Topic 3 (Part IV: I/O Libraries and Exception Handling)

C++ advanced features review: *when can/should I use them?*

資料結構與程式設計

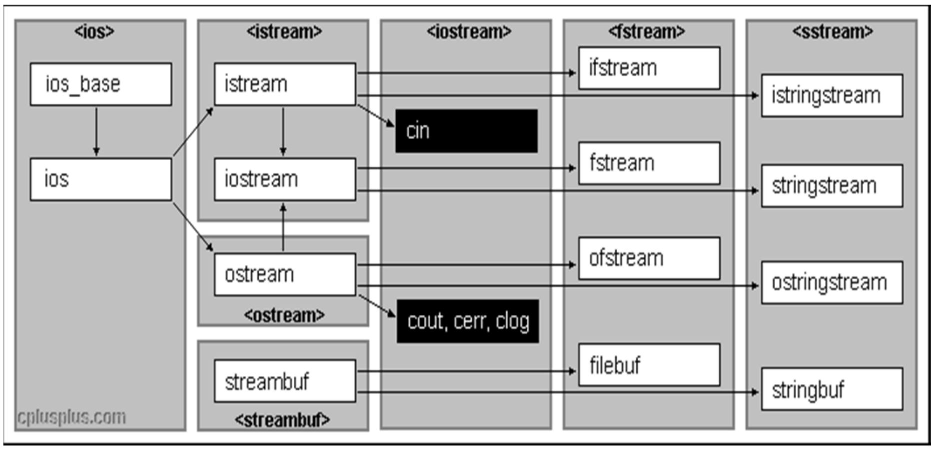
Data Structure and Programming

Sep, 2011

Outline

- C++ standard I/O
  - Introduction
  - Class hierarchy and included files
  - Class data members and member functions
  - I/O manipulators
  - Tying istream to ostream
- File I/O
- String stream

Key Concept #1: C++ Stream Classes



For more information, recommended:
http://www.cplusplus.com/reference/iostream/

Stream classes, objects, and manipulators

- "Stream", a nice name
  - ➔ Data are conveyed in a steam by "<<" or ">>"

1. Header files
   - iostream, fstream, sstream, iomanip
2. Classes
   - istream, ostream, iostream, ifstream, ofstream, fstream, istringstream, ostringstream
3. Objects
   - Standard: cin, cout, cerr, clog
   - User defined
4. Manipulators
   - dec, endl, ends, flush, hex, oct, left, right, ws, setbase(n), setw(n), setioflags(i), resetioflags(i), setfill(c), setprecision(n)
5. Member functions

C++ Standard I/O Library Files

- `<iostream>`
  - Basic services for ALL stream-I/O operations
  - Defines `cin`, `cout`, `cerr` and `clog`
  - For both unformatted- and formatted-I/O services
- `<iomanip>`
  - Formatted I/O with parameterized stream manipulators
- `<fstream>`
  - User-controlled file processing
- `<sstream>`
  - String manipulations as I/O stream

Key Concept #2: Standard I/O Stream Objects

Standard Input

- `cin`
  - Connected to the standard input device, usually the keyboard

Standard Output

- `cout`
  - Connected to the standard output device, usually the display screen
- `cerr`
  - Connected to the standard error device
  - Unbuffered - output appears immediately
- `clog`
  - Connected to the standard error device
  - Buffered - output is held until the buffer is filled or flushed

Key Concept #3: User Defined Stream Objects

- File I/O

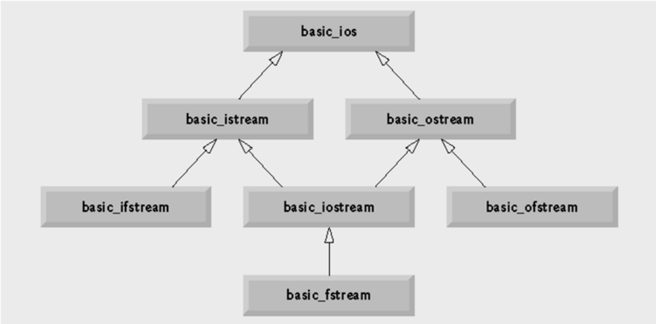
```
ifstream inFile("test.in");
ofstream outFile("test.out");
fstream ioFile;
if (!inFile) {
   cerr << "Cannot open file" << endl;
   exit(0);
}
int i, j, k;
inFile >> i >> j >> k;
outFile.close();
ioFile.open("test.io");
```


Key Concept #4: File Stream

- A file is viewed by C++ as a sequence of bytes
- Ends either with an end-of-file marker or at a system-recorded byte number (Why diff?)
- Communication between a program and a file is performed through stream objects
  - `<fstream>` header file
    - Stream class templates
      - `basic_ifstream` – for file input
      - `basic_ofstream` – for file output
      - `basic_fstream` – for file input and output
    - Files are opened by creating objects of stream template specializations
      - (i/o)fstream are the char-type template specializations

(FYI) basic_iostream

- Actually, in <iostream>, the I/O stream classes are defined as basic_iostream template classes
  - template <class Elem, class Tr = char_traits<Elem> >
    class basic_iostream : public basic_istream<Elem, Tr>,
    public basic_ostream<Elem, Tr>
    { ... };



(FYI) iostream vs. basic_iostream

- `istream`
  - typedef basic_iostream<char, char_traits<char> > iostream;
  - Represents a specialization of `basic_istream`
  - Enables `char` input
- `ostream`
  - Represents a specialization of `basic_ostream`
  - Enables `char` output
- `iostream`
  - Represents a specialization of `basic_iostream`
  - Enables `char` input and output

Key Concept #5: Open a file

- Two methods
  - By passing arguments to (i/o)fstream constructor
  - By calling member function open()
- Two arguments
  - A filename // mandatory; char*, not string
  - A file-open mode // optional; default = “out” for ostream, “in” for istream
    - Can use ‘|’ for multiple modes
    - fstream fstr("test.txt", fstream::in | fstream::out | fstream::app);

Mode	Description
`ios::app`	Append all output to the end of the file.
`ios::ate`	Open a file for output and move to the end of the file (normally used to append data to a file). Data can be written anywhere in the file.
`ios::in`	Open a file for input.
`ios::out`	Open a file for output.
`ios::trunc`	Discard the file’s contents if they exist (this also is the default action for `ios::out`).
`ios::binary`	Open a file for binary (i.e., nontext) input or output.

fstream object

- open(): takes the same arguments as constructor
- Note: you cannot “copy” a stream object
  - So, vector<ifstream> is not possible
- bool operator !()
  - Returns true if either the `failbit` or `badbit` is set
  - if (!fin) {
    cerr << “Open file failed...” << endl;
    exit(-1);
    }

Key Concept #6: Close a file

- Releases the file resource (recommended!!!)
- Two methods
  - By destructor (exit the scope)
  - By calling member function close()

Key Concept #7: I/O Stream Manipulators

1. endl
2. Number base (sticky)
   - hex (e.g. 0x38ab), oct (e.g. 0236), dec (all others)
   - showbase(), setbase(int) // int = 16, 8, 10
3. Precision of floating-point numbers (sticky)
   - fixed, scientific
   - setprecision(int)
   - Note: precision(int) is a member function
4. Field width (not sticky)
   - setw(int) // c.f. "width()" member function
   - For both istream (input size) and ostream (display size)

I/O Stream Manipulators

5. Alignment (sticky)
   - left, right
   - internal (padding fill characters between sign and magnitude)
6. I/O formatting (sticky)
   - showpoint, noshowpoint
   - showpos, noshowpos
   - uppercase, nouppercase
   - boolalpha, noboolalpha
   - setfill (cf. fill() member function)
   - skipws
7. Flush stream buffer
   - flush

Sticky or not sticky?

- Most IO manipulators are "sticky"
  - Exception: field width
- "Sticky" to the manipulated object
  - Not across to another object of the same stream class, or any other object of other stream classes

Use of Manipulators

```
int main()
{
   int i = 100;
   fstream iof("ttt");
   if (!iof) { cerr << "Error" << endl; exit(0); }
   iof << hex << i << endl;
   iof.close();

   int j;
   iof.open("ttt");
   iof >> j;

   cout << setw(10) << right << j << endl;
}
// What’s in file “ttt”? What’s the output??
```


What’s the difference?

```
int main()
{
   int i = 100;
   fstream iof("ttt");
   if (!iof) { cerr << "Error" << endl; exit(0); }
   iof << hex << i << endl;
   iof.close();

   int j;
   iof.open("ttt");
   iof >> dec >> j;

   cout << setw(10) << right << j << endl;
}
// What’s in file “ttt”? What’s the output??
```

(FYI) About I/O Manipulators

- About floating number display
  - fixed --- in fixed-point notation (e.g. 3.14159)
  - scientific --- in scientific notation (e.g. 3.14159e+002)
  - (none) --- in default floating-point notation; floating-point number's value determines the output format
- About the precision of display
  - setprecision(*numDigits*)
    - For "fixed" and "scientific", *numDigits* is the number of digits after the decimal point
    - For default floating-point notation, *numDigits* is the total number of digits to display

Key Concept #7:
User-Defined Stream Manipulators

- Programmers can create their own stream manipulators
  - cf: ostream& operator << (ostream& (*p)(ostream&));
- [e.g.] Output stream manipulators
  - Must have return type and parameter type as `ostream &`
  - e.g.

```
ostream& myEndl(ostream& os) {
   return (os << endl << "Ric> ");
}
===============================
int main() {
   cout << myEndl;
}
```

Key Concept #8: Formatted vs. Unformatted I/O

- Formatted I/O
  - "High-level", bytes are grouped into meaningful units
    - Integers, floating-point numbers, characters, etc.
    - Satisfactory for most I/O other than high-volume file processing
  - I/O operations are sensitive to data types
    - Improper data cannot "sneak" through
  - Using operators "<<" and ">>", I/O manipulators
- Unformatted I/O
  - Low-level, individual bytes are the items of interest
  - High-speed, high-volume
  - Not particularly convenient for programmers
  - Member functions (e.g. get, getline, put, read, write...)
  - May have portability problem

Type-Safe I/O (Formatted I/O)

- << and >> operators are overloaded to accept data of specific types
  - Attempts to input or output a user-defined type that << and >> have not been overloaded for result in compiler errors
- If unexpected data is processed, error bits are set
  - User may test the error bits to determine I/O operation success or failure
- ostream& operator <<
  - Does not print out until '\n" or "flush()" is called
- istream& perator >>
  - Stop at white space, but not process until '\n' is entered

Key Concept #9: Overloading "<<" operator for user-defined types

```
class MyClass {
   // friend to "global domain"
   //        so that it can be accessed by "<<(cout, m)"
   friend ostream& operator <<
         (ostream& os, const MyClass& m);
}; // Why friend? friend to whom???

ostream& operator << (ostream& os, const MyClass& m) {
   os << m._dataMember1 << " is "  << m._dataMember2...
   return os; // Why return "os"? Return to whom?
}

int main()
{
   MyClass m(100);
   cout << m << endl;
}
```


"friend" is NOT a must, just a custom

```
class MyClass {

   ostream& operator <<
         (ostream& os, const MyClass& m);
};

ostream& operator << (ostream& os, const MyClass& m) {
   os << m.getData1() << " is "  << m.getData2()...
   return os;
}

int main()
{
   MyClass m(100);
   cout << m << endl;
}
```

Not a member function!!

Try this...

- ```
  int i;
  while (true) {
     cin >> i;
     // ... do something on i,
     // for example:
     cout << i << endl;
  }
  ```

➔ What will you see if we enter ‘a’?

Key Concept #10: I/O Stream State Bits

- Control the state of the stream (as ios data members)
  - `failbit`
    - Set if input data is of wrong type (format error)
    - Data still remains in stream buffer
    - Usually can be recovered
  - `badbit`
    - Set if stream extraction operation fails (more serious)
    - Usually difficult to recover
  - `eofbit`
    - Set if the end of file is reached during stream input
  - goodbit
    - ! (failbit | badbit | eofbit)
  ```

I/O Stream State Bits

- Functions
  - bool eof() const;
    - Returns `true` when end-of-file has occurred
    - [What's wrong??] while (!infile.eof()) { infile >> ch; }
  - good(), fail(), bad()
  - rdstate()
  - clear(iostate state=ios::goodbit)
    - Sets the specified bit for the stream
    - Default argument is `goodbit`
    - Examples

      `cin.clear();`
      - Clears `cin` and sets `goodbit`

      `cin.clear( ios::failbit );`
      - Sets `failbit`
  - setstate(iostate state) ➔ clear(rdstate() | state)

To fix the previous problem...

```
int i;
while (true) {
   cin >> i;
   while (cin.fail()) {
      cin.clear();
      string str;
      cin >> str;
      cerr << "Error: " << str
           << " is NOT an int!!" << endl;
      cin >> i;
   }
   cout << i << endl;
}
```

while (fstream)?

- What does this do?

```
int main()
{
   ifstream inf("aaa.txt");
   char ch;
   while (inf >> ch) cout << ch;
}
```

- void* ios::operator ( ) const
  - Converted to void*; return NULL if failbit or badbit is set

Key Concept #11: Flags for I/O Stream Printing Format

- Member function `flags()`
  - With no argument
    - Returns a value of type `fmtflags`
      - Represents the current format settings
  - With a `fmtflags` as an argument
    - Sets the format settings as specified
    - Returns the prior state settings as a `fmtflags`
  - Initial return value may differ across platforms
  - Type `fmtflags` is of class `ios_base`

What will be the output?

```
int main() {
   int i = 100;
   ofstream outf("ttt");
   outf << showbase << hex << i << endl;
   ios_base::fmtflags origFlags = outf.flags();
   outf.close();

   ifstream inf("ttt");
   inf.flags(origFlags);
   inf >> i;
   cout << setw(10) << right << i << endl;
}
```

◆What's the content in "ttt"?

Key Concept #12: Unformatted I/O

- Think: sometimes you just want to read/write a file as a "stream of bytes"
  - You don't care/know about the type of each piece of data
  - ➔ Unformatted I/O
- Use member functions to do file accesses

istream::get

1. With no arguments
   - int get ();
   - Returns one character input from the stream
     - Any character, including white-space and non-graphic characters
   - Returns `EOF` when end-of-file is encountered
2. With a character-reference argument
   - istream& get (char& c);
   - Stores input character in the character-reference argument
   - Returns a reference to the `istream` object

istream::get

3. With three arguments: a character array, a size limit and a delimiter (default delimiter is `'\n'`)
   - istream& get (char* s, streamsize n);
     istream& get (char* s, streamsize n, char delim);
     istream& get (streambuf& sb);
     istream& get (streambuf& sb, char delim);
   - Reads and stores characters in the character array
   - Terminates at one fewer characters than the size limit or upon reading the delimiter
     - Delimiter is left in the stream, not placed in array
   - Null character is inserted after end of input in array
   - [note] “streamsize” may be platform dependent, usually signed int or signed long.

istream::getline

- istream& getline (char* s, streamsize n);
  istream& getline (char* s, streamsize n, char delim);
  - Similar to the three-argument version of `get`
    - Except the delimiter *is* removed from the stream
  - Three arguments: a character array, a size limit and a delimiter (default delimiter is `'\n'`)
    - Reads and stores characters in the character array
    - Terminates at one fewer characters than the size limit or upon reading the delimiter
      - Delimiter is removed from the stream, but not placed in the array
    - Null character is inserted after end of input in array

ostream::put

- ostream& put (char c); // unformatted
  - Outputs a character
  - Returns a reference to the same `ostream` object
    - Can be cascaded
  - Can be called with a numeric expression that represents an ASCII value
  - Examples
    - `cout.put( 'A' );`
    - `cout.put( 'A' ).put( '\n' );`
    - `cout.put( 65 );`

More Unformatted I/O Functions

- istream& read (char* s, streamsize n);
  - Inputs some number of bytes to a character array
  - If fewer characters are read than the designated number, `failbit` is set
- streamsize gcount ( ) const;
  - Reports number of characters read by last input operation
- ostream& write (const char* s , streamsize n);
  - Outputs some number of bytes from a character array

More istream member functions

- istream& ignore
  (streamsize n = 1, int delim = EOF);
  - Reads and discards a designated number of characters or terminates upon encountering a designated delimiter
- istream& putback (char c);
  - Places previous character obtained by a `get` from the input stream back into the stream
- int peek ( );
  - Returns the next character in the input stream, but does not remove it from the stream

Key Concept #13:
Tying an Output Stream to an Input Stream

- `istream` member function `tie`
  - ostream* tie ( ) const;
    - Returns a pointer to the tied output stream
  - ostream* tie (ostream* tiestr);
    - Ties the istream object to *tiestr* and returns a pointer to the ostream object previously tied
- Synchronizes an `istream` and an `ostream`
  - Ensures outputs appear before their subsequent inputs
- By default, the standard objects cin, cerr and clog are tied to cout (Why?)
  - Examples
    - `cin.tie( &cout );`
      - Ties standard input to standard output
      - C++ performs this operation automatically
    - `inputStream.tie( 0 );`
      - Unties `inputStream` from the `ostream` it is tied to

istream::tie Example

```
int main () {
   ostream *prevstr;
   ofstream ofs;
   ofs.open ("test.txt");
   cout << "tie example:" << endl;
   *(cin.tie()) << "This is inserted into cout";
   prevstr = cin.tie(&ofs);
   *(cin.tie()) << "This is inserted into the file";
   cin.tie (prevstr);
   ofs.close(); return 0;
}
```

Key Concept #14: File-position pointer

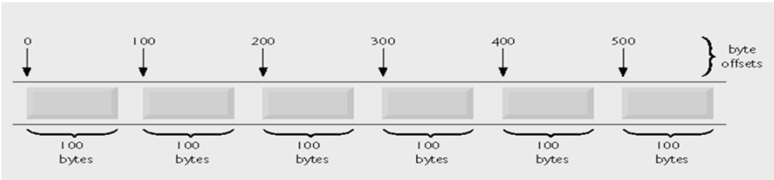
- The **byte number** of the next byte to be read or written
- `seekg()` for ifstream and
  `seekp()` for ofstream
  - Repositions the file-position pointer to the specified location
  - Two prototypes
    - seekg(pos) or seekg(offset, direction)
- `tellg()` for ifstream and
  `tellp()` for ofstream
  - Returns current position of the file-position pointer as type long

Seek direction

- `ios::beg` – default, position relative to the beginning
  `ios::cur` – relative to current position
  `ios::end` – relative to the end
- `Examples`
  - `fileObject.seekg( n );`
    - Position to the *n*th byte of `fileObject`
  - `fileObject.seekg( n, ios::cur );`
    - Position *n* bytes forward in `fileobject`
  - `fileObject.seekg( n, ios::end );`
    - Position *n* bytes back from end of `fileObject`
  - `fileObject.seekg( 0, ios::end );`
    - Position at end of `fileObject`

Key Concept #15: Random-Access Files

- Necessary for instant-access applications
  - Such as transaction-processing systems
    - cf: use ">>", "<<" for *sequential file* access
  - A record can be inserted, deleted or modified without affecting other records
- Various techniques can be used
  - Require that all records be of the same length, arranged in the order of the record keys
    - Program can calculate the exact location of any record
      - Base on the record size and record key



Functions for Random-Access Files

- istream& read(char *str, streamsize nBytes)
  - Read a number of bytes from the current file position in the stream into an object
- ostream& write
  (const char *str, streamsize nBytes)
  - Writes a number of bytes from a location in memory to the stream

Random-Access Files

```
int main() {
  StudentRecord rec;
  ofstream outf("studentRecord.dat");
  for (int i = 0; i < numRecords; ++i) {
    cin >> rec;
    outf.write(reinterpret_cast<const char *>(&rec),
               sizeof(StudentRecord));
  }
  outf.close();
  ifstream inf("studentRecord.txt");
  for (int i = 0; i < numRecords; ++i)
    inf.read(reinterpret_cast<const char *>(&rec),
             sizeof(StudentRecords));
}
```


Operator `reinterpret_cast`

StudentRecord rec;

outf.write(reinterpret_cast<const char *>(&rec),
sizeof(StudentRecord));

➔

- Casts a pointer of one type to an unrelated type
  - Also converts between pointer and integer types
- Is performed at compile time
  - Does not change the value of the object pointed to
- Could lead to serious execution-time errors

Key Concept #16:
String Stream (Stream of string)

```
// #include <sstream>
int main()
{
   int i;
   cin >> i;

   ostringstream  st;
   st << i << " square is " << i * i;

   string str = st.str();

   cout << str << endl;
}
// What’s the output??
```


String Stream

```
int main()
{
   int i;
   cin >> i;

   ostringstream  st;
   st << i << " square is " << i * i;
   string str = st.str();
   cout << str << endl;


   st << i << " is " << i;
   str = st.str();
   cout << str << end
}
// What’s the output??
// How to clear the previous string? clear()?
```

The Solution is.... ^^|||

```
int main()
{
   int i;
   cin >> i;

   ostringstream  st;
   st << i << " square is " << i * i;
   string str = st.str();
   cout << str << endl;

   st.str(“”);
   st << i << " is " << i;
   str = st.str();
   cout << str << end
}
```


Key Concept #17: Exceptions in your program

1. Runtime error (system exception)
   - Segmentation fault, bus error, etc
   - e.g. class bad_alloc
2. User-defined exception
   - If that happens, I don’t want to handle it...
3. Interrupt
   - Control-C, etc

What is exception handling?

- When an exception happens, detect it and stop the program "gracefully" (usually by going back to a command prompt), instead of terminating the program abruptly
- Purposes
  - To keep the partial results
  - Continue the program without losing previous efforts
  - (e.g. Windows crashing vs. "a program terminating abnormally")

Key Concept #18: C++ Exception Handling Mechanism

```
Try {
   // your main program
   // if (exception happens)
   //    throw exception!!
}
catch (ExpectedException1) {
   // exception handling code 1
}
// More exceptions to catch here
catch (...) {
   // The rest of the exceptions
   // note: "..." above is a reserved
   // symbol here
}
```

Predefined Classes for Exception Handling

- int, char*, etc

```
try {
   buf = new char[512];
   if( buf == 0 )
      throw “Memory alloc failure!”;
} catch(const char * str ) {
   cout << “Exception raised: ”
        << str << '\n';
}
```

- Predefined classes

```
try {
   ...
} catch (bad_alloc) {  // defined in “std”
   // Handle memory out
   ...
}
```


User-defined Classes for Exception Handling

-

```
class MyException    {
   int  _type;
public:
   MyException(int i) : _type(i) {}
   void print() const { ... }
};
===============
int main()     {
   try {
      ...
      if (...) throw MyException(type);
   }
   catch (MyException& ex) {
      ex.print();
      // handle the exception here...
   }
}
```

Hierarchical exception handling

```
void g() {
   ......
   if (.....)
      throw Ex4f();
}
void f() {
   try {
      .....
      g();
   } catch (Ex4F& e4f) {
      // do something....
      if (.....)
         throw Ex4Main();
      else
         throw e4f;
   }
}
```

```
main() {
   try {
      f();
   } catch (Ex4F& e){
      ......
   } catch (Ex4Main& e) {
      ......
   } catch (...) {
      ...
   }
}
```


Key Concept #19: Limited Throw

- Limit only certain types of exceptions to pass through
  - void f() throw(OnlyException&);
    - ➔ Only exceptions of class “OnlyException” are allowed
  - void f() throw();
    - ➔ None of the exception is allowed
- If disallowed exception is thrown

  `> terminate called after throwing an instance of ‘xxxx'`

  `> Abort`

  Uh??? Why do we limit the types of thow?

  ➔ catch the problematic code earlier!!

The Challenges in Exception Handling

1. Make sure the program is reset to a “clean state”
   - Memory used by unfinished routines needs to be released back to OS
   - All the data fields (e.g. _flags) needs to be made consistent
2. Be able to continue the execution
   - The unaffected data should not be deleted

Key Concept #20: Handling Interrupt

- Associate an interrupt signal to a handler
  - void signal(int sigNum, void sigHandler(sigNum));
- system-defined sigNum
  - SIGABRT Abnormal termination
  - SIGFPE Floating-point error
  - SIGILL Illegal instruction
  - SIGINT CTRL+C signal
  - SIGSEGV Illegal storage access
  - SIGTERM Termination request
- sigHandler()
  - Predefined: SIG_IGN(), SIG_DFL()
  - User-defined functions
    - void myHandler(int)

Interrupt Handler Implementation

1. Define interrupt handler function
   - Using “signal(int signum, sighandler_t handler)”;

   ➔ “signum” example: SIGINT ➔ Control-C
   ➔ “handler” is: “void myHandler(int)”
   ➔ man signal
2. Define a flag to denote the detection of the interrupt
3. Initialize the flag to “undetected” (e.g. false)
4. Associate the target interrupt to the handler function
5. (In handler function)
   - Re-associate this target interrupt to “SIG_IGN” (why?)
   - Set the flag to “detected”
6. (In upper-level/main function)
   - Check the flag “detected”
   - If (detected) ➔ reset to “undetected”; re-associate this interrupt with your handler;
   - Do something;

Random Number Generator by Control-C

```
static bool
      _ctrlCDetected = false;
unsigned rnGen(unsigned max)
{
  unsigned count = 0;
  while (1) {
    if (isCtrlCDetected()) {
      setCtrlCDectected(false);
      return count;
    }
    if (++count == max)
      count = 0;
  }
  return 0;
}
```

```
static void ctrlCHandler(int) {
  signal(SIGINT, SIG_IGN);
  if (!isCtrlCDetected())
    setCtrlCDectected(true);
}
static void ctrlCHandlerReset() {
  setCtrlCDectected(false);
  signal(SIGINT, ctrlCHandler);
}
int main(int argc, char** argv) {
  ctrlCHandlerReset();
  unsigned max = atoi(argv[1]);
  cout << rnGen(max) << endl;
  return 0;
}
```