CH08-320143

Programming in C++ II

C++ II

Lecture 1 & 2

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Who am I?

- PhD in Computer Science at the Carl von Ossietzky University of Oldenburg
- University lecturer at the Department of Computer Science
- Joined Jacobs University in January 2013
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Course Goals

- Learn more advanced aspects of object-oriented programming
- Learn advanced details of the C++ programming language
- Write, test, debug programs
- "Hands on": not just theory, but practice lab sessions to apply what you have learned in the lectures

Course Details

- 3 weeks = 24 hours
- Every week will consist of
  - 2 lectures: Thu/Fri afternoon, 14:15 – 16:15
  - 2 lab sessions: Thu/Fri afternoon, 16:15 – 18:30
- During each lab session you will have to solve a programming assignment sheet (consisting of multiple exercises) related to the corresponding lecture

Course Resources

Textbooks:

- Frank B. Brokken, C++ Annotations Version 10.7.2 `http://www.icce.rug.nl/documents/cplusplus/`
- Bruce Eckel, Thinking in C++: Introduction to Standard C++, second edition, volume 1, Prentice Hall, 2000
- Bruce Eckel, Chuck Allison: Thinking in C++: Practical Programming, volume 2, Prentice Hall, 2004

Slides, program assignments, and code will be posted on Grader

- `https://grader.eecs.jacobs-university.de/courses/320143/2019_1r3/`

Grading Policy

- 35% – average grade of the assignments
- 65% – grade of the final exam
- In the (written) final exam you will be asked to solve exercises similar to ones in the assignments.
- The final exam will take place at the end of the semester

Programming Assignments

- There will be presence assignments that need to be solved in the lab
- Other assignments are due on the following Tuesday and Wednesday morning at 10:00
- Solutions have to be submitted via web interface to `https://grader.eecs.jacobs-university.de`
- Assignments are graded by the TAs
- Grading criteria `https://grader.eecs.jacobs-university.de/courses/320143/2019_1r3/Grading-Criteria-C++.pdf`

Lab Sessions

- TAs will be available to help you in case of problems
- Solve the assignments during lab sessions
- Do not copy the solutions for the assignments, you will certainly fail the written final exam without practice in programming

Syllabus of the Course

- More on Overloading
- Streams
- Multiple Inheritance
- Templates: Functions, Classes
- Standard Template Library (STL): Containers, Algorithms, Iterators
- Features of C++11
- Exception Handling
- Debugging Techniques
- Memory Leaks
- Unit Testing and Makefiles

Programming Environment (1)

- C++ is available on practically every operating system
- Commercial
  - Microsoft C++, Intel C++, Portland
- As well as free compilers available
  - g++
- g++ available on many platforms
- g++ `6.3.0` is used on Grader

Programming Environment (2)

- We will refer to the Unix operating system and related GNU tools (`g++`, `gdb`, some editor, IDE, etc.)
- Install a C++ compiler on your notebook
- IDE (Integrated Development Environment) may be helpful
- CodeLite `http://www.codelite.org/`
  - powerful IDE
  - runs on Linux, Mac, Windows

Programming Environment (3)

- Linux
  - preferred environment
  - prepare to get to know Unix/Linux
  - g++ should be already on your machine
  - you can install CodeLite from http://codelite.org/LiteEditor/Repositories
  - any other IDE or editor is also fine

Programming Environment (4)

- Mac OS
  - it is a Unix system as well
  - XCode (is on MacOS DVD)
  - if the DVD is not available you might need to register as Apple Developer to be able to download XCode
  - the rest you will need to figure out yourself
  - CodeLite `http://downloads.codelite.org/`

Programming Environment (5)

- Windows
  - CodeLite includes a C++ compiler
    `http://downloads.codelite.org/`
  - choose: CodeLite Installer 10.0 for Windows
  - download and install it
  - includes `gdb` and g++
  - Alternatives: Visual C++ Express (free of charge), Eclipse, NetBeans

Programming Environment (6)

- You will upload your solutions to Grader, where your source code will be automatically compiled
- Your programs must compile without any warning with g++
- On your local machine turn on all warnings:
  `g++ -Wall -o executable file.cpp`

Agenda Week 1

- More on Overloading
- Streams
- Multiple Inheritance
- Templates: Functions, Classes
- Standard Template Library (STL): Containers, Iterators

Overloading Operators for Casting

- It is possible to create operators for converting a type to another, thus performing a sort of casting
  `operatorconversion.cpp`
- This can also be done by implementing an ad-hoc constructor taking the type we want convert from
  `constructorconversion.cpp`

The `explicit` Keyword

- If a constructor is declared with the explicit modifier, it will be used for type conversion only if the typename is explicitly inserted
- Then it is possible to choose which kind of conversion will take place: constructor driven or operator driven
  `explicitconversion.cpp`

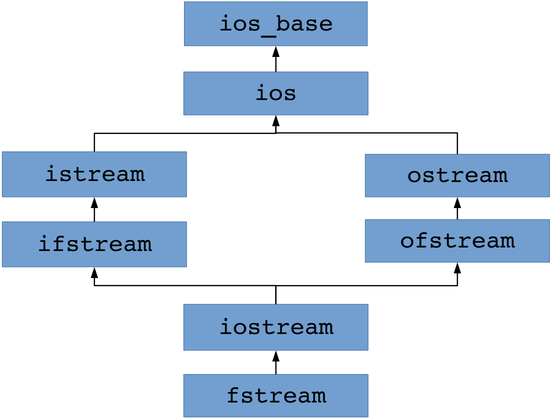
Streams

- A stream is a flow of data from a source to a destination
  - Widely used concept in Unix
  - Think to water flowing in a pipe
- Standard C++ provides classes for handling streams of data connected to the console or to files
  - Common interface: learn once use everywhere

Iostreams

- You already used them
- The instances `cin`, `cout` and `cerr` are declared in the header files included in `<iostream>`
- Exceptional use due to their wide use
  - Preprocessor directives for conditional compiling avoid multi-declaration problems
- Extractors and inserters are overloaded operators designed to work with different data types
  - Consider to overload them to work with your own developed classes

Class Hierarchy



Output Streams and the Inserter Operator <<

- Operator << has been overloaded to work with all language data types and many classes
  - It sends data to an output stream (`ostream`)
- Inserters can be concatenated
- Additionally, manipulators can modify the output
  - `endl`, `flush`, `hex`, `oct`, `dec`
    Example: `cout << hex << "0x" << 34 << flush;`

The << Operator

- Converts internal data type into sequence of ASCII characters

```
ostream& operator<<(const char *)
ostream& operator<<(char)
ostream& operator<<(int)
ostream& operator<<(float)
ostream& operator<<(double)
```

- Returns reference to `ostream`

Input Streams and the Extractor Operator >>

- The operator >> has been overloaded to work with predefined language data types
  - It gets data from an input stream (`istream`)
- Extractor stops reading when it finds a whitespace
- The manipulator `ws` removes leading and trailing white space from an `istream`

Line Oriented Input

- Istreams provide two methods to get a whole line of text:
  - `get()` get the text but do not remove the delimiter
  - `getline()` get the text and remove the delimiter
  - Both accept three parameters: char buffer to store data, buffersize and terminator character
  - Default value of terminator is `'\n'`
- It can be useful to grab input as a char sequence and then convert it using C functions

Raw I/O

- Binary files: images, audio, self-defined formats, etc.
- Raw I/O member functions are used to write/read binary data to/from streams
  - Istreams:
    - `read(char *, int)`
    - `gcount()` returns the number of characters extracted
  - Ostreams:
    - `write(char *, int)`

The State of a Stream

The following member functions can be used to investigate on the state of a stream:

- `good()` true if `goodbit` is the current state
- `eof()` true if `endoffile`
- `fail()` true if `failbit` or `badbit` set
- `bad()` true if `badbit` set
- `clear()` set state to `goodbit`

File Streams

`ifstream` and `ofstream` classes can be used to connect a stream to a file

- Just provide the name of the file as a parameter to the constructor
- You do not need to open or close the file (up to constructor and destructor)
- Classes are declared in the `fstream` header file

Open Mode Flags

Flag	Function
`ios::in`	Open as input
`ios::out`	Open as output
`ios::binary`	Open in binary mode
`ios::app`	Open for appending
`ios::ate`	Open and go at end
`ios::nocreate`	Open only if exists
`ios::noreplace`	Open only if does not exits
`ios::trunc`	Open and delete the old if present

Moving Within a Stream

- The next byte you will put/get to/from a stream has a position
- `tell` functions return the current absolute position in a stream
- `seek` functions move the specified positions
- Positions can be either absolute or relative:
  - `ios::beg` relative to beginning (absolute)
  - `ios::cur` relative to current position
  - `ios::end` relative to end of file
- `p` (put) suffix for ostreams
- `g` (get) suffix for istreams

How to Move in a Stream?

- `ios::pos_type tellp()` returns current position
- `ios::pos_type tellg()` returns current position
- `seekp(pos_type)` moves to given absolute position
- `seekg(pos_type)` moves to given absolute position
- `seekp(pos_type, off_type)` moves to relative position, as given by `off_type`
- `seekg(pos_type, off_type)` moves to relative position, as given by `off_type`
- `pos_type` can be converted to `int` or `long`
- `off_type` is either `ios::beg`, `ios::cur` or `ios::end`

Some Examples

- seek.cpp
- The same stream can be used multiple times for reading from different files
  - Just close it and reopen it to bind to a different file
- filestream.cpp

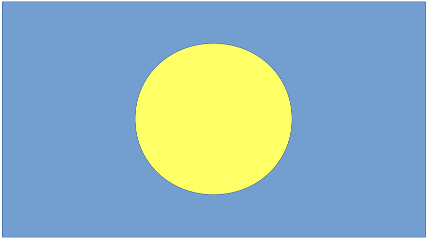
Overloading Extractors and Inserters for your Types

- It can be useful to overload << and >> to dump and/or read classes instances to streams
  - For example to save/retrieve the state of the application to/from a file
- Add an overloaded operator << or >> definition to the class
  - Should be `friend`
  - Returns an `ostream`/`istream` reference
  - Should take an `istream`/`ostream` reference and a (`const`) reference to the class as parameters
  - `overloadedstream.cpp`

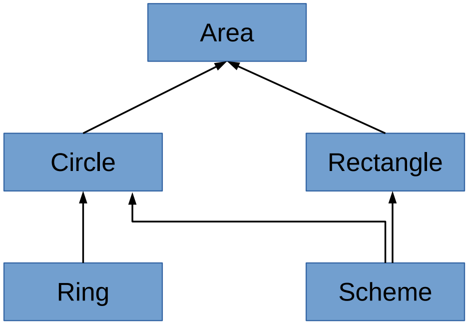
Beware of the Namespace

- `istream` and `ostream` are in the `std` namespace
- So if you try to overload inside a header file, where you are not supposed to use the namespace directive you must specify the namespace explicitly
- `friend std::ostream& operator<<(std::ostream&, const worker&);`

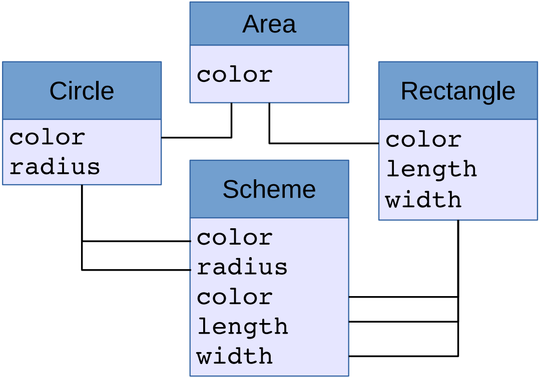
Multiple Inheritance: A Scheme



Class Hierarchy



Class Hierarchy (non-virtual Base Class)



Non-virtual Base Classes

- With polymorphism it is possible that a class can act as indirect base class multiple times
- Here `Scheme` will include members of the indirect base class `Area` multiple times
- One possibility to solve this problem is to use `static_cast<Circle *>` to create unambiguousness

Virtual Base Class

- Create unambiguousness by declaring a base class as `virtual` (i.e., inherit with `: public virtual`)
- Then only one subobject will be created
- In our example we need to explicitly call the `Area` constructor (with parameters) since no default constructor exists
- `nonvirtualinheritance.cpp`
- `virtualinheritance.cpp`
- `nonvirtualinheritance2.cpp`
- `virtualinheritance2.cpp`

Templates

- Templates allow to write generic code, i.e., code which will work with different types
  - Again those types could be unknown at code time
- A template tells the compiler that "what is following" will deal with an unknown type
- Later a specific type will be provided and the compiler will substitute it and generate ad-hoc code

Templates: Motivation

- Many times it is required to write different snippets of code which differ only in the types dealt with, but not in the underlying logic
  - Imagine the code to check for the existence of an element in an array of floats, or an array of pointers to a class, or an array of images
  - The logic is always the same
- So, why do not we write code which is parametric with respect to the possible types?

Searching in a Vector

- Assuming that a comparison operator is defined, the following code captures the logic to locate an element in a vector

```
int seek(sometype A[], int n, sometype toseek) {
  for (int i = 0; i < n; i++)
    if (A[i] == toseek)
      return i;
  return -1;
}
```

- Should write different versions if sometype is `int`, or `float`, or `Complex`, or ...?

Templates: Functions and Classes

Type parameterization can be introduced for:

- Functions: like in the previous example; this helps in developing “algorithms”; you can concentrate on the logic, rather than on type details
  - Also, this decreases your coding time
- Classes: helps in developing “generic” classes; think about an array: the underlying logic is the same, whether it holds elements of type `int`, `Car`, `Student`, `double`, etc.
  - Again: concentrate on developing a working generic version

Templates: Basic Syntax (1)

- Two keyphrases are involved: `template class` and `template typename`
- They are functionally equivalent
- Template function: `template_function.cpp`

```
template <class T>
class Something {
  T *p;
  public: Something() { p = new T[100]; }
};
```

- Here the type `T` is not known, it will (and must) be specified when declaring instances of the class `Something`

Templates: Basic Syntax (2)

- When declaring an instance, the type is provided between angular brackets

```
int main(int argc, char** argv) {
  Something<int> ints;
  Something<char*> chars;
  Something<student> studentsome;
}
```

- The complier will generate the code necessary for the three different types
- templatesone.cpp

Some Remarks

- The code is generated by the compiler, which substitutes the generic `T` with the provided type
- Templates can be used both for methods and for “algorithms”, i.e., functions which work with different data types
- It is common (and necessary ...) to put both declaration and definition of the templatized classes in the same header file
    - Does not break anything
    - The compiler will not allocate space and will not run into duplicate definition problems
- `stemplate.h`
- `stemplate.cpp`
- `stemplate_main.cpp`

Additional Remarks

- Multiple definitions are merged together
- If you specify `template<class T>`, the type parameter can be either a class or a basic data type
- You can have more than one parameter (generic or not):
  `template<class T, int, double>`

One More Example

- Templates are very useful when developing general purpose containers, i.e., classes whose task is to store objects
- Most of containers use the same business logic to access data; the only difference is the data type
- A good container library can dramatically cut down your developing time
- `templatestack.cpp`

The Ownership Problem

What should a container hold? Objects or pointers to objects?

- If it contains object instances, we say it owns the objects
- If it contains pointers, we say it does not own objects
  - If it holds objects, they can be safely removed from memory during destructor execution
  - If it holds pointers to objects, other code is in charge of the destruction
    - Both seem to have their own advantages

Ownership: General Guidelines

Containers should not own objects; thus their destruction should be managed in places other than container destructors

- In general it is better to create objects on the heap and to access them via pointers
  - This opens the doors to a consistent use of polymorphism
- Management of object instances created on the heap is the source of many many bugs
  - Always double check your code involving `new` and `delete`

Are Templates Against OOP?

- Some OOP languages do not provide templates
- To write generic code, they just play with inheritance
  - For example, inherit everything from a single class and write code dealing with that class
  - Java and Smalltalk use this approach, but newer versions of Java have introduced something like templates
  - By offering both, C++ allows you to use both, at your choice

The Standard Template Library (STL)

- C++ standardization began in 1989 (until 1998)
- STL was later added in 1994
- STL is part of the Standard C++ Library
- Extends the core language by some general components
- May be reused for different purposes
- Programmers do not need to reinvent the wheel again and again
- Eases development of applications
- Makes software more maintainable

Brief Definitions

- Containers
  - Manage collections of objects
- Iterators
  - Navigate (step) through the elements of a container
- Algorithms
  - Process elements of collections
  - E.g., search, sort, modify

Standard Template Library (1)

- Data and algorithm separated rather than combined
- Every kind of container can be combined with every kind of algorithm
- All components work with arbitrary types
- Components are templates for (almost) any type
- STL good example for "generic programming"

Standard Template Library (2)

- Containers are objects used to store other objects
- Containers size changes dynamically
- Very useful when objects are created on the heap
  - In that case containers hold their pointers
- Based on templates, containers can be used to store any data type

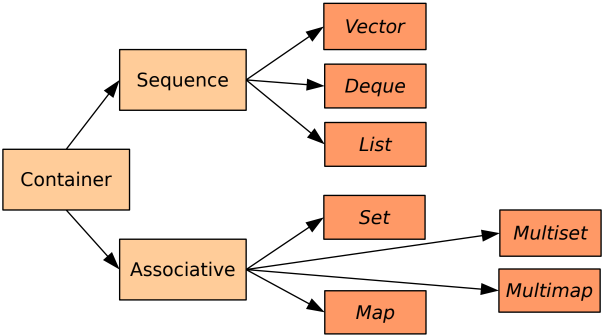
The Standard C++ Containers Library

- Derived from the STL, the two terms are often used as synonyms, but they are two different things (although pretty similar)
- Before reinventing the wheel check the standard library
  - In most of the situations, it is unlikely that you will need to develop yet another linked list class, or vector, or other widely used containers
  - Rely on widely used code developed by specialists
- Good documentation at `http://www.sgi.com/tech/stl/`

Containers Library

- Built over a restricted set of simple concepts, it can be used to quickly develop your software
- The two main concepts are containers and iterators
  - Containers hold objects, while iterators are used to move through containers to get/set objects
  - The iterator's mechanism is independent from the underlying container implementation, so you can use the same approach in many different situations
    - And of course without knowing how containers work
  - Containers dynamically grow or shrink to accommodate your storage needs

Fundamental Container Classes

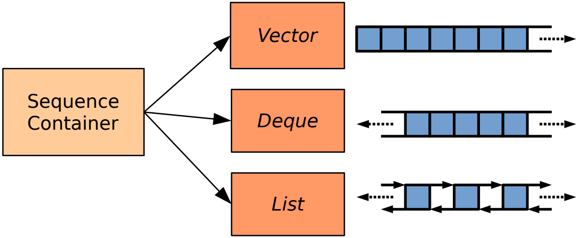


Predefined classes have different characteristics regarding insert/access speed, size, usability

Containers

- Different containers for different needs
  - Sequences:
    - `vector`, `deque`, `list`
  - Associations:
    - `set`, `multiset`, `map`, `multimap`
- Common operations:
  - Insert an object into it
  - Remove an object from it
  - Iterate over all the elements (using an iterator)

Sequence Containers



- Ordered collection where every element has certain position
- Position depends on time and place of insertion, but independent of value of element
- Predefined containers differ in speed of insertion of elements and access to elements

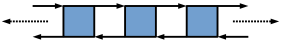
Vector

- Mimics an array
  - Provides random access
  - Fast insertion at the end, and fast indexing through overloaded `[]` operator
  - Needs more time if element is added at the middle of array
  - Not very efficient while resizing, and for what concerns memory allocation
- Constructors: `vector()`, `vector(int)`
- Basic methods: `push_back`, `pop_back`, `back`, `clear`, `size`, `max_size`, `empty`
- `vectorexample.cpp`

Deque

- Double ended queue
  - Elements are managed in dynamic array, which can grow in both directions
  - Appending and removing elements at beginning / end very fast
  - Needs more time if element is added at the middle of array
- Basic interface: very similar to vector; in addition `push_front`, `pop_front`, `front`
- Preferred to vector, unless you know exactly how many elements you will store
- `dequeexample.cpp`

List



- A double linked list
  - Element consists of
    - value
    - link to predecessor
    - link to successor
  - No random access
  - Fast insertion at both ends, slow access to intermediate elements
- Basic interface: similar to deque, but missing the `[]` operator; in addition
  - `reverse`, `sort`
- `listexample.cpp`

A Few Comments

- There are many more methods in every class
- If you use just the common methods of the containers, you will be able to change container by just changing their declaration and not the client code
- As with all containers, you can use them as black boxes
    - You do not need to care about their internal implementation

And More

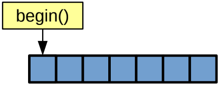
Stacks, queues, priority queues

- All implemented over the basic containers seen before
- Sometimes called adapters
- They do not provide additional capabilities, but rather reshape underlying containers

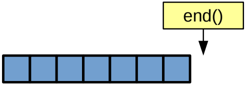
Iterators (1)

- Object that iterates over elements, which are all or part of the elements of an STL container
- Represents a certain position in a container
- Operations
  - `*` returns element at current position
  - `++` step forward to next element
  - `==` equals same position
  - `!=` not equals same position
- May iterate over complicated data structures of containers (such as binary trees)
- Internal implementation depends on container

Member functions `begin()` and `end()` return Iterators



- Returns an iterator, that points to beginning of the elements in container



- Returns an iterator, that points to end of the elements in container; this is the position behind the last element (past-the-end-iterator)
- Both functions define a half-open range (includes first, but excludes last element)

Iterators (2)

- Iterators can be dereferenced, to gain access to the element they point to
  - Think to iterators as "very smart pointers"
  - But do not push this similarity too far
- Iterators are declared as follows:

```
vector<int> vint;
vector<int>::iterator viterator;
```

  - This is because iterators are declared as container inner classes
- iteratorsexample.cpp

Using Iterators on Vectors

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

int main() {
  vector<int> v; // vector container for integers
  v.push_back(2);
  v.push_back(5);

  vector<int>::const_iterator pos;

  for (pos = v.begin(); pos != v.end(); ++pos) {
    cout << *pos << ' ';
  }
  cout << endl;
  return 0;
}

// if using C++11, you can use cbegin() and cend() instead
// of begin() and end()
```

Nested Templates

- Templates can be nested
- Keyword `typename` can be needed if not the current instatiation of a type but a dependent type is used
- templ_in_templ1.cpp
- templ_in_templ2.cpp