DM560

Introduction to Programming in C++

Input/Output Streams

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[*Based on slides by Bjarne Stroustrup*]

Outline

1. Input and Output Streams

2. Reading from a File

3. Example: Error Handling

4. User-Defined Output

Outline

- Fundamental I/O concepts
- Files
  - Opening
  - Reading and writing streams
- I/O errors
- Reading a single integer

Outline

1. Input and Output Streams
2. Reading from a File
3. Example: Error Handling
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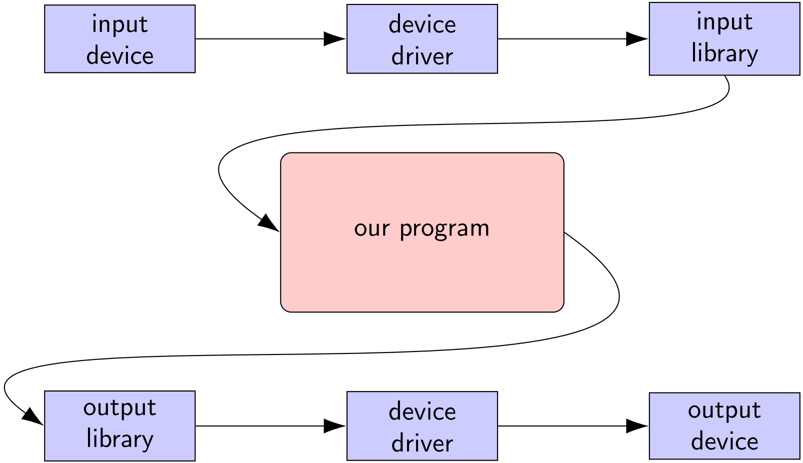
Input and Output



input device

device driver

input library

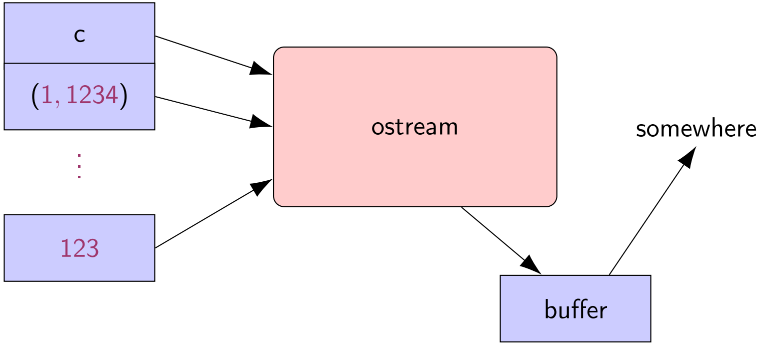
our program

output library

device driver

output device

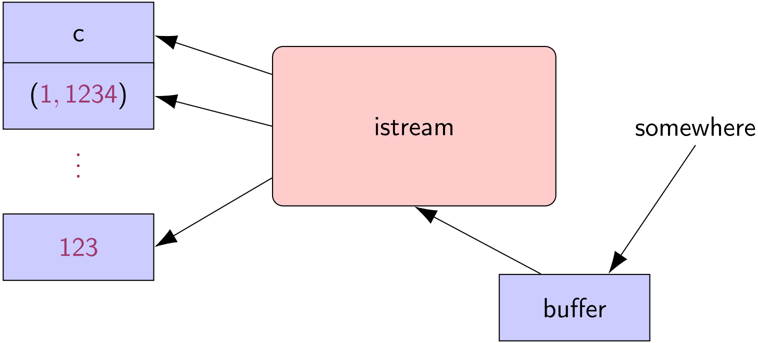
The Stream Model



An ostream

- turns values of various types into character sequences
- sends those characters somewhere (e.g., console, file, main memory, another computer)

The Stream Model



An istream

- turns character sequences into values of various types
- gets those characters from somewhere (e.g., console, file, main memory, another computer)

The Stream Model

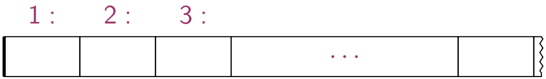
Reading and writing

- Of typed entities
  - << (output) and >> (input) plus other operations
  - Type safe
  - Formatted
- Typically stored (entered, printed, etc.) as text
  But not necessarily (e.g. see binary streams chp. 11)
- Extensible: You can define your own I/O operations for your own types
- A stream can be attached to any I/O or storage device

Files

- We turn our computers on and off
  The contents of our main memory is transient
- We keep what we want to preserve on disks and similar permanent storage
- A **file** is a sequence of bytes stored in permanent storage
  - A file has a name
  - The data on a file has a format
- We can read/write a file if we know its name and format

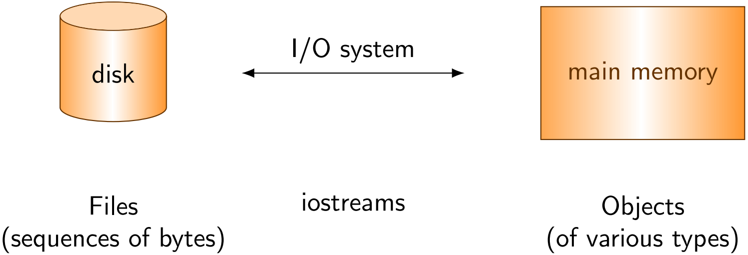
A File



- At the fundamental level, a file is a sequence of bytes numbered from 0 upwards
- Other notions can be supplied by programs that interpret a file format:
  For example, the 6 bytes "123.45"might be interpreted as the floating-point number 123.45

Files

General model:



disk

I/O system

main memory

Files
(sequences of bytes)

iostreams

Objects
(of various types)

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Files

- To **read** a file
  - We must know its name
  - We must open it (for reading)
  - Then we can read
  - Then we must close it (typically done implicitly)

- To **write** a file
  - We must name it
  - We must open it (for writing) or create a new file of that name
  - Then we can write it
  - We must close it (typically done implicitly)

Opening a File for Reading

```
// ...
int main()
{
    cout << "Please enter input file name: ";
    string iname;
    cin >> iname;
    ifstream ist {iname};       // ifstream is an "input stream from a file"
                                // defining an ifstream with a name string
                                // opens the file of that name for reading
    if (!ist) error("can't open input file ", iname);
    // ...
```

Opening a File for Writing

```
    // ...
    cout << "Please enter name of output file: ";
    string oname;
    cin >> oname;
    ofstream ofs {oname};    // ofstream is an "output stream from a file"
                              // defining an ofstream with a name string
                              // opens the file with that name for writing
    if (!ofs) error("can't open output file ", oname);
    //...
}
```

Reading from a File

- Suppose a file contains a sequence of pairs representing hours and temperature readings

```
0 60.7
1 60.6
2 60.3
3 59.22
```

- The hours are numbered 0..23
- No further format is assumed (Maybe we can do better than that, but not just now)
- Termination
  - Reaching the end of file terminates the read
  - Anything unexpected in the file terminates the read (e.g., q)

Reading a File

```
struct Reading {        // a temperature reading
   int hour;    // hour after midnight [0:23]
   double temperature;
};

vector<Reading> temps;  // create a vector to store the readings

int hour;
double temperature;
while (ist >> hour >> temperature) {                            // read
   if (hour < 0 || 23 <hour) error("hour out of range");        // check
   temps.push_back( Reading{hour,temperature} );                // store
}
```

I/O Error Handling

- Sources of errors
  - Human mistakes
  - Files that fail to meet specifications
  - Specifications that fail to match reality
  - Programmer errors
  - ...

- `iostream` reduces all errors to one of four states
  - `good() //the operation succeeded`
  - `eof() //we hit the end of input ("end of file")`
  - `fail() //something unexpected happened`
  - `bad() //something unexpected and serious happened`

Sample Integer Read "Failure"

- Ended by “terminator character”
  - `1 2 3 4 5 *`
  - State is `fail()`
- Ended by format error
  - 1 2 3 4 5.6
  - State is `fail()`
- Ended by “end of file”
  - `1 2 3 4 5` end of file
  - `1 2 3 4 5` Control-Z (Windows)
  - `1 2 3 4 5` Control-D (Unix)
  - State is `eof()`
- Something really bad
  - Disk format error
  - State is `bad()`

I/O Error Handling

```
void fill_vector(istream& ist, vector<int>& v, char terminator)
{
   // read integers from ist into v until we reach eof() or terminator
   for (int i; ist >> i; )   // read until "some failure"
      v.push_back(i);        // store in v
   if (ist.eof()) return;    // fine: we found the end of file
   if (ist.bad()) error("ist is bad"); // stream corrupted; let's get out of here!

   if (ist.fail()) {   // clean up the mess as best we can and report the problem
      ist.clear();     // clear stream state,  so that we can look for terminator
      char c;
      ist >> c;        // read a character, hopefully terminator
      if (c != terminator) {    // unexpected character
         ist.unget();           // put that character back
         ist.clear(ios_base::failbit);  // set the state back to fail()
      }
   }
}
```

Throw an Exception for `bad()`

```
// How to make ist throw if it goes bad:
ist.exceptions(ist.exceptions()|ios_base::badbit);

// can be read as
// "set ist's exception mask to whatever it was plus badbit"
// or as "throw an exception if the stream goes bad"
```

Given that, we can simplify our input loops by no longer checking for bad

Simplified Input Loop

```
void fill_vector(istream& ist, vector<int>& v, char terminator)
{
   // read integers from ist into v until we reach eof() or terminator
   for (int i; ist >> i; )
      v.push_back(i);
   if (ist.eof()) return;         // fine: we found the end of file

   // not good() and not bad() and not eof(), ist must be fail()
   ist.clear();         // clear stream state
   char c;
   ist >> c;            // read a character, hopefully terminator
   if (c != terminator) {         // ouch: not the terminator, so we must fail
        ist.unget();    // maybe my caller can use that character
        ist.clear(ios_base::failbit);   // set the state back to fail()
   }
}
```

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Reading a Single Value

```
// first simple and flawed attempt:

cout << "Please enter an integer in the range 1 to 10 (inclusive):\n";
int n = 0;
while (cin>>n) {                        // read
   if   (1<=n && n<=10) break;  // check range
   cout << "Sorry, "
        << n
        << " is not in the [1:10] range; please try again\n";
}

// use n here
```

Three kinds of problems are possible

- the user types an out-of-range value
- getting no value (end of file)
- the user types something of the wrong type (here, not an integer)

Reading a Single Value

What do we want to do in those three cases?

- handle the problem in the code doing the read?
- throw an exception to let someone else handle the problem (potentially terminating the program)?
- ignore the problem?

Reading a single value

- Is something we often do many times
- We want a solution that is very simple to use

Handle Everything: What a Mess!

```
cout << "Please enter an integer in the range 1 to 10 (inclusive):\n";
int n = 0;
while (cin >> n) {
   if (cin) {   // we got an integer; now check it:
      if (1<=n && n<=10) break;
      cout << "Sorry, " << n << " is not in the [1:10] range; please try again\n";
   }
   else if (cin.fail()) {       // we found something that wasn't an integer
      cin.clear();      // we'd like to look at the characters
      cout << "Sorry, that was not a number; please try again\n";
      for (char ch; cin>>ch && !isdigit(ch); )  // throw away non-digits
        /* nothing */ ;
      if (!cin) error("no input");      // we didn't find a digit: give up
      cin.unget();      // put the digit back, so that we can read the number
   }
   else
      error("no input");        // eof or bad: give up
}
// if we get here n is in [1:10]
```

The Mess: Trying to Do Everything at Once

- Problem: We have all mixed together
  - reading values
  - prompting the user for input
  - writing error messages
  - skipping past "bad" input characters
  - testing the input against a range
- Solution: Split it up into logically separate parts

What Do We Want?

What logical parts do we want?

- `int get_int(int low, int high);` read an int in `[low..high]` from cin
- `int get_int();` read an int from cin so that we can check the range int
- `void skip_to_int();` we found some “garbage” character so skip until we find an int

Separate functions that do the logically separate actions

Skip “Garbage” and Get (Any) Integer

```
void skip_to_int()
{
   if (cin.fail()) {    // we found something that wasn’t an integer
      cin.clear();      // we’d like to look at the characters
      for(char ch; cin>>ch; ) { // throw away non-digits
         if (isdigit(ch) || ch=='-') {
            cin.unget();        // put the digit back, to read the number
            return;
         }
      }
   }
   error("no input");   // eof or bad: give up
}
```

```
int get_int()
{
   int n = 0;
   while (true) {
      if (cin >> n) return n;
      cout << "Sorry, that was not a number; please try again\n";
      skip_to_int();
   }
}
```

Get Integer in Range

```
int get_int(int low, int high)
{
    cout << "Please enter an integer in the range "
         << low << " to " << high << " (inclusive):\n";
    while (true) {
        int n = get_int();
        if (low<=n && n<=high) return n;
        cout << "Sorry, "
             << n << " is not in the [" << low << ’:’ << high
             << "] range; please try again\n";
    }
}
```

Usage:

```
int n = get_int(1,10);
cout << "n: " << n << endl;

int m = get_int(2,300);
cout << "m: " << m << endl;
```

⇝ Problem: the dialog is built into the read operations

What Do We Really Want?

- That’s often the really important question
- Ask it repeatedly during software development
- As you learn more about a problem and its solution, your answers improve

```
// parameterize by integer range and "dialog"

int strength = get_int(1, 10,
                                "enter strength",
                                "Not in range, try again");
cout << "strength: " << strength << endl;

int altitude = get_int(0, 50000,
                                "please enter altitude in feet",
                                "Not in range, please try again");
cout << "altitude: " << altitude  << "ft. above sea level\n";
```

Parametrize

```
int get_int(int low, int high, const string& greeting, const string& sorry)
{
    cout << greeting << ": [" << low << ':' << high << "]\n";
    while (true) {
        int n = get_int();
        if (low<=n && n<=high) return n;
        cout << sorry  << ": [" << low << ':' << high << "]\n";
    }
}
```

Incomplete parameterization: `get_int()` still “blabbers”

- “utility functions” should not produce their own error messages
- Serious library functions do not produce error messages at all
  They throw exceptions (possibly containing an error message)

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User-Defined Output: Operator <<()

```
ostream& operator<<(ostream& os, const Date& d)
{
   return os << '(' << d.year()
             << ',' << d.month()
             << ',' << d.day() << ')';
}
```

Use:

```
void do_some_printing(Date d1, Date d2)
{
   cout << d1;            // means operator<<(cout,d1) ;

   cout << d1 << d2;
         // means (cout << d1)  <<  d2;
         // means (operator<<(cout,d1)) <<  d2;
         // means operator<<((operator<<(cout,d1)), d2) ;
}
```

User-Defined Input: Operator >>()

```
istream& operator>>(istream& is, Date& dd)
// Read date in format: ( year , month , day )
{
   int y, d, m;
   char ch1, ch2, ch3, ch4;
   is >> ch1 >> y >> ch2 >> m >> ch3 >> d >> ch4;
   if (!is) return is;   // we didn't get our values, so just leave
   if (ch1!='(' || ch2!=',' || ch3!=',' || ch4!=')') {   // oops: format error
      is.clear(ios_base::failbit);      // something wrong: set state to fail()
      return is;         // and leave
   }
   dd = Date{y,Month(m),d};   // update dd
   return is;           // and leave with is in the good() state
}
```

Summary

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