ΕΛΛΗΝΙΚΗ ΔΗΜΟΚΡΑΤΙΑ
ΠΑΝΕΠΙΣΤΗΜΙΟ ΚΡΗΤΗΣ

Εισαγωγή στον Προγραμματισμό
Introduction to Programming

Διάλεξη 17: Πρότυπα και Εξαιρέσεις

Γ. Παπαγιαννάκης

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
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ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

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HY-150 Προγραμματισμός
CS-150 Programming

Lecture 17:
Templates and exceptions

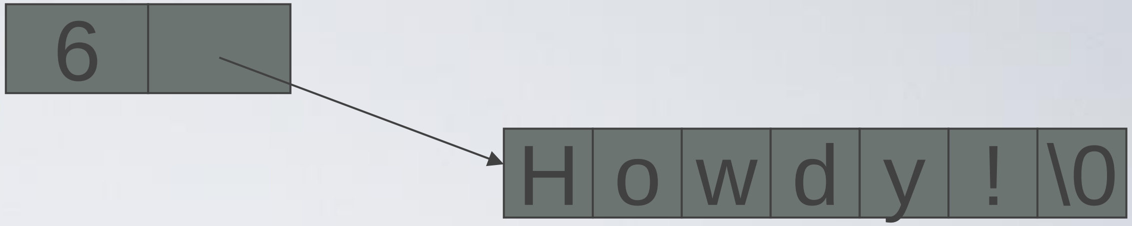
G. Papagiannakis

Abstract

- This is the third of the lectures exploring the **design** of the standard library vector and the **techniques** and **language features** used to **implement** it. Here, we deal with changing the **size** of a vector, parameterization of a vector with an element **type** (templates), and range **checking** (exceptions).

Overview

- Vector revisited
  - How are they implemented?
- Pointers and free store
- Destructors
- Copy constructor and copy assignment
- Arrays
- Array and pointer problems
- Changing size
  - resize() and push_back()
- Templates
- Range checking and exceptions



Changing vector size

- Fundamental problem addressed
  - We (humans) want **abstractions** that can change size (*e.g.*, a vector where we can change the number of elements). However, in computer memory everything must have a fixed size, so how do we create the illusion of change?
- Given

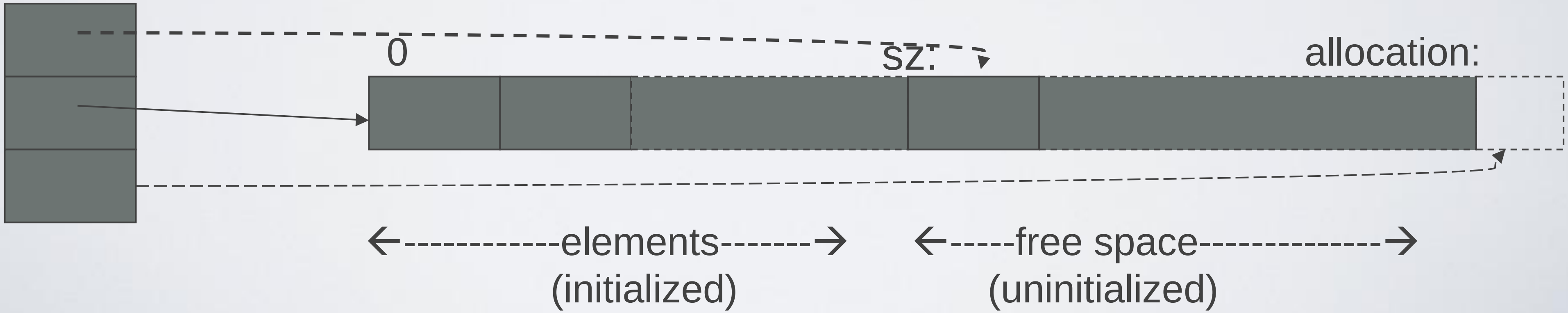
  vector v(n); *// **v.size()==n***

  we can change its size in three ways
  - Resize it
    - **v.resize(10);** *// **v** now has **10** elements*
  - Add an element
    - **v.push_back(7);** *// add an element with the value **7** to the end of **v***
*// **v.size()** increases by **1***
  - Assign to it
    - **v = v2;** *// **v** is now a copy of **v2***
*// **v.size()** now equals **v2.size()***

Representing vector

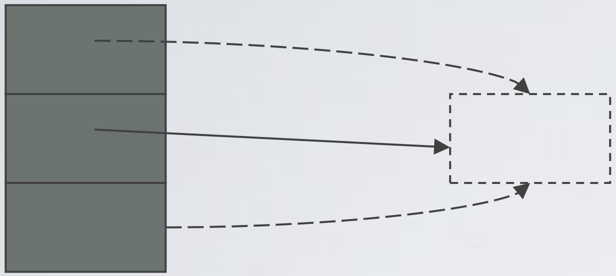
- If you **resize()** or **push_back()** once, you'll probably do it again;
  - let's prepare for that by sometimes keeping a bit of free space for future expansion

```
class vector {
   int sz;
   double* elem;
   int space;        // number of elements plus "free space"
                     // (the number of "slots" for new elements)
public:
   // …
};
```

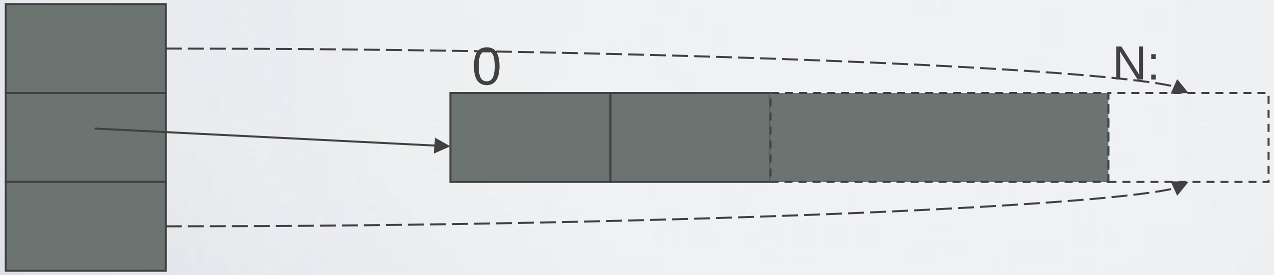


Representing vector

- An empty vector (no free store use):



- A vector(N) (no free space):



vector::reserve()

- First deal with space (allocation);
  - Note: **reserve()** doesn't mess with size or element values

```
void vector::reserve(int newalloc)
   // make the vector have space for newalloc elements
{
   if (newalloc<=space) return;               // never decrease allocation
   double* p = new double[newalloc];          // allocate new space
   for (int i=0; i<sz; ++i) p[i]=elem[i];     // copy old elements
   delete[ ] elem;                            // deallocate old space
   elem = p;
   space = newalloc;
}
```

vector::resize()

- Given **reserve()**, **resize()** is easy
  - **reserve()** deals with space/allocation
  - **resize()** deals with element values

```
void vector::resize(int newsize)
   // make the vector have newsize elements
   // initialize each new element with the default value 0.0
{
   reserve(newsize);                          // make sure we have sufficient space
   for(int i = sz; i<newsize; ++i) elem[i] = 0;      // initialize new elements
   sz = newsize;
}
```

vector::push_back()

- Given **reserve()**, **push_back()** is easy
  - **reserve()** deals with space/allocation
  - **push_back()** just adds a value

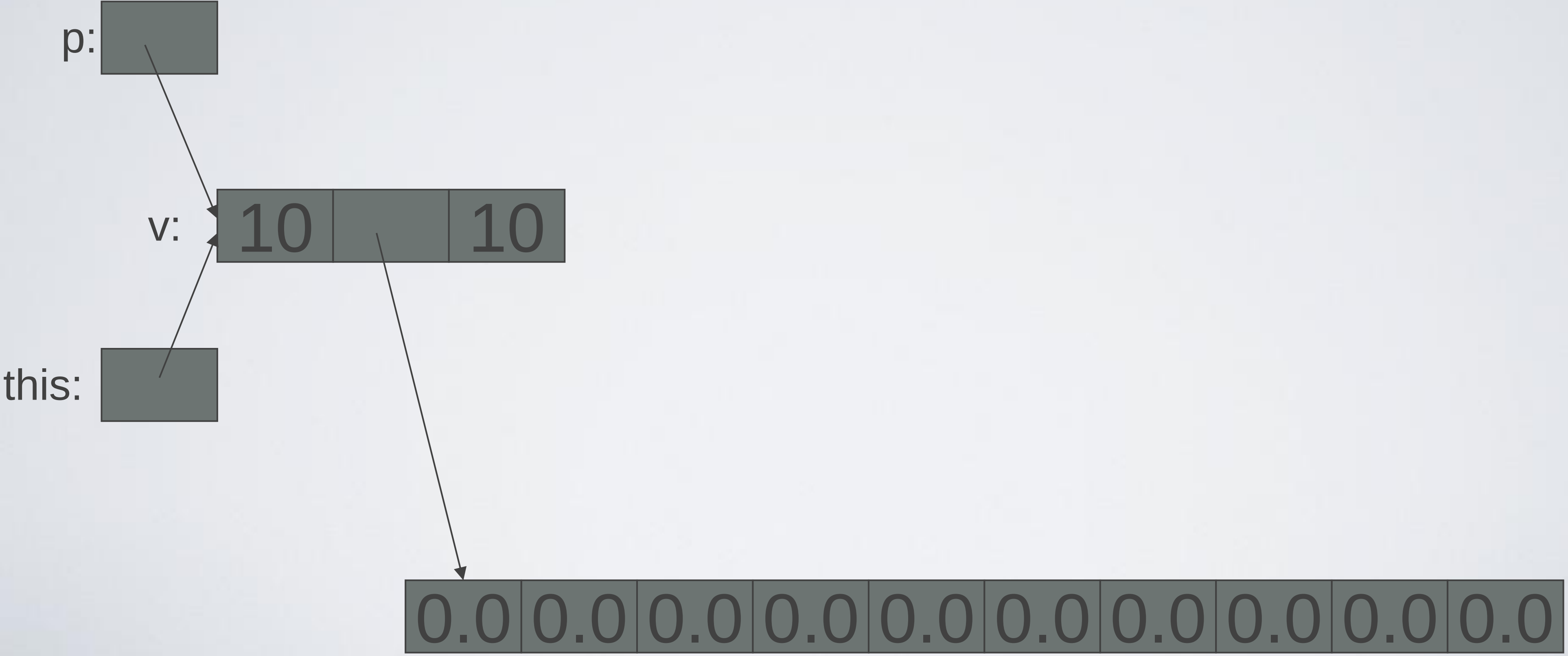
```
void vector::push_back(double d)
   // increase vector size by one
   // initialize the new element with d
{
   if (sz==0)                    // no space: grab some
            reserve(8);
   else if (sz==space)           // no more free space: get more space
            reserve(2*space);
   elem[sz] = d;                 // add d at end
   ++sz;              // and increase the size (sz is the number of elements)
}
```

resize() and push_back()

```
class vector {                                        // an almost real vector of doubles
    int sz;                                           // the size
    double* elem;                                     // a pointer to the elements
    int space;                                        // size+free_space
public:
    vector() : sz(0), elem(0), space(0) { }                              // default constructor
    explicit vector(int s) :sz(s), elem(new double[s]) , space(s) { }// constructor
    vector(const vector&);                                               // copy constructor
    vector& operator=(const vector&);                                            // copy assignment
    ~vector() { delete[ ] elem; }                                        // destructor

    double& operator[ ](int n) { return elem[n]; }                       // access: return reference
    int size() const { return sz; }                                      // current size

    void resize(int newsize);                         // grow (or shrink)
    void push_back(double d);                                   // add element

    void reserve(int newalloc);                                 // get more space
    int capacity() const { return space; }                      // current available space
};
```

The **this** pointer

- A vector is an object
  - **vector v(10);**
  - **vector* p = &v;** *// we can point to a **vector** object*
- Sometimes, **vector**'s member functions need to refer to that object
  - The name of that "pointer to self" in a member function is **this**



The **this** pointer

```
vector& vector::operator=(const vector& a)
    // like copy constructor, but we must deal with old elements
{
    // …
    return *this;     // by convention,
                      // assignment returns a reference to its object: *this
}

void f(vector v1, vector v2, vector v3)
{
    // …
    v1 = v2 = v3;     // rare use made possible by operator=() returning *this
    // …
}
```

- The **this** pointer has uses that are less obscure
  - one of which we'll get to in two minutes

Templates

- But we don't just want vector of double
- We want vectors with element types we specify
  - **vector<double>**
  - **vector<int>**
  - **vector<Month>**
  - **vector<Record*>** *// vector of pointers*
  - **vector< vector<Record> >** *// vector of vectors*
  - **vector<char>**
- We must make the element type a parameter to **vector**
- **vector** must be able to take both built-in types and user-defined types as element types
- This is not some magic reserved for the compiler, we can define our own parameterized types, called "templates"

Templates

- The basis for generic programming in C++
  - Sometimes called “parametric polymorphism”
    - Parameterization of types (and functions) by types (and integers)
  - Unsurpassed flexibility and performance
    - Used where performance is essential (*e.g.*, hard real time and numerics)
    - Used where flexibility is essential (*e.g.*, the C++ standard library)

- Template definitions

```
template<class T, int N> class Buffer { /* … */ };
template<class T, int N> void fill(Buffer<T,N>& b) { /* … */  }
```

- Template specializations (instantiations)

```
// for a class template, you specify the template arguments:
Buffer<char,1024> buf;          // for buf, T is char and N is 1024

// for a function template, the compiler deduces the template arguments:
fill(buf);        // for fill(), T is char and N is 1024; that’s what buf has
```

Parameterize with element type

```
// an almost real vector of Ts:
template<class T> class vector {
   // …
};

vector<double> vd;                     // T is double
vector<int> vi;                        // T is int
vector< vector<int> > vvi;             // T is vector<int>
                                       //                in which T is int
vector<char> vc;                       // T is char
vector<double*> vpd;                   // T is double*
vector< vector<double>* > vvpd;            // T is vector<double>*
                                       //                in which T is double
```

Basically, **vector<double>** is

```
// an almost real vector of doubles:
class vector {
    int sz;             // the size
    double* elem; // a pointer to the elements
    int space;                      // size+free_space
public:
    vector() : sz(0), elem(0), space(0) { }                    // default constructor
    explicit vector(int s) :sz(s), elem(new double[s]), space(s) { } // constructor
    vector(const vector&);                           // copy constructor
    vector& operator=(const vector&);                   // copy assignment
    ~vector() { delete[ ] elem; }                       // destructor

    double& operator[ ] (int n) { return elem[n]; }     // access: return reference
    int size() const { return sz; }                     // the current size

    // …
};
```

Basically, **vector<char>** is

```
// an almost real vector of chars:
class vector {
    int sz;                 // the size
    char* elem;                     // a pointer to the elements
    int space;                      // size+free_space
public:
    vector() : sz(0), elem(0), space(0) { }                     // default constructor
    explicit vector(int s) :sz(s), elem(new char[s]), space(s) { } // constructor
    vector(const vector&);                              // copy constructor
    vector& operator=(const vector&);                           // copy assignment
    ~vector() { delete[ ] elem; }                               // destructor

    char& operator[ ] (int n) { return elem[n]; }           // access: return reference
    int size() const { return sz; }                             // the current size

    // …
};
```

Basically, **vector<T>** is

```
// an almost real vector of Ts:
template<class T> class vector {   // read “for all types T” (just like in math)
   int sz;            // the size
   T* elem;                    // a pointer to the elements
   int space;                  // size+free_space
public:
   vector() : sz(0), elem(0), space(0);                    // default constructor
   explicit vector(int s) :sz(s), elem(new T[s]), space(s) { }     // constructor
   vector(const vector&);                        // copy constructor
   vector& operator=(const vector&);                       // copy assignment
   ~vector() { delete[ ] elem; }                           // destructor

   T& operator[ ] (int n) { return elem[n]; }              // access: return reference
   int size() const { return sz; }                         // the current size

   // …
};
```

Templates

- Problems (“there’s no free lunch”)
  - Poor error diagnostics
    - Often spectacularly poor
  - Delayed error messages
    - Often at link time
  - All templates must be fully defined in each translation unit
    - (the facility for separate compilation of templates, called “export”, is not widely available)
    - So place template definitions in header files
- Recommendation
  - Use template-based libraries
    - Such as the C++ standard library
      - *E.g.*, **vector**, **sort()**
      - Soon to be described in some detail
  - Initially, write only very simple templates yourself
    - Until you get more experience

Range checking

```
// an almost real vector of Ts:

struct out_of_range { /* … */ };


template<class T> class vector {
   // …
   T& operator[ ](int n);                // access
   // …
};

template<class T>  T& vector<T>::operator[ ](int n)
{
   if (n<0 || sz<=n) throw out_of_range();
   return elem[n];
}
```

Range checking

```
void fill_vec(vector<int>& v, int n) // initialize v with factorials
{
   for (int i=0; i<n; ++i) v.push_back(factorial(i));
}

int main()
{
   vector<int> v;
   try {
          fill_vec(v,10);
          for (int i=0; i<=v.size(); ++i)
                 cout << "v[" << i << "]==" << v[i] << '\n';
   }
   catch (out_of_range) {          // we'll get here (why?)
          cout << "out of range error";
          return 1;
   }
}
```

Exception handling (primitive)

```
// sometimes we cannot do a complete cleanup

vector<int>* some_function()      // make a filled vector
{
   vector<int>* p = new vector<int>;          // we allocate on free store,
                                              // someone must deallocate
   try {
            fill_vec(*p,10);
            // …
            return p;            // all's well; return the filled vector
   }
   catch (…) {
            delete p;            // do our local cleanup
            throw;               // re-throw to allow our caller to deal
   }
}
```

Exception handling

(simpler and more structured)

```
// When we use scoped variables cleanup is automatic

vector<int> glob;

void some_other_function()         // make a filled vector
{
   vector<int> v; // note: vector handles the deallocation of elements

   fill_vec(v,10);
   // use v
   fill_vec(glob,10);
   // …
}
```

- if you feel that you need a try-block: think.
  - You might be able to do without it

RAII (Resource Acquisition Is Initialization)

- Vector
  - acquires memory for elements in its constructor
  - Manage it (changing size, controlling access, etc.)
  - Gives back (releases) the memory in the destructor
- This is a special case of the general resource management strategy called RAII
  - Also called “scoped resource management”
  - Use it wherever you can
  - It is simpler and cheaper than anything else
  - It interacts beautifully with error handling using exceptions
  - Examples of “resources”:
    - Memory, file handles, sockets, I/O connections (iostreams handle those using RAII), locks, widgets, threads.

A confession

- The standard library **vector** doesn’t guarantee range checking of **[ ]**
- You have been using
  - *Either* our debug version, called **Vector**, which does check
  - *Or* a standard library version that does check (several do)

- Unless your version of the standard library checks, we “cheated”
  - In **std_lib_facilities.h**, we use the nasty trick (a macro substitution) of redefining **vector** to mean **Vector**

    #define vector Vector

    (This trick is nasty because what you see looking at the code is not what compiler sees – in real code macros are a significant source of obscure errors)
  - We did the same for **string**

What the standard guarantees

```
// the standard library vector doesn't guarantee a range check in operator[ ]:
template<class T> class vector {
   // …
   T& at(int n);                        // checked access
   T& operator[ ](int n);               // unchecked access
};

template<class T>  T& vector<T>::at (int n)
{
   if (n<0 || sz<=n) throw out_of_range();
   return elem[n];
}

template<class T>  T& vector<T>::operator[ ](int n)
{
   return elem[n];
}
```

What the standard guarantees

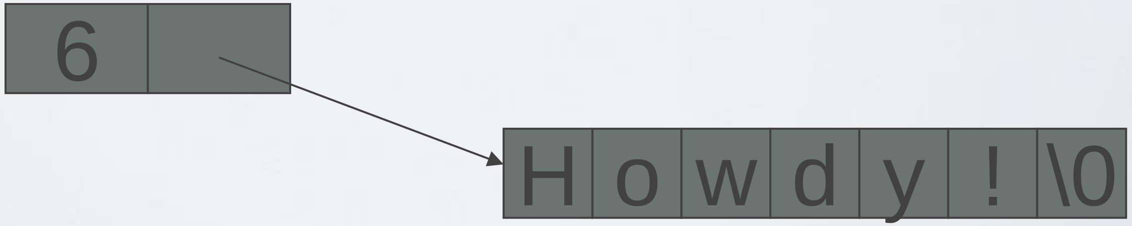
- Why doesn’t the standard guarantee checking?
  - Checking cost in speed and code size
    - Not much; don’t worry
      - No student project needs to worry
      - Few real-world projects need to worry
  - Some projects need optimal performance
    - Think huge (e.g., Google) and tiny (e.g., cell phone)
  - The standard must serve everybody
    - You can build checked on top of optimal
    - You can’t build optimal on top of checked
  - Some projects are not allowed to use exceptions
    - Old projects with pre-exception parts
    - High reliability, hard-real-time code (think airplanes)

Access to const vectors

```
template<class T> class vector {
    // …
    T& at(int n);                                // checked access
    const T& at(int n) const;                    // checked access

    T& operator[ ](int n);                       // unchecked access
    const T& operator[ ](int n) const;           // unchecked access
    // …
};

void f(const vector<double> cvd, vector<double> vd)
{
    // …
    double d1 = cvd[7];    // call the const version of [ ]
    double d2 = vd[7];     // call the non-const version of [ ]
    cvd[7] = 9;            // error: call the const version of [ ]
    vd[7] = 9;             // call the non-const version of [ ]: ok
}
```

String

- A **string** is rather similar to a vector<char>
  - E.g. **size(), [ ], push_back()**
  - Built with the same language features and techniques
- A **string** is optimized for character string manipulation
  - Concatenation (**+**)
  - Can produce C-style string (**c_str()**)
  - >> input terminated by whitespace



Next lecture

- An introduction to the STL, the containers and algorithms part of the C++ standard library. Here we'll meet sequences, iterators, and containers (such as **vector, list**, and **map**). The algorithms include **find()**, **find_if()**, **sort()**, **copy()**, **copy_if()**, and **accumulate()**.

Acknowledgements

Bjarne Stroustrup

Programming -- Principles and Practice Using C++

http://www.stroustrup.com/Programming/

Thank you!

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