      if (num%i = =  0)
      {
      printf("Not a prime number");
      break;
      }
}
```

```
main( )
{
   int i,j;
   for(i = 1; i< = 2; i++)
   {
     for(j=1; j<=2; j++)
     {
        if (i= =j) continue;
        printf("%d%d", i,j);
      }
    }
}
```

Information representation Memory and types

- Main memory consists of the physical and virtual memory available to the operating system.
- When a program is loaded into main memory, a sufficient space to hold the program instructions and program data is allocated.
- How much memory do we assign to the individual data variables in the program? The answer: introduce data types.
- Using data types allows to define the amount of memory needed to represent a data item.
- Another important reason for using data types is to allow the compiler checks of a program for consistency.

Information representation
Basic data types

- C provides a standard, minimal set of basic (primitive) data types. More complex data structures can be built up from these basic types.
- Integer types:
  - **char** ASCII character at least 8 bits, which is sufficient to store a single ASCII character.
  - **short** has at least 16 bits which provides a signed range of integers [-32768,32767].
  - **int** is a default integer, typically 32 bits long, supporting the range of numbers [-2 billion, +2 billion].
  - **long** Large integer, either 32 or 64 bites long (depending on a compiler).

Information representation Basic data types

- Floating point types.
  - **float** is a single precision floating point number of typical size 32 bits.
  - **double** is a double precision floating point number of typical size 64 bits.
  - **long double** is a possibly even bigger floating point number (compiler dependent).
  - Constants in the source code such as 3.14 are default to type **double** unless the are suffixed with an ‘f’ (**float**) or ‘l’ (**long double**).
  - Single precision (float) gives about 6 digits of precision and double about 15.
- Mathematical operators.
  - + Addition
  - — Subtraction
  - / Division
  - * Multiplication
  - % Remainder (mod)
- Unitary increment operators. They pre/post increment/decrement the variable.
  - ++ or — —

Information representation Basic data types

- Boolean type.
  - There is no Boolean type – use **int** and constants 0 and 1.
  - The value 0 is false, anything else is true. The operators evaluate left to right and stop as soon as the truth or falsity of the expression can be deduced (short cutting).
  - Boolean type is equipped with logical operations (! not (unary), && and || or).
- Bitwise operators.
  - C includes operators to manipulate information at the bit level. This is useful for writing low-level hardware or operating system code.
  - The user needs to check whether the bit manipulation code works correctly on a given architecture. The bitwise operations are typically used with unsigned types.
  - Bitwise operators are: ~ bitwise negation (unary), & bitwise and, | bitwise or,

    ^ bitwise exclusive or, >> right shift by right hand side (RHS) (divide by power of 2),

    << left shift by RHS (multiply by power of 2).

Information representation Variable definitions

- Every variable must be defined by its type prior to its first use.
- Examples:

```
short number;
char letter;
float fraction;
const double pi;
for(int=0; i<10; i++)
```

- In the above definitions the memory location of a prescribed size is allocated for a variable, but its value can be arbitrary.

```
short number=1;
char letter='n';
float fraction=100.2;
const double pi=3.1416;
```

Information representation
Type conversions

- When an expression contains the operators of different (but compatible) types, C may perform an *implicit type conversion*. This means it may treat the operand as though it were a type suitable for the operator.
- Example:

```
int lower (int c)
{
   if (c >= 'A' && c <= 'Z') return c + 'a' – 'A';
   else return c;
}
```

- The above function is correct, since chars are actually short integers (with the values -128 to 127).
- The implicit conversions of types in an expression should not lead to the loss of information:

```
int i= 123;
float f;
f= i;
```

Information representation
Type conversions and casting

- Example:

```
int x = 5;
int y = 6;
y + x;
```

```
short x = 5;
int y = 6;
y + x;
```

- The example on the right is a mixed expression.
- In this expression the value of x (a **short**) is converted to an **int**:
  1. x is copied into a register and converted into an **int** ;
  2. y is copied into a register ;
  3. The registers are added to give an **int** result
- Note that the value of x as stored in memory is **not** changed. Only the temporary copy is converted during the computation of the expression's value.

Information representation
Type conversions and casting

- The process of converting operands of an arithmetic expression to a different type in order to evaluate an expression is referred to as implicit conversion. The rules for determining the type of a mixed arithmetic expression are:

1. Operands of type **char** or **short** are converted to an **int**. (**unsigned char** or **unsigned short** is converted to **unsigned int)**.
2. If the expression is still of a mixed type, the operand of lower type is converted to that of the higher type operand according to:

$$\boxed{\text{int} < \text{unsigned} < \text{long} < \text{unsigned long} < \text{float} < \text{double}}$$

The result is always of the higher type.

Information representation
Type conversions and casting

- Implicit conversion occurs across assignment and in mixed arithmetic expressions.
- In addition to this, a programmer can state explicitly the type of a variable or value. This is known as casting or explicit conversion.
- Example: If ch is of type **char** then (int)ch will cast the value stored in ch as an **int**. Note that the value of ch in memory will still be a **char** and that only a copy is cast.
- Example: Casting of an expression:

```
(double)(6 * x +4.6)
(int)(f * 3.142)
```

- The casting operator is a unary operator, thus it has the same precedence as other unary operators.

Information representation
Assignment operators, conditional expressions

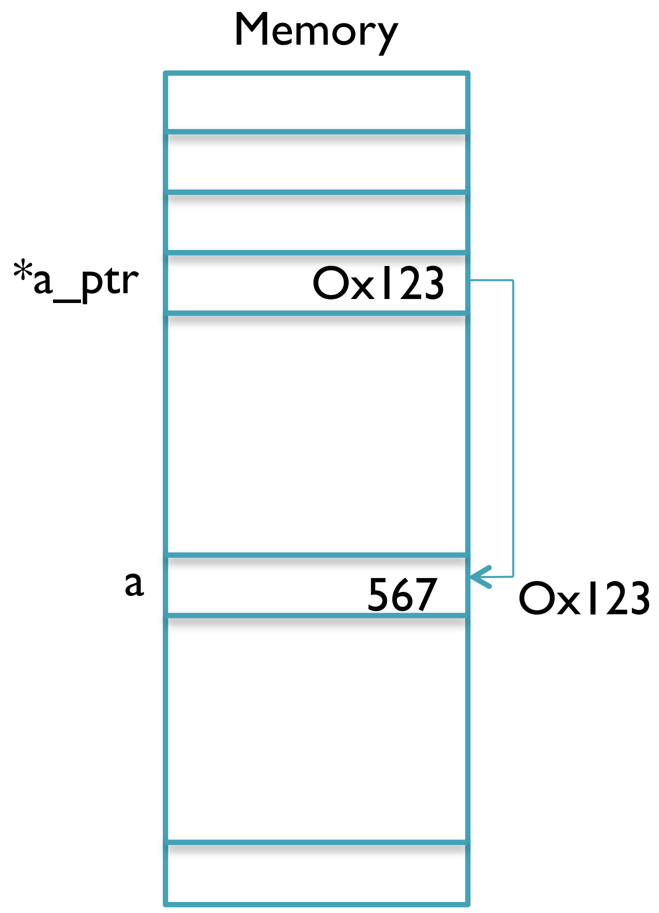
- Homework. Find the meaning of the following expressions (yes, they are all legal in C):
  - i%=5;
  - a = (b = (c = 5));
  - x = (a<b) ? a : b;

Information representation Pointers

- You have met these already in Java (and ARM –recall indirect addressing).
- Pointers need to be declared as any other variable:

```
int a;
int *a_ptr;
a=567;
a_ptr=&a;
```

- The operator & assigns the address to a pointer.

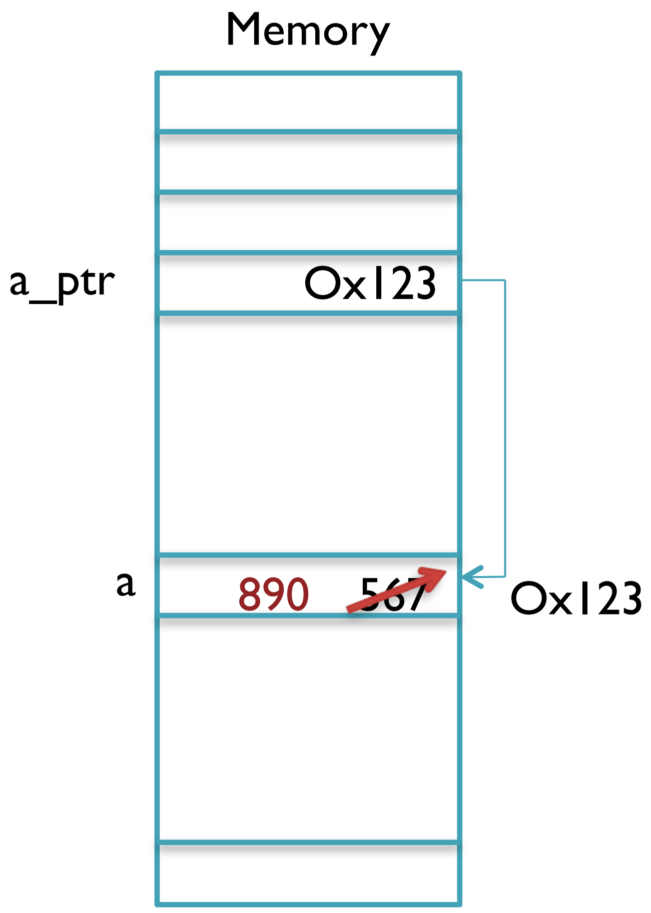


Information representation Pointers

- Using the address stored in a pointer is called dereferencing a pointer and is achieved by the operator *. When applied to a pointer variable, it access the data the pointer is referring to.

```
int a;
int *a_ptr;
a=567;
a_ptr=&a;
a=890; (alternatively *a_ptr=890)
```

- Notice that the value of a has changed to 890, but the value of the pointer a_ptr is still Ox123.

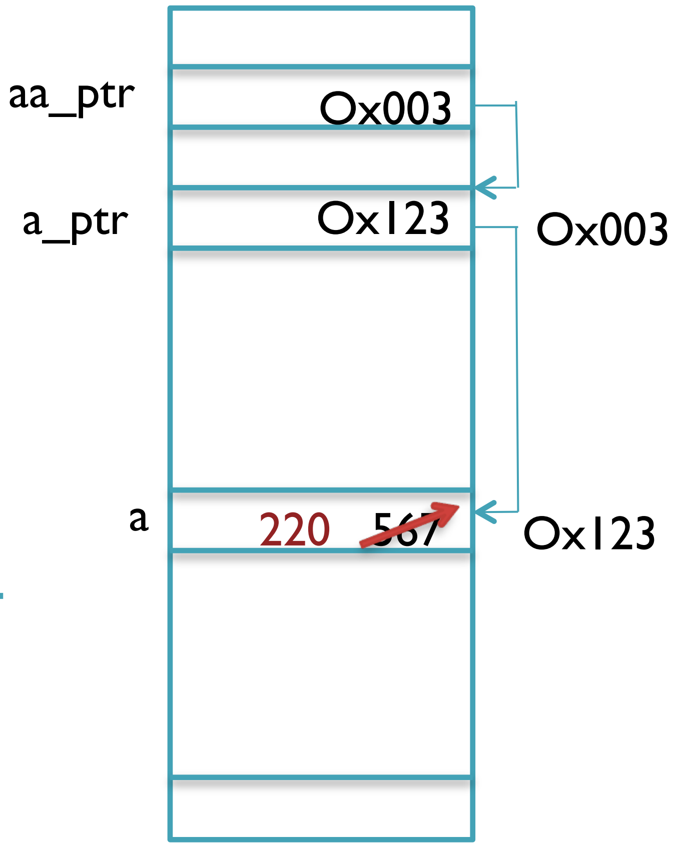


Information representation Pointers

- In C, a pointer can point to anything, even to another pointer, for example:

```
int a;
int *a_ptr = &a;
int **aa_ptr = &a_ptr;
**aa_ptr= 220;
```

- What is the value of *a_ptr and what is the value of **aa_ptr?



```
int i = 5, j = 6; k = 7;
int *ip1 = &i, *ip2 = &j, **ipp=&ip1;
*ipp=ip2;    (?)
*ipp=&k;     (?)
```

Information representation Pointers

- <u>Example</u>: Remember the scanf() function?

```
char c1;
char c2;
scanf("%c %c", &c1, &c2);
```

- Remember also that you need to read about the functions?
- The main purpose of functions is to structure the program. Functions are often passed some data to operate on and will often return data.
- In your tutorial you have had a question why do we need to pass the addresses to the char variables c1 and c2, rather than the variables themselves?

Information representation Pointers

- By sending the addresses to scanf we let the function “know” where to store the values it has scanned in, i.e. it needs to change the actual memory locations where these values are stored.
- We say that scanf reqires the arguments to be passed by reference, and thus it expects to be sent arguments of type pointer, which are addresses. This is achieved by using the & operator on n.
- We could have sent a pointer that contained the address of n instead, for example:

```
char c1;
char c2;
char *ptr_c1;
char *ptr_c2;
ptr_c1=&c1;
ptr_c2=&c2;
scanf(″%c %c″, ptr_c1, ptr_c2);
```

Information representation Pointers

- This is an instance of the problem of passing the arguments to a function by reference vs. passing them by value.
- If you use the address of a variable, you pass this variable by reference. This means that whenever one changes the variable within the function, this change will be registered in the memory.
- When passing a variable by value, a separate copy of this variable is created and whatever changes in the function are made to that copy will not affect the value of an original variable.
- In scanf() function we need to change the value of a variable itself, and hence we need to pass it by reference (i.e. pass its address).

Information representation Memory allocation

- Until now we know in advance the amount of memory that we need for each of the variables in a program. But, is this always the case? Think of an example…
- If not, how can we make the code to allocate/free the memory dynamically (on demand)?
- In C this can be achieved by the following functions:
  - **sizeof(type)** This function returns the type size (in bytes). Remember that the number of bytes for various types can be machine/compiler dependent.
  - **malloc(size)** This function allocates a storage of a certain size. It returns a pointer to this storage.
  - **free(pointer)** This function will free a part of memory previously allocated with **malloc**. The input argument is the pointer to the memory to free.

Information representation The sizeof() function

- Before a dynamical allocation of memory we need to know how much memory different types of data take up.
- The **sizeof()** function can perform this task.
- Example:

```
sizeof (int)
sizeof (char)
sizeof (double)
```

- The function returns an integer that represents the number of bytes used to store an object of that type.

Information representation The malloc() function

- The memory allocation is performed by the function **malloc()** (which means memory allocation).
- The argument of **malloc** is an integer argument which is the number of bytes of memory that we want. The memory is allocated from the heap and a pointer to that block of memory is returned.
- If there is insufficient storage in the heap, **malloc** returns **NULL**.
- The pointer returned when malloc is successful is 'untyped' (it is a pointer of type void *). It needs to be casted to a particular type before its use.
- Example:

```
char *new_memory;
int memory_size = 20 * sizeof(char);
new_memory = (char *)malloc(memory_size);
if(new_memory == NULL)
   printf("No memory allocated!\n");
else
   printf("Memory for 20 characters allocated\n");
```

- Homework: Extend this program to write 2 chars at the start of this block.

Information representation
The free() function

- Good programming practice is to free the allocated memory when we no longer need it (C does not have automatic garbage collection!).
- The argument of **free()** function is a pointer to the beginning of a block that you have been allocated using the **malloc** function. (need to be preserved between the calls to **malloc** and **free**, or make a copy of it).
- In the previous example `free(new_memory)` will release the allocated block.
- Homework: How would you free the memory after doing the homework from the previous slide?