Ve 280

Programming and Introductory Data Structures

Improve ADT Efficiency;

Midterm Review

Abstract Data Types

Improving Efficiency

```
void IntSet::insert(int v) {
  if (indexOf(v) == MAXELTS) { // duplicate not found
    if (numElts == MAXELTS) throw MAXELTS; // no room
    int cand = numElts-1; // largest (last) element
    while ((cand >= 0) && elts[cand] > v) {
      elts[cand+1] = elts[cand];
      cand--;
    }
    // Now, cand points to the left of the "gap".
    elts[cand+1] = v;
    numElts++; // repair invariant
  }
}
```

<u>Question</u>: What is the situation when the loop terminates due to `cand < 0`? Is our implementation correct?

Abstract Data Types

Improving Efficiency

- **Question**: Do we have to change `indexOf`?

```
int IntSet::indexOf(int v) {
  for (int i = 0; i < numElts; i++) {
    if (elts[i] == v) return i;
  }
  return MAXELTS;
}
```

Abstract Data Types

Improving Efficiency

- **Question**: Do we have to change `indexOf`?
- **Answer**: No, but it can be made more efficient with the new representation.
- **How?**

Using **binary search**! (The array is sorted)

```
int IntSet::indexOf(int v) {
  for (int i = 0; i < numElts; i++) {
    if (elts[i] == v) return i;
  }
  return MAXELTS;
}
```

Abstract Data Types

Complexity

	Unsorted	Sorted
query	O(N)	?
insert	?	?
remove	?	?

Abstract Data Types

Complexity

	Unsorted	Sorted
`query`	`O(N)`	`O(log N)`
`insert`	`O(N)`	`O(N)`
`remove`	`O(N)`	`O(N)`

`insert` and `remove` are still **linear**, because they may have to "swap" an element to the beginning/end of the array.

Abstract Data Types

Complexity

	Unsorted	Sorted
`query`	`O(N)`	`O(log N)`
`insert`	`O(N)`	`O(N)`
`remove`	`O(N)`	`O(N)`

- If you are going to do more searching than inserting/removing, you should use the "sorted array" version, because `query` is faster there.
- However, if `query` is relatively rare, you may as well use the "unsorted" version. It's "about the same as" the sorted version for `insert` and `remove`, but it's MUCH simpler!

Midterm Review

Midterm

- 10:00 am – 11:40 am, June 27th, 2017
- Find your seat on Canvas
- Closed book and closed notes
- No electronic devices are allowed
  - These include laptops and cell phones
  - We will show a clock on the screen

Midterm

- Written exam
  - A number of questions which only require you to provide a very short answer
  - A few questions which require you to write code on the paper. Be clear!

- Abide by the **Honor Code**!

Midterm Topics

- Linux Commands
- Compiling and Developing Program on Linux
- C++ Basics: Pointers, References, const Qualifier
- Procedural Abstraction and Specification Comments
- Recursion
- Function Pointers
- enum Type
- Program Taking Arguments
- I/O Streams
- Testing/Debugging
- Exception
- Class Basics

Lecture 1 to this lecture

Linux Commands

- cd; ls; mkdir; rmdir;
- cp; mv; rm;
- nano; gedit;
- less;
- diff; man; …
- I/O redirection
  - <, >
- Command options
  - ls -l; cp -r dir1 dir2; …
- Wildcard: *
  - cp *.h dir/

Compiling Program on Linux

- Write the source code, for example, using **gedit**
- Compile the program: g++ -o program source.cpp
- Run the program: ./program
- Compile multiple source files:
  - g++ -o program src1.cpp src2.cpp src3.cpp
  - E.g., g++ -o run_add run_add.cpp add.cpp
- Header guard: avoiding multiple inclusions

```
// add.h
#ifndef ADD_H
#define ADD_H
int add(int a, int b);
#endif
```

- What happens if the .h file is included **first** time?
- What happens if the .h file is included **second** time?

A Better Way of Compiling: Makefile

```
all: run_add

run_add: run_add.o add.o
	g++ -o run_add run_add.o add.o

run_add.o: run_add.cpp
	g++ -c run_add.cpp

add.o: add.cpp
	g++ -c add.cpp

clean:
	rm -f run_add *.o
```

- The file name is "Makefile"
- Type "make" on command-line

A Rule

Target: Dependency
<Tab> Command

Don't forget the Tab!

Dependency: A list of files that the target depends on

Function Call Mechanisms

There are two function call mechanisms:

1. Call-by-value
2. Call-by-reference

What will a be?

```
void f(int x)
{
   x *= 2;
}
```

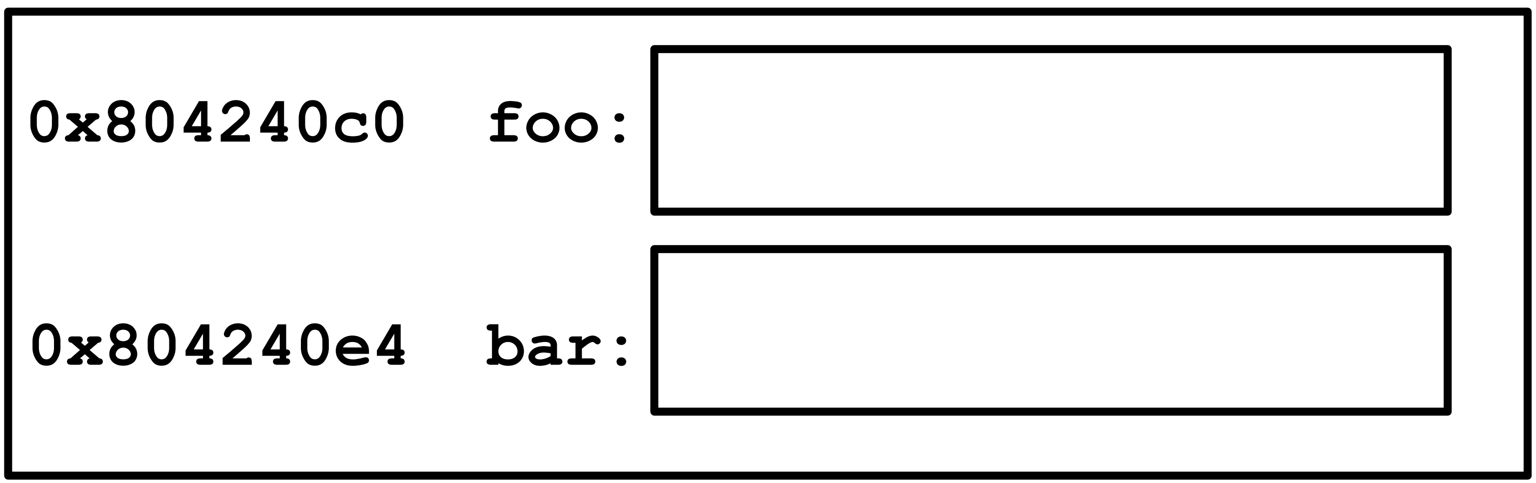
```
int main()
{
   …
   int a=4;
   f(a);
   …
}
```

```
void f(int& x)
{
   x *= 2;
}
```

```
int main()
{
   …
   int a=4;
   f(a);
   …
}
```

Pointers

```
int foo = 1;
int *bar;
bar = &foo;   // addressing operation
*bar = 2;   // dereference operation
```



References

- An alternative name for an object

```
int iVal = 1024;
int &refVal = iVal;
```

- Reference **must be initialized** using a **variable** of the same type.

References Versus Pointers

Example

```
int x = 0;
int &r = x;
int y = 1;
r = y;
r = 2;
```

```
int x = 0;
int *p = &x;
int y = 1;
p = &y;
*p = 2;
```

What's the final values of `x`, `y`, and `r`?

x = 2, y = 1, r = 2

What's the final values of `x`, `y`, and `*p`?

x = 0, y = 2, *p = 2

const Qualifier

- Once you defined a constant variable, it cannot be modified later on.
  - ```
    const int a = 10;
    a = 11; // Error
    ```

- Because we cannot subsequently change the value of an object declared to be const, we must initialize it when it is defined:
  - ```
    const int i;
    // Error: i is an uninitialized const
    ```

const Reference

```
int avg_exam(const struct Grades & gr){
    return (gr.midterm+gr.final)/2;
}
```

- It gives us the best of both worlds:
  - We don't have the expense of a copy.
  - We have the safety guarantee that the function cannot change the caller's state. Compiler will catch the error of accident change!

const Pointers

- When you have pointers, there are two things you might change:
    1. The value of the pointer.
    2. The value of the object to which the pointer points.

- Either (or both) can be made unchangeable:

```
const T *p;   // "T" (the pointed-to object)
pointer to const  // cannot be changed by pointer p
T *const p;   // "p" (the pointer) cannot be
const pointer     // changed
const T *const p; // neither can be changed.
```

Pointers to const

Example

```
int a = 53;
const int *cptr = &a;
  // OK: A pointer to a const object
  // can be assigned the address of a
  // nonconst object
*cptr = 42;
  // ERROR: We cannot use a pointer to
  // const to change the underlying
  // object.
a = 28 // OK
int b = 39;
cptr = &b; // OK: the value in the pointer
           // can be changed.
```

const Pointers

Example

```
int a = 53;
int *const cptr = &a;
  // OK: initialization
*cptr = 42;
  // OK: We can use a const pointer to
  // change the underlying object.
int b = 39;
cptr = &b;
  // ERROR: We cannot change the value of
  // a const pointer.
```

Pointer to const versus Normal Pointer

- Pointers-to-const-T are not the same type as pointers-to-T.
- You can use a pointer-to-T anywhere you expect a pointer-to-const-T, but NOT vice versa.

```
int const_ptr(const int *ptr)
{
    …
}

int main()
{
    int a = 0;
    int *b = &a;
    const_ptr(b);
}
```

✓

```
int nonconst_ptr(int *ptr)
{
    …
}

int main()
{
    int a = 0;
    const int *b = &a;
    nonconst_ptr(b);
}
```

✗

Abstraction

- Abstraction
  - Provides only those details that matter.
  - Eliminates unnecessary details and reduces complexity.

- Example: Multiplication algorithm
  - Many ways to do: table lookup, summing, etc.
  - Each looks quite different, but they do the **same** thing.
  - In general, a user won't care how it's done, just that it multiplies.

Procedural Abstraction

- Two important properties of procedural abstraction
  - Local: the implementation of an abstraction does not depend on any other abstraction implementation.
  - Substitutable: you can replace one (correct) implementation of an abstraction with another (correct) one, and no callers of that abstraction will need to be modified.

Procedural Abstraction

Specification Comments

- We describe procedural abstraction by specification comments.

- There are three clauses of specification comments:
  - **REQUIRES**: the pre-conditions that must hold, if any.
  - **MODIFIES**: how inputs are modified, if any.
  - **EFFECTS**: what the procedure computes given legal inputs.

- Note that the first two clauses have an "if any", which means they may be empty, in which case you may omit them.

Call Stacks

How a function call really works

- When a function is called, an activation record (also known as stack frame) is created. It holds the function's formal parameters and local variables.
- The **activation record** for **the current** invocation is added to the "top" of the stack.
- When that function returns, its **activation record** is removed from the "top" of the stack.

double add(double a, double b): a = 1, b = 0, result = 0
double sin(double x): x = 1, result = 0
int main(): x = 1, sinResult = 0

Recursion

$$n! = \begin{cases} 1 & (n == 0) \\ n * (n-1)! & (n > 0) \end{cases}$$

```
int factorial (int n)
   // REQUIRES: n >= 0
   // EFFECTS:  computes n!
{
  if (n == 0) {
     return 1;  // 'base case'
  } else {
    return n*factorial(n-1); // 'recursive step'
  }
}
```

Recursion

Writing a function for the general case

- Treat it like an inductive proof.

- To <u>write</u> a correct recursive function, do two things:
  1. Identify the "trivial" case (or cases), and write them explicitly.
  2. For all other cases, first assume there is a function that can solve smaller versions of the same problem, then figure out how to get from the smaller solution to the bigger one.

Recursive Helper Function

- Sometimes it is easier to find a recursive solution to a problem if you change the original problem slightly, and then solve that problem using a **recursive helper function**.

```
soln()
{
   …
   soln_helper();
   …
}
```

```
soln_helper()
{
   …
   soln_helper();
   …
}
```

Function Pointers

Motivation

- If you were asked to write a function to add all the elements in a list, and another to multiply all the elements in a list, your functions would be almost exactly **the same**.

- Writing almost the exact same function twice is almost certainly a bad idea

Function pointers to the rescue!

Function Pointers

A first look

```
int min(int a, int b);
  // EFFECTS: returns the smaller of a and b.
int max(int a, int b);
  // EFFECTS: returns the larger of a and b.
```

- These two functions have precisely the same type signature:
  - They both take two integers, and return an integer.
- Of course, they do completely different things:
  - One returns a min and one returns a max.
  - **However, from a syntactic point of view, you call either of them the same way.**

Function Pointers

Basic Format

- Declaration

```
int  (*foo)(int, int);
```

- Once defined, we can assign it to a function that has **the same type signature**

```
int min(int a, int b);
foo = min;
```

- Furthermore, after assigning min to foo, we can just call it as follows:

```
foo(3, 5)
```

…and we'll get back 3!

Enum Type

- Define an enumeration type as follows:

```
enum Suit_t {CLUBS, DIAMONDS,
             HEARTS, SPADES};
```

- Define variables of this enum type:

```
enum Suit_t suit;
```

- You can initialize them as:

```
enum Suit_t suit = DIAMONDS;
```

- Once you have such an enum type defined, you can use it as an argument for a function.

Enum Type

- If you write

```
enum Suit_t {CLUBS, DIAMONDS,
             HEARTS, SPADES};
```

then numerically

```
CLUBS = 0, DIAMONDS = 1,
HEARTS = 2, SPADES = 3
```

- Using this fact, it will sometimes make life easier

```
enum Suit_t s = CLUBS;
const string suitname[] = {"clubs",
    "diamonds", "hearts", "spades"};
cout << "suit s is " << suitname[s];
```

Passing Arguments to a Program

- Programs can take arguments.

  `diff file1 file2`

- Arguments are passed to the program through main() function.
- We need to change the argument list of main():
  - `int main(int argc, char *argv[])`
- `argv` stores the array of C-strings that user inputs.
  - `argv[0]` is the name of the program being executed.
- `argc` is the number of strings in the array

I/O Streams

- Output Stream `cout`
  - Insertion operator <<
- Input Stream `cin`
  - extraction operator >>
  - `getline(cin, str)`
  - `cin.get(ch)`
  - Failed input stream: check stream state `if(cin)`
- `cout` and `cin` streams are buffered.

I/O Streams

- File Stream
  - `ifstream; ofstream`
  - Opening a file: `iFile.open("myText.txt");`
  - extraction >> ; insertion <<

- String Stream
  - `istringstream; ostringstream`
  - extraction >> ; insertion <<
  - Assign a string to an input string stream
    `iStream.str(line);`
  - fetch the string value from an output string stream
    `oStream.str();`

Testing

- Be skeptical!
- Incremental testing
- Five Steps:

1. Understand the specification
2. Identify the required behaviors
3. Write specific tests
    - **Simple inputs**
    - **Boundary conditions**
    - **Nonsense**
4. Know the answers in advance
5. Include stress tests

Debugging Using Assert

- Using the `assert` function
  - The `assert` function is a special function, which takes a Boolean argument.
  - If the argument is **true**, `assert()` does nothing.
  - If the argument is **false**, `assert()` causes your program to stop, printing an **error message** to the `cerr` stream.
- `assert` for the condition that should hold.

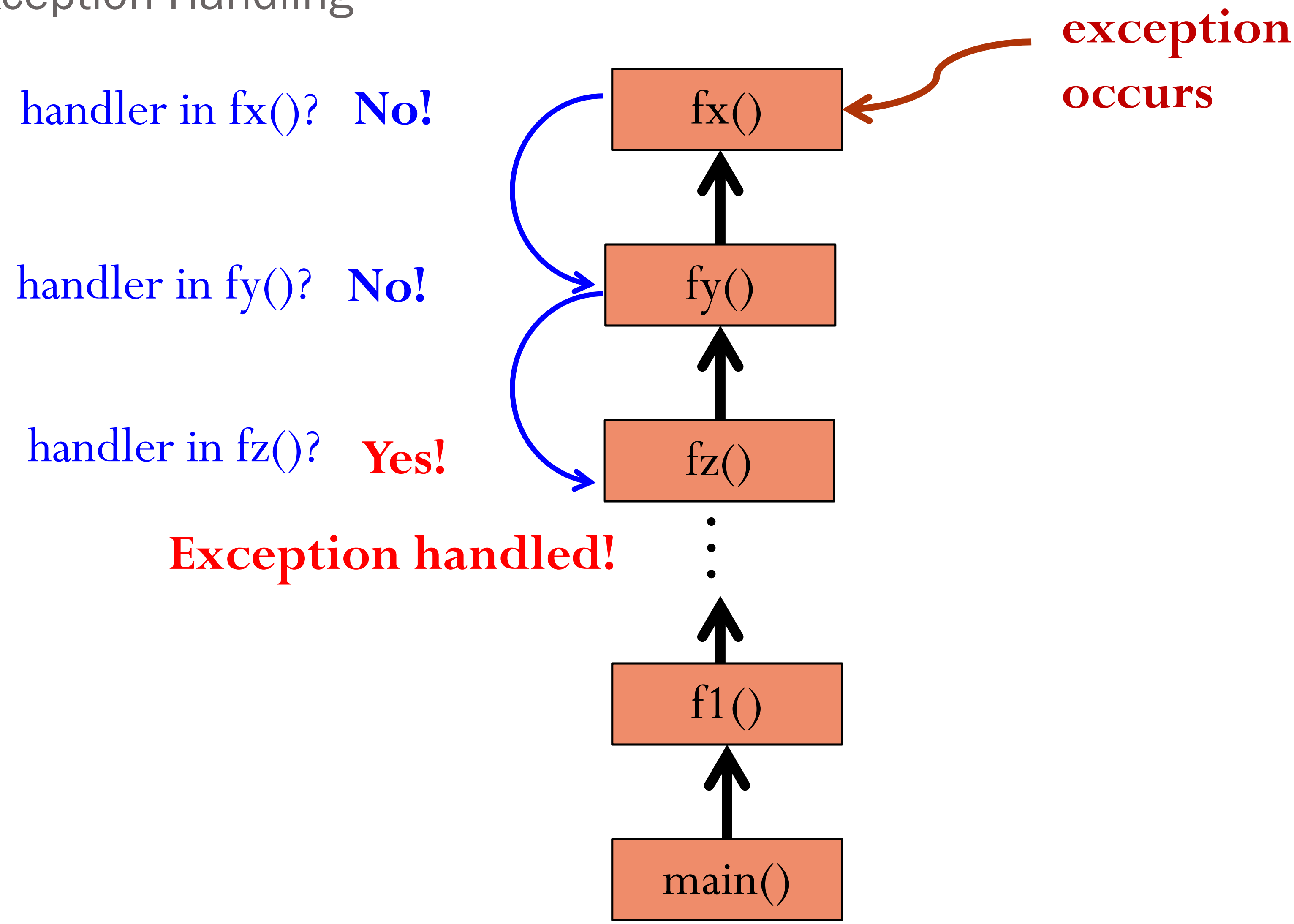
Exceptions

- Exceptions and exception handling mechanism

- **Exception propagation** mechanism: where to find the handler

Exceptions

Exception Handling



Exceptions

- Throwing an exception
- Catching an exception
- Exceptions have **types** and **objects**.
  - `throw errorObj;`
- Exceptions Handling in C++

```
void foo() {
    try {              }
    catch (Type var) {              }
}
```

Abstract Data Types

- The role of a type:
  - The set of values that can be represented by items of the type
  - The set of operations that can be performed on items of the type.
- An abstract data type provides an **abstract description** of **values** and **operations**.
- Advantages: Information hiding and encapsulation.

C++ Classes

- Data members and function members are defined in a single entity.
- **Public** versus **private** members.
- Defining a class type.
- Class object as a function argument: pass by value

C++ Classes

- **Constructor** for intilization: `IntSet();`
- Initialization syntax:
```
IntSet::IntSet(): numElts(0)
{}
```

- const member function: **`int size() const;`**
  - Means: the member function **`size()`** cannot change the object on which **`size()`** is called.
  - Syntax: if a const member function calls other **member** functions, they must be **const** too!

```
void A::g() const { f(); }
```

```
void A::f() {...}
```
✘
```
void A::f() const {...}
```
✓