Software Development and Abstract Data Types

Chapters 2, 4, 10

Phases of Software Development

1. Problem statement
2. Specification of the task
3. Design of a solution for each task
4. Implementation of a solution
5. Testing and Debugging
6. Documentation and Maintenance

Specification of a Method

- Short introduction/summary
- Description of parameters
- Preconditions
- Postconditions or Returns
- Exceptions thrown
- Special notes on usage

Example

area

public static double area(double radius)

Parameters:
radius – radius of a circle in inches

Preconditions:
radius > 0

Returns:
Returns the area of the circle with the given radius.

Throws: IllegalRadius
Indicates that the radius is non positive.

Efficiency

- What's the best way to program an algorithm?
- Efficiency in terms of
  - Time (running time)
  - Space (memory requirements)
  - Resources (Input/Output such as disk I/O)
- Most analysis focuses on time efficiency

Order of Complexity

- Measuring running time(Benchmark, Analysis)
- Count the number of “operations”
- What is an “operation”?
- Example:
  C = A + B;
- 1 operation?
- 4 operations?
  (LOAD A, LOAD B, ADD, STORE C)

Order of Complexity (cont'd)

```
for (x=1; x<=n; x++)
  c = a + b;
```

# of ops: n 4n 3n+2 ?

```
for (x=1; x<=n; x++)
{
  c = a + b;
  d = e + f;
}
```

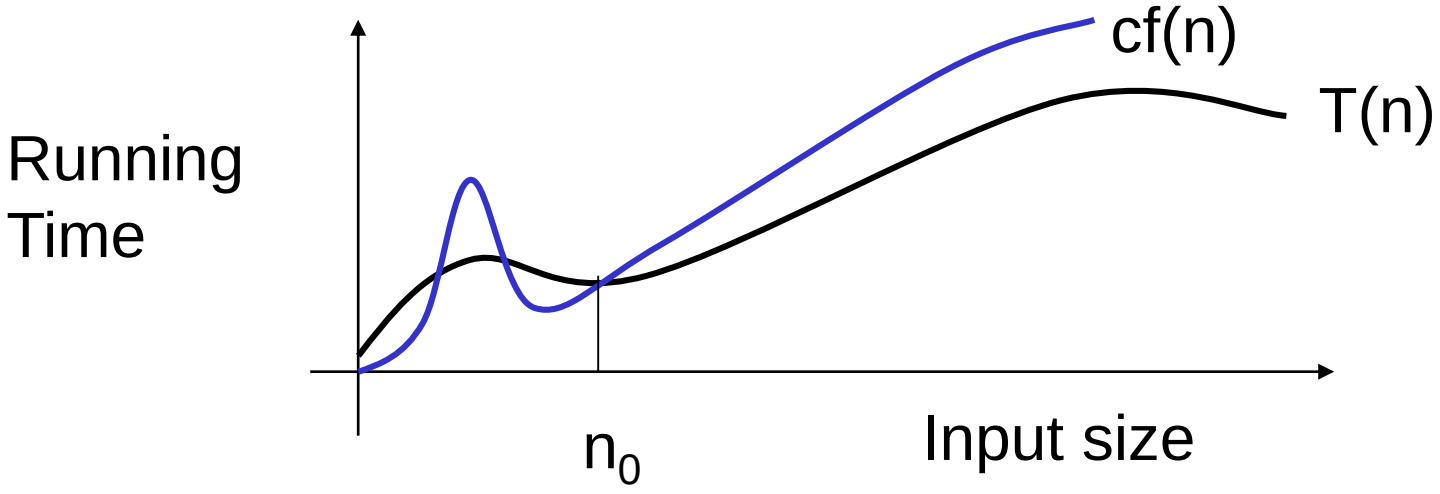
# of ops: 2n 8n 4n+2 ?

Big O Notation(upper bound)

- Given an algorithm/routine processing n inputs, what is the number of operations as a function of n?
- Big O expresses this function as a simplified function of n (input size)
- O(n) – a function of n
- $O(n^2)$ – a function of n^2

Big O Notation (cont'd)

- Let T(n) and f(n) be functions mapping nonnegative integers to real numbers.
- We say that T(n) is O(f(n)) if there is a real constant c > 0 and an integer constant $n_0 \geq 1$ such that $T(n) \leq cf(n)$ for every integer $n \geq n_0$.



Big O Examples

```
for (x=1; x<=n; x++)
  c = a + b;
```

n operations

O(n)

```
for (x=1; x<=n; x++)
{
  c = a + b;
  d = e + f;
}
```

2n operations

O(2n) = O(n)

Big O Examples (cont'd)

```
for (x=1; x<=n; x++)
     c = a + b;
c = c + d;
```

n+1 operations

O(n+1) = O(n)

```
for (x=1; x<=n; x=x*2)
  c = a + b;
```

Assume n is a power of 2 for simplicity.

$\log_2 n + 1$ operations

$O(\log_2 n + 1) = O(\log n)$

Big O Examples (cont'd)

```
for (x=1; x<=n; x++) {
     d = e + f;
     for (y=n; y>0; y--) {
          c = a + b;
          c = c * 2;
          d = c + d;
     }
}
```

$3n^2+n$ operations

$O(3n^2+n) = O(n^2)$

Worst-, Average-, Best-Case

- Many algorithms give their worst-case performance in terms of big-O.
- Other measures include average-case or best-case analysis.
- Example: Sequential Search on n elements

  This time, an operation is a "comparison".

  – Worst Case: O(n)
  – Average Case: O(n/2) = O(n)
  – Best Case: O(1)

One more example

- Consider an algorithm that processes n data items in one minute. How long will it take to process 32 times as many items on the same computer using the same algorithm?

  original_time * new_number_of_ops / original_number_of_ops

- # of operations APPROX TIME
  - $n = O(n)$
  - $n^2 = O(n^2)$
  - $2^n = O(2^n)$

Another view

- What is the maximum number of inputs that can be processed by an algorithm in one hour if one operation takes 1 microsecond?
- Number of Ops — Max. Problem Size
  - $400n = O(n)$ — **n =**
  - $2n^2 = O(n^2)$ — **n =**
  - $2^n = O(2^n)$ — **n =**

Misuse of the Big O!

- Number of Operations: $10^{10}n$

  Is this O(n)? (probably not)
- What's considered an efficient measure for an algorithm?

  Yes: O(log n), O(n), O(n log n), even $O(n^2)$ sometimes

  No: $O(n^{100})$, $O(2^n)$
- Is O(1)+O(1)+ ….. +O(1) = O(1) ?

Tale of Two Algorithms

- Given an array X storing n numbers, we want to compute an array A such that A[i] is the average of elements X[0],…,X[i], for i=0,…,n-1.
- Calculating “prefix averages”
- Used in economics: Given year-by-year returns on a mutual fund, an investor will want to know the average return over the past 3 years, 5 years, 10 years, etc.

First Attempt

```
prefixAverages1(X)
    Let A[ ] be an array of n numbers
    for i ← 0 to n-1 do
        sum ← 0
        for j ← 0 to i do
            sum ← sum + X[ j ]
        A[ i ] ← sum/(i + 1)
    return array A
```

CAREFUL!

Order of Complexity?

An Observation

- In the original algorithm, a lot of computations are recomputed over and over again.
- A[i-1] = (X[0] + X[1] + … + X[i-1]) / i
- A[i] = (X[0] + X[1] + … + X[i-1] + X[i]) / (i+1)
- Let the prefix sum
  S_i = X[0] + X[1] + … + X[i-1] + X[i]
- A[i-1] = (S_{i-1}) / i
- A[i] = (S_{i-1} + X[i])/ (i+1)

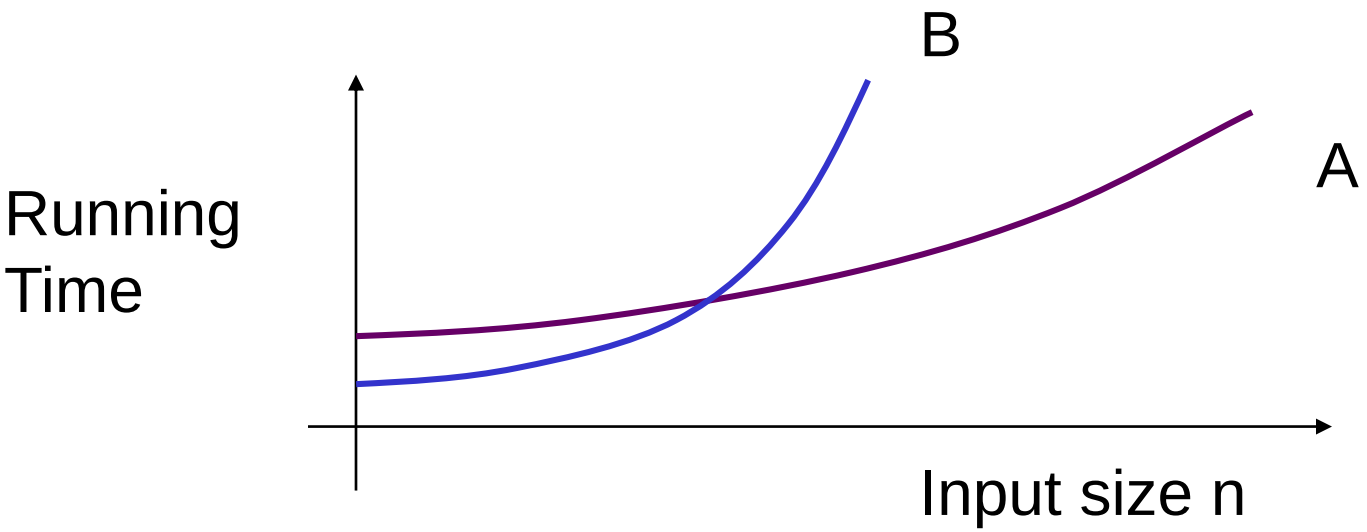
Second Attempt

```
prefixAverages2(X)
    Let A[ ] be an array of n numbers
    sum ← 0
    for i ← 0 to n-1 do
        sum ← sum + X[ i ]
        A[ i ] ← sum/(i + 1)
    return array A
```

Order of Complexity?

Competing Algorithms

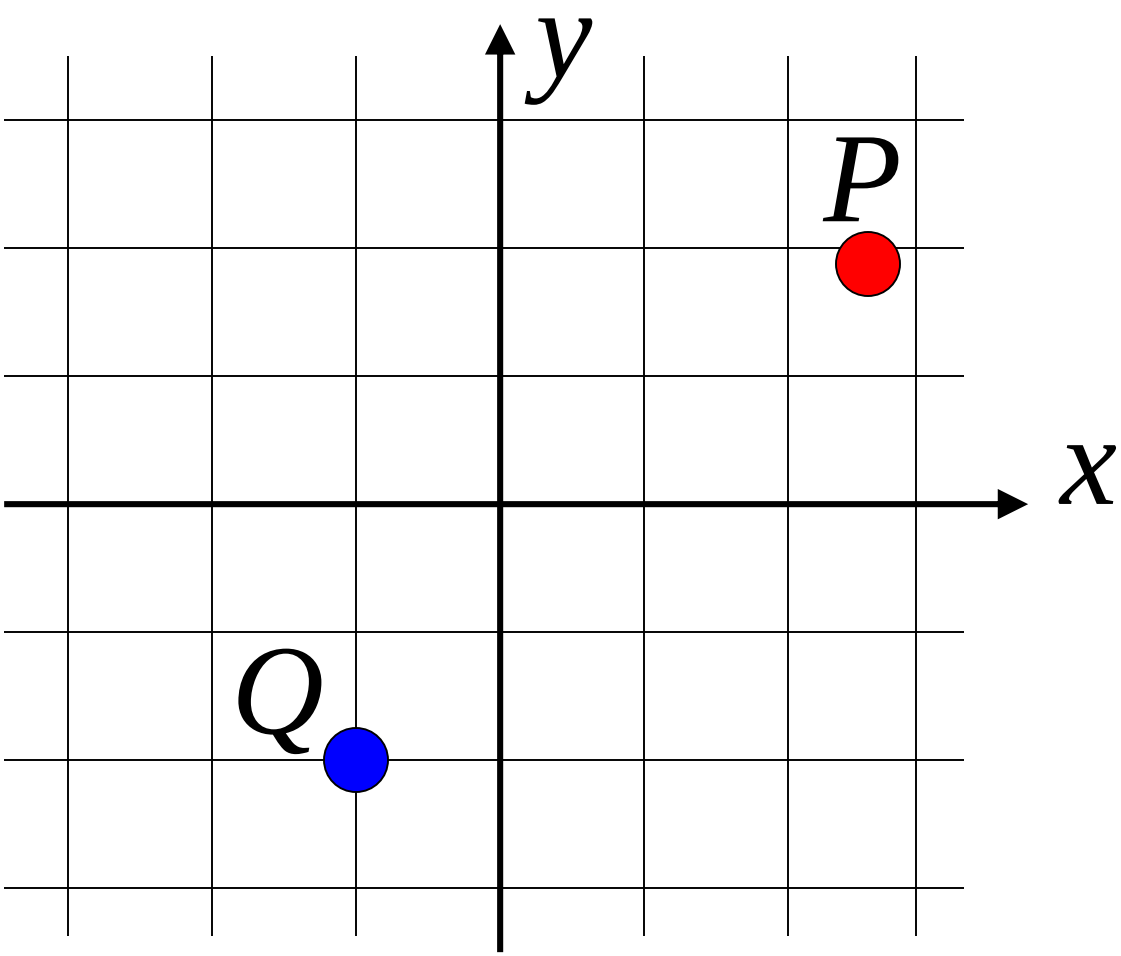
- Algorithm A: O(n log n)
- Algorithm B: $O(n^2)$
- Which is more efficient?



Abstract Data Types

- Information hiding – separation of specification from implementation
- Abstract Data Type –
  A mathematical specification of a data structure that specifies:
  - the type of data stored
  - the operations supported on that data
  - the types of parameters of the operations
- An ADT specifies what, but not how

Example 1: Location ADT



Specification – p.63

Constructor

`public Location(double xInitial, double yInitial)`

Construct a location with specified coordinates.

Parameters:

xInitial – the initial x coordinate of this Location

yInitial – the initial y coordinate of this Location

Postcondition:

This Location has been initialized at the given coordinates.

Specification (cont'd)

clone

`public Object clone()`

Generate a copy of this Location.

Returns:

The return value is a copy of this Location.

Special note:

The return value must be typecast to a Location before it can be used.

Specification (cont'd)

distance

```
public static double distance
  (Location p1, Location p2)
```

Compute the distance between two Locations.

Parameters:
p1 – the first Location
p2 – the second Location

Returns: The distance between p1 and p2.

Special Note: Returns Double.NaN if either Location is null.

Specification (cont'd)

equals

`public boolean equals (Object obj)`

Compare this Location to another for equality.

Parameters:

obj – an object with which this Location is compared

Returns: True if obj refers to the same Location as this Location object. False otherwise.

Special Note: Returns false if obj is null or not a Location object.

Specification (cont'd)

getX (and getY)

`public double getX( )  ( or getY() )`

Get the x (or y) coordinate of this Location

Returns: the x (or y) coordinate of this location

Specification (cont'd)

midpoint

```
public static Location midpoint
  (Location p1, Location p2)
```

Generates and returns a Location halfway between two Locations

Parameters:
p1 – the first Location
p2 – the second Location

Returns: a Location halfway between p1 and p2

Special note: Returns null if either p1 or p2 is null.

Specification (cont'd)

rotate90

`public void rotate90()`

Rotate this Location 90 degrees in a clockwise fashion around the origin

Postcondition: This Location has been rotated clockwise 90 degrees around the origin

Specification (cont'd)

shift

```
public void shift(double xAmount,
  double yAmount)
```

Move this location by given amounts along the x and y axes.

Postcondition: This location has been moved by the given amounts along the two axes.

Special note: (see text)

Specification (cont'd)

toString

`public String toString()`

Generate a string representation of this Location object.

Returns: a string representation of this Location

Method Types

- Accessor method – returns information about the state of an object without altering the state of the object [getX, getY]
- Modification (mutator) method – may change the state of an object through its invocation [rotate90, shift]
- Static method – returns information about a set of one or more objects [distance, midpoint]
- Support method – provides common support for objects [the constructor, clone, equals, toString]

Implementation – p. 65

```
public class Location implements Cloneable
{
    private double x;  // state variables
    private double y;

    public Location (double xInitial,
      double yInitial) // constructor
    {
        x = xInitial;
        y = yInitial;
    }
```

Implementation (cont'd)

```
public Object clone()
{
    Location answer;
    try {
        answer = (Location)super.clone();
    }
    catch (CloneNotSupportedException e){
        throw new RunTimeException("…");
    }
    return answer;
}
```

Implementation (cont'd)

```
public static double distance
  (Location p1, Location p2) {
    double a, b, c_squared;
    if ((p1==null)||(p2==null))
        return Double.NaN;
    a = p1.x - p2.x;
    b = p1.y - p2.y;
    c_squared = a*a + b*b;
    return Math.sqrt(c_squared);
}
```

Implementation (cont'd)

```
public boolean equals(Object obj)
{
     if (obj instanceof Location)
     {
          Location candidate =
             (Location) obj;
          return (candidate.x == x) &&
                    (candidate.y == y);
     }
     else
          return false;
}
```

Implementation (cont'd)

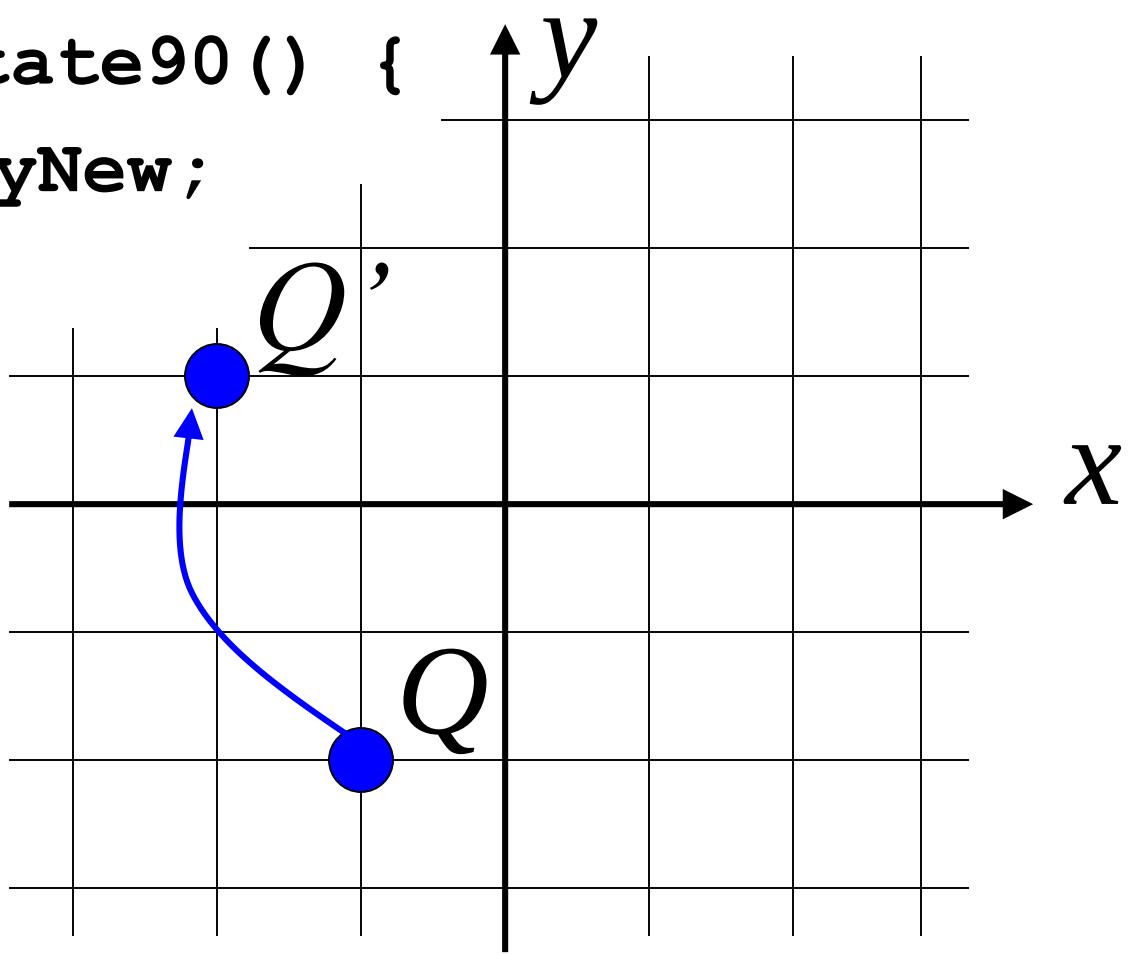
```
public double getX()
{
    return x;
}
public double getY()
{
    return y;
}
```

Implementation (cont'd)

```
public static Location midpoint
  (Location p1, Location p2) {
    double xMid, yMid;
    if ((p1==null)||(p2==null))
        return null;
    xMid = (p1.x/2)+(p2.x/2);
    yMid = (p1.y/2)+(p2.y/2);
    Location answer =
        new Location(xMid, yMid);
    return answer;
}
```

Implementation (cont'd)

```
public void rotate90() {
   double xNew, yNew;
   xNew = y;
   yNew = -x;
   x = xNew;
   y = yNew;
}
```



Implementation (cont'd)

```
  public void shift(double xAmount,
    double yAmount) {
    x += xAmount;
    y += yAmount;
  }
  public String toString()
  {
    return "(x=" + x + "  y=" + y + ")";
  }
} // end class Location
```

Use of Location ADT

```
class LocationTester {
  public static void main(String[] args)
  {
     Location server = new Location(2.0,4.5);
     Location mobile = (Location) server.clone();
     mobile.shift(-3.0, -3.0);
     System.out.println("The devices are " +
          Location.distance(server, mobile) +
          " blocks away from each other.");


  etc.
```

Example 2: Bag ADT

- Bag: A collection of items of the same type.
- A specific item may appear any number of times in a bag.
- A bag is not a set.
- A bag is not ordered.
- The items of a bag will be stored in an array (for now).
- A bag may have limited size due to memory constraints.

Specification – p.107

Constructors

`public IntArrayBag( )`

`public IntArrayBag(int initialCapacity)`

Construct a bag of integers with capacity 10 (default) or initialCapacity.

Precondition: initialCapacity $\geq$ 0

Postcondition: This bag is empty and has an initial capacity.

Throws: IllegalArgumentException, OutOfMemoryError

Specification (cont'd)

getCapacity

`public int getCapacity()`

Determines the current capacity of this bag.

Returns: the current capacity of this bag.

size

`public int size()`

Determines the number of elements in this bag.

Returns: the number of elements in this bag.

Specification (cont'd)

ensureCapacity

```
public void ensureCapacity
  (int minimumCapacity)
```

Change the current capacity of this bag.

Parameters: minimumCapacity – the new capacity for this bag

Postcondition: This bag's capacity has been changed to minimumCapacity, if this is greater than its current capacity.

Throws: OutOfMemoryException

Specification (cont'd)

add

`public void add(int element)`

Add a new element to this bag.

Parameters:
element – the new element being added to the bag

Postcondition: A new copy of the element has been added to this bag.

Special Note: If the new element cannot be stored in the bag at its current capacity, the bag's capacity is increased.

Throws: OutOfMemoryError

Specification (cont'd)

addAll

`public void addAll(IntArrayBag addend)`

Add the contents of another bag to this bag.

Parameters:

addend – a bag whose contents will be added to this bag

Postcondition: This bag will contain its original contents and the contents of the other bag.

Throws: NullPointerException, OutOfMemoryError

Specification (cont'd)

union

`public static IntArrayBag union (IntArrayBag b1, IntArrayBag b2)`

Create a new bag that contains all the elements from two other bags.

Parameters:
b1 – the first of two bags
b2 – the second of two bags

Precondition: neither b1 nor b2 is null

Returns: A new bag that is the union of b1 and b2

Throws: NullPointerException, OutOfMemoryError

Specification (cont'd)

countOccurrences

`public int countOccurrences(int target)`

Count the number of occurrences of a particular value in this bag.

Parameters:
target – the element that needs to be counted

Returns: The number of times the target is in this bag.

Specification (cont'd)

remove

`public boolean remove(int target)`

Remove one copy of a specified element from this bag.

Parameter:

target – the element search for in this bag for removal

Postcondition: If the target was found in this bag, then one copy is removed and the method returns true. Otherwise, this bag remains unchanged and the method returns false.

Specification (cont'd)

trimToSize

`public void trimToSize()`

Reduce the current capacity of this bag to its actual size.

Postcondition: This bag's capacity has been changed to its current size.

Throws: OutOfMemoryError

Specification (cont'd)

clone

`public Object clone()`

Generate a copy of this bag.

Returns:

The return value is a copy of this bag.

Special note:

The return value must be typecast to an IntArrayBag before it can be used.

Throws: OutOfMemoryError

Invariant of the ADT

- An invariant is a condition that remains true before and after some operation is performed (i.e. precondition = postcondition)
- All the methods of an ADT (except the constructors) must ensure that the invariant of the ADT is valid before and after execution.

Invariant of the Bag ADT

- Let data = the array that holds the bag items
- Let data.length = the capacity of the array
- Let manyItems = the number of items in the bag (i.e. its size)
- INVARIANTS:
  - The elements of a bag are stored in data[0..manyItems-1].
  - manyItems ≤ data.length

Implementation – p. 113

```
public class IntArrayBag
  implements Cloneable
{
    private int[] data;
    private int manyItems;
```

Implementation (cont'd)

```
public IntArrayBag(int initialCapacity) {
  if (initialCapacity < 0)
     throw new IllegalArgumentException();
  manyItems = 0;
  data = new int[initialCapacity];
}
public IntArrayBag() {
  manyItems = 0;
  data = new int[10];
}
```

Implementation (cont'd)

```
public int getCapacity() {
  return data.length;
}

public int size() {
  return manyItems;
}
```

Order of Complexity?

Sidenote: System.arraycopy

```
System.arraycopy(src,si,dest,di,n);
```

src = reference of array to copy FROM

si = starting position to copy FROM

dest = reference of array to copy TO

di = starting position to copy TO

n = how many elements to copy

Implementation (cont'd)

```
public void ensureCapacity(int
  minimumCapacity) {
  int biggerArray[];
  if (data.length < minimumCapacity) {
     biggerArray = new
          int[minimumCapacity];
     System.arrayCopy(data, 0,
          biggerArray, 0, manyItems);
     data = biggerArray; // previous data?
  }
} Order of Complexity?
```

Implementation (cont'd)

```
public void add(int element) {
  if (manyItems == data.length)
     ensureCapacity(manyItems*2+1);
  data[manyItems] = element;
  manyItems++;
}
```

Order of Complexity?

Implementation (cont'd)

```
public void addAll(IntArrayBag addend) {
  ensureCapacity(manyItems +
     addend.manyItems);
  System.arraycopy(addend.data, 0, data,
     manyItems, addend.manyItems);
  manyItems += addend.manyItems;
}
```

Order of Complexity?

Implementation (cont'd)

```
public static IntArrayBag union
  (IntArrayBag b1, IntArrayBag b2) {
  IntArrayBag answer = new IntArrayBag
     (b1.getCapacity()+ b2.getCapacity());
  System.arraycopy(b1.data,0,answer.data,
     0,b1.manyItems);
  System.arraycopy(b2.data,0,answer.data,
     b1.manyItems, b2.manyItems);
  answer.manyItems =
     b1.manyItems + b2.manyItems;
  return answer;
}
```

Order of Complexity?

Implementation (cont'd)

```
public int countOccurrences(int target)
{
  int answer = 0;
  int index;
  for (index = 0; index < manyItems;
     index++)
  {
     if (target == data[index])
          answer++;
  }
  return answer;
}
```

Order of Complexity?

Implementation (cont'd)

```
public boolean remove(int target) {
  int index = 0;
  while ((index < manyItems) &&
         (target != data[index]))
    index++;
  if (index == manyItems)
    return false;
  else {
    manyItems--;
    data[index] = data[manyItems];
    return true;
  }
}
```

Order of Complexity?

Implementation (cont'd)

```
public void trimToSize() {
  int trimmedArray[];
  if (data.length != manyItems) {
   trimmedArray = new int[manyItems];
   System.arraycopy(data,0,
     trimmedArray, 0,manyItems);
   data = trimmedArray; // previous data?
  }
}
```

Order of Complexity?

Implementation (cont'd)

```
  public Object clone() {
    IntArrayBag answer;
    try {
      answer = (IntArrayBag)super.clone();
    }
    catch (CloneNotSupportedException e) {
      throw new RunTimeException("...");
    }
    answer.data = (int []) data.clone();
    return answer;
  }
} // end class IntArrayBag
```

Order of Complexity?

Order of Complexity

- **Given a bag with n items and capacity c.**
- **add**
  - **Without a capacity increase: O(1)**
  - **With a capacity increase: O(n)**
- **countOccurrences O(n)**
- **getCapacity O(1)**
- **remove O(n)**
- **clone O(c)**