CSCI-1200 Data Structures — Fall 2021
Lecture 15 – Associative Containers (Maps), Part 1

Review from Lecture 14

- Operators as non-member functions, as member functions, and as friend functions.

Today's Class — Associative Containers (STL Maps)

- STL Maps: associative containers for fast insert, access and remove
- Example: Counting word occurrences
- STL Pairs
- Map iterators
- Map member functions: `operator[]`, `find`, `insert`, `erase`.
- Efficiency
- STL maps vs. STL vectors vs. STL lists

15.1 STL Maps: Associative Containers

- STL maps store pairs of "associated" values.
- We will see several examples today, in lab 9, and in Lecture 16:
  - An association between a string, representing a word, and an int representing the number of times that word has been seen in an input file.
  - An association between a string, representing a word, and a vector that stores the line numbers from a text file on which that string occurs (next lecture).
  - An association between a phone number and the name of the person with that number (tomorrow's lab).
  - An association between a class object representing a student name and the student's info (next lecture).
- A particular instance of a `map` is defined (declared) with the syntax:

  ```
  std::map<key_type, value_type>  var_name
  ```

  In our first two examples above, `key_type` is a string. In the first example, the `value_type` is an `int` and in the second it is a `std::vector<int>`.
- Entries in maps are *pairs*:

  ```
  std::pair<const key_type, value_type>
  ```

- Map iterators refer to pairs.
- Map search, insert and erase are all very fast: $O(\log n)$ time, where n is the number of pairs stored in the map.
- Note: The STL `map` type has similarities to the Python dictionary, Java HashMap, or a Perl hash, but the data structures *are not the same*. The organization, implementation, and performance is different. In a couple weeks we'll see an STL data structure that is even more similar to the Python dictionary.
- Map search, insert and erase are $O(\log n)$. Python dictionaries are $O(1)$.

First, let's see how this some of this works with a program to count the occurrences of each word in a file. We'll look at more details and more examples later.

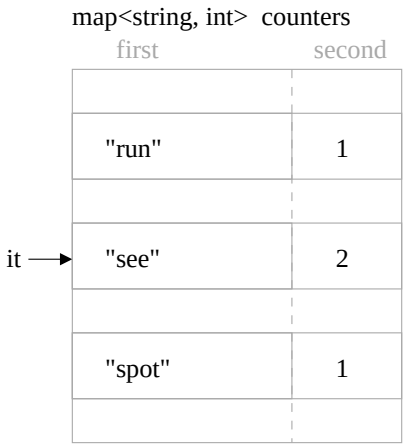
15.2 Counting Word Occurrences

- Here's a simple and elegant solution to this problem using a map:

```
#include <iostream>
#include <map>
#include <string>

int main() {
  std::string s;
  std::map<std::string, int> counters; // store each word and an associated counter

  // read the input, keeping track of each word and how often we see it
  while (std::cin >> s)
    ++counters[s];

  // write the words and associated counts
  std::map<std::string, int>::const_iterator it;
  for (it = counters.begin(); it != counters.end(); ++it) {
    std::cout << it->first << "\t" << it->second << std::endl;
  }
  return 0;
}
```

15.3 Maps: Uniqueness and Ordering

- Maps are ordered by increasing value of the `key`. Therefore, there must be an `operator<` defined for the key.
- Once a key and its value are entered in the map, the key can't be changed. It can only be erased (together with the associated value).
- Duplicate keys can not be in the map.
- Note: Python dictionaries are *not* ordered!



15.4 STL Pairs

The mechanics of using `std::pair`s are relatively straightforward:

- `std::pair`s are a templated `struct` with just two members, called `first` and `second`. *Reminder: a* `struct` *is basically a wimpy* `class` *and in this course you aren't allowed to create new structs. You should use classes with private variables instead – to practice good object-oriented programming design.*
- To work with pairs, you must `#include <utility>`. Note that the header file for maps (`#include <map>`) itself includes utility, so you don't have to include utility explicitly when you use pairs with maps.
- Here are simple examples of manipulating pairs:

```
std::pair<int, double> p1(5, 7.5);
std::pair<int, double> p2 = std::make_pair(8, 9.5);
p1.first = p2.first;
p2.second = 13.3;
std::cout << p1.first << " " << p1.second << std::endl;
std::cout << p2.first << " " << p2.second << std::endl;
p1 = p2;

std::pair<const string, double> p3 = std::make_pair(string("hello"), 3.5);
p3.second = -1.5;
// p3.first = string("illegal");      // (a)
// p1 = p3;                           // (b)
```

- The function `std::make_pair` creates a pair object from the given values. It is really just a simplified constructor, and as the example shows there are other ways of constructing pairs.
- Most of the statements in the above code show accessing and changing values in pairs.

- The two statements at the end are commented out because they cause syntax errors:
  - In (a), the `first` entry of `p3` is `const`, which means it can't be changed.
  - In (b), the two pairs are different types! Make sure you understand this.
- Returning to maps, each entry in the map is a pair object of type:

```
std::pair<const key_type, value_type>
```

  The const is needed to ensure that the keys aren't changed! This is crucial because maps are sorted by keys!

15.5 Maps: `operator[]`

- We've used the `[]` operator on vectors, which is conceptually very simple because vectors are just resizable arrays. Arrays and vectors are efficient *random access data structures*.
- But `operator[]` is actually a function call, so it can do things that aren't so simple too, for example:

```
++counters[s];
```

- For maps, the `[]` operator searches the map for the `pair` containing the `key` (string) `s`.
  - If such a pair containing the key is **not** there, the operator:
    1. creates a `pair` containing the key and a default initialized value,
    2. inserts the `pair` into the map in the appropriate position, and
    3. returns a reference to the value stored in this new pair (the second component of the pair).

    This second component may then be changed using operator++.
  - If a pair containing the key **is** there, the operator simply returns a reference to the value in that pair.
- In this particular example, the result in either case is that the `++` operator increments the value associated with string `s` (to 1 if the string wasn't already it a pair in the map).
- For the user of the map, `operator[]` makes the map feel like a vector, except that indexing is based on a `string` (or any other key) instead of an int.
- Note that the result of using `operator[]` is that the key is ALWAYS in the map afterwards.

15.6 Map Iterators

- Iterators may be used to access the map contents sequentially. Maps provide `begin()` and `end()` functions for accessing the bounding iterators. Map iterators have `++` and `--` operators.
- Each iterator refers to a pair stored in the map. Thus, given map iterator `it`, `it->first` is a `const string` and `it->second` is an `int`. Notice the use of `it->` , and remember it is just shorthand for `(*it).`

15.7 Exercise

Write code to create a map where the key is an integer and the value is a double. (Yes, an integer key!) Store each of the following in the map: 100 and its sqrt, 100,000 and its sqrt, 5 and its sqrt, and 505 and its sqrt. Write code to output the contents of the map. Draw a picture of the map contents. What will the output be?

15.8 Map Find

- One of the problems with `operator[]` is that it always places a key / value pair in the map. Sometimes we don't want this and instead we just want to check if a key is there.
- The `find` member function of the map class does this for us. For example:

```
m.find(key);
```

  where `m` is the map object and `key` is the search key. It returns a map iterator:

  If the key is in one of the pairs stored in the map, `find` returns an iterator referring to this pair.
  If the key is not in one of the pairs stored in the map, `find` returns `m.end()`.

15.9 Map Insert

- The prototype for the map `insert` member function is:

```
m.insert(std::make_pair(key, value));
```

  insert returns a pair, but not the pair we might expect. Instead it is pair of a map iterator and a bool:

```
std::pair<map<key_type, value_type>::iterator, bool>
```

- The `insert` function checks to see if the key being inserted is already in the map.
  - If so, it does not change the value, and returns a (new) pair containing an iterator referring to the *existing pair* in the map and the bool value `false`.
  - If not, it enters the pair in the map, and returns a (new) pair containing an iterator referring to the *newly added pair* in the map and the bool value `true`.

15.10 Map Erase

Maps provide three different versions of the erase member function:

- `iterator erase(iterator p)` — erase the pair referred to by iterator `p`, and return an iterator pointing at the next pair (or end).
- `iterator erase(iterator first, iterator last)` — erase all pairs from the map starting at `first` and going up to, but not including, `last`. Also returns iterator pointing at the next pair (or end).
- `size_type erase(const key_type& k)` — erase the pair containing key `k`, returning either 0 or 1, depending on whether or not the key was in a pair in the map

15.11 Exercise

Re-write the `word_count` program so that it uses `find` and `insert` instead of `operator[]`.

15.12 Choices of Containers

- We can solve this word counting problem using several different approaches and different containers:
  - a vector or list of strings
  - a vector or list of pairs (string and int)
  - a map
  - ?
- How do these approaches compare? Which is cleanest, easiest, and most efficient, etc.?