deep se

dependable evolvable pervasive software engineering group

Streams & I/O

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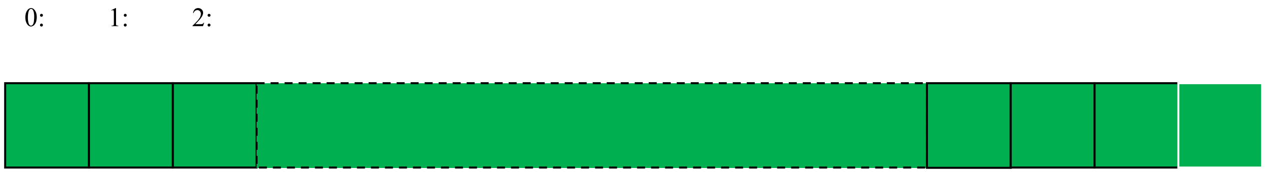
Content

- Fundamental I/O concepts
- Files
  - Opening
  - Reading and writing streams
- File modes and Binary I/O
- String streams
  - Line-oriented input
- Examples

Files

- We turn our computers on and off
  - The contents of its main memory is transient
- Data needs to be preserved
  - It must be stored on disks and similar permanent storage devices
- 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

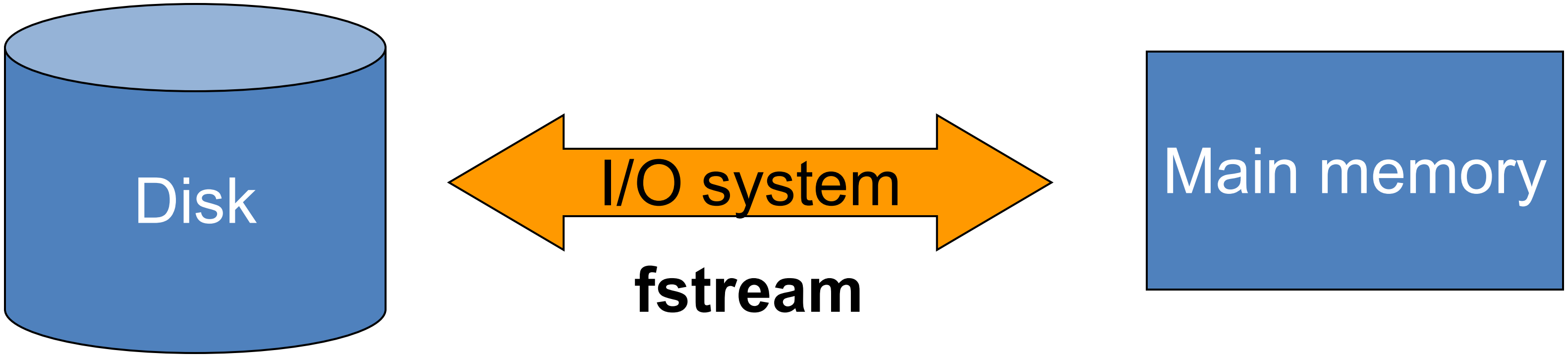
A file



- 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 corresponding to "123.45" might be interpreted as the floating-point number 123.45

Files

- General model



Disk

I/O system

fstream

Main memory

Files
(sequences of bytes)

Objects
(of various types)

Files

- To **read** a file
  - We must know its name
  - We must open it (for reading)
  - Then we can read it
  - Once finished, we must close it
    - That is typically done implicitly (when the stream object is destroyed)
- 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
  - Once finished, we must close it
    - That is typically done implicitly (when the stream object is destroyed)

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);
    // …
}
```

Implicit close

- When an **fstream** object goes out of scope, the file it is bound to is automatically closed

```
if (read) {
      // create input and open the file
      ifstream input{name};
      if (input) {  // if the file is ok, "process" this file
            process(input);
      } else
            cerr << "couldn't open: " + ;
      } // input goes out of scope and is destroyed on each iteration
}
```

Reading from a file

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

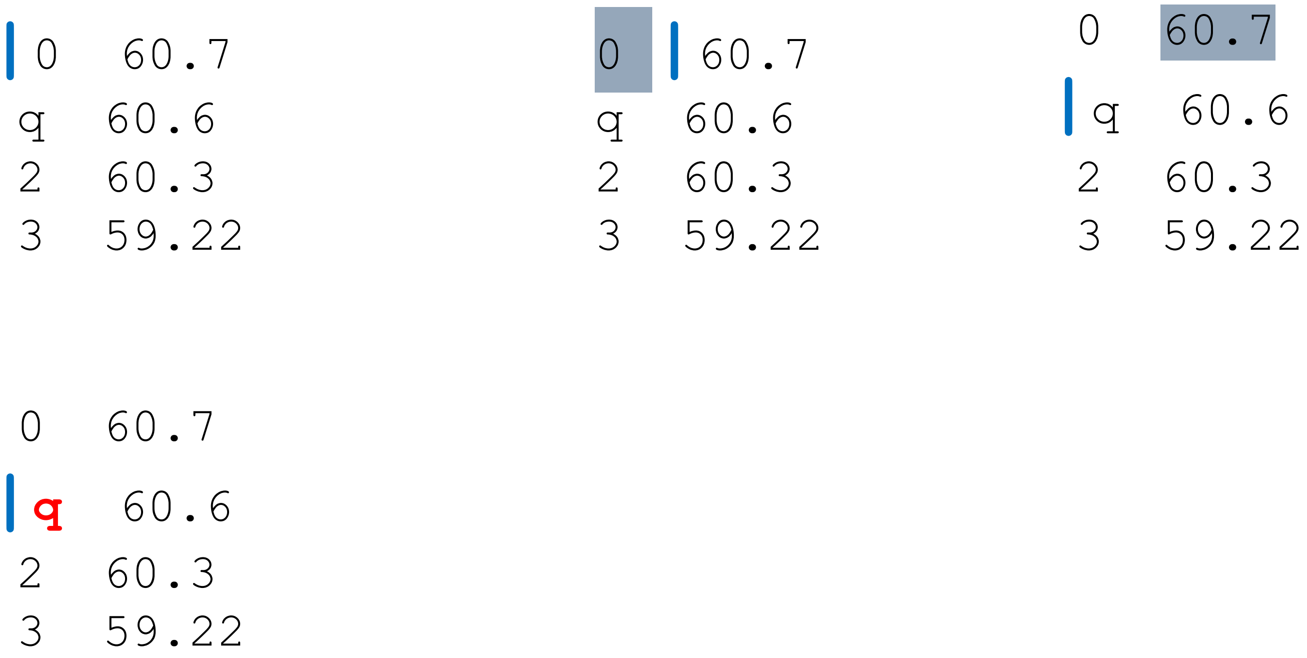
```
0   60.7
1   60.6
2   60.3
3   59.22
```

- The hours are numbered from **0** to **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., character ‘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;
ifstream ist{fname};
while (ist >> hour >> temperature) {                  // read
     if (hour < 0 || 23 <hour)
           cout << "hour out of range” <<endl;
     temps.push_back( Reading{hour, temperature} ); // store
}
```

```
ifstream ist{fname};
while (ist >> hour >> temperature) {.   // read
      temps.push_back( Reading{hour, temperature} ); // store
}
```



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

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

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

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

No Copy or Assign for I/O Objects

- **We cannot copy or assign objects of the IO types:**

```
ofstream out1, out2;
out1 = out2; // error: cannot assign stream objects ofstream
ofstream print(ofstream); // error: can't initialize the ofstream param
out2 = print(out2); // error: cannot copy stream objects
```

Because we can't copy the IO types, we cannot have a parameter or return type that is one of the stream types

- Functions that do IO typically pass and return the stream through **references**
- Reading or writing an IO object changes its state, so the reference **must not be const**

```
void print(ofstream&); // OK
```

Use

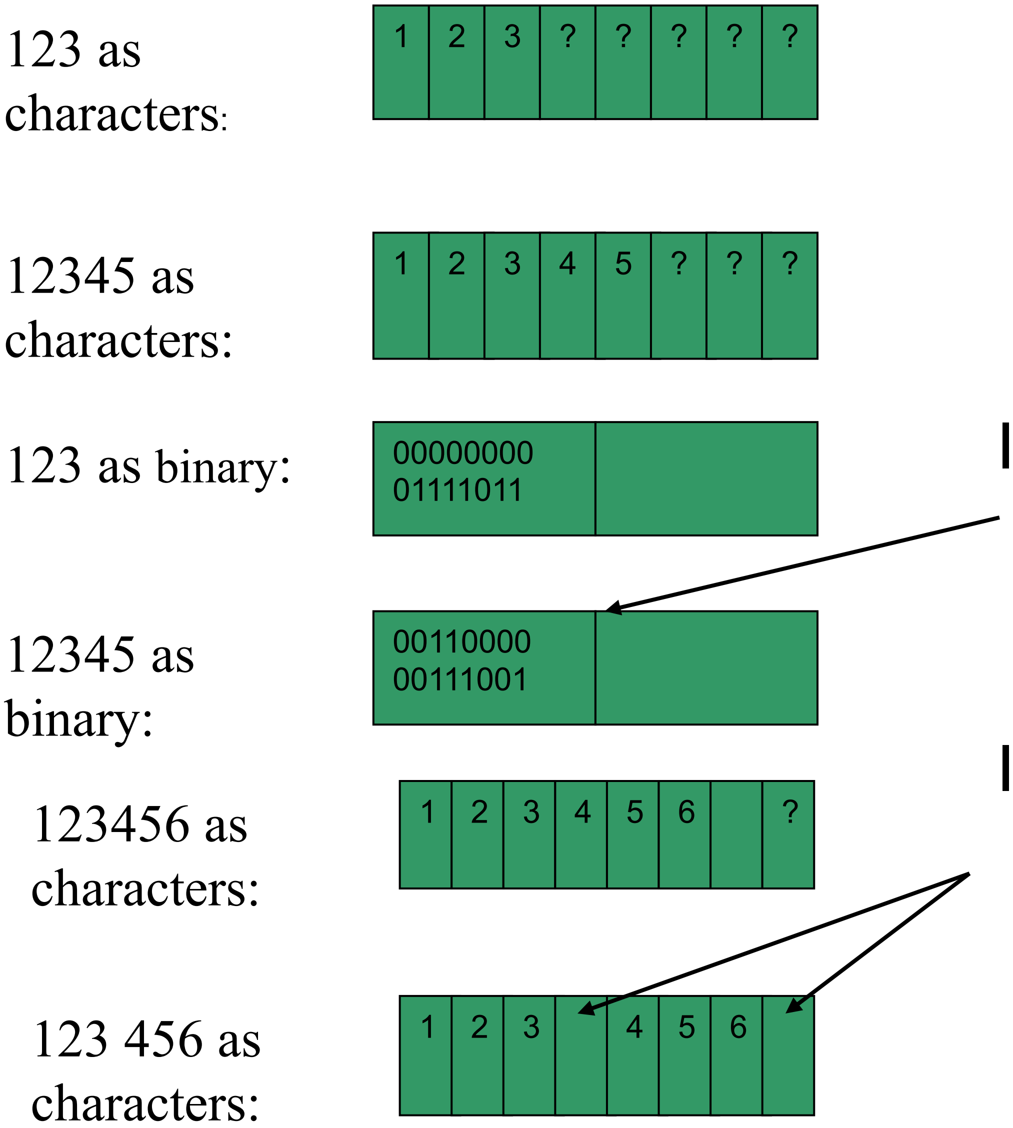
```
void do_some_printing(Date d1, Date d2)
{
  cout << d1; // means:
              // operator<<(cout,d1) ;

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

File Modes and Binary I/O

File open modes

- By default, an ifstream opens its file for reading
- By default, an ofstream opens its file for writing.
- Alternatives:
  - ios_base::**app** // append (i.e., output adds to the end of the file)
  - ios_base::**ate** // “at end” (open and seek to end)
  - ios_base::**binary** // binary mode – beware of system specific behavior
  - ios_base::**in** // for reading
  - ios_base::**out** // for writing
  - ios_base::**trunc** // truncate file to 0-length
- A file mode is optionally specified after the name of the file:
  - **ofstream** of1 {name1}; // defaults to **ios_base::out**
  - **ifstream** if1 {name2}; // defaults to **ios_base::in**
  - ofstream ofs {name, **ios_base**::**app**}; // append rather than overwrite
  - fstream fs {"myfile", **ios_base::in | ios_base::out**}; // both in and out

Text vs. binary files



123 as characters:	1	2	3	?	?	?	?	?
12345 as characters:	1	2	3	4	5	?	?	?
123 as binary:	00000000 01111011							
12345 as binary:	00110000 00111001							
123456 as characters:	1	2	3	4	5	6		?
123 456 as characters:	1	2	3		4	5	6	

In binary files, we use sizes to delimit values

In text files, we use separation/termination characters

Text vs. binary

- Use text when you can
  - You can read it (without a fancy program)
  - You can debug your programs more easily
  - Text is portable across different systems
  - Most information can be represented reasonably as text
- Use binary when you must
  - E.g. image files, sound files

String Streams

String streams

- A **stringstream** reads/writes from/to a **string** rather than a file or a keyboard/screen

```
double str_to_double(string s)
// if possible, convert characters in s to floating-point value
{
    istringstream is {s};// make a stream so that
                         // we can read from s
    double d;
    is >> d;
    if (!is) error("double format error: ",s);
    return d;
}

double d1 = str_to_double("12.4");      // testing
double d2 = str_to_double("1.34e-3");
double d3 = str_to_double("twelve point three");// error
```

String streams

- See textbook for **ostringstream**

- String streams are very useful for
  - formatting into a fixed-sized space (think GUI)
  - for extracting typed objects out of a string

Type vs. line

- Read a string

```
string name;
cin >> name;                 // input: Dennis Ritchie
cout << name << '\n';        // output: Dennis
```

- Read a line

```
string name;
getline(cin,name);           // input: Dennis Ritchie
cout << name << '\n';        // output: Dennis Ritchie
// now what?
// maybe:
istringstream ss{name};
ss >> first_name;
ss >> second_name;
```

Examples

Example 1: reading a CSV file

- An istringstream is often used when we have some work to do on an entire line, and other work to do with individual words within a line

```
Morgan,2015552368,8625550123
Drew,9735550130
Lee,6095550132,2015550175,8005550000
```

// members are public by default

```
struct PersonInfo {
  string name;
  vector<string> phones;
};
```

```
 vector<PersonInfo> people; // will hold all the records from the input
 string line;
 ifstream data("data.csv");

// read the input a line at a time until cin hits end-of-file (or another error)
while ( getline(data, line) ) {
    PersonInfo info; // create an object to hold this record's data
    istringstream record(line); // bind record to the line we just read

    // read the name
    // note that we are changing the delimenter of getline to “,”
    getline(record, info.name, ',’) ;
    string phone;
    // read the phone numbers
    while (getline(record, phone, ',’)){
      info.phones.push_back(phone); // and store them
    }
    people.push_back(info); // append this record to people
}
```

Example 2: A Word Transformation Map

Write a program that given one string, transforms it into another. The input to our program is two files. The first file contains **rules** that we will use **to transform** the **text** in the second file. Each rule consists of a word that might be in the input file and a phrase to use in its place.

word-transformation file:

```
y why
r are
u you
```

second file:

```
where r u
```

output file:

```
where are you
```

DEMO

An example: A Word Transformation Map

```
void word_transform(ifstream &map_file, ifstream &input)
{
auto trans_map = buildMap(map_file);
string text;
while (getline(input, text)) {
       istringstream stream(text);
       string word;
       bool firstword = true;
       while (stream >> word) {
              if (firstword)
                     firstword = false;
              else
                     cout << " ";
              cout << transform(word, trans_map);
       }
       cout << endl;
}
}
```

An example: A Word Transformation Map

```
map<string, string> buildMap(ifstream &map_file)
{
map<string, string> trans_map;
string key;
string value;
while (map_file >> key && getline(map_file,
                                   value))
     if (value.size() > 1)
           trans_map[key] = value.substr(1);
     else
           cout << "no rule for " + key << endl;
return trans_map;
}
```

An example: A Word Transformation Map

```
const string &
transform(const string &s, const map<string,
                                     string> &m)
{
auto map_it = m.find(s);
if (map_it != m.cend())
      // if this word is in the transformation map
      return map_it->second;
else
      return s;
}
```

Readings

User-defined output: operator<<()

- Usually **trivial:**

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

- We often use several different ways of outputting a value
  - Tastes for output layout and detail vary

User-defined input: operator>>()

```
istream& operator>>(istream& is, Date& dd)
 // Read date in format: year month day
{
 int y, d, m;
 if (is >> y >> m >> d){
      dd = Date{y,m,d};  // update dd
 }
 return is;
}
```

Binary files

```
int main()    // use binary input and output
{
 cout << "Please enter input file name\n";
 string iname;
 cin >> iname;
 ifstream ifs {iname, ios_base::binary};// note: binary
 if (!ifs) error("can't open input file ", iname);

 cout << "Please enter output file name\n";
 string oname;
 cin >> oname;
 ofstream ofs {oname, ios_base::binary};// note: binary
 if (!ofs) error("can't open output file ", oname);


 // "binary" tells the stream not to try anything clever operation
 //  with the bytes
```

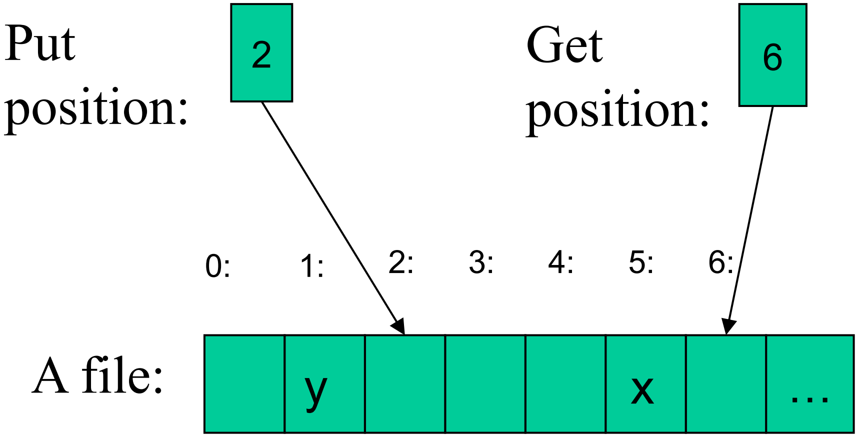
Binary files

```
  vector<int> v;

  // read from binary file:
  for (int i; ifs.read(as_bytes(i), sizeof(int)); )
  // note: reading bytes
          v.push_back(i);

  // … do something with v …

  // write to binary file:
  for(int i=0; i<v.size(); ++i)
          ofs.write(as_bytes(v[i]), sizeof(int));// note: writing
                                                 // bytes
  return 0;
}

// For now, treat as_bytes() as a primitive
// Warning!  Beware transferring between different systems
```

Positioning in a filestream

- To support random access, the system maintains a marker that determines where the next read or write will happen
- We also have two functions:
  - One **repositions the marker** by seeking to a given position
  - The second **tells the current position** of the marker
- The library actually defines two pairs of seek and tell functions:
  - One pair is used by input streams, the other by output streams
  - The input and output versions are distinguished by a suffix that is either a **g** (“getting”, i.e. reading data), or **p** (“putting”, i.e. writing data)

Positioning in a filestream



```
fstream fs {name};  // open for input and output
// …
fs.seekg(5);   // move reading position ( ‘g’ for ‘get’) to 5 (the 6th character)
char ch;
fs>>ch;        // read the x and increment the reading position to 6
cout << "sixth character is " << ch << '(' << int(ch)
    << ")\n";
fs.seekp(1);   // move writing position ( ‘p’ for ‘put’) to 1 (the 2nd character)
fs<<'y';                // write and increment writing position to 2
```

Positioning in a filestream

- We can use only the **g** versions on an **istream** and on the types that inherit from it, **ifstream** and **istringstream**

- We can use only the **p** versions on an **ostream** and on the types that inherit from it, **ofstream** and **ostringstream**

- An **iostream**, **fstream**, or **stringstream** can both **read** and **write** the associated stream; we can use either the **g** or **p** versions on objects of these types

There Is Only One Marker

- The fact that the library distinguishes between the “**putting**” and “**getting**” versions of the **seek** and **tell** functions can be misleading
- Even though the library makes this distinction, **it maintains only a single marker in a stream** — there are no distinct **read** and **write** markers

Repositioning the Marker

```
// set the marker to a fixed position
seekg(new_position);  // set the read marker to the given pos_type
                      // location
seekp(new_position);  // set the write marker to the given pos_type
                      // location
// offset some distance ahead of or behind the given starting point
seekg(offset, from);  // set the read marker offset distance from
from seekp(offset, from);  // offset has type off_type
```

Reading and writing to the same file

abcd

efg

hi

j

→

abcd

efg

hi

j

5 9 12 14

Reading and writing to the same file

```
int main()
{
      // open for input and output and preposition file pointers to end-of-file
      // file mode argument
      fstream inOut("copyOut", fstream::ate | fstream::in |
                                    fstream::out);
      if (!inOut) {
            cerr << "Unable to open file!" << endl;
            return EXIT_FAILURE;//EXIT_FAILURE
      }
      // inOut is opened in ate mode, so it starts out positioned at the end
      auto end_mark = inOut.tellg();// remember original end-of-file
                                  // position
      inOut.seekg(0, fstream::beg); // reposition to the start of the file
      size_t       cnt = 0; // accumulator for the byte count string line;
      string line;  // hold each line of input
```

Reading and writing to the same file

```
    // while we haven't hit an error and are still reading the original
    // data and can get another line of input
    while (inOut && inOut.tellg() != end_mark
            && getline(inOut, line))
    {
            cnt += line.size() + 1; // add 1 to account for the newline
            auto mark = inOut.tellg(); // remember the read position
            inOut.seekp(0, fstream::end); // set the write marker to the end
            inOut << cnt; // write the accumulated length
            // print a separator if this is not the last line
            if (mark != end_mark) inOut << " ";
            inOut.seekg(mark); // restore the read position
    }
    inOut.seekp(0, fstream::end); // seek to the end
    inOut << "\n"; // write a newline at end-of- file
    return 0;
}
```

Positioning

- Whenever you can
  - Use simple streaming
    - Streams/streaming is a very powerful metaphor
    - Write most of your code in terms of "plain" istream and ostream
  - Positioning is far more error-prone
    - Handling of the end of file position is system dependent and basically unchecked

Using ostringstreams

- An **ostringstream** is useful when we need to build up our output a **little at a time** but **do not** want to print the output **until later**
- For example, we might want to validate and reformat the phone numbers we read in the previous example
  - If all the numbers are valid, we want to print a new file containing the reformatted numbers
  - If a person has any invalid numbers, we won't put them in the new file. Instead, we'll write an error message containing the person's name and a list of their invalid numbers

Using ostringstreams

```
for (const auto &entry : people) { // for each entry in people
    ostringstream formatted, badNums; // objects created on each loop
    for (const auto &nums : entry.phones) { // for each number
       if (!valid(nums)) {
             badNums << " " << nums; // string in badNums
       } else
       // "writes" to formatted's string
             formatted << " " << format(nums);
       }
       if (badNums.str().empty()) // there were no bad numbers
             os << entry.name << " " // print the name
             << formatted.str() << endl; // and reformatted numbers
       else
             // otherwise, print the name and bad numbers
             cerr << "input error: " << entry.name
             << " invalid number(s) " << badNums.str() << endl;
}
```

References

- Lippman Chapters 8, 17

Credits

- Bjarne Stroustrup. www.stroustrup.com/Programming