Introduction to C++

Leo Liberti

DIX, École Polytechnique, Palaiseau, France

II semester 2008/09

Preliminary remarks

Teacher

Leo Liberti: liberti@lix.polytechnique.fr.
Office: LIX 412-29 (prefab). Telephone: 4138

Aim of the course

Teach the basics of the C++ language

Means

Mixed lecture/practical teaching style
Develop a complex C++ application

http://www.lix.polytechnique.fr/~liberti/teaching/c++/dmap-08/

Course structure

Timetable

Lectures: Mondays 14:00-15:45(36) and 16:00-17:45(36)

Examination

23/03/09 practical + oral

Course material

- Bjarne Stroustrup, *The C++ Programming Language*, 3rd edition, Addison-Wesley, Reading (MA), 1999
- Stephen Dewhurst, *C++ Gotchas: Avoiding common problems in coding and design*, Addison-Wesley, Reading (MA), 2002
- Herbert Schildt, *C/C++ Programmer's Reference*, 2nd edition, Osborne McGraw-Hill, Berkeley (CA)

Course contents

Syllabus

1. Preamble
   - Course
2. Introduction
   - Programming Languages
   - C++ Language basics
   - Syntax
   - Basic Linux development tools
3. Classes
   - Basic class semantics
   - Input and output
   - Inheritance and polymorphism
4. Templates
   - User-defined templates
   - Standard Template Library

Generalities

Definitions

- *Program*: set of instructions that can be interpreted by a computer
- *Instructions*: well-formed sequences of characters (syntax)
- *Interpretation*: sequence of operations performed by the computer hardware (semantics)
- *Programming language*: set of rules used to form valid instructions
- *Algorithm*: a program which terminates (though sometimes find "non-terminating algorithm" with abuse of notation)

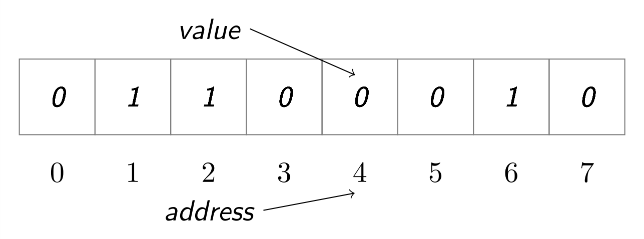
Operations

Valid computer operations

- *Input*: transfer data from external device to processor
- *Output*: transfer data from processor to external device
- *Storage*: transfer data from processor to memory
- *Retrieval*: transfer data from memory to processor
- *AL operation*: perform arithmetic/logical operation on data
- *Test*: verify condition on data and act accordingly
- *Loop*: repeat a sequence of operations

Memory

- Usual representation for memory: indexed array of cells where values can be stored



- unit of measure: **bit** (Binary digIT) — can hold a 0 or a 1
- 8b (bit) = 1B (byte), 1024 B = 1 KB (Kilobyte), 1024 KB = 1MB
- sometimes find 1KB = 1000 B and 1MB = 1000 KB

Creating and using data

- **Declaration**: the compiler is told about a new symbol and its type `void myFunction(void);`
- **Definition**: a segment of memory is associated to a symbol (called *variable name*) `char varName;`

`varName` $\longrightarrow$	1	1	0	1	0	1	1	0
	0	1	2	3	4	5	6	7

- **Assignment**: a value is stored in the memory associated to the variable name

`char varName(9);`

`varName` $\longrightarrow$	0	0	0	0	0	1	0	1
	0	1	2	3	4	5	6	7

varName = 100;

`varName` $\longrightarrow$	0	1	1	0	0	1	0	0
	0	1	2	3	4	5	6	7

- **Deallocation**: the variable name is discarded and the associated memory is considered free

Basic data types

- boolean value: `bool` (1 bit), true or false
- ASCII character: `char` (1 byte), integer between -128 and 127
- integer number:
  - `int` (usually 4 bytes), between -2^{31} and $2^{31} - 1$
  - `long` (usually 8 bytes)
  - can be prefixed by `unsigned`
- floating point: `double` (also `float`, rarely used)
- arrays:

  typeName variableName[*constArraySize*] ;

  ```
  char myString[15];
  ```
- pointers (a pointer contains a memory address):

  typeName * *pointerName* ;

  ```
  char* stringPtr;
  ```

Declaration, Assignment, Test, AL Operators

- declaration: *typeName variableName* ; `int i;`
- assignment: *variableName* = *expression* ; `i = 0;`
- test:

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

```
if (i == 0) {
   i = 1;
} else if (i < 0) {
   i = 0;
} else {
   i += 2;
}
```

- logical operators: and (`&&`), or (`||`), not (`!`)
  condition1 logical_op condition2 ;
  `if (!(i == 0 || (i > 5 && i % 2 == 1))) { ...`
- arithmetic operators: `+`, `-`, `*`, `/`, `%`, `++`, `--`, `+=`, `-=`, `*=`, `/=`, ...

Loops

- loop (while):

```
while ( condition ) {
   statements ;
}
```

```
while (i < 10) {
   i = i + 1;
}
```

- loop (for):

```
for ( initial_statement ; condition ; itn_statement ) {
   statements ;
}
```

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

Functions

- function declaration:

  typeName functionName(*typeName1 argName1*, . . .) ;

```
double performSum(double op1, double op2);
```

- function call:

  varName = `functionName`(*argName1*, . . .) ;

```
double d = performSum(1.0, 2.1);
```

- return control to calling code: `return` *value* ;

```
double performSum(double op1, double op2) {
  return op1 + op2;
}
```

Functions: Argument passing

- Arguments are passed from the calling function to the called function in two possible ways:
  1. by *value*
  2. by *reference*
- Passing by value (default): the calling function makes a copy of the argument and passes the copy to the called function; **the called function cannot change the argument**

```
double performSum(double op1, double op2);
```

- Passing by reference (prepend a &): the calling function passes the argument directly to the called function; **the called function can change the argument**

```
void increaseArgument(double& arg) { arg++; }
```

Functions: Overloading

- Different functions with the same name but different arguments: *overloading*
- Often used when different algorithms exist to obtain the same aim with different data types

```
void getInput(int theInput) {
   std::cout << "an integer" << std::endl;
}
void getInput(std::string theInput) {
   std::cout << "a string" << std::endl;
}
```

- Can be used in recursive algorithms to differentiate initialization and recursive step

```
void retrieveData(std::string URL, int maxDepth, Digraph& G,
          bool localOnly, bool verbose);
void retrieveData(std::string URL, int maxDepth, Digraph& G,
          bool localOnly, bool verbose,
          int currentDepth, VertexURL* vParent);
```

Pointers

- retrieve the address of a variable:

pointerName = &*variableName* ;

```
int* pi;
pi = &i;
```

- retrieve the value stored at an address:

variableName = ∗*pointerName* ;

```
int j;
j = *i;
```

- using pointers as arrays:

```
const int bufferSize = 10;
char buffer[bufferSize] = "J. Smith";
char* bufPtr = buffer;
while(*bufPtr != ' ') {
  bufPtr++;
}
std::cout << ++bufPtr << std::endl;
```

Pointer warnings

- Pointers allow you to access memory directly, hence can be very dangerous
- Attempted memory corruption results in "segmentation fault" error and abort, or garbage output, or unpredictable behaviour
- Most common dangers:
  1. writing to memory outside bounds

```
char buffer[] = "LeoLiberti";
char* bufPtr = buffer;
while(*bufPtr != ' ') {
   *bufPtr = ' ';
   bufPtr++;
}
```

  2. deallocating memory more than once
- Pointer bugs are usually very hard to track

Indentation

- Not necessary for the computer
- **Absolutely necessary for the programmer / maintainer**
- After each opening brace {: new line and tab (2 characters)
- Each closing brace } is on a new line and "untabbed"

```
double x, y, z, epsilon;
...
if (fabs(x) < epsilon) {
  if (fabs(y) < epsilon) {
    if (fabs(z) < epsilon) {
      for(int i = 0; i < n; i++) {
        x *= y*z;
      }
    }
  }
}
```

Comments

- Not necessary for the computer
- **Absolutely necessary for the programmer / maintainer**
- One-line comments: introduced by //
- Multi-line comments: /* ... */
- Avoid over- and under-commentation
- Example of over-commentation

```
// assign 0 to x
double x = 0;
```

- Example of under-commentation

```
char buffer[] = "01011010 01100100";
char* bufPtr = buffer;
while(*bufPtr &&
   (*bufPtr++ = *bufPtr == '0' ? 'F' : 'T'));
```

Structure of a C++ Program I

```
/**********************************************
* Name:       helloworld.cxx
* Author:     Leo Liberti
* Source:     GNU C++
* Purpose:    hello world program
* Build:      c++ -o helloworld helloworld.cxx
* History:    060818 work started
**********************************************/

#include<iostream>

int main(int argc, char** argv) {
  using namespace std;
  cout << "Hello World" << endl;
  return 0;
}
```

Structure of a C++ Program II

- Each executable program coded in C++ must have one function called **main()**

```
int main(int argc, char** argv);
```

- The `main` function is the entry point for the program
- It returns an integer *exit code* which can be read by the shell
- The integer `argc` contains the number of arguments on the command line
- The array of character arrays `**argv` contains the arguments: the command `./mycode arg1 arg2` gives rise to the following storage:

  `argv[0]` is a `char` pointer to the string `./mycode`
  `argv[1]` is a `char` pointer to the string `arg1`
  `argv[2]` is a `char` pointer to the string `arg2`
  `argc` is an `int` variable containing the value 3

Structure of a C++ Program III

- C++ programs are stored in one or more text files
- Source files: contain the C++ code, extension `.cxx`
- Header files: contain the declarations which may be common to more source files, extension `.h`
- Source files are compiled
- Header files are included from the source files using the *preprocessor directive* `#include`

```
#include<standardIncludeHeader>
```

```
#include "userDefinedIncludeFile.h"
```

Development stages

- Creating a directory for your project(s) `mkdir` *directoryName*
- Entering the directory `cd` *directoryName*
- Creating/editing the C++ program
- Building the source
- Debugging the program/project
- Packaging/distribution (Makefiles, READMEs, documentation...)

Basic UNIX tools

- `cd` *directoryName* : change working directory
- `pwd` : print the working directory
- `cat` *fileName* : display the (text) file *fileName* to standard output
- `mv` *file position* : move *file* to a new *position*: e.g. `mv /etc/hosts .` moves the file `hosts` from the directory `/etc` to the current working directory (`.`)
- `cp` *file position* : same as `mv`, but copy the file
- `rm` *file* : remove *file*
- `rmdir` *directory* : remove an empty *directory*
- `grep` *string file(s)* : look for a *string* in a set of *files*: e.g. `grep -Hi complex *` looks in all files in the current directory (`*`) for the string `complex` ignoring upper/lower case (`-i`) and displays the name of the file (`-H`) as well as the line where the match occurs

Combining UNIX tools

- By default, unix tools send their output messages to the *standard output* stream (`stdout`) and their error messages to the *standard error* stream (`stderr`)
- Both streams can be redirected. E.g., to redirect both `stdout` and `stderr`, use:

  `sh -c '`*command options arguments* > *outFile* 2>&1`'`
- The output stream of a command can become the input stream of the next command in a chain:
  e.g. `find ~ | grep \.cxx` finds all files with extension `.cxx` in all subdirectories of the home directory; the first command (`find`) sends a recursive list across subdirectories of the home directory (denoted by ~) to `stdout`. This stream is transformed by the pipe character (|) in the standard input (`stdin`) stream of the following command (`grep`), which filters out all lines *not* containing `.cxx`.

Editing

- Traditional GNU/Linux text editor: `emacs`

  `emacs` *programName*`.cxx`

- Many key-combination commands (try ignoring menus!)
- Legenda: `C-`*key*: CTRL+*key*, `M-`*key*: ALT+*key* (for keyboards with no ALT key or for remote connections can obtain same effect by pressing and releasing ESC and then *key*)
- Basics:
  1. `C-x C-s`: save file in current buffer (screen) with current name (will ask for one if none is supplied)
  2. `C-x C-c`: exit (will ask for confirmation for unsaved files)
  3. `C-space`: start selecting text (selection ends at cursor position)
  4. `C-w`: cut, `M-w`: copy, `C-y`: paste
  5. `tab`: indents C/C++ code
  6. `M-x indent-region`: properly indents all selected region

Building

- Computer needs instructions in machine language (executable), C++ is text
- The translation process from C++ to executable is called *building*
- Two stages:
  1. *compilation*: production of an intermediate object file (`.o`) possibly with unresolved symbols
  2. *linking*: resolve symbols by reading code from other objects, standard, and user-defined libraries
- Can perform both in one go with the GNU command `c++`:
  `c++ -o helloworld helloworld.cxx`
- Can perform separately: `c++ -c helloworld.cxx` (produces `helloworld.o`),
  `c++ -o helloworld helloworld.o` (useful for combining multiple object files into one executable)

File types

- C++ *declarations* are stored in text files with extension `.h` (*header files*)
- C++ source code is stored in text files with extension `.cxx`
- Executable files have no extensions but their "executable" property is set to on (e.g. `ls -la /bin/bash` returns `'x'` in the properties field)
- Each executable must have exactly *one* symbol `main` corresponding to the first function to be executed
- An executable can be obtained by *compiling* many source code files (`.cxx`), *exactly one of which* contains the definition of the function `int main(int argc, char** argv);`, and linking all the objects together
- Source code files are compiled into object files with extension `.o` by the command `c++ -c` *sourceCode.cxx*

Objects and symbols

- An object file (`.o`) contains a table of symbols used in the corresponding source file (`.cxx`)
- The symbols whose definition was given in the corresponding source file are *resolved*
- The symbols whose definition is found in another source file are *unresolved*
- Unresolved symbols in an object file can be resolved by *linking* the object with another object file containing the missing definitions
- An executable cannot contain any unresolved symbol
- A group of object files `file1.o`, ..., `fileN.o` can be linked together as a single executable `file` by the command `c++ -o file file1.o ... fileN.o` only if:
  1. the symbol `main` is resolved exactly once in exactly one object file in the group
  2. for each object file in the group and for each unresolved symbol in the object file, the symbol must be resolved in exactly one other file of the group

Debugging

- GNU/Linux debugger: `gdb`
- Graphical front-end: `ddd`
- Designed for Fortran/C, not C++
- Can debug C++ programs but has troubles on complex objects (use the "insert a print statement" technique when `gdb` fails)
- Memory debugger: `valgrind` (to track pointer bugs)
- In order to debug, compile with -g flag:

```
c++ -g -o helloworld helloworld.cxx
```

- More details during labs

Packaging and Distribution

- For big projects with many source files, a `Makefile` (detailing how to build the source) is essential
- Documentation for a program is **absolutely necessary** for both users and maintainers
- Better insert a minimum of help within the program itself (to be displayed on screen with a particular option, like `-h`)
- A `README` file to briefly introduce the software is usual
- There exist tools to embed the documentation within the source code itself and to produce Makefiles more or less automatically
- UNIX packages are usually distributed in tarred, compressed format (extension `.tar.gz` obtained with the command `tar zcvf` *directoryName*`.tar.gz` *directoryName*

Classes: motivations

1. Problem analysis is based on data and algorithm break-down structuring ⇒ hierarchical design for data and algorithms
2. Fewer bugs if data inter-dependency is low ⇒ design data structure first, then associate algorithms to data (not the reverse)
3. Data structures are usually complex entities ⇒ need for sufficiently rich expressive powers for data design
4. Different data objects may share some properties ⇒ exploit this fact in hierarchical design

The class concept

Class

A *class* is a user-defined data type. It contains some data *fields* and the *methods* (i.e. algorithms) acting on them.

```
class TimeStamp {
 public:  // can be accessed from outside
  TimeStamp(); // constructor
  ~TimeStamp(); // destructor
  long get(void) const; // some methods
  void set(long theTimeStamp);
  void update(void);
 private:  // can only be accessed from inside
  long timestamp; // a piece of data
};
```

Objects of a class

- An *object* is a piece of data having a class data type
- A class is declared, an object is defined
- In a program there can only be one class with a given name, but several objects of the same class
- Example:

```
TimeStamp theTimeStamp; // declare an object
theTimeStamp.update(); // call some methods
long theTime = theTimeStamp.get();
std::cout << theTime << std::endl;
```

Referring to the current object

- Occasionally, we may want to know the address of an object within one of its methods
- Each object is endowed with the `this` pointer

```
cout << this << endl;
```

Constructors and destructors

- The class constructor defines the data fields and performs all user-defined initialization actions necessary to the object
- The class constructor is called only once when the object is defined
- The class destructor performs all user-defined actions necessary to object destruction
- The class destructor is called only once when the object is destroyed
- An object is destroyed when its *scope* ends (i.e. at the first brace } closing its level)

Lifetime of an object I

```
int main(int argc, char** argv) {
  using namespace std;
  TimeStamp theTimeStamp; // object created here
  theTimeStamp.update();
  long theTime = theTimeStamp.get();
  if (theTime > 0) {
    cout << "seconds from 1/1/1970:  "
         << theTime << endl;
  }
  return 0;
} // object destroyed before brace (scope end)
```

Lifetime of an object II

Constructor and destructor code:

```
TimeStamp::TimeStamp() {
   std::cout << "TimeStamp object constructed at address "
         << this << std::endl;
}
TimeStamp::~TimeStamp() {
   std::cout << "TimeStamp object at address "
         << this << " destroyed" << std::endl;
}
```

Output:

```
TimeStamp object constructed at address 0xbffff24c
seconds from 1/1/1970:  1157281160
TimeStamp object at address 0xbffff24c destroyed
```

Data access privileges

```
class ClassName {
  public:
    members with no access restriction
  protected:
    access by: this, derived classes, friends
  private:
    access by: this, friends
} ;
```

- a *derived* class is a class which inherits from this (see inheritance below)
- a function can be declared *friend* of a class to be able to access its protected and private data

```
class TheClass {
    ...
    friend void theFriendMethod(void);
};
```

Namespaces

- All C++ symbols (variable names, function names, class names) exist within a *namespace*
- The complete symbol is `namespaceName::symbolName`
- The only pre-defined namespace is the *global namespace* (its name is the empty string `::varName`)
- Standard C++ library: namespace `std` `std::string`

```
namespace WET {
    const int maxBufSize = 1024;
    const char charCloseTag = '>';
}
```

```
char buffer[WET::maxBufSize];
```

```
using namespace WET;
for(int i = 0; i < maxBufSize - 1; i++) {
    buffer[i] = charCloseTag;
}
```

Exceptions I

- Upon failure, a method may abort its execution
- We do not wish the whole program to abort
- Mechanism:
  1. method *throws* an *exception*
  2. caller method *catches* it
  3. called method handles it if it can
  4. otherwise it re-throws the exception
- Exceptions are passed on the method calling hierarchy levels until one of the method can handle it
- If exceptions reaches `main()`, the program is aborted

Exceptions II

Definition

An *exception* is a class. Exceptions can be thrown and caught by methods. If a method throws an exception, it must be declared:

returnType methodName(arguments) `throw` (*ExceptionName*)

- The `TimeStamp::update()` method obtains the current time through the operating system, which is outside the program's control
- `update()` does not know how to deal with a failure directly, as it can only update the time; should failure occur, control is delegated to higher-level methods

```
class TimeStampException {
 public:
   TimeStampException();
   ~TimeStampException();
}
```

Exceptions III

```
void TimeStamp::update(void) throw (TimeStampException) {
  using namespace std;
  struct timeval tv;
  struct timezone tz;
  try {
    int retVal = gettimeofday(&tv, &tz);
    if (retVal == -1) {
      cerr << "TimeStamp::updateTimeStamp():  "
            << "could not get system time" << endl;
      throw TimeStampException();
    }
  } catch (...)  {
    cerr << "TimeStamp::updateTimeStamp():  "
          << "could not get system time" << endl;
    throw TimeStampException();
  }
  timestamp = tv.tv_sec;
}
```

Overloading operators in and out of classes I

- Suppose you have a class `Complex` with two pieces of private data, `double real;` and `double imag;`
- You wish to overload the + operator so that it works on objects of type `Complex`
- There are two ways: (a) declare the operator outside the class as a friend of the `Complex` class; (b) declare the operator to be a member of the `Complex` class

Overloading operators in and out of classes II

- (a) declaration:

```
class Complex {
  public:
    Complex(double re, double im) :  real(re), imag(im) {}
    ...
    friend Complex operator+(Complex& a, Complex& b);
  private:
    double real;
    double imag;
}
```

definition (out of the class):

```
Complex operator+(Complex& a, Complex& b) {
    Complex ret(a.real + b.real, a.imag + b.imag);
    return ret;
}
```

Overloading operators in and out of classes III

- (b) declaration:

```
class Complex {
  public:
    Complex(double re, double im) :  real(re), imag(im) {}
    ...
    Complex operator+(Complex& b);
  private:
    double real;
    double imag;
}
```

  definition (in the class):

```
Complex Complex::operator+(Complex& b) {
    Complex ret(this->real + b.real, this->imag + b.imag);
    return ret;
}
```

- `this->` is not strictly required, but it makes it clear that *the left operand is now the object calling the* `operator+` *method*

The stack and the heap

- Executable program can either refer to near memory (the *stack*) or far memory (the *heap*)
- Accessing the stack is **faster** than accessing the heap
- The stack is **smaller** than the heap
- Variables are allocated on the stack `TimeStamp tts;`
- Common bug (but hard to trace): **stack overflow** `char veryLongArray[1000000000];`
- Memory allocated on the stack is deallocated automatically at the end of the scope where it was allocated (closing brace })
- Memory on the heap can be accessed through *user-defined memory allocation*
- Memory on the heap must be deallocated explicitly, otherwise *memory leaks* occur, exhausting all the computer's memory
- Memory on the heap **must not be deallocated more than once** (causes unpredictable behaviour)

User-defined memory allocation

- Operator `new`: allocate memory from the heap

  pointerType pointerName* = `new` *pointerType* ;

  ```
  TimeStamp* ttsPtr = new TimeStamp;
  ```

- Operator `delete`: release allocated memory

  `delete` *pointerName*;   delete ttsPtr;

- Commonly used with arrays in a similar way:

  pointerType pointerName* = `new` *pointerType* [*size*] ;

  ```
  double* positionVector = new double [3];
  ```

  `delete []` *pointerName* ;

  ```
  delete [] positionVector;
  ```

- **Improper user memory management causes the most difficult C++ bugs!!**

Using object pointers

- Suppose `ttsPtr` is a pointer to a `TimeStamp` object
- Two equivalent ways to call its methods:
  1. `(*ttsPtr).update();`
  2. `ttsPtr->update();`
- Prefer second way over first

Streams

- Data “run” through *streams*
- Stream types: input, output, input/output, standard, file, string, user-defined

outputStreamName << varName or literal . . . ;

```
std::cout << "i = " << i << std::endl;
```

inputStreamName >> varName ;

```
std::cin >> i;
```

```
stringstream buffer;
char myFileName[] = "config.txt";
ifstream inputFileStream(myFileName);
char nextChar;
while(inputFileStream && !inputFileStream.eof()) {
   inputFileStream.get(nextChar);
   buffer << nextChar;
}
cout << buffer.str();
```

Object onto streams

- Complex objects may have a complex output procedure
- **Example**: we want to be able to say
  `cout << theTimeStamp << endl;` and get
  Thu Sep 7 12:23:11 2006 as output
- Solution: overload the << operator

```
std::ostream& operator<<(std::ostream& s, TimeStamp& t)
   throw (TimeStampException);
```

Object onto streams II

```
#include <ctime>
std::ostream& operator<<(std::ostream& s, TimeStamp& t)
   throw (TimeStampException) {
   using namespace std;
   time_t theTime = (time_t) t.get();
   char* buffer;
   try {
      buffer = ctime(&theTime);
   } catch (...)  {
      cerr << "TimeStamp::updateTimeStamp():  "
            "couldn't print system time" << endl;
      throw TimeStampException();
   }
   buffer[strlen(buffer) - 1] = '\0';
   s << buffer;
   return s;
}
```

Overloading the << and >> operators I

- How does an instruction like
  `cout << "time is " << theTimeStamp << endl;` work?
- Can parenthesize is as
  `(((cout << "time is ") << theTimeStamp) << endl);`
  to make it clearer
- Each << operator is a binary operator whose left operand is an object of type `ostream` (like the `cout` object); we need to define an operator overloading for each new type that the right operand can take
- Luckily, many overloadings are already defined in the Standard Template Library

Overloading the << and >> operators II

- The declaration to overload is:

```
std::ostream& operator<<(std::ostream& outStream,
                         newType& newObject)
```

- To output objects of type `TimeStamp`, use:

```
std::ostream& operator<<(std::ostream& outStream,
                         TimeStamp& theTimeStamp)
```

- Note: in order for the chain of << operators to output all their data to the same `ostream` object, each operator must return the same object given at the beginning of the chain (in this case, `cout`)
- In other words, each overloading must end with the statement `return outStream;` (notice `outStream` is the *very same name* of the input parameter — so if the input parameter was, say, `cout`, then that's what's being returned by the overloading)

Inheritance

- Consider a class called `FileParser` which is equipped with methods for parsing text occurrences like `tag = value` in text files
- We now want a class `HTMLPage` representing an HTML page with all links
- `HTMLPage` will need to parse an HTML (text) file to find links; these are found by looking at occurrences like `HREF="url"`
- It is best to keep the text file parsing data/methods and HTML-specific parts independent
- `HTMLPage` can *inherit* the public data/methods from `FileParser`:

```
class HTMLPage : public FileParser {...} ;
```

Nested inheritance

- Consider a corporate personnel database
- Need `class Employee;`
- Certain employees are "empowered" (have more responsibilities): need `class Empowered : public Employee;`
- Among the empowered employees, some are managers: need `class Manager : public Empowered;`
- `Manager` contains public data and methods from `Empowered`, which contains public data and methods from `Employee`

Nested inheritance II

```
class Employee {
  public:
    Employee();
    ~Employee();
    double getMonthlySalary(void);
    void getEmployeeType(void);
};
```

$\leftarrow$

```
class Empowered : public Employee {
  public:
    Empowered();
    ~Empowered();
    bool isOverworked(void);
    void getEmployeeType(void);
};
```

$\uparrow$

```
class Manager : public Empowered {
  public:
    Manager();
    ~Manager();
    bool isIncompetent(void);
    void getEmployeeType(void);
};
```

Hiding

Consider method `getEmployeeType`: can be defined in different ways for `Manager`, `Empowered`, `Employee`: *hiding*

```
void Employee::getEmployeeType(void) {
   std::cout << "Employee" << std::endl;
}
void Empowered::getEmployeeType(void) {
   std::cout << "Empowered" << std::endl;
}
void Manager::getEmployeeType(void) {
   std::cout << "Manager" << std::endl;
}
```

Nested inheritance and hiding

Examples of usage

```
Employee e1;
Empowered e2;
Manager e3;
cout << e1.getMonthlySalary(); // output the monthly salary
cout << e2.getMonthlySalary(); // call to the same fn as above
e1.getEmployeeType(); // output:  Employee
e2.getEmployeeType(); // output:  Empowered (call to different fn)
e3.getEmployeeType(); // output:  Manager (call to different fn)
e3.Employee::getEmployeeType(); // output:  Employee (forced call)
cout << e1.isIncompetent(); // ERROR, not in base class
```

Inheritance vs. embedding

- Consider example of a salary object:

```
class Salary {
    Salary();
    ~Salary();
    void raise(double newSalary);
    ...
};
```

- Might think of deriving `Employee` from `Salary` so that we can say `theEmployee.raise();` to raise the employee's salary
- Technically, nothing wrong
- Architecturally, very bad decision!
- Rule of thumb:
  derive B from A only if B can be considered as an A
- In this case, better embed a `Salary` object as a data field of the `Employee` class

Polymorphism I

- Hiding provides *compile-time polymorphism*
- Almost always, this is **not** what is desired, and should be avoided!
- Want to be able to choose the class type of an object *at run-time*
- Suppose we want to write a function such as:

```
void use(Employee* e) {
   e->getEmployeeType();
}
```

  and then call it using Employee, Empowered, Manager objects:

```
use(&e1); // output:  Employee
use(&e2); // output:  Employee
use(&e3); // output:  Employee
```

- As far as `use()` is concerned, the pointers are all of `Employee` type, so wrong method is called

Polymorphism II

Run-time polymorphism can be obtained by declaring the relevant methods as `virtual`

```
class Employee {
   ...
   virtual void getEmployeeType(void);
   ...
};
```

```
class Empowered : public Employee {
   ...
   virtual void getEmployeeType(void);
   ...
};
```

```
class Manager : public Empowered {
   ...
   virtual void getEmployeeType(void);
   ...
};
```

```
use(&e1); // output: Employee
use(&e2); // output: Empowered
use(&e3); // output: Manager
```

Pure virtual classes

- Get objects to interact with each other: need *conformance* to a set of mutually agreed methods
- In other words, need an *interface*
- All classes derived from the interface implement the interface methods as declared in the interface
- Can guarantee the formal behaviour of all derived objects
- In C++, an interface is known as a *pure virtual class*: a class consisting only of method declarations and no data fields
- A pure virtual class has no constructor — no object of that class can ever be created (only objects of derived classes)
- A pure virtual class may have a virtual destructor to permit correct destruction of derived objects
- All methods (except the destructor) are declared as follows:
  returnType methodName(args) `= 0;`
- All derived classes **must** implement all methods

Pure virtual classes

```
class EmployeeInterface {
 public:
  virtual ~EmployeeInterface() { }
  virtual void getEmployeeType(void) = 0;
};
```

```
class Employee : public virtual EmployeeInterface {...};
class Empowered : public Employee, public virtual EmployeeInterface {...};
class Manager : public Empowered, public virtual EmployeeInterface {...};
```

```
void use(EmployeeInterface* e) {...}
...
use(&e1); // output: Employee
use(&e2); // output: Empowered
use(&e3); // output: Manager
```

- Code behaves as before, but clearer architecture
- `public virtual` inheritance: avoids having many copies of `EmployeeInterface` in `Empowered` and `Manager`

Templates I

- *Situation*: action performed on different data types
- *Possible solution*: write many functions taking arguments of many possible data types.
- *Example*: swapping the values of two variables

```
void varSwap(int& a, int& b);
void varSwap(double& a, double& b);
...
```

- Potentially an unlimited number of objects ⇒ invalid approach
- Need for *templates*

`template<class` *TheClassName*`>` *returnType functionName*`(`*args*`);`

```
template<class T> void varSwap(T& a, T& b) {
    T tmp(b);
    b = a;
    a = tmp;
}
```

Templates II

Behaviour with predefined types:

```
int ia = 1;
int ib = 2;
varSwap(ia, ib);
cout << ia << ", " << ib << endl; // output:  2, 1
```

```
double da = 1.1;
double db = 2.2;
varSwap(da, db);
cout << da << ", " << db << endl; // output:  2.2, 1.1
```

Templates III

Behaviour with user-defined types:

```
class MyClass {
  public:
    MyClass(std::string t) :  myString(t) { }
    ~MyClass() { }
    std::string getString(void) { return myString; }
    void setString(std::string& t) { myString = t; }
  private:
    std::string myString;
};
```

```
MyClass ma("A");
MyClass mb("B");
varSwap(ma, mb);
cout << ma << ", " << mb << endl; // output:  B, A
```

Internals and warnings

- Many hidden overloaded functions are created **at compile-time** (one for each argument list that is actually used)
- Very difficult to use debugging techniques such as breakpoints (which of the hidden overloaded functions should get the breakpoints?)
- **Use sparingly**
- But use the Standard Template Library as much as possible (already well debugged and very efficient!)

The STL

- Collection of generic classes and algorithms
- Born at the same time as C++
- Well defined
- Very flexible
- Reasonably efficient
- Use it as much as possible, do not reinvent the wheel!
- Documentation: `http://www.sgi.com/tech/stl/`
- Contains:
  - Classes: `vector`, `map`, `string`, I/O streams, ...
  - Algorithms: `sort`, `swap`, `copy`, `count`, ...

vector example

```
#include<vector>
#include<algorithm>
...
using namespace std;
vector<int> theVector;
theVector.push_back(3);
theVector.push_back(0);
if (theVector.size() >= 2) {
  cout << theVector[1] << endl;
}
for(vector<int>::iterator vi = theVector.begin();
      vi != theVector.end(); vi++) {
  cout << *vi << endl;
}
sort(theVector.begin(), theVector.end());
for(vector<int>::iterator vi = theVector.begin();
      vi != theVector.end(); vi++) {
  cout << *vi << endl;
}
```

map example

```
#include<map>
#include<string>
...
using namespace std;
map<string, int> phoneBook;
phoneBook["Liberti"] = 3412;
phoneBook["Baptiste"] = 3800;
for(map<string,int>::iterator mi = phoneBook.begin();
      mi != phoneBook.end(); mi++) {
   cout << mi->first << ":  " << mi->second << endl;
}
cout << phoneBook["Liberti"] << endl;
cout << phoneBook["Smith"] << endl;
for(map<string,int>::iterator mi = phoneBook.begin();
      mi != phoneBook.end(); mi++) {
   cout << mi->first << ":  " << mi->second << endl;
}
```