C++ STL, Smart Pointers Intro

CSE 333 Spring 2019

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Administrivia

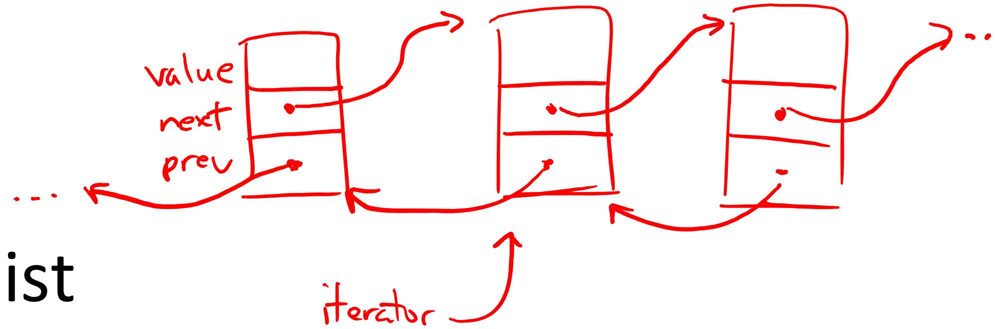
- Exercise 12 released today, due Monday

- Midterm is next Friday (5/10) @ 5-6:10 pm in KNE 130
  - 1 double-sided page of handwritten notes; reference sheet provided on exam
  - **Topics:** everything from lecture, exercises, project, etc. up through C++ classes and new/delete
  - Old exams on course website, review in section next week

Lecture Outline

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

STL `list`



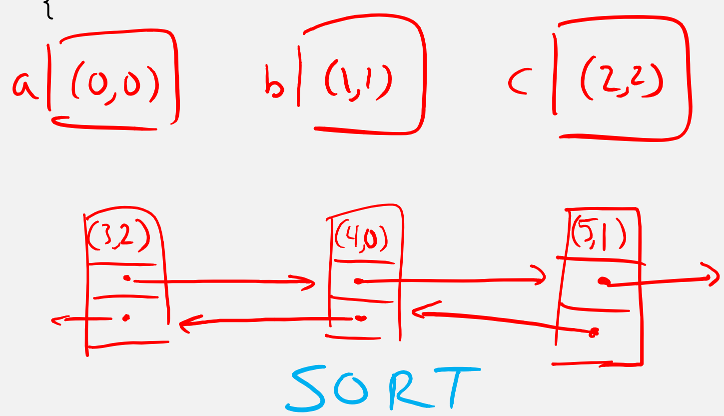
- A generic doubly-linked list
  - http://www.cplusplus.com/reference/stl/list/
  - Elements are ***not*** stored in contiguous memory locations
    - Does not support random access (*e.g.* cannot do `list[5]`)
  - Some operations are much more efficient than vectors
    - Constant time insertion, deletion 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

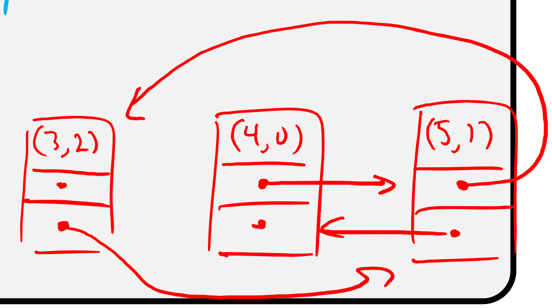
      ↑ copies pointers instead of list elements

list Example

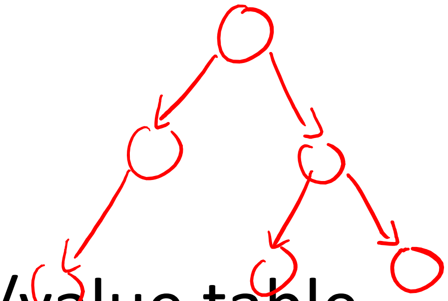
listexample.cc

```
#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
  - http://www.cplusplus.com/reference/stl/map/
  - General form: `map<key_type, value_type> name;`

    independent types
  - 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>

type of element in map <Tracer, Tracer>

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));   } equivalent behavior
  table[c] = d;                                }
  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;
}
```

Basic `map` Usage

- `animals.cc`

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, cctor, 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

- 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 frees the pointer
  - Overloaded * and -> operators that access the pointer

ToyPtr Class Template

ToyPtr.cc

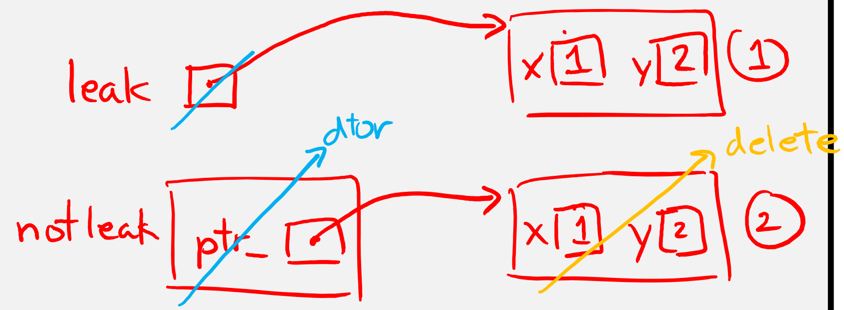
```
#ifndef _TOYPTR_H_
#define _TOYPTR_H_

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_
```

- // clean up (beside the destructor)
- only 1 argument (this) to differentiate from multiplication (pointing to the `()` of `operator*`)
- // points to something in Heap (beside `T *ptr_;`)
- p->x ⟺ (*p).x (linked to `operator->`)

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 dumb 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;
}
```



What Makes This a Toy?

- Can’t handle:
  - Arrays
  - Copying
  - Reassignment
  - 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?