Lecture 10

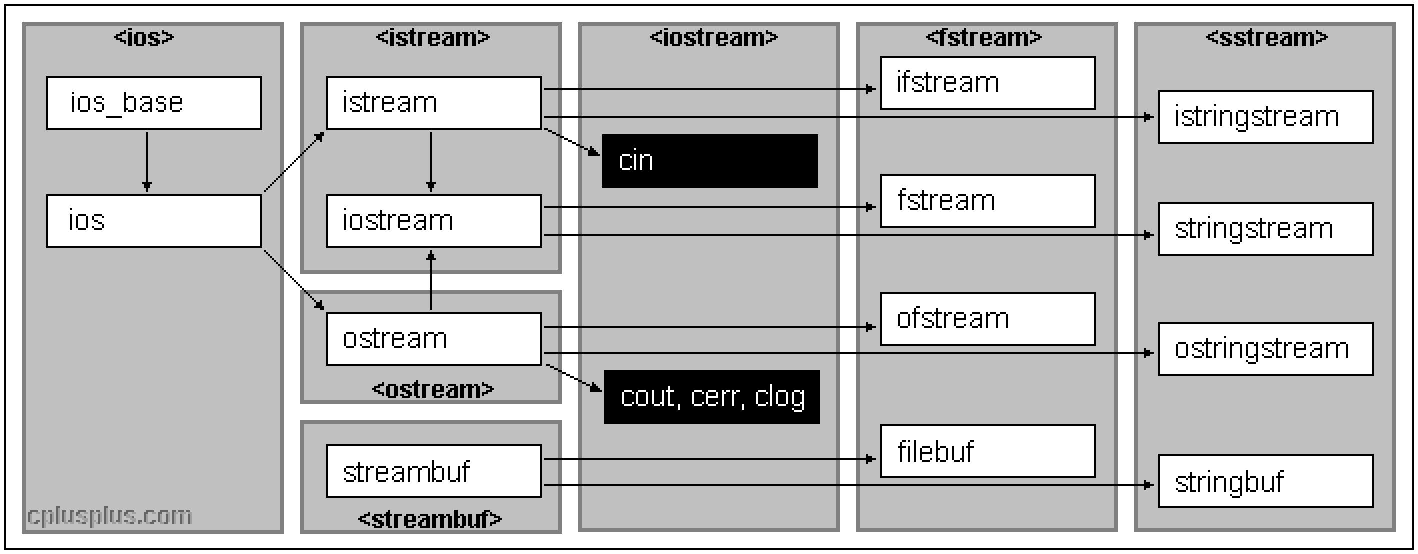
- C++ I/O
- Some useful classes in `<iostream>`
- I/O buffering
- Bit-by-bit I/O

Reading: online documentation on C++ streams

A quick tour of the C++ I/O classes

- The C++ standard library defines classes used for I/O
- We will look at some of the most important classes in that package, to understand how and why to use them
  - (For more details, see the online documentation)
- All C++ I/O class names are in the `std` namespace
- All C++ I/O classes inherit from the class `std::ios_base`
- We will mainly concetrate on the classes used for file I/O...

Class inheritance hierarchy for the C++ I/O classes



- (At the top of each column is shown the system header file that should be included in order to use the classes in that column)
- Note that **`cout`**, **`cerr`** are instances of **`ostream`**; and **`cin`** is an instance of **`istream`**
- In fact, the **`<<`** operator for output, and the **`>>`** operator for input, work for any **`ostream`** or **`istream`** object, respectively
- However, these operators do "formatted" I/O. What if you want to do raw binary I/O?

C++ iostream object error conditions

- When dealing with streams, various errors and exceptional conditions can happen (good things happen too, hopefully)
  - The stream might be corrupted or incapable of working, in some unrecoverable way
  - A particular operation might have failed, but the stream is recoverable
  - On input, the end of stream (EOF) might be reached

- With these C++ classes, these conditions are signaled by *setting flags on the stream object*, which can be inspected with member functions

- These functions are defined in the `ios` class, so are inherited by all I/O stream objects:

```
bool bad ( ) const;    // return true if "bad" flag is set
bool fail ( ) const;   // return true "bad" or "fail" flag is set
bool eof ( ) const;    // return true if "eof" flag is set
bool good ( ) const;   // return true if no flag is set
void clear ( );        // clear (i.e. unset) all flags
```

- (It is also possible to have the stream object throw an exception instead of setting a flag; see documentation for details)

C++ istream

- The `istream` class introduces member functions in common to all input streams (that is, streams used for input into your program)
- Some important ones are:

`istream& operator>> (type & val );`

  - This is the stream extraction operator. It is overloaded for many primitive types ***type***. It performs an input operation on an istream generally involving some sort of interpretation of the data (like translating a sequence of numerical characters to a value of a given numerical type). It returns a reference to the istream, so extractions can be 'chained'.

`int get();`

  - Perform basic unformatted input. Extracts a single byte from the stream and returns its value (cast to an integer).

`istream& read ( char* s, streamsize n );`

  - Perform unformatted input on a block of data. Reads a block of data of `n` bytes and stores it in the array pointed to by `s`.

C++ ostream

- The `ostream` class introduces member functions in common to all output streams (that is, streams used for output from your program)
- Some important ones are:

`ostream & operator<< (type & val );`

  - This is the stream insertion operator. It is overloaded for many primitive types ***type***. It performs an output operation on an ostream generally involving some formatting of the data (like for example writing a numerical value as a sequence of characters). It returns a reference to the ostream, so insertions can be ‘chained’.

`ostream & put(char c);`

  - Perform basic unformatted output. Writes a single byte to the stream and returns a reference to the stream.

`ostream & write ( const char* s , streamsize n );`

  - Perform unformatted output on a block of data. Write a block of data of `n` bytes starting at address `s`.

`ostream & flush ( );`

  - Any unwritten characters in the ostream’s buffer are written to its output destination as soon as possible ("flushed").

C++ ifstream and ofstream

- The **`ifstream`** class introduces functions specialized for doing input from files:

```
void open ( const char * filename,
            ios_base::openmode mode = ios_base::in );
```

  - Opens a file whose name is **`filename`**.

```
void close ( );
```

  - Closes the file associated with the stream. The stream is flushed first

- The **`ofstream`** class introduces functions specialized for doing output to files:

```
void open ( const char * filename,
            ios_base::openmode mode = ios_base::out );
```

  - Opens a file whose name is **`filename`**.

```
void close ( );
```

  - Closes the file associated with the stream.

Binary and nonbinary file streams

- Ultimately, all streams are sequences of bytes: input streams, output streams... text streams, multimedia streams, TCP/IP socket streams...
- However, for some purposes, on some operating systems, text files are handled differently from binary files
  - Line termination characters for a particular platform may be inserted or removed automatically
  - Conversion to or from a Unicode encoding scheme might be performed
- If you don't want those extra manipulations to occur, use the flag **`ios::binary`** when you open it, to specify that the file stream is a binary stream

Reading binary data from a file: an example

```
#include <fstream>
using namespace std;
/** Count and output the number of times char 'a' occurs in
  * a file named by the first command line argument. */
int main(int argc, char** argv) {
   ifstream in;
   in.open(argv[1], ios::binary);
   int count = 0;
   char ch;
   while(1) {
      ch = in.get(); // or: in.read(&ch,1);
      if(! in.good() ) break;  // failure, or eof
      if(ch == 'a') count++;  // read an 'a', count it
   }

   if(! in.eof() ) { // loop stopped for some bad reason...
      cerr << "There was a problem, sorry." << endl; return -1;
   }
   cerr << "There were " << count << " 'a' chars." << endl;
   return 0;
```

Reading formatted data from a file: an example

```
#include <fstream>
using namespace std;
/** Given a file containing whitespace delimited decimal integers
  * named by the first command line argument, output their sum */
int main(int argc, char** argv) {
   ifstream in;
   in.open(argv[1]);
   int sum = 0, n;
   while(1) {
      in >> n; // read the next integer from the ifstream
      if(! in.good() ) break;  // failure, or eof
      sum += n;  // accumulate it in the sum
   }

   if(! in.eof() ) { // loop stopped for some bad reason...
      cerr << "There was a problem, sorry." << endl; return -1;
   }
   cerr << "The sum is: " << sum << endl;
   return 0;
```

Formatted vs unformatted file output: an example

```
#include <fstream>
#include <iomanip>
int main() {
    double d = 3.1415926535;
    ofstream of1;
    of1.open("out1",ios::binary); // to force 1 byte per char
    of1 << setw(12) << d;
    of1.close();

    ofstream of2;
    of2.open("out2",ios::binary);
    of2.write((char*)&d, sizeof(d));
    of2.close();
```

- What is the resulting size of file `out1`? ______ bytes
  - What does it contain?
- What is the resulting size of file `out2`? ______ bytes
  - What does it contain?

Buffering

- The C++ I/O classes **`ofstream`**, **`ifstream`**, and **`fstream`** use *buffering*
- I/O buffering is the use of an intermediate data structure (called the buffer; usually an array used with FIFO behavior) to hold data items
  - Output buffering: the buffer holds items destined for output until there are enough of them to send to the destination; then they are sent in one large chunk
  - Input buffering: the buffer holds items that have been received from the source in one large chunk, until the user needs them
- The reason for buffering is that it is often much faster per byte to receive data from a source, or to send data to a destination, in large chunks, instead of one byte at at time
- This is true, for example, of disk files and internet sockets; even small buffers (512 or 1K bytes), can make a big difference in performance
- Also, operating system I/O calls and disk drives themselves typically perform buffering

Buffering and bit-by-bit I/O

- The standard C++ I/O classes do not have any methods for doing I/O a *bit* at a time
- The smallest unit of input or output is one *byte* (8 bits)
- This is standard not only in C++, but in just about every other language in the world
- If you want to do bit-by-bit I/O, you need to write your own methods for it
- Basic idea: use a byte as an 8-bit buffer!
  - Use bitwise shift and or operators to write individual bits into the byte, or read individual bits from it;
  - flush the byte when it is full, or done with I/O
- For a nice object-oriented design, you can define a class that extends an existing iostream class, or that delegates to an object of an existing iostream class, and that adds **`writeBit`** or **`readBit`** methods (and a **`flush`** method which flushes the 8-bit buffer)

C++ bitwise operators

- C++ has bitwise logical operators **&**, **|**, **^**, **~** and shift operators **<<**, **>>**,
- Operands to these operators can be of any integral type; the type of the result will be the same as the type of the left operand

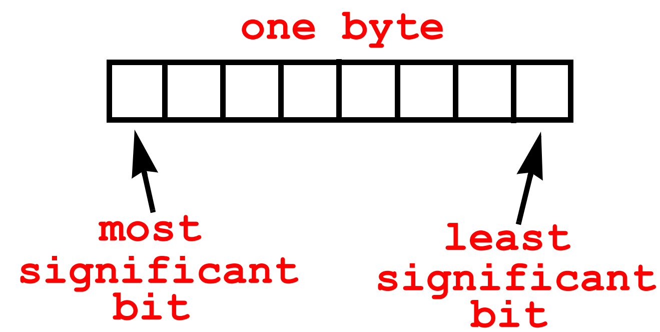
- **&** does bitwise logical **and** of its arguments;
- **|** does logical bitwise **or** of its arguments;
- **^** does logical bitwise **xor** of its arguments;
- **~** does bitwise logical **complement** of its one argument

- **<<** shifts its left argument left by number of bit positions given by its right argument, shifting in 0 on the right;
- **>>** shifts its left argument right by number of bit positions given by its right argument, shifting in the sign bit on the left if the left argument is a signed type, else shifts in 0

C++ bitwise operators: examples

```
unsigned char a = 5, b = 67;
```

a:	0	0	0	0	0	1	0	1
b:	0	1	0	0	0	0	1	1
a & b	0	0	0	0	0	0	0	1
a | b	0	1	0	0	0	1	1	1
~a	1	1	1	1	1	0	1	0
a << 4	0	1	0	1	0	0	0	0
b >> 1	0	0	1	0	0	0	0	1
(b >> 1) & 1	0	0	0	0	0	0	0	1
a | (1 << 5)	0	0	1	0	0	1	0	1



C++ bitwise operators: an exercise

- Selecting a bit: Suppose we want to return the value --- 1 or 0 --- of the nth bit from the right of a byte argument, and return the result. How to do that?

```
byte bitVal(char b, int n) {




   return
}
```

- Setting a bit: Suppose we want to set the value --- 1 or 0 --- of the nth bit from the right of a byte argument, leaving other bits unchanged, and return the result. How to do that?

```
byte setBit(char b, int bit, int n) {




   return
}
```

Defining classes for bitwise I/O

- For a nice object-oriented design, let's define a class **`BitOutputStream`** that delegates to an object of an existing iostream class, and that adds a **`writeBit`** method (and a **`flush`** method which flushes the 8-bit buffer)
- If instead **`BitOutputStream`** subclassed an existing class, it would inherit all the existing methods of its parent class, and so they become part of the subclass's interface also
  - some of these methods might be useful, but...
  - in general it will complicate the interface
- Otherwise the two design approaches are very similar to implement, except that:
  - with inheritance, BitOutputStream uses superclass methods to perform operations
  - with delegation, BitOutputStream uses methods of a contained object to perform operations
- We will also consider a **`BitInputStream`** class, for bitwise input

Outline of a BitOutputStream class, using delegation

```
#include <iostream>
class BitOutputStream {
private:
   char buf;                // one byte buffer of bits
   int nbits;               // how many bits have been written to buf
   std::ostream & out;      // reference to the output stream to use
public:

   /** Initialize a BitOutputStream that will use
     * the given ostream for output.
     */
   BitOutputStream(std::ostream & os) : out(os) {
      buf = nbits = 0;   // clear buffer and bit counter
   }

   /** Send the buffer to the output, and clear it */
   void flush() {
      os.put(buf);
      os.flush();
      bit_buf = nbits = 0;
   }
```

Outline of a BitOutputStream class, using delegation (cont'd)

```
/** Write the least significant bit of the argument to
  * the bit buffer, and increment the bit buffer index.
  * But flush the buffer first, if it is full.
  */
void writeBit(int i)  {
   // Is the bit buffer full? Then flush it



   // Write the least significant bit of i into the buffer
   // at the current index



   // Increment the index

}
```

Outline of a BitInputStream class, using delegation

```
#include <iostream>
class BitInputStream {
private:
   char buf;              // one byte buffer of bits
   int nbits;             // how many bits have been read from buf
   std::istream & in;     // the input stream to use
public:

   /** Initialize a BitInputStream that will use
     * the given istream for input.
     */
   BitOutputStream(std::istream & is) : in(is) {
      buf = 0;  // clear buffer
      nbits = ?? // initialize bit index
   }

   /** Fill the buffer from the input */
   void fill() {
      buf = in.get();
      nbits = 0;
   }
```

Outline of a BitInputStream class, using delegation (cont'd)

```
/** Read the next bit from the bit buffer.
  * Fill the buffer from the input stream first if needed.
  * Return 1 if the bit read is 1;
  * return 0 if the bit read is 0.
  *
  */
int readBit() {
   // If all bits in the buffer are read, fill the buffer first




   // Get the bit at the appriopriate location in the bit
   // buffer, and return the appropriate int




   // Increment the index

}
```

The std::bitset class template

- The STL provides the `bitset` class template that can be useful when needing to manipulate individual bits
  - `#include <bitset>` to access the relevant declarations

- The `bitset` class template takes one template parameter: an integer, specifying how many bits the bitset contains. So to create a bitset containing 8 bits:

```
bitset<8> buf;
```

- By default, a bitset is created with all its bits 0. But the class template overloads the array indexing `operator[]` to enable reading and writing individual bits in the bitset as if they were elements of an array:

```
buf[0] = 1;   // set least-significant bit to 1
buf[2] = 1;   // set bit indexed 2 to 1
int b = buf[7];  // access bit indexed 7 as an int
```

- See the documentation of bitset for more information about its API

Next time

- Graphs
- Vertices, edges, paths, cycles
- Sparse and dense graphs
- Representations: adjacency matrices and adjacency lists
- Implementation notes

Reading: Weiss, Chapter 9