CS100
Introduction to Programming

Lectures 18. STL containers

Today's learning objectives

- Basic introduction to STL data structures:
  - Vector
  - List
  - Map

Outline

- Refresher
- STL vector
- STL list
- STL pairs and map

The C++ Standard Template Libraries

- In 1990, Alex Stepanov and Meng Lee of HP Laboratories extended C++ with a library of class and function templates which has come to be known as the STL
- In 1994, STL was adopted as part of ANSI/ISO Standard C++

The C++ Standard Template Libraries

- STL had three basic components:
  - Containers
    - Generic class templates to store data
  - Algorithms
    - Generic function templates to operate on containers
  - Iterators
    - Generlized ‘smart’ pointers that facilitate use of containers
    - They provide an interface that is needed for STL algorithms to operate on STL containers
  - **String abstraction was added during standardization**

Why use STL?

- STL
  - offers an assortment of containers
  - releases containers' time/storage complexity
  - containers grow/shrink in size automatically
  - provides built-in algorithms to process containers
  - provides iterators that make the containers and algorithms flexible and efficient.
  - is extensible which means that users can add new containers and new algorithms such that
    - algorithms can process STL containers as well as user defined containers
  - User defined algorithms can process STL containers as well as user defined containers

Standard Template Library

- Uses template mechanism for generic …
  - … containers (classes)
    - Data structures that hold **anything**
    - **Ex.:** `list, vector, map, set`
  - … algorithms (functions)
    - handle common tasks (searching, sorting, comparing, etc.)
    - **Ex.:** `find, merge, reverse, sort, count, random shuffle, remove, nth-element, rotate, …`

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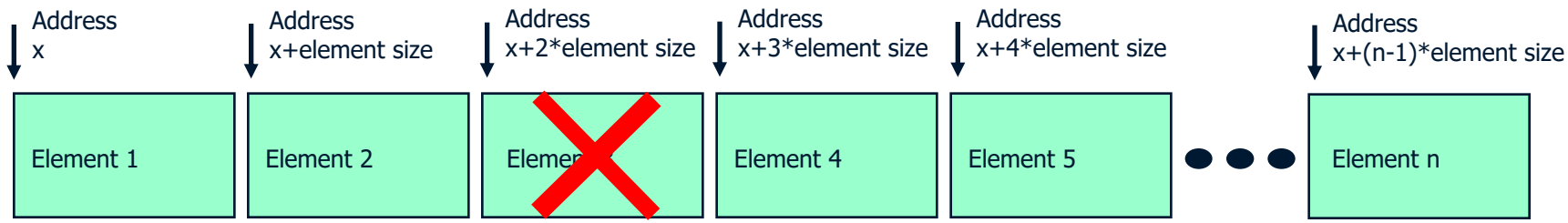
Vector

- Provides an alternative to the built in array
- A vector is self grown (dynamic in size)
- Use it instead of the built in array!
- Contiguous placement in memory
  - Constant-time look-up given known element size!
  - Expensive when adding/removing elements!



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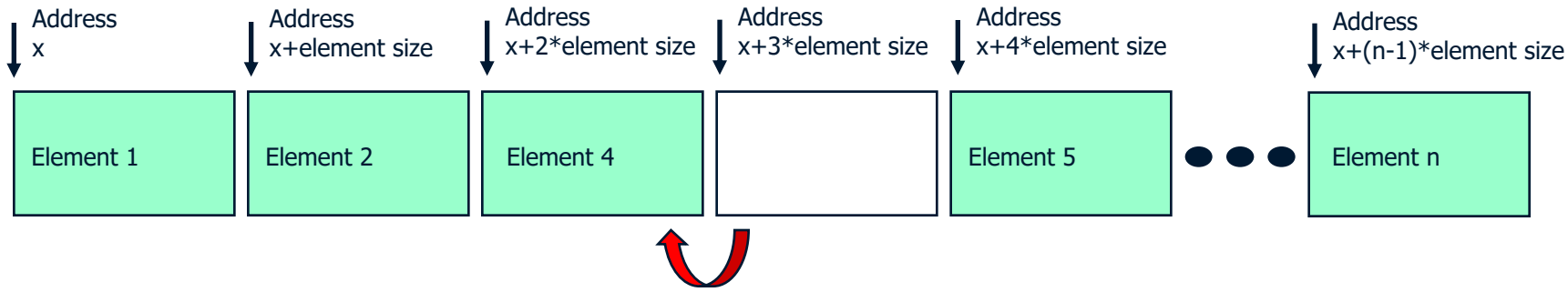

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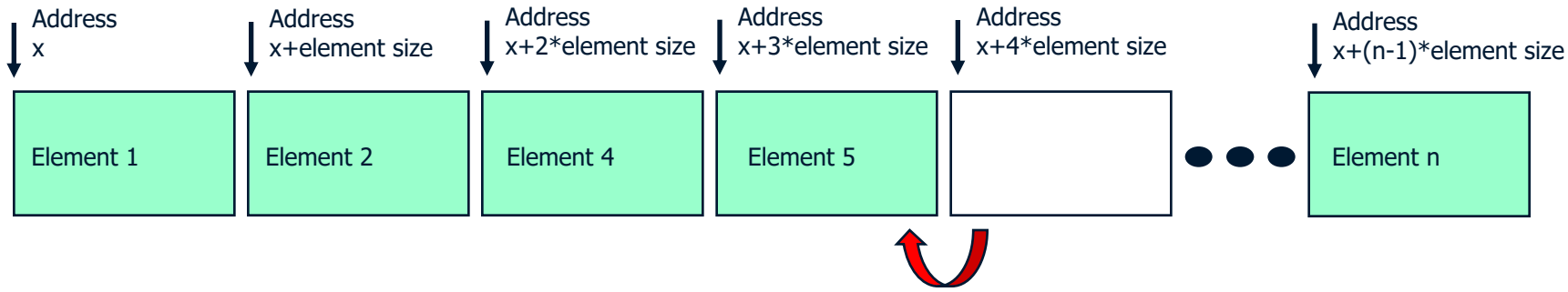

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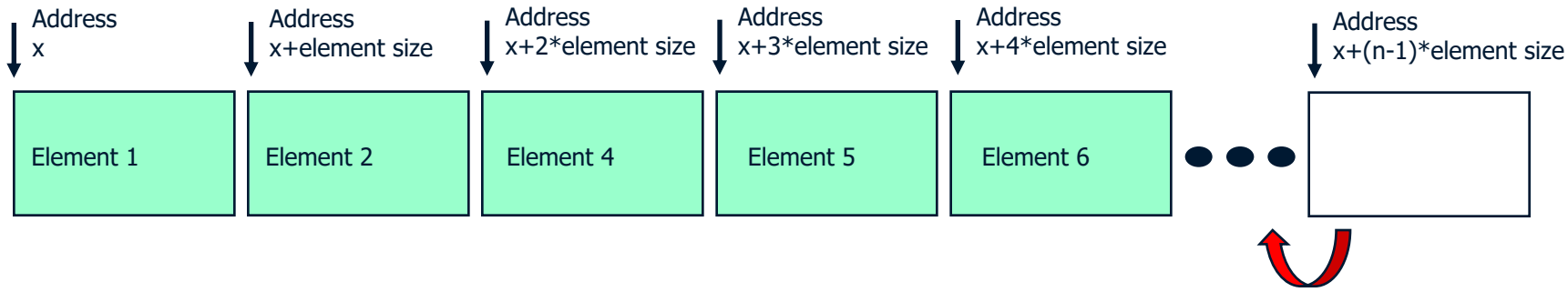


Defining a new vector

- Syntax:
  - `vector<of what>`
- For example :
  - `vector<int>` - vector of integers
  - `vector<string>` - vector of strings
  - `vector<int * >` - vector of pointers to integers
  - `vector<Shape>` - vector of Shape objects, where Shape is a user defined class

Using Vector

- `#include <vector>`

- Two ways to use the vector type:
  - Array style
  - STL style

Using a Vector – Array Style

模仿

- We mimic the use of the C-style array

```
void simple_example()
{
    const int N = 10;
    vector<int> ivec(N);
    for (int i=0; i < 10; ++i)
        cin >> ivec[i];

    int ia[N];
    for (int j = 0; j < N; ++j)
        ia[j] = ivec[j];
}
```

Using a vector – STL style

- We define an empty vector

```
vector<string> svec;
```

- we insert elements into the vector using the method push_back

```
string word;
while ( cin >> word ) //# words "unlimited"
{
    svec.push_back(word);
}
```

Insertion

```
void push_back(const T& x);
```

- Inserts an element with value x at the end of the controlled sequence
  - Example:

```
svec.push_back(str);
```

Size

```
unsigned int size();
```

- Returns the length of the controlled sequence (how many items it contains)
  - Example

```
unsigned int size = svec.size();
```

Example

- A program that read integers from the user, sorts them, and prints the result
- Requirements:
  - Easy way to read in input
  - A “place” to store the input
  - A way to sort the stored input
  - Easy way to print the input

Using STL

```
int main()
{
    int input;
    vector<int> ivec;

    /* rest of code */
}
```

STL - Input

```
while ( cin >> input )
      ivec.push_back(input);
```

STL - Sorting

```
sort(ivec.begin(), ivec.end());
```

- Sort prototype:

```
void sort(Iterator first, Iterator last);
```

  - What are iterators?

Iterators

- Provide a **general way for accessing** each element in sequential (vector, list) or associative (map, set) containers

Pointer Semantics

- Let **`iter`** be an iterator then :
  - **`++iter`** (or **`iter++`**)
    Advances the iterator to the next element
  - **`*iter`** returns element addressed by the iterator

Begin and End

- Each container provide a **`begin()`** and **`end()`** member functions
  - **`begin()`** returns an iterator that addresses the **first** element of the container
  - **`end()`** returns an iterator that addresses **1 past the last** element

Iterating Over Containers

- Iterating over the elements of any container type

```
for ( iter = container.begin();
      iter != container.end();
      ++iter )
{
      // do something with the element
}
```

STL - Output

```
for ( int i = 0; i < ivec.size(); ++i )
      cout << ivec[i] << " ";
cout << endl;
```

- Or (more recommended):

```
vector<int>::iterator it;
for ( it = ivec.begin(); it != ivec.end(); ++it )
      cout << *it << " ";
cout << endl;
```

STL - Include files

```
#include <iostream>  // I/O
#include <vector>    // container
#include <algorithm> // sorting

using namespace std;
```

Putting it all together

```
int main() {
        int input;
        vector<int> ivec;

        // input
        while (cin >> input )
                ivec.push_back(input);

        // sorting
        sort(ivec.begin(), ivec.end());

        // output
        vector<int>::iterator it;
        for ( it = ivec.begin();
              it != ivec.end(); ++it ) {
                cout << *it << " ";
        }
        cout << endl;

        return 0;
}
```

Operations on vector

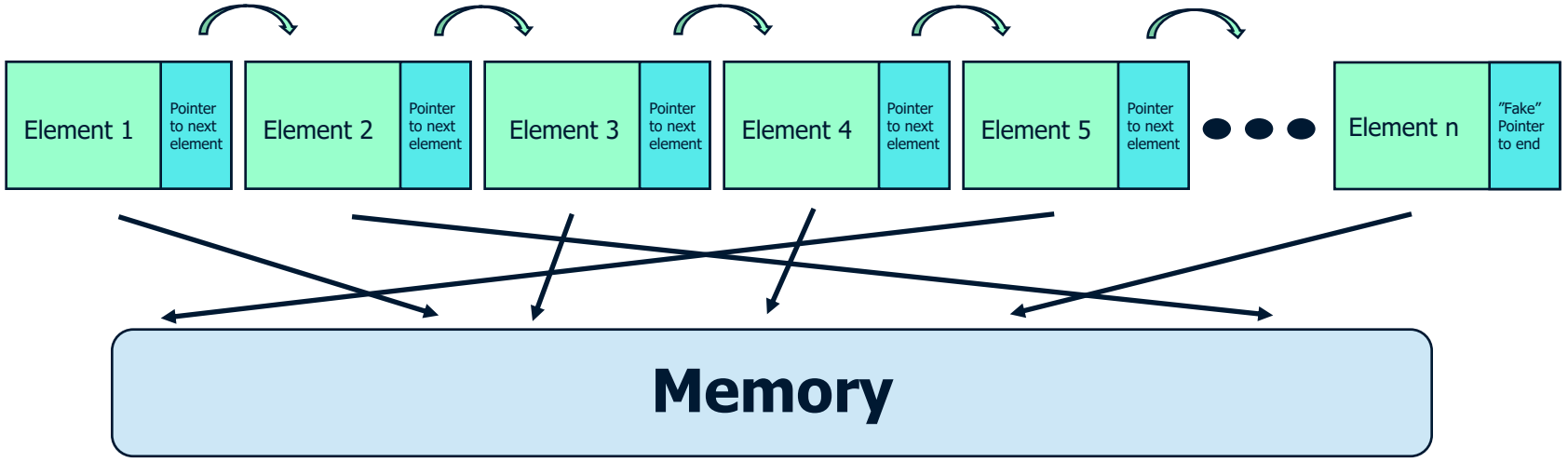
- `iterator begin();`
- `iterator end();`
- `bool empty();`
- `void push_back(const T& x);`
- `iterator erase(iterator it);`
- `iterator erase(iterator first, iterator last);`
- `void clear();`
- …

Outline

- Refresher
- STL vector
- STL list
- STL pairs and map

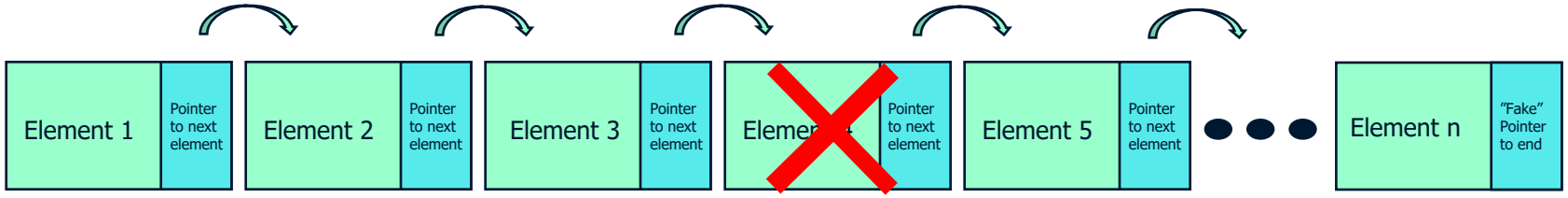
List

- Linked list
- Arbitrary location of elements in memory
  - Expensive to access n^{th} element (have to iterate)



List

- Linked list
- Arbitrary location of elements in memory
  - Expensive to access n^{th} element (have to iterate)
  - Easy to add/remove elements!



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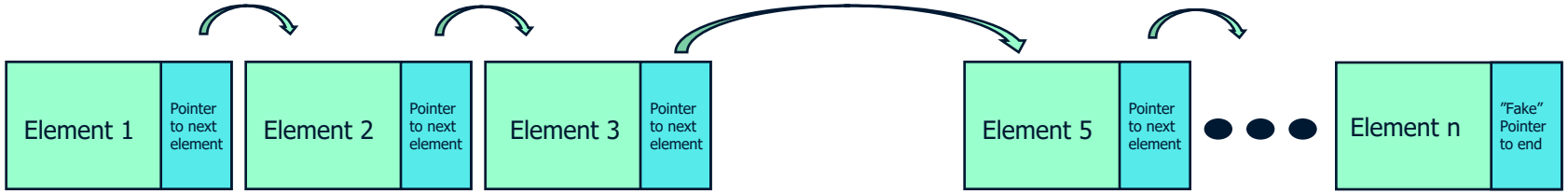

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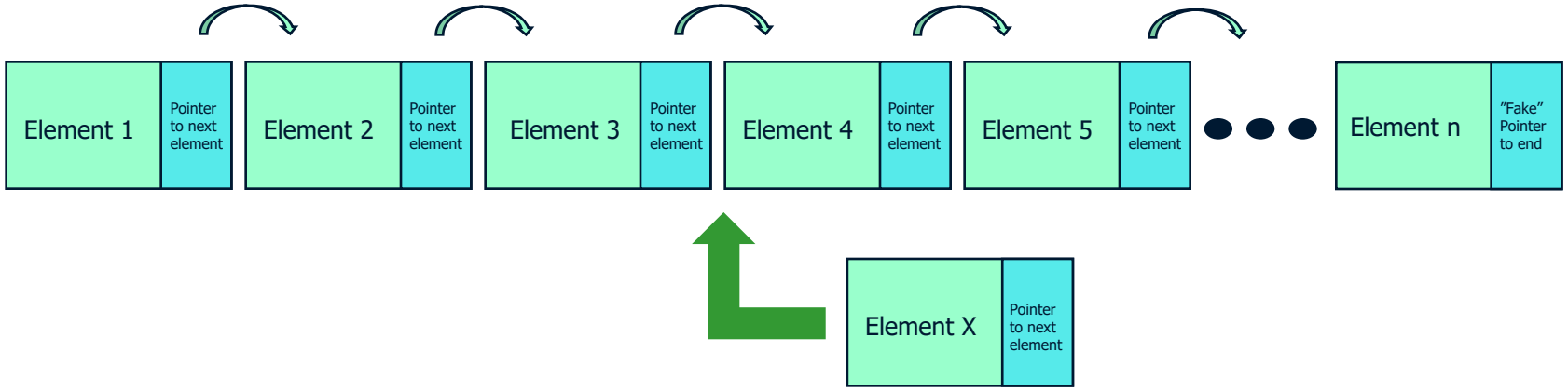

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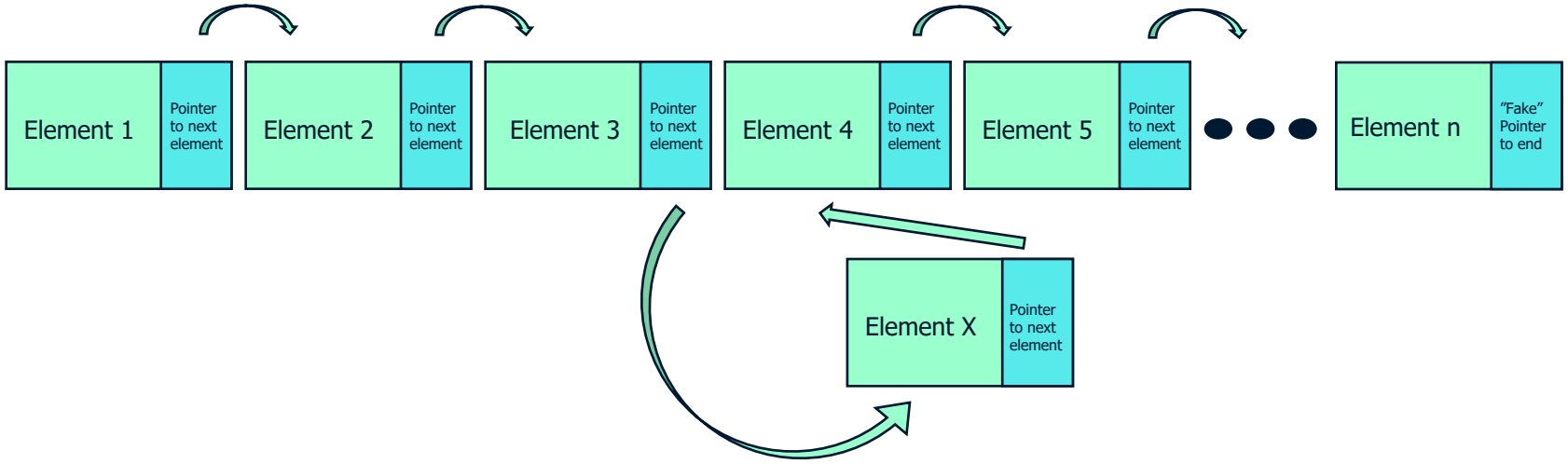

Insertion

```
void push_back(const T& x);
```

- Inserts an element with value x at the end of the list
  - Example:

```
slist.push_back(str);
```

Size

```
unsigned int size();
```

- Returns the number of elements in the list
  - Example

```
unsigned int size = slist.size();
```

Back to our example

- A program that read integers from the user, sorts them, and prints the result
- Requirements:
  - Easy way to read in input
  - A “place” to store the input
  - A way to sort the stored input
  - Easy way to print the input

Using STL

```
int main()
{
    int input;
    list<int> ilist;

    /* rest of code */
}
```

STL – Input and sorting

- No random access iterators!

```
while ( cin >> input )
     ilist.push_back(input);

ilist.sort();
```

STL - Output

- Not possible to use like array anymore!

```
list<int>::iterator it;
for ( it = ilist.begin(); it != ilist.end(); ++it )
      cout << *it << " ";
cout << endl;
```

STL - Include files

```
#include <iostream>  // I/O
#include <list>      // container
#include <algorithm> // sorting

using namespace std;
```

Putting it all together

```
int main() {
        int input;
        list<int> ilist;

        // input
        while (cin >> input )
                ilist.push_back(input);

        // sorting
        ilist.sort();

        // output
        list<int>::iterator it;
        for ( it = ilist.begin();
              it != ilist.end(); ++it ) {
                cout << *it << " ";
        }
        cout << endl;

        return 0;
}
```

Operations on list

- No difference!

- `iterator begin();`
- `iterator end();`
- `bool empty();`
- `void push_back(const T& x);`
- `iterator erase(iterator it);`
- `iterator erase(iterator first, iterator last);`
- `void clear();`
- …

vector vs list

Where are the bottlenecks?

- Sorting: needs easy access to n^{th} element → use **`vector`**!
- Storing: number of elements unknown → use **`list`**!

```
int main() {
    int input;
    vector<int> ivec;

    // input
    while (cin >> input )
        ivec.push_back(input);

    // sorting
    sort(ivec.begin(), ivec.end());

    // output
    vector<int>::iterator it;
    for ( it = ivec.begin();
          it != ivec.end(); ++it ) {
        cout << *it << " ";
    }
    cout << endl;

    return 0;
}
```

```
int main() {
    int input;
    list<int> ilist;

    // input
    while (cin >> input )
        ilist.push_back(input);

    // sorting
    ilist.sort();

    // output
    list<int>::iterator it;
    for ( it = ilist.begin();
          it != ilist.end(); ++it ) {
        cout << *it << " ";
    }
    cout << endl;

    return 0;
}
```

vectors and unknown size

- What is the problem?
  - Needs to be continuous memory block!
  - If pushing back 1 element, and space is insufficient
    - → Entire vector is copied to different place

- How to prevent?
  - Reserve sufficient size upfront!

```
// input
ivec.reserve(100);
while (cin >> input )
  ivec.push_back(input);
```

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Example

Declaration:

```
class Employee {
public:
    // Constructors:
    Employee ();
    Employee ( string & name );

    // Member functions ...:
    void set_salary( int salary);
    int salary();
    void set_name( string& name );
    string& name();

    // …
private:
    int  m_salary;
    string  m_name;
};
```

Implementation:

```
Employee::Employee(){};
Employee::Employee( string & name ) {
    m_name = name;
}

void
Employee::set_salary( int salary ) {
    m_salary = salary;
}
int
Employee::salary() {
    return m_salary;
}
void
Employee::set_name( string & name ) {
    m_name = name;
}
string&
Employee::name() {
    return m_name;
}
```

Locating an Employee

- Save all employees in a vector.
- When we need to find a specific employee:
  - go over all employees until you find one for which the name matches the requested name

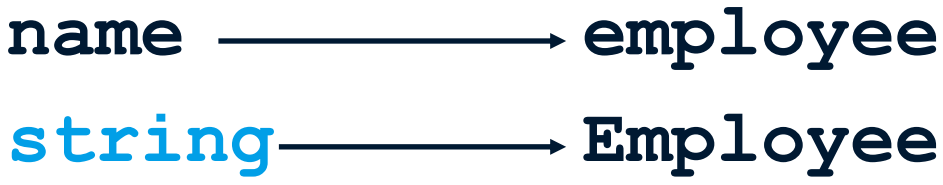
- **Bad solution - not efficient!**

STL - Map

- **Solution:** Map – Associative Array
- We provide a key/value pair. The key serves as an index into the map, the value serves as the data to be stored
- Insertion/find operation:
  - O(log n)

Using Map

- Have a map, where the key will be the employee name and the value the employee object.




```
map<string, Employee *> employees;
```

Populating a Map

```
void main()
{
    map<string, Employee *> employees;
    string name("Pascal");

    Employee * employee;
    employee = new Employee(name);

    //insertion
    employees[name] = employee;
}
```

Locating an Employee

```
map<string, Employee *> employees;
```

- Looking for an employee named **`Pascal`** :

```
//use
Employee *pascal = employees["Pascal"];
//or
map<string, Employee *>::iterator iter =
    employees.find("Pascal");
```

- The returned value is an iterator to map. If **`"Pascal"`** exists on map, it points to this value, otherwise, it returns the **`end()`** iterator of map

Iterating Across a Map

- Printing all map contents.

```
map<string,Employee *>::iterator it;
for ( it = employees.begin();
      it != employees.end(); ++it )
{
    cout << ???
}
```

Map Iterators

```
map<key, value>::iterator iter;
```

- What type of element iter does addresses?
  - The key ?
  - The value ?
- It addresses a key/value **pair**

STL - Pair

- Stores a pair of objects, first of type T1, and second of type T2

```
template<class T1, class T2>
struct pair
{
      T1 first;
      T2 second;
};
```

Our Pair

- In our example it addresses a

```
pair<string, Employee *>
```

Element

- Accessing the **`name`** (key)

```
it->first
```

- Accessing the **`Employee*`** (value)

```
it->second
```

Printing the Salary

```
for ( it = employees.begin();
      it != employees.end();
     ++it )
{
     cout << it->first << " "
          << (it->second)->salary();
}
```

Map Sorting Scheme

- Map holds its content sorted by key
- We would like to sort the map using another sorting scheme (by salary)

Problem: Map Sorting

- **Problem:**
  - Since map already holds the elements sorted, we can't sort them

- **Solution:**
  - Copy the elements to a container where we can control the sorting scheme

STL - Copy

```
copy(Iterator first, Iterator last,
     Iterator where );
```

- Copy from ‘first’ to ‘last’ into ‘where’
- Example:

```
int ia[] = { 0, 1, 1, 2, 3, 5, 5, 8 };
vector<int> ivec1(ia, ia + 8 ), ivec2;

// ...
copy(ivec1.begin(),ivec1.end(),
     ivec2.begin() );
```

Problem: No allocated space

- **`ivec2`** has been allocated no space
- The **`copy`** algorithm uses assignment to copy each element value
- **`copy`** will fail, because there is no space available

Solution: use `back_inserter()`

- Causes the container's `push_back` operation to be invoked.
- The argument to `back_inserter` is the container itself.

```
//ok.copy now inserts using ivec2.push_back()
 copy(ivec1.begin(),ivec1.end(),
      back_inserter(ivec2) );
```

Inserter iterators

- Puts an algorithm into an “insert mode” rather than “over write mode”.

- `*iter =` causes an insertion at that position, (instead of overwriting).

Back to map sorting problem

- Step 1: copy content into other container

```
map<string, Employee *> employees;
vector< pair<string, Employee *> > evec;

copy( employees.begin(), employees.end(),
    back_inserter( evec ) );
```

Sort

- Formal definition :

```
void sort(Iterator first, Iterator last);
```

- Example:

```
vector<int> ivec;
// Fill ivec with integers …

sort(ivec.begin(), ivec.end())
```

Inside Sort

- Sort uses operator $<$ to sort two elements.
- What happens when sorting is meaningful, but no operator $<$ is defined ?

The meaning of operator <

- What does it mean to write :

```
pair<string, Employee *> p1, p2;
if ( p1 < p2 ) {
    …
}
```

Inside Sort

- No operator $<$ is defined between two pairs!
- How can we sort a vector of pairs ?

Sorting Function

- Define a function that knows how to sort these elements, and make the sort algorithm use it!

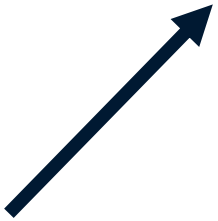
Ordering function

```
bool
lessThen(pair<string, Employee *> &l,
         pair<string, Employee *> &r )
{
     return (l.second)->salary() <
            (r.second)->salary()
}
```

Using the ordering function

```
vector< pair<string, Employee *> > evec;

// Use lessThen to sort the vector.
sort(evec.begin(), evec.end(), lessThen);
```



pointer to function

Putting it all Together

```
bool lessThen( pair<…> &p1, pair<…> &p2 ) { … }


int main() {
    map<string, Employee *> employees;
    /* Populate the map. */

    vector< pair<string, Employee *> > employeeVec;
    copy( employees.begin(), employees.end(),
          back_inserter( employeeVec ) );

    sort( employeeVec.begin(), employeeVec.end(),
          lessThen );

    vector< pair<string, Employee *> >::iterator it;
    for ( it = …; it != employeeVec.end(); ++it ) {
        cout << (it->second)->name() << " "
             << (it->second)->salary() << endl;
    }
    return 0;
}
```