

## Programming Assignment 2

### Double Trouble

**Time due: 9:00 PM Tuesday, January 26**

Homework 1 gave you extensive experience with the Map type using both arrays and dynamically-allocated arrays. In this project, you will re-write the implementation of the Map type to employ a doubly-linked list rather than an array. You must *not* use arrays. You will also implement a couple of algorithms that operate on maps.

#### Implement Map yet again

Consider the Map interface from problem 2 of Homework 1:

```
typedef TheTypeOfTheKeysGoesHere KeyType;
typedef TheTypeOfTheValuesGoesHere ValueType;

class Map
{
public:
    Map();
    bool empty() const;
    int size() const;
    bool insert(const KeyType& key, const ValueType& value);
    bool update(const KeyType& key, const ValueType& value);
    bool insertOrUpdate(const KeyType& key, const ValueType& value);
    bool erase(const KeyType& key);
    bool contains(const KeyType& key) const;
    bool get(const KeyType& key, ValueType& value) const;
    bool get(int i, KeyType& key, ValueType& value) const;
    void swap(Map& other);
};
```

In problem 3 of Homework 1, you implemented this interface using an array. For this project, implement this Map interface using a doubly-linked list. (You must not use the `list` class template from the C++ library.)

For the array implementation of problem 3 of Homework 1, since you declared no destructor, copy constructor, or assignment operator, the compiler wrote them for you, and they did the right thing. For this linked list implementation, if you let the compiler write the destructor, copy constructor, and assignment operator, they will do the wrong thing, so you will have to declare and implement these public member functions as well:

#### Destructor

When a Map is destroyed, the nodes in the linked list must be deallocated.

#### Copy constructor

When a brand new Map is created as a copy of an existing Map, enough new nodes must be allocated to hold a duplicate of the original list.

When an existing Map (the left-hand side) is assigned the value of another Map (the right-hand side), the result must be that the left-hand side object is a duplicate of the right-hand side object, with no memory leak of list nodes (i.e. no list node from the old value of the left-hand side should be still allocated yet inaccessible).

Notice that there is now no *a priori* limit on the maximum number of key/value pairs in the Map (so `insertOrUpdate` should always return `true`). Also, as in Homework 1, if a Map has a size of  $n$ , then the values of the first parameter to the three-parameter form of `get` for which that function retrieves a key and a value and returns `true` are  $0, 1, 2, \dots, n-1$ ; for other values, it returns `false` without setting its second and third parameters.

Another requirement is that as in Problem 5 of Homework 1, the number of statement executions when swapping two maps must be the same no matter how many key/value pairs are in the maps.

### Implement some map algorithms

Using only the *public* interface of Map, implement the following two functions. (Notice that they are *non-member* functions; they are *not* members of Map or any other class.)

```
bool combine(const Map& m1, const Map& m2, Map& result);
```

When this function returns, `result` must consist of pairs determined by these rules:

- If a key appears in exactly one of `m1` and `m2`, then `result` must contain a pair consisting of that key and its corresponding value.
- If a key appears in both `m1` and `m2`, with the same corresponding value in both, then `result` must contain a pair with that key and value.

When this function returns, `result` must contain no pairs other than those required by these rules. (You must *not* assume `result` is empty when it is passed in to this function; it might not be.)

If there exists a key that appears in both `m1` and `m2`, but with different corresponding values, then this function returns `false`; if there is no key like this, the function returns `true`. Even if the function returns `false`, `result` must be constituted as defined by the above rules.

For example, suppose a Map maps strings to doubles. If `m1` consists of the three pairs (in any order)

```
"Fred"  123    "Ethel"  456    "Lucy"  789
```

and `m2` consists of (in any order)

```
"Lucy"  789    "Ricky"  321
```

then no matter what value it had before, `result` must end up as a map consisting of (in any order)

```
"Fred"  123    "Ricky"  321    "Lucy"  789    "Ethel"  456
```

and `combine` must return `true`. If instead, `m1` were as before, and `m2` consisted of

```
"Lucy"  654    "Ricky"  321
```

then no matter what value it had before, `result` must end up as a map consisting of (in any order)

"Fred" 123      "Ricky" 321      "Ethel" 456

and `combine` must return `false`.

```
void subtract(const Map& m1, const Map& m2, Map& result);
```

When this function returns, `result` must contain a copy of all the pairs in `m1` whose keys don't appear in `m2`; it must not contain any other pairs. (You must *not* assume `result` is empty when it is passed in to this function; it may not be.)

For example, if `m1` consists of the three pairs (in any order)

"Fred" 123      "Ethel" 456      "Lucy" 789

and `m2` consists of (in any order)

"Lucy" 789      "Ricky" 321      "Ethel" 654

then no matter what value it had before, `result` must end up as a map consisting of

"Fred" 123

If English is not your native language, make extra sure you spell the name of this function correctly: it's `subtract`, not `substract`.

Be sure these functions behave correctly in the face of *aliasing*: What if `m1` and `result` refer to the same `Map`, for example?

### Other Requirements

Regardless of how much work you put into the assignment, your program will receive a zero for correctness if you violate these requirements:

- Your class definition, declarations for the two required non-member functions, and the implementations of any functions you choose to inline must be in a file named `Map.h`, which must have appropriate include guards. The implementations of the functions you declared in `Map.h` that you did not inline must be in a file named `Map.cpp`. Neither of those files may have a main routine (unless it's commented out). You may use a separate file for the main routine to test your `Map` class; you won't turn in that separate file.
- Except to add a destructor, copy constructor, assignment operator, and `dump` function (described below), you must not add functions to, delete functions from, or change the public interface of the `Map` class. You must not declare any additional struct/class outside the `Map` class, and you must not declare any *public* struct/class inside the `Map` class. You may add whatever private data members and private member functions you like, and you may declare *private* structs/classes inside the `Map` class if you like. The source files you submit for this project must not contain the word `friend` or the character `[` (open square bracket). You must not use any global variables whose values may be changed during execution.

If you wish, you may add a public member function with the signature `void dump() const`.

The intent of this function is that for your own testing purposes, you can call it to print

information about the map; we will never call it. You do not have to add this function if you don't want to, but if you do add it, it must not make any changes to the map; if we were to replace your implementation of this function with one that simply returned immediately, your code must still work correctly. The `dump` function must not write to `cout`, but it's allowed to write to `cerr`.

- `Map.cpp` must not contain the word `string` or `double`. (`Map.h` may contain them only in the typedef statements, and must contain `#include <string>` if a typedef statement contains the word `string`.)
- Your code must build successfully (under both Visual C++ and either `clang++` or `g++`) if linked with a file that contains a main routine.
- You must have an implementation for every member function of `Map`, as well as the non-member functions `combine` and `subtract`. Even if you can't get a function implemented correctly, it must have an implementation that at least builds successfully. For example, if you don't have time to correctly implement `Map::erase` or `subtract`, say, here are implementations that meet this requirement in that they at least build successfully:

```
bool Map::erase(const KeyType& value)
{
    return false; // not correct, but at least this compiles
}

void subtract(const Map& m1, const Map& m2, Map& result)
{
    // does nothing; not correct, but at least this compiles
}
```

You've probably met this requirement if the following file compiles and links with your code. (This uses magic beyond the scope of CS 32.)

```
#include "Map.h"
#include <type_traits>

#define CHECKTYPE(f, t) { auto p = (t)(f); (void)p; }

static_assert(std::is_default_constructible<Map>::value,
    "Map must be default-constructible.");
static_assert(std::is_copy_constructible<Map>::value,
    "Map must be copy-constructible.");

void ThisFunctionWillNeverBeCalled()
{
    CHECKTYPE(&Map::operator=,      Map& (Map::*)(const Map&));
    CHECKTYPE(&Map::empty,          bool (Map::*)() const);
    CHECKTYPE(&Map::size,           int (Map::*)() const);
    CHECKTYPE(&Map::insert,         bool (Map::*)(const KeyType&, const ValueType&
    CHECKTYPE(&Map::update,         bool (Map::*)(const KeyType&, const ValueType&
    CHECKTYPE(&Map::insertOrUpdate, bool (Map::*)(const KeyType&, const ValueType&
    CHECKTYPE(&Map::erase,          bool (Map::*)(const KeyType&));
```

```

CHECKTYPE(&Map::contains,      bool (Map::*)(const KeyType&) const);
CHECKTYPE(&Map::get,           bool (Map::*)(const KeyType&, ValueType&) const);
CHECKTYPE(&Map::get,           bool (Map::*)(int, KeyType&, ValueType&) const);
CHECKTYPE(&Map::swap,          void (Map::*)(Map&));

CHECKTYPE(combine, bool (*)(const Map&, const Map&, Map&));
CHECKTYPE(subtract, void (*)(const Map&, const Map&, Map&));
}

int main()
{}

```

- If you add `#include <string>` to `Map.h`, have `Map`'s typedefs define `KeyType` as `std::string` and `ValueType` as `double`, and link your code to a file containing

```

#include "Map.h"
#include <string>
#include <iostream>
#include <cassert>
using namespace std;

void test()
{
    Map m;
    assert(m.insert("Fred", 123));
    assert(m.insert("Ethel", 456));
    assert(m.size() == 2);
    double d = 42;
    assert(m.get("Fred", d) && d == 123);
    d = 42;
    string s1;
    assert(m.get(0, s1, d) &&
           ((s1 == "Fred" && d == 123) || (s1 == "Ethel" && d == 456)));
    string s2;
    assert(m.get(1, s2, d) && s1 != s2 &&
           ((s2 == "Fred" && d == 123) || (s2 == "Ethel" && d == 456)));
}

int main()
{
    test();
    cout << "Passed all tests" << endl;
}

```

the linking must succeed. When the resulting executable is run, it must write `Passed all tests` to `cout` and nothing else to `cout`.

- If we successfully do the above, then make no changes to `Map.h` other than to change the typedefs for `Map` so that `KeyType` specifies `int` and `ValueType` specifies `std::string`, recompile `Map.cpp`, and link it to a file containing

```

#include "Map.h"
#include <string>
#include <iostream>
#include <cassert>
using namespace std;

void test()
{
    Map m;
    assert(m.insert(123, "Fred"));
    assert(m.insert(456, "Ethel"));
    assert(m.size() == 2);
    string s;
    assert(m.get(123, s) && s == "Fred");
    s = "";
    int i1;
    assert(m.get(0, i1, s) &&
           ((i1 == 123 && s == "Fred") || (i1 == 456 && s == "Ethel")));
    int i2;
    assert(m.get(1, i2, s) && i1 != i2 &&
           ((i2 == 123 && s == "Fred") || (i2 == 456 && s == "Ethel")));
}

int main()
{
    test();
    cout << "Passed all tests" << endl;
}

```

the linking must succeed. When the resulting executable is run, it must write `Passed all tests` to `cout` and nothing else to `cout`.

- During execution, if a client performs actions whose behavior is defined by this spec, your program must not perform any undefined actions, such as dereferencing a null or uninitialized pointer.
- Your code in `Map.h` and `Map.cpp` must not read anything from `cin` and must not write anything whatsoever to `cout`. If you want to print things out for debugging purposes, write to `cerr` instead of `cout`. `cerr` is the standard error destination; items written to it by default go to the screen. When we test your program, we will cause everything written to `cerr` to be discarded instead — we will never see that output, so you may leave those debugging output statements in your program if you wish.

### Turn it in

By Monday, January 25, there will be a link on the class webpage that will enable you to turn in your source files and report. You will turn in a zip file containing these three files:

- `Map.h`. When you turn in this file, the typedefs must specify `std::string` as the `KeyType` and `double` as the `ValueType`.

- `Map.cpp`. Function implementations should be appropriately commented to guide a reader of the code.
- `report.doc` or `report.docx` (in Microsoft Word format) or `report.txt` (an ordinary text file) that contains:
  - a description of the design of your doubly-linked list implementation. (A couple of sentences will probably suffice, perhaps with a picture of a typical Map and an empty Map. Is the list circular? Does it have a dummy node? What's in your list nodes? Are they in any particular order?)
  - [pseudocode](#) for non-trivial algorithms (e.g., `Map::erase` and `subtract`).
  - a list of test cases that would thoroughly test the functions. Be sure to indicate the purpose of the tests. For example, here's the beginning of a presentation in the form of code:

The tests were performed on a map from strings to doubles

```
// default constructor
Map m;
// For an empty map:
assert(m.size() == 0);      // test size
assert(m.empty());         // test empty
assert(!m.erase("Ricky")); // nothing to erase
```

Even if you do not correctly implement all the functions, you must still list test cases that would test them. Don't lose points by thinking "Well, I didn't implement this function, so I won't bother saying how I would have tested it if I *had* implemented it."