DM550 / DM857
Introduction to Programming

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ABSTRACT DATATYPES

Abstract Datatype (ADT)

- abstract datatype = data + operations on the data
- **Idea:** encapsulate data + operations with uniform interface

- operations of a datatype
  - at least one constructor
  - modifiers / setters
  - readers / getters
  - computations

- ADTs typically specified by interfaces in Java

Abstract Datatype (ADT)

- abstract datatype = data + operations on the data
- when specifying an ADT, we describe
  - the data and its *logical* organization
  - which operations we want to be able to perform
  - what the results of the operations should be
- we do NOT describe
  - where and how the data is stored
  - how the operations are performed
- ADTs are independent of the implementation (& language)
- one ADT can have many different implementations!

Examples for ADTs

- Numbers: (integer, rational or real)
  - addition, subtraction, multiplication, division, …
- Collections: (collections of elements)
  - List: (ordered collections of elements)
    - Stack (insert & remove elements at one end)
    - Queue (insert at one end, remove at the other)
  - Set: (unordered collection without duplicates)
    - SortedSet (ordered collection without duplicates)
  - Map: (mapping from keys to values)

Developing ADTs

- three steps (like in programming!)

1. specification of an ADT by mathematical means
   - focus on WHAT we want
2. design (still independent of implementation & language)
   - which data structures to use
   - which algorithms to use
   - focus on efficiency of representation and algorithms
   - different data structures give different efficiency for operations
3. implementation (language dependent)
   - select "right" programming language!
   - implement design in that programming language

Specification of an ADT

- mathematically precise!

- data is represented by mathematical objects
- Example: real numbers $\Re$

- operations are mathematical functions
  - explicit specifications
  - Example: $f(x) = x^2$

  - indirect specifications
  - Example: $sqrt : x \in \Re^{\geq 0} \mapsto y \in \Re^{\geq 0}$
    $x = y^2 \wedge y \geq 0$

Integer ADT

- specification:
  - data: all $n \in \mathbb{Z}$
  - operations: addition +, subtraction -, negation -, multiplication *, division /, modulo %
- Design 1: use primitive data type int
  use primitive operations
- Implementation 1: nothing to implement when using Java
- Design 2: use array of bytes to store bit
  provide all relevant operations
- Implementation 2: see class java.math.BigInteger

Integer ADT

- specifying by mathematics often cumbersome
- alternatively use interfaces to specify operations
- alternative specification:
  - data: all $n \in \mathbb{Z}$
  - operations:

```
public interface MyInteger {
    public MyInteger add(MyInteger val);     // addition
    public MyInteger sub(MyInteger val);     // subtraction
    public MyInteger neg();                  // negation
    public MyInteger mul(MyInteger val);     // multplication
    public MyInteger div(MyInteger val);     // division
}
```

ABSTRACT DATATYPE FOR LISTS

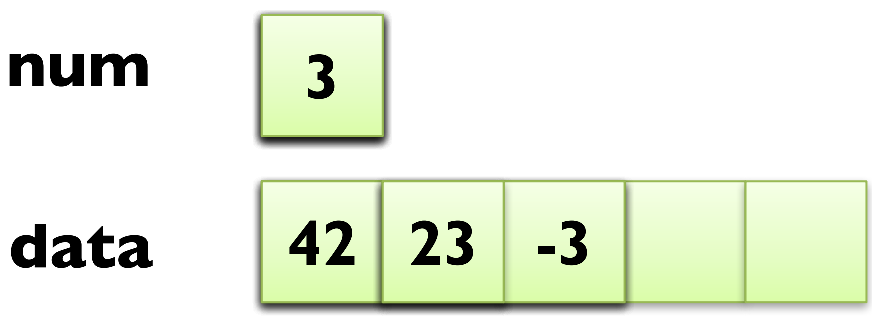
List ADT: Specification

- data are all lists of integers, here represented as primitive int
- operations are defined by the following interface

```
public interface ListOfInt {
    public int get(int i);                 // get i-th integer (0-based)
    public void set(int i, int elem);      // set i-th element
    public int size();                     // return length of list
    public void add(int elem);             // add element at end
    public void add(int i, int elem);      // insert element at pos. i
    public void remove(int i);             // remove i-th element
}
```

Partially Full Arrays

- arrays are fixed-length
- lists are variable-length
- **Idea:**
  - use an array of (fixed) length
  - track number of elements in variable
- **Example:** add(23) add(42) add(-3) remove(0) add(1, 23)



List ADT: Design & Implementation 1

- Design 1: partially full arrays of int
- Implementation 1:

```
public class PartialArrayListOfInt implements ListOfInt {
    private int limit;          // maximal number of elements
    private int[] data;         // elements of the list
    private int num = 0;        // current number of elements
    public PartialArrayListOfInt(int limit) {
        this.limit = limit;
        this.data = new int[limit];
    }
    …
}
```

List ADT: Implementation 1

- Implementation 1 (continued):

```
public class PartialArrayListOfInt implements ListOfInt {   …
    private int[] data;
    private int num = 0;   …
    public int get(int i) {
        if (i < 0 || i >= num) {
            throw new IndexOutOfBoundsException();
        }
        return this.data[i];
    }
    …
}
```

List ADT: Implementation 1

- Implementation 1 (continued):

```
public class PartialArrayListOfInt implements ListOfInt {   …
    private int[] data;
    private int num = 0;   …
    public void set(int i, int elem) {
        if (i < 0 || i >= num) {
            throw new IndexOutOfBoundsException();
        }
        this.data[i] = elem;
    }
    …
}
```

List ADT: Implementation 1

- Implementation 1 (continued):

```
public class PartialArrayListOfInt implements ListOfInt {   …
    private int[] data;
    private int num = 0;   …
    public int size() {
        return this.num;
    }
    public void add(int elem) {
        this.add(this.num, elem);            // insert at end
    }
    …
}
```

List ADT: Implementation 1

- Implementation 1 (continued):

```
public class PartialArrayListOfInt implements ListOfInt {   …
    public void add(int i, int elem) {
        if (i < 0 || i > num) {  throw new Index…Exception();  }
        if (num >= limit) {  throw new RuntimeException("full!");  }
        for (int j = num-1; j >= i; j--) {
            this.data[j+1] = this.data[j];   // move elements right
        }
        this.data[i] = elem;                 // insert new element
        num++;                               // one element more!
    }
    …   }
```

List ADT: Implementation 1

- Implementation 1 (continued):

```
public class PartialArrayListOfInt implements ListOfInt {   …
    public void remove(int i) {
         if (i < 0 || i >= num) {  throw new Index…Exception();  }
        for (int j = i; j+1 < num; j++) {
            this.data[j] = this.data[j+1];   // move elements left
        }
        num--;                                          // one element less!
    }
    // DONE!
}
```

Dynamic Arrays

- arrays are fixed-length
- lists are variable-length
- **Idea:**
  - use an array of (fixed) length & track number of elements
  - extend array as needed by add method

add(23) add(42) add(-3) add(17) add(31)

- **Example:**

num **5**

data

23	**42**	**-3**	**17**	**31**			

List ADT: Design & Implementation 2

- Design 2: dynamic arrays of int
- Implementation 2:

```
public class DynamicArrayListOfInt implements ListOfInt {
    private int limit;              // current maximum number
    private int[] data;             // elements of the list
    private int num = 0;            // current number of elements
    public DynamicArrayListOfInt(int limit) {
        this.limit = limit;
        this.data = new int[limit];
    }
    …
}
```

List ADT: Implementation 2

- Implementation 2 (continued):

```
public void add(int i, int elem) {
    if (i < 0 || i > num) {  throw new Index…Exception();  }
    if (num >= limit) {          // array is full
        int[] newData = new int[2*this.limit];
        for (int j = 0; j < limit; j++) {
            newData[j] = data[j];
        }
        this.data = newData;
        this.limit *= 2;
    }
    …   }      // rest of add method
```

List ADT: Design 2 Revisited

- Design 2 (revisited): symmetric dynamic arrays of int
  - keep startIndex and endIndex of used indices
  - start with startIndex = endIndex = limit / 2
  - i.e., limit / 2 free positions at the beginning
  - i.e., limit / 2 free positions at the end
  - extend array at the beginning when startIndex < 0 needed
  - extend array at the end when endIndex > limit needed
  - shrink array in remove, when
    (endIndex – startIndex) < limit / 4

List ADT: Design 3

- goal is to use list for arbitrary data types
- Design 3: dynamic arrays of objects
- Implementation 3:

How to use with int, double etc.?

```
public class DynamicArrayList implements List {
    private int limit;              // current maximum number
    private Object[] data;          // elements of the list
    private int num = 0;            // current number of elements
    public DynamicArrayListOfInt(int limit) {
        this.limit = limit;
        this.data = new Object[limit];
    } …
}
```

Boxing and Unboxing

- primitive types like int, double, … are not objects!

- Java provides wrapper classes Integer, Double, …
- Example:

```
Integer myInteger = new Integer(13);
int myInt = myInteger.intValue();
```

- transparent due to *automatic boxing* and *unboxing*
- Example:

```
Integer myInteger = 13;
int myInt = myInteger;
```

- useful when e.g. storing int values in a Object[]

List ADT: ArrayList

- Java provides pre-defined symmetric dynamic array list implementation in class java.util.ArrayList
- Example:

```
ArrayList myList = new ArrayList(10);          // initial limit 10
for (int i = 0;  i < 100;  i++) {
    myList.add(i*i);                  // list of squares of 0 … 99
}
System.out.println(myList);
for (int i = 99;  i >= 0;  i--) {
    int n = (Integer) myList.get(i);       // get returns Object
    myList.set(i, n*n);                    // now to the power of 4!
}
```

Generic Types

- 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];
    }
}
```

List ADT: MyArrayList (generic)

- Unsafe type casts avoided when using generic types
- Example:

```
MyArrayList<Integer> myList = new MyArrayList<Integer>();
for (int i = 0;  i < 100;  i++) {
    myList.add(i*i);                  // list of squares of 0 … 99
}
System.out.println(myList);
for (int i = 99;  i >= 0;  i--) {
    int n = myList.get(i);                  // get returns Integer
    myList.set(i, n*n);                     // now to the power of 4!
}
```

List ADT: ArrayList (generic)

- Unsafe type casts avoided when using generic types
- Example:

```
ArrayList<Integer> myList = new ArrayList<Integer>();
for (int i = 0;  i < 100;  i++) {
    myList.add(i*i);                    // list of squares of 0 … 99
}
System.out.println(myList);
for (int i = 99;  i >= 0;  i--) {
    int n = myList.get(i);              // get returns Integer
    myList.set(i, n*n);                 // now to the power of 4!
}
```

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 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 static <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 static <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!