Poll Everywhere

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Which concept did you find the most difficult in the context of Homework 2?

A. The data structures
B. C-string manipulations
C. POSIX I/O (files/directories)
D. Dynamic memory allocation
E. GDB/Valgrind
F. Style considerations
G. Prefer not to say

Systems Programming

C++ STL (end), Smart Pointers (start)

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Relevant Course Information

- Exercise 8 released today and is due Monday (11/9)
  - Practice using templates and `std::map`
- Homework 3 was released last Friday, due 11/19
  - Please watch the two starter videos before section tomorrow!
- Mid-quarter survey (Canvas) due Friday (11/6)
- We are currently grading a lot (*e.g.*, HW2, Midterm, Ex7); please have patience while we work through everything
  - For exercises, in particular, reference sample solutions in the meantime

Lecture Outline (1/2)

- **STL (finish)**
  - **List**
  - **Map**
- Smart Pointers Intro

STL `list`

- A generic doubly-linked list
  - https://cplusplus.com/reference/list/list/
  - Elements are ***not*** stored in contiguous memory locations
    - Does not support random access (*e.g.*, cannot do `list[5]`)
  - Some operations are much more efficient than vectors
    - Constant time insertion, deletion anywhere in list
    - Can iterate forward or backwards
  - Has a built-in sort member function
    - Doesn't copy! Manipulates list structure instead of element values

`list` Example

```
#include <algorithm>
#include <list>
#include "Tracer.h"
using std::…;

void PrintOut(const Tracer& p) {
  cout << " printout: " << p << endl;
}

int main(int argc, char* argv[]) {
  Tracer a, b, c;
  list<Tracer> lst;

  lst.push_back(c);
  lst.push_back(a);
  lst.push_back(b);
  cout << "sort:" << endl;
  lst.sort();
  cout << "done sort!" << endl;
  for_each(lst.begin(), lst.end(), &PrintOut);
  return EXIT_SUCCESS;
}
```

listexample.cc

STL `map`

- One of C++'s *associative* containers: a key/value table, implemented as a search tree
  - https://cplusplus.com/reference/map/map/
  - General form: `map<key_type, value_type> name;`
- Properties:
  - Keys must be *unique* (use `multimap` instead for duplicate keys)
  - Efficient lookup ($\mathcal{O}(\log n)$) and insertion ($\mathcal{O}(\log n)$)
    - Access `value` via `name[key]`
  - Elements are type `pair<key_type, value_type>` and are stored in *sorted* order (key is field `first`, value is field `second`)
    - Key type must support less-than operator (`<`)

map Example

```
void PrintOut(const pair<Tracer, Tracer>& p) {
  cout << "printout: [" << p.first << "," << p.second << "]" << endl;
}

int main(int argc, char* argv[]) {
  Tracer a, b, c, d, e, f;
  map<Tracer, Tracer> table;
  map<Tracer, Tracer>::iterator it;

  table.insert(pair<Tracer, Tracer>(a, b));
  table[c] = d;
  table[e] = f;
  cout << "table[e]:" << table[e] << endl;
  it = table.find(c);

  cout << "PrintOut(*it), where it = table.find(c)" << endl;
  PrintOut(*it);

  cout << "iterating:" << endl;
  for_each(table.begin(), table.end(), &PrintOut);

  return EXIT_SUCCESS;
}
```

mapexample.cc

Basic `map` Usage

- `animals.cc`

Homegrown `pair<>`

Usage we've seen:

```
pair<std::string, std::string> p;
p.first
p.second
```

Unordered Containers (C++11)

- `unordered_map`, `unordered_set`
  - And related classes `unordered_multimap`, `unordered_multiset`
  - Average case for key access is $\mathcal{O}(1)$
    - But range iterators can be less efficient than ordered `map`/`set`
  - See *C++ Primer*, online references for details

Lecture Outline (2/2)

- STL (finish)
  - List
  - Map
- **Smart Pointers Intro**

Motivation

- We noticed that STL was doing an enormous amount of copying
- A solution: store pointers in containers instead of objects
  - But who's responsible for deleting and when???

C++ Smart Pointers

- A smart pointer is an *object* that stores a pointer to a heap-allocated object
  - A smart pointer looks and behaves like a regular C++ pointer
    - By overloading `*`, `->`, `[]`, etc.
  - These can help you manage memory
    - The smart pointer will delete the pointed-to object *at the right time* including invoking the object's destructor
      - When that is depends on what kind of smart pointer you use
    - With correct use of smart pointers, you no longer have to remember when to `delete` `new`'d memory!

A Toy Smart Pointer

- We can implement a simple one with:
  - A constructor that accepts a pointer
  - A destructor that deletes the pointer
  - Overloaded `*` and `->` operators that access the pointer

ToyPtr Class Template

ToyPtr.h

```
#ifndef TOYPTR_H_
#define TOYPTR_H_

template <typename T> class ToyPtr {
 public:
  ToyPtr(T* ptr) : ptr_(ptr) { }    // constructor
  ~ToyPtr() { delete ptr_; }        // destructor

  T& operator*() { return *ptr_; }  // * operator
  T* operator->() { return ptr_; }  // -> operator

 private:
  T* ptr_;                          // the pointer itself
};

#endif  // TOYPTR_H_
```

ToyPtr Example

```
#include <iostream>
#include "ToyPtr.h"

// simply struct to use
typedef struct { int x = 1, y = 2; } Point;
std::ostream& operator<<(std::ostream& out, const Point& rhs) {
  return out << "(" << rhs.x << "," << rhs.y << ")";
}

int main(int argc, char* argv[]) {
  // Create a raw ("not smart") pointer
  Point* leak = new Point;

  // Create a "smart" pointer (OK, it's still pretty dumb)
  ToyPtr<Point> notleak(new Point);

  std::cout << "     *leak: " << *leak << std::endl;
  std::cout << "   leak->x: " << leak->x << std::endl;
  std::cout << "  *notleak: " << *notleak << std::endl;
  std::cout << "notleak->x: " << notleak->x << std::endl;

  return EXIT_SUCCESS;
}
```

usetoy.cc

What Makes This a Toy?

- Can't handle:
  - Arrays
  - Copying (broke the Rule of Three!)
  - Reassignment (broke the Rule of Three!)
  - Comparison
  - … plus many other subtleties…

- Luckily, others have built non-toy smart pointers for us!
  - More next lecture!

Extra Exercise #1

- Take one of the books from HW2's `test_tree` and:
  - Read in the book, split it into words (you can use your hw2)
  - For each word, insert the word into an STL `map`
    - The key is the word, the value is an integer
    - The value should keep track of how many times you've seen the word, so each time you encounter the word, increment its map element
    - Thus, build a histogram of word count
  - Print out the histogram in order, sorted by word count
  - Bonus: Plot the histogram on a log-log scale (use Excel, gnuplot, etc.)
    - x-axis: log(word number), y-axis: log(word count)

Extra Exercise #2

- Implement `Triple`, a class template that contains three "things," *i.e.*, it should behave like `std::pair` but hold 3 objects instead of 2
  - The "things" can be of different types

- Write a program that:
  - Instantiates several `Triple`s that contain `ToyPtr<int>`s
  - Insert the `Triple`s into a `vector`
  - Reverse the `vector`
  - Doesn't have any memory errors (use Valgrind!)
  - Note: You will need to update `ToyPtr.h` – how?