C++ for C Programmers

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Introduction

Stop Coding C!

1. C++ is a more structured and safer variant of C:
   There are very few reasons not to switch to C++.
2. C++ (almost) contains C as a subset.
   So you can use any old mechanism you know from C
   However: where new and better mechanisms exist, stop using the old style C-style idioms.

In this course

1. Object-oriented programming.
2. New mechanisms that replace old ones:
   I/O, strings, arrays, pointers.
3. Other new mechanisms:
   exceptions, namespaces, closures, templating

I'm assuming that you know how to code C loops and functions and you understand what structures and pointers are!

About this course

Slides and codes are from my open source text book:

`https://bitbucket.org/VictorEijkhout/`
`textbook-introduction-to-scientific-programming`

General note about syntax

Many of the examples in this lecture need the compiler option `-std=c++11`. This works for both compilers, so:

```
// for Intel:
icpc -std=c++11 yourprogram.cxx
// for gcc:
g++ -std=c++11 yourprogram.cxx
```

Later examples with `auto` even need `-std=c++17`.
There is no reason not to use that all the time.

Minor enhancements

Just to have this out of the way

- There is a `bool` type with values `true`, `false`
- Single line comments:

  ```
  int x{1}; // set to one
  ```
- Loop variable can be local:

  ```
  for (int i=0; i<N; i++) // do whatever
  ```

Simple I/O

Headers:

```
#include <iostream>
using std::cin;
using std::cout;
using std::endl;
```

Ouput:

```
int main() {
  int OC=4;
  cout << "Hello world (ABEND CODE OC" << OC << ")" << endl
```

Input:

```
int i;
cin >> i;
```

C standard header files

```
#include <cmath>
#include <cstdlib>
```

But a number of headers are not needed anymore.

Functions

Big and small changes

- Minor changes: default values on parameters, and polymorphism.
- Big change: use references instead of addresses for argument passing.

Parameter passing

Mathematical type function

Pretty good design:

- pass data into a function,
- return result through `return` statement.
- Parameters are copied into the function. (Cost of copying?)
- pass by value
- 'functional programming'

Results other than through return

Also good design:

- Return no function result,
- or return return status (0 is success, nonzero various informative statuses), and
- return other information by changing the parameters.
- *pass by reference*
- Parameters are also called 'input', 'output', 'throughput'.

C++ references different from C

- C does not have an actual pass-by-reference:
  C mechanism passes address by value.
- C++ has 'references', which are different from C addresses.
- The `&` ampersand is used, but differently.
- Asterisks are out:
  rule of thumb for now,
  if you find yourself writing asterisks, you're not writing C++.

Reference

A reference is indicated with an ampersand in its definition, and it acts as an alias of the thing it references.

Code:

```
int i;
int &ri = i;
i = 5;
cout << i << "," << ri << endl;
i *= 2;
cout << i << "," << ri << endl;
ri -= 3;
cout << i << "," << ri << endl;
```

Output [basic] ref:

```
5,5
10,10
7,7
```

(You will not use references often this way.)

Parameter passing by reference

The function parameter `n` becomes a reference to the variable `i` in the main program:

```
void f(int &n) {
  n = /* some expression */ ;
};
int main() {
  int i;
  f(i);
  // i now has the value that was set in the function
}
```

Pass by reference example 1

Code:

```
void f( int &i ) {
  i = 5;
}
int main() {

  int var = 0;
  f(var);
  cout << var << endl;
```

Output
[basic] setbyref:

```
5
```

Compare the difference with leaving out the reference.

Pass by reference example 2

```
bool can_read_value( int &value ) {
  int file_status = try_open_file();
  if (file_status==0)
    value = read_value_from_file();
  return file_status!=0;
}

int main() {
  int n;
  if (!can_read_value(n))
    // if you can't read the value, set a default
    n = 10;
```

Exercise 1

Write a `void` function `swapij` of two parameters that exchanges the input values:

```
int i=2,j=3;
swapij(i,j);
// now i==3 and j==2
```

Optional exercise 2

Write a divisibility function that takes a number and a divisor, and gives:

- a `bool` return result indicating that the number is divisible, and
- a remainder as output parameter.

```
int number,divisor,remainder;
// read in the number and divisor
if ( is_divisible(number,divisor,remainder) )
  cout << number << " is divisible by " << divisor << endl;
else
  cout << number << "/" << divisor <<
      " has remainder " << remainder << endl;
```

More about functions

Default arguments

Functions can have default argument(s):

```
double distance( double x, double y=0. ) {
  return sqrt( (x-y)*(x-y) );
}
  ...
  d = distance(x); // distance to origin
  d = distance(x,y); // distance between two points
```

Any default argument(s) should come last in the parameter list.

Polymorphic functions

You can have multiple functions with the same name:

```
double sum(double a,double b) {
  return a+b; }
double sum(double a,double b,double c) {
  return a+b+c; }
```

Distinguished by type or number of input arguments: can not differ only in return type.

Const parameters

You can prevent local changes to the function parameter:

```
/* This does not compile:
   void change_const_scalar(const int i) { i += 1; }
*/
```

This is mostly to protect you against yourself.

Parameter passing summary

- Standard mechanism: call by value, copying.
- Using `Type &var`: call by reference, no copy, data in calling environment can be altered.
- Using `const Type &var`: const-ref, by reference so no copy, but data in calling environment can not be changed.

Object-Oriented Programming

Definition of object

An object is an entity that you can request to do certain things. These actions are the *methods* and to make these possible the object probably stores data, the *members*.

When designing an object, first ask yourself: ‘what functionality should this support’.

Object functionality

Small illustration: vector objects.

Code:

```
Vector v(1.,2.); // make vector (1,2)
cout << "vector has length "
     << v.length() << endl;
v.scaleby(2.);
cout << "vector has length "
     << v.length() << endl
     << "and angle " << v.angle()
     << endl;
```

Output
[object] functionality:

```
vector has length 2.23607
vector has length 4.47214
and angle 1.10715
```

Note the 'dot' notation; in a `struct` we use it for the data members; in an object we (also) use it for methods.

Exercise 3

Thought exercise:
What data does the object need to store to do this?
Is there more than one possibility?

Constructor

Use a constructor: function with same name as the class.
Typically used to initialize data members.

```
class Vector {
private:
  double x,y;
public:
  Vector( double x,double y )
    : x(x),y(y) {};
```

The synxtax `x(x)` copies the argument to the data member.

Member default values

Class members can have default values, just like ordinary variables:

```
class Point {
private:
  float x=3., y=.14;
private:
  // et cetera
}
```

Each object will have its members initialized to these values.

Member initialization in the constructor

```
class Vector {
private:
  double r,theta;
public:
  Vector( double x,double y ) {
    r = sqrt(x*x+y*y);
    theta = atan(y/x);
  }
```

Methods

Functions on objects

Code:

```
class Vector {
private:
  double x,y;
public:
  Vector( double x,double y )
    : x(x),y(y) {};
  double length() {
    return sqrt(x*x + y*y); };
  double angle() {
    return 0.; /* something trig */; };
};

int main() {
  Vector p1(1.,2.);
  cout << "p1 has length "
       << p1.length() << endl;
```

Output
[geom] pointfunc:

```
p1 has length 2.23607
```

We call such internal functions 'methods'.

Data members, even `private`, are global to the methods.

Methods that alter the object

Code:

```
class Vector {
  /* ... */
  void scaleby( double a ) {
    vx *= a; vy *= a; };
  /* ... */
};
  /* ... */
  Vector p1(1.,2.);
  cout << "p1 has length "
       << p1.length() << endl;
  p1.scaleby(2.);
  cout << "p1 has length "
       << p1.length() << endl;
```

Output
[geom] pointscaleby:

```
p1 has length 2.23607
p1 has length 4.47214
```

Methods that create a new object

Code:

```
class Vector {
  /* ... */
  Vector scale( double a ) {
    return Vector( vx*a, vy*a ); };
  /* ... */
//codesnippet pointmultop
  /* ... */
  cout << "p1 has length "
       << p1.length() << endl;
  Vector p2 = p1.scale(2.);
  cout << "p2 has length "
       << p2.length() << endl;
```

Output
[geom] pointscale:

```
p1 has length 2.23607
p2 has length 4.47214
```

Exercise 4

Make class `Point` with a constructor

```
Point( float xcoordinate, float ycoordinate );
```

Write the following methods:

- `distance_to_origin` returns a `float`.
- `printout` uses cout to display the point.
- `angle` computes the angle of vector (x, y) with the x-axis.

Exercise 5

Extend the `Point` class of the previous exercise with a method: `distance` that computes the distance between this point and another: if `p,q` are `Point` objects,

```
p.distance(q)
```

computes the distance between them.

Hint: remember the 'dot' notation for members.

Exercise 6

Write a method `halfway_point` that, given two `Point` objects `p,q`, construct the `Point` halfway, that is, $(p+q)/2$.

You can write this function directly, or you could write functions `Add` and `Scale` and combine these.

Default constructor

```
Vector v1(1.,2.), v2;
cout << "v1 has length " << v1.length() << endl;
v2 = v1.scale(2.);
cout << "v2 has length " << v2.length() << endl;
```

gives (g++; different for intel):

```
pointdefault.cxx: In function 'int main()':
pointdefault.cxx:32:21: error: no matching function for call to
                'Vector::Vector()'
```

Default constructor

The problem is with *v2*:

```
Vector v1(1.,2.), v2;
```

- *v1* is created with the constructor;
- *v2* uses the default constructor;
- as soon as you define a constructor, the default constructor goes away;
- you need to redefine the default constructor:

```
Vector() {};
Vector( double x,double y )
  : x(x),y(y) {};
```

Classes for abstact objects

Objects can model fairly abstract things:

Code:

```
class stream {
private:
  int last_result{0};
public:
  int next() {
    return last_result++; };
};

int main() {
  stream ints;
  cout << "Next: "
       << ints.next() << endl;
  cout << "Next: "
       << ints.next() << endl;
  cout << "Next: "
       << ints.next() << endl;
```

Output
[object] stream:

```
Next: 0
Next: 1
Next: 2
```

Preliminary to the following exercise

A prime number generator has:
an API of just one function: `nextprime`

To support this it needs to store:
an integer `last_prime_found`

Exercise 7

Write a class primegenerator that contains

- members how_many_primes_found and last_number_tested,
- a method nextprime;
- Also write a function isprime that does not need to be in the class.

Your main program should look as follows:

```
cin >> nprimes;
primegenerator sequence;
while (sequence.number_of_primes_found()<nprimes) {
  int number = sequence.nextprime();
  cout << "Number " << number << " is prime" << endl;
}
```

Direct alteration of internals

Return a reference to a private member:

```
class Vector {
private:
  double vx,vy;
public:
  double &x() { return vx; };
};
int main() {
  Vector v;
  v.x() = 3.1;
}
```

Reference to internals

Returning a reference saves you on copying.

Prevent unwanted changes by using a 'const reference'.

```
class Grid {
private:
  vector<Point> thepoints;
public:
  const vector<Point> &points() {
    return thepoints; };
};
int main() {
  Grid grid;
  cout << grid.points()[0];
  // grid.points()[0] = whatever ILLEGAL
}
```

‘this’ pointer to the current object

Inside an object, a pointer to the object is available as `this`:

```
class Myclass {
private:
  int myint;
public:
  Myclass(int myint) {
    this->myint = myint;
  };
};
```

‘this’ use

You don’t often need the `this` pointer. Example: you need to call a function inside a method that needs the object as argument)

```
class someclass;
void somefunction(const someclass &c) {
  /* ... */ }
class someclass {
// method:
void somemethod() {
  somefunction(*this);
};
```

(Rare use of dereference star)

More constructors

Copy constructor

- Several default copy constructors are defined
- They copy an object:
  - simple data, including pointers
  - included objects recursively.
- You can redefine them as needed, for instance for deep copy.

```
class has_int {
private:
  int mine{1};
public:
  has_int(int v) {
    cout << "set: " << v <<
     endl;
    mine = v; };
  has_int( has_int &h ) {
    auto v = h.mine;
    cout << "copy: " << v <<
     endl;
    mine = v; };
  void printme() { cout
      << "I have: " << mine <<
     endl; };
};
```

Copy constructor in action

Code:

```
has_int an_int(5);
has_int other_int(an_int);
an_int.printme();
other_int.printme();
```

Output
[object] copyscalar:

```
set: 5
copy: 5
I have: 5
I have: 5
```

Destructor

- Every class `myclass` has a *destructor* `~myclass` defined by default.
- The default destructor does nothing:

  ```
  ~myclass() {};
  ```

- A destructor is called when the object goes out of scope. Great way to prevent memory leaks: dynamic data can be released in the destructor. Also: closing files.

Destructor example

Just for tracing, constructor and destructor do `cout`:

```
class SomeObject {
public:
  SomeObject() {
    cout << "calling the constructor"
         << endl;
  };
  ~SomeObject() {
    cout << "calling the destructor"
         << endl;
  };
};
```

Destructor example

Destructor called implicitly:

Code:

```
cout << "Before the nested scope"
     << endl;
{
  SomeObject obj;
  cout << "Inside the nested scope"
       << endl;
}
cout << "After the nested scope"
     << endl;
```

Output [object] destructor:

```
Before the nested scope
calling the constructor
Inside the nested scope
calling the destructor
After the nested scope
```

Headers

C headers plusplus

You know how to use `.h` files in C.

Classes in C++ need some extra syntax.

Class prototypes

Header file:

```
class something {
private:
  int i;
public:
  double dosomething( std::vector<double> v );
};
//codesnippet
```

Implementation file:

```
double something::dosomething( std::vector<double> v ) {
  // do something with v
};
```

Data members in proto

Data members, even private ones, need to be in the header file:

```
class something {
private:
  int localvar;
public:
  double somedo(vector);
};
```

Implementation file:

```
double something::somedo(vector v) {
   .... something with v ....
   .... something with localvar ....
};
```

Static class members

A static member acts as if it's shared between all objects.

(Note: C++17 syntax)

Code:

```
class myclass {
private:
  static inline int count=0;
public:
  myclass() { count++; };
  int create_count() { return count; };
};
  /* ... */
  myclass obj1,obj2;
  cout << "I have defined "
       << obj1.create_count()
       << " objects" << endl;
```

Output
[link] static17:

```
I have defined 2 objects
```

In C++11 this was:

```
class myclass {
private:
  static int count;
public:
```

Class relations: has-a

Has-a relationship

A class usually contains data members. These can be simple types or other classes. This allows you to make structured code.

```
class Course {
private:
  Person the_instructor;
  int year;
}
class Person {
  string name;
  ....
}
```

This is called the has-a relation.

Literal and figurative has-a

A line segment has a starting point and an end point.

A Segment class can store those points:

```
class Segment {
private:
  Point starting_point,
    ending_point;
public:
  Point get_the_end_point() {
    return ending_point; };
}
  ...
  Segment somesegment;
  Point somepoint =
    somesegment.
    get_the_end_point();
```

or store one and derive the other:

```
class Segment {
private:
  Point starting_point;
  float length,angle;
public:
  Point get_the_end_point() {
    /* some computation from
    the
       starting point */ };
}
```

Implementation vs API: implementation can be very different from user interface.

Polymorphism in constructors

You have to decide what to store and what to derive, but you can construct two ways:

```
class Segment {
private:
 // up to you how to implement!
public:
  Segment( Point start,float length,float angle )
    { .... }
  Segment( Point start,Point end ) { ... }
```

Advantage: with a good API you can change your mind about the implementation without changing the calling code.

Exercise 8

- Make a class `Rectangle` (sides parallel to axes) with a constructor:

  ```
  Rectangle(Point bl,float w,float h);
  ```

  The logical implementation is to store these quantities. Implement methods

  ```
  float area(); float rightedge(); float topedge();
  ```

- Add a second constructor

  ```
  Rectangle(Point bl,Point tr);
  ```

  Can you figure out how to use member initializer lists for the constructors?
- Write another version of your class so that it stores two `Point` objects.

Class inheritance: is-a

Examples for base and derived cases

- Base case: employee. Has: salary, employee number.
  Special case: manager. Has in addition: underlings.
- Base case: shape in drawing program. Has: extent, area, drawing routine.
  Special case: square et cetera; has specific drawing routine.

General case, special case

You can have classes where an object of one class is a special case of the other class. You declare that as

```
class General {
protected: // note!
 int g;
public:
 void general_method() {};
};

class Special : public General {
public:
  void special_method() { g = ... };
};

int main() {
  Special special_object;
  special_object.general_method();
  special_object.special_method();
}
```

Inheritance: derived classes

Derived class `Special` *inherits* methods and data from base class `General`:

```
int main() {
  Special special_object;
  special_object.general_method();
```

Members and methods need to be `protected`, not `private`, to be inheritable.

Constructors

When you run the special case constructor, usually the general constructor needs to run too. By default the 'default constructor', but usually explicitly invoked:

```
class General {
public:
  General( double x,double y ) {};
};
class Special : public General {
public:
  Special( double x ) : General(x,x+1) {};
};
```

Access levels

Methods and data can be

- private, because they are only used internally;
- public, because they should be usable from outside a class object, for instance in the main program;
- protected, because they should be usable in derived classes (see section **??**).

Exercise 9

Take your code where a `Rectangle` was defined from one point, width, and height.

Make a class `Square` that inherits from `Rectangle`. It should have the function `area` defined, inherited from `Rectangle`.

First ask yourself: what should the constructor of a `Square` look like?

Overriding methods

- A derived class can inherit a method from the base class.
- A derived class can define a method that the base class does not have.
- A derived class can *override* a base class method:

```
class Base {
public:
  virtual f() { ... };
};
class Deriv : public Base {
public:
  virtual f() override { ... };
};
```

Override and base method

Code:

```
class Base {
protected:
  int i;
public:
  Base(int i) : i(i) {};
  virtual int value() { return i; };
};

class Deriv : public Base {
public:
  Deriv(int i) : Base(i) {};
  virtual int value() override {
    int ivalue = Base::value();
    return ivalue*ivalue;
  };
};
```

Output
[object] virtual:

25

Operator overloading

`<returntype> operator<op>( <argument> ) { <definition> }`

For instance:

Code:

```
Vector operator*(double factor) {
  return Vector(factor*vx,factor*vy);
};
/* ... */
cout << "p1 has length "
     << p1.length() << endl;
Vector scale2r = p1*2.;
cout << "scaled right: "
     << scale2r.length() << endl;
// ILLEGAL Vector scale2l = 2.*p1;
```

Output
[geom] pointmult:

```
p1 has length 2.23607
scaled right: 4.47214
```

Can even redefine equals and parentheses.

Friend classes

A `friend` class can access private data and methods even if there is no inheritance relationship.

```
class A;
class B {
  friend class A;
private:
  int i;
};
class  A {
public:
  void f(B b) { b.i; };
};
```

More

- Multiple inheritance: an X is-a A, but also is-a B.
  This mechanism is somewhat dangerous.
- Virtual base class: you don't actually define a function in the base class, you only say 'any derived class has to define this function'.

Vectors

Initialization

Array creation

New syntax for creation:

```
{
  vector<int> numbers{5,6,7,8,9,10};
  cout << numbers.at(3) << endl;
}
{
  vector<int> numbers = {5,6,7,8,9,10};
  numbers.at(3) = 21;
  cout << numbers.at(3) << endl;
}
```

(Initializer-lists have more uses than this)

Range over elements

You can write a range-based for loop, which considers the elements as a collection.

```
for ( float e : array )
  // statement about element with value e
for ( auto e : array )
  // same, with type deduced by compiler
```

Code:

```
vector<int> numbers = {1,4,2,6,5};
int tmp_max = numbers[0];
for (auto v : numbers)
  if (v>tmp_max)
    tmp_max = v;
cout << "Max: " << tmp_max
     << " (should be 6)" << endl;
```

Output
[array] dynamicmax:

```
Max: 6 (should be 6)
```

Range over elements by reference

Range-based loop indexing makes a copy of the array element. If you want to alter the array, use a reference:

```
for ( auto &e : my_vector)
  e = ....
```

Code:

```
vector<float> myvector
  = {1.1, 2.2, 3.3};
for ( auto &e : myvector )
  e *= 2;
cout << myvector.at(2) << endl;
```

Output
[array] vectorrangeref:

```
6.6
```

Vector definition

Definition, mostly without initialization.

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

vector<type> name;
vector<type> name(size);
vector<type> name(size,init_value);
```

where

- `vector` is a keyword,
- `type` (in angle brackets) is any elementary type or class name,
- `name` is up to you, and
- `size` is the (initial size of the array). This is an integer, or more precisely, a `size_t` parameter.
- `init_value` will be used for all elements.

Accessing vector elements

Square bracket notation:

```
vector<double> x(5, 0.1 );
x[1] = 3.14;
cout << x[2];
```

Alteratively:

```
x.at(1) = 3.14;
cout << x.at(2);
```

Safer, slower.

Vectors, the new and improved arrays

- C array/pointer equivalence is silly
- C++ vectors are just as efficient
- ... and way easier to use.

Don't use use explicitly allocated arrays anymore

```
double *array = new double[n]; // please don't
```

Exercise 10

Create a `vector` x of `float` elements, and set them to random values.

Now normalize the vector in L_2 norm and check the correctness of your calculation, that is,

1. Compute the L_2 norm of the vector:

$$\|v\| \equiv \sqrt{\sum_i v_i^2}$$

2. Divide each element by that norm;
3. The norm of the scaled vector should now by 1. Check this.

What type of loop are you using?

Vector initialization

You can initialize a vector as a whole:

Code:

```
{
  vector<int> numbers{5,6,7,8,9,10};
  cout << numbers.at(3) << endl;
}
{
  vector<int> numbers = {5,6,7,8,9,10};
  numbers.at(3) = 21;
  cout << numbers.at(3) << endl;
}
```

Output
[array] dynamicinit:

```
8
21
```

Vector constant initialization

There is a syntax for initializing a vector with a constant:

```
vector<float> x(25,3.15);
```

which gives a vector of size 25, with all elements initialized to 3.15.

Range over vector denotation

Code:

```
for ( auto i : {2,3,5,7,9} )
  cout << i << ",";
cout << endl;
```

Output
[array] rangedenote:

```
2,3,5,7,9,
```

Vector copy

Vectors can be copied just like other datatypes:

Code:

```
vector<float> v(5,0), vcopy;
v.at(2) = 3.5;
vcopy = v;
vcopy.at(2) *= 2;
cout << v.at(2) << ","
     << vcopy.at(2) << endl;
```

Output
[array] vectorcopy:

```
3.5,7
```

Vector methods

- Get elements with `ar[3]` (zero-based indexing).
- Get elements, including bound checking, with `ar.at(3)`.
- Size: `ar.size()`.
- Other functions: `front`, `back`, `empty`.
- `vector` is a 'templated class'

Dynamic behaviour

Dynamic extension

Extend with `push_back`:

Code:

```
vector<int> array(5,2);
array.push_back(35);
cout << array.size() << endl;
cout << array[array.size()-1] << endl;
```

Output
[array] vectorend:

```
6
35
```

also *pop_back*, *insert*, *erase*.

Flexibility comes with a price.

Dynamic size extending

```
vector<int> iarray;
```

creates a vector of size zero. You can then

```
iarray.push_back(5);
iarray.push_back(32);
iarray.push_back(4);
```

Vector extension

You can push elements into a vector:

```
  vector<int> flex;
/* ... */
  for (int i=0; i<LENGTH; i++)
    flex.push_back(i);
```

If you allocate the vector statically, you can assign with `at`:

```
  vector<int> stat(LENGTH);
/* ... */
  for (int i=0; i<LENGTH; i++)
    stat.at(i) = i;
```

Vector extension

With subscript:

```
  vector<int> stat(LENGTH);
/* ... */
  for (int i=0; i<LENGTH; i++)
    stat[i] = i;
```

You can also use `new` to allocate (see section **??**):

```
  int *stat = new int[LENGTH];
/* ... */
  for (int i=0; i<LENGTH; i++)
    stat[i] = i;
```

Timing

```
Flexible time: 2.445
Static at time: 1.177
Static assign time: 0.334
Static assign time to new: 0.467
```

Exercise 11

Write code to take a vector of integers, and construct two vectors, one containing all the odd inputs, and one containing all the even inputs. So:

input:
```
5,6,2,4,5
```
output:
```
5,5
6,2,4
```

Can you write a function that accepts a vector and produces two vectors as described?

Vectors and functions

Vector as function return

You can have a vector as return type of a function.

Example: this function creates a vector, with the first element set to the size:

Code:

```
vector<int> make_vector(int n) {
  vector<int> x(n);
  x.at(0) = n;
  return x;
}
  /* ... */
  vector<int> x1 = make_vector(10);
  // "auto" also possible!
  cout << "x1 size: " << x1.size() <<
    endl;
  cout << "zero element check: " << x1.
    at(0) << endl;
```

Output
[array] vectorreturn:

```
x1 size: 10
zero element check: 10
```

Vector as function argument

You can pass a vector to a function:

```
void print0( vector<double> v ) {
  cout << v.at(0) << endl;
};
```

Vectors, like any argument, are passed by value, so the vector is actually copied into the function.

Vector pass by value example

Code:

```
void set0
  ( vector<float> v,float x )
{
  v.at(0) = x;
}
  /* ... */
  vector<float> v(1);
  v.at(0) = 3.5;
  set0(v,4.6);
  cout << v.at(0) << endl;
```

Output
[array] vectorpassnot:

```
3.5
```

Vector pass by reference

If you want to alter the vector, you have to pass by reference:

Code:

```
void set0
  ( vector<float> &v,float x )
{
  v.at(0) = x;
}
  /* ... */
  vector<float> v(1);
  v.at(0) = 3.5;
  set0(v,4.6);
  cout << v.at(0) << endl;
```

Output [array] vectorpassref:

```
4.6
```

Vectors in classes

Can you make a class around a vector?

Vector needs to be created with the object, so you can not have the size in the class definition

```
class witharray {
private:
  vector<int> the_array( ???? );
public:
  witharray( int n ) {
    thearray( ???? n ???? );
  }
}
```

Create and assign

The following mechanism works:

```
class witharray {
private:
  vector<int> the_array;
public:
  witharray( int n )
    : the_array(vector<int>(n)) {
  };
};
```

Better than

```
  witharray( int n ) {
    the_array = vector<int>(n);
  };
```

Multi-dimensional vectors

Multi-dimensional is harder with vectors:

```
vector<float> row(20);
vector<vector<float>> rows(10,row);
```

Create a row vector, then store 10 copies of that:
vector of vectors.

Matrix class

```
class matrix {
private:
  vector<vector<double>> elements;
public:
  matrix(int m,int n) {
    elements =
      vector<vector<double>>(m,vector<double>(n));
  }
  void set(int i,int j,double v) {
    elements.at(i).at(j) = v;
  };
  double get(int i,int j) {
    return elements.at(i).at(j);
  };
};
```

Matrix class'

Better idea:

```
elements = vector<double>(rows*cols);
...
void get(int i,int j) {
  return elements.at(i*cols+j);
}
```

(Old-style solution: use cpp macro)

Exercise 12

Add methods such as `transpose`, `scale` to your matrix class.

Implement matrix-matrix multiplication.

Vectors from C arrays

Use a range constructor to make a vector from a C array:

```
vector<double> x( pointer_to_first, pointer_after_last );
```

Note subtleties:

Code:

```
float *x;
x = (float*)malloc(length*sizeof(
  float));
/* ... */
vector<float> xvector(x,x+length);
cout << "xvector has size: " <<
  xvector.size() << endl;
xvector.push_back(5);
cout << "Push back was successful" <<
   endl;
cout << "pushed element: " << xvector
  .at(length) << endl;
cout << "original array: " << x[
  length] << endl;
```

Output [array] cvector:

```
xvector has size: 53
Push back was successful
pushed element: 5
original array: 2.11245e+22
```

Span

To be written.

Strings

String declaration

```
#include <string>
using std::string;

// .. and now you can use 'string'
```

(Do not use the C legacy mechanisms.)

String creation

A string variable contains a string of characters.

```
string txt;
```

You can initialize the string variable or assign it dynamically:

```
string txt{"this is text"};
string moretxt("this is also text");
txt = "and now it is another text";
```

Concatenation

Strings can be *concatenated*:

```
txt = txt1+txt2;
txt += txt3;
```

String indexing

You can query the *size*:

```
int txtlen = txt.size();
```

or use subscripts:

```
cout << "The second character is <<" <<
        txt[1] << ">>" << endl;
```

More vector methods

Other methods for the vector class apply: `insert`, `empty`, `erase`, `push_back`, et cetera.

Methods only for `string`: `find` and such.

`http://en.cppreference.com/w/cpp/string/basic_string`

I/O

Default unformatted output

Code:

```
for (int i=1; i<200000000; i*=10)
  cout << "Number: " << i << endl;
cout << endl;
```

Output
[io] cunformat:

```
Number: 1
Number: 10
Number: 100
Number: 1000
Number: 10000
Number: 100000
Number: 1000000
Number: 10000000
Number: 100000000
```

Reserve space

You can specify the number of positions, and the output is right aligned in that space by default:

Code:

```
cout << "Width is 6:" << endl;
for (int i=1; i<200000000; i*=10)
  cout << "Number: "
       << setw(6) << i << endl;
cout << endl;

cout << "Width is 6:" << endl;
cout << "."
     << setw(6) << 1 << 2 << 3 << endl;
cout << endl;
```

Output [io] width:

```
Width is 6:
Number:      1
Number:     10
Number:    100
Number:   1000
Number:  10000
Number: 100000
Number: 1000000
Number: 10000000
Number: 100000000

Width is 6:
.     123
```

Padding character

Normally, padding is done with spaces, but you can specify other characters:

Code:

```
#include <iomanip>
using std::setfill;
using std::setw;
  /* ... */
  for (int i=1; i<200000000; i*=10)
    cout << "Number: "
         << setfill('.')
         << setw(6) << i
         << endl;
```

Output
[io] formatpad:

```
Number: .....1
Number: ....10
Number: ...100
Number: ..1000
Number: .10000
Number: 100000
Number: 1000000
Number: 10000000
Number: 100000000
```

Note: single quotes denote characters, double quotes denote strings.

Left alignment

Instead of right alignment you can do left:

Code:

```
#include <iomanip>
using std::left;
using std::setfill;
using std::setw;
  /* ... */
  for (int i=1; i<200000000; i*=10)
    cout << "Number: "
         << left << setfill('.')
         << setw(6) << i << endl;
```

Output
[io] formatleft:

```
Number: 1.....
Number: 10....
Number: 100...
Number: 1000..
Number: 10000.
Number: 100000
Number: 1000000
Number: 10000000
Number: 100000000
```

Number base

Finally, you can print in different number bases than 10:

Code:

```
#include <iomanip>
using std::setbase;
using std::setfill;
  /* ... */
  cout << setbase(16) << setfill(' ');
  for (int i=0; i<16; i++) {
    for (int j=0; j<16; j++)
      cout << i*16+j << " " ;
    cout << endl;
  }
```

Output
[io] format16:

```
0  1  2  3  4  5  6  7  8  9  a  b  c  d  e
10 11 12 13 14 15 16 17 18 19
20 21 22 23 24 25 26 27 28 29
30 31 32 33 34 35 36 37 38 39
40 41 42 43 44 45 46 47 48 49
50 51 52 53 54 55 56 57 58 59
60 61 62 63 64 65 66 67 68 69
70 71 72 73 74 75 76 77 78 79
80 81 82 83 84 85 86 87 88 89
90 91 92 93 94 95 96 97 98 99
a0 a1 a2 a3 a4 a5 a6 a7 a8 a9
b0 b1 b2 b3 b4 b5 b6 b7 b8 b9
c0 c1 c2 c3 c4 c5 c6 c7 c8 c9
d0 d1 d2 d3 d4 d5 d6 d7 d8 d9
e0 e1 e2 e3 e4 e5 e6 e7 e8 e9
f0 f1 f2 f3 f4 f5 f6 f7 f8 f9
```

Exercise 13

Make the first line in the above output align better with the other lines:

```
00 01 02 03 04 05 06 07 08 09 0a 0b 0c 0d 0e 0f
10 11 12 13 14 15 16 17 18 19 1a 1b 1c 1d 1e 1f
20 21 22 23 24 25 26 27 28 29 2a 2b 2c 2d 2e 2f
etc
```

Fixed point precision

Fixed precision applies to fractional part:

Code:

```
x = 1.234567;
cout << fixed;
for (int i=0; i<10; i++) {
  cout << setprecision(4) << x << endl;
  x *= 10;
}
```

Output
[io] fix:

```
1.2346
12.3457
123.4567
1234.5670
12345.6700
123456.7000
1234567.0000
12345670.0000
123456700.0000
1234567000.0000
```

Exercise 14

Use integer output to print real numbers aligned on the decimal:

```
  1.345
 23.789
456.1234
```

Use four spaces for both the integer and fractional part; test only with numbers that fit this format.

Scientific notation

```
cout << "Combine width and precision:" << endl;
x = 1.234567;
cout << scientific;
for (int i=0; i<10; i++) {
  cout << setw(10) << setprecision(4) << x << endl;
  x *= 10;
}
```

Output

```
Combine width and precision:
1.2346e+00
1.2346e+01
1.2346e+02
1.2346e+03
1.2346e+04
1.2346e+05
1.2346e+06
1.2346e+07
1.2346e+08
1.2346e+09
```

Text output to file

Streams are general: work the same for console out and file out.

```
#include <fstream>
```

Use:

```
#include <fstream>
using std::ofstream;
  /* ... */
  ofstream file_out;
  file_out.open("fio_example.out");
  /* ... */
  file_out << number << endl;
  file_out.close();
```

Redefine less-less

If you want to output a class that you wrote yourself, you have to define how the << operator deals with your class.

```
class container {
  /* ... */
  int value() const {
  /* ... */
  };
  /* ... */
ostream &operator<<(ostream &os,const container &i) {
  os << "Container: " << i.value();
  return os;
};
  /* ... */
  container eye(5);
  cout << eye << endl;
```

Smart pointers

C pointers are barely needed.

- Use `std::string` instead of `char` array; use `std::vector` for other arrays.
- Parameter passing by reference: use actual references.
- Ownership of dynamically created objects: smart pointers.
- Pointer arithmetic: iterators.

Pointers and references

C and F pointers

C++ and Fortran have a clean reference/pointer concept: a reference or pointer is an 'alias' of the original object

C/C++ also has a very basic pointer concept:
a pointer is the address of some object
(including pointers)

If you're writing C++ you should not use it.
if you write C, you'd better understand it.

Reference: change argument

A reference makes the function parameter a synonym of the argument.

```
void f( int &i ) { i += 1; };
int main() {
  int i = 2;
  f(i); // makes it 3
```

Reference: save on copying

```
class BigDude {
public:
   vector<double> array
    (5000000);
}

void f(BigDude d) {
  cout << d.array[0];
};

int main() {
   BigDude big;
   f(big); // whole thing is
    copied
```

Instead write:

```
void f( BigDude &thing ) { ....
     };
```

Prevent changes:

```
void f( const BigDude &thing )
    { .... };
```

Smart pointers

Creating a shared pointer

Allocation and pointer in one:

```
shared_ptr<Obj> X =
    make_shared<Obj>( /* constructor args */ );
  // or:
auto X = make_shared<Obj>( /* args */ );

X->method_or_member;
```

Much better than

```
Obj *X;
*X = Obj( /* args */ );
```

Simple example

Code:

```
class HasX {
private:
  double x;
public:
  HasX( double x) : x(x) {};
  auto &val() { return x; };
};

int main() {
  auto X = make_shared<HasX>(5);
  cout << X->val() << endl;
  X->val() = 6;
  cout << X->val() << endl;
```

Output
[pointer] pointx:

```
5
6
```

Pointers to arrays

The constructor syntax is a little involved for vectors:

```
auto x = make_shared<vector<double>>(vector<double>{1.1,2.2});
```

Getting the underlying pointer

```
X->y;
// is the same as
X.get()->y;
// is the same as
( *X.get() ).y;
```

Code:

```
auto Y = make_shared<HasY>(5);
cout << Y->y << endl;
Y.get()->y = 6;
cout << ( *Y.get() ).y << endl;
```

Output
[pointer] pointy:

```
5
6
```

Pointers don't go with addresses

The oldstyle `&y` address pointer can not be made smart:

```
auto
  p1 = shared_ptr<HasY>( &y ),
  p2 = shared_ptr<HasY>( &y );
p1->y = 3;
cout << "Pointer 2's y: "
     << p2->y << endl;
```

gives:

```
address(56325,0x7fff977cc380) malloc: *** error for object
    0x7ffeeb9caf08: pointer being freed was not allocated
```

Automatic memory management

Memory leaks

- Vectors obey scope: deallocated automatically.
- Destructor called when object goes out of scope, including exceptions.
- ‘RAII’
- Dynamic allocation doesn’t obey scope: objects with smart pointers get de-allocated when no one points at them anymore.
  (Reference counting)

Reference counting illustrated

We need a class with constructor and destructor tracing:

```
class thing {
public:
  thing()  { cout << ".. calling constructor\n"; };
  ~thing() { cout << ".. calling destructor\n"; };
};
```

Pointer overwrite

Let's create a pointer and overwrite it:

Code:

```
cout << "set pointer1"
     << endl;
auto thing_ptr1 =
  make_shared<thing>();
cout << "overwrite pointer"
     << endl;
thing_ptr1 = nullptr;
```

Output
[pointer] ptr1:

```
set pointer1
.. calling constructor
overwrite pointer
.. calling destructor
```

Pointer copy

Code:

```
cout << "set pointer2" << endl;
auto thing_ptr2 =
  make_shared<thing>();
cout << "set pointer3 by copy"
     << endl;
auto thing_ptr3 = thing_ptr2;
cout << "overwrite pointer2"
     << endl;
thing_ptr2 = nullptr;
cout << "overwrite pointer3"
     << endl;
thing_ptr3 = nullptr;
```

Output
[pointer] ptr2:

```
set pointer2
.. calling constructor
set pointer3 by copy
overwrite pointer2
overwrite pointer3
.. calling destructor
```

Linked list code, old style

```
node *node::prepend_or_append(node *other) {
  if (other->value>this->value) {
    this->tail = other;
    return this;
  } else {
    other->tail = this;
    return other;
  }
};
```

Can we do this with shared pointers?

A problem with shared pointers

```
shared_pointer<node> node::prepend_or_append
    ( shared_ptr<node> other ) {
  if (other->value>this->value) {
    this->tail = other;
```

So far so good. However, `this` is a `node*`, not a `shared_ptr<node>`, so

```
    return this;
```

returns the wrong type.

Solution: shared from this

It is possible to have a 'shared pointer to this' if you define your node class with (warning, major magic alert):

```
class node : public enable_shared_from_this<node> {
```

This allows you to write:

```
    return this->shared_from_this();
```

Smart pointer example: linked lists

Linked list structures

Linked list: data structure with easy insertion and deletion of information.

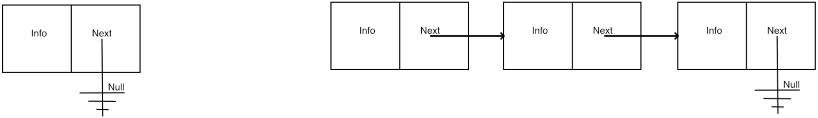
Two basic elements:

- List, has pointer to first element, or null pointer
- Node, has information, plus pointer to next element (or null)

We are going to look at info routines about a list ('length'), or routines that alter the list ('insert').

(in pictures)

Node data structure and linked list of nodes



Definition of List class

A linked list has as its only member a pointer to a node:

```
class List {
private:
  unique_ptr<Node> head{nullptr};
public:
  List() {};
```

Initially null for empty list.

Definition of Node class

A node has information fields, and a link to another node:

```
class Node {
  friend class List;
private:
  int datavalue{0},datacount{0};
  unique_ptr<Node> next{nullptr};
public:
  friend class List;
  Node() {}
  Node(int value,unique_ptr<Node> tail=nullptr)
    : datavalue(value),datacount(1),next(move(tail)) {};
  ~Node() { cout << "deleting node " << datavalue << endl; };
```

A Null pointer indicates the tail of the list.

Recursive computation of the list length

```
int recursive_length() {
  if (head==nullptr)
    return 0;
  else
    return head->listlength();
};

int listlength_recursive() {
  if (!has_next()) return 1;
  else return 1+next->listlength();
};
```

Iterative computation of the list length

Use a bare pointer, which is appropriate here because it doesn't own the node.

```
int listlength_iterative() {
  int count = 0;
  Node *current_node = head.get();
  while (current_node!=nullptr) {
    current_node = current_node->next.get(); count += 1;
  }
  return count;
};
```

(You will get a compiler error if you try to make `current_node` a smart pointer.

Exercise 15

Write a function

```
bool List::contains_value(int v);
```

to test whether a value is present in the list.

Try both recursive and iterative.

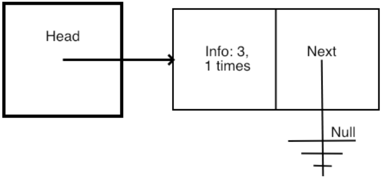
Insert routine design

We will write functions

```
void List::insert(int value);
void Node::insert(int value);
```

that add the value to the list. The `List::insert` value can put a new node in front of the first one; the `Node::insert` assumes the the value is on the current node, or gets inserted after it.

Insert in empty list

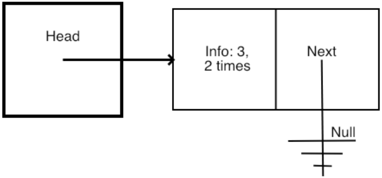


Exercise 16

Next write the case of `Node::insert` that handles the empty list. You also need a method `List::contains` that tests if an item if in the list.

```
mylist.insert(3);
cout << "After one insertion the length is: "
     << mylist.length() << endl;
if (mylist.contains_value(3))
  cout << "Indeed: contains 3" << endl;
else
  cout << "Hm. Should contain 3" << endl;
if (mylist.contains_value(4))
  cout << "Hm. Should not contain 4" << endl;
else
  cout << "Indeed: does not contain 4" << endl;
cout << endl;
```

Element is already present

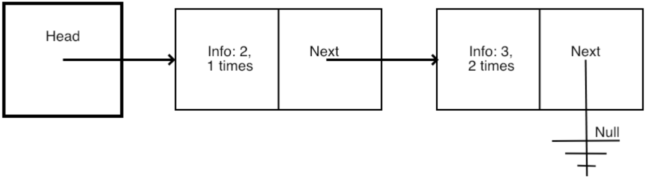


Exercise 17

Inserting a value that is already in the list means that the count value of a node needs to be increased. Update your `insert` method to make this code work:

```
mylist.insert(3);
cout << "Inserting the same item gives length: "
     << mylist.length() << endl;
if (mylist.contains_value(3)) {
  cout << "Indeed: contains 3" << endl;
  auto headnode = mylist.headnode();
  cout << "head node has value " << headnode->value()
       << " and count " << headnode->count() << endl;
} else
  cout << "Hm. Should contain 3" << endl;
cout << endl;
```

Insert element before

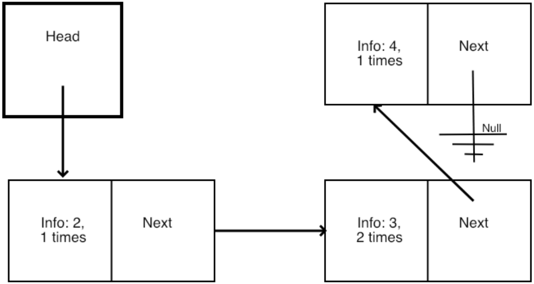


Exercise 18

One of the remaining cases is inserting an element that goes at the head. Update your `insert` method to get this to work:

```
mylist.insert(2);
cout << "Inserting 2 goes at the head; now the length is: "
     << mylist.length() << endl;
if (mylist.contains_value(2))
  cout << "Indeed: contains 2" << endl;
else
  cout << "Hm. Should contain 2" << endl;
if (mylist.contains_value(3))
  cout << "Indeed: contains 3" << endl;
else
  cout << "Hm. Should contain 3" << endl;
cout << endl;
```

Insert an element at the tail



Exercise 19

Finally, if an item goes at the end of the list:

```
mylist.insert(4);
cout << "Inserting 4 goes at the tail; now the length is: "
     << mylist.length() << endl;
if (mylist.contains_value(4))
  cout << "Indeed: contains 4" << endl;
else
  cout << "Hm. Should contain 4" << endl;
if (mylist.contains_value(3))
  cout << "Indeed: contains 3" << endl;
else
  cout << "Hm. Should contain 3" << endl;
cout << endl;
```

Advanced pointer topics

Void pointer

Use `std::any` instead of void pointers.

Null pointer

C++ has the `nullptr`, which is an object of type `std::nullptr_t`.

```
void f(int);
void f(int*);
  f(NULL);    // calls the int version
  f(nullptr); // calls the ptr version
```

Note: dereferencing is undefined behaviour; does not throw an exception.

Namespaces

You have already seen namespaces

Safest:

```
#include <vector>
int main() {
  std::vector<stuff> foo;
}
```

Drastic:

```
#include <vector>
using namespace std;
int main() {
  vector<stuff> foo;
}
```

Prudent:

```
#include <vector>
using std::vector;
int main() {
  vector<stuff> foo;
}
```

Why not ‘using namespace std’?

This compiles, but should not:

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

int main() {
  int i=1,j=2;
  swap(i,j);
  cout << i << endl;
  return 0;
}
```

This gives an error:

```
#include <iostream>
using std::cout;
using std::endl;

int main() {
  int i=1,j=2;
  swap(i,j);
  cout << i << endl;
  return 0;
}
```

Big namespace no-no

Do not put `using` in a header file that a user may include.

Defining a namespace

You can make your own namespace by writing

```
namespace a_namespace {
  // definitions
  class an_object {
  };
|
```

Namespace usage

```
a_namespace::an_object myobject();
```

or

```
using namespace a_namespace;
an_object myobject();
```

or

```
using a_namespace::an_object;
an_object myobject();
```

Templates

Templated type name

If you have multiple routines that do 'the same' for multiple types, you want the type name to be a variable. Syntax:

```
template <typename yourtypevariable>
// ... stuff with yourtypevariable ...
```

Example: function

Definition:

```
template<typename T>
void function(T var) { cout << var << end; }
```

Usage:

```
int i; function(i);
double x; function(x);
```

and the code will behave as if you had defined `function` twice, once for `int` and once for `double`.

Exercise 20

Machine precision, or 'machine epsilon', is sometimes defined as the smallest number ϵ so that $1 + \epsilon > 1$ in computer arithmetic.

Write a templated function `epsilon` so that the following code prints out the values of the machine precision for the `float` and `double` type respectively:

Code:

```
float float_eps;
epsilon(float_eps);
cout << "Epsilon float: "
     << setw(10) << setprecision(4)
     << float_eps << endl;

double double_eps;
epsilon(double_eps);
cout << "Epsilon double: "
     << setw(10) << setprecision(4)
     << double_eps << endl;
```

Output [template] eps:

```
Epsilon float: 1.0000e-07
Epsilon double: 1.0000e-15
```

Templated vector

the Standard Template Library (STL) contains in effect

```
template<typename T>
class vector {
private:
  // data definitions omitted
public:
  T at(int i) { /* return element i */ };
  int size() { /* return size of data */ };
  // much more
}
```

Exceptions

Exception throwing

Throwing an *exception* is one way of signalling an error or unexpected behaviour:

```
void do_something() {
  if ( oops )
    throw(5);
}
```

Catching an exception

It now becomes possible to detect this unexpected behaviour by *catching* the exception:

```
try {
  do_something();
} catch (int i) {
  cout << "doing something failed: error=" << i << endl;
}
```

Exception classes

```
class MyError {
public :
  int error_no; string error_msg;
  MyError( int i,string msg )
  : error_no(i),error_msg(msg) {};
}

throw( MyError(27,"oops");

try {
  // something
} catch ( MyError &m ) {
  cout << "My error with code=" << m.error_no
    << " msg=" << m.error_msg << endl;
}
```

You can use exception inheritance!

Multiple catches

You can multiple `catch` statements to catch different types of errors:

```
try {
  // something
} catch ( int i ) {
  // handle int exception
} catch ( std::string c ) {
  // handle string exception
}
```

Catch any exception

Catch exceptions without specifying the type:

```
try {
  // something
} catch ( ... ) { // literally: three dots
  cout << "Something went wrong!" << endl;
}
```

Exceptions in constructors

A function try block will catch exceptions, including in initializer lists of constructors.

```
f::f( int i )
  try : fbase(i) {
    // constructor body
  }
  catch (...) { // handle exception
  }
```

More about exceptions

- Functions can define what exceptions they throw:

```
void func() throw( MyError, std::string );
void funk() throw();
```

- Predefined exceptions: `bad_alloc`, `bad_exception`, etc.
- An exception handler can throw an exception; to rethrow the same exception use '`throw;`' without arguments.
- Exceptions delete all stack data, but not `new` data. Also, destructors are called; section **??**.
- There is an implicit `try/except` block around your main. You can replace the handler for that. See the `exception` header file.
- Keyword `noexcept`:

```
void f() noexcept { ... };
```

- There is no exception thrown when dereferencing a `nullptr`.

Destructors and exceptions

The destructor is called when you throw an exception:

Code:

```
class SomeObject {
public:
  SomeObject() {
    cout << "calling the constructor"
         << endl; };
  ~SomeObject() {
    cout <<  "calling the destructor"
         << endl; };
};
  /* ... */
  try {
    SomeObject obj;
    cout << "Inside the nested scope"
    << endl;
    throw(1);
  } catch (...) {
    cout << "Exception caught" << endl;
  }
```

Output [object] exceptdestruct:

```
calling the constructor
Inside the nested scope
calling the destructor
Exception caught
```

Use assertions during development

```
#include <cassert>
...
assert( bool expression )
```

Assertions are disabled by

```
#define NDEBUG
```

before the include.

You can pass this as compiler flag:
`icpc -DNDEBUG yourprog.cxx`

Iterators

Auto iterators

```
vector<int> myvector(20);
for ( auto copy_of_int :
    myvector )
  s += copy_of_int;
for ( auto &ref_to_int :
    myvector )
  ref_to_int = s;
```

is actually short for:

```
for ( std::iterator it=myvector
     .begin() ;
      it!=myvector.end() ; ++it
     )
   s += *it ; // note the deref
```

Range iterators can be used with anything that is iteratable (vector, map, your own classes!)

Other iterator uses

Reverse iteration can not be done with range-based syntax.

Use general syntax with reverse iterator: `rbegin`, `rend`.

Also:

```
auto first = myarray.begin();
first += 2;
auto last  = myarray.end();
last  -= 2-;
myarray.erase(first,last);
```

Simple illustration

Let's make a class, called a `bag`, that models a set of integers, and we want to enumerate them. For simplicity sake we will make a set of contiguous integers:

```
class bag {
  // basic data
private:
  int first,last;
public:
  bag(int first,int last) : first(first),last(last) {};
```

Use case

We can iterate over our own class:

Code:

```
bag digits(0,9);

bool find3{false};
for ( auto seek : digits )
  find3 = find3 || (seek==3);
cout << "found 3: " << boolalpha
     << find3 << endl;

bool find15{false};
for ( auto seek : digits )
  find15 = find15 || (seek==15);
cout << "found 15: " << boolalpha
     << find15 << endl;
```

Output
[loop] bagfind:

```
found 3: true
found 15: false
```

(for this particular case, use `std::any_of`)

Requirements

- a method `iteratable iteratable::begin()`: initial state
- a method `iteratable iteratable::end()`: final state
- an increment operator `void iteratable::operator++`: advance
- a test `bool iteratable::operator!=(const iteratable&)`
- a dereference operator `iteratable::operator*`: return state

Internal state

When you create an iterator object it will be copy of the object you are iterating over, except that it remembers how far it has searched:

```
private:
  int seek{0};
```

Initial/final state

The `begin` method gives a `bag` with the seek parameter initialized:

```
public:
  bag &begin()  {
    seek = first; return *this;
  };
  bag end() {
    seek = last; return *this;
  };
```

These routines are public because they are (implicitly) called by the client code.

Termination test

The termination test method is called on the iterator, comparing it to the `end` object:

```
bool operator!=( const bag &test ) const {
  return seek<=test.last;
};
```

Dereference

Finally, we need the increment method and the dereference. Both access the `seek` member:

```
void operator++() { seek++; };
int operator*() { return seek; };
```

Exercise 21

Make a `primes` class that can be ranged:

Code:

```
primegenerator allprimes;
for ( auto p : allprimes ) {
  cout << p << ", ";
  if (p>100) break;
}
cout << endl;
```

Output [primes] range:

```
2, 3, 5, 7, 11, 13, 17, 19, 2
```

Auto

Type deduction

In:

```
std::vector< std::shared_ptr< myclass >>*
  myvar = new std::vector< std::shared_ptr< myclass >>
              ( 20, new myclass(1.3) );
```

the compiler can figure it out:

```
auto myvar =
  new std::vector< std::shared_ptr< myclass >>
          ( 20, new myclass(1.3) );
auto result = someobject.somemethod();
```

Type deduction in functions

Return type can be deduced in C++17:

```
auto equal(int i,int j) {
  return i==j;
};
```

Type deduction in functions

Return type can be deduced in C++17:

```
class A {
private: float data;
public:
  A(float i) : data(i) {};
  auto &access() {
    return data; };
  void print() {
    cout << "data: " << data << endl; };
};
```

Auto and references, 1

`auto` discards references and such:

Code:

```
A my_a(5.7);
auto get_data = my_a.access();
get_data += 1;
my_a.print();
```

Output [auto] plainget:

```
data: 5.7
```

Auto and references, 2

Combine `auto` and references:

Code:

```
A my_a(5.7);
auto &get_data = my_a.access();
get_data += 1;
my_a.print();
```

Output
[auto] refget:

```
data: 6.7
```

Auto and references, 3

For good measure:

Code:

```
A my_a(5.7);
const auto &get_data = my_a.
    access();
get_data += 1;
my_a.print();
```

Output [auto] constrefget:

```
make[2]: *** No rule to make target ‘e
```

Lambdas

Lambda expressions

```
[capture] ( inputs ) -> outtype { definition };
```

Example:

```
[] (float x,float y) -> float {
  return x+y; } ( 1.5, 2.3 )
```

Store lambda in a variable:

```
auto summing =
  [] (float x,float y) -> float {
  return x+y; };
cout << summing ( 1.5, 2.3 ) << endl;
```

Capture parameter

Capture value and reduce number of arguments:

```
auto powerfunction = [exponent] (float x) -> float {
  return pow(x,exponent); };
```

Now `powerfunction` is a function of one argument, which computes that argument to a fixed power.

Code:

```
cout << "To the power " << exponent <<
    endl;
for (float x=1.; x<=9.; x+=1.)
  cout << x << ":" << powerfunction(x)
    << endl;
```

Output
[func] lambdait:

```
To the power 1
1:1
2:2
3:3
4:4
5:5
6:6
7:7
8:8
9:9
To the power 2
1:1
```

Lambda in object

```
#include <functional>
using std::function;
  /* ... */
class SelectedInts {
private:
  vector<int> bag;
  function< bool(int) > selector;
public:
  SelectedInts( function< bool(int) > f ) {
    selector = f; };
  void add(int i) {
    if (selector(i))
      bag.push_back(i);
  };
  int size() { return bag.size(); };
  std::string string() { std::string s;
    for ( int i : bag )
      s += to_string(i)+" ";
    return s;
  };
};
```

Illustration

Code:

```
SelectedInts multiples
  ( [divisor] (int i) -> bool {
      return i%divisor==0; } );
for (int i=1; i<50; i++)
  multiples.add(i);
```

Output
[func] lambdafun:

```
Give a divisor:
.. using 7
Multiples of 7:
7 14 21 28 35 42 49
```

Background Square roots through Newton

Early computers had no hardware for computing a square root. Instead, they used Newton's method. Suppose you have a value y and you want want to compute $x = \sqrt{y}$. This is equivalent to finding the zero of

$$f(x) = x^2 - y$$

where y is fixed. To indicate this dependence on y, we will write $f_y(x)$. Newton's method then finds the zero by evaluating

$$x_{\mathrm{next}} = x - f_y(x)/f_y'(x)$$

until the guess is accurate enough, that is, until $f_y(x) \approx 0$.

Exercise 22

Refer to 217 for background, and note that finding x such that $f(x) = a$ is equivalent to applying Newton to $f(x) - a$.

Implement a class `valuefinder` and its `double find(double)` method.

```
class valuefinder {
private:
  function< double(double) >
      f,fprime;
  double tolerance{.00001};
public:
  valuefinder
  ( function< double(double) > f,
    function< double(double) > fprime )
    : f(f),fprime(fprime) {};
```

used as

```
double root = newton_root.find(number);
```

Casts

C++ casts

Old-style 'take this byte and pretend it is XYZ':
`reinterpret_cast`

Casting with classes:

- `static_cast` cast base to derived without check.
- `dynamic_cast` cast base to derived with check.

Adding/removing const: `const_cast`

Syntactically clearly recognizable.

Const cast

```
int hundredk = 100000;
int overflow;
overflow = hundredk*hundredk;
cout << "overflow: " << overflow << endl;
size_t bignumber = static_cast<size_t>(hundredk)*hundredk;
cout << "bignumber: " << bignumber << endl;
```

Code:

```
long int hundredg = 100000000000;
cout << "long number:      "
     << hundredg << endl;
int overflow;
overflow = static_cast<int>(hundredg);
cout << "assigned to int: "
     << overflow << endl;
```

Output
[cast] intlong:

```
long number:     100000000000
assigned to int: 1215752192
```

Pointer to base class

Class and derived:

```
class Base {
public:
  virtual void print() = 0;
};
class Derived : public Base {
public:
  virtual void print() {
    cout << "Construct derived!"
         << endl; };
};
class Erived : public Base {
public:
  virtual void print() {
    cout << "Construct erived!"
         << endl; };
};
```

Cast to derived class

This is how to do it:

Code:

```
void f( Base *obj ) {
  Derived *der =
    dynamic_cast<Derived*>(obj);
  if (der==nullptr)
    cout << "Could not be cast to
    Derived"
         << endl;
  else
    der->print();
};
  /* ... */
    Base *object = new Derived();
    f(object);
    Base *nobject = new Erived();
    f(nobject);
```

Output
[cast] deriveright:

```
Construct derived!
Could not be cast to Derived
```

Cast to derived class, the wrong way

Do not use this function g:

Code:

```
void g( Base *obj ) {
  Derived *der =
    static_cast<Derived*>(obj);
  der->print();
};
  /* ... */
    Base *object = new Derived();
    g(object);
    Base *nobject = new Erived();
    g(nobject);
```

Output
[cast] derivewrong:

```
Construct derived!
Construct erived!
```

Tuples

C++11 style tuples

```
std::tuple<int,double> id = std:
id = std::make_tuple<int,double>(3,5.12);
std::get<0>(id) += 1;
```

Function returning tuple

```
auto maybe_root1(float x) {
  if (x<0)
    return make_tuple
      <bool,float>(false,-1);
  else
    return make_tuple
      <bool,float>(true,sqrt(x)
    );
};
```

```
tuple<bool,float> maybe_root2(
    float x) {
  if (x<0)
    return {false,-1};
  else
    return {true,sqrt(x)};
};
```

Catching a returned tuple

The calling code is particularly elegant:

Code:

```
  auto [succeed,y] = maybe_root1(x);
  if (succeed)
    cout << "Root of " << x << " is "
   << y << endl;
  else
    cout << "Sorry, " << x << " is
  negative" << endl;
  //codesnippet tupleauto
/* ... */
}

if (false) {
  auto [succeed,y] = maybe_root2(x);
  if (succeed)
    cout << "Root of " << x << " is "
   << y << endl;
  else
    cout << "Sorry, " << x << " is
  negative" << endl;
```

Output [stl] tuple:

```
Root of 2 is 1.41421
Sorry, -2 is negative
```

Optional results

The most elegant solution to ‘a number or an error’ is to have a single quantity that you can query whether it’s valid.

```
optional<float> MaybeRootPtr(float x) {
  if (x<0)
    return {};
  else
    return sqrt(x);
};
  /* ... */
  for ( auto x : {2.f,-2.f} )
    if ( auto root = MaybeRootPtr(x) ; root.has_value() )
      cout << "Root is " << *root << endl;
    else
      cout << "could not take root of " << x << endl;
```

More STL

Iterators outside a loop

First, you can use them by themselves:

Code:

```
vector<int> v{1,3,5,7};
auto pointer = v.begin();
cout << "we start at "
     << *pointer << endl;
pointer++;
cout << "after increment: "
     << *pointer << endl;

pointer = v.end();
cout << "end is not a valid element
: "
     << *pointer << endl;
pointer--;
cout << "last element: "
     << *pointer << endl;
```

Output
[stl] iter:

```
we start at 1
after increment: 3
end is not a valid element: 0
last element: 7
```

(Note: the `auto` actually stands for `vector::iterator`)

Iterators in vector methods

Methods `erase` and `insert` indicate their range with begin/end iterators

Code:

```
vector<int> v{1,3,5,7,9};
cout << "Vector: ";
for ( auto e : v ) cout << e << " ";
cout << endl;
auto first = v.begin();
first++;
auto last = v.end();
last--;
v.erase(first,last);
cout << "Erased: ";
for ( auto e : v ) cout << e << " ";
cout << endl;
```

Output
[stl] erase:

```
Vector: 1 3 5 7 9
Erased: 1 9
```

Note: end is exclusive.

Reduction operation

Default is sum reduction:

Code:

```
vector<int> v{1,3,5,7};
auto first = v.begin();
auto last  = v.end();
auto sum = accumulate(first,last,0);
cout << "sum: " << sum << endl;
```

Output
[stl] accumulate:

```
sum: 16
```

Reduction with supplied operator

Supply multiply operator:

Code:

```
vector<int> v{1,3,5,7};
auto first = v.begin();
auto last  = v.end();
first++; last--;
auto product =
  accumulate(first,last,2,multiplies
    <>());
cout << "product: " << product << endl;
```

Output
[stl] product:

```
product: 30
```

Templated functions for limits

Use header file `limits`:

```
#include <limits>
using std::numeric_limits;

cout << numeric_limits<long>::max();
```

Random number example

```
// set the default generator
std::default_random_engine generator;

// distribution: ints 1..6
std::uniform_int_distribution<int> distribution(1,6);

// apply distribution to generator:
int dice_roll = distribution(generator);
  // generates number in the range 1..6
```