ADTs, Generic Types, and the Java Collections Framework

Lecture 19
CS211 – Fall 2006

Announcements

- Prelim 2
  - In 2 weeks
  - Tuesday, Nov 14
  - 7:30-9:00PM
  - If you have a conflict
    - Contact Kelly Patwell (Course Administrator) soon!

PQ Application: Simulation

- Example: Given a probabilistic model of bank-customer arrival times and transaction times, how many tellers are needed
  - Assume we have a way to generate random inter-arrival times
  - Assume we have a way to generate transaction times
  - Can simulate the bank to get some idea of how long customers must wait

Time-Driven Simulation

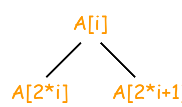
- Check at each *tick* to see if any event occurs

Event-Driven Simulation

- Advance clock to next event, skipping intervening *ticks*
- This uses a PQ!

Heap Implementation (the Big Trick)

- Can avoid using pointers!



- Use a *complete* binary tree stored in an array
  - Definition: *Complete* means that each level of the tree is filled except possibly the last, which is filled from left to right
- For A[i]
  - left child = 2 * i
  - right child = 2 * i + 1
  - parent = $\lfloor i / 2 \rfloor$

To Build a Heap

- How long to construct a heap, given the items?
- Worst-case time for insert() is O(log n)
- Total time to build heap using insert() is
  O(log 1) + O(log 2) + ... + O(log n)
  or O(n log n)

Can we do better?

- We had two heap-fixing methods
  - bubbleUp: move up the tree as long as we're > our parent
  - bubbleDown: move down the tree as long as we're < one of our children
- If we build the heap from the bottom-up using bubbleDown then we can build it in time O(n) (Wow!)

Efficient Heap Building

- Build from the bottom-up
- If there are n items in the heap then...
  - There are about n/2 mini-heaps of height 1
  - There are about n/4 mini-heaps of height 2
  - There are about n/8 mini-heaps of height 3 and so on
- The time to fix up a mini-heap is O(its height)
- Total time spent fixing heaps is thus bounded by
  n/2 + 2n/4 + 3n/8 + ...
- This can be rewritten as
  $n(1/2 + 2/4 + \ldots + i/2^i + \ldots)$
  $= n(2)$
- Thus total heap-building time (using the bottom-up method) is O(n)

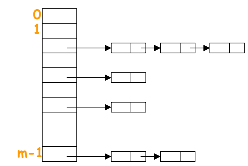
HeapSort

- Given a Comparable[ ] array of length n,
  - Put all n elements into a heap: O(n) or O(n log n)
  - Repeatedly get the min: O(n log n)

```
public static void heapSort(Comparable[] a) {
  PriorityQueue<Comparable> pq = new PriorityQueue<Comparable>();
  for (Comparable x : a) { pq.put(x); }
  for (int i = 0; i < a.length; i++) { a[i] = pq.get(); }
}
```

Another PQ Implementation

- If there are only a few possible priorities then can use an array of queues
  - Each array position represents a priority (0..m-1 where m is the array size)
  - Each queue holds all items that have that priority
- One text [Skiena] calls this a *bounded height priority queue*
- Time for insert: O(1)
- Time for getMax:
  - O(m) in the worst-case
- Example: airline check-in



Other PQ Operations

<u>delete</u>
a particular item

<u>update</u>
an item (change its priority)

<u>join</u>
two priority queues

- For delete and update, we need to be able to find the item
  - One way to do this: Use a Dictionary to keep track of the item's position in the heap
- Efficient joining of 2 Priority Queues requires another data structure
  - Skew Heaps or Pairing Heaps
    - Chapter 23 in text
    - Not part of 211

Selecting a Priority Queue Scheme

- Use an unordered array for small sets (< 20 or so)
- Use a sorted array or sorted linked list if few insertions are expected
- Use an array of linked lists if there are few priorities
  - Each linked list is a queue of equal-priority items
  - Very easy to implement
- Otherwise, use a Heap if you can
- Heap + Hashtable
  - Allow *change-priority* operation to be done in O(log n) expected time
- Balanced tree schemes
  - Useful and practical
- There are a number of alternate implementations that allow additional operations
  - Skew heaps
  - Pairing heaps
  - Fibonacci heaps
  - …

Generic Types in Java 5.0

- When using a collection (e.g., LinkedList, HashSet, HashMap), we generally have a single type T of elements that we store in it (e.g., Integer, String)
- Before 1.5, when extracting an element, had to cast it to T before we could invoke T's methods
- Compiler could not check that the cast was correct at compile-time, since it didn't know what T was
- Inconvenient and unsafe, could fail at runtime
- Generics in Java 1.5 provide a way to communicate T, the type of elements in a collection, to the compiler
  - Compiler can check that you have used the collection consistently
  - Result is safer and more-efficient code

Example

old

```
//removes 4-letter words from c
//elements must be Strings
static void purge(Collection c) {
  Iterator i = c.iterator();
  while (i.hasNext()) {
    if (((String)i.next()).length() == 4)
      i.remove();
}}
```

new

```
//removes 4-letter words from c
static void purge(Collection<String> c) {
  Iterator<String> i = c.iterator();
  while (i.hasNext()) {
    if (i.next().length() == 4)
      i.remove();
}}
```

Another Example

old

```
HashMap grades = new HashMap();
grades.put("John",new Integer(67));
grades.put("Jane",new Integer(88));
grades.put("Fred",new Integer(72));
Integer x = (Integer)grades.get("John");
sum = sum + x.intValue();
```

new

```
HashMap<String,Integer> grades = new HashMap<String,Integer>();
grades.put("John",new Integer(67));
grades.put("Jane",new Integer(88));
grades.put("Fred",new Integer(72));
Integer x = grades.get("John");
sum = sum + x.intValue();
```

Type Casting

- In effect, Java inserts the correct cast automatically, based on the declared type
- In this example, grades.get("John") is automatically cast to Integer

```
HashMap<String,Integer> grades = new HashMap<String,Integer>();
grades.put("John",new Integer(67));
grades.put("Jane",new Integer(88));
grades.put("Fred",new Integer(72));
Integer x = grades.get("John");
sum = sum + x.intValue();
```

An Aside: Autoboxing

- Java 5.0 also has autoboxing and auto-unboxing of primitive types, so the example can be further simplified

```
HashMap<String,Integer> grades = new HashMap<String,Integer>();
grades.put("John",new Integer(67));
grades.put("Jane",new Integer(88));
grades.put("Fred",new Integer(72));
Integer x = grades.get("John");
System.out.println(x.intValue());
```

```
HashMap<String,Integer> grades = new HashMap<String,Integer>();
grades.put("John", 67);
grades.put("Jane", 88);
grades.put("Fred", 72);
sum = sum + grades.get("John");
```

Using Generic Types

- <T> is read, "of T"
  - For example: Stack<Integer> is read, "Stack of Integer"
- The type annotation <T> informs the compiler that all extractions from this collection should be automatically cast to T
- Specify type in declaration, can be checked at compile time
  - Can eliminate explicit casts

Advantage of Generics

- Declaring Collection<String> c tells us something about the variable c (i.e., c holds only Strings)
  - This is true wherever c is used
  - The compiler checks this and won't compile code that violates this
- Without use of generic types, explicit casting must be used
  - A cast tells us something the programmer thinks is true at a single point in the code
  - The Java virtual machine checks whether the programmer is right only at runtime

Subtypes

Stack<Integer> is *not* a subtype of Stack<Object>

```
Stack<Integer> s = new Stack<Integer>();
s.push(new Integer(7));
Stack<Object> t = s; // Gives compiler error
t.push("bad idea");
System.out.println(s.pop().intValue());
```

However, Stack<Integer> *is* a subtype of Stack (for backward compatibility with previous Java versions)

```
Stack<Integer> s = new Stack<Integer>();
s.push(new Integer(7));
Stack t = s;              // Compiler allows this
t.push("bad idea");       // Produces a warning
System.out.println(s.pop().intValue());     // Runtime error
```

Programming Generic Types

```
public interface List<E> { // E is a type variable
   void add(E x);
   Iterator<E> iterator();
}

public interface Iterator<E> {
   E next();
   boolean hasNext();
}
```

- To use the interface List<E>, supply an actual type argument, e.g., List<Integer>
- All occurrences of the formal type parameter (E in this case) are replaced by the actual type argument (Integer in this case)

Wildcards

old

```
void printCollection(Collection c) {
  Iterator i = c.iterator();
  while (i.hasNext()) {
    System.out.println(i.next());
}}
```

bad

```
void printCollection(Collection<Object> c) {
  for (Object e : c) {
    System.out.println(e);
}}
```

good

```
void printCollection(Collection<?> c) {
  for (Object e : c) {
    System.out.println(e);
}}
```

Bounded Wildcards

```
static void sort (List<? extends Comparable> c) {
  ...
}
```

- Note that if we declared the parameter c to be of type List<Comparable> then we could not sort an object of type List<String> (even though String is a subtype of Comparable)
  - Suppose Java treated List<String> as a subtype of List<Comparable>
  - Then, for instance, a method passed an object of type List<Comparable> would be able to store Integers in our List<String>
- Wildcards let us specify exactly what types are allowed

Generic Methods

- Adding all elements of an array to a Collection

bad

```
static void a2c(Object[] a, Collection<?> c) {
  for (Object o : a) {
    c.add(o); //compile time error
}}
```

good

```
static <T> void a2c(T[] a, Collection<T> c) {
  for (T o : a) {
    c.add(o); //ok
}}
```

- See the online Java Tutorial for more information on generic types and generic methods
- The text also has a section (4.7) on this topic

Java Collections Framework

- Collections: holders that let you store and organize objects in useful ways for efficient access
- Since Java 1.2, the package java.util includes interfaces and classes for a general collection framework
- Goal: conciseness
  - A few concepts that are broadly useful
  - Not an exhaustive set of useful concepts
- Two types of concepts are provided
  - Interfaces (i.e., ADTs)
  - Implementations

JCF Interfaces and Classes

- Interfaces
  - Collection
  - Set (no duplicates)
  - SortedSet
  - List (duplicates OK)
  - Map (i.e., Dictionary)
  - SortedMap
  - Iterator
  - Iterable
  - ListIterator
- Classes
  - HashSet
  - TreeSet
  - ArrayList
  - LinkedList
  - HashMap
  - TreeMap

java.util.Collection<E> (an interface)

public int size( );
- Return number of elements in collection

public boolean isEmpty( );
- Return true iff collection holds no elements

public boolean add (E x);
- Make sure the collection includes x; returns true if collection has changed (some collections allow duplicates, some don't)

public boolean contains (Object x);
- Returns true iff collection contains x (uses equals( ) method)

public boolean remove (Object x);
- Removes a single instance of x from the collection; returns true if collection has changed

public Iterator<E> iterator ( );
- Returns an Iterator that steps through elements of collection

java.util.Iterator<E> (an interface)

public boolean hasNext ( );
- Returns true if the iteration has more elements

public E next ( );
- Returns the next element in the iteration
- Throws NoSuchElementException if no next element

public void remove ( );
- The element most-recently returned by next( ) is removed from the collection
- Throws IllegalStateException if next( ) not yet used or if remove( ) already called
- Throws UnsupportedOperationException if remove( ) not supported

Additional Methods of Collection

public Object[ ] toArray ( )
- Returns a new array containing all the elements of this collection

public <T> T[ ] toArray (T[ ] dest)
- Returns an array containing all the elements of this collection; uses dest as that array if it can

Bulk Operations:
- public boolean containsAll (Collection<?> c);
- public boolean addAll (Collection<? extends E> c);
- public boolean removeAll (Collection<?> c);
- public boolean retainAll (Collection<?> c);
- public void clear ( );

java.util.Set<E> (an interface)

- Set extends Collection
  - Set inherits all its methods from Collection
- A Set contains no duplicates
  - If you attempt to add( ) an element twice then the second add( ) will return false (i.e., the Set has not changed)

- Write a method that checks if a given word is within a Set of words
- Write a method that removes all words longer than 5 letters from a Set
- Write methods for the union and intersection of two Sets

Set Implementations

- java.util.HashSet<E> (a hashtable)
  - Constructors

    public HashSet ( );
    public HashSet (Collection<? extends E> c);
    public HashSet (int initialCapacity);
    public HashSet (int initialCapacity, float loadFactor);

- java.util.TreeSet (a balanced BST [red-black tree])
  - Constructors

    public TreeSet ( );
    public TreeSet (Collection<? extends E> c);
    …

java.util.SortedSet<E> (an interface)

- SortedSet *extends* Set
- For a SortedSet, the iterator( ) returns the elements in sorted order
- Methods (in addition to those inherited from Set):
  - public E first ( );
    - Returns the first (lowest) object in this set
  - public E last ( );
    - Returns the last (highest) object in this set
  - public Comparator<? super E> comparator ( );
    - Returns the Comparator being used by this sorted set if there is one; returns null if the natural order is being used
  - …

java.lang.Comparable<T> (an interface)

public int compareTo (T x);

- Returns a value (< 0), (= 0), or (> 0)
  - (< 0) implies this is before x
  - (= 0) implies this.equals(x) is true
  - (> 0) implies this is after x

- Many classes implement Comparable
  - String, Double, Integer, Char, java.util.Date,...
  - If a class implements Comparable then that is considered to be the class's *natural ordering*

java.util.Comparator<T> (an interface)

public int compare (T x1, T x2);

- Returns a value (< 0), (= 0), or (> 0)
  - (< 0) implies x1 is before x2
  - (= 0) implies x1.equals(x2) is true
  - (> 0) implies x1 is after x2

- Can often use a Comparator when a class's natural order is not the one you want
  - String.CASE_INSENSITIVE_ORDER is a predefined Comparator
  - java.util.Collections.reverseOrder( ) returns a Comparator that reverses the natural order

SortedSet Implementations

- java.util.TreeSet<E>
  - This is the only class that implements SortedSet
  - TreeSet's constructors

    public TreeSet ( );

    public TreeSet (Collection<? extends E> c);

    ...

- Write a method that prints out a SortedSet of words in order
- Write a method that prints out a Set of words in order

java.util.List<E> (an interface)

- List extends Collection
- Items in a list can be accessed via their index (position in list)
- The add( ) method always puts an item at the end of the list
- The iterator( ) returns the elements in list-order
- Methods (in addition to those inherited from Collection):
  - public E get (int index);
    - Returns the item at position index in the list
  - public E set (int index, E x);
    - Places x at position index, replacing previous item; returns the previous item
  - public void add (int index, E x);
    - Places x at position index, shifting items to make room
  - public E remove (int index);
    - Remove item at position index, shifting items to fill the space; returns the removed item
  - public int indexOf (Object x);
    - Return the index of the first item in the list that equals x (x.equals())
  - ...

List Implementations

java.util.ArrayList<E> (an array; expands via array-doubling)

- Constructors
  - public ArrayList ( );
  - public ArrayList (int initialCapacity);
  - public ArrayList (Collection<? extends E> c);

java.util.LinkedList <E> (a doubly-linked list)

- Constructors
  - public LinkedList ( );
  - public LinkedList (Collection<? extends E> c);
- Both include some additional useful methods specific to that class

Efficiency Depends on Implementation

- Object x = list.get(k);
  - O(1) time for ArrayList
  - O(k) time for LinkedList

- list.remove(0);
  - O(n) time for ArrayList
  - O(1) time for LinkedList

- If (set.contains(x))...
  - O(1) expected time for HashSet
  - O(log n) for TreeSet