香港中文大學（深圳）
The Chinese University of Hong Kong

OCTE: http://octe.cuhk.edu.cn

(Materials of this lecture will NOT be tested in the final exam)

CSC3100 Data Structures
Lecture 25: Java data structures

Li Jiang
School of Data Science (SDS)
The Chinese University of Hong Kong, Shenzhen

Outline

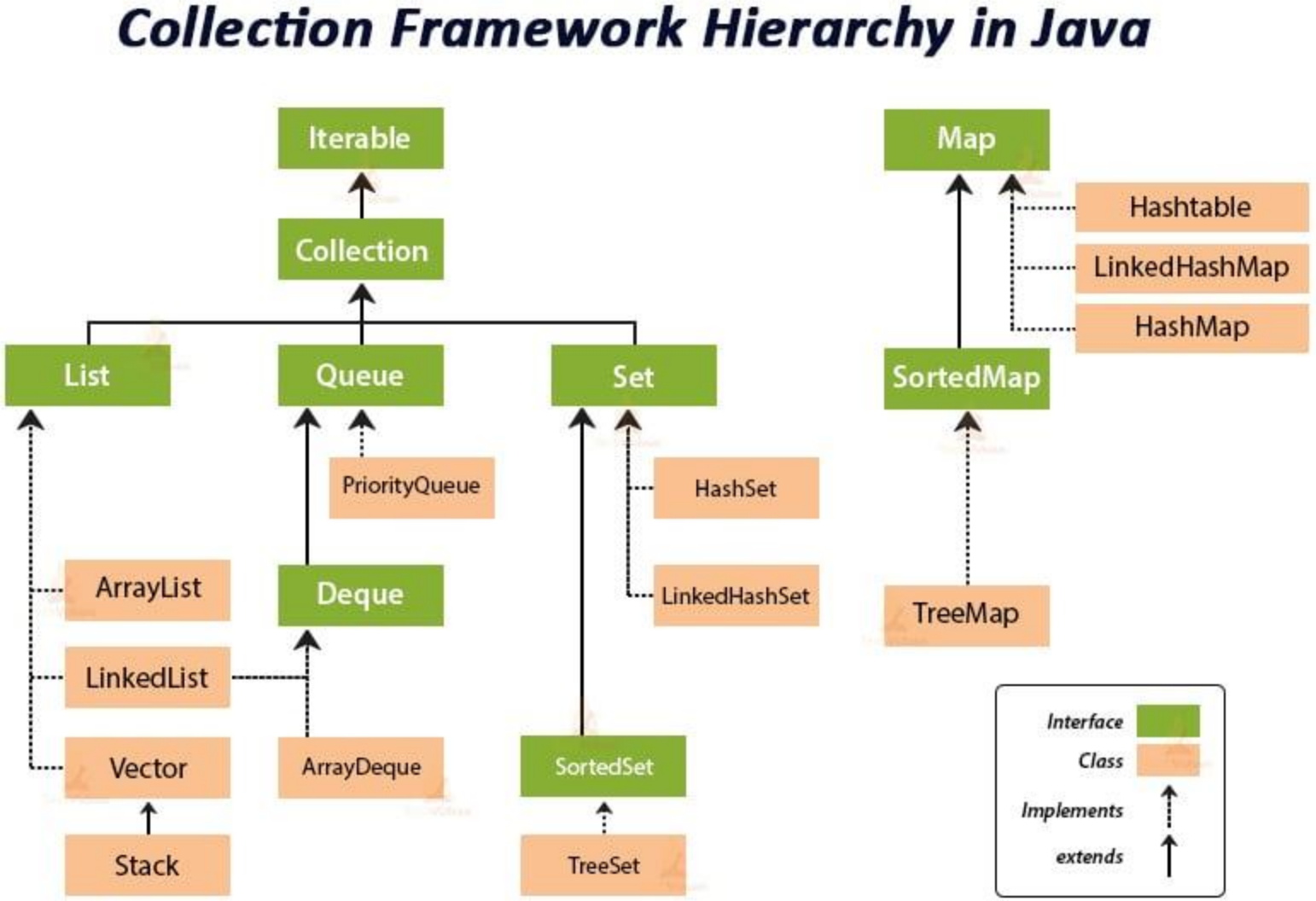
- Java collection framework
  - Iterator/Iterable interface
  - List interface
  - Queue/Deque interface
  - Set/SortedSet interface
  - Map interface

Java collection framework

- What is a framework in Java?
  - It provides readymade architecture
  - It represents a set of classes and interfaces
  - It is optional
- What is a collection framework?
  - Represents a unified architecture for storing and manipulating a group of objects
- Java collection framework has:
  - Interfaces and its implementations, i.e., classes
  - Some algorithms

An Interface is defined as an abstract type used to specify what a class must do and not how, i.e., a blueprint of a class

Hierarchy of collection framework



No.	Method	Description
1	public boolean add(E e)	It is used to insert an element in this collection.
2	public boolean addAll(Collection<? extends E> c)	It is used to insert the specified collection elements in the invoking collection.
3	public boolean remove(Object element)	It is used to delete an element from the collection.
4	public boolean removeAll(Collection<?> c)	It is used to delete all the elements of the specified collection from the invoking collection.
5	default boolean removeIf(Predicate<? super E> filter)	It is used to delete all the elements of the collection that satisfy the specified predicate.
6	public boolean retainAll(Collection<?> c)	It is used to delete all the elements of invoking collection except the specified collection.
7	public int size()	It returns the total number of elements in the collection.
8	public void clear()	It removes the total number of elements from the collection.
9	public boolean contains(Object element)	It is used to search an element.
10	public boolean containsAll(Collection<?> c)	It is used to search the specified collection in the collection.
11	public Iterator iterator()	It returns an iterator.
12	public Object[] toArray()	It converts collection into array.
13	public <T> T[] toArray(T[] a)	It converts collection into array. Here, the runtime type of the returned array is that of the specified array.
14	public boolean isEmpty()	It checks if collection is empty.
15	default Stream<E> parallelStream()	It returns a possibly parallel Stream with the collection as its source.
16	default Stream<E> stream()	It returns a sequential Stream with the collection as its source.
17	default Spliterator<E> spliterator()	It generates a Spliterator over the specified elements in the collection.
18	public boolean equals(Object element)	It matches two collections.
19	public int hashCode()	It returns the hash code number of the collection.

Iterator interface

- Iterator interface provides the facility of iterating the elements in a forward direction only
- Iterable interface contains one method: iterator

It contains only one abstract method. i.e.,

```
Iterator<T> iterator()
```

It returns the iterator over the elements of type T.

No.	Method	Description
1	public boolean hasNext()	It returns true if the iterator has more elements otherwise it returns false.
2	public Object next()	It returns the element and moves the cursor pointer to the next element.
3	public void remove()	It removes the last elements returned by the iterator. It is less used.

Iterable and Collection interfaces

- The Iterable interface is the root interface for all the collection classes

- The Collection interface extends the Iterable interface
  - All the subclasses of Collection interface also implement the Iterable interface
  - The Collection interface declares the methods that every collection will have,
    - boolean add (Object obj)
    - boolean addAll (Collection c)
    - void clear( )
    - And so on

List interface

- List interface is the child interface of Collection interface
  - It exhibits a list type data structure which can store the ordered collection of objects
  - It can have duplicate values
  - List interface is implemented by the classes ArrayList, LinkedList, Vector, and Stack

To instantiate the List interface, we must use :

```
List <data-type> list1= new ArrayList();
List <data-type> list2 = new LinkedList();
List <data-type> list3 = new Vector();
List <data-type> list4 = new Stack();
```

There are various methods in List interface that can be used to insert, delete, and access the elements from the list.

```java
import java.util.*;
class TestJavaCollection1
{
    public static void main(String args[])
    {
        ArrayList<String> list = new ArrayList<String>(); //Creating arraylist
        list.add("Ravi");//Adding object in arraylist
        list.add("Vijay");
        list.add("Ravi");
        list.add("Ajay");
        //Traversing list through Iterator
        Iterator itr = list.iterator();
        while(itr.hasNext())
        {
            System.out.println(itr.next());
        }
    }
}
```

```
Ravi
Vijay
Ravi
Ajay
```

The ArrayList class implements the List interface
It uses a dynamic array to store the duplicate element of different data types
The ArrayList class maintains the insertion order and is non-synchronized (pay attention to the scenario when there are multiple threads/CPUs)
The elements stored in the ArrayList class can be randomly accessed

```java
import java.util.*;
public class TestJavaCollection2
{
    public static void main(String args[])
    {
        LinkedList<String> al = new LinkedList<String>();
        al.add("Ravi");
        al.add("Vijay");
        al.add("Ravi");
        al.add("Ajay");
        Iterator<String> itr = al.iterator();
        while(itr.hasNext())
        {
            System.out.println(itr.next());
        }
    }
}
```

```
Ravi
Vijay
Ravi
Ajay
```

LinkedList implements the Collection interface
It uses a doubly linked list internally to store the elements
It can store the duplicate elements
It maintains the insertion order and is non-synchronized
The manipulation is fast because no shifting is required

```java
import java.util.*;
public class TestJavaCollection3
{
    public static void main(String args[])
    {
        Vector<String> v = new Vector<String>();
        v.add("Ayush");
        v.add("Amit");
        v.add("Ashish");
        v.add("Garima");
        Iterator<String> itr = v.iterator();
        while(itr.hasNext())
        {
            System.out.println(itr.next());
        }
    }
}
```

```
Ayush
Amit
Ashish
Garima
```

Vector uses a dynamic array to store the data elements, which is similar to ArrayList However, it is synchronized and contains many methods that are not the part of Collection framework

```java
import java.util.*;
public class TestJavaCollection4
{
    public static void main(String args[])
    {
        Stack<String> stack = new Stack<String>();
        stack.push("Ayush");
        stack.push("Garvit");
        stack.push("Amit");
        stack.push("Ashish");
        stack.push("Garima");
        stack.pop();
        Iterator<String> itr = stack.iterator();
        while(itr.hasNext())
        {
            System.out.println(itr.next());
        }
    }
}
```

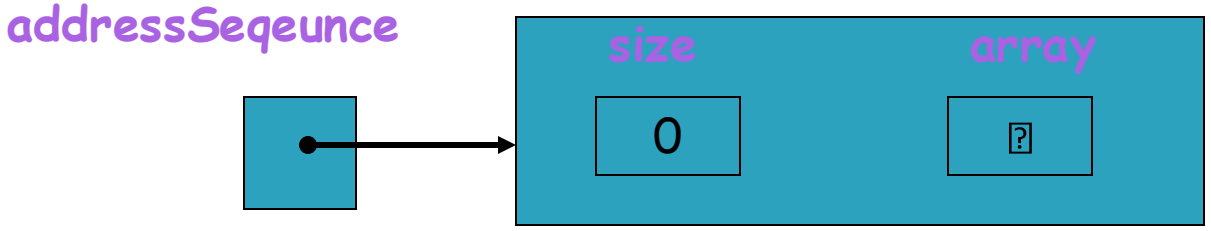
```
Ayush
Garvit
Amit
Ashish
```

Stack is the subclass of Vector
It implements the last-in-first-out data structure, i.e., Stack
The stack contains all of the methods of Vector class and also provides its methods like object pop(), object peek(), object push(object o), which define its properties

ArrayList class

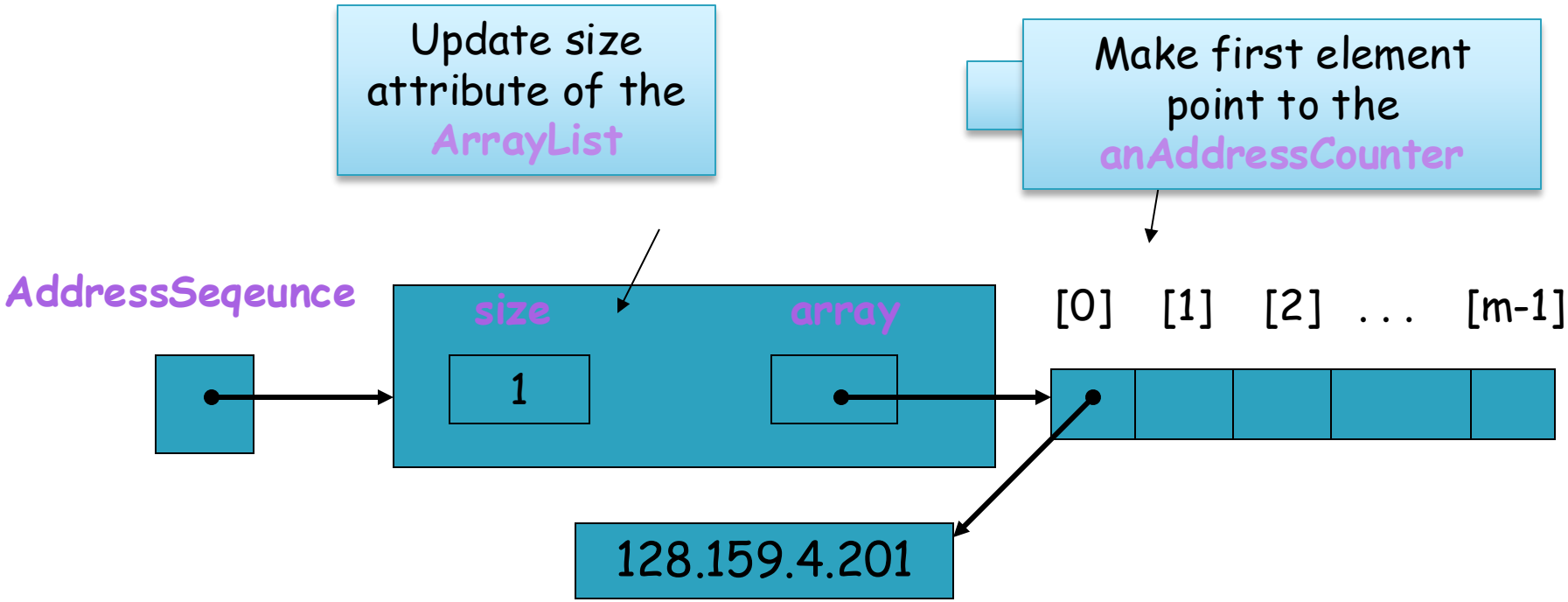
- Implements the List using an array
  - By using an Object array, it can store any reference type
  - It cannot directly store primitive types, but can indirectly store such values by using instances of their wrapper types

- Consider the declaration:
  `ArrayList addressSequence = new ArrayList();`



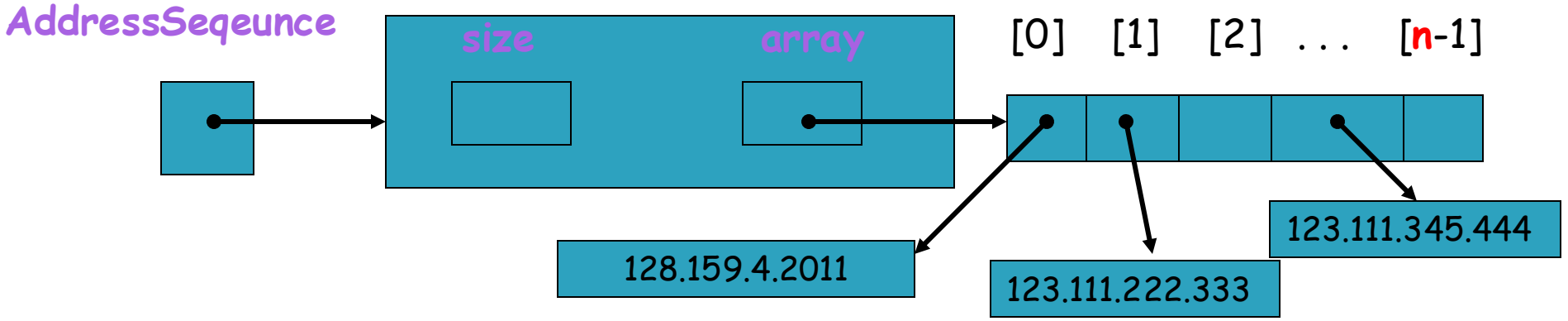
Add to addressSequence

- The command
  addressSequence.add(anAddressCounter);
  - appends anAddressCounter object to the sequence
- The system will then …



Enlarge the AddressSequence array

- When the allocated array is full, adding another element forces replacing array with larger one
  - A new array of n > m is allocated
  - Values from old array are copied into new array
  - Old array is replaced by new one



ArrayList drawback

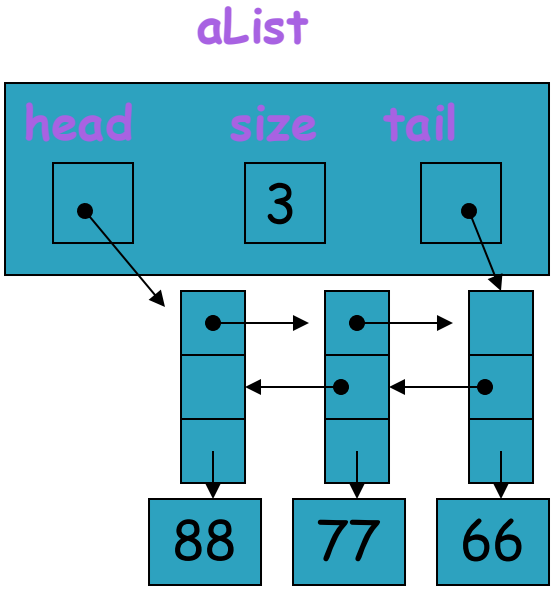
- Problems arise from using an array
  - Values can be added only at back of ArrayList
  - To insert a value, "shifting" may be required
  - Similarly, deleting a value requires shifting

- We need a slightly different structure to allow simple insertions and deletions
  - The LinkedList class will accomplish this

The LinkedList class

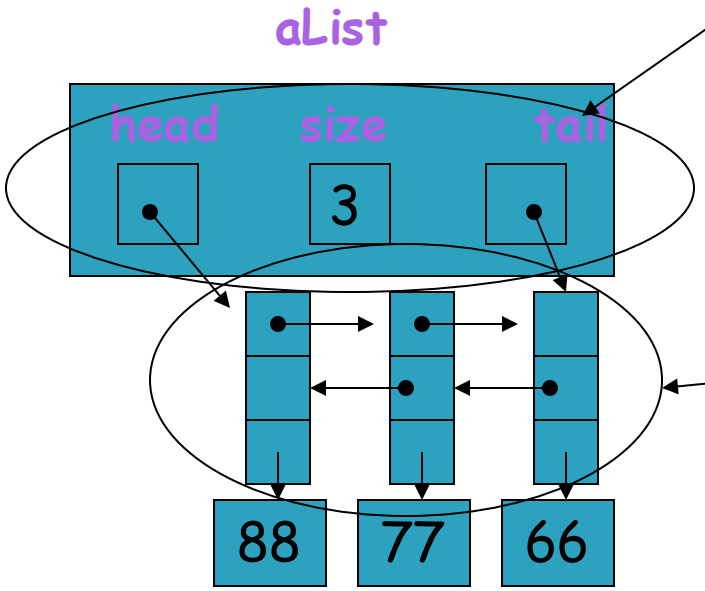
- Given

```
LinkedList aList = new LinkedList();
. . .
aList.add(new Integer(88));
aList.add(new Integer(77));
aList.add(new Integer(66));
```



Linkedlist containers

Attributes:
- link to first item in the list
- size of the list
- link to last item in the list

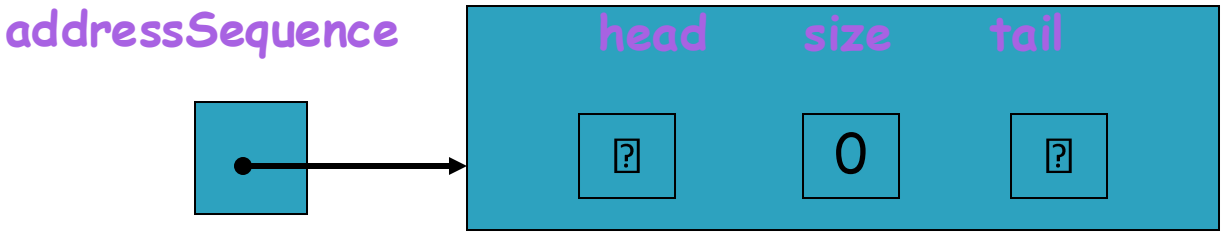


Nodes:
- Contain 3 handles
  - link to next node
  - link to previous node
  - link to stored object
- Links to next and previous make it a doubly linked list

LinkedList class

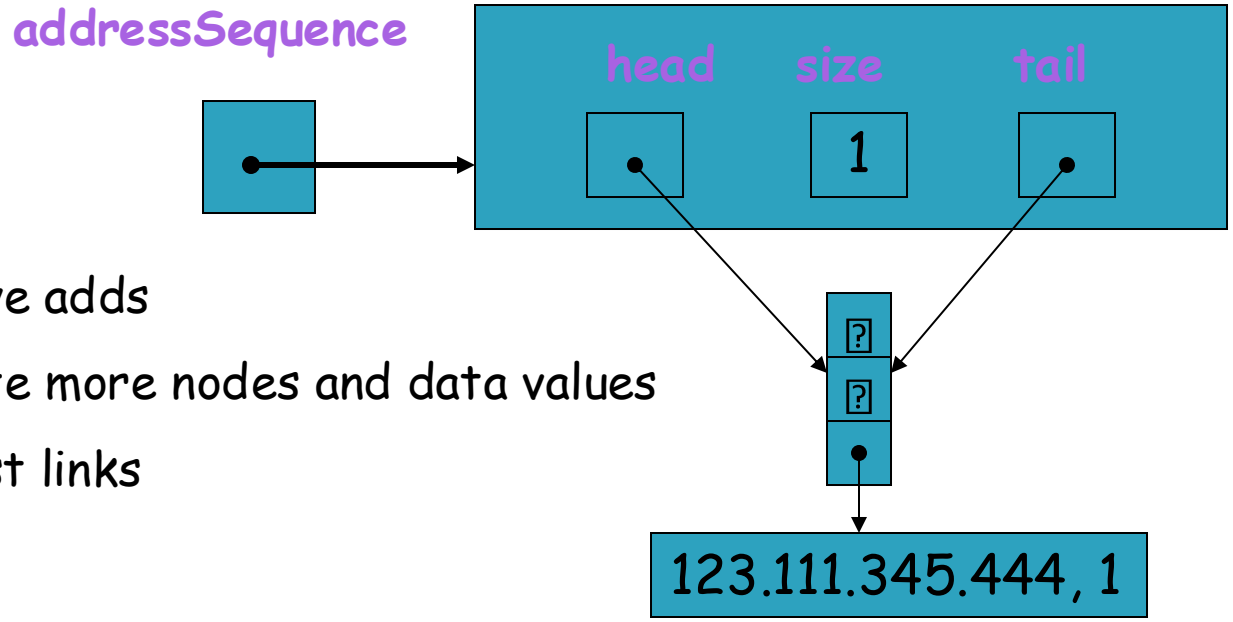
- Given the command
  `LinkedList addressSequence = new LinkedList();`

- Uses LinkedList constructor to build an empty list



Add to a LinkedList

- Results of command for first add
  `addressSequence.add(anAddressCounter);`



- Successive adds
  - create more nodes and data values
  - adjust links

Accessing values in a LinkedList

- Must use the get method

```
((AddressCounter)addresssSequence.get(index)).incrementCount();
```

- A LinkedList has no array with an index to access an element

- get method must …
  - begin at head node
  - iterate through index nodes to find match
  - return reference of object in that node

- Command then does cast and incrementCount()

Accessing values in a LinkedList

- To print successive values for the output

```
for (int i = 0; i < addressSequence.size(); i++)
    System.out.println(addressSequence.get(i));
```

size method determines limit of loop counter

get(i) starts at first node, iterates i times to reach desired node

• Note that each **get(i)** must pass over the same first **i-1** nodes previously accessed; this, of course, is inefficient

Insert nodes anywhere in a LinkedList

- Recall problem with ArrayList
  - It can add only at end of the list
  - LinkedList has capability to insert nodes anywhere

- We can use `addressSequence.add(n, new anAddressCounter);`
  which will …
  - build a new node
  - update head and tail links if required
  - update node handle links to place new node to be n^{th} item in the list
  - allocate memory for the data item

Queue interface

- Queue interface maintains the property of first-in-first-out
  - It can be defined as an ordered list that is used to hold the elements to be processed
  - Classes PriorityQueue, LinkedList, and ArrayDeque implement the Queue interface
    - PriorityQueue holds the elements or objects which are to be processed by their priorities
    - PriorityQueue doesn't allow null values to be stored

Queue interface can be instantiated as:

```
Queue<String> q1 = new PriorityQueue();
Queue<String> q2 = new ArrayDeque();
```

```java
import java.util.*;
public class TestJavaCollection5
{
    public static void main(String args[])
    {
        PriorityQueue<String> queue = new PriorityQueue<String>();
        queue.add("Amit Sharma");
        queue.add("Vijay Raj");
        queue.add("JaiShankar");
        queue.add("Raj");
        System.out.println("head:" + queue.element());
        System.out.println("head:" + queue.peek());
        System.out.println("iterating the queue elements:");
        Iterator itr = queue.iterator();
        while(itr.hasNext())
        {
            System.out.println(itr.next());
        }
        queue.remove();
        queue.poll();
        System.out.println("after removing two elements:");
        Iterator<String> itr2 = queue.iterator();
        while(itr2.hasNext())
        {
            System.out.println(itr2.next());
        }
    }
}
```


```
head:Amit Sharma
head:Amit Sharma
iterating the queue elements:
Amit Sharma
Raj
JaiShankar
Vijay Raj
after removing two elements:
Raj
Vijay Raj
```

```java
import java.util.*;

public class HelloWorld {
    public static void main(String[] args) {
        PriorityQueue<String> q = new PriorityQueue<String>();
        q.add("Amit Sharma");
        q.add("Vijay Raj");
        q.add("JaiShankar");
        q.add("Raj");

        Iterator itr = q.iterator();
        while(itr.hasNext())   System.out.println("iter: " + itr.next());
        System.out.println();

        while(q.size() > 0){
            System.out.println("pool:" + q.poll());
        }
    }
}
```

```
iter: Amit Sharma
iter: Raj
iter: JaiShankar
iter: Vijay Raj

pool:Amit Sharma
pool:JaiShankar
pool:Raj
pool:Vijay Raj
```

PriorityQueue is implemented by heap data structure
When we remove an element from it, the element with the highest priority will be removed

When we use an iterator to enumerate its elements, the enumeration does not consider the priority values

Deque interface

- Deque interface extends the Queue interface
- A double-ended queue which enables us to perform the operations at both the ends

Deque can be instantiated as:

```
Deque d = new ArrayDeque();
```

```java
import java.util.*;
public class TestJavaCollection6
{
    public static void main(String[] args)
    {
        //Creating Deque and adding elements
        Deque<String> deque = new ArrayDeque<String>();
        deque.add("Gautam");
        deque.add("Karan");
        deque.add("Ajay");
        //Traversing elements
        for (String str : deque)
        {
            System.out.println(str);
        }
    }
}
```

```
Gautam
Karan
Ajay
```

ArrayDeque class implements the Deque interface
Unlike queue, we can add or delete the elements from both ends
ArrayDeque is faster than ArrayList and Stack, and has no capacity restrictions

Set interface

- Set interface extends the Collection interface
  - It represents the unordered set of elements which doesn't allow duplicate items
  - We can store at most one null value in Set
  - Set is implemented by HashSet, LinkedHashSet, and TreeSet

Set can be instantiated as:

```
Set<data-type> s1 = new HashSet<data-type>();
Set<data-type> s2 = new LinkedHashSet<data-type>();
Set<data-type> s3 = new TreeSet<data-type>();
```

```java
import java.util.*;
public class TestJavaCollection7
{
    public static void main(String args[])
    {
        //Creating HashSet and adding elements
        HashSet<String> set = new HashSet<String>();
        set.add("Ravi");
        set.add("Vijay");
        set.add("Ravi");
        set.add("Ajay");
        //Traversing elements
        Iterator<String> itr = set.iterator();
        while(itr.hasNext())
        {
            System.out.println(itr.next());
        }
    }
}
```

```
Vijay
Ravi
Ajay
```

HashSet class implements Set interface
It represents the collection that uses a hash table for storage
Hashing is used to store the elements in the HashSet
It contains unique items

```java
import java.util.*;
public class TestJavaCollection8
{
    public static void main(String args[])
    {
        LinkedHashSet<String> set = new LinkedHashSet<String>();
        set.add("Ravi");
        set.add("Vijay");
        set.add("Ravi");
        set.add("Ajay");
        Iterator<String> itr = set.iterator();
        while(itr.hasNext())
        {
            System.out.println(itr.next());
        }
    }
}
```

```
Ravi
Vijay
Ajay
```

LinkedHashSet class represents the LinkedList implementation of Set interface
It extends the HashSet class and implements Set interface
Like HashSet, it also contains unique elements
It maintains the insertion order and permits null elements

Sortedset interface

- SortedSet is the alternate of Set interface that provides a total ordering on its elements
  - The elements of the SortedSet are arranged in the increasing (ascending) order
  - It provides additional methods that exhibit the natural ordering of the elements

The SortedSet can be instantiated as:

```
SortedSet<data-type> set = new TreeSet();
```

```java
import java.util.*;
public class TestJavaCollection9
{
    public static void main(String args[])
    {
        //Creating and adding elements
        TreeSet<String> set = new TreeSet<String>();
        set.add("Ravi");
        set.add("Vijay");
        set.add("Ravi");
        set.add("Ajay");
        //traversing elements
        Iterator<String> itr = set.iterator();
        while(itr.hasNext())
        {
            System.out.println(itr.next());
        }
    }
}
```

```
Ajay
Ravi
Vijay
```

TreeSet class implements the Set interface that uses a tree for storage
TreeSet uses the red-black tree to store the data
Like HashSet, TreeSet also contains unique elements
The access and retrieval time of TreeSet is quite fast
The elements in TreeSet are stored in ascending order

Map interface

- The Map interface is not a subtype of the Collection interface, so it behaves a bit differently from the previous collection types
  - A map contains unique keys

- HashMap class
  - It is an implementation of Map interface based on hash table
  - It stores elements in key & value pair

```
class Demo
{
  public static void main(String args[])
  {
  // Creating HashMap
    HashMap<Integer,String> hashMap = new HashMap<Integer,String>();
    // Adding elements
    hashMap.put(1, "One");
    hashMap.put(2, "Two");
    hashMap.put(3, "Three");
    hashMap.put(4, "Four");
    // Displaying HashMap
    System.out.println(hashMap);
  }
}
```

Output:
{1=One, 2=Two, 3=Three, 4=Four}

Questions for self-study

- What are the two ways to iterate the elements of a collection?
- What is the difference between ArrayList and LinkedList classes in collection framework?
- What is the difference between ArrayList and Vector classes in collection framework?
- What is the difference between HashSet and ArrayList classes in collection framework?
- How can we sort the elements of an object?
- Give an application example that we should use HashSet, instead of other collection classes?

Recommended reading

- Reading materials
  - https://fileadmin.cs.lth.se/cs/Education/EDA040/common/java21.pdf
  - https://www.guru99.com/java-tutorial.html
  - Book: Think in Java