

# 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.  
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](https://bitbucket.org/VictorEijkhout/textbook-introduction-to-scientific-programming)

## 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

```
#include <iostream>
using std::cout;
using std::endl;
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.
- *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'.

# 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 from running ref in code directory basic:

(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  
}
```



# Different from C

- C mechanism passes address by value.
- If you find yourself writing asterisks, you're not writing C++.

# Pass by reference example 1

## Code:

```
void f( int &i ) {  
    i = 5;  
}  
int main() {  
  
    int var = 0;  
    f(var);  
    cout << var << endl;
```

Output from running setbyref in  
code directory basic:

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

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

## Exercise 2

Write a function that tests divisibility and returns a remainder:

```
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.



# Even more new features

Use of `auto` and `const`. Later.

# Object-Oriented Programming

# Classes look a bit like structures

## Code:

```
class Vector {  
public:  
    double x,y;  
};  
  
int main() {  
    Vector p1;  
    p1.x = 1.; p1.y = 2.; // This Is Not A Good Idea. See later.  
    cout << "sum of components: " << p1.x+p1.y << endl;
```

Output from running pointstruct in  
code directory geom:

We'll get to that 'public' in a minute.

# Class initialization and use

Use a *constructor*: function with same name as the class.

```
class Vector {  
private: // recommended!  
    double vx,vy;  
public:  
    Vector( double x,double y ) {  
        vx = x; vy = y;  
    };  
  
}; // end of class definition  
  
int main() {  
    Vector p1(1.,2.);  
}
```

# Example of accessor functions

Getting and setting of members values is done through accessor functions:

```
class Vector {
private: // recommended!
    double vx,vy;
public:
    Vector( double x,double y ) {
        vx = x; vy = y;
    };

    double x() { return vx; };
    double y() { return vy; };

    void setx( double newx ) {
        vx = newx; };
    void sety( double newy ) {
        vy = newy; };

}; // end of class definition

int main() {
    Vector p1(1.,2.);
```

Usage:

```
p1.setx(3.12);
/* ILLEGAL: p1.x() = 5; */
cout << "P1's x=" << p1.x() << endl;
```

# Interface versus implementation

- Implementation: data members, keep private,
- Interface: public functions to get/set data.
- Protect yourself against inadvertant changes of object data.
- Possible to change implementation without rewriting calling code.

# Private access gone wrong

We make a class with two members that sum to one.  
You don't want to be able to change just one of them!

```
class SumIsOne {
public:
    float x,y;
    SumIsOne( double xx ) { x = xx; y = 1-x; };
}
int main() {
    SumIsOne pointfive(.5);
    pointfive.y = .6;
}
```

In general: enforce predicates on the members.

# 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

Other syntax for initialization:

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

Even:

**Code:**

```
class Vector {  
private:  
    double x,y;  
public:  
    Vector( double x,double y ) : x(x),y(y) {  
    }  
    /* ... */  
    Vector p1(1.,2.);  
    cout << "p1 = "  
        << p1.getx() << ", " << p1.gety()  
        << endl;
```

**Output from running pointintitxy in  
code directory geom:**

# 'this'

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 is not often needed. Typical use case: you need to call a function inside a method that needs the object as argument)

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

## Methods

# Functions on objects

## Code:

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

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

Output from running pointfunc in  
code directory geom:

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 from running pointscaleby  
in code directory geom:

# Methods that create a new object

## Code:

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

Output from running pointscale in  
code directory geom:

# Default constructor

```
Vector p1(1.,2.), p2;  
cout << "p1 has length " << p1.length() << endl;  
p2 = p1.scale(2.);  
cout << "p2 has length " << p2.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()'  
      Vector p1(1.,2.), p2;
```

The problem is with p2. How is it created? We need to define two constructors:

```
Vector() {};  
Vector( double x,double y ) {  
    vx = x; vy = y;  
};
```

# 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 3

Write a class `primegenerator` that contains members `number_of_primes_found` and `last_number_tested`, and methods `nextprime`, `isprime`.

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  
}
```

## More constructors

# Copy constructor

- Several default copy constructors are defined
- They copy an object, recursively.
- You can redefine them as needed.

```
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; };  
};
```

## Code:

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

## Output from running copyscalar in code directory object:

# 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.

# Destructor example

Destructor called implicitly:

**Code:**

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

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

**Output from running destructor in  
code directory object:**

# 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 from running exceptobj in code directory object:



**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 bothering the user.

## Exercise 4

- 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 width(); float height();
```

- Add a second constructor

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

Can you figure out how to use initializer lists for passing the points?

- Rewrite your class so that it stores two `Point` objects.

**Class inheritance: is-a**

# 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 case needs to run too. By default the 'default constructor', but:

```
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 5

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 { ... };  
};
```

# Operator overloading

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

For instance:

```
class Point {  
private:  
    float x,y;  
public:  
    Point operator*(float factor) {  
        return Point(factor*x,factor*y);  
    };  
};
```

Can even redefine equals and parentheses.

# 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'.
- Friend classes:

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

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

# Arrays

# 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.



## Static arrays

# Array creation

```
{  
    int numbers[] = {5,4,3,2,1};  
    cout << numbers[3] << endl;  
}  
  
{  
    int numbers[5]{5,4,3,2,1};  
    numbers[3] = 21;  
    cout << numbers[3] << endl;  
}
```

# 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:

```
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 from running rangemax in code directory array:

# 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:

## Code:

```
int numbers[] = {1,4,2,6,5};  
for ( auto &v : numbers )  
    v *= 3;  
cout << "Scale 0'th by 3: " << numbers[0] << endl;
```

## Output from running rangescale in code directory array:

# Vectors

# Vector definition

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

vector<type> name;
vector<type> name(size);
vector<type> name(size,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.
- value is the uniform initial value of all elements.

# Accessing vector elements

In a number of ways, vector behaves like an array:

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

# 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
```



# Ranging over a vector

```
for ( auto e : my_vector)
    cout << e;
```

Note that `e` is a copy of the array element:

## Code:

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

**Output from running  
vectorrangepcopy in code directory  
array:**

# Ranging over a vector by reference

To set array elements, make `e` 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[2] << endl;
```

**Output from running `vectorrangler` in code directory array:**

# Vector initialization

You can initialize a vector with much the same syntax as an array:

```
vector<int> odd_array{1,3,5,7,9};  
vector<int> even_array = {0,2,4,6,8};
```

(This syntax requires compilation with the `-std=c++11` option.)

# Vector 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.

# Vector copy

Vectors can be copied just like other datatypes:

## Code:

```
vector<float> v(5,0), vcopy;  
v[2] = 3.5;  
vcopy = v;  
cout << vcopy[2] << endl;
```

**Output from running vectorcopy in  
code directory array:**

# Vector methods

- Get elements with `ar[3]` (zero-based indexing).  
(for C programmers: this is not dereferencing, this uses an operator method)
- Get elements, including bound checking, with `ar.at(3)`.
- Size: `ar.size()`.
- Other functions: `front`, `back`.

# Vector indexing

Your choice: fast but unsafe, or slower but safe

```
vector<double> x(5);  
x[5] = 1.; // will probably work  
x.at(5) = 1.; // runtime error!
```

# 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 from running vectorend in  
code directory array:**

also `pop_back`, `insert`, `erase`.  
Flexibility comes with a price.



# Multi-dimensional vectors

Multi-dimensional is harder with vectors:

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

Vector of vectors.

# Dynamic behaviour

# 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

# Vectors and functions

# Vector as function return

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

## Code:

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

## Output from running vectorreturn in code directory array:



# Vector as function argument

You can pass a vector to a function:

```
void print0( vector<double> v ) {  
    cout << v[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[0] = x;
}
/* ... */
vector<float> v(1);
v[0] = 3.5;
set0(v,4.6);
cout << v[0] << endl;
```

Output from running vectorpassnot  
in code directory array:

# 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[0] = x;
}
/* ... */
vector<float> v(1);
v[0] = 3.5;
set0(v,4.6);
cout << v[0] << endl;
```

**Output from running `vectorpassref`  
in code directory array:**

## 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 ) {  
        thearray = vector<int>(n);  
    }  
}
```

# Matrix class

```
class matrix {  
private:  
    int rows,cols;  
    vector<vector<double>> elements;  
public:  
    matrix(int m,int n) {  
        rows = m; cols = 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);  
}
```



## Exercise 6

Add methods such as transpose, scale to your matrix class.  
Implement matrix-matrix multiplication.

# 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 (use `-std=c++11`), 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 is like vector

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.

[http://en.cppreference.com/w/cpp/string/basic\\_string](http://en.cppreference.com/w/cpp/string/basic_string)

# 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

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

# Reference: save on copying

```
class BigDude {  
private:  
    vector<double> array(5000000);  
}  
int main() {  
    BigDude big;  
    f(big); // whole thing is copied
```

Instead write:

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

Prevent changes:

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

## Automatic memory management

# Memory leaks

- Vectors obey scope: deallocated automatically.
- Stuff in objects get destructed when the object is destructed:
- Vectors in objects prevent memory leaks!
- Destructor called when object goes out of scope, including exceptions.
- 'RAII'

# Shared pointers

Shared pointers look like regular pointers:

```
#include <memory>

std::shared_ptr<myobject> obj_ptr
    = std::make_shared<myobject>(x);
    // = std::shared_ptr<myobject>( new myobject(x) );
obj_ptr->mymethod(1.1);
cout << obj_ptr->member << endl;

auto array = std::shared_ptr<double>( new double[100] );
// ILLEGAL: array[1] = 2.14;
array->at(2) = 3.15;
```

# 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 from running ptr1 in code directory pointer:



# 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 from running ptr2 in code directory pointer:

# Linked list code

```
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();
```

# 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 {  
public:  
    double somedo(vector);  
};
```

Implementation file:

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

Strangely, data members also go in the header file.

# 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

Basically, 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 << endl; }
```

## 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 7

Machine precision, or ‘machine epsilon’, is sometimes defined as the smallest number  $\epsilon$  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:

```
float float_eps;  
epsilon(float_eps);  
cout << "For float, epsilon is " << float_eps << endl;  
  
double double_eps;  
epsilon(double_eps);  
cout << "For double, epsilon is " << double_eps << endl;
```

# 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;  
}
```



# 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.

# 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 from running exceptobj in code directory object:

# 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;
```

Can be used with anything that is iterable  
(vector, map, your own classes!)

# 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: " << find3 << endl;

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

## Output from running bagfind in code directory loop:

# 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) {};
```

# Requirements

- a method `iteratable::begin()`: initial state
- a method `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:  
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 8

Write a class `primegenerator` with methods `begin`, `end` and operators `++`, `!=` so that primes can be generated as:

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

I/O

# Basic formatting

## Code:

```
#include <iomanip>
using std::setfill;
using std::setw;
//codesnippet formatpad
/* ... */

int main() {

    //codesnippet formatpad
    /* ... */
    for (int i=1; i<2000000000; i*=10)
        cout << "Number: "
            << setfill('.') << setw(6) << i
            << endl;
```

Output from running formatpad in  
code directory io:

## 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 << " ";
```

Output from running format16 in  
code directory io:

# Streams

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

**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) );
```

# 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 from running plainget in  
code directory auto:

# 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 from running refget in code directory auto:

# 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 from running constrefget in  
code directory auto:**

# 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;
```

Can be used with anything that is iterable  
(vector, map, your own classes!)

# 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.

# 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(); };
};
```

# Illustration

```
SelectedInts greaterthan
( [threshold] (int i) -> bool { return i>threshold; } );
for (int i=0; i<upperbound; i++)
    greaterthan.add(i);
cout << "Ints under " << upperbound
    << " greater than " << threshold << ": "
    << greaterthan.size() << endl;
```

# Exercise 9

Refer to exercise ?? for background.

## Code:

```
class rootfinder {
private:
    function< double(double) >
        f,fprime;
    double tolerance{.00001};
public:
    rootfinder
    ( function< double(double) > f,
      function< double(double) > fprime )
      : f(f),fprime(fprime) {};
    double find() {
        double guess = .5;
        do {
            auto fvalue = f(guess);
            if (abs(fvalue)<tolerance) break;
            auto prev = guess;
            guess = prev - fvalue / fprime(prev);
        } while (true);
        return guess;
    };
};
```

This is a class for zero finding with the newton method. The constructor takes a function and the derivative. Figure out what functions to supply to implement root finding.

# 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 = 10000000000000;
cout << "long number: "
    << hundredg << endl;
int overflow;
overflow = static_cast<int>(hundredg);
cout << "assigned to int: "
    << overflow << endl;
```

## Output from running intlong in code directory cast:



# 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; };
};
```

## Pass base pointer:

```
Base *object = new Derived();
f(object);
Base *nobject = new Erived();
f(nobject);
```

# 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();  
};
```

**Output from running deriveright in  
code directory cast:**

Do not use this function g:

**Code:**

```
void g( Base *obj ) {  
    Derived *der =  
        static_cast<Derived*>(obj);  
    der->print();  
};
```

**Output from running derivewrong  
in code directory cast:**