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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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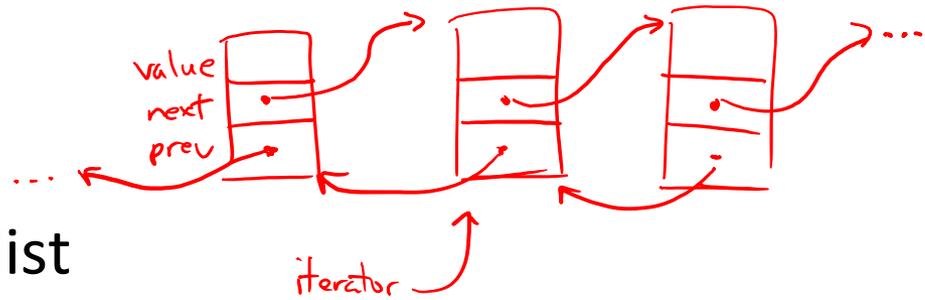
Relevant Course Information

- ❖ Exercise 12 is due Friday (2/13)
 - Practice using `std::map`
- ❖ Homework 3 was released on Monday, due 2/26
 - Please watch the two starter videos before section tomorrow!
- ❖ Mid-quarter survey (Canvas) due Friday (2/13)

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
 - ↑ copies pointers instead of list elements

List Example

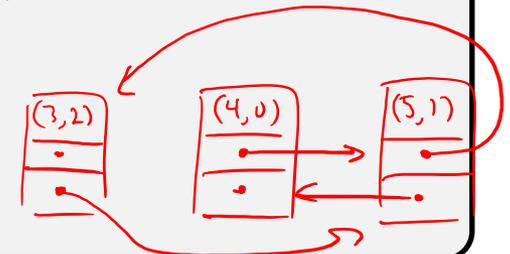
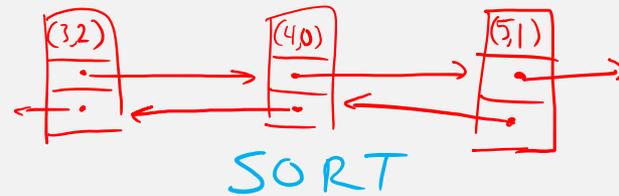
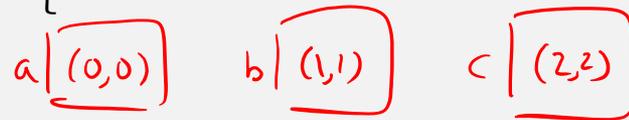
listexample.cc

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

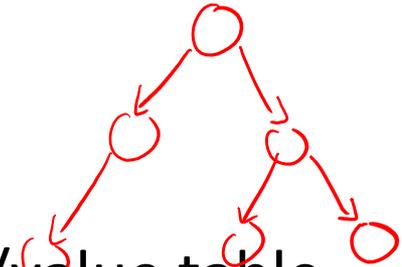
void PrintOut(const Tracer& p) {
    cout << " printout: " << p << endl;
}

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;
}
```



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;`
 - Keys must be *unique*
 - `multimap` allows 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

```
#include <map>
```

mapexample.cc

```
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; } equivalent behavior
```

```
    table[e] = f;
```

```
    cout << "table[e]:" << table[e] << endl;
```

```
    it = table.find(c); // returns iterator (end if not found)
```

```
    // should check if found here before accessing element  
    cout << "PrintOut(*it), where it = table.find(c)" << endl;
```

```
    PrintOut(*it);
```

```
    cout << "iterating:" << endl;
```

```
    for_each(table.begin(), table.end(), &PrintOut);
```

```
    return EXIT_SUCCESS;
```

```
}
```

type of element
in map <Tracer, Tracer>

Basic map Usage

❖ `animals.cc`

Basic map Usage

❖ `animals.cc`



- https://www.youtube.com/watch?v=jofNR_WkoCE

Homegrown pair<>

Usage we've seen: `pair<std::string, std::string> p;`
 `p.first`
 `p.second`

```
template <typename T1, typename T2> struct Pair {  
    // methods here - ctor, ctor, op =, dtor as needed  
  
    T1 first;  
    T2 second;  
};
```

Note: just a bag of data, so struct works instead of class
↳ automatically makes first { second public

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 // clean up

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

private:
    T* ptr_; // points to something in heap // the pointer itself
};

#endif // TOYPTR_H_

```

only 1 argument (this) to differentiate from multiplication
 $p \rightarrow x \iff (*p).x$

ToyPtr Example

usetoy.cc

```

#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;
}

```

Diagram illustrating memory management for Point objects:

- Object (1) is pointed to by a variable `leak` (marked with a red 'X' and "leak").
- Object (2) is pointed to by a variable `ptr_` (marked with a blue 'X' and "notleak").
- A blue arrow labeled "dtor" points from `ptr_` to object (2).
- A yellow arrow labeled "delete" points from object (2) to the right.
- Red circles with numbers 1 and 2 are placed below the `new Point` expressions in the code.

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: $\log(\text{word number})$, y-axis: $\log(\text{word count})$

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