Introduction to Programming and Computing for Scientists

Lecture 5

Programming in C++: control structures, functions, pointers, arrays, data structures

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Today's goals

You will learn

- to use `if` and `if...else` selection statements to choose among alternative actions
- to use `for, while` repetition statements to execute statements in a program repeatedly
- how to read and write to text files
- to use data structures to represent a set of data items
- to use C++ standard library class template `vector`
- how to access variables in computer memory
- to declare and use pointers

Control structures - `if`, `else`

```
if(condition) {
  statement;
}
else if(condition) {
  statement;
}
else {
  statement;
}
```

- `if` evaluates the condition. If it is true, the statement is executed.
- If it is false, the statement in the optional `else` clause is executed.
- `if` and `else` can be nested.

Control structures - `if`, `else`

```
if(condition) {
  statement;
}
else if(condition) {
  statement;
}
else {
  statement;
}
```

- `if` evaluates the condition. If it is true, the statement is executed.
- If it is false, the statement in the optional `else` clause is executed.
- `if` and `else` can be nested.

```
if(5 == 10) {
  std::cout << "This computer is insane" << std::endl;
}
else if(5 == 5) {
  std::cout << "Everything is fine" << std::endl;
}
else {
  std::cout << "This will never happen" << std::endl;
}
```

Control structures - `for`, `while`

```
for(initialization; condition; statement) {
  statement;
}

while(condition) {
  statement;
}
```

- The `for` and `while` loops execute statements while some condition is met. They are functionally equivalent.
- Use a `for` loop when you know how many iterations you want to do.
- Use a `while` loop when the number of iterations is unknown, for example if the stopping condition depends on user input.

Control structures - `for`, `while`

```
for(initialization; condition; statement) {
  statement;
}

while(condition) {
  statement;
}
```

- The `for` and `while` loops execute statements while some condition is met. They are functionally equivalent.
- Use a `for` loop when you know how many iterations you want to do.
- Use a `while` loop when the number of iterations is unknown, for example if the stopping condition depends on user input.

```
for(int i = 0; i < 10; i++) {
  std::cout << "i equals " << i << std::endl;
}

bool keepGoing = true;
while(keepGoing) {
  std::cout << "Still going!" << std::endl;
  keepGoing = readUserInput(); //This magical function returns true or false
}
```

Control structures - continue, break

- The continue statement is used in loops to skip directly to the next iteration. It works in both for and while loops.

```
for(int i = 0; i < 10; ++i) {
  if(i == 5) continue; //5 won't be printed
  std::cout << "i equals " << i << std::endl;
}
```

- The break statement is used to exit the loop entirely. It works in for and while loops as well as switch clauses (next slide).

```
while(true) {
  std::cout << "Still going!" << std::endl;
  if(readUserInput() != true) break;
}
```

Control structures - switch, do-while

- The `switch` clause can be used to replace many `if` statements.

```
switch(variable) {
  case 0:
  std::cout << "variable is 0" << std::endl;
  break;

  case 1:
  std::cout << "variable is 1" << std::endl;
  break;

  default:
  std::cout << "variable is neither 0 nor 1" << std::endl;
}
```

- The `do-while` loop works like a `while` loop, except the condition is checked at the end of the loop instead of the beginning.
- This guarantees that the statement will be executed at least once.

```
bool keepGoing = true;
do {
  std::cout << "Still going!" << std::endl;
  keepGoing = readUserInput(); //This magical function returns true or false
} while(keepGoing);
```

Exercise 1

Write a program that prints on the screen all the even numbers up to 10.

Namespaces

- A namespace is a place where variables, classes and functions live.
- They can share names as long as they live in different namespaces.
- Typing `std::` in front of all standard functions soon gets tiresome. The `using` keyword allows them to be used without a qualifier.
- If you use an entire namespace, beware of collisions (e.g `std::count` exists).

```
#include <iostream> //For cout

using std::cout; //Now we don't have to type std::cout. Just cout will do.
using namespace std; //Like the above but for everything in the std namespace

namespace first {
  int a = 10;
}

namespace second {
  int a = 20;
}

int main() {
  cout << first::a << endl; //Will print 10
  cout << second::a << endl; //Will print 20
  first::a = 30;
  std::cout << first::a << std::endl; //Will print 30. Using std:: still works.
  // std::cout << a << std::endl;  this would give an error: a is not declared
}
```

Exercise 2

Temperatures in rainy Lund were measured from Monday to Sunday. Write a C++ program that takes in the temperatures as a user input, and displays and calculates the average temperature of that week.

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Temperatures in rainy Lund were measured from Monday to Sunday. Write a C++ program that takes in the temperatures as a user input, and displays and calculates the average temperature of that week.

```
Set total temperature to zero
Set day counter to one

While day counter is less than or equal to seven
  Prompt the user to enter the next temperature
  Input the next temperature
  Add the temperature into the total temperature
  Add one to the day counter

Set the temperature average to the total temperature divided by seven
Print the temperature average
```

A word of warning

```
#include <iostream>

using namespace std;

int main()
{
  int loopCount;
  cout << "Enter loopCount: ";
  cin >> loopCount;
  while (loopCount > 0){
     cout << "Only " << loopCount << " loops to go!\n";
  }
  return 0;
}
```

- What is the problem in the example above?
- How would you fix it?

A word of warning

```
#include <iostream>

using namespace std;

int main()
{
  int loopCount;
  cout << "Enter loopCount: ";
  cin >> loopCount;
  while (loopCount > 0){
     cout << "Only " << loopCount << " loops to go!\n";
  }
  return 0;
}
```

- What is the problem in the example above?
- How would you fix it?

```
for (int i = 1; i <= loopCount; i++){
   cout << "We've finished " << i << " loops\n";
}
// or:
while (loopCount > 0){
   cout << "Only " << loopCount << " loops to go!\n";
   loopCount = loopCount - 1;
}
```

Details are important: `++i` vs `i++`

- `++i` is known as pre increment whereas `i++` is called post increment.

```
#include <iostream>
using namespace std;

int main(){

  // Loop 1: pre increment
  for(int i = 0; i < 5; ++i){
    cout << i; // 0 1 2 3 4
  }

  // Loop 2: post increment
  for (int j = 0; j < 5; j++){
    cout << j; // 0 1 2 3 4
  }

  //BUT:
  int k = 1, m;
  m = ++k; // increment m's value before the operation

  int x = 1, y;
  y = x++; // increment y's value after the operation
  cout << "\nm: " << m << " y: " << y << endl;  // m: 2 y: 1

}
```

I/O - Reading and writing files

- Reading and writing files is done using the `ifstream` and `ofstream` classes defined in the `fstream` library. The following program reads numbers from a file (input.txt) and prints the sum to another file (output.txt).

```
#include <iostream> //For cout
#include <fstream> //For ifstream and ofstream

int main() {
  std::ifstream inFile("input.txt"); //Name of the file to read from
  if(!inFile) {
    std::cout << "Error: could not read from file input.txt" << std::endl;
    return 1; //A nonzero return value indicates failure
  }
  double variable = 0.;
  double sum = 0.;
  while(inFile >> variable) { //Read numbers until we hit the end of file
    sum += variable;
  }
  inFile.close();

  std::ofstream outFile("output.txt");
  if(!outFile) {
    std::cout << "Error: could not write to file output.txt" << std::endl;
    return 1; //A nonzero return value indicates failure
  }
  outFile << sum << std::endl;
  outFile.close();
        return 0;
}
```

Strings

- A string is a sequence of characters, implemented by the `string` class.

```
#include <iostream> //For cout and cin
#include <string>
using namespace std;

int main() {
  string str("It's dangerous to go alone, take this!");
  size_t pos = str.find("take"); //Position in string where "take" is found

  cout << str.substr(0, 18) << str.substr(pos) << endl; // substring; (string substr(int pos = 0, int n =
      string::npos) const;)
  return 0; //It's dangerous to take this!
}
```

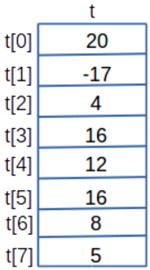
Reading out line by line using string

- For reading out lines of data from a file, you can use the `getline` function.

```
#include <iostream>
#include <fstream> //header file for file writing and reading
#include <string> //header file for strings

using namespace std;

int main () {

  fstream in;
  in.open("inputtext.txt"); //open an input file
  string s;

  cout<<"Line 1:"<<endl;
  getline(in,s); // read first line
  cout<<s<<endl;
  cout<<"Line 2:"<<endl;
  getline(in,s);// read second line
  cout<<s<<endl;

  in.close();
  return 0;
}
```

Containers. Arrays

- How to deal with a collection of data, such as a list of measurement values or a list of names?
- An array is a fixed-size sequential container.
- To refer to a particular location or element in the array, you can specify the name of the array and the position number of the particular element:
  `int t[8] = {20, -17, 4, 16, 12, 16, 8, 5};`
- Multidimensional arrays: `type name[size1][size2]...[sizeN];`
  → `int chessBoard[8][8]`



Containers. Arrays

- Try to avoid using arrays in C++. Use vectors instead (next slide). Comments to the code below contain possible pitfalls of using arrays.
- Arrays allocated on the heap are deleted with the `delete[]` operator.

```cpp
#include <iostream> //For cout and cin
using namespace std;

int main() {
  const int length = 10; //The length must be known at compile time
  int arr[length]; //This array is fixed-size
  int input;
  int pos = 0; //An array doesn’t know its own size or how many elements it contains
  while(cin >> input) {
    arr[pos] = input;
    if(pos == length) break; //Remember that the array can’t grow, so this is our limit
    ++pos; //We have to keep track of the position
  }
  for(int i = 0; i < pos; ++i) cout << arr[i] << endl; //Easy to go out of range
  return 0;
}
```

Vectors

- A `vector` is a sequential container that can change size dynamically.
- It is a *template class*. The `vector` type must be defined at compile time.
- Vectors are fast at element access and insertion/removal at the end.

```
#include <iostream> //For cout and cin
#include <vector>
using namespace std;

int main() {
  vector<int> vec; //Create a vector with base type int
  int input;
  while(cin >> input) vec.push_back(input); //Store each input
  for(size_t i = 0; i < vec.size(); ++i) cout << vec.at(i) << endl; //Print them back
  return 0;
}
```

Vectors

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#include <vector>
using namespace std;

int main() {
  vector<int> vec; //Create a vector with base type int
  int input;
  while(cin >> input) vec.push_back(input); //Store each input
  for(size_t i = 0; i < vec.size(); ++i) cout << vec.at(i) << endl; //Print them back
  return 0;
}
```

- Use `at` to access individual elements. It's also possible to use `[]`. **Try to avoid this!** There is no bounds checking at run time. Your bugs will go unnoticed.

```
vector<int> vec; //Create an empty vector
cout << vec[3] << endl; //Index is out of bounds. Your program will happily print garbage
cout << vec.at(3) << endl; //Using at produces an error at run time, exposing your bug
```

Vectors

Other `vector` member functions include for example

- `size`: Return size
- `front`: Access first element
- `back`: Access last element
- `push_back`: Add element at the end
- `pop_back`: Delete last element
- `clear`: Removes all elements from the vector leaving the container with a size of 0.
- `insert`: Insert new elements

More functions and examples:
`http://www.cplusplus.com/reference/vector/vector/`

Exercise 3: vectors

Write a simple program to manage a shopping list. Each item is a `string` stored in a `vector`. First, write a print function that prints out the contents of the shopping list. Test the print function with a `main()` that should do the following:

1. Create a vector `shoppingList` and add items "eggs," "milk," "sugar," "chocolate," and "flour". Print it using your print function.
2. Remove the last element from the vector. Print it.
3. Append the item "coffee" to the vector. Print it.
4. Print how many items you have on the list.

Pointers - motivation 1/3

- How variables are stored in computer's memory?

Pointers - motivation 1/3

- How variables are stored in computer's memory?
- Variables are stored in memory cells inside the computer's memory. Cells have unique addresses.
- When you refer to a variable by name in your code, the computer looks up the address that the variable name corresponds to, goes to that location in memory, and retrieves or sets the value it contains.
- The `&` (reference) operator gives you the address occupied by a variable.
- If `var` is a variable, then `&var` gives the address of that variable.

```
int variable = 3;
cout << &variable << endl; //0x7fff5fbff8a8
```

Pointers - motivation 2/3

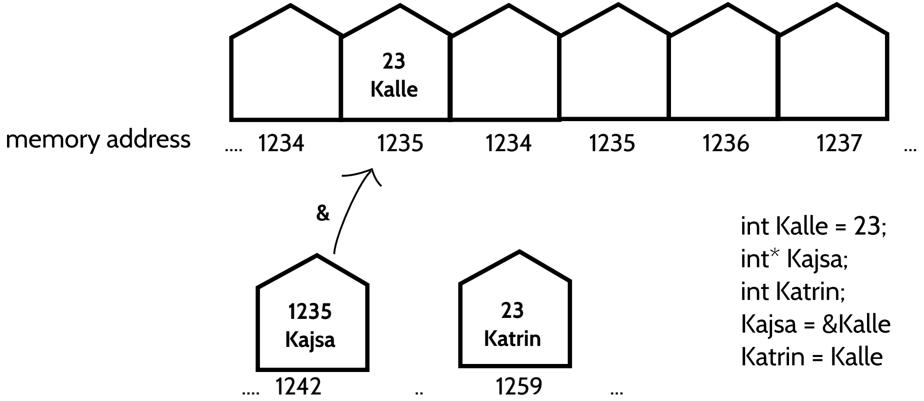
- We can manipulate the data in the computer's memory directly.
- You can assign and de-assign any space in the memory as you wish.
- This is done using *pointers*.
- Pointer = variable that points to a specific address in the memory

Pointers - motivation 3/3

- Manipulating the memory addresses of data can be faster and more efficient than manipulating the data itself.
- If you have a large data structure, and you pass it by value, the computer has to push a copy of it onto the stack. This wastes both time and stack-space!
- If you pass over only the address, you don't need to make a big copy and you only push an address onto the stack.
- Very common use case: a pointer to a resource (file, database, histogram...) that was made somewhere else by some other code, and you have to interact with it for a while
- Or a pointer to a resource that is shared between multiple objects: each object holds a pointer to the resource rather than always copying it.

Kalle's home street - very simplified example

- Example on whiteboard



```
int Kalle = 23;
int* Kajsa;
int Katrin;
Kajsa = &Kalle
Katrin = Kalle
```

Pointers in action

```
int number = 88;            // integer variable with a value
int *ptrNumber = &number;   // assign the address of variable number to pointer ptrNumber (0x22ccec)
cout << ptrNumber<< endl;   // print the content of the pointer, contains an address (0x22ccec)
cout << *ptrNumber << endl; // print the value "pointed to" by the pointer, which is an int (88)
*ptrNumber = 99;            // assign a value to where the pointer is pointed to, NOT to the ptr variable
cout << *ptrNumber << endl; // print the new value "pointed to" by the pointer (99)
cout << number << endl;     // the value of variable number changes as well (99)
```

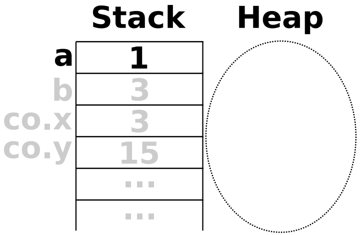
The stack and the heap

- The memory available for a program to use (at least as far as we're concerned) is made up of two areas - The stack and the heap.
- The stack is a small (megabytes), fixed size chunk of memory for local variables. All examples so far have used only the stack.
- When a variable on the stack falls out of scope, it is deallocated. You don't have to worry about memory management with the stack.
- The stack is small, so it overflows if you put too many things on it. But don't worry - This typically only happens due to bugs (e.g an infinite loop).

```
#include "coords.h"

void makeCoordinates(int b) {
  coords co(b, b*5);
}

int main() {
  int a = 1;
  makeCoordinates(a + 2);
  //Grayed out variables have now been deallocated
  return 0;
}
```



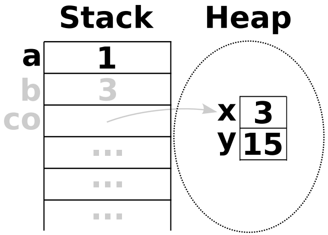
The stack and the heap

- The heap is a large pool of memory that can grow dynamically.
- To put a variable on the heap, create it with the `new` operator. This operator returns a *pointer* through which the variable is accessed.
- A pointer is really just an integer. The number corresponds to a memory address. The pointer *points* to that memory.
- Variables on the heap are never deallocated automatically. The memory must be freed manually using the `delete` operator.
- The pointer itself is on the stack and is deallocated automatically.

```
#include "coords.h"

void makeCoordinates(int b) {
  coords* co = new coords(b, b*5);
}

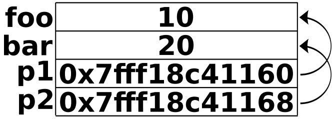
int main() {
  int a = 1;
  makeCoordinates(a + 2);
  //Grayed out variables have now been deallocated
  return 0;
}
```



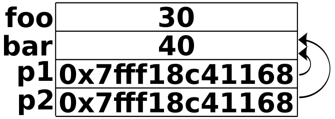
Pointers and references

- A pointer can point anywhere in memory, both the stack and the heap.
- To declare that a variable is a pointer, put an asterisk (∗) after its type.
- To get the memory address of a variable, use the reference operator (&).
- If you have a pointer and you want the value that the pointer points to, use the dereference operator (∗). That's right - The asterisk has *two* uses!

```
int foo = 10; //Two regular variables
int bar = 20;
int* p1; //Two pointers to int
int* p2;
p1 = &foo; //p1 points to foo
p2 = &bar; //p2 points to bar
```



```
*p2 = 30; //bar = 30
*p1 = *p2; //foo = bar
p1 = p2; //p1 now points to bar
*p1 = 40; //bar = 40
```



- To access members of a class via pointer, use the arrow (->) operator.

```
betterCoords a(1, 1); //Regular object
a.SetCartesian(2, 2); //Access with dot
betterCoords* b = new betterCoords(1, 1); //Pointer to object
b->SetCartesian(2, 2); //Access with arrow. This is the same as (*b).SetCartesian(2, 2)
```

Pass by value, reference or pointer

- When calling a function, you are really passing *copies* of all the arguments.
- If you want to change the passed values, you must use references or pointers.

```
int x = 1;
int y = 2;

void swapByValue(x, y); //This will NOT swap the values!
void swapByReference(x, y); //This will work. Using references is recommended.
void swapByPointer(&x, &y); //This will work, but don't use pointers unless necessary.
```

```
void swapByValue(int a, int b) { //a and b are copies of x and y
  int temp = a; //Whatever we do here has no effect on the original x and y
  a = b;
  b = temp;
}
```

```
void swapByReference(int& a, int& b) { //a and b are references to x and y
  int temp = a; //For all intents and purposes, they ARE x and y
  a = b;
  b = temp;
}
```

```
void swapByPointer(int* a, int* b) { //a and b are pointers to x and y
  int temp = *a; //Not safe - What if they are NULL pointers? Use references instead.
  *a = *b;
  *b = temp;
}
```

Exercise 5: basic pointer manipulations

What are the outputs of the following program?

```
#include <iostream>
using namespace std;
int main( )
{
  int *p1, *p2;
  p1 = new int;
  *p1 = 42;
  p2 = p1;
  cout << "*p1 == " << *p1 << endl;
  cout << "*p2 == " << *p2 << endl;
  *p2 = 20;
  cout << "*p1 == " << *p1 << endl;
  cout << "*p2 == " << *p2 << endl;
  p1 = new int;
  *p1 = 100;
  cout << "*p1 == " << *p1 << endl;
  cout << "*p2 == " << *p2 << endl;
  return 0;
}
```

Exercise 5: basic pointer manipulations

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using namespace std;
int main( )
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  int *p1, *p2;
  p1 = new int;
  *p1 = 42;
  p2 = p1;
  cout << "*p1 == " << *p1 << endl;
  cout << "*p2 == " << *p2 << endl;
  *p2 = 20;
  cout << "*p1 == " << *p1 << endl;
  cout << "*p2 == " << *p2 << endl;
  p1 = new int;
  *p1 = 100;
  cout << "*p1 == " << *p1 << endl;
  cout << "*p2 == " << *p2 << endl;
  return 0;
}
```

```
*p1 == 42
*p2 == 42
*p1 == 20
*p2 == 20
*p1 == 100
*p2 == 20
```

Summary

- Control structures: `if-else`, `for`, `while`, `continue`, `break`, `switch`, `do-while`
- Containers: arrays and vectors
- Stack and heap
- Pointers

Next Lecture

- Classes
- Inheritance
- Polymorphism
- The `const` keyword
- Type Casting
- Operator overloading
- Templates

Command line parameters

```cpp
#include <iostream> //For cout

int main(int argc, char* argv[]) {
  std::cout << "Received " << argc << " parameters:" << std::endl;
  for(int i = 0; i < argc; ++i) {
    std::cout << argv[i] << std::endl;
  }
  return 0;
}
```

- You can pass parameters to a program via command line. They arrive as C-strings contained within an array.
- The first parameter is always the name of the program. Let's say, for the sake of example, that it's called 'commandLineParams'.
- Here is what it would look like if built and run from a terminal.

```
$ g++ -o commandLineParams commandLineParams.cpp
$ ./commandLineParams abc 123 -bla --bla
Received 5 parameters
./commandLineParams
abc
123
-bla
--bla
```

Lists, Pairs

- A `list` is a container with fast element insertion and removal.
- Unlike vectors, elements in a `list` have no absolute position. Use an `iterator` to loop through them. Iterators act similarly to pointers.

```
#include <iostream> //For cout and cin
#include <list>
using namespace std;

int main() {
  list<int> lst; //List with base type int
  lst.push_back(10); //Insert some elements, then iterate over the list and print them
  lst.push_back(15);
  for(list<int>::iterator it = lst.begin(); it != lst.end(); ++it) cout << *it << endl;
  return 0;
}
```

- A `pair` is a simple container that stores two values.

```
#include <iostream> //For cout and cin
#include <utility> //For pair
using namespace std;

int main() {
  pair<int, double> p(5, 3.14); //A pair of int and double
  cout << "The pair is " << p.first ", " << p.second << endl;
  return 0;
}
```

Sets

- A set is a container that stores unique objects. If a set already contains a certain element, adding that element again does nothing. Sets are ordered.
- Adding/removing elements takes logarithmic time, which is relatively slow.
- Searching also takes logarithmic time - This is as fast as a search can get!

```
#include <iostream> //For cout and cin
#include <set>
using namespace std;

int main() {
  set<int> s; //Set with base type int
  s.insert(7); //Add some elements. The order in which they are added doesn't matter.
  s.insert(1);
  s.insert(5);
  for(set<int>::iterator it = s.begin(); it != s.end(); ++it) { //Traverse with iterator
    cout << *it << endl; //Prints 1, 5, 7
  }
  if(s.count(8)) cout << "The set contains the number 8" << endl; //Search in the set
  return 0;
}
```

Maps

- A `map` is an associative container that stores key/value pairs. A key can not be inserted twice, but the value of an existing key can be changed.

```cpp
#include <iostream> //For cout and cin
#include <string>
#include <map>
#include <utility> //For make_pair
using namespace std;

int main() {
  map<string, int> pBook; //Map associating strings to ints. It's a phone book!
  pBook.insert(make_pair("Reginald", 123)); //Pairs can be inserted in various ways
  pBook.insert(pair<string, int>("Marmaduke", 456));
  pBook["Bobby Floyd"] = 789;

  map<string, int>::iterator it = pBook.find("Bruce Lee"); //How to search a map
  if(it != pBook.end()) cout << it->first << "has number " << it->second << endl;
  pBook["Reginald"] = pBook["Jim Bob"]; //Beware of using [] - Jim Bob is now in the book

  for(map<string, int>::iterator it2 = pBook.begin(); it2 != pBook.end(); ++it2) {
    cout << it2->first << " - " << it2->second << endl; //Print everyone in the book
  }
  return 0;
}
```

```
Bobby Floyd - 789
Jim Bob - 0
Marmaduke - 456
Reginald - 0
```