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Computer Science II
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Week 5: Generics,
Java Collection Framework

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Generic Types in Java

(Ch. 21 in Liang)

What are 'Generic Types' or 'Generics'?

Definition

– Reference type parameters for use in class and method definitions
– Unlike formal parameters for methods, generic types define 'macros:' the class name replaces the type parameter in the source code ("search and replace")

Syntax

<C> for parameter, use as C elsewhere (*C must be a class*)

- public class Widget <C> { .... }   // definition
- Widget<String> = new Widget<String>(); // instantiation
- public <C> void test(C o1, int x) { C temp; .... } // method

Purpose: Avoiding 'Dangerous' Polymorphism

Prevent run-time errors (*exceptions)* due to improper casting (type errors)

Example: Comparable Interface

Prior to JDK 1.5 (and Generic Types):

public interface Comparable {
    public int compareTo(Object o) }

Comparable c = new Date();
System.out.println(c.compareTo("red"));

} run-time error

JDK 1.5 (Generic Types):

public Interface Comparable<T> {
    public int compareTo(T o) }

Comparable<Date> c = new Date();
System.out.println(c.compareTo("red"));

} compile-time error

"Raw Types" and Associated Compiler Warnings

Raw Types

(Provided for backward compatability)

Generic types (classes) that are used without the type parameter(s) defined

- e.g. Comparator c ~= Comparator<Object> c

Compiler Warnings

– javac will give a warning about possibly unsafe operations (type errors) at run-time for raw types
  - use -Xlint:unchecked flag

– javac will not compile programs whose generic types cannot be properly defined
  - e.g. Max.java, Max1.java (pp. 699-700 in Liang)

Wildcards and Expressions to Restrict Generic Types

Purpose

Allow to define valid generic type sets, stipulate restrictions on these

The Wildcard (?)

Represents any reference type (i.e. any subclass of Object)

Restricting to subclasses

e.g. public static <T> void add(GenericStack<T> s1,
            GenericStack<? super T>) { ... }
    public static <E extends Comparable<E>> C max(E o1, E o2)
        // previous example

Restricting to superclasses

e.g. <? super MyClass>

Generic Types and the Inheritance Hierarchy

See Figure 21.6, page 703

**** Generic class is shared by all instances of the class, regardless of concrete types for type parameters (<T,G>, etc.)**

**** Caution: A<Number> *is not* a superclass of A<Integer> (etc.)**

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Overview: Data Structures and Abstract Data Types

Storing Data in Java

Variables

Primitive type (int, double, boolean, etc.)
- Variable name refers to a memory location containing a primitive value

Reference type (Object, String, Integer, MyClass, etc.)
- Variable name refers to a memory location containing a reference value for data belonging to an object

Data Structure

Formal organization for a set of data (e.g. variables)

e.g. Arrays: variables in an integer-indexed sequence
- int intArray[ ] = {1, 2}; int a = intArray[0]; intArray[1] = 5;

e.g. Objects: data member names representing variables
- player.name, player.hits, player.team ... player.hits = 100;

Abstract Data Types (ADTs)

Purpose

Define interfaces to data structures while hiding *(abstracting)* implementation details

Examples of Common ADTs

List: Sequence of elements. Elements may be inserted or removed from any position in the list

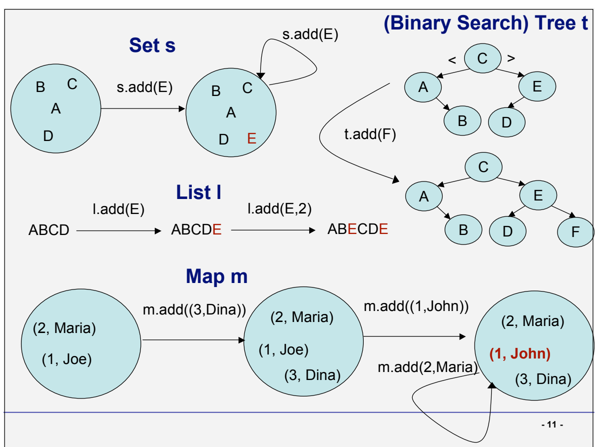
Stack: List with last-in, first-out (LIFO) behaviour ("most recent," call stack)

Queue: List with first-in, first-out (FIFO) ("in-order", lining up)

Set: Unordered group of unique items

Map: Set of entries, each with a unique key and a value
- (e.g. Student database: (StudentId, StudentRecordRef))

Tree: Graph with directed edges, each node has one parent (except root), no cycles.



Example: Implementing Abstract Data Types

List ADT

Represents series of elements, insertion and deletion of elements

Some Possible Implementations:

- An array and operations on it
  - l.add(E) would copy E at the end of the array, l.get(4) returns 5^{th} item in array
- A set of objects with references to one another representing a simple graph (a "linked list") and operations on it
  - L.add(E) would create a link from last node to a new node for E ; l.get(4) traverses the graph and then returns the 5^{th} item

Choosing an Implementation for an ADT

Depending on common operations, some better than others
- Finding elements in list faster for array implementation
- Inserting, deleting arbitrary elements faster for linked list implementation

Ordering in 'Unordered' ADTs

'Unordered' on paper vs. in code
In practice, some type of order must be used to implement a set, as memory and files contain ordered lists of bytes

Sets
By definition, a set is an unordered group of unique elements

Maps
By definition, a map is a set of (key,value) pairs

Ordering Sets and Maps
We can order the storage of set elements by:

1. A value computed for each element ("hash code") that determines where an element is stored (e.g. in a "hash table", a sophisticated ADT built on arrays); for maps, usually based on key value
2. The order in which elements are added (e.g. in a list)
3. The element (for map: key) values themselves (e.g. using a binary search tree)

Exercise: Generics and ADTs

Part A

1. In one sentence, what is a generic type?
2. What errors are generic types designed to prevent?
3. Which javac flag will show details for (type) unsafe operations?
4. What do the following represent:
   a) <? extends MyClass>
   b) <? super YourClass>
   c) <E extends Comparator<E>>
5. Write a java class *GenX* which has a generic type parameter *T*, a public data member *identity* of type *T*, and a constructor that takes an initial value for *identity*. Add a main method that constructs one *GenX* object using type *String*, and another using type *Integer*.

Part B

1. What is an abstract data type?
2. How is a list different from a set?
3. How are elements stored in a binary search tree (BST)?
4. In what ways can we order the elements of a set, or pairs of a map?
5. Are sets and map elements/pairs ordered in their ADT definitions?

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ADTs in Java: The Java Collections Framework

The Java Collections Framework

Definition
Set of interfaces, abstract and concrete classes that define common abstract data types in Java

- e.g. list, set, map, queue, stack

Part of the java.util package

Implementation
Extensive use of generic types, hash codes (e.g. hashCode()) , and Comparable interface (compareTo(), e.g. for sorting)

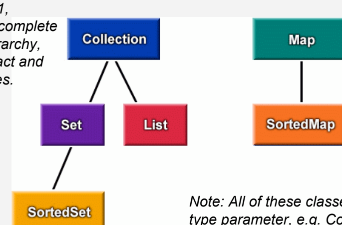
Collection Interface
Defines common operations for sets and lists ('unordered' ops.)

Maps
Represented by separate interfaces

Java Collections Interfaces

(slide: Carl Reynolds)

See Figure 22.1, 22.2 in text for complete inheritance hierarchy, including abstract and concrete classes.



Note: All of these classes have a generic type parameter, e.g. Collection<E>: see course text (Ch. 22)

Note: Some of the material on these slides was taken from the Java Tutorial at http://www.java.sun.com/docs/books/tutorial

Common List and Set Operations: the Collection Interface

See Figure 22.3 (page 715)

List of operations to add, remove, and search for elements (of a generic type (E)).

Operations:

- add elements (add/addAll) to a set/list
- Remove elements (remove/removeAll)
- Take intersection (for sets), keep a set of elements (for lists) using retainAll()
- Search for elements in a collection (contains/containsAll)
- Many operations return a boolean value, to indicate whether an operation was successful.
- Return an iterator, which allows us to visit each element in a set or list one-at-a-time (similar to getting tokens from a Scanner object)

Iterator Interface

Purpose

Provide uniform way to traverse sets and lists

Instance of Iterator given by iterator() method in Collection

Operations

– Check if all elements have been visited (hasNext())
– Get next element in order imposed by the iterator (next())
– remove() the last element returned by next()
– Roughly similar to operations used in *Scanner* to obtain a sequence of tokens

Implementation Classes

(*slide derived from: Carl Reynolds*)

Interface	Implementation				Historical
`Set`	`HashSet`		`TreeSet`	`LinkedHashSet`	
`List`		`ArrayList`		`LinkedList`	`Vector` `Stack`
`Map`	`HashMap`		`TreeMap`	`LinkedHashMap`	`HashTable` `Properties`

Note: When writing programs think about interfaces and not implementations. This way the program does not become dependent on any added methods in a given implementation, leaving the programmer with the freedom to change implementations.

Notes on 'Unordered' Collections (Set, Map Implementations)

HashMap, HashSet

Hash table implementation of set/map

Use hash codes (integer values) to determine where set elements or (key,value) pairs are stored in the hash table

LinkedHashMap, LinkedHashSet

Provide support for ordering set elements or (key,value) pairs by order of insertion by adding a *linked list within the hash table elements*

TreeSet, TreeMap

Use binary search tree implementations to order set elements by value, or (key,value) pairs by key value

Set Classes

See Figure 22.4

Note that Set interface takes a generic type <T>

Sorted set classes (such as TreeSet) have additional methods defined (e.g. first/last) as well as the Collection interface methods

All set classes (really, any Collection (List/Set)) allow a new set to be defined using the elements of an existing collection, using the constructor.

HashSet (Example: TestHashSet.java, p. 717)

Methods

Except for constructors, method interface identical to Collection

Element Storage:

'Unordered,' according to their hash codes

**All elements are unique

Do not expect to see elements in the order you add them

Hash Codes

– Most classes in Java API override the hashCode() method in the Object class
– Need to be defined to properly disperse set elements in storage (i.e. throughout the hash table)
– For two equivalent objects, hash codes must be the same

LinkedHashSet
(example: TestLinkedHashSet.java, p. 718)

Methods

Again, same as Collection Interface except for constructors

Addition to HashSet

– Elements contain extra field defining order in which elements are added (as a linked list)
– List (quietly) maintained by the class

Hash Codes

Notes from previous slide still apply (e.g. equivalent objects, equivalent hash codes)

Ordered Sets: TreeSet
(example: TestTreeSet.java)

Methods

Add methods from *SortedSet* interface:
first(), last(), headSet(toElement: E), tailSet(fromElement: E)

Implementation

A binary search tree, such that either:

1. Objects (elements) implement the *Comparable* interface (compareTo()) ("natural order" of objects in a class), *or*
2. TreeSet is constructed using an object implementing the *Comparator* interface (compare()), which may be used to compare objects of different classes

One of these will determine the ordering of elements.

Notes

– It is faster to use a hash set to add elements, as TreeSet keeps elements in a sorted order
– Can construct a tree set using an existing collection (e.g. a hash set)

`List` Interface

(slide: Carl Reynolds)

```
List

// Positional Access
get(int):Object;
set(int,Object):Object;            // Optional
add(int, Object):void;             // Optional
remove(int index):Object;          // Optional
addAll(int, Collection):boolean;   // Optional

// Search
int indexOf(Object);
int lastIndexOf(Object);

// Iteration
listIterator():ListIterator;
listIterator(int):ListIterator;

// Range-view List
subList(int, int):List;
```


`ListIterator`

(slide: Carl Reynolds)

the `ListIterator` interface extends `Iterator`

Forward and reverse directions are possible

`ListIterator` is available for Java Lists, such as the `LinkedList` implementation

```
ListIterator

hasNext():boolean;
next():Object;

hasPrevious():boolean;
previous(): Object;

nextIndex(): int;
previousIndex(): int;

remove():void;
set(Object o): void;
add(Object o): void;
```


List: Example

TestArrayAndLinkedList.java

`Map` Interface

(slide: Carl Reynolds)

```
Map

// Basic Operations
put(Object, Object):Object;
get(Object):Object;
remove(Object):Object;
containsKey(Object):boolean;
containsValue(Object):boolean;
size():int;
isEmpty():boolean;

// Bulk Operations
void putAll(Map t):void;
void clear():void;

// Collection Views
keySet():Set;
values():Collection;
entrySet():Set;
```

```
EntrySet

getKey():Object;
getValue():Object;
setValue(Object):Object;
```

Map Examples

TestMap.java

CountOccurranceOfWords.java

The Collections Class

Operations for Manipulating Collections

Includes static operations for sorting, searching, replacing elements, finding max/min element, and to copy and alter collections in various ways.

(using this in lab5)

Note!

Collection is an interface for an abstract data type, *Collections* is a separate class for methods operating on collections.

Comparator Interface (a generic class similar to *Comparable*)

(comparator slides adapted from Carl Reynolds)

You may define an alternate ordering for objects of a class using objects implementing the Comparator Interface (i.e. rather than using compareTo())

- Sort people by age instead of name
- Sort cars by year instead of Make and Model
- Sort clients by city instead of name
- Sort words alphabetically regardless of case

Comparator<T> Interface

One method:

```
compare( T o1, T o2 )
```

Returns:

```
negative if o1 < o2
Zero     if o1 == o2
positive if o1 > o2
```


Example Comparator: Compare 2 Strings regardless of case

```
import java.util.*;
public class CaseInsensitiveComparator implements Comparator<String> {
  public int compare( String stringOne, String stringTwo ) {

    // Shift both strings to lower case, and then use the
    //  usual String instance method compareTo()
    return stringOne.toLowerCase().compareTo( stringTwo.toLowerCase() );
  }
}
```


Using a Comparator...

```
Collections.sort( myList, myComparator );
Collections.max( myCollection, myComparator );
Set myTree = new TreeSet<String>( myComparator );
Map myMap  = new TreeMap<String>( myComparator );
```

```
import java.util.*;
public class SortExample2B {
  public static void main( String args[] ) {

    List aList = new ArrayList<String>();

    for ( int i = 0; i < args.length; i++ ) {
        aList.add( args[ i ] );
    }
    Collections.sort( aList , new CaseInsensitiveComparator() );
    System.out.println( aList );
  }
}
```