Classes and Objects in C++

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Computing Methods in Physics

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Today's Lecture

- Classes
  - data members and member functions
- Constructors
  - Special member functions
- private and public members
- Helper and utility methods
  - setters
  - getters
  - accessors

Classes in C++

- A class is a set of data and functions that define the characteristics and behavior of an object
  - Characteristics also known as attributes
  - Behavior is what an object can do and is referred to also as its interface

Interface
or
Member Functions

Data members or attributes

```
class Result {
 public:

  // constructors
  Result() { }
  Result(const double& mean, const double& stdDev) {
    mean_ = mean;
    stdDev_ = stdDev;
  }

  // accessors
  double getMean() { return mean_; };
  double getStdDev() { return stdDev_; };

 private:
  double mean_;
  double stdDev_;
};
```

Don’t’s forget ; at the end of definition!

Data Members (Attributes)

```
class Datum {
    double value_;
    double error_;
};
```

- Data defined in the scope of a class are called data members of that class
- Data members are defined in the class and can be used by all member functions
- Contain the actual data that characterise the content of the class
- Can be public or private
  - public data members are generally bad and symptom of bad design
  - More on this topic later in the course

Interface: Member Functions

- Member functions are methods defined inside the scope of a class
  - Have access to all data members

```
// Student
#include <iostream>
#include <string>

class Student {
  using namespace std;
  public:
   // default constructor
   Student() { name_ = ""; }

   // another constructor
   Student(const string& name) { name_ = name; }

   // getter method: access to info from the class
   string name() { return name_; }

   // setter: set attribute of object
   void setName(const string& name) { name_ = name; }

   // utility method
   void print() {
     cout << "My name is: " << name_ << endl;
   }

  private:
   string name_; // data member
};
```

name_ is a datamember

No declaration of name_ in member functions!

name is a local variable only within setName()

Arguments of Member Functions

- All C++ rules discussed so far hold
- You can pass variables by value, pointer, or reference
- You can use the constant qualifier to protect input data and restrict the capabilities of the methods
  - This has implications on declaration of methods using constants
  - We will discuss constant methods and data members next week
- **Member functions can return any type**
  - Exceptions! Constructors and Destructor
    - Have no return type
    - More on this later

Access specifiers **public** and **private**

- Public functions and data members are available to anyone
- Private members and methods are available ONLY to other member functions

```
 1 #include <iostream>
 2 using std::cout;
 3 using std::endl;
 4
 5 class Datum {
 6   public:
 7     Datum() { }
 8     Datum(double val, double error) {
 9       value_ = val;
10       error_  = error;
11     }
12
13   double value() { return value_; }
14   double error() { return error_; }
15
16   void setValue(double value) { value_ = value; }
17   void setError(double error) { error_ = error; }
18
19   double value_; // public data member!!!
20
21   private:
22     double error_; // private data member
23 };
```

Access elements of an object through member selection operator "."

```
25 int main() {
26
27   Datum d1(1.1223,0.23);
28
29   cout << "d1.value(): " << d1.value()^
30        << " d1.error(): " << d1.error()
31        << endl;
32
33
34   cout << "d1.value_: " << d1.value_
35        << " d1.error_: " << d1.error_
36        << endl;
37
38   return 0;
39 }
```

Accessing private members is a compilation error!

```
$ g++ -o class1 class1.cc
class1.cc: In function `int main()':
class1.cc:22: error: `double Datum::error_' is private
class1.cc:35: error: within this context
```

private members

```
#include <iostream>
using namespace std;

class Datum {
  public:
    Datum(double val, double error) {
      value_ = val;
      error_  = error;
    }

    double value() { return value_; }
    double error() { return error_; }

    void setValue(double value)
      { value_ = value; }
    void setError(double error)
      { error_ = error; }

    void print() {
      cout << "datum: " << value_
           << " +/- " << error_
           << endl;
    }

  private:
    double value_; // private data member!!!
    double error_; // private data member
};
```

```
int main() {

  Datum d1(1.1223,0.23);
  // setter with no return value
  d1.setValue( 8.563 );

  // getter to access private data
  double x = d1.value();

  cout << "d1.value(): " << d1.value()
       << " d1.error(): " << d1.error()
       << endl;

  d1.print();

  return 0;
}
```

```
$ g++ -o class2 class2.cc
$ ./class2
d1.value(): 8.563 d1.error(): 0.23
datum: 8.563 +/- 0.23
```

private methods

- Can be used only inside other methods but not from outside

```
 1 // class3.cc
 2 #include <iostream>
 3 using namespace std;
 4
 5 class Datum {
 6   public:
 7     Datum() { reset(); } // reset data members
 8
 9     double value() { return value_; }
10     double error() { return error_; }
11
12     void setValue(double value) { value_ = value; }
13     void setError(double error) { error_ = error; }
14
15     void print() {
16       cout << "datum: " << value_ << " +/- "
               << error_ << endl;
17     }
18
19   private:
20     void reset() {
21       value_ = 0.0;
22       error_ = 0.0;
23     }
24
25     double value_;
26     double error_;
27 };
```

```
int main() {

  Datum d1;
  d1.setValue( 8.563 );
  d1.print();

  return 0;
}
```

```
$ g++ -o class3 class3.cc
$ ./class3
datum: 8.563 +/- 0
```

```
30 int main() {
31
32   Datum d1;
33   d1.setValue( 8.563 );
34   d1.print();
35   d1.reset();
36
37   return 0;
38 }
```

```
$ g++ -o class4 class4.cc
class4.cc: In function `int main()':
class4.cc:20: error: `void Datum::reset()' is private
class4.cc:35: error: within this context
```

Hiding Implementation from Users/Clients

- How to decide what to make public or private?

- Principle of Least Privilege
  - elements of a class, data or functions, must be private unless proven to be needed as public!

- Users should rely solely on the interface of a class

- They should never use the internal details of the class

- ***That's why having public data members is a VERY bad idea!***
  - name and characteristics of data members can change
  - Functionalities and methods remain the same
  - You must be able to change internal structure of the class without affecting the clients!

Bad Example of Public Data Members

```
class Datum {
  public:
    Datum(double val, double error) {
      value_ = val;
      error_  = error;
    }

    double value() { return value_; }
    double error() { return error_; }

    void setValue(double value) { value_ = value; }
    void setError(double error) { error_ = error; }

    void print() {
      cout << "datum: " << value_ << " +/- " << error_ << endl;
    }

  //private:        // all data are public!
    double value_;
    double error_;
};
```

```
int main() {

  Datum d1(1.1223,0.23);
  double x = d1.value();
  double y = d1.error_;
  cout << "x: " << x << "\t y: " << y << endl;

  return 0;
}
```

application uses directly the data member!

```
$ g++ -o class6 class6.cc
$ ./class6
x: 1.1223        y: 0.23
```

Bad Example of Public Data Members

Same Application as before

Change the names of data members

No change of functionality so no one should be affected!

```
class Datum {
  public:
    Datum(double val, double error) {
      val_ = val;
      err_  = error;
    }

    double value() { return val_; }
    double error() { return err_; }

    void setValue(double value) { val_ = value; }
    void setError(double error) { err_ = error; }

    void print() {
      cout << "datum: " << val_ << " +/- " << err_ << endl;
    }

  //private:        // alla data are public!
    double val_;  // value_ → val_
    double err_;  // error_ → err_
};
```

```
28 int main() {
29
30   Datum d1(1.1223,0.23);
31   double x = d1.value();
32   double y = d1.error_;
33
34   cout << "x: " << x << "\t y: " << y << endl;
35
36   return 0;
37 }
```

Our application is now broken!

But Datum has not changed its behavior!

Bad programming!

Only use the interface of an object not its internal data!

Private data members prevent this

```
$ g++ -o class7 class7.cc
class7.cc: In function `int main()':
class7.cc:32: error: 'class Datum' has no member named `error_'
```

Constructors

```
class Datum {
  public:
    Datum() { }
    Datum(double val, double error) {
      value_ = val;
      error_  = error;
    }

  private:
    double value_; // public data member!!!
    double error_; // private data member
};
```

- Special member functions
  - Required by C++ to create a new object
  - MUST have the same name of the class
  - Used to initialize data members of an instance of the class
  - Can accept any number of arguments
    - Same rules as any other C++ function applies

- Constructors have no return type!

- There can be several constructors for a class
  - Different ways to declare and an object of a given type

Different Types of Constructors

- Default constructor
  - Has no argument
  - On most machines the default values for data members are assigned
- Copy Constructor
  - Make a new object from an existing one
- Regular constructor
  - Provide sufficient arguments to initialize data members

```
class Datum {
  public:
    Datum() { }


    Datum(double x, double y) {
      value_ = x;
      error_ = y;
    }


    Datum(const Datum& datum) {
      value_ = datum.value_;
      error_ = datum.error_;
    }


  private:
    double value_;
    double error_;
};
```

Using Constructors

```
// class5.cc
#include <iostream>
using namespace std;

class Datum {
  public:
    Datum() { }

    Datum(double x, double y) {
      value_ = x;
      error_ = y;
    }

    Datum(const Datum& datum) {
      value_ = datum.value_;
      error_ = datum.error_;
    }

    void print() {
      cout << "datum: " << value_
           << " +/- " << error_
           << endl;
    }

  private:
    double value_;
    double error_;
};
```

```
int main() {

  Datum d1;
  d1.print();

  Datum d2(0.23,0.212);
  d2.print();

  Datum d3( d2 );
  d3.print();


  return 0;
}
```

```
$ g++ -o class5 class5.cc
$ ./class5
datum: NaN +/- 8.48798e-314
datum: 0.23 +/- 0.212
datum: 0.23 +/- 0.212
```

Default Constructors on Different Architectures

```
$ uname -a
CYGWIN_NT-5.1 lajolla 1.5.18(0.132/4/2) 2005-07-02 20:30 i686 unknown
unknown Cygwin
$ gcc -v
Reading specs from /usr/lib/gcc/i686-pc-cygwin/3.4.4/specs
…
gcc version 3.4.4 (cygming special) (gdc 0.12, using dmd 0.125)

$ g++ -o class5 class5.cc
$ ./class5
datum: NaN +/- 8.48798e-314
datum: 0.23 +/- 0.212
datum: 0.23 +/- 0.212
```

Windows XP with CygWin

```
$ uname -a
Linux pccms02.roma1.infn.it 2.6.14-1.1656_FC4smp #1 SMP Thu Jan 5 22:24:06 EST
 2006 i686 i686 i386 GNU/Linux
$ gcc -v
Using built-in specs.
Target: i386-redhat-linux
…
gcc version 4.0.2 20051125 (Red Hat 4.0.2-8)
$ g++ -o class5 class5.cc
$ ./class5
datum: 6.3275e-308 +/- 4.85825e-270
datum: 0.23 +/- 0.212
datum: 0.23 +/- 0.212
```

Fedora Core4

Default Assignment

```
// ctor.cc
#include <iostream>
using std::cout;
using std::endl;

class Datum {
  public:
    Datum(double x) { x_ = x; }
    double value()  { return x_; }
    void setValue(double x) { x_ = x; }
    void print() {
      cout << "x: " << x_ << endl;
    }

  private:
    double x_;
};
```

```
int main() {

  Datum d1(1.2);
  d1.print();

  // no default ctor. compiler error if uncommented
  //Datum d2;
  //d2.print();

  Datum d3 = d1; // default assigment by compiler
  d3.print();
  cout << "&d1: " << &d1
       << "\t &d3: " << &d3 << endl;
  return 0;
}
```

d3.x_ = d1.x_

done by compiler

```
$ g++ -o ctor ctor.cc
$ ./ctor
x: 1.2
x: 1.2
&d1: 0x23ef10    &d3: 0x23ef08
```

Question

- Can a constructor be private?
  - Is it allowed by the compiler?
  - How to instantiate an object with no public constructor?

- *Find a working example of a very simple class for next week*

Accessors and Helper/Utility Methods

- Methods that allow read access to data members
- Can also provide functionalities commonly needed by users to elaborate information from the class
  - for example formatted printing of data
- Usually they do not modify the objects, i.e. do not change the value of its attributes

```
class Student {
  public:

    // getter method: access to data members
    string name() { return name_; }

    // utility method
    void print() {
      cout << "My name is: " << name_ << endl;
    }

  private:
    string name_; // data member
};
```

```
class Datum {
  public:

    double value() { return value_; }
    double error() { return error_; }

    void print() {
      cout << "datum: " << value_
           << " +/- " << error_
           << endl;
    }

  private:
    double value_; // public data member!!!
    double error_; // private data member
};
```

Getter Methods

- getters are helpers methods with explicit names returning individual data members
  - Do not modify the data members simply return them
  - Good practice: call these methods as getFoo() or foo() for member foo_
- Return value of a getter method should be that of the data member

```
class Datum {
  public:
    Datum(double val, double error) {
      val_ = val;
      err_  = error;
    }

    double value() { return val_; }
    double error() { return err_; }

    void setValue(double value) { val_ = value; }
    void setError(double error) { err_ = error; }

    void print() {
      cout << "datum: " << val_ << " +/- " << err_
           << endl;
    }

  private:
    double val_;
    double err_;
};
```

```
// Student
#include <iostream>
#include <string>
using namespace std;

class Student {
  public:
   // default constructor
   Student() { name_ = ""; }

   // another constructor
   Student(const string& name) { name_ = name; }

   // getter method: access to info from the class
   string name() { return name_; }

   // setter: set attribute of object
   void setName(const string& name) { name_ = name; }

   // utility method
   void print() {
     cout << "My name is: " << name_ << endl;
   }

  private:
   string name_; // data member
};
```

Setter Methods

- Setters are member functions that modify attributes of an object after it is created
  - Typically defined as void
  - Could return other values for error handling purposes
  - Very useful to assign correct attributes to an object in algorithms
  - As usual abusing setter methods can cause unexpected problems

```
// class8.cc
#include <iostream>
using namespace std;

class Datum {
  public:
    Datum(double val, double error) {
      value_ = val;
      error_  = error;
    }

    double value() { return value_; }
    double error() { return error_; }

    void setValue(double value) { value_ = value; }
    void setError(double error) { error_ = error; }

    void print() {
      cout << "datum: " << value_ << " +/- "
           << error_ << endl;
    }

  private:
    double value_;
    double error_;
};
```

```
int main() {

  Datum d1(23.4,7.5);
  d1.print();

  d1.setValue( 8.563 );
  d1.setError( 0.45 );
  d1.print();

  return 0;
}
```

```
$ g++ -o class8 class8.cc
$ ./class8
datum: 23.4 +/- 7.5
datum: 8.563 +/- 0.45
```

Pointers and References to Objects

```
// app2.cpp
#include <iostream>
using std::cout;  // use using only for specific
classes
using std::endl;  // not for entire namespace

class Counter {
  public:
    Counter() { count_ = 0; x_=0.0; };
    int value()  { return count_; }
    void reset() { count_ = 0; x_=0.0; }
    void increment() { count_++; }
    void increment(int step)
       { count_ = count_+step; }
    void print() {
      cout << "---- Counter::print() ----" << endl;
      cout << "my count_: " << count_ << endl;
      // this is special pointer
      cout << "my address: " << this << endl;
      cout << "&x_ : " << &x_ << "  sizeof(x_): "
           << sizeof(x_) << endl;
      cout << "&count_ : " << &count_
      << "  sizeof(count_): "
      << sizeof(count_) << endl;
      cout << "---- Counter::print()----" << endl;
    }

  private:
    int count_;
    double x_; // dummy variable
};
```

```
void printCounter(Counter& counter)  {
  cout << "counter value: " << counter.value() << endl;
}

void printByPtr(Counter* counter)  {
  cout << "counter value: " << counter->value() << endl;
}
```

```
int main() {
  Counter counter;
  counter.increment(7);

  // ptr is a pointer to a Counter Object
  Counter* ptr = &counter;
  cout << "ptr = &counter: " << &counter << endl;

  // use . to access member of objects
  cout << "counter.value(): " << counter.value() << endl;

  // use -> with pointer to objects
  cout << "ptr->value(): " << ptr->value() << endl;

  printCounter( counter );
  printByPtr( ptr );

  ptr->print();

  cout << "sizeof(ptr): " << sizeof(ptr) << "\t"
       << "sizeof(counter): " << sizeof(counter)
       << endl;

return 0;
}
```

-> instead of . When using pointers to objects

Size and Address of Objects

gcc 3.4.4 on cygwin

```
$ g++ -o app2 app2.cpp
$ ./app2
ptr = &counter: 0x22ccd0
counter.value(): 7
ptr->value(): 7
printCounter: counter value: 7
printByPtr: counter value: 7
---- Counter::print() : begin ----
my count_: 7
my address: 0x22ccd0
&count_ : 0x22ccd0  sizeof(count_): 4
&x_ : 0x22ccd8  sizeof(x_): 8
---- Counter::print() : end ----
&i: 0x22ccc8
sizeof(ptr): 4  sizeof(counter): 16
sizeof(int): 4  sizeof(double): 8
```

gcc 4.1.1 on fedora core 6

```
$ g++ -o app2 app2.cpp
$ ./app2
ptr = &counter: 0xbf841e20
counter.value(): 7
ptr->value(): 7
printCounter: counter value: 7
printByPtr: counter value: 7
---- Counter::print() : begin ----
my count_: 7
my address: 0xbf841e20
&count_ : 0xbf841e20  sizeof(count_): 4
&x_ : 0xbf841e24  sizeof(x_): 8
---- Counter::print() : end ----
&i: 0xbf841e1c
sizeof(ptr): 4  sizeof(counter): 12
sizeof(int): 4  sizeof(double): 8
```

- Different size of objects on different platform!
  - Different configuration of compiler
  - Optimization for access to memory

- Address of object is address of first data member in the object

Classes and Applications

- So far we have always included the definition of classes together with the main application in one file

- The advantage is that we have only one file to modify

- Disadvantage are many
  - There is always ONE file to modify no matter what kind of modification you want to make
  - This file becomes VERY long after a very short time
  - Hard to maintain everything in only one place
  - We compile everything even after very simple changes

Example of Typical Application So Far

```
// app3.cpp
#include <iostream>
using std::cout;
using std::endl;

#include "Counter.h"

Counter makeCounter() {
  Counter c;
  return c;
}

void printCounter(Counter& counter)  {
  cout << "counter value: " << counter.value() << endl;
}

void printByPtr(Counter* counter)  {
  cout << "counter value: " << counter->value() << endl;
}
```

```
int main() {
  Counter counter;
  counter.increment(7);

  Counter* ptr = &counter;

  cout << "counter.value(): " << counter.value()
       << endl;
  cout << "ptr = &counter: " << &counter << endl;
  cout << "ptr->value(): " << ptr->value() << endl;

  Counter c2 = makeCounter();
  c2.increment();

  printCounter( c2 );

  cout << "sizeof(ptr): " << sizeof(ptr)
       << " sizeof(c2): " << sizeof(c2)
       << endl;

  return 0;

}
```

Separating Classes and Applications

- It's good practice to separate classes from applications

- Create one file with only your application
  - Use #include directive to add all classes needed in your application

  - Keep a separate file for each class

- Compile your classes separately

- Include compiled classes (or libraries) when linking your application

First Attempt at Improving Code Management

```
// Datum1.cc
// include all header files needed
#include <iostream>
using namespace std;

class Datum {
  public:
    Datum() { }

    Datum(double x, double y) {
      value_ = x;
      error_ = y;
    }

    Datum(const Datum& datum) {
      value_ = datum.value_;
      error_ = datum.error_;
    }

    void print() {
      cout << "datum: " << value_
           << " +/- " << error_
           << endl;
    }

  private:
    double value_;
    double error_;
};
```

```
// app1.cpp
#include "Datum1.cc"

int main() {

  Datum d1;
  d1.print();

  Datum d2(0.23,0.212);
  d2.print();

  Datum d3( d2 );
  d3.print();

  return 0;
}
```

```
$ g++ -o app1 app1.cpp
$ ./app1
datum: NaN +/- 8.48798e-314
datum: 0.23 +/- 0.212
datum: 0.23 +/- 0.212
```

Problems with Previous Example

- Although we have two files it is basically if we had just one!

- Datum1.cc includes not only the declaration but also the definition of class Datum
  - Implementation of all methods exposed to user

- When compiling app1.cpp we also compile class Datum every time!
  - We do not need any library because app1.cpp includes all source code!
  - When compiling and linking app1.cpp we also create compiled code for Datum to be used in our application

  - *Remember what #include does!*

Pre-Compiled version of `Datum1.cc`

- Our source file is only a few lines long

```
$ wc -l Datum1.cc
30 Datum1.cc

$ wc -l app1.cpp
16 app1.cpp

$ g++ -E -c Datum1.cc > Datum1.cc-precomoiled

$ wc -l Datum1.cc-precompiled
23740 Datum1.cc-precompiled
```

- The precompiled version is almost 24000 lines!
  - This is all code included in and by iostream

```
$ grep "#include"  /usr/lib/gcc/i686-pc-cygwin//3.4.4/include/c++/
iostream
 *  This is a Standard C++ Library header.  You should @c #include
this header
#include <bits/c++config.h>
#include <ostream>
#include <istream>
```

iostream

```
#ifndef _GLIBCXX_IOSTREAM
#define _GLIBCXX_IOSTREAM 1

#pragma GCC system_header

#include <bits/c++config.h>
#include <ostream>
#include <istream>

namespace std
{
  /**
   *  @name Standard Stream Objects
   *
*/
  //@{
  extern istream cin;          ///< Linked to standard input
  extern ostream cout;         ///< Linked to standard output
  extern ostream cerr;         ///< Linked to standard error (unbuffered)
  extern ostream clog;         ///< Linked to standard error (buffered)

#ifdef _GLIBCXX_USE_WCHAR_T
  extern wistream wcin;        ///< Linked to standard input
  extern wostream wcout;       ///< Linked to standard output
  extern wostream wcerr;       ///< Linked to standard error (unbuffered)
  extern wostream wclog;       ///< Linked to standard error (buffered)
#endif
  //@}

  // For construction of filebuffers for cout, cin, cerr, clog et. al.
  static ios_base::Init __ioinit;
} // namespace std

#endif /* _GLIBCXX_IOSTREAM */
```

I have removed all comments from the file to make it fit in this slide

Additional code included by the header files in this file

How do you find **`iostream`** file on your computer?

Separating Interface from Implementation

- Clients of your classes only need to know the interface of your classes

- Remember:
  - Users should only rely on public members of your class
  - Internal data structure must be hidden and not needed in applications

- Compiler needs only the declaration of your classes, its functions and their signature to compile the application
  - Signature of a function is the exact set of arguments passed to a function and it return type

- The compiled class code (definition) is needed only at link time
  - Libraries are needed to link not to compile!

Header and Source Files

- We can separate the declaration of a class from its implementation
  - Declaration tells the compiler about data members and member functions of a class
  - We know how many and what type of arguments a function has by looking at the declaration but we don't know how the function is implemented

- Declaration of a class Counter goes into a file usually called Counter.h or Counter.hh suffix

- Implementation of methods goes into the source file usually called Counter.cc

Counter.h and Counter.cc

```
// Counter.h
// Counter Class: simple counter class.
// Allows simple or step
// increments and also a reset function

// include header files for types
// and classes used in the declaration

class Counter {
  public:
    Counter();
    int value();
    void reset();
    void increment();
    void increment(int step);

  private:
    int count_;
};
```

```
// Counter.cc
// include class header files
#include "Counter.h"

// include any additional header files
//  needed in the class
// definition
#include <iostream>
using std::cout;
using std::endl;

Counter::Counter() {
  count_ = 0;
};

int Counter::value()  {
  return count_;
}

void Counter::reset() {
  count_ = 0;
}

void Counter::increment() {
  count_++;
}

void Counter::increment(int step) {
  count_ = count_+step;
}
```

Scope operator :: is used to tell methods belong to Class Counter

What is included in header files?

- Declaration of the class
  - Public and data members

- All header files for types and classes used in the header
  - data members, arguments or return types of member functions

- Sometimes when we have very simple methods these are directly implemented in the header file

- Methods implemented in the header file are referred to as inline functions
  - For example getter methods are a good candidate to become inline functions

What is included in source file?

- Header file of the class being implemented
  - Compiler needs the prototype (declaration) of the methods

- Implementation of methods declared in the header file
  - Scope operator :: must be used to tell the compiler methods belong to a class

- Header files for all additional types used in the implementation but not needed in the header!
  - Nota bene: header files include in the header file of the class are automatically included in the source file

Compiling Source Files of a Class

```
$ g++ Counter.cc
/usr/lib/gcc/i686-pc-cygwin/3.4.4/../../../libcygwin.a(libcmain.o)::
undefined reference to `_WinMain@16'
collect2: ld returned 1 exit status
```

WinXP+ cygwin

```
$ g++ Counter.cc
/usr/lib/gcc/i386-redhat-linux/4.0.2/../../../crt1.o(.text+0x18):
In function `_start':: undefined reference to `main'
collect2: ld returned 1 exit status
```

Linux

- Do you understand the error?
- What does undefined symbol usually mean?
- Why we did not encounter this error earlier?