DM503
Programming B

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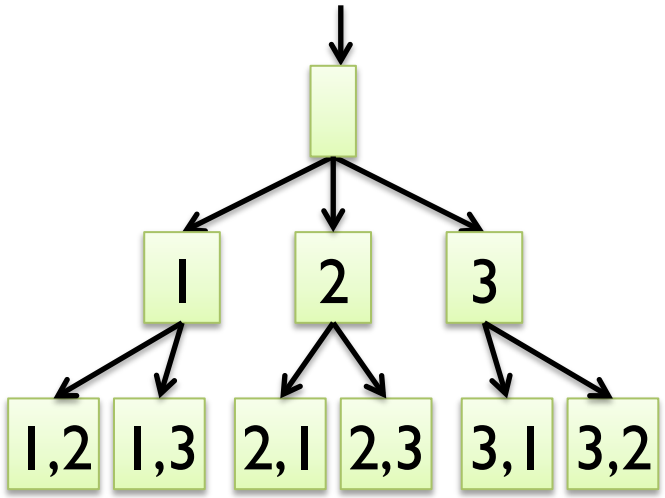
MULTIVARIATE TREES

Multivariate Trees

- general class of trees
- nodes can have any number of children
- our application:
  - k-permutations of n
  - all sequences without repetition
  - total of n elements
  - sequences of length k < n
- Example:
  - total of n = 3 elements
  - sequences of length k = 2



MTree ADT: Specification

- data are sequences of integers (List<Integer>)
- operations are defined by the following interface

```
public interface MTreeADT extends javax.swing.tree.TreeModel {
    public Object getRoot();
    public boolean isLeaf(Object node);
    public int getChildCount(Object node);
    public Object getChild(Object parent, int index);
    public int getIndexOfChild(Object parent, Object child);
}
```

- TreeModel specifies additional operations needed for JTree

MTree ADT: Design & Implement.

- Design: use recursive data structure
- Implementation:

```
public class MTreeNode {
    private List<Integer> seq;  // sequence of integers
    private List<MTreeNode> children =
        new ArrayList<MTreeNode>();
    public MTreeNode(List<Integer> seq) {  this.seq = seq;  }
    public List<Integer> getSeq() {  return this.seq;  }
    public List<MTreeNode> getChildren() {  return this.children;  }
    public String toString() {  return this.seq.toString();  }
}
```

MTree ADT: Implementation

- Implementation (continued):

```
public class MTree implements MTreeADT {
    private MTreeNode root = new MTreeNode(
        new ArrayList<Integer>());
    public Object getRoot() {  return this.root;  }
    public boolean isLeaf(Object node) {
        return this.getChildCount(node) == 0;
    }
    public int getChildCount(Object node) {
        return ((MTreeNode)node).getChildren().size();
    }
    …
```

MTree ADT: Implementation

- Implementation (continued)

```
public class MTree implements MTreeADT {   …
    public Object getChild(Object parent, int index) {
        return ((MTreeNode)parent).getChildren().get(index);
    }
    public int getIndexOfChild(Object parent, Object child) {
        return ((MTreeNode)parent).getChildren().indexOf(child);
    }
    public void addTreeModelListener(TreeModelListener l) {}
    public void removeTreeModelListener(TreeModelListener l) {}
    public void valueForPathChanged(TreePath p, Object o) {}
    …
```

MTree ADT: Implementation

- Implementation (continued)

```
public class MTree implements MTreeADT {   …
    private static MTree makeTree(String title) {
        MTree tree = new MTree();
        JScrollPane content = new JScrollPane(new JTree(tree));
        JFrame window = new JFrame(title);
        window.setContentPane(content);
        window.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
        window.setSize(400,400);
        window.setVisible(true);
        return tree;
    }   …
```

MTree ADT: Implementation

- Implementation (continued)

```
public class MTree implements MTreeADT {   …
    public static void main(String[] args) {
        int n = 4;
        int k = 3;
        MTree tree1 = makeTree("MTree queue");
        tree1.expandQueue(n,k);
        MTree tree2 = makeTree("MTree stack");
        tree2.expandStack(n,k);
        MTree tree3 = makeTree("MTree recursive");
        tree3.expandRecursively(n,k);
    }   …
```

MTree ADT: Implementation

- Implementation (continued)

```
public class MTree implements MTreeADT {
    …
    private void expandRecursively(int n, int k) {
        expandRecursively(this.root, n, k);
    }
    private List<Integer> copyAdd(List<Integer> seq, int i) {
        List<Integer> copySeq = new ArrayList<Integer>(seq);
        copySeq.add(i);
        return copySeq;
    }
    …
```

MTree ADT: Implementation

- Implementation (continued):

```
private void expandRecursively(MTreeNode node, int n, int k) {
    List<Integer> seq = node.getSeq();
    if (seq.size() < k) {
        for (int i = 1; i <= n; i++) {
            if (!seq.contains(i)) {
                List<Integer> newSeq = copyAdd(seq, i);
                MTreeNode child = new MTreeNode(newSeq);
                node.getChildren().add(child);
                expandRecursively(child, n, k);
} } } }
…
```

MTree ADT: Implementation

- Implementation (continued):

```
private void expandStack(int n, int k) {
    Stack<MTreeNode> stack = new LinkedStack<MTreeNode>();
    stack.push(this.root);
    while (!stack.isEmpty()) {
        MTreeNode node = stack.pop();
        List<Integer> seq = node.getSeq();
        if (seq.size()<k) {  for (int i=1; i<=n; i++) {  if (!seq.contains(i)) {
            MTreeNode child = new MTreeNode(copyAdd(seq, i));
            node.getChildren().add(child);
            stack.push(child);
        }}}   }   }   …
```

MTree ADT: Implementation

- Implementation (continued):

```
private void expandQueue(int n, int k) {
    Queue<MTreeNode> queue = new LinkedQueue<MTreeNode>();
    queue.offer(this.root);
    while (!queue.isEmpty()) {
        MTreeNode node = queue.poll();
        List<Integer> seq = node.getSeq();
        if (seq.size()<k) {  for (int i=1; i<=n; i++) {  if (!seq.contains(i)) {
            MTreeNode child = new MTreeNode(copyAdd(seq, i));
            node.getChildren().add(child);
            queue.offer(child);
        }}}   }   }   } // DONE!
```

COLLECTION CLASSES & GENERIC PROGRAMMING

Java Collections Framework

- Java comes with a wide library of *collection classes*
- Examples:
  - ArrayList
  - TreeSet
  - HashMap

- idea is to provide well-implemented standard ADTs
- your own ADTs can build upon this foundation
- collection classes store arbitrary objects

- all collection classes implement Collection or Map
- thus, simple and standardized interface across different classes

Generic Types (revisited)

- type casts for accessing elements are unsafe!
- solution is to use *generic types*
- instead of using an array of objects, use array of some type E
- Example:

```
public class MyArrayList<E> implements List<E> {
    …
    private E[] data;
    …
    public E get(int i) {
        return this.data[i];
    }
}
```

Generic Programming

- the use of generic types is referred to as *generic programming*
- generic types can and should be used:
  - by the user of collection classes
  - Example: `List<String> list = new ArrayList<String>();`
  - when implementing ADTs
  - Example: `public class MyCollection<E> …`
  - when implementing constructors and methods
  - Example: `public E getElement(int index) { … }`
  - when implementing static functions
  - Example: `public <E> void add(ListNode<E> n, E elem);`

Generic Programming

- when a class has parameter type <E>, E is used like normal type
- instances of the class are defined by substituting concrete type
- Example: public class Mine<E> … Mine<String> mine = …

- more than one parameter is possible
- Example: public interface Map<K,V> …

- when defining static function, prefix return type by parameter <E>
- inside function, E is used like normal type
- Example: public <E> void add(ListNode<E> n, E elem);

Generic Programming

- we can define that a parameter type extends some interface/class
- Example:

  public interface BinTree<E extends Comparable> { … }
- then all types E are usable, that implement Comparable

- using "?" we can define wildcard types
- Example:

  public boolean addAll(Collection<? extends E> c) { … }
- here, elements can be any type that extends E
- the same works with "? super E"

Collection ADT: Specification

- interface Collection<E> specifies standard operations
  - boolean isEmpty(); // true, if there are no elements
  - int size(); // returns number of elements
  - boolean contains(Object o); // is object element?
  - boolean add(E e); // add an element; true if modified
  - boolean remove(Object o); // remove an element
  - Iterator<E> iterator(); // iterate over all elements
  - boolean addAll(Collection<? extends E> c); // add all …
  - clear, containsAll, removeAll, retainAll, toArray, …
- operations make sense both for lists, queues, stacks, sets, …
- next: interface Iterator<E>

Iterator ADT: Specification

- iterate over elements of collections (= data)
- operations defined by interface Iterator<E>:

```
public interface Iterator<E> {
    public boolean hasNext();          // is there another element?
    public E next();                   // get next element
    public void remove();              // remove current element
}
```

- can be used to access all elements of the collection
- order is determined by specification or implementation

Iterator ADT: Example 1

- Example (iterate over all elements of an ArrayList):

```
ArrayList<String> list = new ArrayList<String>();
list.add("Hej");
list.add("med");
list.add("dig");
Iterator<String> iter = list.iterator();
while (iter.hasNext()) {
    String str = iter.next();
    System.out.println(str);
}
```

- no need to iterative over indices 0, 1, …, list.size()-1

Extended for Loop

- also called "for each loop"
- iterative over each element of an array or a collection
- Example 1 (summing elements of an array):

```
int[] numbers = new int[] {1, 2, 3, 5, 7, 11, 13};
int sum = 0;
for (int n : numbers) {
    sum += n;
}
```

- Example 2 (multiplying elements of a list):

```
List<Integer> list = new ArrayList(Arrays.asList(numbers));
int prod = 1;
for (int i : list) {  prod *= i;  }
```

List ADT: Usage

- interface List<E> extends Collection<E>
- additional operation that make no sense for non-lists (e.g. get)
- can be sorted by static method in class Collections
- Example:

```
int[] numbers = new int[] {1, 2, 3, 5, 7, 11, 13};
List<Integer> list = new ArrayList(Arrays.asList(numbers));
Collections.sort(list);
```

- requires that elements implement Comparable
- full signature:

```
public static <T extends Comparable<? super T>> void
    sort(List<T> list);
```

List ADT: Implementations

- ArrayList based on dynamic arrays
  - very good first choice in >90% of applications
- LinkedList based on doubly-linked lists
  - has prev member variable pointing to previous list node
  - useful when adding and removing a lot in the middle
  - do not use for Queue – use ArrayDeque instead!
- Vector based on dynamic arrays
  - old implementation, not synchronized – use ArrayList!
- Stack based on Vector
  - do not use for Stack – use ArrayDeque instead!

Queue ADT: Specification & Implem.

- interface Queue<E> extends Collection<E>
- data are arbitrary objects of type E
- defines additional operations over Collection<E>:
  - public boolean offer(E e); // alternative name to add
  - public E peek(); // return head
  - public E element(); // alternative name to peek
  - public E poll(); // remove and return head
- extended again by interface Deque<E> providing support for adding AND removing at both ends
- Implementations:
  - ArrayDeque – with offer == offerLast and poll == pollFirst
  - LinkedList – only useful, when not a pure Queue

Stack ADT: Specification & Implem.

- class Stack<E> implements Collection<E>
- data are arbitrary objects of type E
- defines additional operations over Collection<E>:
  - public E push(E e); // add on top of stack
  - public E peek(); // return top element
  - public E pop(); // remove and return top
  - public int search(Object o); // return 1-based index
- superseded by interface Deque<E> providing support for adding AND removing at both ends
- Alternative Implementations:
  - ArrayDeque – with push == addFirst and pop == removeFirst

Deque ADT: Specification & Implem.

- interface Deque<E> extends Collection<E>
- data are arbitrary objects of type E
- defines additional operations over Collection<E>:
  - addFirst, offerFirst, addLast, offerLast
  - removeFirst, pollFirst, removeLast, pollLast
  - getFirst, peekFirst, getLast, peekLast
- add*, remove*, get* throw exceptions
- offer*, poll*, peek* return special value
- Implementations:
  - ArrayDeque – with push == addFirst and pop == removeFirst
  - LinkedList – only use when more than Deque needed

Set ADT: Specification

- interface List<E> extends Collection<E>
- unordered sequences of objects without duplicates
- no additional operations, as Collection<E> already specifies
  - isEmpty, size, contains, add, remove, …
- no index-based access to elements, as order undefined
- elements MUST implement equals and hashCode correctly:
  1. for two elements e1 and e2 that are equal, both e1.equals(e2) and e2.equals(e1) must return true
  2. for two elements e1 and e2 that are equal, we must have e1.hashCode() == e2.hashCode()
  3. for two elements e1 and e2 that are NOT equal, both e1.equals(e2) and e2.equals(e1) must return false

Set ADT: Example

- Example (intersecting two sets):

```
int[] n1 = new int[] {1, 2, 3, 5, 7, 11, 13};
Set<Integer> set1 = new HashSet<Integer>(Arrays.asList(n1));
int[] n2 = new int[] {1, 3, 5, 7, 9};
Set<Integer> set2 = new HashSet<Integer>(Arrays.asList(n2));
Set<Integer> set3 = new HashSet<Integer>(set1);
set3.retainAll(set2);
```

- retainAll modifies set3, thus we have (informally):
  - set1 == {1, 2, 3, 5, 7, 11, 13}
  - set2 == {1, 3, 5, 7, 9}
  - set3 == {1, 3, 5, 7}

Iterator ADT: Example 2

- Example (iterate over all elements of a HashSet):

```
Set<String> set = new HashSet<String>();
set.add("Hej");
set.add("hej");
set.add("Hej");
Iterator<String> iter = set.iterator();
while (iter.hasNext()) {
    String str = iter.next();
    System.out.println(str);
}
```

- prints the two strings in some undefined order

Interface Comparator

- allows to specify how to compare elements

```
public interface Comparator<E> {
    public int compare(T o1, T o2);      // compare o1 and o2
    public boolean equals(Object obj);  // equals other Comparator?
}
```

- compare behaves like o1.compareTo(o2) from Comparable<E>
  - < 0 for o1 less than o2
  - ==0 for o1 equals o2
  - > 0 for o1 greater than o2
- Comparable defines *natural* ordering
- Comparator can define additional orderings

Set ADT: TreeSet Implementation

- TreeSet implements sets as special sort trees (Red-Black Trees)
- elements are compared to according to natural ordering
- Example:

```
public class Compi implements Comparator<Integer> {
    public int compare(Integer i1, Integer i2) {
    return i2.compareTo(i1); }
    public boolean equals(Object other) { return false; } } …
TreeSet<Integer> set1 = new TreeSet<Integer>();
set1.add(23); set1.add(42); set1.add(-3);
for (int n : set1) { System.out.print(" "+n); } // -3 23 42
TreeSet<Integer> set2 = new TreeSet<Integer>(new Compi());
set2.addAll(set1);
for (int n : set2) { System.out.print(" "+n); } // 42 23 -3
```

Set ADT: Implementations

- HashSet based on hash tables
  - very good choice if order really does not matter
- LinkedHashSet based on hash tables + linked list
  - in addition to hash table keeps track of insertion order
  - useful for keeping algorithms deterministic
- TreeSet based on special sort trees
  - implements the SortedSet<E> interface
  - useful for ordered sequences without duplicates
  - can use Comparators for different orderings
  - also useful when e.g. hash code not available

Map ADT: Specification

- maps work like dictionaries in Python
- interface Map<K,V> specifies standard operations
  - boolean isEmpty(); // true, if there are no mappings
  - int size(); // returns number of mappings
  - boolean containsKey(Object key); // is key mapped?
  - boolean containsValue(Object value); // is value mapped?
  - V get(Object key); // return mapped value or null
  - V put(K key,V value); // add mapping from key to value
  - Set<K> keySet(); // set of all keys
  - Collection<V> values(); // collection of all values
  - Set<Map.Entry<K,V>> entrySet(); // (key,value) pairs
  - clear, putAll, remove, …

Map ADT: Example

- Example (using and modifying a phone directory):

```
Map<String,Integer> dir = new HashMap<String,Integer>();
dir.put("petersk", 65502327);  dir.put("bwillis", 55555555);
for (String key : dir.keySet()) {
    System.out.println(key+" -> "+dir.get(key));
}
for (Map.Entry<String,Integer> entry : dir.entrySet()) {
    System.out.println(entry.getKey()+" -> "+entry.getValue());
    entry.setValue(12345678);
}
dir.keySet().remove("bwillis");
System.out.println(dir);      // only petersk is mapped
```

Hash Table

- a hash table uses the hashCode method to map objects to ints
- objects are stored in an array
- the position of the object is determined by its hash code modulo the length of the array
- Example: if o has hash code 10 and array has length 7,
  o is stored at position 10 % 7 == 3
- more in **DM507 Algorithms and Data Structures**
- efficient for get and put
- assuming that hashCode is implemented in a useful way
- if two or more objects have the same hash code, the array stores a list of objects in that position

Map ADT: Implementations

- HashMap based on hash tables
  - very good choice if order does not matter
- LinkedHashMap based on hash tables + linked list
  - in addition to hash table keeps track of insertion order
  - useful for keeping algorithms deterministic
- TreeMap based on special sort trees
  - implements the SortedMap<K,V> interface
  - useful for ordered mappings
  - can use Comparators for different orderings
  - also useful when e.g. hash code not available
- Hashtable based on hash tables
  - old implementation – only use for synchronization