VE280 Programming and Elementary Data Structures

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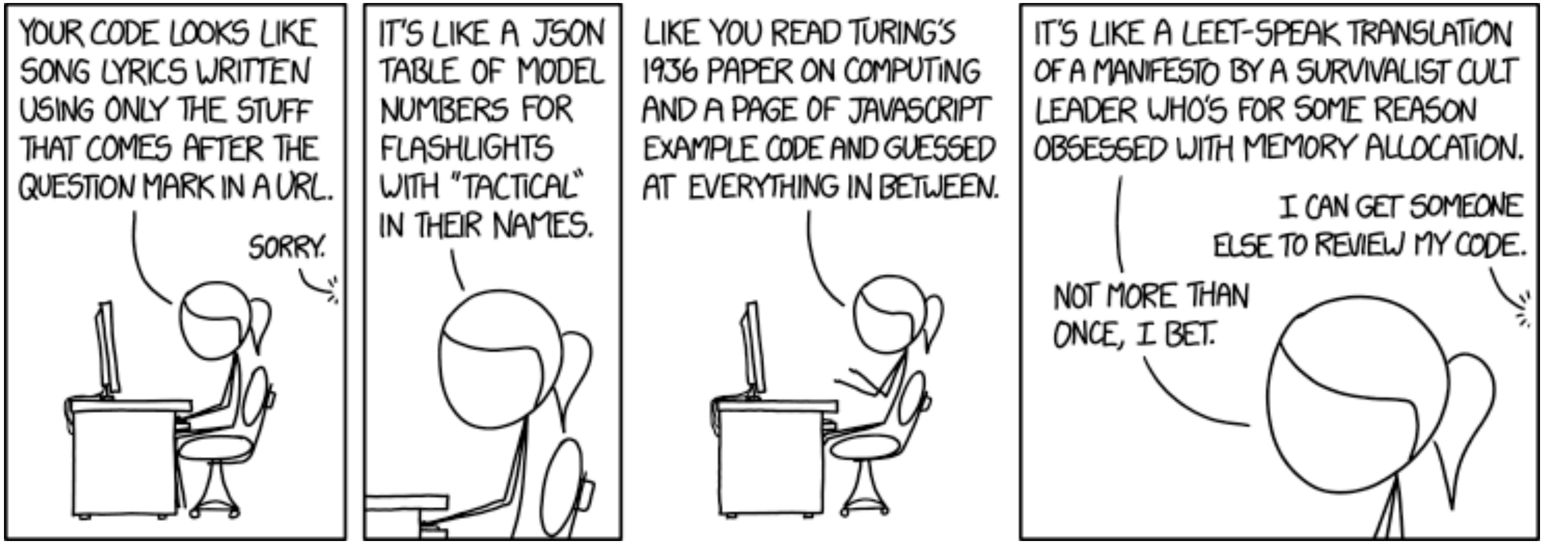
Standard Template Library: Container Adaptors; Associative Containers



Learning Objectives

- Understand what is an STL container adaptor and know how to use it (for `stack` and `queue`)
- Understand what is an associative container and know how to use its STL implementation `map`

Outline

- Container Adaptors

- ADT: Dictionary
- Associative Container: `map`

Adaptor

- An adaptor is a mechanism for making one thing act like another
  - A container adaptor takes an existing container type and makes it act like a different abstract data type
- Three sequential container adaptors
  - stack
  - queue
  - priority_queue
- To use stack, `#include <stack>`
- To use queue, `#include <queue>`

Initializing an Adaptor

- `A a;`
  - The default adaptor. Create an empty object
  - E.g. `stack<int> stk;`
- `A a(c);`
  - Take a container and make a copy of that container as its underlying value
  - By default, both stack and queue are implemented using deque, so if you use a sequential container `c` to initialize, `c` must be a deque type

```
deque<int> deq(10, 1);
stack<int> stk(deq);
```

Initializing an Adaptor

- How do we use a vector to initialize a stack?

```
// Assume ivec is vector<int>
stack<int,vector<int> > stk(ivec);
```

Note the **space**. Otherwise, treated as an extraction operator – an error!

- We can use vector, list, and deque to build stack

size, empty, pop, push, ~~peek~~ top

✓ ✓ pop_back push_back back

To build a queue, we can use:

Select all the correct answers.

- **A.** vector.
- **B.** list.
- **C.** deque.
- **D.** stack.

push_back

pop_front

Operations of Stack Adaptor

- `s.empty()`
  - Returns true if the stack is empty; false otherwise
- `s.size()`
  - Returns a count of the number of elements of the stack
- `s.pop()`
  - Removes, but does not return, the top element from the stack
- `s.push(item)`
  - Places a new top element of the stack
- `s.top()`
  - Returns a reference to the top element of the stack

Note: although stack is implemented using another container, you cannot use other operations. For example, cannot call push_back().

Example

```
stack<int> stk;
for(int i=0; i<5; i++)
   stk.push(i);
while(!stk.empty()) {
   cout << stk.top() << endl;
   stk.pop();
}
```

~~4~~
~~3~~
~~2~~
~~1~~
~~0~~
stk

What's the output?

4
3
2
1
0

Operations on Queue Adaptor

queue<string, list<string>> q;

- `q.empty()` ✓
  - Returns true if the queue is empty; false otherwise
- `q.size()` ✓
  - Returns a count of the number of elements of the queue
- `q.push(item)` ✓
  - Places a new element at the end of the queue
- `q.pop()` ✓
  - Removes, but does not return, the front element from the queue
- `q.front()` ✓
  - Returns a reference to the front element of the queue
- `q.back()` ✓
  - Returns a reference to the back element of the queue

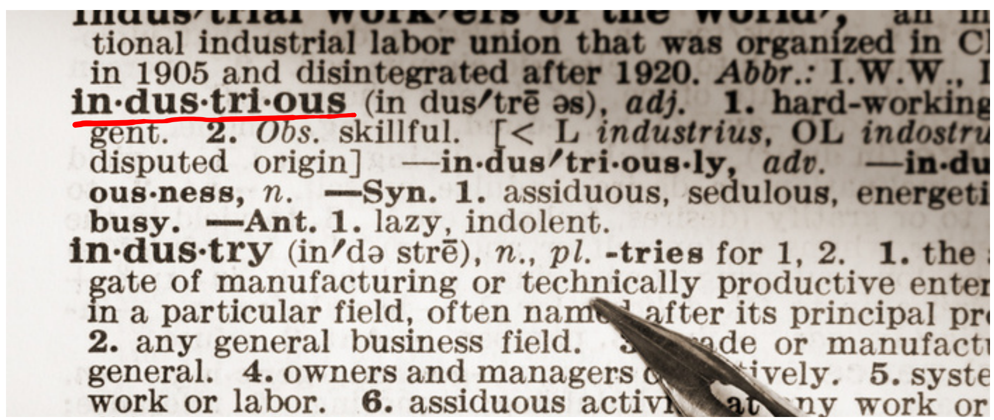
Outline

- Container Adaptors
- ADT: Dictionary
- Associative Container: `map`

Dictionary

- How do you use a dictionary?
  - Look up a "word" and find its meaning.
- We also have an **ADT** of dictionary.
  - It is a collection of pairs, each containing a **key** and an **value**

    `(key, value)`
  - **Important**: Different pairs have different keys.



Dictionary

- Key space is usually more regular/structured than value space, so easier to search.

- Dictionary is optimized to quickly **add** **`(key, value)`** pair and **retrieve value** by key.

Methods

- `Value find(Key k)`: Return the value whose key is **k**. Return `Null` if none.
- `void insert(Key k, Value v)`: Insert a pair `(k, v)` into the dictionary. If the pair with key as **k** already exists, update its value.
- `Value remove(Key k)`: Remove the pair with key as **k** from the dictionary and return its value. Return `Null` if none.
- `int size()`: return number of pairs in the dictionary.

Example

- Collection of student records in the class
  - (key, value) = (student name, linear list of assignment and exam scores)
  - All keys are distinct

- Operations
  - Get the value whose key is John Adams.
  - Insert a record for the student whose name is Diana Ross.

Implementation

- Method #1: using an array
  - Just like our **`IntSet`**
  - The difference is that each array element is a **`(key, value)`** pair
  - If keys can be sorted, can use either sorted array or unsorted array on keys
- Method #2: using a linked list
  - Each node now stores both the key and value
  - The differences over **`IntList`** are:
    - When inserting, it needs to verify there is no duplicated key. If key already exists, update the value entry
    - It removes on key, not just the first and last element

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- Container Adaptors
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- Associative Container: `map`

Introduction

- Elements in an associative container are stored and retrieved by a **key**, in contrast to elements in a sequential container, which are stored and accessed sequentially by their position within the container
- Two primary associative container types: `map` and `set`
  - Elements in a `map` are (key, value) pairs
  - `set` contains only a key and supports efficient queries to whether a given key is present
- Applications
  - `map`: dictionary
  - `set`: store a collection of distinct key values efficiently. For example, the distinct English words in an article

Associative vs. Sequential Containers

- Associative containers share many, but not all, of the operations on sequential containers
  - They <u>do not</u> have the front(), push_front(), pop_front(), back(), push_back(), or pop_back() operations
- Common operations
  - C<T> c; // creates an empty container
  - C<T> c1(c2); // copies elements from c2 into c1
    // c2 must be the same type as c1
  - C<T> c(b, e); // b and e are iterators denoting a
    // sequence. Copy elements from the sequence into c
  - begin(), end(), size(), empty(), clear(), =

Associative vs. Sequential Containers

- The associative container types define additional operations
- The big difference: for associative containers, elements are accessed by key
  - We focus here on associative containers where the elements are ordered by key (not in the order of their insertions)
  - When we iterate across such an associative container, we are guaranteed that the elements are **accessed in key order**, irrespective of the order in which the elements were placed in the container.

Map

- map is also known as **associative array**
- It stores (key, value) pair
- To use it, `#include <map>`
- Constructors
  - `map<k, v> m;` // Create an empty map named m
    // with key and value types k and v.
  - E.g., **`map<string,int> word_count`** ;
  - `map<k, v> m(m2);` // Create m as a copy of m2;
    // m and m2 must have the same key and value types
  - `map<k, v> m(b, e);` //Create m as a copy of the
    //elements from the range denoted by iterators b and e

Constraints on the Key Type

- Since elements in map are ordered by keys, we require that key type has an extra operation: **strict weak ordering**

Examples:
- < for int
- alphabetical order for string

- Strict weak ordering:
  - Think as less than (<)
- Technically
  - Yield false when we compare a key with itself
  - Given two keys, they cannot both be "less than" each other
  - Satisfy transitive property: if k1<k2 and k2<k3, then k1<k3
  - If we have two keys, neither of which is "less than" the other, then they are treated as equal

Preliminaries: the pair Type

- A simple companion type, holding two data values
- It is a template. Need to supply two type names

```
pair<string,string> spair; // hold two strings
```

- `pair<T1, T2> p1;`
    - Create a pair with two elements of types T1 and T2. The elements are value-initialized (use default constructor for class type; 0 for built-in type)
- `pair<T1, T2> p1(v1, v2);`
    - Create a pair with types T1 and T2. Initialize the first member from v1 and the second from v2.
    - **`pair<string, int> count("blue", 2);`**

Preliminaries: the pair Type

- We can access the two data members in the pair
  - `p.first //` return the **reference** to the first member
  - `p.second //` return the **reference** to the second member
  - They are **public**

- `make_pair(v1,v2)`
  - Create a new pair from the values v1 and v2. The type of the pair is inferred from the types of v1 and v2
    `pair<string,string> name = make_pair("John", "Adams");`

Map Iterator

- Dereferencing a map iterator yields a **pair** in which the first member holds a **const key** and the second member holds the **value**

```
map<string, int>::iterator it =
                              word_count.begin();
```

- `*it` is a reference to a `pair<const string, int>` object
  - It refers to neither the key nor the value
- To access its key, use `it->first`

```
  cout << it->first;
```

- However, the first member is a **const key**, so we cannot change it

```
  it->first = "new key"; // Error!
```

Map Iterator

```
map<string, int>::iterator it =
                              word_count.begin();
```

- To access its value, use **`it->second`**

```
cout << it->second;
```

- We can change value through iterator

```
it->second = 2;
```

Adding Elements to a map

- There are two ways:
  - Using the subscript operator
  - Using the insert member

Insert Using Subscripting

- If key k is not in the map m, you can insert (k, v) using

```
m[k] = v;
```

- Example

```
map <string, int> word_count; // empty map
// insert element with key "Anna";
// then assign 1 to its value
word_count["Anna"] = 1;
```

- You inserted a pair **("Anna", 1)** into **word_count**.

Insert Using Subscripting

```
map <string, int> word_count; // empty map
// insert element with key "Anna";
// then assign 1 to its value
word_count["Anna"] = 1;
```

- What really happens is
  - **`word_count`** is searched for the element whose **`key`** is **`Anna`**. The element is not found.
  - A new (key, value) pair is inserted. key = "Anna". Value is value-initialized to 0.
  - The newly inserted element is fetched and is given the value 1.

Subscripting a map

- Subscripting a map behaves quite differently from subscripting an array or vector
  - Using an index (key) that **does not exist** adds an element with that index to the map
- If the key exists, the value associated with the key is returned. We can read and write to the value

```
cout << word_count["Anna"];
++word_count["Anna"]; // fetch the element
                      // and add one to it
```

- Subscripting a vector = dereferencing a vector iterator
- Subscripting a map ≠ dereferencing a map iterator

Use Subscript Behavior in a Smart Way

```
// count #times each word occurs from input
map<string, int> word_count;
// empty map from string to int
string word;
while (cin >> word)
  ++word_count[word];
```

Question: what's the behavior for the first time we encounter a word?

- The first time we encounter a word, a new element indexed by word is created and inserted into map
  - Its value is initialized with zero
- Then, the value of that element is immediately incremented. So, the count is the (correct) value of one
- If word is already in the map, then its value is incremented.

insert()

- `m.insert(e)`
  - `e` is a (key, value) pair. If the key is not in `m`, insert the pair. If the key is in `m`, then `m` is unchanged

key

value

("Anna", 1)

map

```
word_count.insert(make_pair("Anna", 1));
```

insert()

- `m.insert(e)`
  - Returns a pair of (map iterator, bool)
    - map iterator refers to the element with key
    - bool indicates whether the element was inserted or not.

```
// count #times each word occurs from input
map<string, int> word_count;
while (cin >> word) {
  pair<map<string, int>::iterator, bool> ret =
      word_count.insert(make_pair(word, 1));
  if (!ret.second) // word already in word_count
      ++ret.first->second; // increment count
}
```

Finding and Retrieving a map Element

- The subscript operator provides the simplest method of retrieving a value
- But, it has a side effect. What is it?
  - If that key is not already in the map, then subscript inserts an element with that key.
- How can we determine if a key is present without causing it to be inserted?
  - **`m.find(k)`**

find()

- `m.find(k)`
  - Returns an iterator to the element indexed by key `k`, if there is one
  - Otherwise, returns an off-the-end iterator (i.e., end()) if the key is not present

```
int occurs = 0;
map<string,int>::iterator it =
   word_count.find("abc");
if (it != word_count.end())
   occurs = it->second;
```

erase()

- `m.erase(iter)`
  - Removes element referred to by the iterator `iter` from `m`. `iter` must refer to an actual element in `m`; it must not be equal to `m.end()`.
  - Returns void.
- `m.erase(k)`
  - Removes the element with key `k` from `m` if it exists
  - Otherwise, do nothing
  - Returns the number of elements removed. For map, this is either 0 or 1

```
if (word_count.erase(rm_word)) // rm_word is a key
  cout << "ok: " << rm_word << "removed\n";
else cout << rm_word << " not found!\n";
```

Iterate across a map

- map has `begin()` and `end()`, with which we can traverse the map
- Example: print all the elements in `word_count`

```
map<string, int>::iterator it;
for(it=word_count.begin();
    it!=word_count.end(); ++it)
    cout << it->first << " occurs "
      << it->second << " times";
```

- The output prints the words in **alphabetical order**.
  - <u>**Note**</u>: When we use an iterator to traverse a map, the iterators yield elements in **ascending key order**.

Which of the following statements are true?

Select all the correct answers.

- **A.** A dictionary can be seen as a generalization of an array.
- **B.** A key has to be a string.
- **C.** A same key can be associated to several different values in a dictionary.
- **D.** A same value can be associated to several different keys in a dictionary.

Reference

- **C++ Primer (4th Edision)**, by *Stanley Lippman, Josee Lajoie, and Barbara Moo*, Addison Wesley Publishing (2005)
  - Chapter 10 Associative Containers

- Course notes, pages 220-223