Basic syntax in C++

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Brief History of C

- C was developed in 1967 mainly as a language for writing operating systems and compilers
  - Think about the gcc compiler and Linux today
  - You can compile the gcc compiler yourself
  - You can get the latest linux kernel (core of the linux operating system) from www.kernels.org and compile it yourself

- C was the evolution of two previous languages: B and BCPL
  - Both used to develop early versions of UNIX at Bell Labs

- C became very popular and was ported to variety of different hardware platforms
  - C was standardized in 1990 by International Organization for Standardization (ISO) and American National Standards Institute (ANSI)
    - ANSI/ISO 9899: 1990

Object Oriented Programming and Birth of C++

- By 1970's the difficulties of maintaining very large software projects for companies and businesses had lead to structured programming
  - From Wikipedia:

    Structured programming can be seen as a subset or subdiscipline of procedural programming, one of the major programming paradigms. It is most famous for removing or reducing reliance on the GOTO statement (also known as "go to")

- By late 70's a new programming paradigm was becoming trendy: object orientation

- In early 1980's Bjarne Stroustrup developed C++ using features from C but adding capabilities for object orientation

What is 'Object Oriented Programming` anyway?

- Objects are software units modelled after entities in real life
  - Objects are entities with attributes: length, density, elasticity, thermal coefficient, color
  - Objects have a behavior and provide functionalities
    - A door can be opened
    - A car can be driven
    - A harmonic oscillator oscillates
    - A nucleus can decay
    - A planet moves in an orbit
- Object orientation means writing your program in terms of well defined units (called objects) which have attributes and offer functionalities
  - Program consists in interaction between objects using methods offered by each of them

C++ is not C !

- Don’t be fooled by the name!

- C++ was developed to overcome limitations of C and improve upon it
  - C++ looks like C but feels very differently
  - C++ shares many basic functionalities but improves upon many of them
    - For example input/output significantly better in C++ than in C

- C excellent language for structural programming
  - Focused around actions on data structures
  - Provides methods which act on data and create data

- C++ focused on inter-action between objects
  - Objects are ‘smart’ data structures: data with behavior!

What You Need to compile your C++ Program?

- On Linux machines you should have the g++ compiler installed by default
- On Windows you can use the C++ compiler provided by the free version of Visual Studio
- On Mac OS, you can install the g++ compiler via XCode, available for free on Mac App Store

- The easiest way is to use the virtual box available on the course website

Structure of a C++ Program

```
// your first C++ application!
#include <iostream> // required to perform C++ stream I/O

// function main begins program execution
int main() {
   return 0; // indicate that program ended successfully

} // end function main
```

Precompiler/Preprocessor Directives

What is the preprocessor? What does it do?

```
// your first C++ application!
#include <iostream> // required to perform C++ stream I/O

// function main begins program execution
int main() {
   return 0; // indicate that program ended successfully

} // end function main
```

`iostream` will be included before compiling this code!

What does the Preprocessor do?

```
// Foo.h
class Foo {
public:
 Foo() {};
 Foo(int a) { x_ = a; };

private:
 int x_;
};
```

```
// ExamplePreprocessor.cpp
#include "Foo.h"


int main() {

  return 0;
}
```

Pre-compile only

```
$ g++ -E ExamplePreprocessor.cpp > prep.cc
$ cat prep.cc
# 1 "ExamplePreprocessor.cpp"
# 1 "<built-in>"
# 1 "<command line>"
# 1 "ExamplePreprocessor.cpp"

# 1 "Foo.h" 1
class Foo {
public:
 Foo() {};
 Foo(int a) { x_ = a; };

private:
 int x_;
};
# 3 "ExamplePreprocessor.cpp" 2

int main() {

  return 0;
}
```

- Replace user directives with requested source code
  - Foo.h is included in ExamplePreprocessor.cpp

Comments in C++

```
// your first C++ application!
#include <iostream> // required to perform C++ stream I/O

// function main begins program execution
int main() {
   return 0; // indicate that program ended successfully

} // end function main
```

- Comments preceded by //
  - Can start anywhere in the program either at the beginning or right after a statement in the middle of the line

Compiling a C++ application

```
$ g++ -o Welcome Welcome.cpp
```

Name of the binary output

C++ file to compile and link

```
$ ls -l
-r--r--r--  1 rahatlou None   1379 Apr 18 22:55
Welcome.cpp
-rwxr-xr-x  1 rahatlou None 476600 Apr 18 22:57
Welcome
```

- We will be using the free compiler gcc throughout the examples in this course

Some basic aspects of C++

- All statements must end with a semi-colon ;
  - Carriage returns are not meaningful and ignored by the compiler

- Comments are preceded by //
  - Comments can be an entire line or in the middle of the line after a statement

- Any C++ application must have a **`main`** method

- **`main`** must return an **`int`**
  - Return value can be used by user/client/environment
  - E.g. to understand if there was an error condition

What about changing a different type of **`main`**?

```
// VoidMain.cpp
#include <iostream>
using namespace std;

void main(){

  // no return type

} // end function main
```

```
$ g++ -o VoidMain VoidMain.cpp
VoidMain.cpp:6: error: `main' must return `int'
```

- Compiler requires **`main`** to return an **`int`** value!
- Users must simply must satisfy this requirement
  - If you need a different type there is probably a mistake in your design!

Typical Compilation Errors So Far

```
// BadCode1.cpp
#include <iostream>
using namespace std;

int main() { // main begins here

   int nIterations;

   cout << "How many
           iterations? "; // cannot break in the middle of the string!

   cin >> nIteration; // wrong name! the s at the end missing

   // print message to STDOUT
   cout << "Number of requested iterations: " << nIterations << endl;

   return 0 // ; is missing!

} // end of main
```

```
$ g++ -o BadCode1 BadCode1.cpp
BadCode1.cpp: In function `int main()':
BadCode1.cpp:9: error: missing terminating " character
BadCode1.cpp:10: error: `iterations' undeclared (first use this function)
BadCode1.cpp:10: error: (Each undeclared identifier is reported only once for each function
 it appears in.)
BadCode1.cpp:10: error: missing terminating " character
BadCode1.cpp:12: error: `nIteration' undeclared (first use this function)
BadCode1.cpp:12: error: expected `:' before ';' token
BadCode1.cpp:12: error: expected primary-expression before ';' token
BadCode1.cpp:19: error: expected `;' before '}' token
```

Some C reminders

Always initialise your variables!

```
// tinput_bad2.cc
#include <iostream>
using namespace std;

int main() {

  int iters;
  cout << "iters before cin: " << iters << endl;

  cout << "iterations? ";
  cin >> iters;

  cout << "requested " << iters << " iterations" << endl;

  return 0;
}
```

Random value since not initialized!

```
$ g++ -Wall -o tinput_bad2 tinput_bad2.cc
$ ./tinput_bad2
iters before cin: 134514841
iterations? 3
requested 3 iterations
$ ./tinput_bad2
iters before cin: 134514841
iterations? er
requested 134514841 iterations
```

Arrays (same as in C)

```
// vect3.cc
#include <iostream>
using namespace std;

int main() {


   float vect[3] = {0.4,1.34,56.156}; // vector of int
   float v2[3];
   float v3[] = { 0.9, -0.1, -0.65}; // array of size 3

   for(int i = 0; i<3; ++i) {
     cout << "i: " << i << "\t"
          << "vect[" << i << "]: " << vect[i] << "    \t"
          << "v2[" << i << "]: " << v2[i] << " \t"
          << "v3[" << i << "]: " << v3[i]
           << endl;
   }

   return 0;
}
```

Index of arrays starts from 0 !!

v2[0] is the first elements of array **v2** of size 3.

v2[2] is the last element of **v2**

What happened to **v2**?

```
$ g++ -o vect3 vect3.cc
$ ./vect3
i: 0    vect[0]: 0.4          v2[0]: 5.34218e+36      v3[0]: 0.9
i: 1    vect[1]: 1.34         v2[1]: 2.62884e-42      v3[1]: -0.1
i: 2    vect[2]: 56.156       v2[2]: 3.30001e-39      v3[2]: -0.65
```

Arrays and Pointers

- The name of the array is a pointer to the first element of the array

```
// array.cpp
#include <iostream>
using namespace std;

int main() {

   int vect[3] = {1,2,3}; // vector of int
   int v2[3]; //what is the default value?
   int v3[] = { 1, 2, 3, 4, 5, 6, 7 }; // array of size 7

   int* d = v3;
   int* c = vect;
   int* e = v2;

   for(int i = 0; i<5; ++i) {
     cout << "i: " << i << ", d = " << d << ", *d: " << *d;
     ++d;
     cout << ", c = " << c << ", *c: " << *c;
     ++c;
     cout << ", e = " << e << ", *e: " << *e << endl;
     ++e;
   }
   return 0;
}
```

What happened to `e`?

```
$ g++ -o array array.cc
$ ./array
i: 0, d = 0x23eec0, *d: 1, c = 0x23eef0, *c: 1, e = 0x23eee0, *e: -1
i: 1, d = 0x23eec4, *d: 2, c = 0x23eef4, *c: 2, e = 0x23eee4, *e: 2088773120
i: 2, d = 0x23eec8, *d: 3, c = 0x23eef8, *c: 3, e = 0x23eee8, *e: 2088772930
i: 3, d = 0x23eecc, *d: 4, c = 0x23eefc, *c: 1627945305, e = 0x23eeec, *e: 2089866642
i: 4, d = 0x23eed0, *d: 5, c = 0x23ef00, *c: 1876, e = 0x23eef0, *e: 1
```

Another bad example of using arrays

```
// vect2.cc
#include <iostream>
using namespace std;

int main() {


   float vect[3] = {0.4,1.34,56.156}; // vector of int
   float v2[3]; // use default value 0 for each element
   float v3[] = { 0.9, -0.1, -0.65, 1.012, 2.23, -0.67, 2.22 }; // array of size 7

   for(int i = 0; i<5; ++i) {
     cout << "i: " << i << "\t"
          << "vect[" << i << "]: " << vect[i] << "  \t"
          << "v2[" << i << "]: " << v2[i] << "  \t"
          << "v3[" << i << "]: " << v3[i]
           << endl;
   }

   return 0;
}
```

Accessing out of range component!

```
$ g++ -o vect2 vect2.cc
$ ./vect2
i: 0    vect[0]: 0.4            v2[0]: 5.34218e+36      v3[0]: 0.9
i: 1    vect[1]: 1.34           v2[1]: 2.62884e-42      v3[1]: -0.1
i: 2    vect[2]: 56.156         v2[2]: 3.30001e-39      v3[2]: -0.65
i: 3    vect[3]: 5.60519e-45    v2[3]: 1.57344e+20      v3[3]: 1.012
i: 4    vect[4]: 1.72441e+20    v2[4]: 0.4              v3[4]: 2.23
```

Example of Bad non-initialized Arrays

```
// vect1.cc
#include <iostream>
#include <cmath>

using namespace std;


int main() {

   float vect[3]; // no initialization

   cout << "printing garbage since vector not initialized" << endl;
   for(int i=0; i<3; ++i) {
     cout << "vect[" << i << "] = " << vect[i]
          << endl;
   }

   vect[0] = 1.1;
   vect[1] = 20.132;
   vect[2] = 12.66;

   cout << "print vector after setting values" << endl;
   for(int i=0; i<3; ++i) {
     cout << "vect[" << i << "] =    " << vect[i] << "\t"
          << "sqrt( vect[" << i << "] ) = " << sqrt(vect[i])
          << endl;
   }

   return 0;
}
```

```
$ ./vect1
printing garbage since vector not initialized
vect[0] = 2.62884e-42
vect[1] = NaN
vect[2] = 0
print vector after setting values
vect[0] =    1.1        sqrt( vect[0] ) = 1.04881
vect[1] =    20.132     sqrt( vect[1] ) = 4.48687
vect[2] =    12.66      sqrt( vect[2] ) = 3.55809
```

Control Statements in C++

```
// SimpleIf.cpp
#include <iostream>
using namespace std;

int main() { // main begins here

   if( 1 == 0 ) cout << "1==0" << endl;

   if( 7.2 >= 6.9 ) cout << "7.2 >= 6.9" << endl;

   bool truth = (1 != 0);
   if(truth) cout << "1 != 0" << endl;

   if( ! ( 1.1 >= 1.2 ) ) cout << "1.1 < 1.2" << endl;

   return 0;
} // end of main
```

```
$ g++ -o SimpleIf SimpleIf.cpp
$ ./SimpleIf
7.2 >= 6.9
1 != 0
1.1 < 1.2
```

Declaration and Definition of Variables

```
// SimpleVars.cpp
#include <iostream>
using namespace std;

int main() {

   int samples; // declaration only

   int events = 0; // declaration and assignment

   samples = 123; // assignment

   cout << "How many samples? " ;
   cin >> samples; // assigment via I/O

    cout << "samples: " << samples
         << "\t"  // insert a tab in the printout
         <<  "events: " << events
         << endl;

   return 0;
} // end of main
```

```
$ g++ -o SimpleVars SimpleVars.cpp
$ ./SimpleVars
How many samples? 3
samples: 3      events: 0
```

Loops and iterations in C++

```
int main() { // main begins here

   int nIterations;
   cout << "How many iterations? ";
   cin >> nIterations;

   int step;
   cout << "step of iteration? " ;
   cin >> step;

   for(int index=0; index < nIterations; index+=step) {
     cout << "index: " << index << endl;
   }
   return 0;
} // end of main
```

Maximum

Starting value

step

```
$ g++ -o SimpleLoop SimpleLoop.cpp
$ ./SimpleLoop
How many iterations? 7
step of iteration? 3
index: 0
index: 3
index: 6
```

Namespace, Pointers and References, Constants
Introduction to Class

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Output with **iostream**

```
// SimpleIO.cpp
#include <iostream>
using namespace std;

int main() { // main begins here

   // print message to STDOUT
   cout << "Moving baby steps in C++!" << endl;

   return 0;

} // end of main
```

End of line
start a new line!

```
$ g++ -o SimpleIO SimpleIO.cpp
$ ./SimpleIO
Moving baby steps in C++!
```

- **iostream** provides output capabilities to your program

Input with `iostream`

```
// SimpleInput.cpp
#include <iostream>
using namespace std;

int main() { // main begins here

   int nIterations;

   cout << "How many iterations? ";
   cin >> nIterations;

   // print message to STDOUT
   cout << "Number of requested iterations: " << nIterations << endl;

   return 0;
} // end of main
```

Put content of cin into variable nIterations

```
$ g++ -o SimpleInput SimpleInput.cpp
$ ./SimpleInput
How many iterations? 7
Number of requested iterations: 7
```

- **`iostream`** provides also input capabilities to your program

Problems with **cin**

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

int main() {

  cout << "iterations? ";

  int iters;
  cin >> iters;

  cout << "requested " << iters << " iterations" << endl;

  return 0;
}
```

```
$ g++ -Wall -o tinput_bad tinput_bad.cc
$ ./tinput_bad
iterations? 23
requested 23 iterations
$ ./tinput_bad
iterations? dfed
requested 134514793 iterations
```

Checking **cin** success or failure

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

int main() {

  cout << "iterations? ";

  int iters = 0;
  cin >> iters;

  if(cin.fail()) cout << "cin failed!" << endl;

  cout << "requested " << iters << " iterations" << endl;

  return 0;
}
```

Fails if input data doesn't match expected data type

```
$ g++ -Wall -o tinput tinput.cc
$ ./tinput
iterations? 34
requested 34 iterations
$ ./tinput
iterations? sfee
cin failed!
requested 0 iterations
```

Scope of Variables

```
// scope.cc
#include <iostream>


double f1() {
  double y = 2;
  return y;
}

int main() {

   double x = 3;
   double z = f1();

   std::cout << "x: " << x << ", z: " << z << ", y: " << y
             << std::endl;
   return 0;
}
```

```
$ g++ -o scope scope.cc
scope.cc: In function `int main()':
scope.cc:16: error: `y' undeclared (first use this function)
scope.cc:16: error: (Each undeclared identifier is reported
 only once for each function it appears in.)
```

What is the difference between **`cout`** and **`std::cout`**?

- The scope of a name is the block of program where the name is valid and can be used
  - A block is delimited by { }
  - It can be the body of a method, or a simple scope defined by the user using { }

What is **namespace** ?

- A mechanism to group declarations that logically belong to each other

```
namespace physics {
  class vector;
  class unit;
  class oscillator;
  void sort(const vector& value);
}

namespace electronics {
  void sort(const vector& value);
  class oscillator;
}

namespace graphics {
  void sort(const vector& value);
  class unit;
}
```

- Provides an easy way for logical separation of parts of a big project

- Basically a ‘scope’ for a group of related declarations

How do I use **namespaces** ?

```
#include <iostream>

namespace physics {
  double mean(const double& a, const double& b) { return (a+b)/2.; }
}

namespace foobar {
  double mean(const double& a, const double& b) { return (a*a+b*b)/2.; }
}

int main() {
   double x = 3;
   double y = 4;

   double z1 = physics::mean(x,y);
   std::cout << "physics::mean(" << x << "," << y << ") = " << z1
             << std::endl;

   double z2 = foobar::mean(x,y);
   std::cout << "foobar::mean(" << x << "," << y << ") = " << z2
             << std::endl;
   return 0;
}
```

physics::mean

foobar::mean

Use "::" to specify the namespace

```
$ g++ -o namespace1 namespace1.cc
$ ./namespace1
physics::mean(3,4) = 3.5
foobar::mean(3,4) = 12.5
```

Defined in iostream

Common Errors with **namespaces**

```
// namespaceBad.cc
#include <iostream>

namespace physics {
  double mean(const double& a, const double& b) {
    return (a+b)/2.;
  }
}

int main() {

   double x = 3;
   double y = 4;

   double z1 = mean(x,y); // forgot the namespace!
   cout << "physics::mean(" << x << "," << y << ") = " << z1
             << std::endl;

   return 0;
}
```

If you forget to specify the namespace the compiler doesn't know where to find the method

```
$ g++ -o namespaceBad namespaceBad.cc
namespaceBad.cc: In function `int main()':
namespaceBad.cc:15: error: `mean' undeclared (first use this function)
namespaceBad.cc:15: error: (Each undeclared identifier is reported only
 once for each function it appears in.)
namespaceBad.cc:16: error: `cout' undeclared (first use this function)
```

using namespace directive

```
// namespace2.cc
#include <iostream>

namespace physics {
  double mean(const double& a, const double& b) {
    return (a+b)/2.;
  }
}

using namespace std; // make all names in std namespace available!

int main() {

   double x = 3;
   double y = 4;

   double z1 = physics::mean(x,y);
   cout << "physics::mean(" << x << "," << y << ") = " << z1
             << endl;

   return 0;
}
```

Provide default namespace for un-qualified names

Same concepts used also in python

Compiler looks for **cout** and **endl** first

if not found looks for **std::cout** and **std::endl**;

```
$ g++ -o namespace2 namespace2.cc
$ ./namespace2.exe
physics::mean(3,4) = 3.5
```

Be careful with **`using`** directive!

```
// namespaceBad2.cc
#include <iostream>

namespace physics {
  double mean(const double& a, const double& b) { return (a+b)/2.; }
}

namespace foobar {
  double mean(const double& a, const double& b) { return (a*a+b*b)/2.; }
}

using namespace foobar;
using namespace physics;
using namespace std;

int main() {
   double x = 3;
   double y = 4;

   double z1 = mean(x,y);
   double z2 = mean(x,y);

   return 0;
}
```

Ambiguous use of method **`mean`**!

Is it in **`foobar`** or in **`physics`**?

```
$ g++ -o namespaceBad2 namespaceBad2.cc
namespaceBad2.cc: In function `int main()':
namespaceBad2.cc:21: error: call of overloaded `mean(double&, double&)' is ambiguous
namespaceBad2.cc:5: note: candidates are: double physics::mean(const double&, const double&)
namespaceBad2.cc:9: note:  double foobar::mean(const double&, const double&)
namespaceBad2.cc:25: error: call of overloaded `mean(double&, double&)' is ambiguous
namespaceBad2.cc:5: note: candidates are: double physics::mean(const double&, const double&)
namespaceBad2.cc:9: note:  double foobar::mean(const double&, const double&)
```

Some tips on **using** directive

```
// namespace3.cc
#include <iostream>

namespace physics {
  double mean(const double& a, const double& b) {
    return (a+b)/2.;
  }
}

void printMean(const double& a, const double& b) {
  double z1 = physics::mean(a,b);

  using namespace std; // using std namespace within this method!
  cout << "physics::mean(" << a << "," << b << ") = " << z1 << endl;
}

int main() {

   double x = 3;
   double y = 4;
   printMean(x,y);

   cout << "no namespace available in the main!" << endl;
   return 0;
}
```

Namespace defined only within printMean

```
$ g++ -o namespace3 namespace3.cc
namespace3.cc: In function `int main()':
namespace3.cc:23: error: `cout' undeclared (first use this function)
namespace3.cc:23: error: (Each undeclared identifier is reported only
once for each function it appears in.)
namespace3.cc:23: error: `endl' undeclared (first use this function)
```

No default namespace in the main()

Another Example on Scopes

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

using std::cout;
using std::endl;

int main() {

  double x = 1.2;

  cout << "in main before scope, x: " << x << endl;

  { // just a local scope
     x++;
     cout << "in local scope before int, x: " << x << endl;

     int x = 4;
     cout << "in local scope after int, x: " << x << endl;
  }

  cout << "in main after local scope, x: " << x << endl;

  return 0;
}
```

Another way to declare ONLY classes and functions we are going to use instead of entire namespace

```
$ g++ -o scope scope.cc
$ ./scope
in main before scope, x: ???
in local scope before int, x: ???
in local scope after int, x: ???
in main after local scope, x: ???
```

What do you think the output is going to be?

Another Example on Scopes

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

using std::cout;
using std::endl;

int main() {

  double x = 1.2;

  cout << "in main before scope, x: " << x << endl;

  { // just a local scope
     x++;
     cout << "in local scope before int, x: " << x << endl;

     int x = 4;
     cout << "in local scope after int, x: " << x << endl;
  }

  cout << "in main after local scope, x: " << x << endl;

  return 0;
}
```

Another way to declare ONLY classes and functions we are going to use instead of entire namespace

Changed value of x from main scope

Define new variable in this scope

Back to the main scope

```
$ g++ -o scope scope.cc
$ ./scope
in main before scope, x: 1.2
in local scope before int, x: 2.2
in local scope after int, x: 4
in main after local scope, x: 2.2
```

Functions and Methods

- A function is a set of operations to be executed
  - Typically there is some input to the function
  - Usually functions have a return value
  - Functions not returning a specific type are **`void`**

```
// func1.cc
#include <iostream>

double pi() {
  return 3.14;
}

void print() {
  std::cout << "void function print()" << std::endl;
}

int main() {

   std::cout << "pi: " << pi() << std::endl;
   print();

   return 0;
}
```

```
$ g++ -o func1 func1.cc
$ ./func1
pi: 3.14
void function print()
```

Functions must be declared before being used

```
// func2.cc
#include <iostream>

double pi() {
  return 3.14;
}

int main() {

   std::cout << "pi: " << pi() << std::endl;
   print();

   return 0;
}

void print() {
  std::cout << "void function print()" << std::endl;
}
```

Compiler does not know what the name **`print`** stands for!

No declaration at this point!

```
$ g++ -o func2 func2.cc
func2.cc: In function `int main()':
func2.cc:11: error: `print' undeclared (first use this function)
func2.cc:11: error: (Each undeclared identifier is reported only
 once for each function it appears in.)
func2.cc: In function `void print()':
func2.cc:16: error: `void print()' used prior to declaration
```

Definition can be elsewhere

```
// func3.cc
#include <iostream>

double pi() {
  return 3.14;
}

extern void print(); // declare to compiler print() is a void method

int main() {

   std::cout << "pi: " << pi() << std::endl;
   print();

   return 0;
}

// now implement/define the method void print()
void print() {
  std::cout << "void function print()" << std::endl;
}
```

```
$ g++ -o func3 func3.cc
$ ./func3
pi: 3.14
void function print()
```

Pointers and References

- A variable is a label assigned to a location of memory and used by the program to access that location

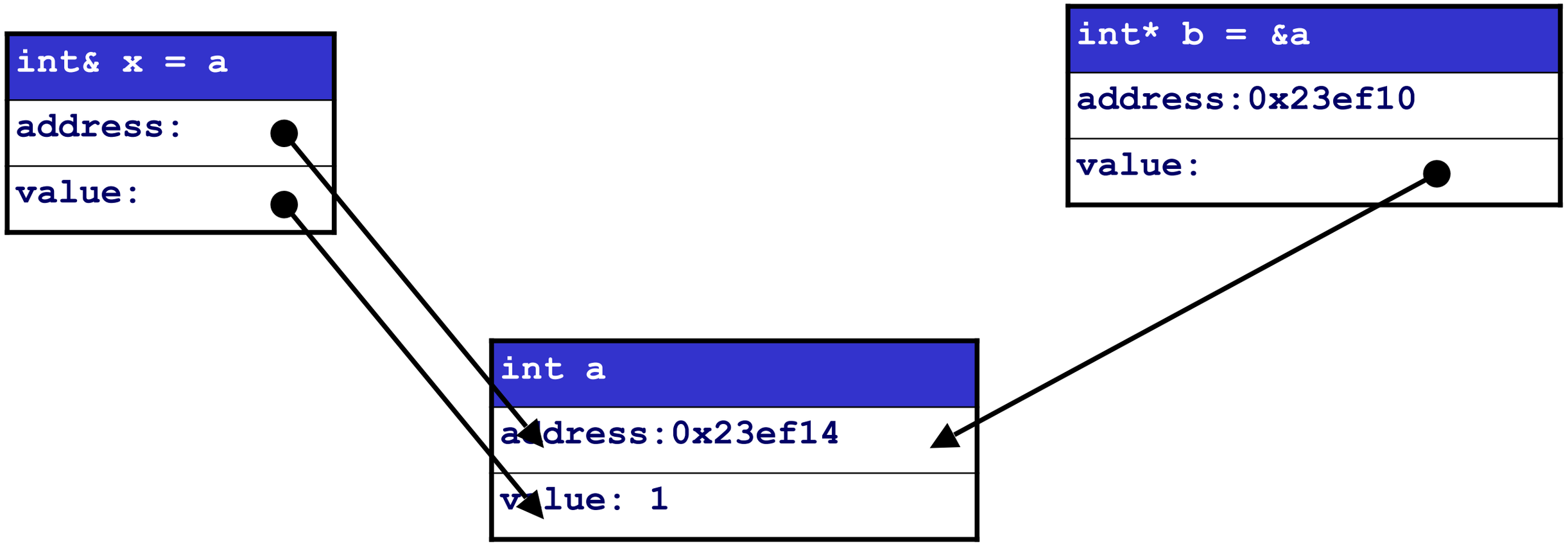
`int a` → 4 bytes==32bit of memory

```
// Pointers.cpp
#include <iostream>
using namespace std;

int main() { // main begins here

   int a; // a is a label for a location of memory dtor'ing an int value

   cout << "Insert value of a: ";
   cin >> a; // store value provided by user
             // in location of memory held by a

   int* b; // b is  a pointer to variable of
           // type a

   b  = &a; // value of b is the address of memory
            // location assigned to a

   cout << "value of a: " << a << endl;
   cout << "address of a: " << b << endl;

   return 0;
} // end of main
```

Same location in memory but different values!

```
$ g++ -o Pointers Pointers.cpp
$ ./Pointers
Insert value of a: 3
value of a: 3
address of a: 0x23ef14
$ ./Pointers
Insert value of a: 1.2
value of a: 1
address of a: 0x23ef14
```

Pointers and References



- **x** is a reference to **a**
  - A different name for the same physical location in memory
  - Using **x** or **a** is exactly the same!

- **b** is a pointer to location of memory named **x** or **a**

Pointers and References

```
// refs.cpp
#include <iostream>
using namespace std;

int main() {

   int a = 1;

   int* b; // b is  a pointer to variable of type int

   b  = &a; // value of b is the address of memory location assigned to a

   int& x = a; //

   cout << "value of a: " << a
        << ", address of a, &a: " << &a
        << endl;

   cout << "value of x: " << x
        << ", address of x, &x: " << &x
        << endl;

   cout << "value of b: " << b
        << ", address of b, &b: " << &b
        << ", value of *b: " << *b
        << endl;

   return 0;
}
```

```
$ ./refs
value of a: 1, address of a, &a: 0x23ef14
value of x: 1, address of x, &x: 0x23ef14
value of b: 0x23ef14, address of b, &b: 0x23ef10, value of *b: 1
```

Using pointers and references

```
// refs2.cpp
#include <iostream>
using namespace std;

int main() {

   int a = 1;

   int* b = &a;
   *b = 3;

   cout << "value of a: " << a
        << ", address of a, &a: " << &a
        << endl;

   int& x = a;
   x = 45;

   cout << "value of a: " << a
        << ", address of a, &a: " << &a
        << endl;

   return 0;
}
```

Change value of a with pointer b

Change value of a with reference x

```
$ g++ -o refs2 refs2.cc
$ ./refs2
value of a: 3, address of a, &a: 0x23ef14
value of a: 45, address of a, &a: 0x23ef14
```

Bad and Null Pointers

```
// badptr1.cpp
#include <iostream>
using namespace std;

int main() {

   int* b; // b is  a pointer to varible of type int

   int vect[3] = {1,2,3}; // vector of int

   int* c; // non-initialized pointer
   cout << "c: " << c << ", *c: " << *c <<endl;

   for(int i = 0; i<3; ++i) {
     c = &vect[i];
     cout << "c = &vect[" << i << "]: " << c << ", *c: " << *c << endl;
   }

   // bad pointer
   c++;
   cout << "c: " << c << ", *c: " << *c <<endl;

   // null pointer causing trouble
   c = 0;
   cout << "c: " << c << endl;
   cout << "*c: " << *c <<endl;

   return 0;
}
```

What is the size of an int in memory?

No problem compiling

```
$ g++ -o badptr1 badptr1.cc
$ ./badptr1
c: 0x7c90d592, *c: -1879046974
c = &vect[0]: 0x23eef0, *c: 1
c = &vect[1]: 0x23eef4, *c: 2
c = &vect[2]: 0x23eef8, *c: 3
c: 0x23eefc, *c: 1627945305
c: 0
Segmentation fault (core dumped)
```

Crash at runtime

Constants

- C++ allows to ensure value of a variable does not change within its scope
  - Can be applied to variables, pointers, references, vectors etc.
  - Constants must be ALWAYS initialized since they can't change at a later time!

```
// const1.cpp

int main() {

   const int a = 1;
   a = 2;

   const double x;

   return 0;
}
```

```
$ g++ -o const1 const1.cc
const1.cc: In function `int main()':
const1.cc:6: error: assignment of read-only variable `a'
const1.cc:8: error: uninitialized const `x'
```

Constant Pointer

Read from right to left:
`int * const b`:

`b` is a constant pointer to int

```
// const2.cpp

int main() {

   int a = 1;
   int * const b = &a; // const pointer to int

   *b = 5; // OK. can change value of what b points to

   int c = 3;
   b = &c; // Not OK. assign new value to c

   return 0;
}
```

```
$ g++ -o const2 const2.cc
const2.cc: In function `int main()':
const2.cc:11: error: assignment of read-only variable `b'
```

Pointer to Constant

`a` is not a constant!
But we can treat it as such when pointing to it

```
// const3.cpp

int main() {

   int a = 1;
   const int * b = &a; // pointer to const int

   int c = 3;
   b = &c; // assign new value to c ... OK!

   *b = 5; // assign new value to what c point to ... NOT OK!

   return 0;
}
```

Read from right to left:
`const int * b`:

`b` is a pointer to constant int

```
$ g++ -o const3 const3.cc
const3.cc: In function `int main()':
const3.cc:11: error: assignment of read-only location
```

NB: the error is different!

Constant Pointer to Constant Object

- Most restrictive access to another variable
  - Specially when used in function interface
- Can not change neither the pointer nor what it points to!

```
// const4.cpp

int main() {

   float a = 1;
   const float * const b = &a; // const pointer to const float

   *b = 5; // Not OK. can't change value of what b points to

   float c = 3;
   b = &c; // Not OK. can't change what b points to!

   return 0;
}
```

```
$ g++ -o const4 const4.cc
const4.cc: In function `int main()':
const4.cc:8: error: assignment of read-only location
const4.cc:11: error: assignment of read-only variable
```

Bad Use of Pointers

```
int vect[3] = {1,2,3};
int v2[3];
int v3[] = { 1, 2, 3, 4, 5, 6, 7 };
```

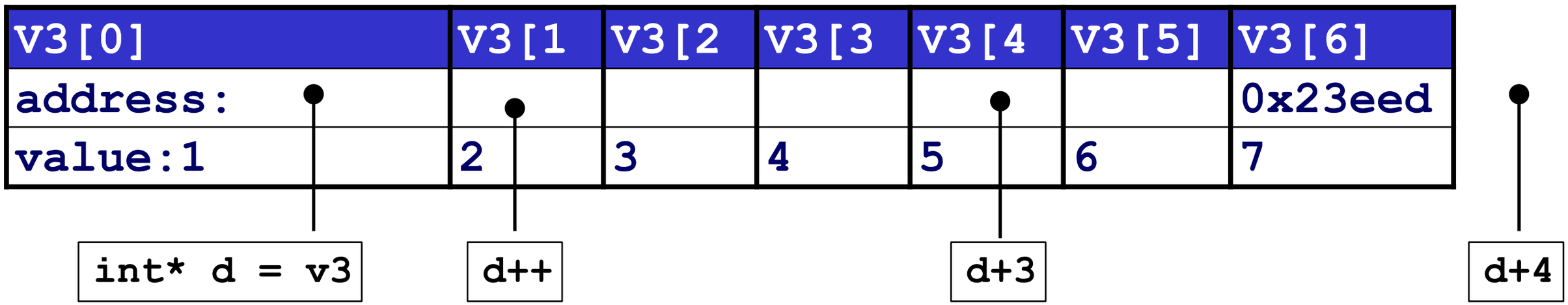
```
$ g++ -o array array.cc
$ ./array
i: 0, d = 0x23eec0, *d: 1, c = 0x23eef0, *c: 1, e = 0x23eee0, *e: -1
i: 1, d = 0x23eec4, *d: 2, c = 0x23eef4, *c: 2, e = 0x23eee4, *e: 2088773120
i: 2, d = 0x23eec8, *d: 3, c = 0x23eef8, *c: 3, e = 0x23eee8, *e: 2088772930
i: 3, d = 0x23eecc, *d: 4, c = 0x23eefc, *c: 1627945305, e = 0x23eeec, *e:
2089866642
i: 4, d = 0x23eed0, *d: 5, c = 0x23ef00, *c: 1876, e = 0x23eef0, *e: 1
```

V3[0]	V3[1	V3[2	V3[3	V3[4	V3[5]	V3[6]
address:						0x23eed
value:1	2	3	4	5	6	7

How many bytes in memory between v3[6] and v2[0] ?

V2[0]	V2[1]	V2[2]		vect[0]	vect[1]	Vect[2]
0x23eee	0x23eee	0x23eee	0x23eee	0x23eef	0x23eef	0x23eef
-1	2	3		1	2	3

Pointer Arithmetic




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

int main() {

   int v3[] = { 1, 2, 3, 4, 5, 6, 7 }; // array of size 7
   int* d = v3;
   cout << "d = " << d << ", *d: " << *d <<endl;

   d++;
   cout << "d = " << d << ", *d: " << *d <<endl;

   d = d+3;
   cout << "d = " << d << ", *d: " << *d <<endl;

   d = d+4;
   cout << "d = " << d << ", *d: " << *d <<endl;

   return 0;
}
```

```
$ g++ -o ptr ptr.cc
$ ./ptr
d = 0x23eef0, *d: 1
d = 0x23eef4, *d: 2
d = 0x23ef00, *d: 5
d = 0x23ef10, *d: 1628803505
```

+ and – operators with Pointers

```
// ptr2.cc
#include <iostream>
using namespace std;

int main() {

   int v3[] = { 1, 2, 3, 4, 5, 6, 7 }; // array of size 7

   int* d = v3;
   int*c = &v3[4];
   cout << "d = " << d << ", *d: " << *d <<endl;
   cout << "c = " << c << ", *c: " << *c <<endl;

   //int* e = c + d;  // not allowed

   cout << "c-d: " << c - d << endl;
   cout << "d-c: " << d - c << endl;

   //int* e = c-d; // wrong!

   int f = c - d;
   float g = c - d;

   cout << "f: " << f << " g: " << g << endl;

   int *  h = &v3[6] + (d-c);
   cout << "int *  h = &v3[6] + (d-c): " << h << " *h: " << *h << endl;

   return 0;
}
```

Arguments of Functions

- Arguments of functions can be passed in two different ways

– By value
  - x is a local variable in f1()

– Pointer or reference
  - x is reference to argument used by caller

```
// funcarg1.cc
#include <iostream>

using namespace std;

void emptyLine() {
  cout
  << "\n--------------------------------\n"
       << endl;
}

void f1(double x) {
  cout << "f1: input value of x = "
       << x << endl;
  x = 1.234;
  cout << "f1: change value of x in f1(). x =
"
       << x << endl;
}

void f2(double& x) {
  cout << "f2: input value of x = "
       << x << endl;
  x = 1.234;
  cout << "f2: change value of x in f2(). x =
"
       << x << endl;
}
```

Pointers and References in Functions

```
int main() {

   double a = 1.; // define a

   emptyLine();
   cout << "main: before calling f1, a = " << a<< endl;
   f1(a);  // void function
   cout << "main: after calling f1, a = " << a<< endl;

   emptyLine();
   cout << "main: before calling f2, a = " << a<< endl;
   f2(a);  // void function
   cout << "main: after calling f2, a = " << a<< endl;

   return 0;
}
```

f1 has no effect on variables in main

Because a is passed by value

x is a copy of a

f2 modifies the value of the variable in the main!

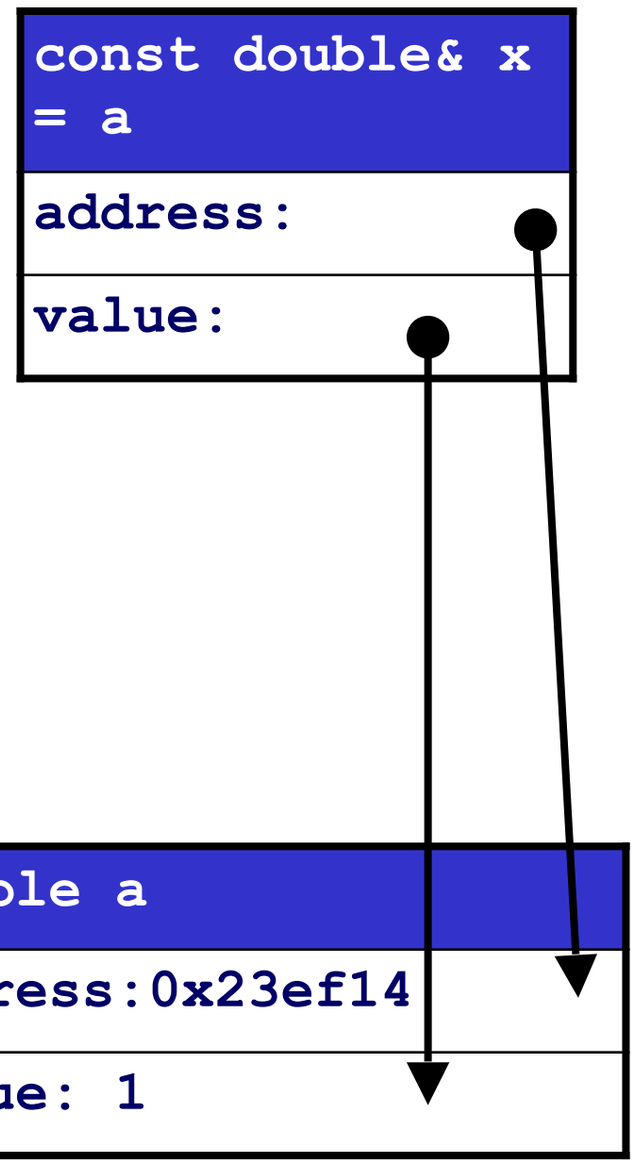
Because a is passed by reference

double& x = a;

```
$ ./funcarg1
-----------------------------------
main: before calling f1, a = 1
f1: input value of x = 1
f1: change value of x in f1(). x = 1.234
main: after calling f1, a = 1
-----------------------------------

main: before calling f2, a = 1
f2: input value of x = 1
f2: change value of x in f2(). x = 1.234
main: after calling f2, a = 1.234
```

Constant Pointers and References in Functions

```
// funcarg2.cc
#include <iostream>

using namespace std;

void f2(const double& x) {
  cout << "f2: input value of x = "
       << x << endl;
  x = 1.234;
  cout << "f2: change value of x in f2(). x = "
        << x << endl;
}

int main() {

   double a = 1.;
   f2(a);

   return 0;
}
```




```
$ g++ -o funcarg2  funcarg2.cc
funcarg2.cc: In function `void f2(const double&)':
funcarg2.cc:9: error: assignment of read-only reference `x'
```

Pointers, References and Passing by Value in Functions

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

void computeMean(const double* data, int nData, double& mean) {
  mean = 0.;
  for(int i=0; i<nData; ++i) {
    cout << "data: " << data << ", *data: " << *data << endl;
    mean += *data;
    data++;
  }
  mean /= nData; // divide by number of data points
}

int main() {

   double pressure[] = { 1.2, 0.9, 1.34, 1.67, 0.87, 1.04, 0.76 };
   double average;

   computeMean( pressure, 7, average );

   cout << "average pressure: "
        << average << endl;
   return 0;
}
```

```
$ g++ -o mean mean.cc
$ ./mean
data: 0x23eed0, *data: 1.2
data: 0x23eed8, *data: 0.9
data: 0x23eee0, *data: 1.34
data: 0x23eee8, *data: 1.67
data: 0x23eef0, *data: 0.87
data: 0x23eef8, *data: 1.04
data: 0x23ef00, *data: 0.76
average pressure: 1.11143
```

Closer Look at **computeMean()**

```
void computeMean(const double* data, int nData, double& mean) {
  mean = 0.;
  for(int i=0; i<nData; ++i) {
    cout << "data: " << data << ", *data: " << *data << endl;
    mean += *data;
    data++;
  }
  mean /= nData; // divide by number of data points
}
```

- Input data passed as constant pointer
  - Good: can't cause trouble to caller! Integrity of data guaranteed
  - Bad: No idea how many data points we have!

- Number of data pointer passed by value
  - Simple int. No gain in passing by reference
  - Bad: separate variable from array of data. Exposed to user error

- Very bad: void function with no return type
  - Good: appropriate name. computeMean() suggests an action not a type

New implementation with Return Type

```
double mean(const double* data, int nData) {
  double mean = 0.;
  for(int i=0; i<nData; ++i) {
    cout << "data: " << data << ", *data: " << *data << endl;
    mean += *data;
    data++;
  }
  mean /= nData; // divide by number of data points
  return mean
}
```

- Make function return the computed mean
- New name to make it explicit function returns something
  - Not a rule, but simple courtesy to users of your code
- No need for variables passed by reference to be modified in the function
- Still exposed to user error…

Possible Problems with use of Pointers

```
// mean2.cc
#include <iostream>
using namespace std;

double mean(const double* data, int nData) {

  double mean = 0.;
  for(int i=0; i<nData; ++i) {
    cout << "data: " << data << ", *data: " << *data << endl;
    mean += *data;
    data++;
  }
  mean /= nData; // divide by number of data points
  return mean;
}

int main() {
   double pressure[] = { 1.2, 0.6, 1.8 }; // only 3 elements
   double average = mean(pressure, 4); // mistake!
   cout << "average pressure: " << average << endl;

   return 0;
}
```

```
$ g++ -o mean2 mean2.cc
$ ./mean2
data: 0x23eef0, *data: 1.2
data: 0x23eef8, *data: 0.6
data: 0x23ef00, *data: 1.8
data: 0x23ef08, *data: 8.48798e-314
average pressure: 0.9
```

Simple luck!
Additional value not changing the average!

No protection against possible errors!

What about computing other quantities?

- What if we wanted to compute also the standard deviation of our data points?

```
void computeMean(const double* data, int nData, double& mean, double& stdDev) {
 // two variables passed by reference to void function
 // not great. But not harmful.
}


double meanWithStdDev(const double* data, int nData, double& stdDev) {
  // error passed by reference to mean function! ugly!! anti-intuitive
}

double mean(const double* data, int nData) {
  // one method to compute only average
}

double stdDev(const double* data, int nData) {
  // one method to compute standard deviation
  // use mean() to compute average needed by std deviation
}
```

What if we had a new C++ type?

- Imagine we had a new C++ type called **`Result`** including data about both mean and standard deviation

- We could then simply do the following

```
Result mean(const double* data, int nData) {
  Result result;
  // do your calculation
  return result;
}
```

- *This is exactly the idea of classes in C++!*

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!

Using class **Result**

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

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_;
};
```

```
int main() {

  Result r1;
  cout << "r1, mean: " << r1.getMean()
       << ", stdDev: " << r1.getStdDev()
       << endl;

  Result r2(1.1,0.234);
  cout << "r2, mean: " << r2.getMean()
       << ", stdDev: " << r2.getStdDev()
       << endl;

  return 0;
}
```

```
$ g++ -o results2 result2.cc
$ ./results2
r1, mean: NaN, stdDev: 8.48798e-314
r2, mean: 1.1, stdDev: 0.234
```

`r1` is ill-defined. Why?

What is wrong with Result::Result() ?

C++ Data Types

Name	Description	Size*	Range*
`char`	Character or small integer.	1byte	signed: -128 to 127 unsigned: 0 to 255
`short int (short)`	Short Integer.	2bytes	signed: -32768 to 32767 unsigned: 0 to 65535
`int`	Integer.	4bytes	signed: -2147483648 to 2147483647 unsigned: 0 to 4294967295
`long int (long)`	Long integer.	4bytes	signed: -2147483648 to 2147483647 unsigned: 0 to 4294967295
`bool`	Boolean value. It can take one of two values: true or false.	1byte	true or false
`float`	Floating point number.	4bytes	3.4e +/- 38 (7 digits)
`double`	Double precision floating point number.	8bytes	1.7e +/- 308 (15 digits)
`long double`	Long double precision floating point number.	8bytes	1.7e +/- 308 (15 digits)
`wchar_t`	Wide character.	2 *or* 4 bytes	1 wide character

- Size is architecture dependent!
  - Difference between 32-bit and 64-bit machines
  - Above table refers to typical 32-bit architecture
- **`int`** is usually has size of 'one word' on a given architecture

- Four integer types: **`char`**, **`short`**, **`int`**, and **`long`**
  - Each type is at least as large as previous one
    - **`size(char) <= size(short) <= size(int) <= size(long)`**

- Long **`int == int`**; similarly **`short int == short`**

Size of Objects/Types in C++

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

int main() {
  char*       aChar = "c"; // char
  bool        aBool = true; // boolean
  short       aShort = 33; // short
  long        aLong  = 123421; // long
  int         anInt = 27; // integer
  float       aFloat = 1.043; // single precision
  double      aDbl = 1.243e-234; // double precision
  long double aLD = 0.432e245; // double precision

  cout << "char* aChar = " << aChar << "\tsizeof(" << "*char" << "): " << sizeof(*aChar) << endl;
  cout << "bool aBool = " << aBool << "\tsizeof(" << "bool" << "): " << sizeof(aBool) << endl;
  cout << "short aShort = " << aShort << "\tsizeof(" << "short" << "): " << sizeof(aShort) << endl;
  cout << "long aLong = " << aLong << "\tsizeof(" << "long" << "): " << sizeof(aLong) << endl;
  cout << "int aInt = " << anInt << "\tsizeof(" << "int" << "): " << sizeof(anInt) << endl;
  cout << "float aFloat = " << aFloat << "\tsizeof(" << "float" << "): " << sizeof(aFloat) << endl;
  cout << "double aDbl = " << aDbl << "\tsizeof(" << "double" << "): " << sizeof(aDbl) << endl;
  cout << "long double aLD = " << aLD << "\tsizeof(" << "long double" << "): " << sizeof(aLD) << endl;

  return 0;
}
```

```
$ g++ -o cpptypes cpptypes.cc
$ ./cpptypes
char* aChar = c                    sizeof(*char): 1
bool aBool = 1                     sizeof(bool): 1
short aShort = 33                  sizeof(short): 2
long aLong = 123421                sizeof(long): 4
int aInt = 27                      sizeof(int): 4
float aFloat = 1.043               sizeof(float): 4
double aDbl = 1.243e-234           sizeof(double): 8
long double aLD = 4.32e+244        sizeof(long double): 12
```

Topics

- 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

name_ is a datamember

No declaration of name_ in member functions!

name is a local variable only within setName()

```
// 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
};
```

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

```
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;
}
```

```
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_;
};
```

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?

- Separating Interface
- Implementation of Classes
- Header and Source Files
- Dynamic Memory Management
- Class Destructors

Reminder about g++

- g++ by default looks for a main function in the file being compiled unless differently instructed

- The main function becomes the program to run when the compiler is finished linking the binary application
  - Compiling: translate user code in high level language into binary code that system can use
  - Linking: put together binary pieces corresponding to methods used in the main function
  - Application: product of the linking process

- Source files of classes do not have any main method

- We need to tell g++ (and other compilers) no linking is needed

Compiling without Linking

- g++ has a `-c` option that allows to specify only compilation is needed

- User code is translated into binary but no attempt to look for main method and creating an application

```
$ ls -l Counter.*
-rw-r--r--  1 rahatlou users 449 May 15 00:55 Counter.cc
-rw-r--r--  1 rahatlou users 349 May 15 00:55 Counter.h

$ g++ -c Counter.cc

$ ls -l Counter.*
-rw-r--r--  1 rahatlou users  449 May 15 00:55 Counter.cc
-rw-r--r--  1 rahatlou users  349 May 15 00:55 Counter.h
-rw-r--r--  1 rahatlou users 1884 May 15 01:23 Counter.o
```

By default g++ creates a .o (object file) for the .cc file

Using Header Files in Applications

```
// app2.cpp
#include <iostream>
using namespace std;

#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 );

  return 0;
}
```

```
$ g++ -o app2 app2.cpp
/tmp/ccJuugJc.o:app2.cpp:(.text+0x10d): undefined reference to `Counter::Counter()'
/tmp/ccJuugJc.o:app2.cpp:(.text+0x124): undefined reference to `Counter::value()'
/tmp/ccJuugJc.o:app2.cpp:(.text+0x16e): undefined reference to `Counter::value()'
/tmp/ccJuugJc.o:app2.cpp:(.text+0x1dc): undefined reference to `Counter::Counter()'
/tmp/ccJuugJc.o:app2.cpp:(.text+0x1ef): undefined reference to `Counter::increment(int)'
/tmp/ccJuugJc.o:app2.cpp:(.text+0x200): undefined reference to `Counter::value()'
/tmp/ccJuugJc.o:app2.cpp:(.text+0x272): undefined reference to `Counter::value()'
/tmp/ccJuugJc.o:app2.cpp:(.text+0x2b7): undefined reference to `Counter::increment()'
collect2: ld returned 1 exit status
```

Providing compiled Class Code at Link Time

- Including the header file is not sufficient!
  - It tells the compiler only about arguments and return type
  - But it does not tell him what to execute
  - Compiler doesn't have the binary code to use to create the application!

- We must use the compiled object file at link time
  - g++ is told to make an application called app2 from source code in app2.cpp and using also the binary file Counter.o to find any symbol needed in app2.cpp

```
$ g++ -o app2 app2.cpp Counter.o
$ ./app2
counter.value(): 7
ptr = &counter: 0x23ef10
ptr->value(): 7
counter value: 1
```

Problem: Multiple Inclusion of Header Files!

- What if we include the same header file several times?
  - This can happen in many ways

- Some pretty common ways are
  - **`App.cpp`** includes both **`Foo.h`** and **`Bar.h`**
  - **`Foo.h`** is included in **`Bar.h`** and **`Bar.cc`**

```
// Bar.h

#include "Foo.h"

class Bar {

  // class goes here
  Bar(const Foo& afoo, double x);


}`
```

```
// App.cpp

#include "Foo.h"
#include "Bar.h"

int main() {

  // program goes here
  Foo f1;
  Bar b1(f1, 0.3);

  return 0;
}
```

Example of Multiple Inclusion

```
// app3.cpp
#include <iostream>
using namespace std;
#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;
}

#include "Counter.h"
int main() {
  Counter counter;
  counter.increment(7);

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

  printCounter( counter );
  printCounter( c2 );

  return 0;
}
```

Line 19

```
// Counter.h
// Counter Class: simple counter class. Allows simp
// 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_;
}
```

Line 8

```
$ g++ -o app3 app3.cpp Counter.o
In file included from app3.cpp:19:
Counter.h:8: error: redefinition of `class Counter'
Counter.h:8: error: previous definition of `class Counter'
```

#define, #ifndef and #endif directives

- Problem of multiple inclusion can be solved at pre-compiler level

1: if Datum_h is not defined follow the instruction until #endif

2: define a new variable called Datum_h

3: end of ifndef block

```
#ifndef Datum_h
#define Datum_h
// Datum.h

class Datum {
  public:
    Datum();
    Datum(double x, double y);
    Datum(const Datum& datum);
    double value() { return value_; }
    double error() { return error_; }

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

Example: application using Datum

```
// app4.cpp
#include "Datum.h"
#include <iostream>

void print(Datum& input) {
  using namespace std;
  cout << "input: " << input.value()
       << " +/- " << input.error()
       << endl;
}

#include "Datum.h"

int main() {
  Datum d1(-1.4,0.3);
  print(d1);

  return 0;
}
```

```
$ g++ -c Datum.cc
$ g++ -o app4 app4.cpp Datum.o
$ ./app4
input: -1.4 +/- 0.3
```

Typical Errors

- Forget to use the scope operator :: in .cc files

```
#ifndef FooDatum_h
#define FooDatum_h
// FooDatum.h

class FooDatum {
  public:
    FooDatum();
    FooDatum(double x, double y);
    FooDatum(const FooDatum& datum);
    double value() { return value_; }
    double error() { return error_; }
    double significance();

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

```
#include "FooDatum.h"

FooDatum::FooDatum() { }

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

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

double
significance() {
  return value_/error_;
}
```

```
$ g++ -c FooDatum.cc
FooDatum.cc: In function `double significance()':
FooDatum.cc:17: error: `value_' undeclared (first use this function)
FooDatum.cc:17: error: (Each undeclared identifier is reported only once
 for each function it appears in.)
FooDatum.cc:17: error: `error_' undeclared (first use this function)
```

- Functions implemented as global
- error when applying function as a member function to objects
- No error compiling the classes but error when compiling the application

Reminder: Namespace of Classes

- C++ uses namespace as integral part of a class, function, data member

- Any quantity declared within a namespace can be accessed ONLY by using the scope operator :: and by specifying its namespace

- When using a new class, you must look into its header file to find out which namespace it belongs to
  - There are no shortcuts!

- When implementing a class you must specify its namespace
  - Unless you use the using directive

Another Example of Namespace

```
#ifndef CounterNS_h_
#define CounterNS_h_
#include <string>

namespace rome {
  namespace didattica {

    class Counter {
      public:
        Counter(const std::string& name);
        ~Counter();
        int value();
        void reset();
        void increment(int step =1);
        void print();

      private:
        int count_;
        std::string name_;
    }; // class counter

  } // namespace didattica
} //namespace rome
#endif
```

```
#include "CounterNS.h"

int main() {
  rome::didattica::Counter c1("c1");
  c1.print();
  return 0;
}
```

```
// CounterNS.cc
#include "CounterNS.h"

// include any additional heade files needed in the class
// definition
#include <iostream> // needed for input/output
using std::cout;
using std::endl;
using namespace rome::didattica;

Counter::Counter(const std::string& name) {
  count_ = 0;
  name_ = name;
  cout << "Counter::Counter() called for Counter "<< name_
<< endl;
};

Counter::~Counter() {
  cout << "Counter::~Counter() called for Counter "<<
name_ << endl;
};

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

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

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

void Counter::print() {
  cout << "Counter::print(): name: " << name_ << "  value:
" << count_ << endl;
}
```

Class `std::vector<T>`

```
#include <iostream>
#include <vector>
#include "Datum.h"

int main() {


  std::vector<double> vals;
  vals.push_back(1.3);
  vals.push_back(-2.1);

  std::vector<double> errs;
  errs.push_back(0.2);
  errs.push_back(0.3);

  std::vector<Datum> data;
  data.push_back( Datum(1.3, 0.2) );
  data.push_back( Datum(-2.1, 0.3) );

 std:cout << "# dati:: " << data.size() << std::endl;

  // using traditional loop on an array
  int i=0;
  std::cout << "Using [] operator on vector" << std::endl;
  for(i=0; i< data.size(); ++i) {
    std::cout << "i: " << i
                    << "\t data: " << data[i].value() << " +/- " << data[i].error()
                    << std::endl;
  }

  // using vector iterator
  i=0;
  std::cout << "std::vector<T>::iterator " << std::endl;
  for(std::vector<Datum>::iterator d = data.begin(); d != data.end(); d++) {
    //std::cout << "d: " << d << std::endl;
    i++;
    std::cout << "i: " << i
                    << "\t data: " << d->value() << " +/- " << d->error()
                    << std::endl;
  }

    // using vector iterator
  i=0;
  std::cout << "C+11 extension feature " << std::endl;
  for(Datum dit : data) {
    i++;
    std::cout << "i: " << i
                    << "\t data: " << dit.value() << " +/- " << dit.error()
                    << std::endl;
  }

  return 0;

}
```

```
$ g++ -o app.exe vector1.cc Datum.cc
vector1.cc:45:17: warning: range-based for loop is a C++11 extension
      [-Wc++11-extensions]
  for(Datum dit : data) {
                ^
1 warning generated.
$ ./app.exe
# dati:: 2
Using [] operator on vector
i: 0            data: 1.3 +/- 0.2
i: 1            data: -2.1 +/- 0.3
std::vector<T>::iterator
i: 1            data: 1.3 +/- 0.2
i: 2            data: -2.1 +/- 0.3
C+11 extension feature
i: 1            data: 1.3 +/- 0.2
i: 2            data: -2.1 +/- 0.3
```

Interface of `std::vector<T>`

http://www.cplusplus.com/reference/vector/vector/
https://en.cppreference.com/w/cpp/container/vector

Member functions

(constructor)	constructs the `vector` (public member function)
(destructor)	destructs the `vector` (public member function)
`operator=`	assigns values to the container (public member function)
`assign`	assigns values to the container (public member function)
`get_allocator`	returns the associated allocator (public member function)

Element access

`at`	access specified element with bounds checking (public member function)
`operator[]`	access specified element (public member function)
`front`	access the first element (public member function)
`back`	access the last element (public member function)
`data` (C++11)	direct access to the underlying array (public member function)

Iterators

`begin` **`cbegin`**	returns an iterator to the beginning (public member function)
`end` **`cend`**	returns an iterator to the end (public member function)
`rbegin` **`crbegin`**	returns a reverse iterator to the beginning (public member function)
`rend` **`crend`**	returns a reverse iterator to the end (public member function)

Capacity

`empty`	checks whether the container is empty (public member function)
`size`	returns the number of elements (public member function)
`max_size`	returns the maximum possible number of elements (public member function)
`reserve`	reserves storage (public member function)

Using `std::vector<T>` in functions

```
#include <vector>
Using std::vector;

Datum average(vector<float>&  val,
vector<float>& err) {
  double mean = 0.;
  double meanErr(0.); // same as = 0.

  // loop over data
    // compute average

  Datum  res(mean, meanErr);
  return res;
}
```

Constructor is called with arguments
Same behavior for **`double`** and **`Datum`**

Object **`res`** is like any other variable **`mean`** or **`meanErr`**
`res` simply returned as output to caller

```
#include <vector>
Using std::vector;

Datum average(vector<float>&  val,
vector<float>& err) {
  double mean = 0.;
  double meanErr(0.); // same as =
0.

  // loop over data
    // compute average

  return Datum(mean, meanErr);
}
```

```
#include <vector>
Using std::vector;

double average(vector<float>&  val) {
  double mean = 0.;
    // loop over data
    // compute average

  return mean;
}
```

Since **`res`** not really needed within function
we can just create it while returning the function output

Dynamic Memory Allocation: **`new`** and **`delete`**

- C++ allows dynamic management memory at run time via two dedicated operators: **`new`** and **`delete`**

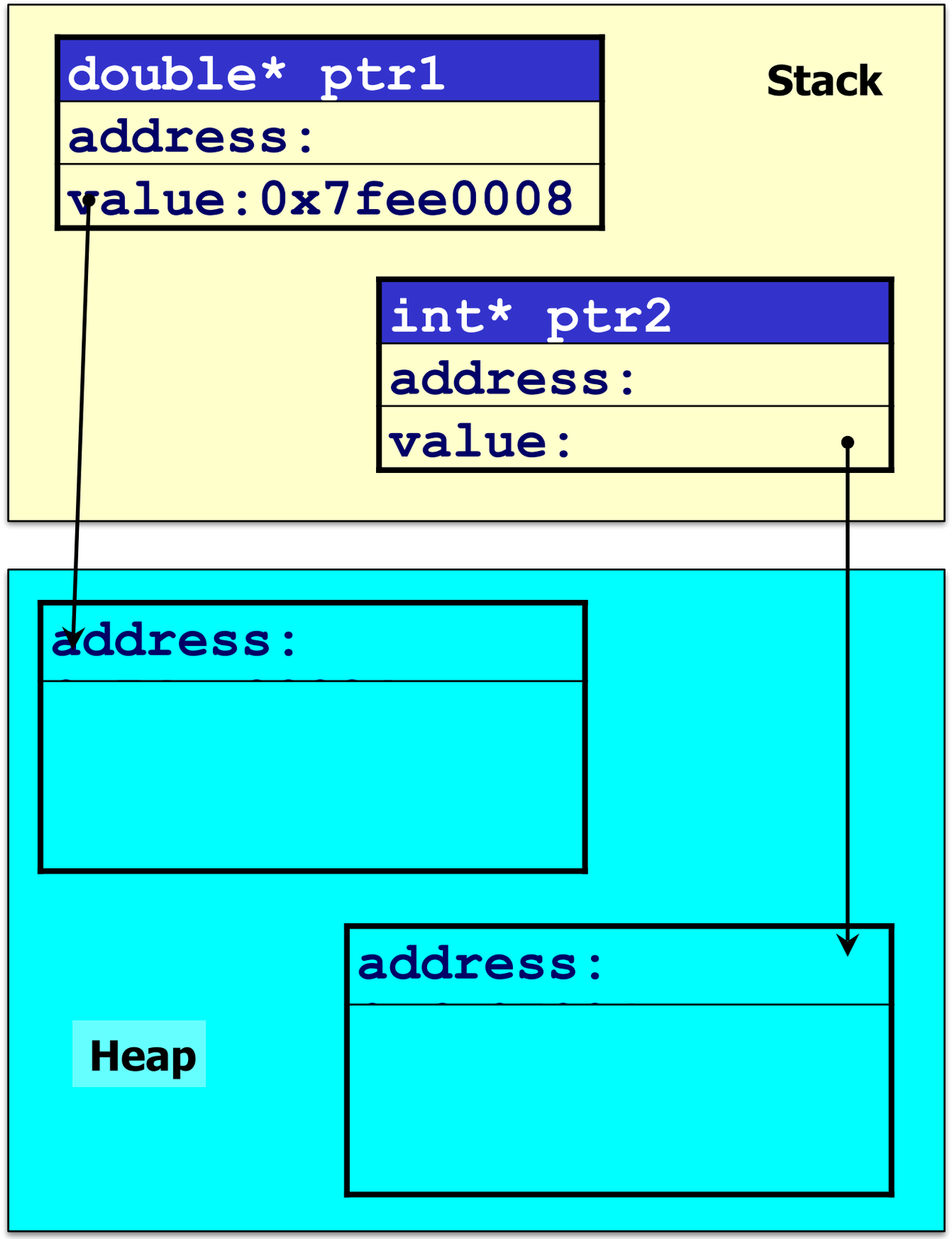
- **`new`**: allocates memory for objects of any built-in or user-defined type
  - The amount of allocated memory depends on the size of the object
  - For user-defined types the size is determined by the data members

- Which memory is used by **`new`**?
  - **`new`** allocated objects in the free store also known as heap
  - This is region of memory assigned to each program at run time
  - Memory allocated by **`new`** is unavailable until we free it and give it back to system via **`delete`** operator

- **`delete`**: de-allocates memory used by new and give it back to system to be re-used

Stack and Heap

```
// app7.cpp
#include <iostream>
using namespace std;

int main() {
    double* ptr1 = new double[100000];
    ptr1[0] = 1.1;

    cout << "ptr1[0]: " << ptr1[0]
         << endl;

    int* ptr2 = new int[1000];
    ptr2[233] = -13423;

    cout << "&ptr1: "<< &ptr1
     << "  sizeof(ptr1): " << sizeof(ptr1)
     << "  ptr1: " << ptr1 << endl;

    cout << "&ptr2: "<< &ptr2
     << "  sizeof(ptr2): " << sizeof(ptr2)
     << " ptr2: " << ptr2 << endl;
    delete[] ptr1;
    delete[] ptr2;
    return 0;
}
```



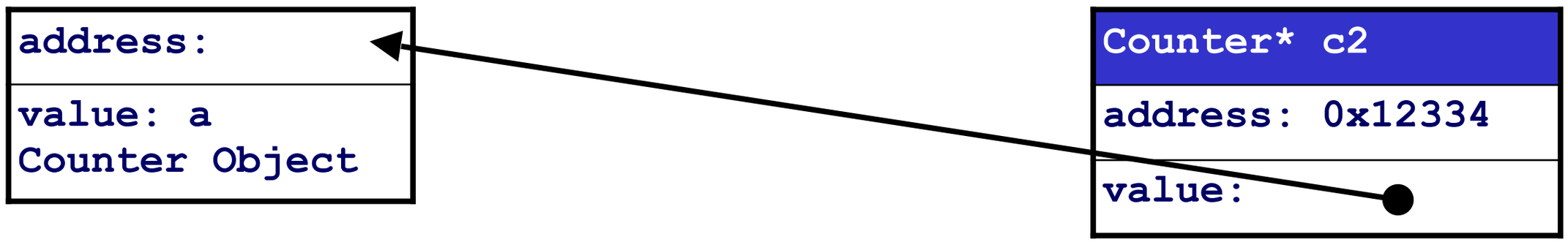

```
$ g++ -Wall -o app7 app7.cpp
$ ./app7
ptr1[0]: 1.1
&ptr1: 0x22cce4  sizeof(ptr1): 4  ptr1: 0x7fee0008
&ptr2: 0x22cce0  sizeof(ptr2): 4
ptr2: 0x6a0700
```

What does **new** do?

Dynamic object in the heap

```
Counter* c2 = new Counter("c2");

delete c2; // de-allocate memory!
```

Automatic variable in the stack



- new allocates an amount of memory given by **`sizeof(Counter)`** somewhere in memory
- returns a pointer to this location
- we assign **`c2`** to be this pointer and access the dynamically allocated memory
- delete de-allocates the region of memory pointed to by **`c2`** and makes this memory available to be re-used by the program

Memory Leak: Killing the System

- Perhaps one of the most common problems in C++ programming
- User allocates memory at run time with new but never releases the memory – forgets to call delete!
- Golden rule: every time you call **`new`** ask yourself
  - Do I really need to use new?
  - where and when **`delete`** is called to free this memory ?
- Even small amount of leak can lead to a crash of the system
  - Leaking 10 kB in a loop over 1M events leads to 1 GB of allocated and un-usable memory!

Simple Example of Memory Leak

```
// app6.cpp
#include <iostream>
using namespace std;

int main() {

  for(int i=0; i<10000; ++i){

    double* ptr = new double[100000];
    ptr[0] = 1.1;

    cout << "i: " << i
         << ", ptr: " << ptr
         << ", ptr[0]: " << ptr[0]
         << endl;

    // delete[] ptr; // ops! memory
leak!
  }
  return 0;
}
```

```
$ g++ -o leak1 leak1.cpp
$ ./leak1
i: 0, ptr: 0x4a0280, ptr[0]: 1.1
i: 1, ptr: 0x563bf8, ptr[0]: 1.1
…
i: 1381, ptr: 0x4247e178, ptr[0]: 1.1
i: 1382, ptr: 0x42541680, ptr[0]: 1.1
Abort (core dumped)
```

- At each iteration **`ptr`** is a pointer to a new (and large) array of 100k doubles!
- This memory is not released because we forgot the **`delete`** operator!
- At each turn more memory becomes unavailable until the system runs out of memory and crashes!

Advantages of Dynamic Memory Allocation

- No need to fix size of data to be used at compilation time
  - Easier to deal with real life use cases with variable and unknown number of data objects
  - No need to reserve very large but FIXED-SIZE arrays of memory
  - Example: interaction of particle in matter
    - How many particles are produced due to particle going through a detector?
    - Number not fixed a priori
    - Use dynamic allocation to create new particles as they are generated

- Disadvantage: correct memory management
  - Must keep track of **ownership** of **objects**
  - If not de-allocated can cause memory leaks which leads to slow execution and crashes
  - Most difficult part specially at the beginning or in complex systems

Destructor Method of a Class

- Constructor used by compiler to initialise instance of a class (an object)
  - Assign proper values to data members and allocate the object in memory

- Destructors are special member function doing reverse work of constructors
  - Do cleanup when object goes out of scope

- Destructor performs termination house keeping when objects go out of scope
  - No de-allocation of memory
  - Tells the program that memory previously occupied by the object is again free and can be re-used

- Destructors are ***FUNDAMENTAL*** when using dynamic memory allocation

Special Features of Destructors

- Destructors have no arguments

- Destructors do not have a return type
  - Similar to constructors

- Destructor of class Counter MUST be called **`~Counter()`**

```
#ifndef Counter_h_
#define Counter_h_
// Counter.h
#include <string>

class Counter {
  public:
    Counter(const std::string& name);
    ~Counter();
    int value();
    void reset();
    void increment();
    void increment(int step);
    void print();

  private:
    int count_;
    std::string name_;
};
#endif
```

Trivial Example of Destructor

Constructor initializes data members

```
#ifndef Counter_h_
#define Counter_h_
// Counter.h
#include <string>

class Counter {
  public:
    Counter(const std::string& name);
    ~Counter();
    int value();
    void reset();
    void increment();
    void increment(int step);
    void print();

  private:
    int count_;
    std::string name_;
};
#endif
```

Destructor does nothing

```
#include "Counter.h"
#include <iostream> // needed for input/output
using std::cout;
using std::endl;

Counter::Counter(const std::string& name) {
  count_ = 0;
  name_ = name;
  cout << "Counter::Counter() called for Counter "
       << name_ << endl;
};

Counter::~Counter() {
  cout << "Counter::~Counter() called for Counter "
       << name_ << endl;
};

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

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

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

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

void Counter::print() {
  cout << "Counter::print(): name: " << name_
       << "  value: " << count_ << endl;
}
```

Who and When Calls the Destructor?

Constructors are called by compiler when new objects are created

```
// app1.cpp
#include "Counter.h"
#include <string>

int main() {

  Counter c1( std::string("c1") );
  Counter c2( std::string("c2") );
  Counter c3( std::string("c3") );

  c2.increment(135);
  c1.increment(5677);

  c1.print();
  c2.print();
  c3.print();

  return 0;
}
```

Destructors are called implicitly by compiler when objects go out of scope!

Destructors are called in reverse order of creation

```
$ g++ -c Counter.cc
$ g++ -o app1 app1.cpp Counter.o
$ ./app1
Counter::Counter() called for Counter c1
Counter::Counter() called for Counter c2
Counter::Counter() called for Counter c3
Counter::print(): name: c1  value: 5677
Counter::print(): name: c2  value: 135
Counter::print(): name: c3  value: 0
Counter::~Counter() called for Counter c3
Counter::~Counter() called for Counter c2
Counter::~Counter() called for Counter c1
```

Create in order objects c1, c2, and c3

Destruct c3, c2, and c1

Another Example of Destructors

```
// app2.cpp
#include "Counter.h"
#include <string>

int main() {

  Counter c1( std::string("c1") );

  int count = 344;

  if( 1.1 <= 2.02 ) {
    Counter c2( std::string("c2") );

    Counter c3( std::string("c3") );
    if( count == 344 ) {
      Counter c4( std::string("c4") );
    }

    Counter c5( std::string("c5") );

    for(int i=0; i<3; ++i) {
      Counter c6( std::string("c6") );
    }
  }

  return 0;
}
```

```
$ g++ -o app2 app2.cpp Counter.o
$ ./app2
Counter::Counter() called for Counter c1
Counter::Counter() called for Counter c2
Counter::Counter() called for Counter c3
Counter::Counter() called for Counter c4
Counter::~Counter() called for Counter c4
Counter::Counter() called for Counter c5
Counter::Counter() called for Counter c6
Counter::~Counter() called for Counter c6
Counter::Counter() called for Counter c6
Counter::~Counter() called for Counter c6
Counter::Counter() called for Counter c6
Counter::~Counter() called for Counter c6
Counter::~Counter() called for Counter c5
Counter::~Counter() called for Counter c3
Counter::~Counter() called for Counter c2
Counter::~Counter() called for Counter c1
```