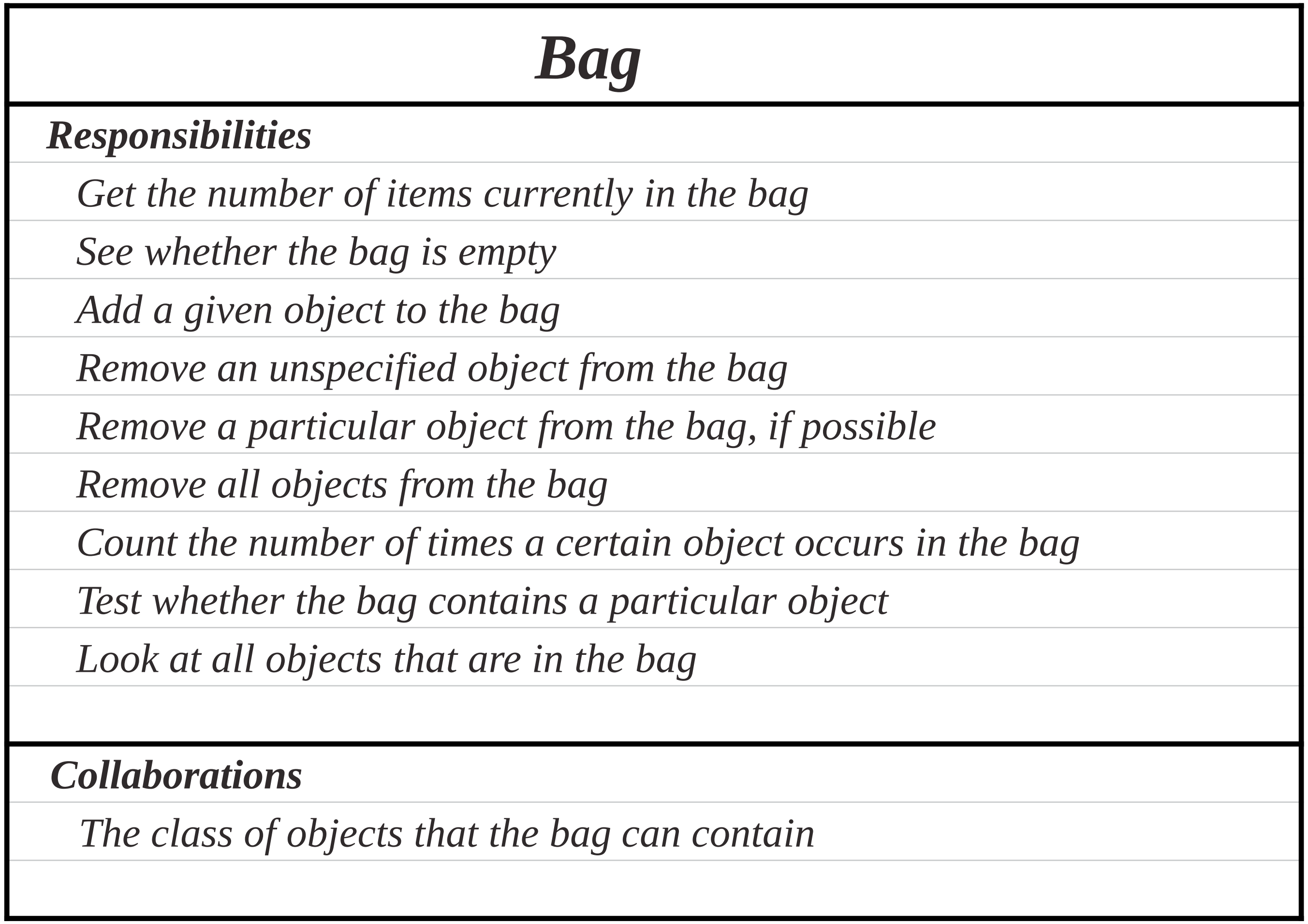
Class 02 – ADTs, Bags, and Algorithm Efficiency

CSIS 3475 Data Structures and Algorithms

The ADT Bag

- Definition
  - A finite collection of objects in no particular order
  - Can contain duplicate items
- Possible behaviors
  - Get number of items
  - Check for empty
  - Add, remove objects

CRC Card



Bag

Responsibilities

Get the number of items currently in the bag

See whether the bag is empty

Add a given object to the bag

Remove an unspecified object from the bag

Remove a particular object from the bag, if possible

Remove all objects from the bag

Count the number of times a certain object occurs in the bag

Test whether the bag contains a particular object

Look at all objects that are in the bag

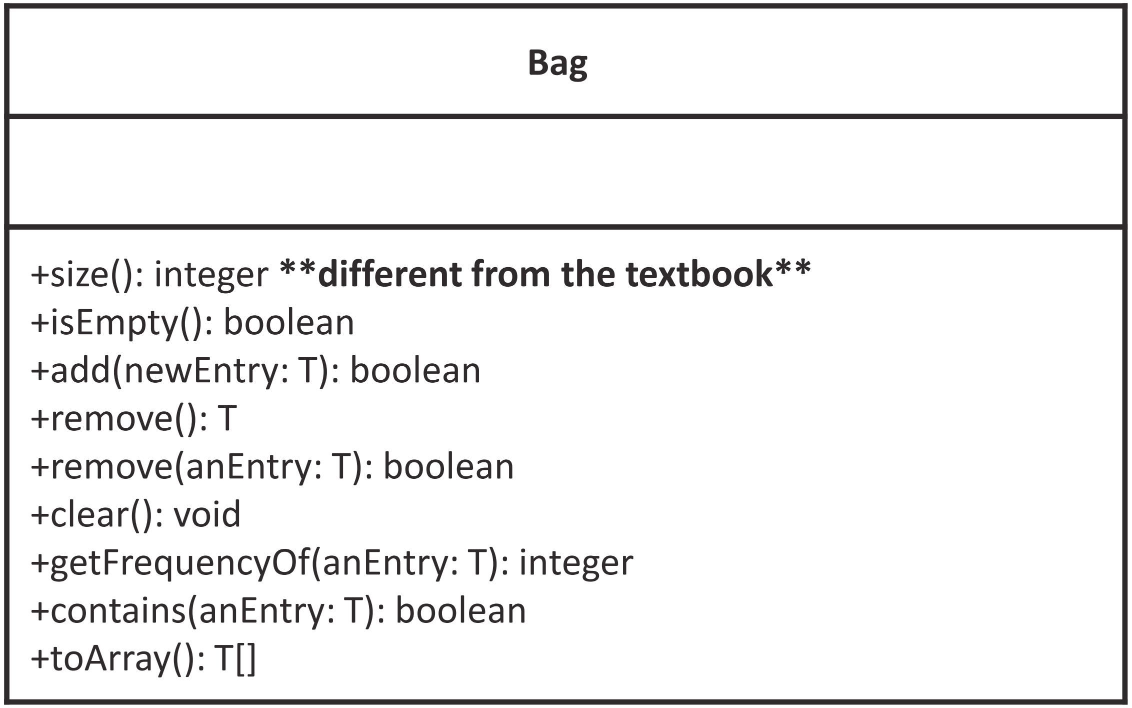
Collaborations

The class of objects that the bag can contain

Specifying a Bag

- Describe its data and specify in detail the methods
- Options that we can take when add cannot complete its task:
    - Do nothing
    - Leave bag unchanged, but signal client
- Note which methods change the object or do not

Using UML Notation to Specify a Class



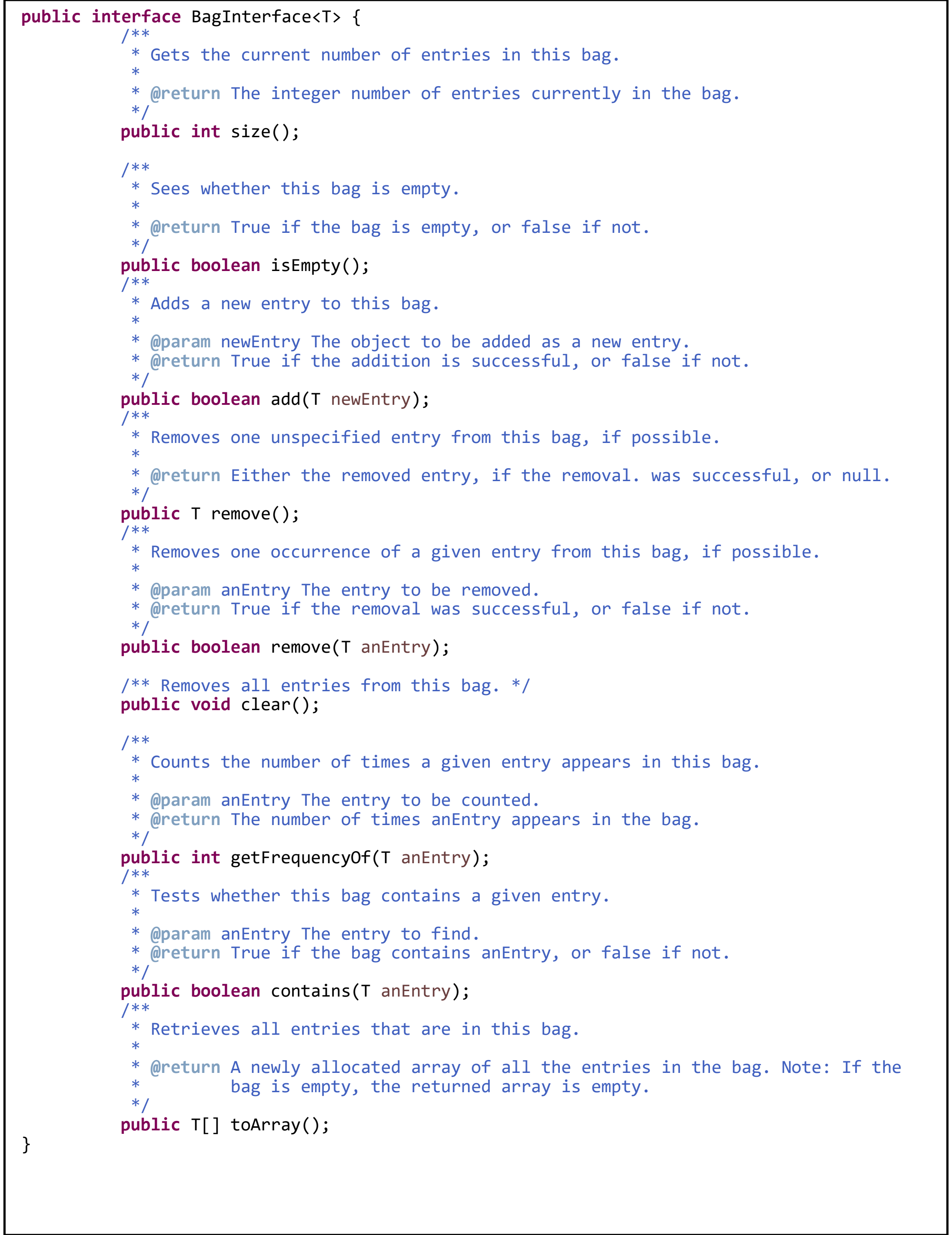
Bag

+size(): integer ****different from the textbook****
+isEmpty(): boolean
+add(newEntry: T): boolean
+remove(): T
+remove(anEntry: T): boolean
+clear(): void
+getFrequencyOf(anEntry: T): integer
+contains(anEntry: T): boolean
+toArray(): T[]

Design Decision

- What to do for unusual conditions?
- Assume it won’t happen
- Ignore invalid situations
- Guess at the client’s intention
- Return value that signals a problem
- Return a boolean
- Throw an exception

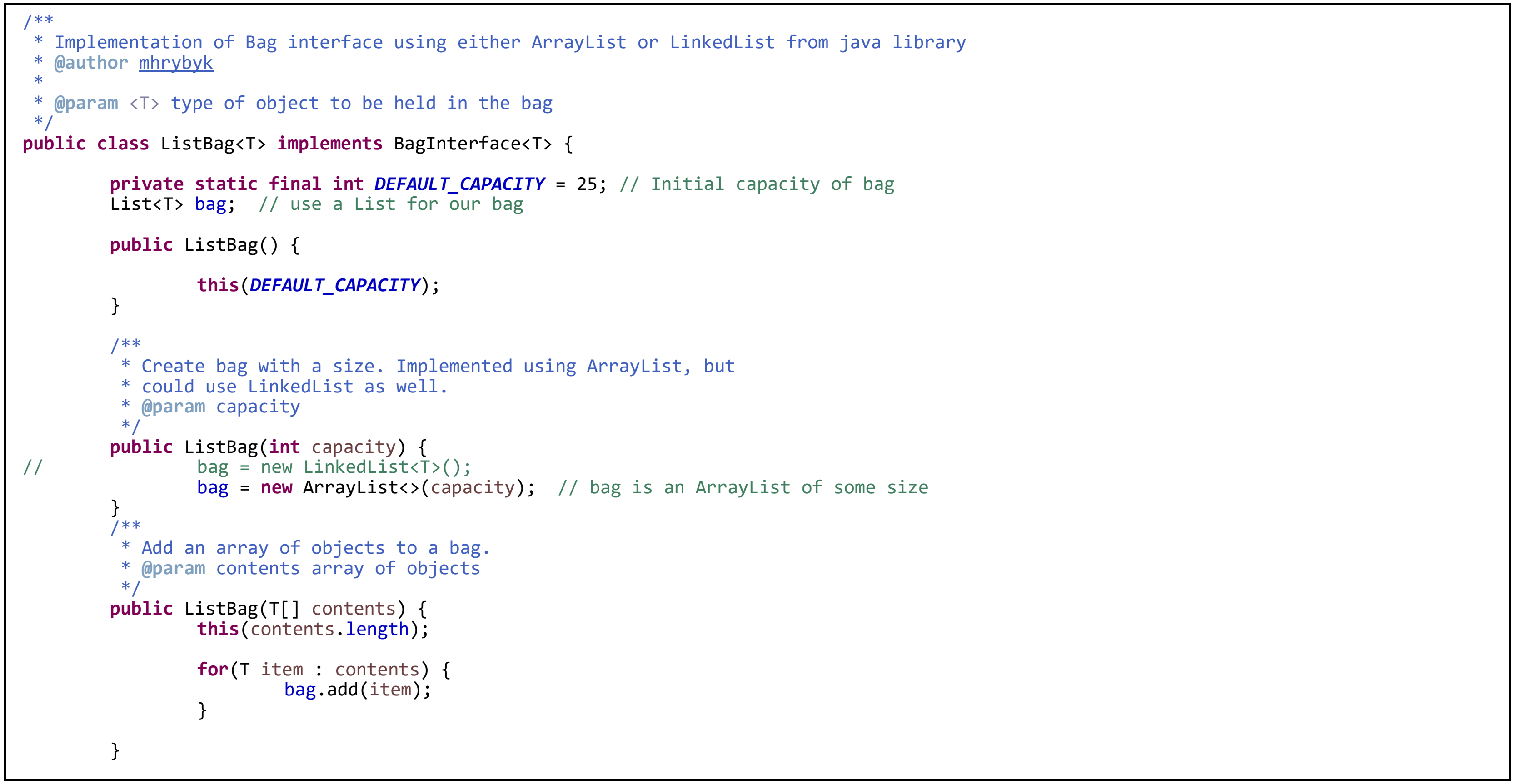
Bag Interface



```
public interface BagInterface<T> {
          /**
           * Gets the current number of entries in this bag.
           *
           * @return The integer number of entries currently in the bag.
           */
          public int size();

          /**
           * Sees whether this bag is empty.
           *
           * @return True if the bag is empty, or false if not.
           */
          public boolean isEmpty();
          /**
           * Adds a new entry to this bag.
           *
           * @param newEntry The object to be added as a new entry.
           * @return True if the addition is successful, or false if not.
           */
          public boolean add(T newEntry);
          /**
           * Removes one unspecified entry from this bag, if possible.
           *
           * @return Either the removed entry, if the removal. was successful, or null.
           */
          public T remove();
          /**
           * Removes one occurrence of a given entry from this bag, if possible.
           *
           * @param anEntry The entry to be removed.
           * @return True if the removal was successful, or false if not.
           */
          public boolean remove(T anEntry);

          /** Removes all entries from this bag. */
          public void clear();

          /**
           * Counts the number of times a given entry appears in this bag.
           *
           * @param anEntry The entry to be counted.
           * @return The number of times anEntry appears in the bag.
           */
          public int getFrequencyOf(T anEntry);
          /**
           * Tests whether this bag contains a given entry.
           *
           * @param anEntry The entry to find.
           * @return True if the bag contains anEntry, or false if not.
           */
          public boolean contains(T anEntry);
          /**
           * Retrieves all entries that are in this bag.
           *
           * @return A newly allocated array of all the entries in the bag. Note: If the
           *         bag is empty, the returned array is empty.
           */
          public T[] toArray();
}
```

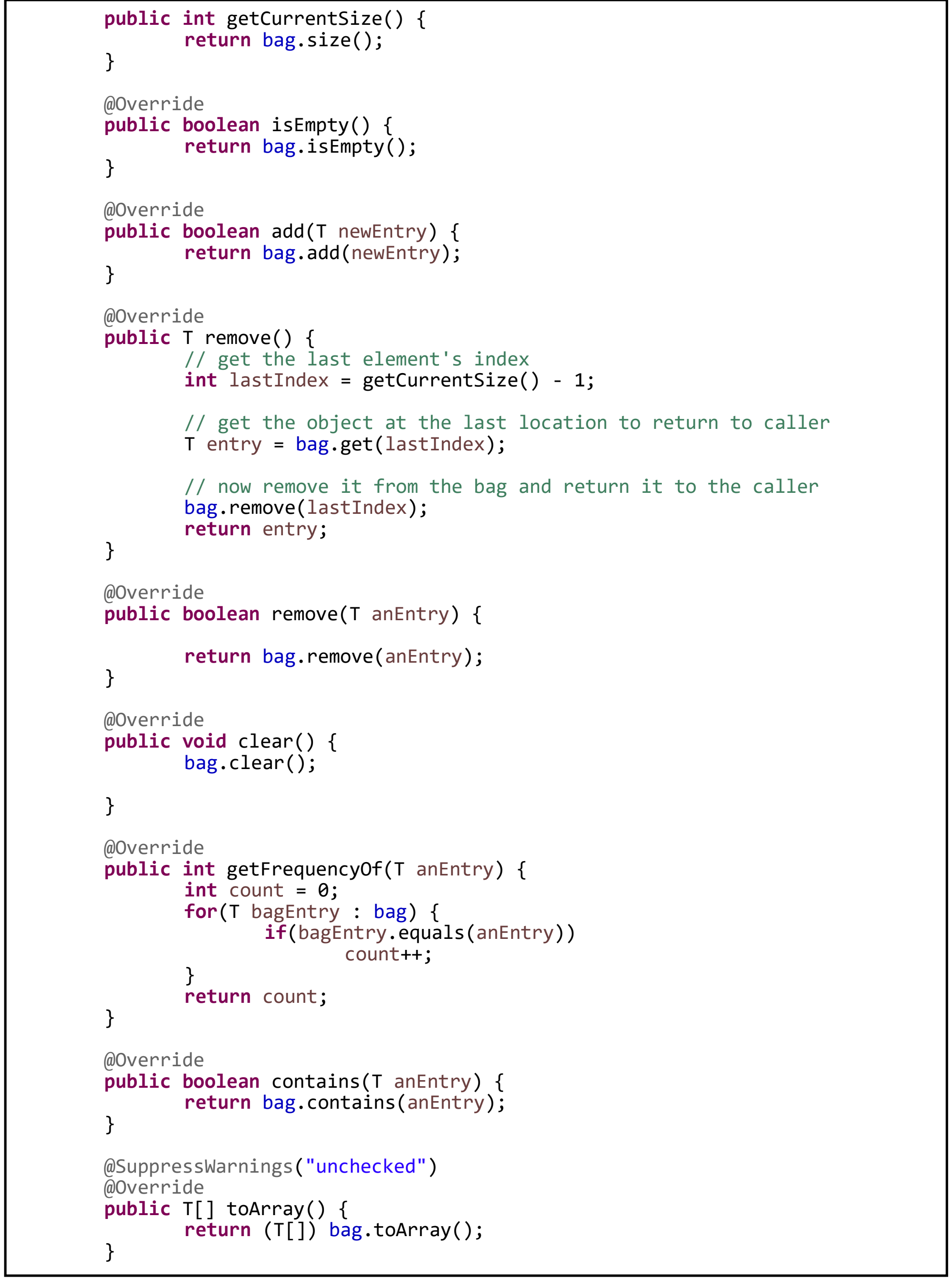
Implementing a Bag using Java Library

- LinkedBag uses an internal Java List
- List is an interface.
- Use ArrayList or LinkedList



```java
/**
 * Implementation of Bag interface using either ArrayList or LinkedList from java library
 * @author mhrybyk
 *
 * @param <T> type of object to be held in the bag
 */
public class ListBag<T> implements BagInterface<T> {

        private static final int DEFAULT_CAPACITY = 25; // Initial capacity of bag
        List<T> bag;  // use a List for our bag

        public ListBag() {

                this(DEFAULT_CAPACITY);
        }

        /**
         * Create bag with a size. Implemented using ArrayList, but
         * could use LinkedList as well.
         * @param capacity
         */
        public ListBag(int capacity) {
//              bag = new LinkedList<T>();
                bag = new ArrayList<>(capacity);  // bag is an ArrayList of some size
        }
        /**
         * Add an array of objects to a bag.
         * @param contents array of objects
         */
        public ListBag(T[] contents) {
                this(contents.length);

                for(T item : contents) {
                        bag.add(item);
                }

        }
```

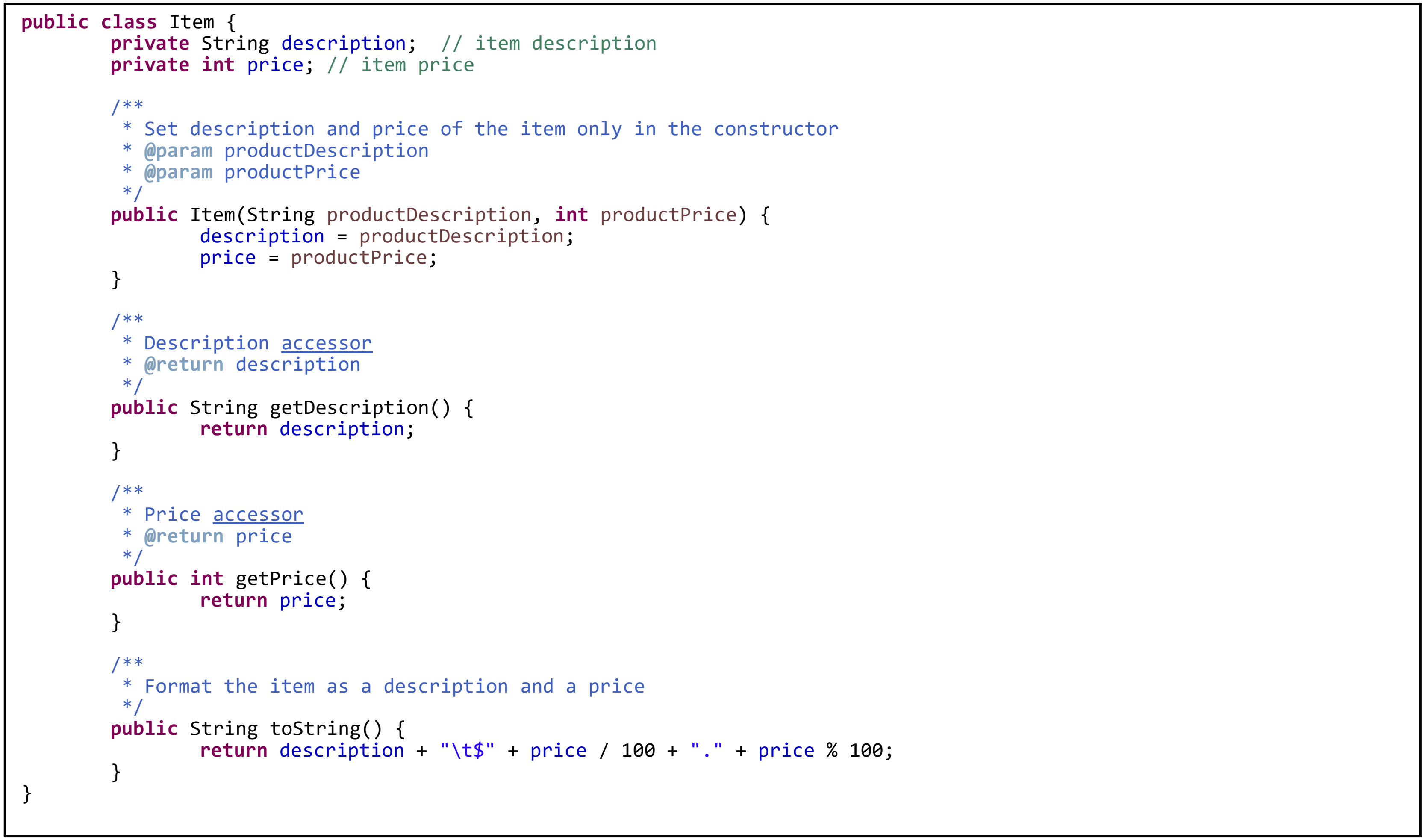
LinkedBag methods



```java
public int getCurrentSize() {
    return bag.size();
}

@Override
public boolean isEmpty() {
    return bag.isEmpty();
}

@Override
public boolean add(T newEntry) {
    return bag.add(newEntry);
}

@Override
public T remove() {
    // get the last element's index
    int lastIndex = getCurrentSize() - 1;

    // get the object at the last location to return to caller
    T entry = bag.get(lastIndex);

    // now remove it from the bag and return it to the caller
    bag.remove(lastIndex);
    return entry;
}

@Override
public boolean remove(T anEntry) {

    return bag.remove(anEntry);
}

@Override
public void clear() {
    bag.clear();

}

@Override
public int getFrequencyOf(T anEntry) {
    int count = 0;
    for(T bagEntry : bag) {
        if(bagEntry.equals(anEntry))
            count++;
    }
    return count;
}

@Override
public boolean contains(T anEntry) {
    return bag.contains(anEntry);
}

@SuppressWarnings("unchecked")
@Override
public T[] toArray() {
    return (T[]) bag.toArray();
}
```

Use of Bag – Online Shopper

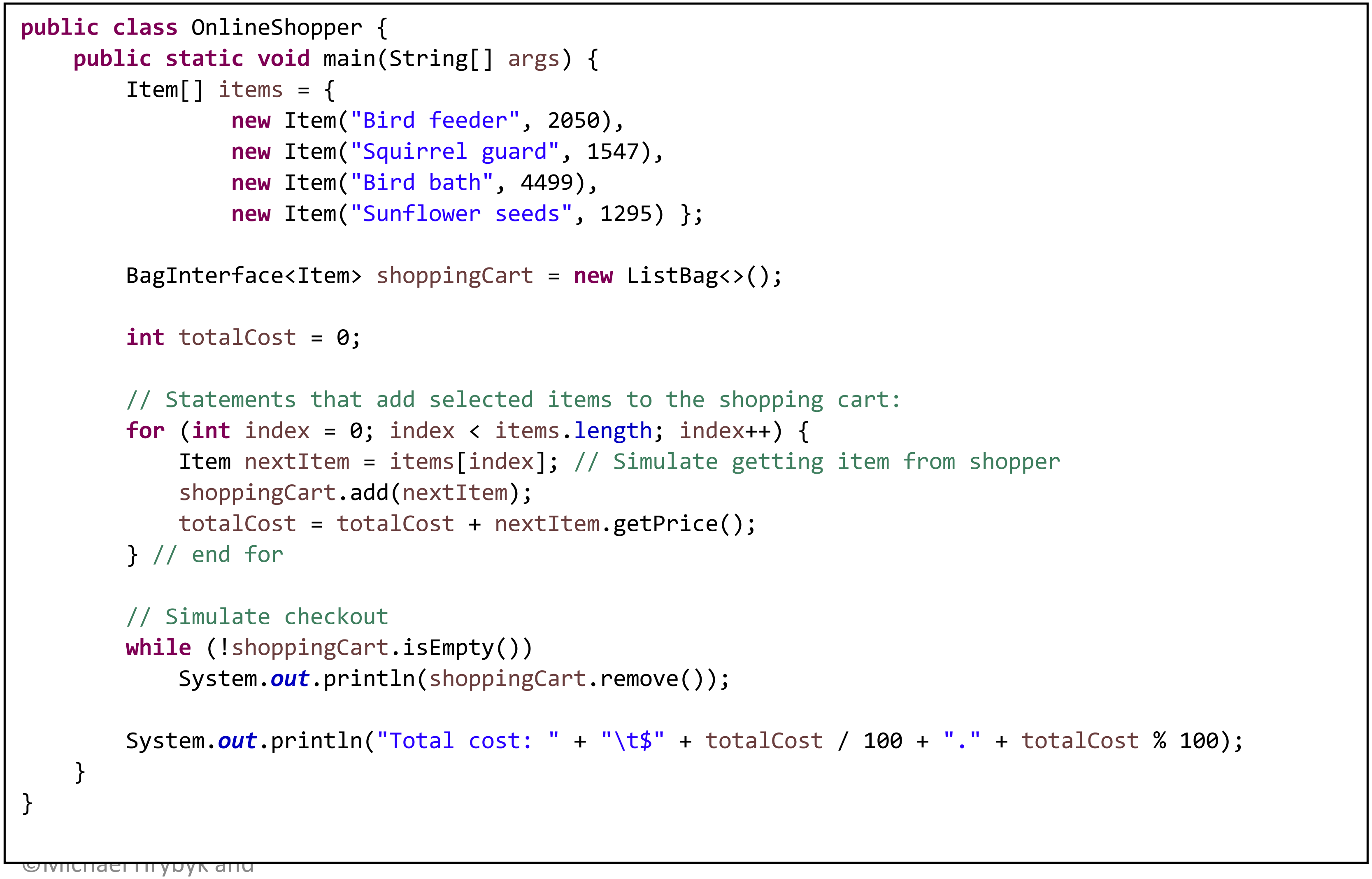
- Purchase an item (see class definition below)
- Put it in a Bag
- Check out by removing them from the bag and adding up the prices



```java
public class Item {
        private String description;  // item description
        private int price; // item price

        /**
         * Set description and price of the item only in the constructor
         * @param productDescription
         * @param productPrice
         */
        public Item(String productDescription, int productPrice) {
                description = productDescription;
                price = productPrice;
        }

        /**
         * Description accessor
         * @return description
         */
        public String getDescription() {
                return description;
        }

        /**
         * Price accessor
         * @return price
         */
        public int getPrice() {
                return price;
        }

        /**
         * Format the item as a description and a price
         */
        public String toString() {
                return description + "\t$" + price / 100 + "." + price % 100;
        }
}
```

OnLine Shopper

- Put items in the bag – use of ListBag class
- Checkout, removing them



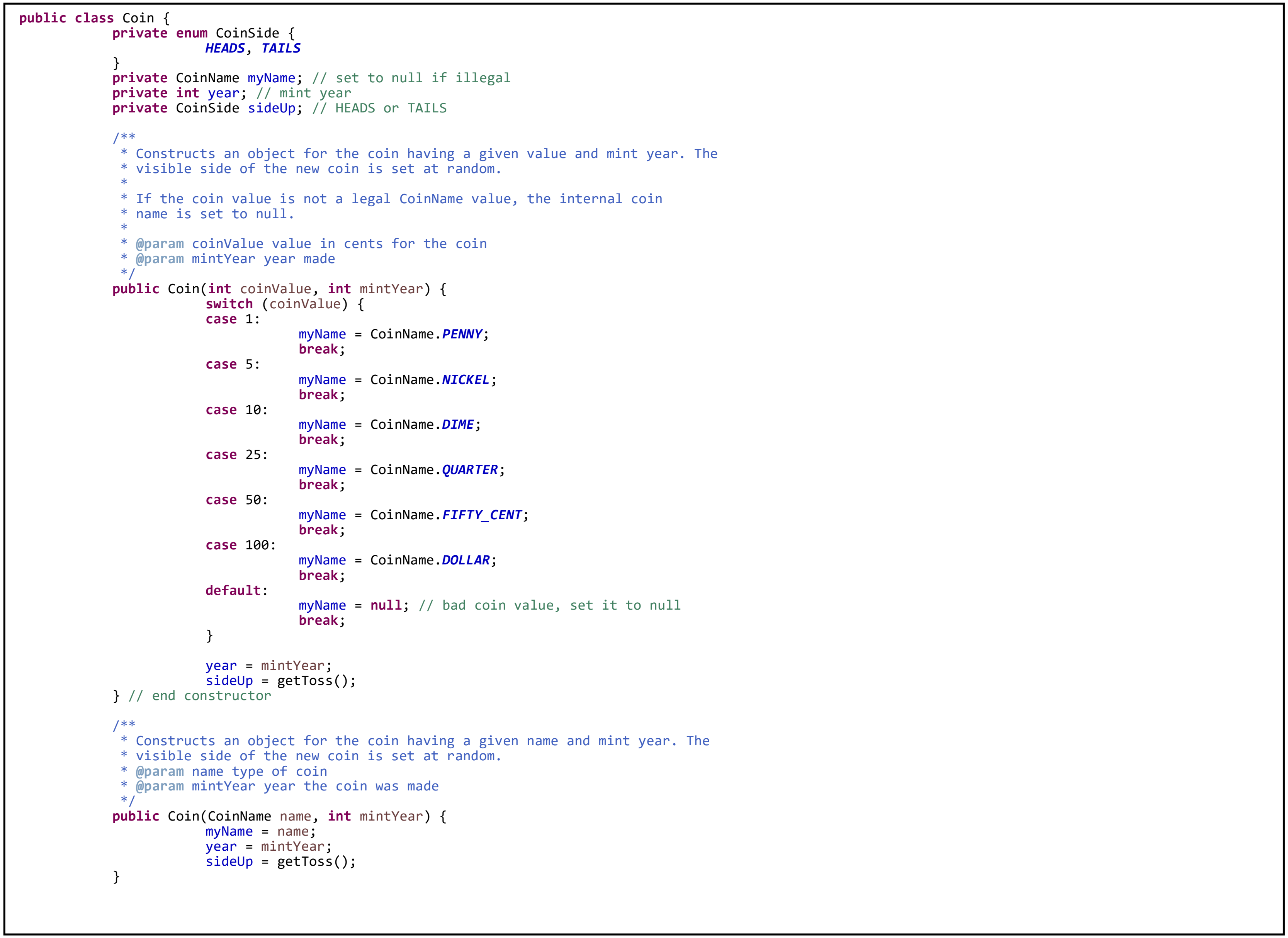
```java
public class OnlineShopper {
    public static void main(String[] args) {
        Item[] items = {
                new Item("Bird feeder", 2050),
                new Item("Squirrel guard", 1547),
                new Item("Bird bath", 4499),
                new Item("Sunflower seeds", 1295) };

        BagInterface<Item> shoppingCart = new ListBag<>();

        int totalCost = 0;

        // Statements that add selected items to the shopping cart:
        for (int index = 0; index < items.length; index++) {
            Item nextItem = items[index]; // Simulate getting item from shopper
            shoppingCart.add(nextItem);
            totalCost = totalCost + nextItem.getPrice();
        } // end for

        // Simulate checkout
        while (!shoppingCart.isEmpty())
            System.out.println(shoppingCart.remove());

        System.out.println("Total cost: " + "\t$" + totalCost / 100 + "." + totalCost % 100);
    }
}
```

PiggyBank as a Bag – Coin and CoinName

- Add coins to a PiggyBank, then remove them
- Need a Coin and CoinName class
- CoinName is an enum with standard values
  - Note use of enum constructor – not public! – and arg that corresponds to enum value

```
public enum CoinName {
     PENNY(1), NICKEL(5), DIME(10), QUARTER(25), FIFTY_CENT(50), DOLLAR(100);

     private int coinValue = 0;

     CoinName(int value) {
          coinValue = value;
     }

     public int getValue( ) {
          return coinValue;
     }
}
```

Coin constructor



```
public class Coin {
            private enum CoinSide {
                        HEADS, TAILS
            }
            private CoinName myName; // set to null if illegal
            private int year; // mint year
            private CoinSide sideUp; // HEADS or TAILS

            /**
             * Constructs an object for the coin having a given value and mint year. The
             * visible side of the new coin is set at random.
             *
             * If the coin value is not a legal CoinName value, the internal coin
             * name is set to null.
             *
             * @param coinValue value in cents for the coin
             * @param mintYear year made
             */
            public Coin(int coinValue, int mintYear) {
                        switch (coinValue) {
                        case 1:
                                    myName = CoinName.PENNY;
                                    break;
                        case 5:
                                    myName = CoinName.NICKEL;
                                    break;
                        case 10:
                                    myName = CoinName.DIME;
                                    break;
                        case 25:
                                    myName = CoinName.QUARTER;
                                    break;
                        case 50:
                                    myName = CoinName.FIFTY_CENT;
                                    break;
                        case 100:
                                    myName = CoinName.DOLLAR;
                                    break;
                        default:
                                    myName = null; // bad coin value, set it to null
                                    break;
                        }

                        year = mintYear;
                        sideUp = getToss();
            } // end constructor

            /**
             * Constructs an object for the coin having a given name and mint year. The
             * visible side of the new coin is set at random.
             * @param name type of coin
             * @param mintYear year the coin was made
             */
            public Coin(CoinName name, int mintYear) {
                        myName = name;
                        year = mintYear;
                        sideUp = getToss();
            }
```

Coin methods

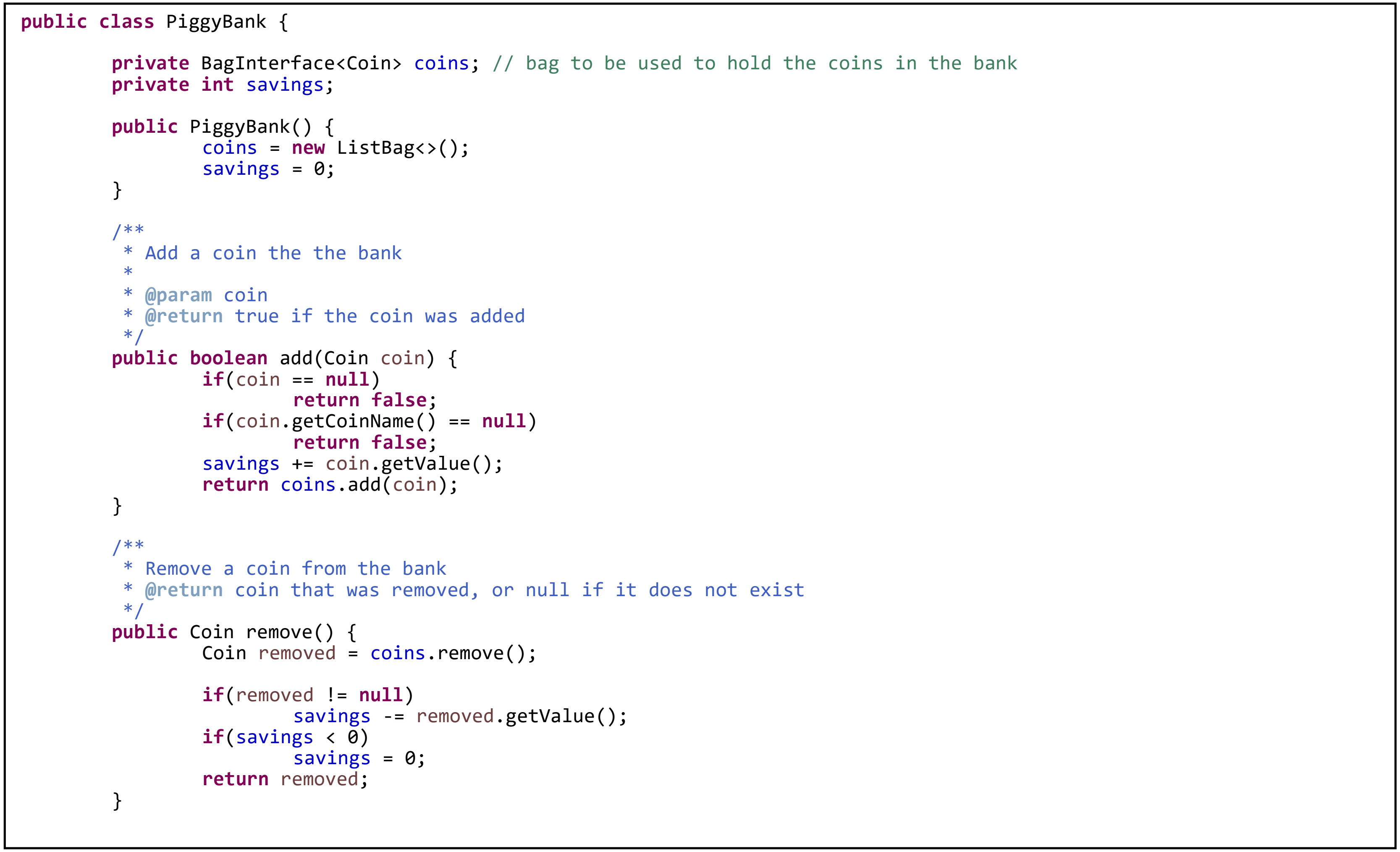
```java
/**
 * Returns name of the coin
 * @return
 */
public CoinName getCoinName() {
            return myName;
}

/**
 * Returns the value of the coin in cents
 * @return
 */
public int getValue() {
            return myName.getValue();
}

/** Returns the coin's mint year as an integer. */
public int getYear() {
            return year;
} // end getYear

/**
 * Returns "HEADS" or "TAILS"
 * @return
 */
public String getSideUp() {
            /*
             * String result = "Tails"; if (sideUp == CoinSide.HEADS) result = "Heads";
             * return result;
             */
            return sideUp.toString();
}

/**
 * Returns true if the coin is heads-side up.
 * @return
 */
public boolean isHeads() {
            return sideUp == CoinSide.HEADS;
}

/**
 * Returns true if the coin is tails-side up.
 * @return
 */
public boolean isTails() {
            return sideUp == CoinSide.TAILS;
}

/**
 * Tosses the coin; sideUp will be either HEADS or TAILS at random.
 */
public void toss() {
            sideUp = getToss();
}
```

Coin methods

```java
    @Override
    public String toString() {
        if(myName == null)
            return "[null coin]";
        return myName + " [" + myName.getValue() + ", " + year + ", " + sideUp + "]";
    }

    /**
     * Returns a random value of either HEADS or TAILS.
     * @return
     */
    private CoinSide getToss() {
        CoinSide result;
        if (Math.random() < 0.5)
            result = CoinSide.HEADS;
        else
            result = CoinSide.TAILS;

        return result;
    }

    @Override
    public boolean equals(Object obj) {
        if (this == obj)
            return true;
        if (obj == null)
            return false;
        if (getClass() != obj.getClass())
            return false;

        Coin other = (Coin) obj;

        if (myName != other.myName)
            return false;
        // let's not worry about the side up
//      if (sideUp != other.sideUp)
//          return false;

        if (year != other.year)
            return false;
        return true;
    }
```

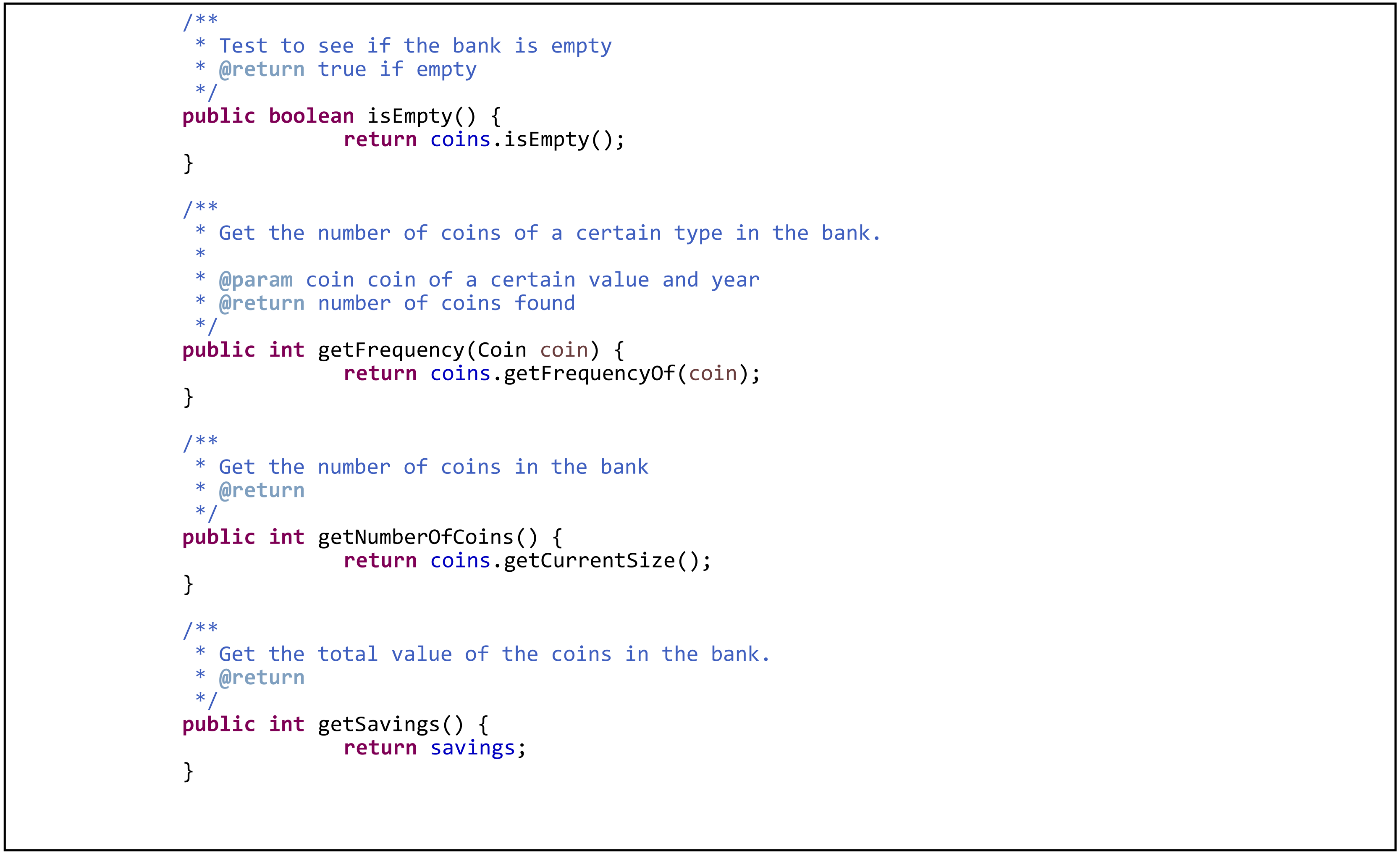
PiggyBank constructor, add(), remove()

- Add a coin to the bank, either by coin value or object



```java
public class PiggyBank {

        private BagInterface<Coin> coins; // bag to be used to hold the coins in the bank
        private int savings;

        public PiggyBank() {
                coins = new ListBag<>();
                savings = 0;
        }

        /**
         * Add a coin the the bank
         *
         * @param coin
         * @return true if the coin was added
         */
        public boolean add(Coin coin) {
                if(coin == null)
                        return false;
                if(coin.getCoinName() == null)
                        return false;
                savings += coin.getValue();
                return coins.add(coin);
        }

        /**
         * Remove a coin from the bank
         * @return coin that was removed, or null if it does not exist
         */
        public Coin remove() {
                Coin removed = coins.remove();

                if(removed != null)
                        savings -= removed.getValue();
                if(savings < 0)
                        savings = 0;
                return removed;
        }
```

PiggyBank methods



```
/**
 * Test to see if the bank is empty
 * @return true if empty
 */
public boolean isEmpty() {
             return coins.isEmpty();
}

/**
 * Get the number of coins of a certain type in the bank.
 * 
 * @param coin coin of a certain value and year
 * @return number of coins found
 */
public int getFrequency(Coin coin) {
             return coins.getFrequencyOf(coin);
}

/**
 * Get the number of coins in the bank
 * @return
 */
public int getNumberOfCoins() {
             return coins.getCurrentSize();
}

/**
 * Get the total value of the coins in the bank.
 * @return
 */
public int getSavings() {
             return savings;
}
```

PiggyBank app

- Add coins to bank, then remove them

```java
public class PiggyBankExample {
        public static void main(String[] args) {
                PiggyBank myBank = new PiggyBank();

                System.out.println(">>> Adding coins to the bank");

                addCoin(new Coin(1, 2010), myBank);
                addCoin(new Coin(5, 2011), myBank);
                addCoin(new Coin(10, 2000), myBank);
                addCoin(new Coin(25, 2012), myBank);
                addCoin(new Coin(25, 2012), myBank);
                addCoin(new Coin(-1, 2000), myBank);  // this is illegal, so should fail

                System.out.println("Number of quarters should be 2, is: "
                                + myBank.getFrequency(new Coin(25, 2012)));
                System.out.println("Bank should have 5 coins, value of 66, has: "
                                + myBank.getNumberOfCoins()
                                + " value: " + myBank.getSavings());

                System.out.println(">>> Removing all the coins from the bank:");

                int amountRemoved = 0;

                while (!myBank.isEmpty()) {
                        Coin removedCoin = myBank.remove();
                        System.out.println("Removed a " + removedCoin.getCoinName() + ".");
                        amountRemoved = amountRemoved + removedCoin.getValue();
                } // end while

                System.out.println(">>> All done. Removed " + amountRemoved + " cents.");
        } // end main

        private static void addCoin(Coin aCoin, PiggyBank aBank) {
                if (aBank.add(aCoin))
                        System.out.println("Added a " + aCoin + ".");
                else
                        System.out.println("Tried to add a " + aCoin + ", but couldn't");
        }
}
```

PiggyBank app output

- Note what happens when an illegal coin is added

```
>>> Adding coins to the bank
Added a PENNY [1, 2010, TAILS].
Added a NICKEL [5, 2011, TAILS].
Added a DIME [10, 2000, TAILS].
Added a QUARTER [25, 2012, TAILS].
Added a QUARTER [25, 2012, HEADS].
Tried to add a [null coin], but couldn't
Number of quarters should be 2, is: 2
Bank should have 5 coins, value of 66, has: 5 value: 66
>>> Removing all the coins from the bank:
Removed a QUARTER.
Removed a QUARTER.
Removed a DIME.
Removed a NICKEL.
Removed a PENNY.
>>> All done. Removed 66 cents.
```

Observations about Vending Machines

- Can perform only tasks machine's interface presents.
- You must understand these tasks
- Cannot access the inside of the machine
- You can use the machine even though you do not know what happens inside.
- Usable even with new insides.

I'm really thirsty— what looks good?
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FIGURE 1-3
A vending machine

Observations about ADT Bag

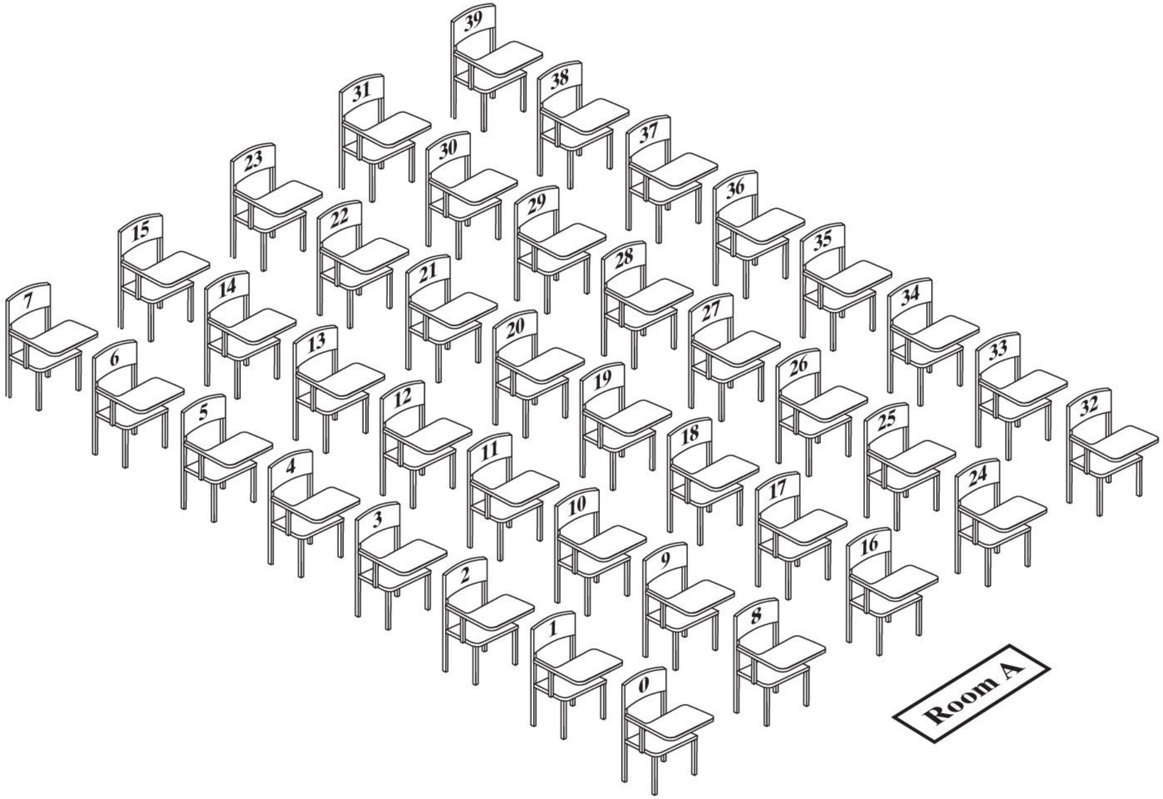
- Can perform only tasks specific to ADT
- Must adhere to the specifications of the operations of ADT
- Cannot access data inside ADT without ADT operations
- Use the ADT, even if don't know how data is stored
- Usable even with new implementation.

Java Class Library: The Interface Set

```
/** An interface that describes the operations of a set of objects. */
public interface SetInterface<T>
{
     public int getCurrentSize();
     public boolean isEmpty();

     /** Adds a new entry to this set, avoiding duplicates.
        @param newEntry  The object to be added as a new entry.
        @return  True if the addition is successful, or
          false if the item already is in the set. */
     public boolean add(T newEntry);

     /** Removes a specific entry from this set, if possible.
    @param anEntry  The entry to be removed.
    @return  True if the removal was successful, or false if not. */
     public boolean remove(T anEntry);

     public T remove();
     public void clear();
     public boolean contains(T anEntry);
     public T[] toArray();
} // end SetInterface
```

Fixed-Size Array to Implement the ADT Bag

- **A classroom that contains desks in fixed positions**



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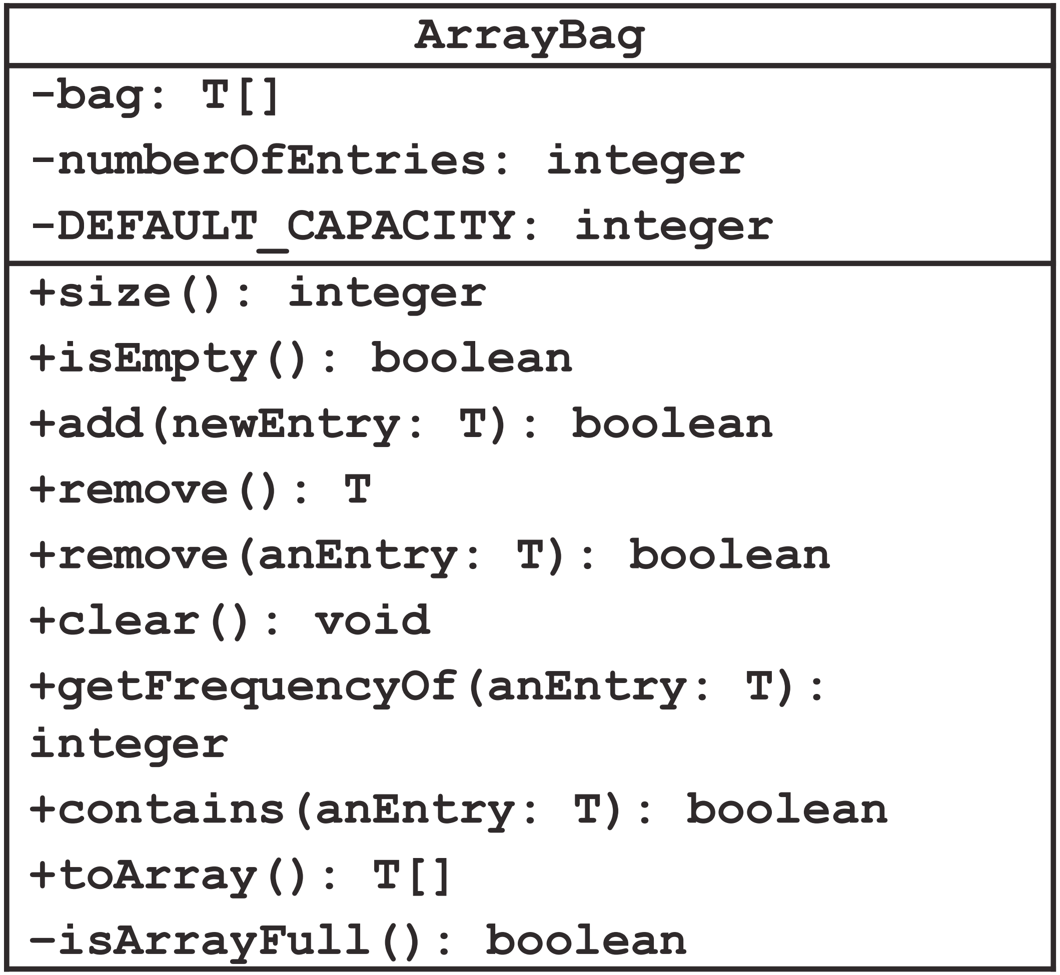
UML for a fixed size `ArrayBag`



```
ArrayBag
-bag: T[]
-numberOfEntries: integer
-DEFAULT_CAPACITY: integer
+size(): integer
+isEmpty(): boolean
+add(newEntry: T): boolean
+remove(): T
+remove(anEntry: T): boolean
+clear(): void
+getFrequencyOf(anEntry: T):
integer
+contains(anEntry: T): boolean
+toArray(): T[]
-isArrayFull(): boolean
```

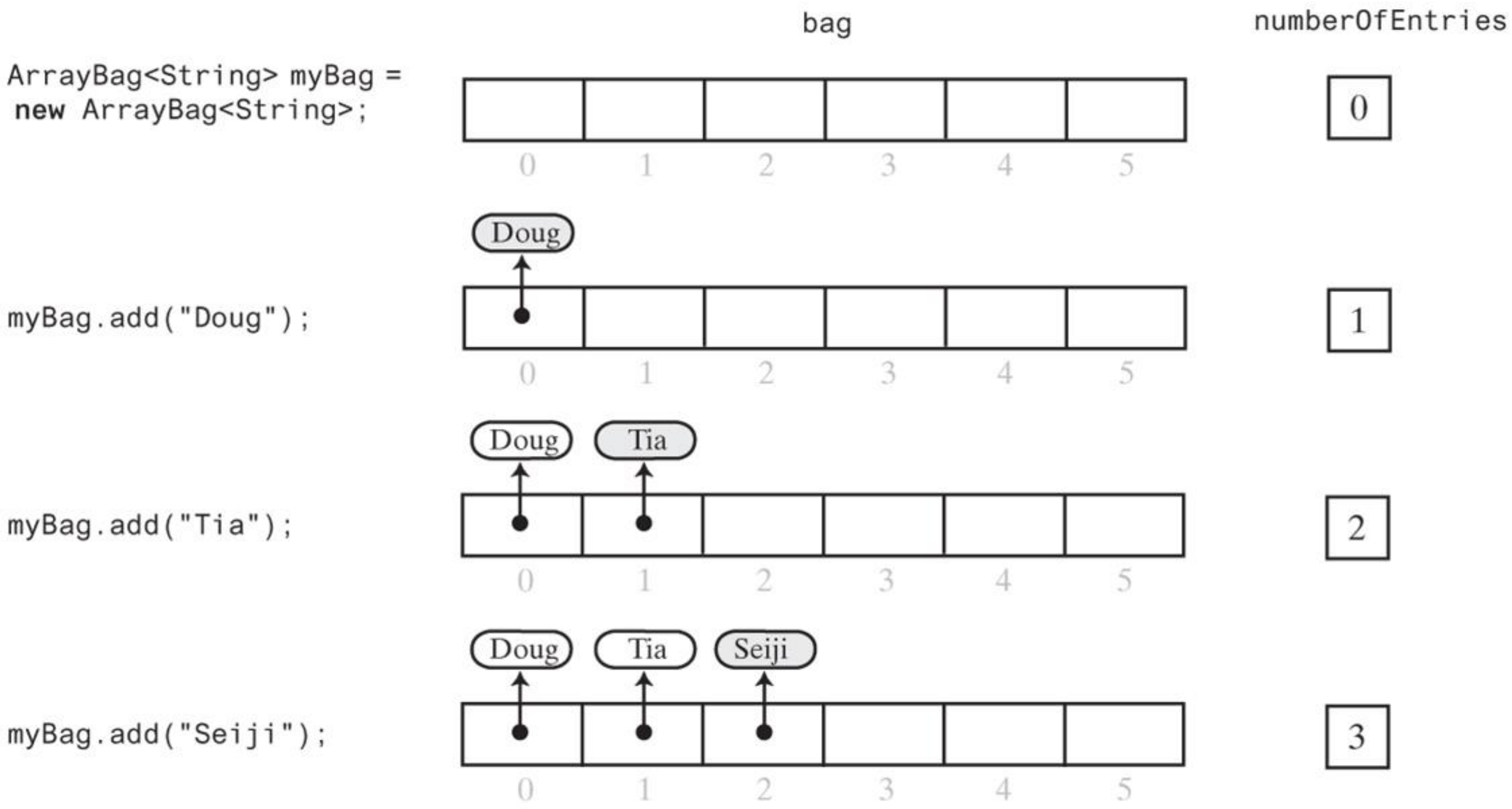
FixedSizeArrayBag

- Implement Bag using a fixed size generic array.
- Constructor creates an array then casts it to the generic type
- Need other methods such as add(), remove(), toArray()

```java
public final class CompletedFixedSizeArrayBag<T> implements BagInterface<T> {
     private final T[] bag;  // array to hold bag of objects
     private int numberOfEntries;  // count of objects in the bag

     private static final int DEFAULT_CAPACITY = 25;
     private static final int MAX_CAPACITY = 10000;

     /**
      * Creates an empty bag whose initial capacity is 25.
      */
     public CompletedFixedSizeArrayBag() {
          this(DEFAULT_CAPACITY);
     }

     /**
      * Creates an empty bag having a given capacity.
      *
      * @param desiredCapacity The integer capacity desired.
      */
     public CompletedFixedSizeArrayBag(int desiredCapacity) {
          if (desiredCapacity <= MAX_CAPACITY) {
               // The cast is safe because the new array contains null entries
               @SuppressWarnings("unchecked")
               T[] tempBag = (T[]) new Object[desiredCapacity]; // Unchecked cast
               bag = tempBag;
               numberOfEntries = 0;
          } else
               throw new IllegalStateException(
                         "Attempt to create a bag " + "whose capacity exceeds " + "allowed maximum.");
     }
```

Adding to a fixed-size `ArrayBag` (Part 1)

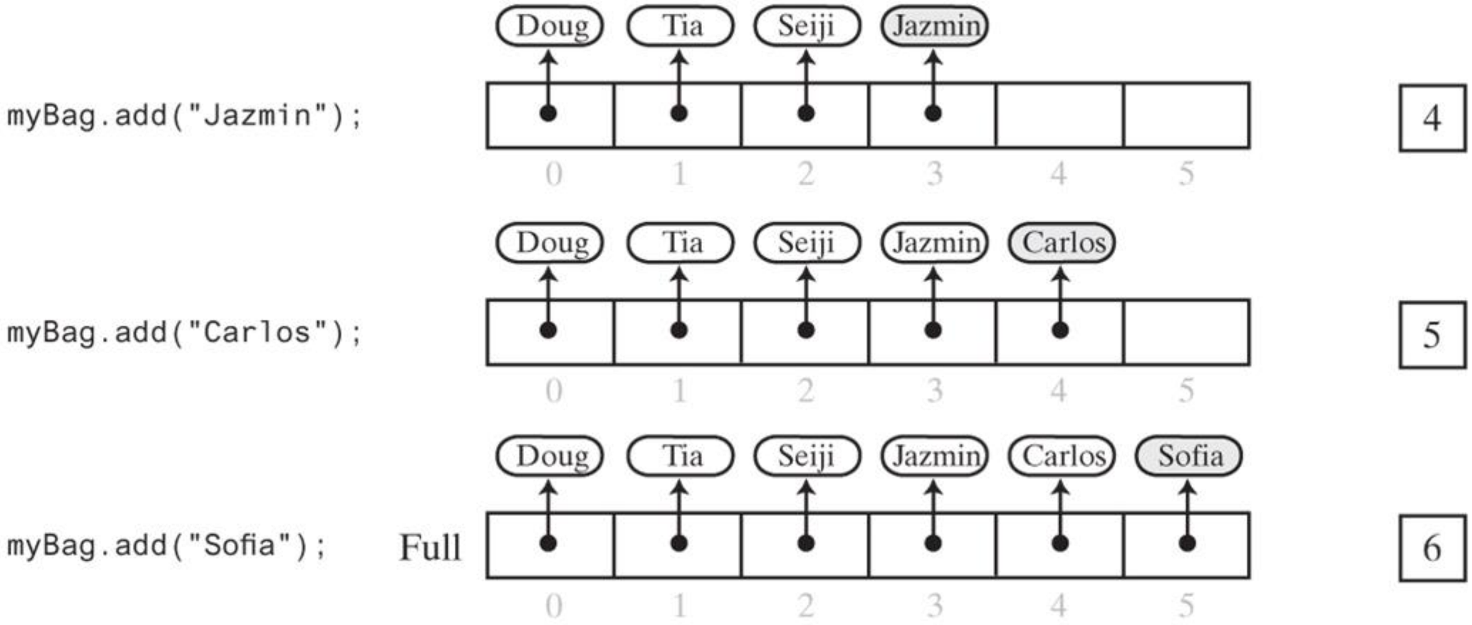
- **Adding entries to an array that represents a bag, whose capacity is six, until it becomes full**



```
ArrayBag<String> myBag =
 new ArrayBag<String>;

myBag.add("Doug");

myBag.add("Tia");

myBag.add("Seiji");
```

Adding to a fixed-size `ArrayBag` (Part 2)

- **Adding entries to an array that represents a bag, whose capacity is six, until it becomes full**



```
myBag.add("Jazmin");
myBag.add("Carlos");
myBag.add("Sofia");
```

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add() method

- Add entry to the next free position (at end)
- Notice this is at the numberOfEntries slot, not at the end of the actual array

```
public boolean add(T newEntry) {
       boolean result = true;
       if (isArrayFull()) {
                   result = false;
       } else { // Assertion: result is true here
                   bag[numberOfEntries] = newEntry;
                   numberOfEntries++;
       }

       return result;
}

/**
 * Returns true if the array bag is full, or false if not.
 * @return
 */
private boolean isArrayFull() {
       return numberOfEntries >= bag.length;
}
```

toArray() – gets a copy of the bag

- Two ways of implementing this
  - Iterate through the internal array, copying to a new array
  - Use Arrays.copyOf() from the java library

```
    public T[] toArray()
    {
//      The cast is safe because the new array contains null entries.
//      @SuppressWarnings("unchecked")
//      T[] result = (T[]) new Object[numberOfEntries]; // Unchecked cast
//
//      for (int index = 0; index < numberOfEntries; index++) {
//          result[index] = bag[index];
//      }
//      return result;

        // Note: The body of this method could consist of one return statement,
        // if you call Arrays.copyOf

        return Arrays.copyOf(bag, numberOfEntries);
    }
```

Testing Bag implementations

- See BagDemo
  - Includes testing for each Bag implementation method
- Simply uncomment the implementation to be tested.

```
public class BagDemo {
    public static void main(String[] args) {
        // A bag that is not full
//      BagInterface<String> aBag = new CompletedFixedSizeArrayBag<>();
        BagInterface<String> aBag = new CompletedLinkedBagWithNodeMethods<>();
//      BagInterface<String> aBag = new CompletedLinkedBag<>();
//      BagInterface<String> aBag = new FixedSizeArrayBag<>();
//      BagInterface<String> aBag = new LinkedBagWithNodeMethods<>();
//      BagInterface<String> aBag = new LinkedBag<>();
        System.out.println("Testing an initially empty bag:");

        // Removing a string from an empty bag:
        String[] testStrings1 = { "", "B" };
        testRemove(aBag, testStrings1);
```

BagDemo displayBag()

- Tests toArray()
- Gets copy of bag items, and iterates through the array to display.

```
/**
 * Display the bag using toArray method
 * 
 * @param aBag
 */
private static void displayBag(BagInterface<String> aBag) {
    System.out.println("The bag contains " + aBag.size() + " string(s), as follows:");
    Object[] bagArray = aBag.toArray();
    for (int index = 0; index < bagArray.length; index++) {
        System.out.print(bagArray[index] + " ");
    }

    System.out.println();
}
```

Other methods

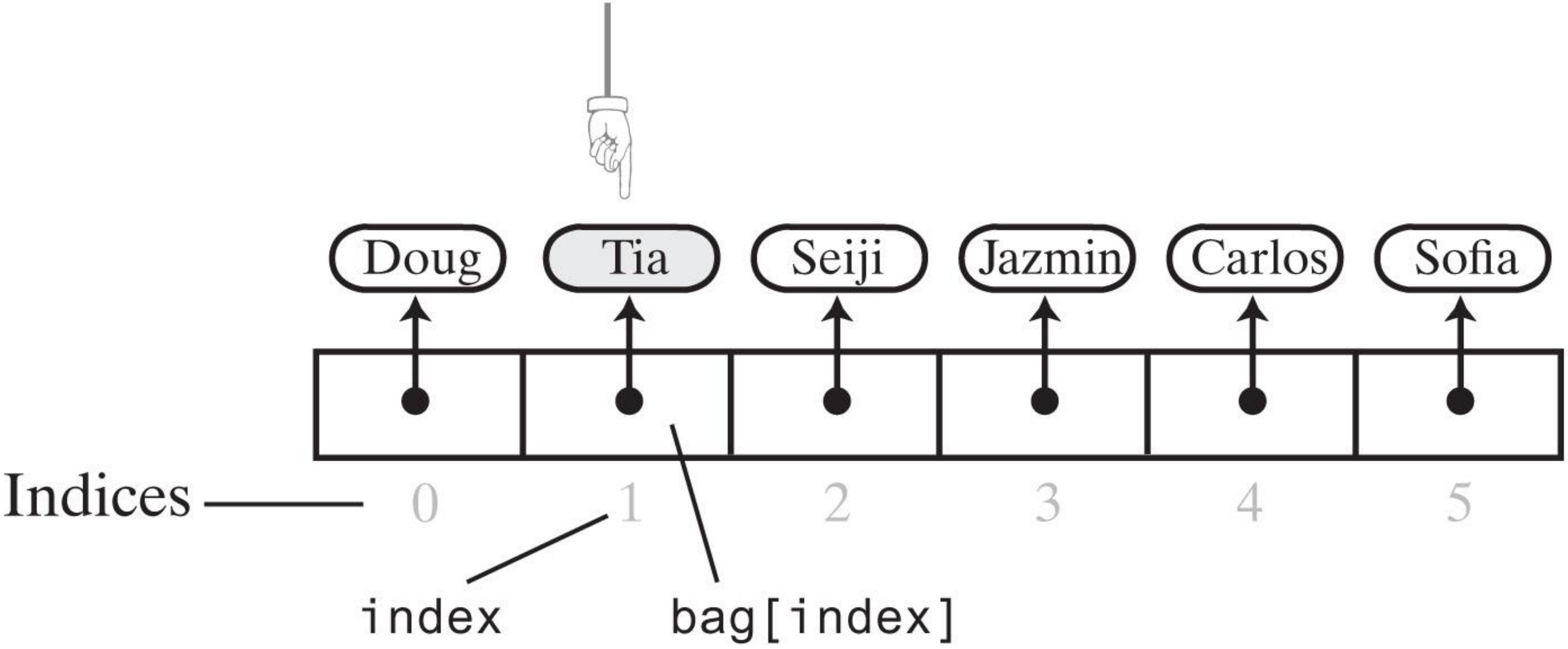
```
public boolean isEmpty() {
    return numberOfEntries == 0;
}

public int getCurrentSize() {
    return numberOfEntries;
}

public int getFrequencyOf(T anEntry) {
    int counter = 0;

    for (int index = 0; index < numberOfEntries; index++) {
        if (anEntry.equals(bag[index])) {
            counter++;
        }
    }

    return counter;
}

public void clear() {
    while (!isEmpty())
        remove();
}
```

contains() and getIndexOf()

- contains() just calls getIndexOf()
- getIndexOf() iterates through the array until entry found.
    - returns -1 if not found

```java
public boolean contains(T anEntry) {
    return getIndexOf(anEntry) > -1; // or >= 0
}

/**
 * Locates a given entry within the array bag.
 * @param anEntry entry to locate
 * @return index of the entry, if located, or -1 otherwise
 */
private int getIndexOf(T anEntry) {
    int where = -1;  // location of entry
    boolean found = false;   // sentinel
    int index = 0;

    // look through all entries until we find a matching one

    while (!found && (index < numberOfEntries)) {
        // if we find it, set the flag, and
        // save the index where found
        if (anEntry.equals(bag[index])) {
            found = true;
            where = index;
        }
        index++;
    }

    return where;
}
```

Methods That Remove Entries



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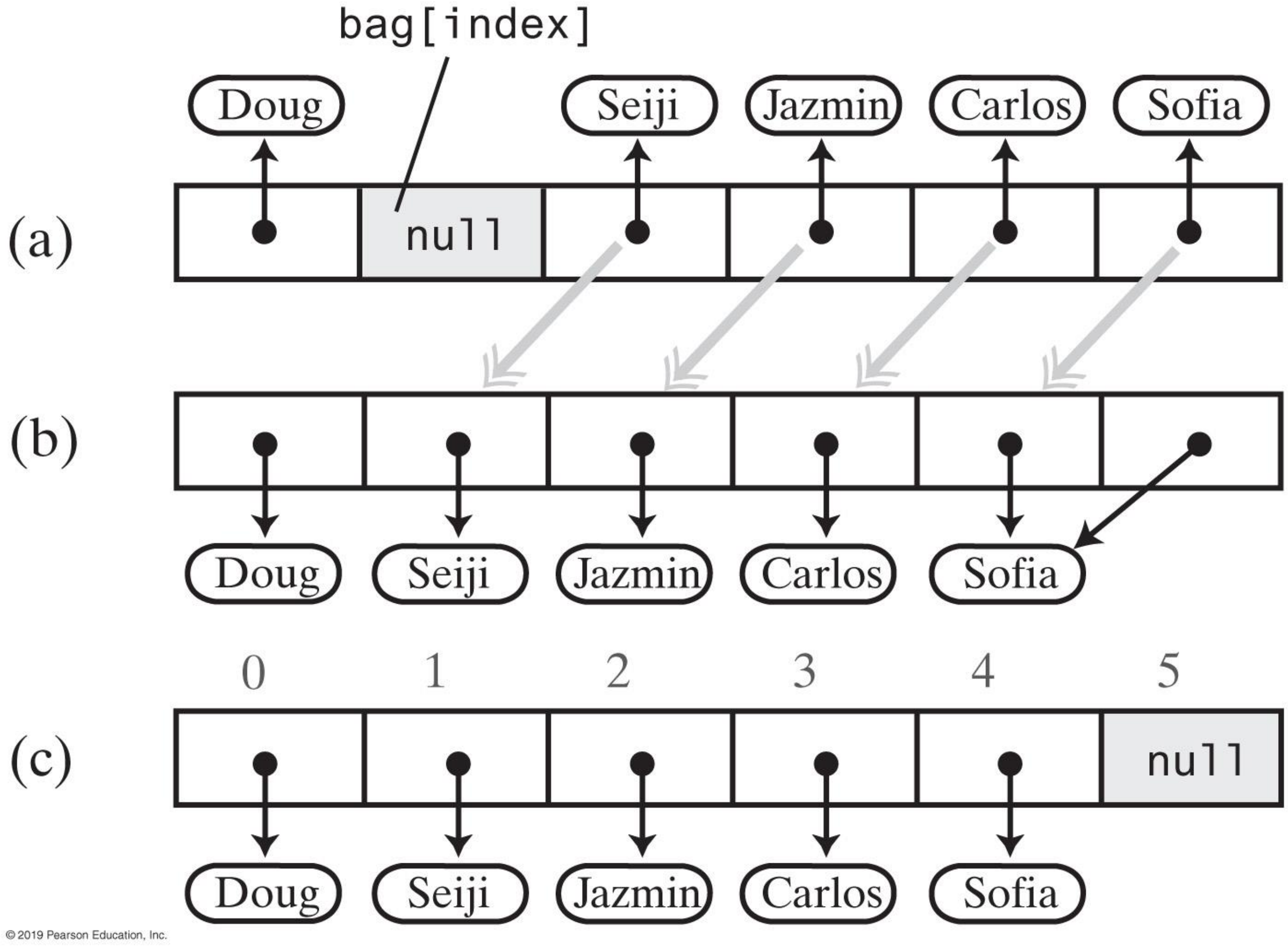
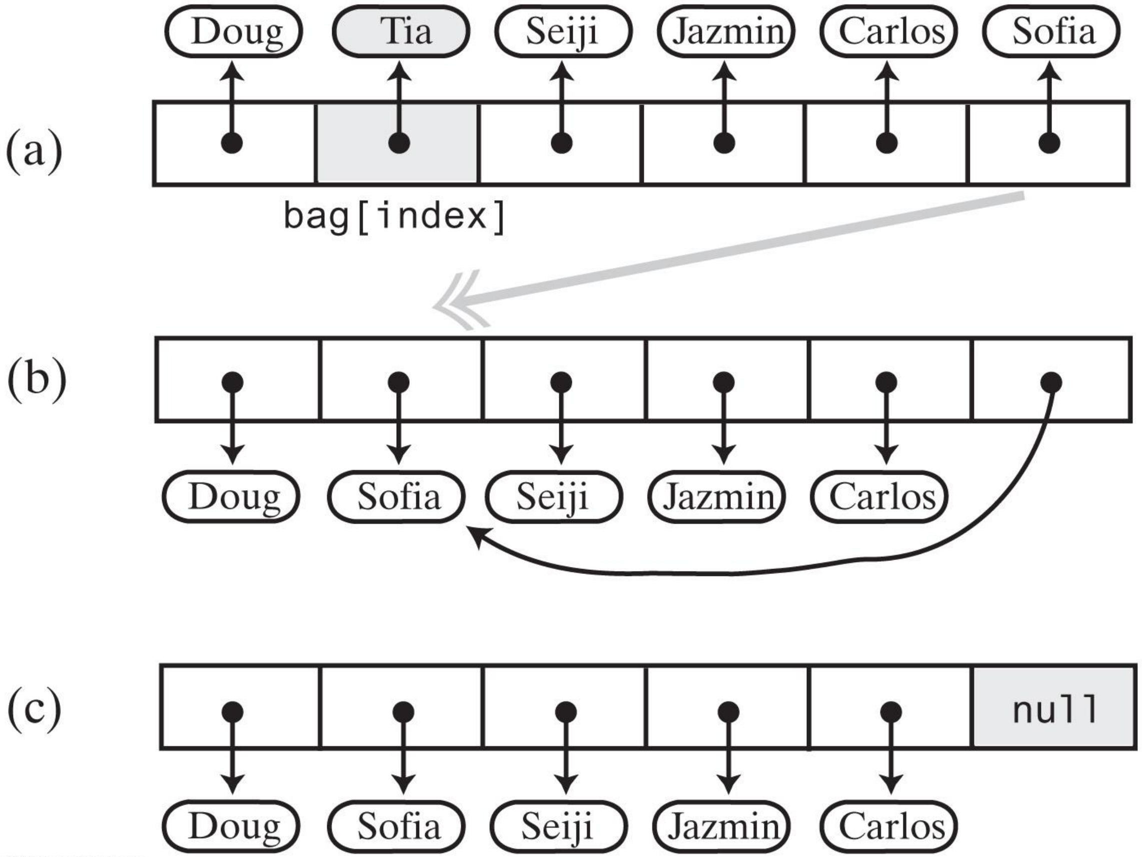
Methods That Remove Entries

- **Shifting entries from back to front to avoid a gap when removing an entry**



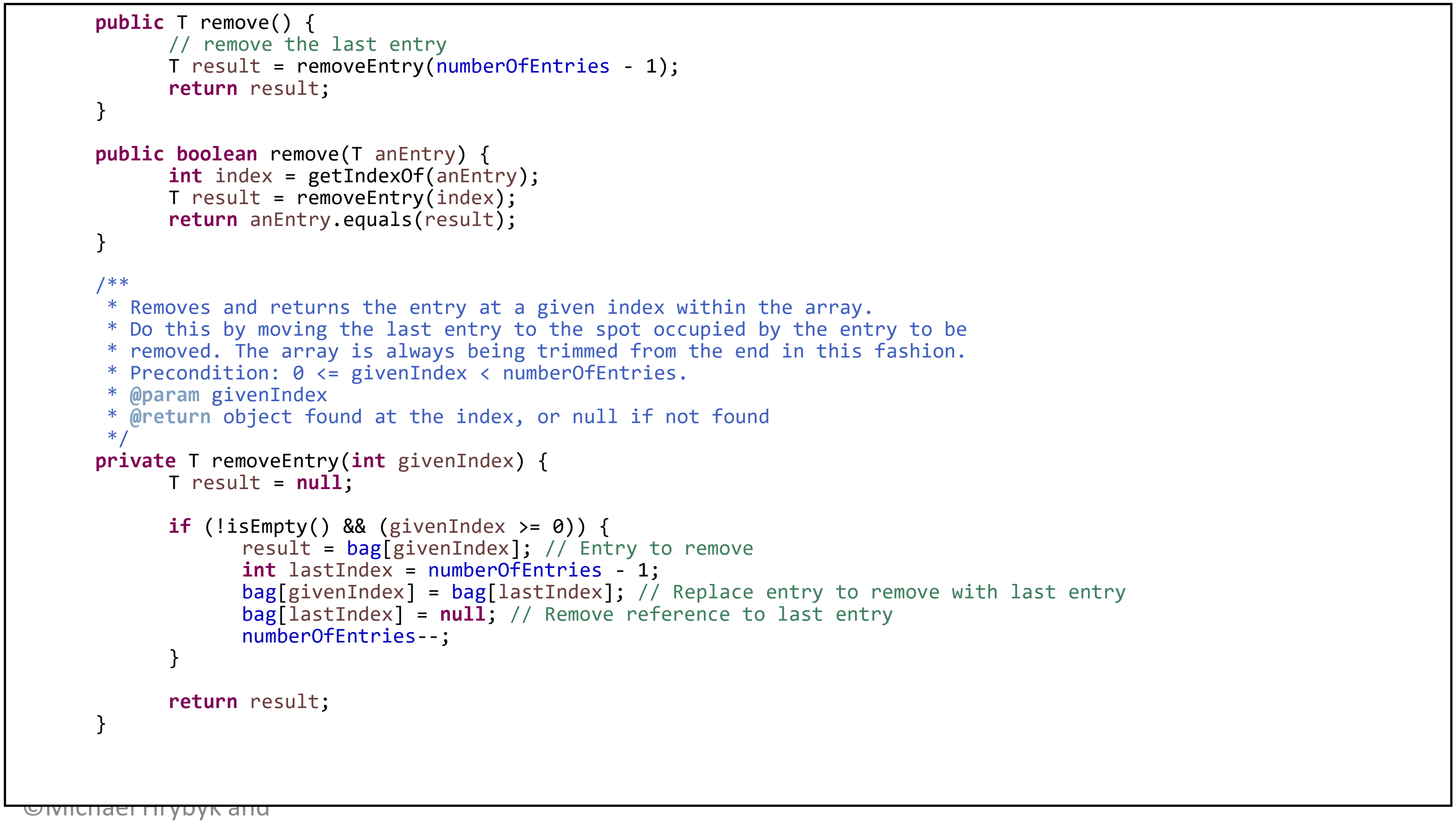
Methods That Remove Entries

- **Swap the last entry into the slot where the entry is removed**



remove()

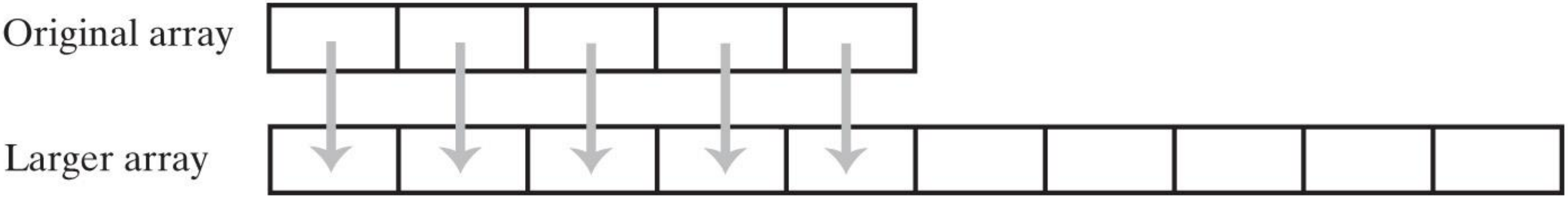
- Removing items from anything is always tricky
- remove() with no args just removes the last entry and returns the data.
    - Note call to removeEntry(), which removes an item at a position
    - In this case, the last position
- remove(T anEntry) first has to find it and get its index, then remove the position.
- removeEntry() works by swapping the entry to be removed with the last entry in the bag.



```
public T remove() {
    // remove the last entry
    T result = removeEntry(numberOfEntries - 1);
    return result;
}

public boolean remove(T anEntry) {
    int index = getIndexOf(anEntry);
    T result = removeEntry(index);
    return anEntry.equals(result);
}

/**
 * Removes and returns the entry at a given index within the array.
 * Do this by moving the last entry to the spot occupied by the entry to be
 * removed. The array is always being trimmed from the end in this fashion.
 * Precondition: 0 <= givenIndex < numberOfEntries.
 * @param givenIndex
 * @return object found at the index, or null if not found
 */
private T removeEntry(int givenIndex) {
    T result = null;

    if (!isEmpty() && (givenIndex >= 0)) {
        result = bag[givenIndex]; // Entry to remove
        int lastIndex = numberOfEntries - 1;
        bag[givenIndex] = bag[lastIndex]; // Replace entry to remove with last entry
        bag[lastIndex] = null; // Remove reference to last entry
        numberOfEntries--;
    }

    return result;
}
```

Resizing an Array

- **Resizing an array copies its contents to a larger second array**



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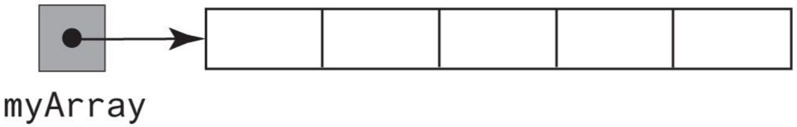
Steps to Resize an Array (Part 1)

(a) An array



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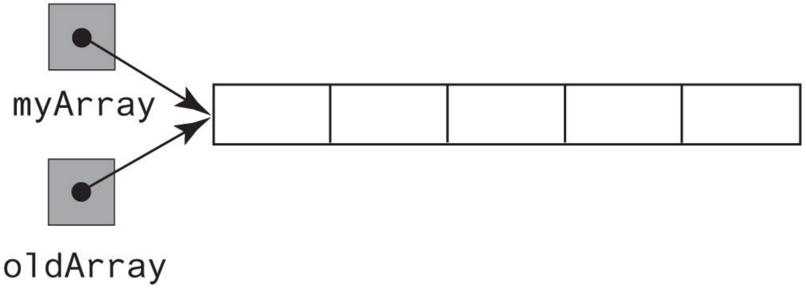
(b) Two references to the same array



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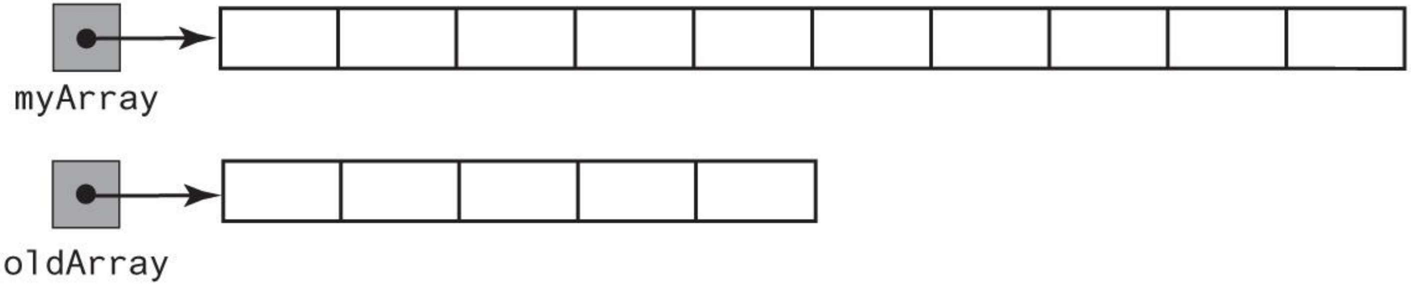
(c) The original array variable now references a new, larger array



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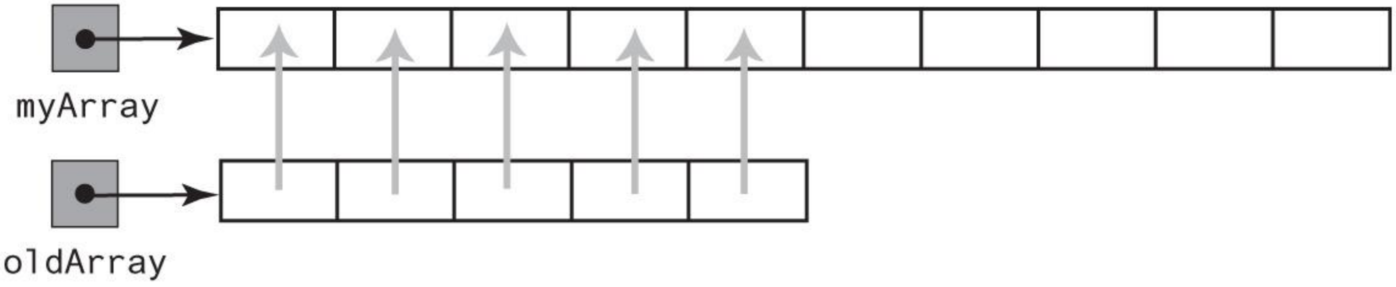
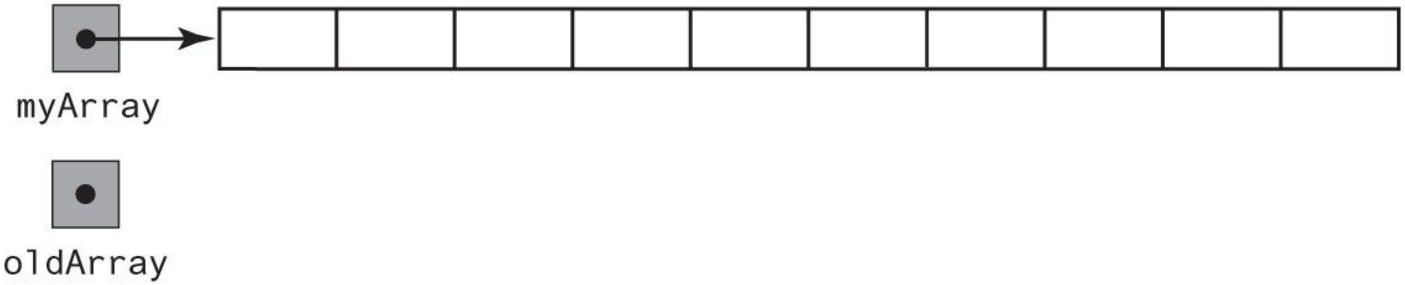
Steps to Resize an Array (Part 2)

(d) The entries in the original array are copied to the new array

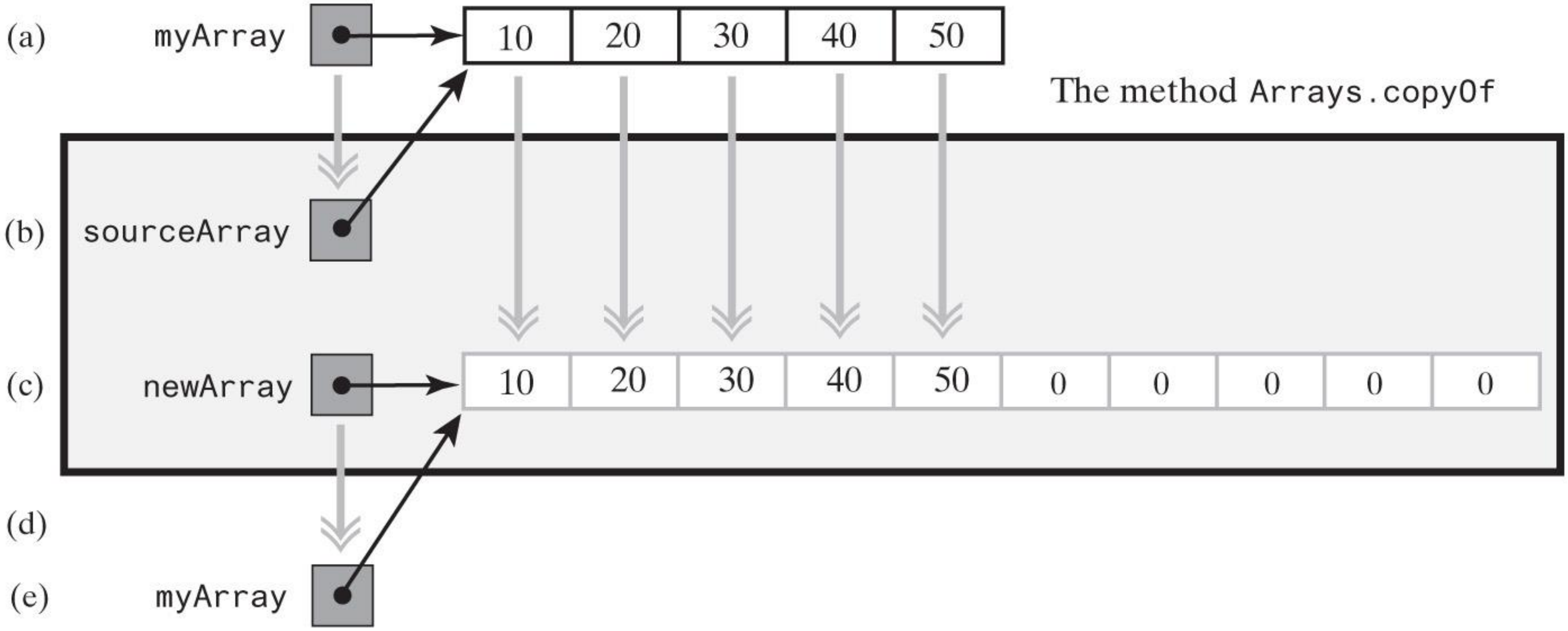


(e) The original array is discarded



Resizing Using `Arrays.copyOf`

- **Alternative steps to resize an array**



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ResizableArrayBag

- Double the size when full in add()

```
    public boolean add(T newEntry) {
       // double the capacity if full then add the entry

       if (isArrayFull()) {
          doubleCapacity();
       }

       bag[numberOfEntries] = newEntry;
       numberOfEntries++;

       return true;
    }

    /**
     * Doubles the size of the bag
     */
    private void doubleCapacity() {
       int newLength = 2 * bag.length;
       checkCapacity(newLength);
       bag = Arrays.copyOf(bag, newLength);
    }

    /**
     * Throws an exception if the client requests a bag capacity that is too large.
     * @param capacity requested size of bag
     */
    private void checkCapacity(int capacity) {
       if (capacity > MAX_CAPACITY)
          throw new IllegalStateException(
                "Attempt to create a bag whose capacity exceeds " + "allowed maximum of " + MAX_CAPACITY);
    }
```

Pros and Cons of Using an Array

- Adding an entry to the bag is fast
- Removing an unspecified entry is fast
- Removing a particular entry requires time to locate the entry
- Increasing the size of the array requires time to copy its entries

Problems with Array Implementation

- Array has fixed size
- May become full
- Alternatively may have wasted space
- Resizing is possible but requires overhead of time

Classroom Analogy

- Empty classroom
- Numbered desks stored in hallway
  - Number on back of desk is the "address"
- Number on desktop references another desk in chain of desks
- Desks are linked by the numbers

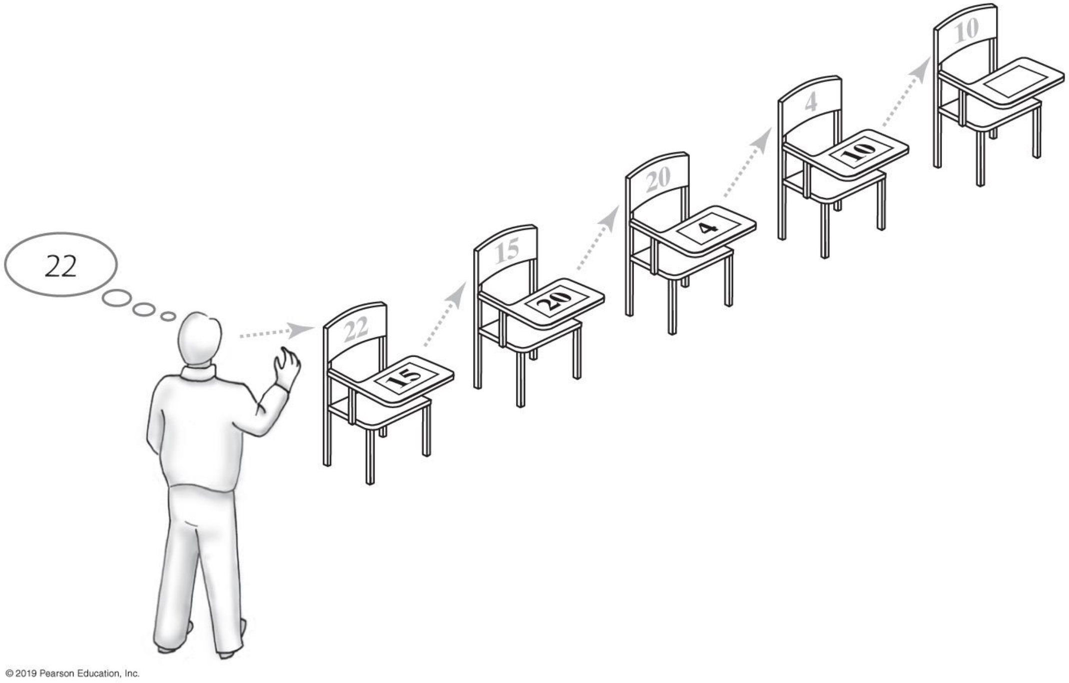

FIGURE 3-1 A chain of five desks

Forming a Chain by Adding to Its Beginning

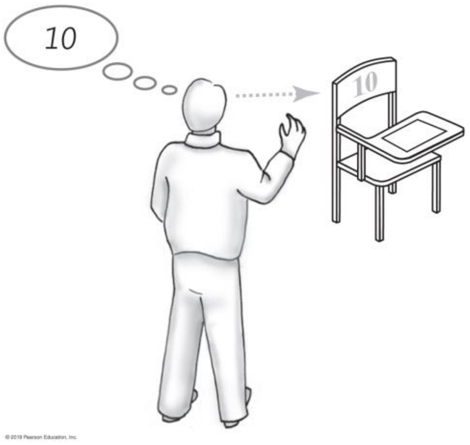

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FIGURE 3-2

One desk in the room

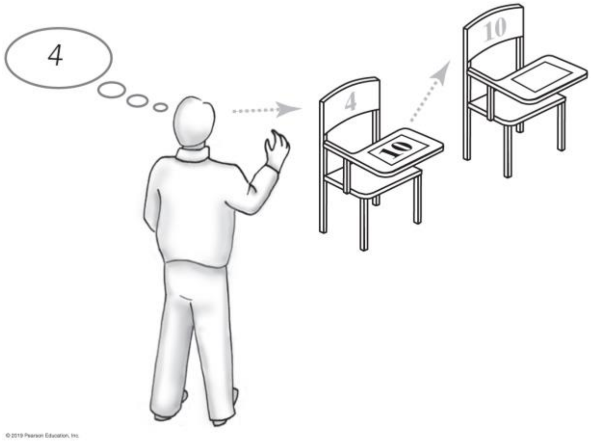

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FIGURE 3-3
Two linked desks, with the newest desk first

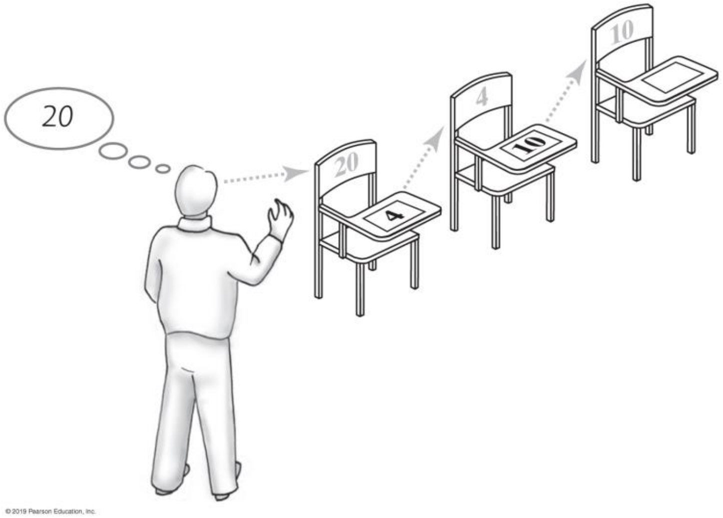

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FIGURE 3-4
Three linked desks, with the newest desk first

Forming a Chain by Adding to Its Beginning

- **Pseudocode detailing steps taken to form a chain of desks**

```
//Process the first student
newDesk represents the new student's desk New student sits at newDesk
Instructor memorizes the address of newDesk
// Process the remaining students
while (students arrive)
{
    newDesk represents the new student's desk New student sits at newDesk
    Write the instructor's memorized address on newDesk
    Instructor memorizes the address of newDesk
}
```

Using linked Nodes to build a chain

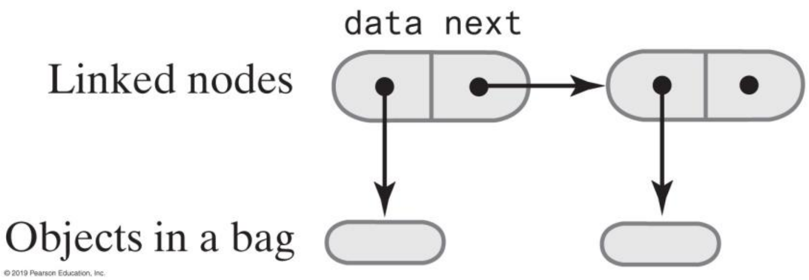


FIGURE 3-5
Two linked nodes that each reference object data

Private Node class

- used in an implementation to link data
- enclosing class can set and get next and data directly without getter/setter
- Might be better to use a public Node class instead

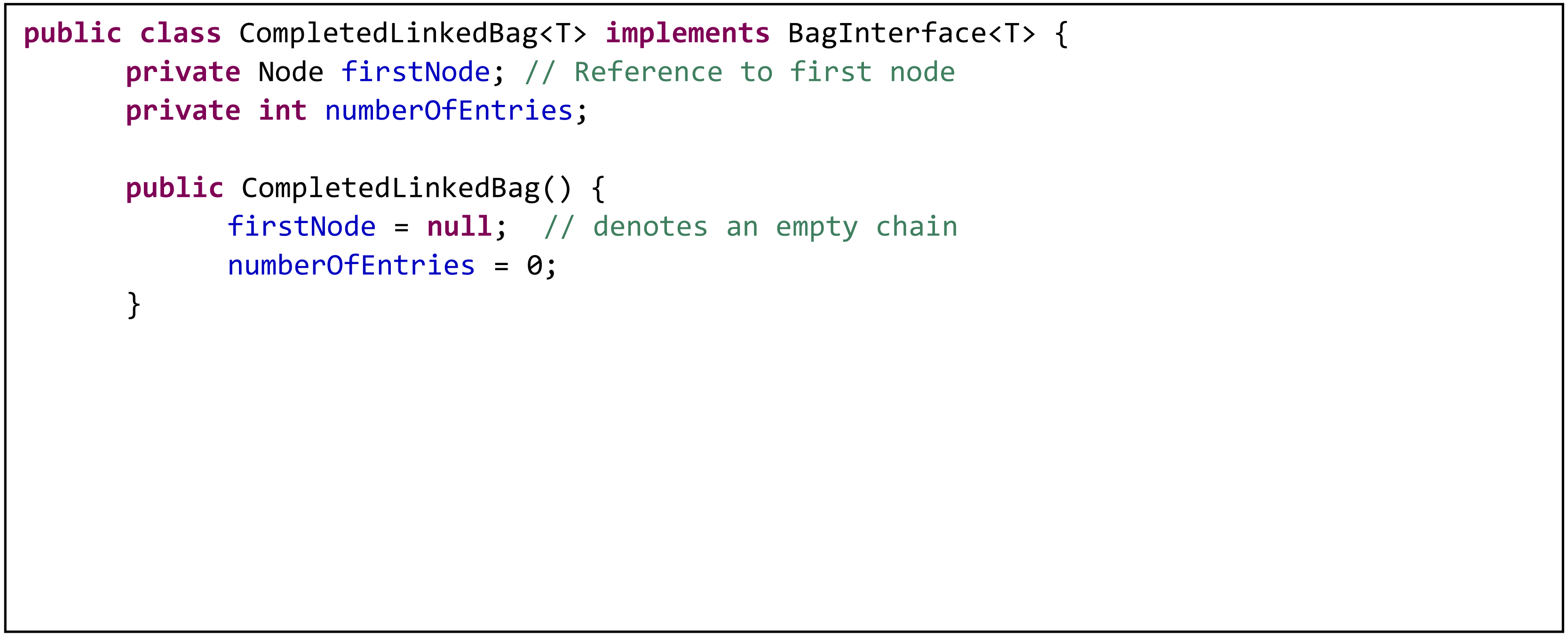
```java
private class Node {
      private T data; // Entry in bag
      private Node next; // Link to next node

      private Node(T dataPortion) {
            this(dataPortion, null);
      } // end constructor

      private Node(T dataPortion, Node nextNode) {
            data = dataPortion;
            next = nextNode;
      }
}
```

LinkedBag

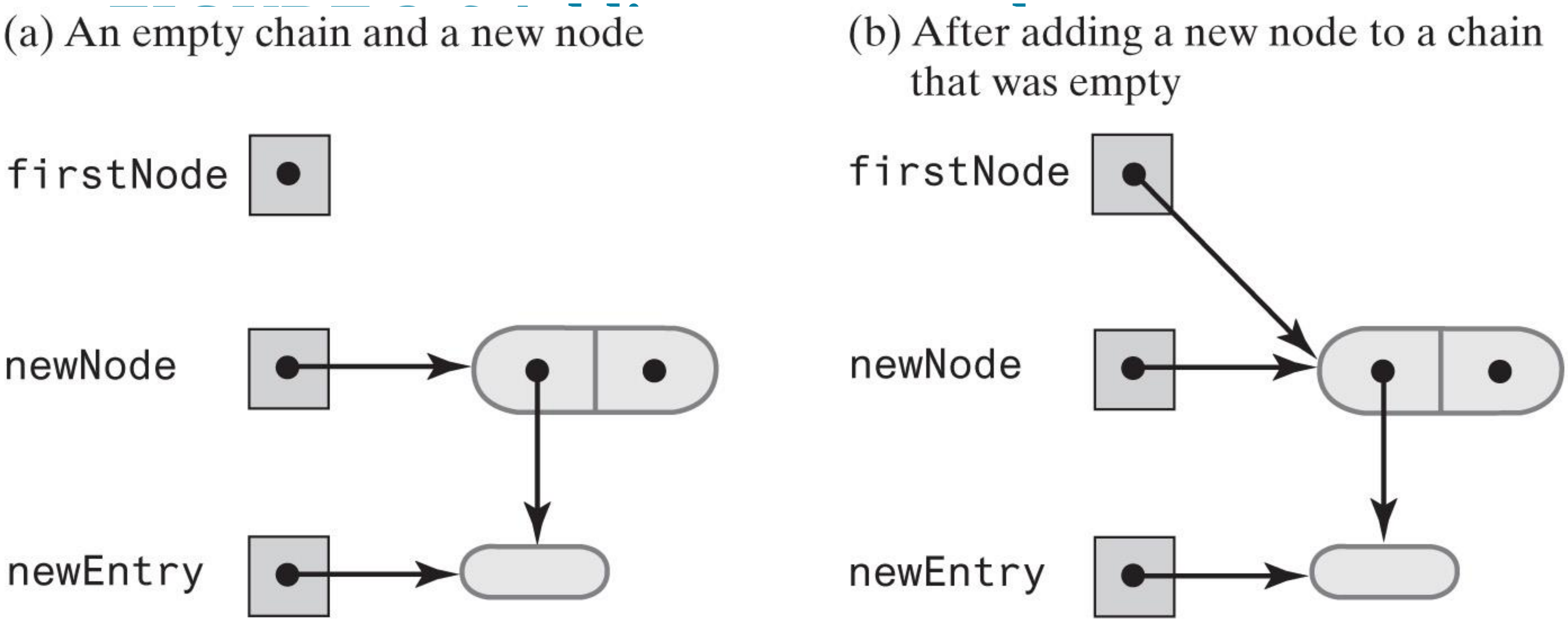
- A bag consisting of a set of linked nodes
- Keep a reference to the head of the list
- Notice that there are no size limits



```
public class CompletedLinkedBag<T> implements BagInterface<T> {
      private Node firstNode; // Reference to first node
      private int numberOfEntries;

      public CompletedLinkedBag() {
            firstNode = null;  // denotes an empty chain
            numberOfEntries = 0;
      }
```

Beginning a Chain of Nodes

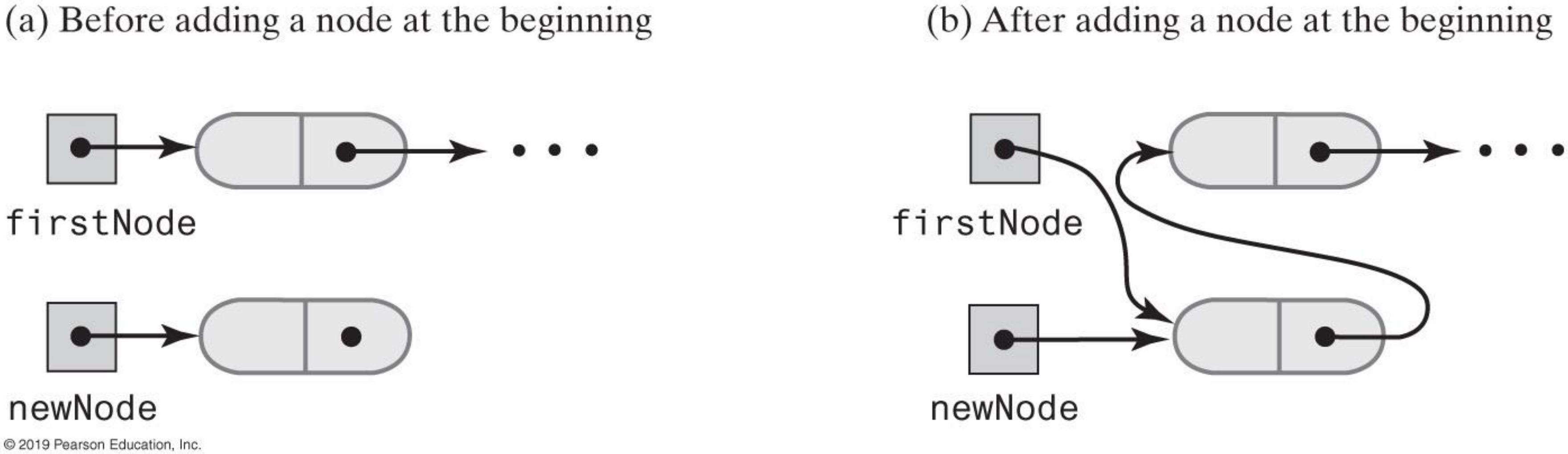


(a) An empty chain and a new node

(b) After adding a new node to a chain that was empty

Beginning a Chain of Nodes

- A chain of nodes just before and just after adding a node at



(a) Before adding a node at the beginning

(b) After adding a node at the beginning

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add()

```
	public boolean add(T newEntry) // OutOfMemoryError possible
	{
		// Add to beginning of chain:
		Node newNode = new Node(newEntry);
		newNode.next = firstNode; // Make new node reference rest of chain
		                                     // (firstNode is null if chain is empty)
		firstNode = newNode; // New node is at beginning of chain
		numberOfEntries++;

		return true;
	}
```

toArray()

- need to walk through chain to get each node, then copy data to an array slot

```java
    public T[] toArray() {
        // The cast is safe because the new array contains null entries
        @SuppressWarnings("unchecked")
        T[] result = (T[]) new Object[numberOfEntries]; // Unchecked cast

        // walk through the chain
        int index = 0;
        Node currentNode = firstNode;  // start at beginning of chain
        while ((index < numberOfEntries) && (currentNode != null)) {
            result[index] = currentNode.data; // copy the data
            index++;
            currentNode = currentNode.next;  // go to the next link on the chain
        } // end while

        return result;
    }
```

contains()

- calls getReferenceTo(), which gets the Node that contains the desired data
- getReferenceTo() walks through the chain until data found
    - Always sets current Node to next

```
public boolean contains(T anEntry) {
    return getReferenceTo(anEntry) != null ? true : false;
}

/**
 * Locates a given entry within this bag.
 * Returns a reference to the node containing the entry, if located,
 * or null otherwise.
 * @param anEntry the data to look for in the list of nodes
 * @return the node containing the data
 */
private Node getReferenceTo(T anEntry) {
    boolean found = false;
    Node currentNode = firstNode;

    while (!found && (currentNode != null)) {
        if (anEntry.equals(currentNode.data))
            found = true;
        else
            currentNode = currentNode.next;
    }

    return currentNode;
}
```

getFrequencyOf()

- like getReferenceTo(), walks through the chain
- counts the number of times data is found

```
public int getFrequencyOf(T anEntry) {
    int frequency = 0;
    int loopCounter = 0;
    Node currentNode = firstNode;

    while ((loopCounter < numberOfEntries) && (currentNode != null)) {
        if (anEntry.equals(currentNode.data)) {
            frequency++;
        }

        loopCounter++;
        currentNode = currentNode.next;
    }

    return frequency;
}
```

Removing an Item from a Linked Chain

- **Case 1:**
  - Your desk is first in the chain of desks.
- **Case 2:**
  - Your desk is not first in the chain of desks.

Removing an Item from a Linked Chain

- **Case 1 – removing first item**
  - Locate first desk by asking instructor for its address.
  - Give address written on the first desk to instructor.
    - This is address of second desk in chain.
  - Return first desk to hallway.

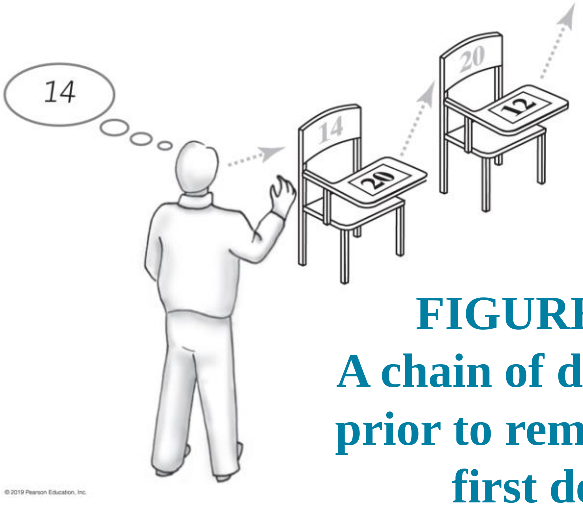


FIGURE 3-8
A chain of desks just prior to removing its first desk

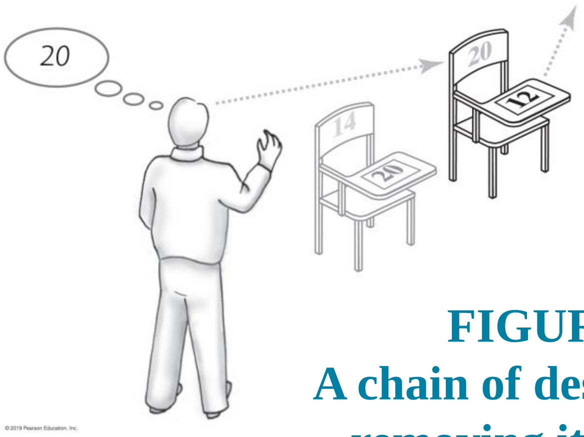
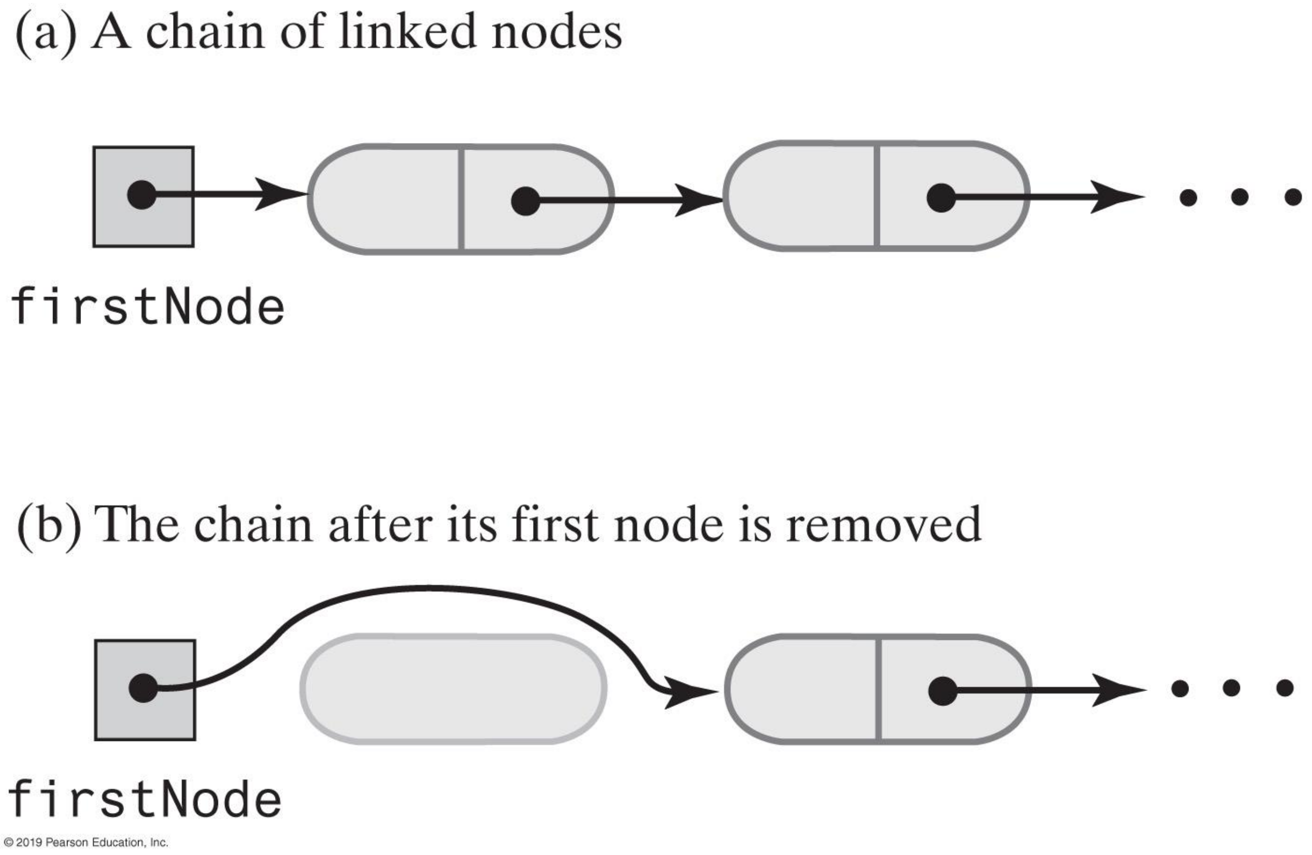


FIGURE 3-9
A chain of desks just after removing its first desk

Removing an Item from a Linked Chain

- **FIGURE 3-10 A chain of nodes just before and just after its first node is removed**


(a) A chain of linked nodes
firstNode
(b) The chain after its first node is removed
firstNode
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Removing an Item from a Linked Chain

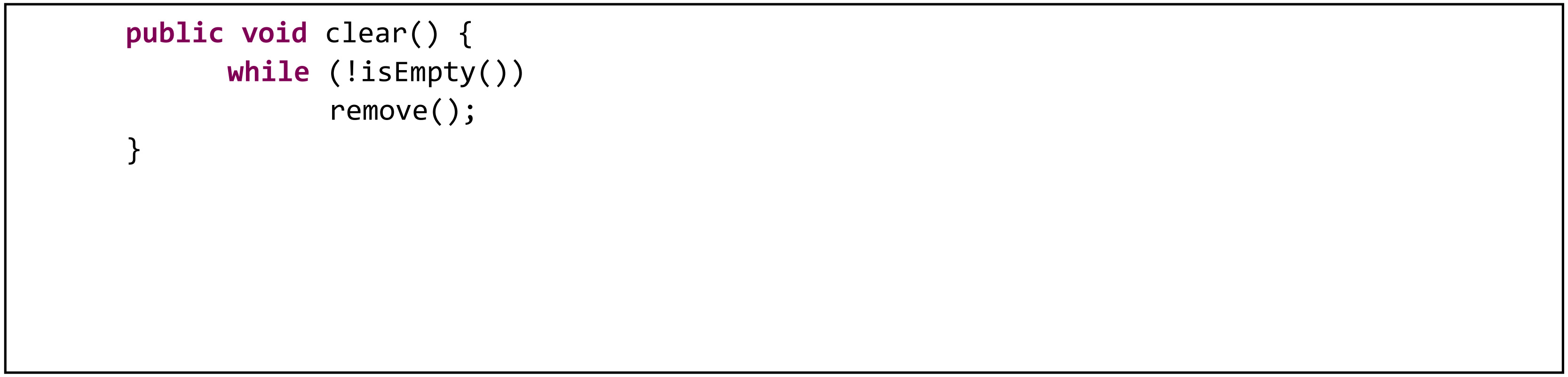
- **Case 2 – removing other items**
  - o Move the student in the first desk to your former desk.
  - o Remove the first desk using the steps described for Case 1.

remove()

- remove() with no args just removes the first entry
- remove() with an arg
    - find the node
    - place data from first node in the found node (duplicates it)
    - remove the first node
    - No need to save the data as it was passed from the caller

```java
    public T remove() {
        T result = null;
        if (firstNode != null) {
            result = firstNode.data;
            firstNode = firstNode.next; // Remove first node from chain
            numberOfEntries--;
        }

        return result;
    }

    public boolean remove(T anEntry) {
        boolean result = false;
        Node entryNode = getReferenceTo(anEntry);

        if (entryNode != null) {
            // Replace located entry with entry in first node
            entryNode.data = firstNode.data;
            firstNode = firstNode.next; // Remove first node
            numberOfEntries--;
            result = true;
        } // end if

        return result;
    }
```

clear() – can use remove()!!



```
public void clear() {
      while (!isEmpty())
            remove();
}
```

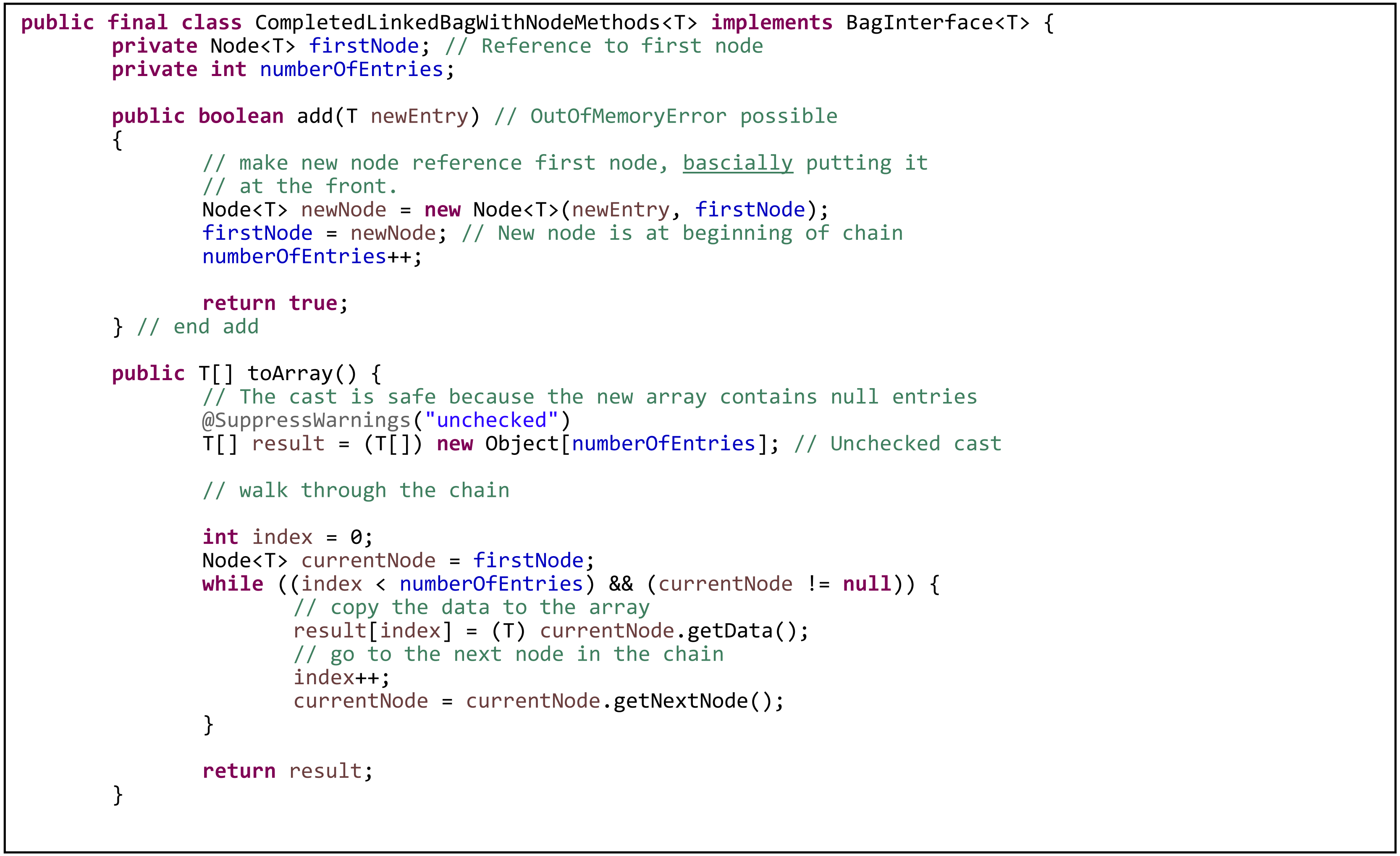
Public class Node

- Need getters/setters as data/next is private

```java
/**
 * Node in a linked list. Each node
 * contains data and a link to the next node in the
 * list.
 */
public class Node<T> {
    private T data; // Entry in bag
    private Node<T> next; // Link to next node

    /**
     * Create a new node containing data
     * @param dataPortion
     */
    public Node(T dataPortion) {
        this(dataPortion, null);
    }
    /**
     * Create a new node containing data
     * and set the next node.
     * @param dataPortion
     * @param nextNode
     */
    public Node(T dataPortion, Node<T> nextNode) {
        data = dataPortion;
        next = nextNode;
    }
    /**
     * Get the data from the node
     * @return
     */
    public T getData() {
        return data;
    }

    /**
     * Set the data in the node
     * @param newData
     */
    public void setData(T newData) {
        data = newData;
    }

    /**
     * Get the next node
     * @return
     */
    public Node<T> getNextNode() {
        return next;
    }

    /**
     * Set the next node
     * @param nextNode
     */
    public void setNextNode(Node<T> nextNode) {
        next = nextNode;
    }
}
```

LinkedBag methods using public Node Class

- Substitute get/set methods when accessing data/next
- Apply changes to other methods such as remove()



```
public final class CompletedLinkedBagWithNodeMethods<T> implements BagInterface<T> {
        private Node<T> firstNode; // Reference to first node
        private int numberOfEntries;

        public boolean add(T newEntry) // OutOfMemoryError possible
        {
                // make new node reference first node, bascially putting it
                // at the front.
                Node<T> newNode = new Node<T>(newEntry, firstNode);
                firstNode = newNode; // New node is at beginning of chain
                numberOfEntries++;

                return true;
        } // end add

        public T[] toArray() {
                // The cast is safe because the new array contains null entries
                @SuppressWarnings("unchecked")
                T[] result = (T[]) new Object[numberOfEntries]; // Unchecked cast

                // walk through the chain

                int index = 0;
                Node<T> currentNode = firstNode;
                while ((index < numberOfEntries) && (currentNode != null)) {
                        // copy the data to the array
                        result[index] = (T) currentNode.getData();
                        // go to the next node in the chain
                        index++;
                        currentNode = currentNode.getNextNode();
                }

                return result;
        }
```

Pros of Using a Chain

- Bag can grow and shrink in size as necessary.
- Remove and recycle nodes that are no longer needed
- Adding new entry to end of array or to beginning of chain both relatively simple
- Similar for removal

Cons of Using a Chain

- Removing specific entry requires search of array or chain
- Chain requires more memory than array of same length

Why Efficient Code?

- Computers are faster, have larger memories
  - So why worry about efficient code?
- And … how do we measure efficiency?

Importance of Efficiency

- Consider the problem of summing

- Compare three algorithms

$$\sum_{k=1}^{n} k = 1 + 2 + 3 + \ldots + n$$

Algorithlm A	Algorithm B	Algorithm C

long sum = 0;
for (long i = 1; i <= n; i++)
  sum = sum + i;
	sum = 0;
	for (long i = 1; i <= n; i++)
	{
	  for (long j = 1; j <= i; j++)
	    sum = sum + 1;
	} // end for
		sum = n * (n + 1) / 2;

What is “best”?

- An algorithm has both time and space constraints – that is complexity
  - Time complexity
  - Space complexity
- This study is called analysis of algorithms

Counting Basic Operations

- A basic operation of an algorithm
  - Most significant contributor to its total time requirement

	Algorithm A	Algorithm B	Algorithm C

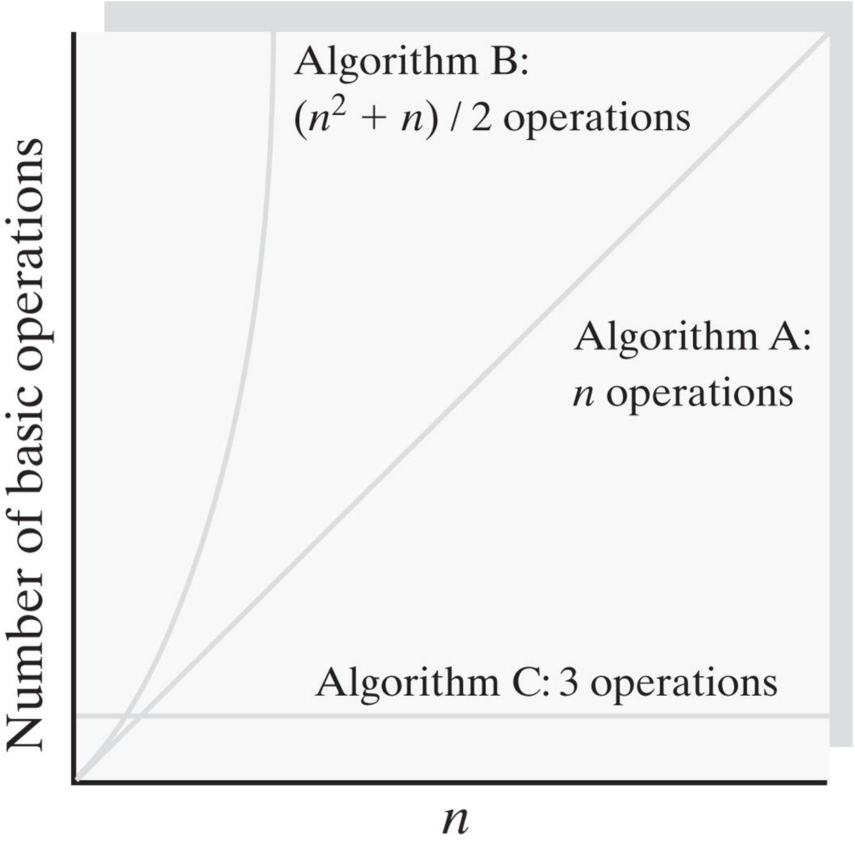
	long sum = 0;
	for (long i = 1; i <= n; i++)
	   sum = sum + i;
		sum = 0;
		for (long i = 1; i <= n; i++)
		{
		   for (long j = 1; j <= i; j++)
		      sum = sum + 1;
		} // end for
			sum = n * (n + 1) / 2;

Additions	n	$n(n + 1)/2$	1
Multiplications	0	0	1
Divisions	0	0	1
Total Basic Operations	n	$(n^2 + n)/2$	3

FIGURE 4-2 The number of basic operations required by the algorithms

Counting Basic Operations

- **Number of basic operations required by the algorithms as a function of *n***



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Counting Basic Operations

- **Typical growth-rate functions evaluated at increasing values of *n***

	(log(log n)	log n	$\log^2 n$		$n \log n$	n^2	n^3	2^n	$n!$
10	2	3	11	10	33	10^{2}	10^{3}	10^{3}	10^{5}
10^{2}	3	7	44	100	664	10^{4}	10^{6}	10^{30}	10^{94}
10^{3}	3	10	99	1,000	9,966	10^{6}	10^{9}	10^{301}	10^{1435}
10^{4}	4	13	177	10,000	132,877	10^{8}	10^{12}	10^{3010}	$10^{19,335}$
10^{5}	4	17	276	100,00	1,660,964	10^{10}	10^{15}	$10^{30,103}$	$10^{243,338}$
10^{6}	4	20	397	1,000,000	19,931,569	10^{12}	10^{18}	$10^{301,301}$	$10^{2,933,369}$

Best, Worst, and Average Cases

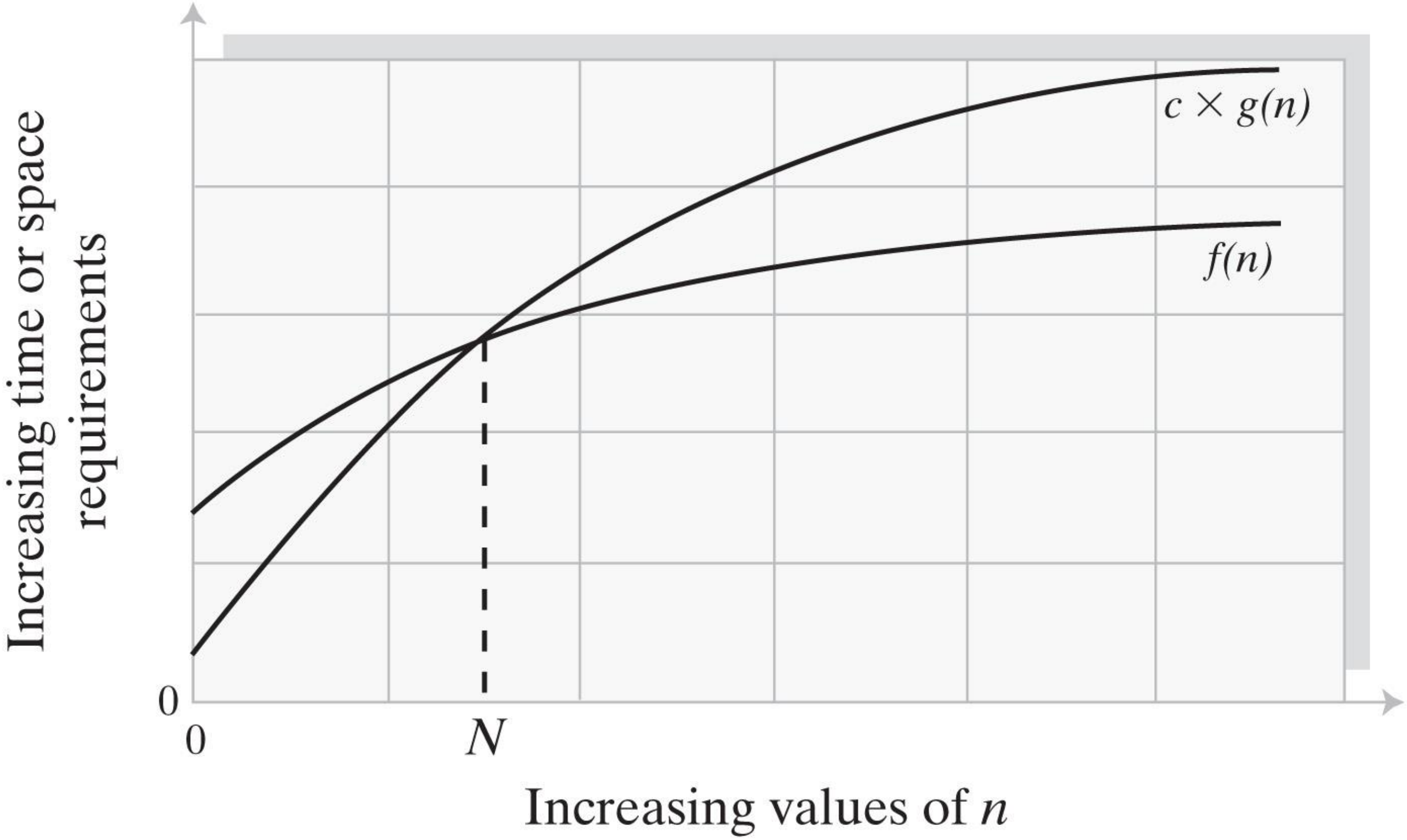
- For some algorithms, execution time depends only on size of data set
- Other algorithms depend on the nature of the data itself
    - Goal is to know best case, worst case, average case

Big Oh Notation

- A function $f(n)$ is of order at most $g(n)$
- That is, $f(n)$ is $O(g(n))$ — if
  - A positive real number c and positive integer N exist …
  - Such that $f(n) \leq c\ x\ g(n)$ for all $n \geq N$
  - That is:
    - c x $g(n)$ is an upper bound on $f(n)$ when n is sufficiently large

Big Oh Notation

- **An illustration of the values of two growth-rate functions**



Identities for Big Oh Notation

$O(k\ g(n)) = O(g(n))$ for a constant k

$O(g\ 1\ (n)) + O(g\ 2\ (n)) = O(g\ 1\ (n) + g\ 2\ (n))$

$O(g\ 1\ (n)) * O(g\ 2\ (n)) = O(g\ 1\ (n) * g\ 2\ (n))$

$O(g\ 1\ (n) + g\ 2\ (n) + \ldots + g\ m\ (n)) =$

$O(max(g\ 1\ (n), g\ 2\ (n), \ldots, g\ m\ (n))$

$O(max(g\ 1\ (n), g\ 2\ (n), \ldots, g\ m\ (n)) =$

$max(O(g\ 1\ (n)), O(g\ 2\ (n)), \ldots, O(g\ m\ (n)))$

Picturing Efficiency of O(n) algorithm

```
long sum = 0;
for (long i = 1; i <= n; i++)
  sum = sum + i;
```

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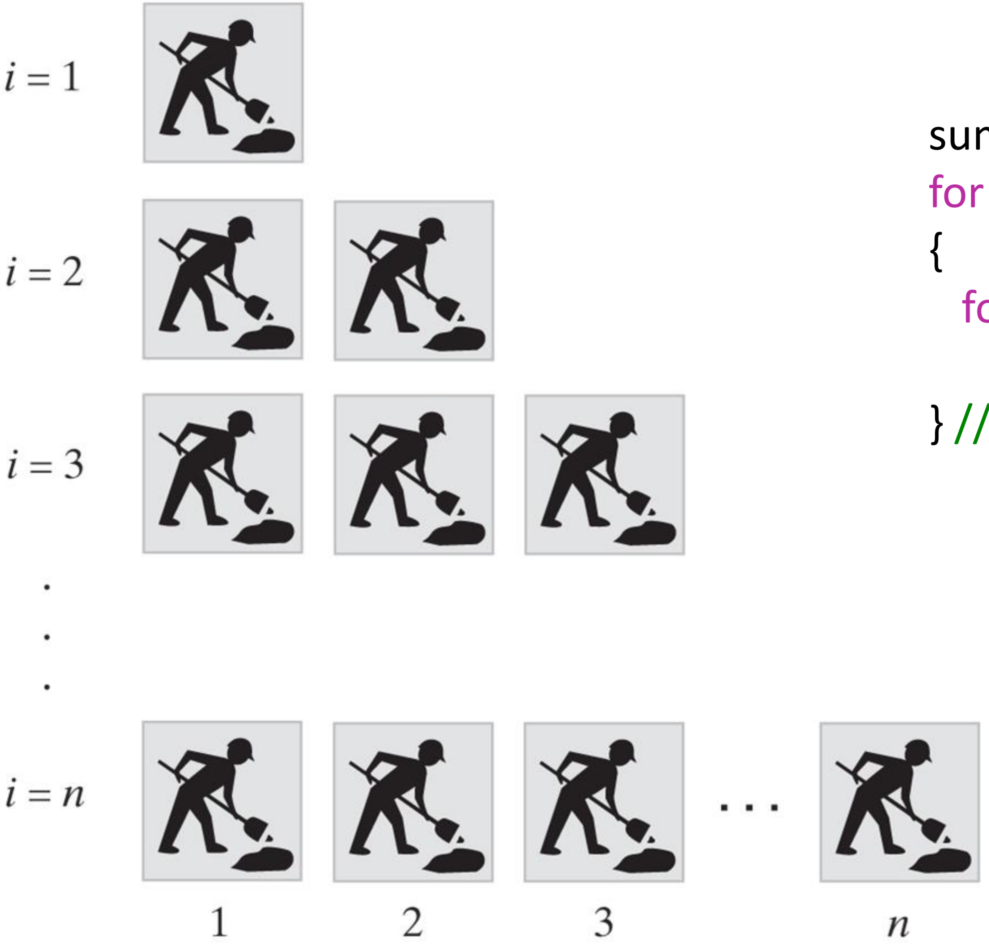
Picturing Efficiency O(n^2)



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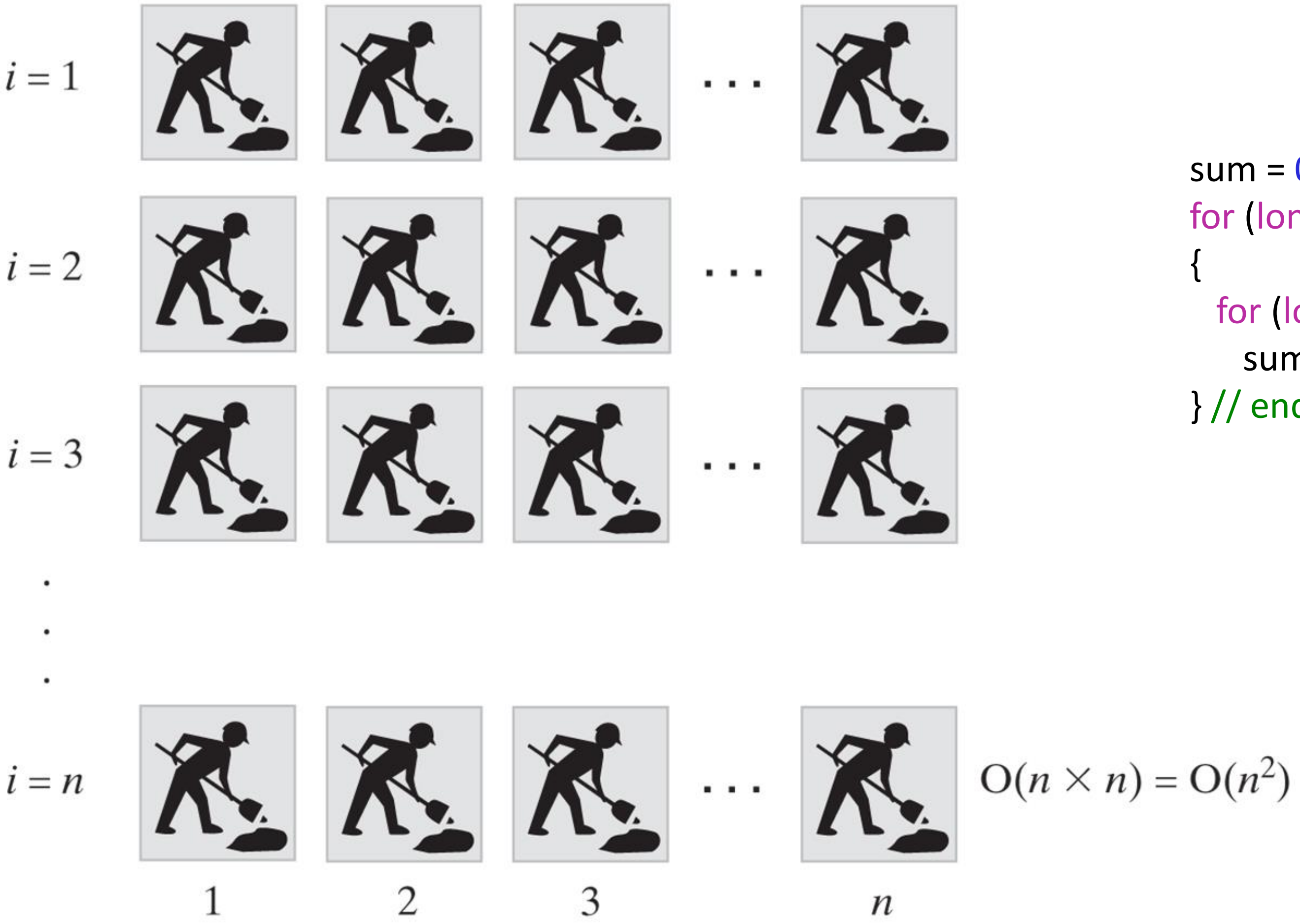
```
sum = 0;
for (long i = 1; i <= n; i++)
{
   for (long j = 1; j <= i; j++)
      sum = sum + 1;
} // end for
```

$$O(1 + 2 + \ldots + n) = O(n^2)$$

Picturing Efficiency $O(n^2)$



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```
sum = 0;
for (long i = 1; i <= n; i++)
{
  for (long j = 1; j <= n; j++)
    sum = sum + 1;
} // end for
```

Picturing Efficiency

- **The effect of doubling the problem size on an algorithm's time requirement**

Growth-Rate Function for Size *n* Problems	Growth-Rate Function for Size 2*n* Problems	
1	1	None
log *n*	1 + log *n*	Negligible
n	2*n*	Doubles
n log *n*	2*n* log *n* + 2*n*	Doubles and then adds 2*n*
n^2	$(2n)^2$	Quadruples
n^3	$(2n)^3$	Multiples by 8
2^n	2^{2n}	Squares

Picturing Efficiency

- **The time required to process one million items by algorithms of various orders at the rate of one million operations per second**
- **See GrowthRateFunctionDemo in MiscellaneousPackage for another example**

Growth-Rate Function *g*	$g(10^6) / 10^6$
log *n*	0.0000199 seconds
n	1 second
n log *n*	19.9 seconds
n^2	11.6 days
n^3	31,709.8 years
2^n	$10^{301,016}$ years

Efficiency of ADT Bag Implementations

- **The time efficiencies of the ADT bag operations for two implementations, expressed in Big Oh notation**

Operation	Fixed-Size Array	**Linked**
`add(newEntry)`	O(1)	O(1)
`remove()`	O(1)	O(1)
`remove(anEntry)`	O(1), O(*n*), O(*n*)	O(1), O(*n*), O(*n*)
`clear()`	O(*n*)	O(*n*)
`getFrequencyOf(anEntry)`	O(*n*)	O(*n*)
`contains(anEntry)`	O(1), O(*n*), O(*n*)	O(1), O(*n*), O(*n*)
`toArray()`	O(*n*)	O(*n*)
`getCurrentSize(), isEmpty()`	O(1)	O(1)

In class activities

- Implement the following using BagInterface
  - FixedSizeArrayBag
  - LinkedBag
  - LinkedBagWithNodeMethods
    - Use Node.java – already completed
  - ResizableArrayBag
- All have been started, just need to complete methods
- Test using BagDemo.java
  - Comment/uncomment the lines to test various implementations
- Use code from the textbook if necessary, but note some changes to BagInterface