Lecture 4.
The Java Collections Framework

Outline

- Introduction to the Java Collections Framework
- Iterators
- Interfaces, Abstract Classes and Classes of the Java Collections Framework

Learning Outcomes

- From this lecture you should understand:
  - The purpose and advantages of the Java Collections Framework
  - How interfaces, abstract classes and classes are used hierarchically to achieve some of the key goals of object-oriented software engineering.
  - The purpose of iterators, and how to create and use them.
  - How the Java Collections Framework can be used to develop code using general collections, lists, array lists, stacks and queues.

Outline

- **Introduction to the Java Collections Framework**
- Iterators
- Interfaces, Abstract Classes and Classes of the Java Collections Framework

The Java Collections Framework

- We will consider the Java Collections Framework as a good example of how to apply the principles of **object-oriented software engineering** (see Lecture 1) to the design of classical data structures.

The Java Collections Framework

- A coupled set of classes and interfaces that implement commonly reusable collection data structures.
- Designed and developed primarily by Joshua Bloch (former Chief Java Architect at Google).

What is a Collection?

- An object that groups multiple elements into a single unit.
- Sometimes called a **container**.

What is a Collection Framework?

- A unified architecture for representing and manipulating collections.
- Includes:
  - **Interfaces:** A hierarchy of ADTs.
  - **Implementations**
  - **Algorithms:** The methods that perform useful computations, such as searching and sorting, on objects that implement collection interfaces.
    - These algorithms are *polymorphic*: that is, the same method can be used on many different implementations of the appropriate collection interface.

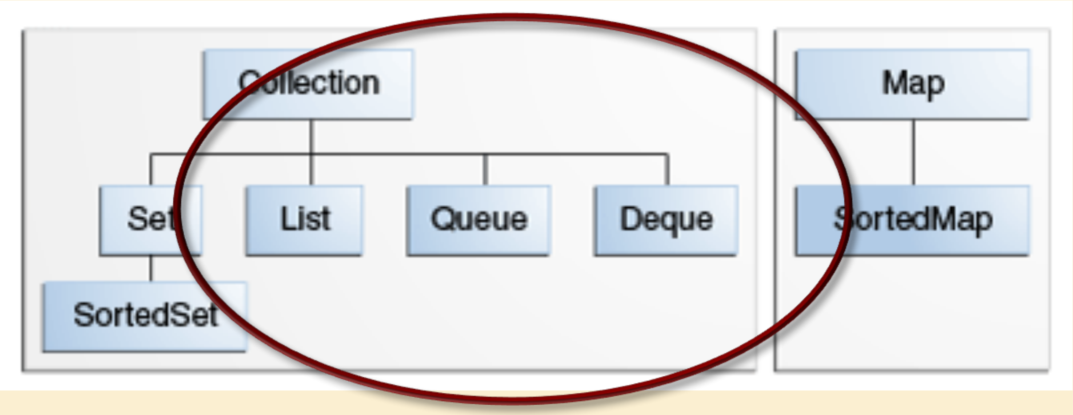
Benefits

- **Reduces programming effort:** By providing useful data structures and algorithms, the Collections Framework frees you to concentrate on the important parts of your program rather than on the low-level "plumbing" required to make it work.
- **Increases program speed and quality:** Provides high-performance, high-quality implementations of useful data structures and algorithms.
- **Allows interoperability among applications:** applications can interoperate seamlessly, even though they were written independently.
- **Reduces effort to learn and to use new applications**
- **Reduces effort to design new applications**
- **Fosters software reuse:** New data structures that conform to the standard collection interfaces are by nature reusable.

Where is the Java Collections Framework?

- Package java.util.
- In this lecture we will survey the interfaces, abstract classes and classes **for linear data structures** provided by the Java Collections Framework.
- We will not cover all of the details (e.g., the exceptions that may be thrown).
- For additional details, please see
  - **Javadoc**, provided with your java distribution.
  - **Comments and code in the specific java.util.*.java files**, provided with your java distribution.
  - **The Collections Java tutorial**, available at http://docs.oracle.com/javase/tutorial/collections/index.html
  - Chan et al, The Java Class Libraries, Second Edition

Core Collection Interfaces



Outline

- Introduction to the Java Collections Framework
- **Iterators**
- Interfaces, Abstract Classes and Classes of the Java Collections Framework

Traversing Collections in Java

- There are two ways to traverse collections:
  - using **Iterators**.
  - with the (enhanced) **for-each** construct

Iterators

- An Iterator is an object that enables you to traverse through a collection and to remove elements from the collection selectively, if desired.
- You get an Iterator for a collection by calling the collection's iterator method.
- Suppose **collection** is an instance of a **Collection**. Then to print out each element on a separate line:

```
Iterator<E> it = collection.iterator();
while (it.hasNext())
        System.out.println(it.next());
```

- Note that next() does two things:
  1. Returns the current element (initially the first element)
  2. Steps to the next element and makes it the current element.

Iterators

Iterator interface:

```
    public interface Iterator<E> {
            boolean hasNext();
            E next();
            void remove(); //optional
}
```

- **hasNext()** returns true if the iteration has more elements
- **next()** returns the next element in the iteration.
  - throws exception if iterator has already visited all elements.
- **remove()** removes the last element that was returned by next.
  - remove may be called only once per call to next
  - otherwise throws an exception.
  - Iterator.**remove** is the *only* safe way to modify a collection during iteration

Implementing Iterators

- Could make a copy of the collection.
  - **Good:** could make copy private – no other objects could change it from under you.
  - **Bad:** **construction** is O(n).
- Could use the collection itself (the typical choice).
  - **Good:** **construction**, **hasNext** and **next** are all O(1).
  - **Bad:** if another object makes a structural change to the collection, the results are unspecified.

The Enhanced For-Each Statement

- Suppose **collection** is an instance of a **Collection**. Then

  ```
  for (Object o : collection)
        System.out.println(o);
  ```

  prints each element of the collection on a separate line.

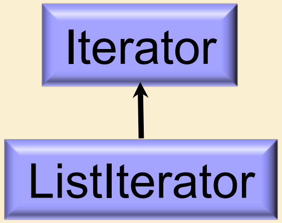
- This code is just shorthand: it compiles to use o.iterator().

The Generality of Iterators

- Note that iterators are general in that they apply to any collection.
  - Could represent a sequence, set or map.
  - Could be implemented using arrays or linked lists.

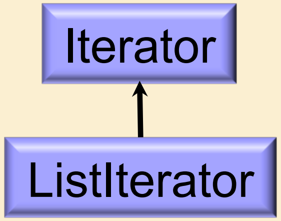
ListIterators

- A **ListIterator** extends Iterator to treat the collection as a list, allowing
  - access to the integer position (index) of elements
  - forward and backward traversal
  - modification and insertion of elements.



- The current position is viewed as being either
  - Before the first element
  - Between two elements
  - After the last element

ListIterators



Iterator

ListIterator

- ListIterators support the following methods:
  - **add(e):** inserts element e at current position
  - **hasNext()**
  - **hasPrevious()**
  - **previous():** returns element before current position and steps backward
  - **next():** returns element after current position and steps forward
  - **nextIndex()**
  - **previousIndex()**
  - **set(e):** replaces the element returned by the most recent **next()** or **previous()** call
  - **remove():** removes the element returned by the most recent **next()** or **previous()** call

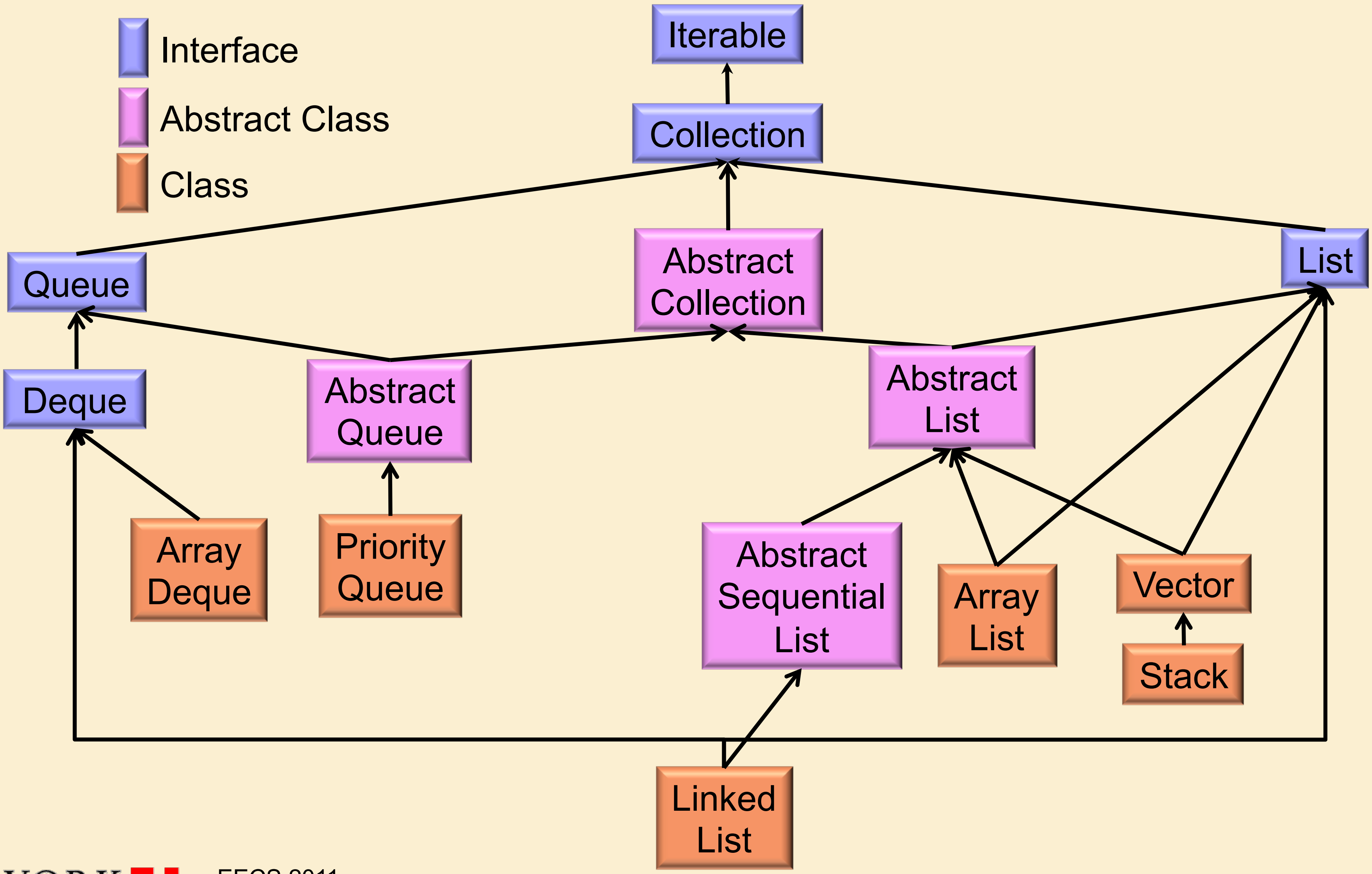
Outline

- Introduction to the Java Collections Framework
- Iterators
- **Interfaces, Abstract Classes and Classes of the Java Collections Framework**

Levels of Abstraction

- Recall that Java supports three levels of abstraction:
  - Interface
    - Java expression of an ADT
    - Includes method declarations with arguments of specified types, but with empty bodies
  - Abstract Class
    - Implements only a subset of an interface.
    - Cannot be used to instantiate an object.
  - (Concrete) Class
    - May extend one or more abstract classes
    - Must fully implement any interface it implements
    - Can be used to instantiate objects.

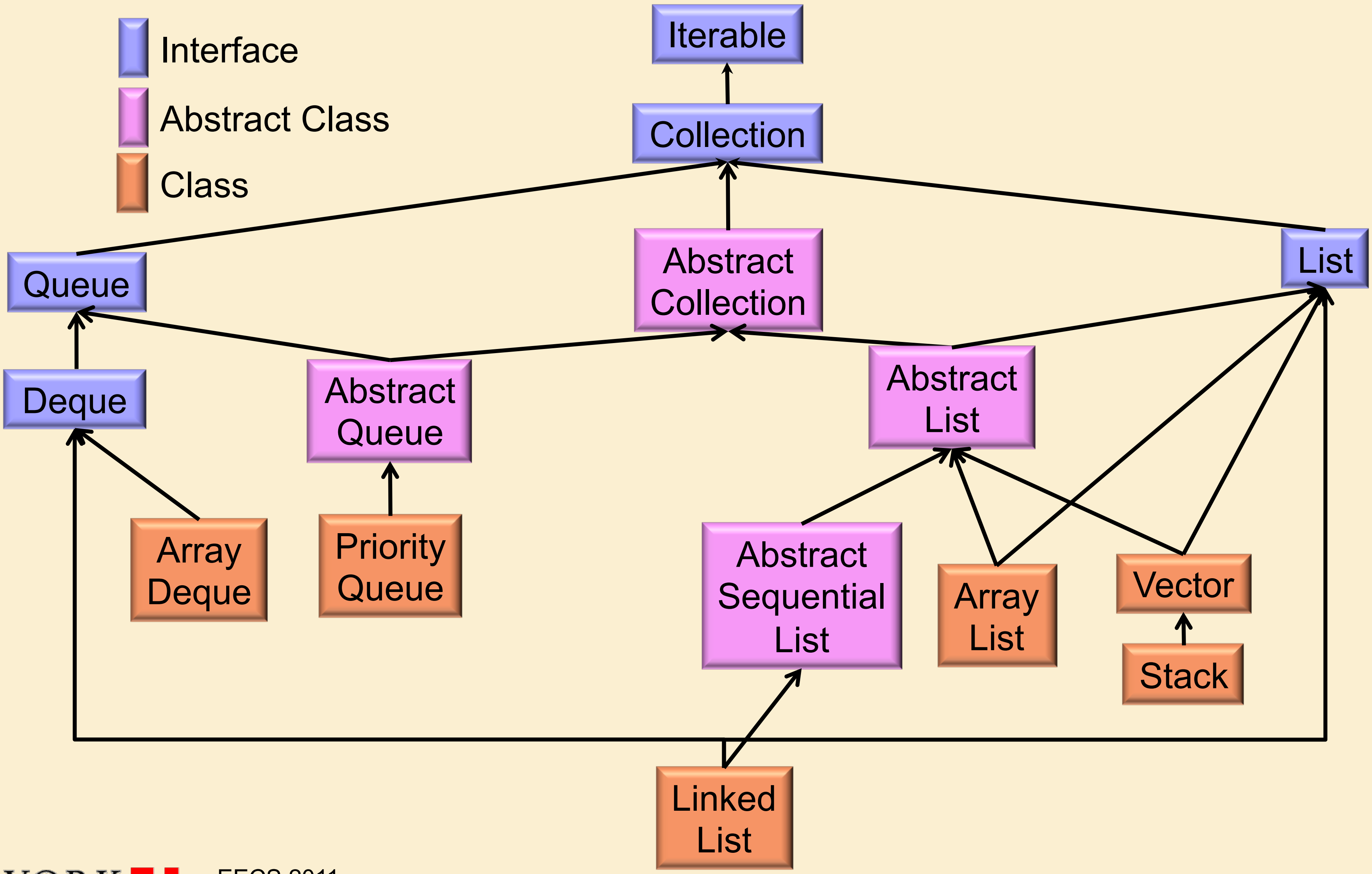
The Java Collections Framework (Ordered Data Types)



The **Iterable** Interface

- Allows an **Iterator** to be associated with an object.
- The iterator allows an existing data structure to be stepped through sequentially, using the following methods:
  - **hasNext()** returns true if the iteration has more elements
  - **next()** returns the next element in the iteration.
    - throws exception if iterator has already visited all elements.
  - **remove()** removes the last element that was returned by next.
    - remove may be called only once per call to next
    - otherwise throws an exception.
    - Iterator.**remove** is the *only* safe way to modify a collection during iteration

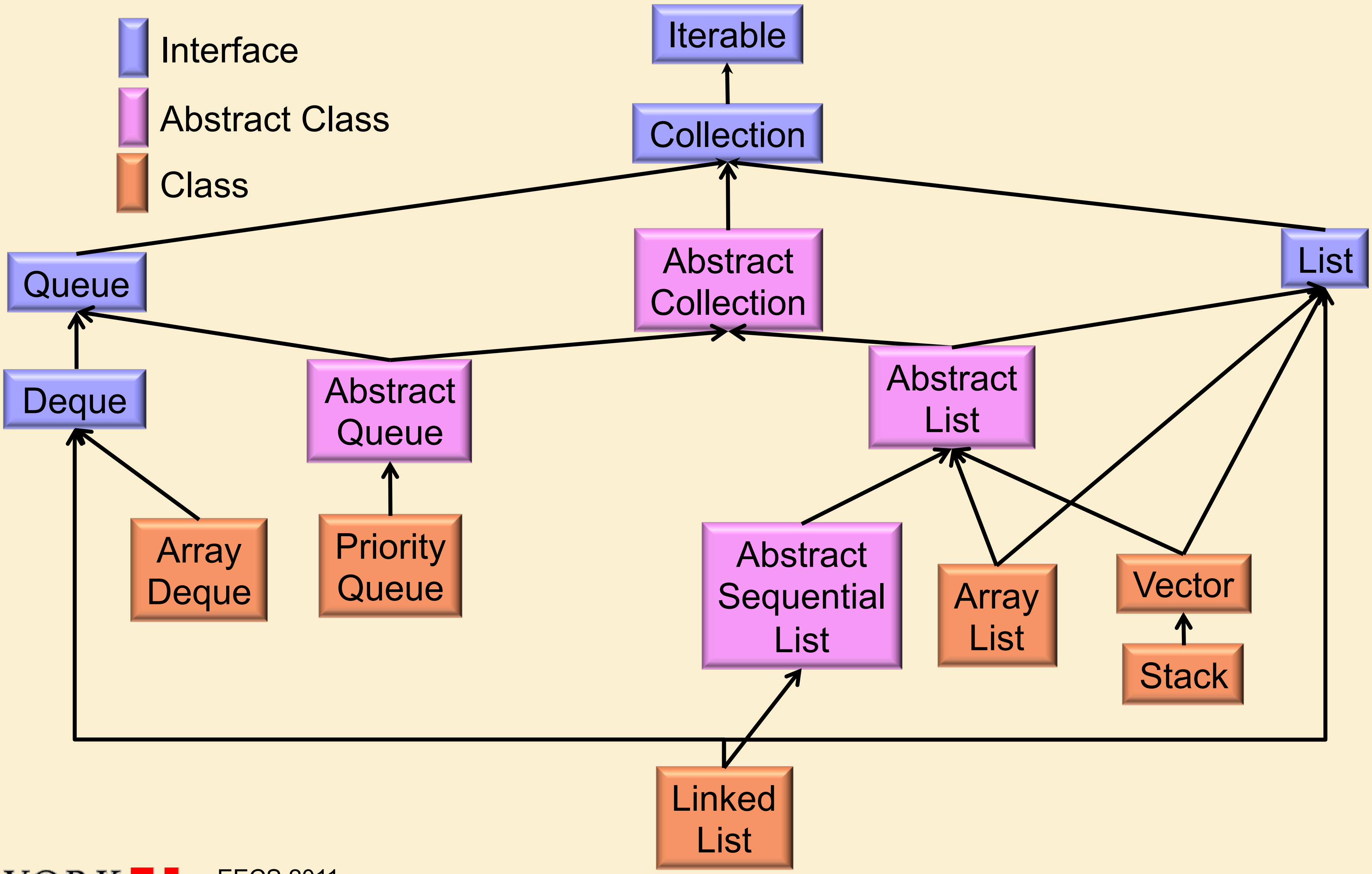
The Java Collections Framework (Ordered Data Types)



The **Collection** Interface

- Allows data to be modeled as a collection of objects. In addition to the **Iterator** interface, provides interfaces for:
  - Creating the data structure
    - **add(e)**
    - **addAll(c)**
  - Querying the data structure
    - **size()**
    - **isEmpty()**
    - **contains(e)**
    - **containsAll(c)**
    - **toArray()**
    - **equals(c)**
  - Modifying the data structure
    - **remove(e)**
    - **removeAll(c)**
    - **retainAll(c)**
    - **clear()**

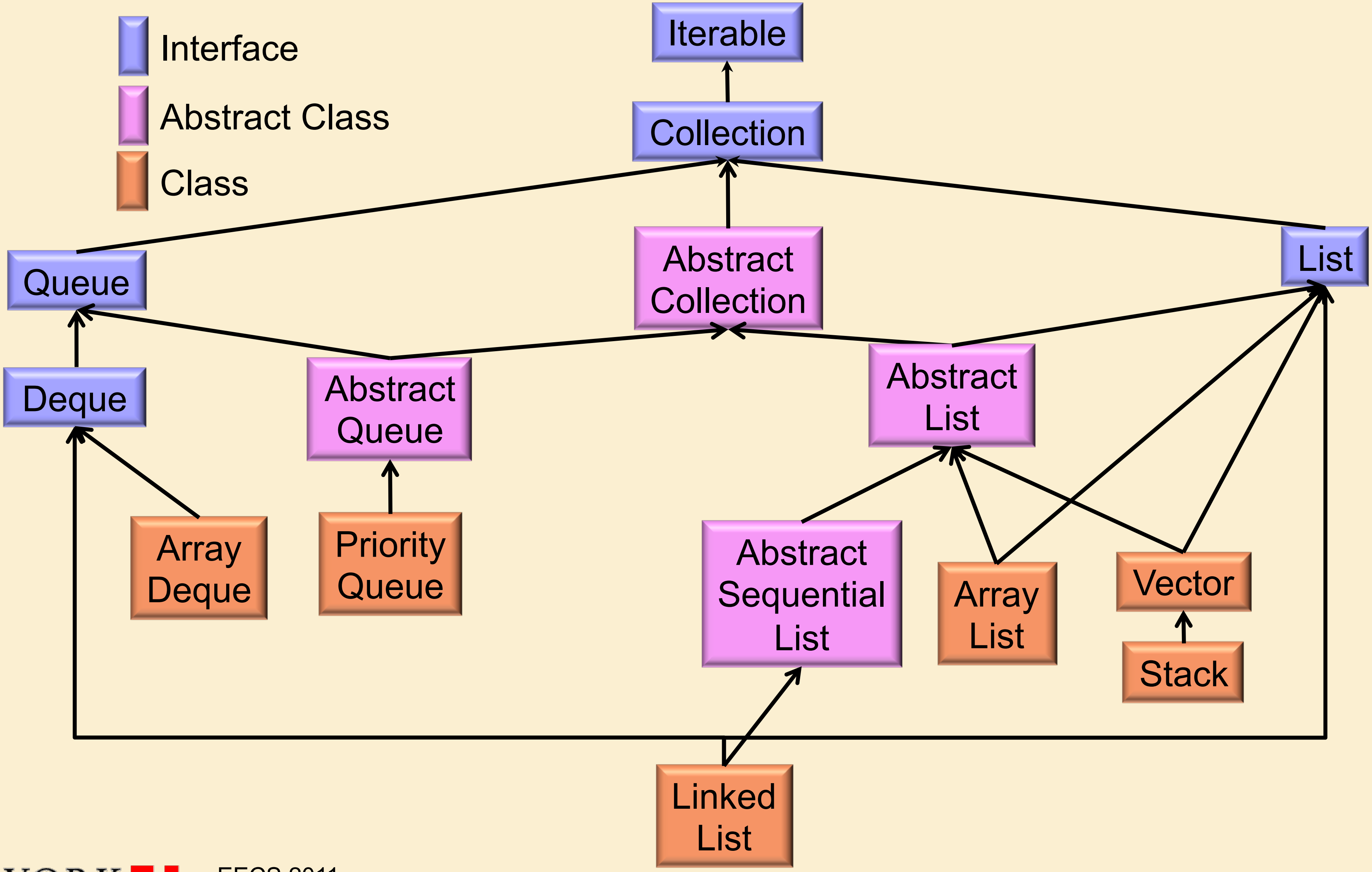
The Java Collections Framework (Ordered Data Types)



The **Abstract Collection** Class

- Skeletal implementation of the **Collection** interface.
- For **unmodifiable** collection, programmer still needs to implement:
  - **iterator** (including **hasNext** and **next** methods)
  - **size**
- For **modifiable** collection, need to also implement:
  - **remove** method for **iterator**
  - **add**

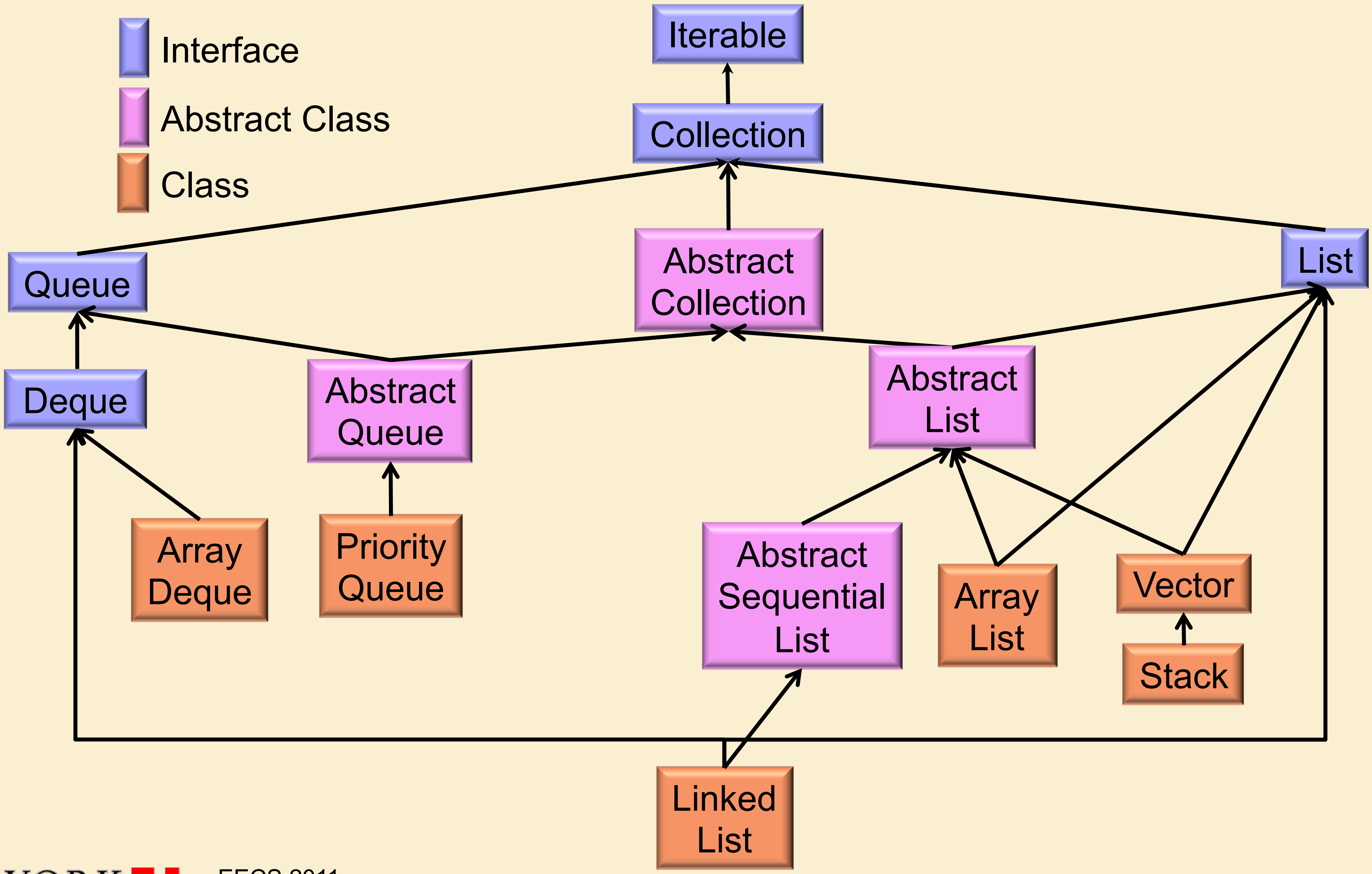
The Java Collections Framework (Ordered Data Types)



The **List** Interface

- Extends the Collections interface to model the data as an **ordered sequence** of elements, **indexed by a 0-based integer index (position)**.
- Provides interface for creation of a **ListIterator**
- Also adds interfaces for:
  - Creating the data structure
    - **add(e)** – append element e to the list
    - **add(i, e)** – insert element e at position i (and shift elements at i and above one to the right).
  - Querying the data structure
    - **get(i)** – return element currently stored at position i
    - **indexOf(e)** – return index of first occurrence of specified element e
    - **lastIndexOf(e)** – return index of last occurrence of specified element e
    - **subList(i1, i2)** – return list of elements from index i1 to i2
  - Modifying the data structure
    - **set(i, e)** – replace element currently stored at index i with specified element e
    - **remove(e)** – remove the first occurrence of the specified element from the list
    - **remove(i)** – remove the element at position i

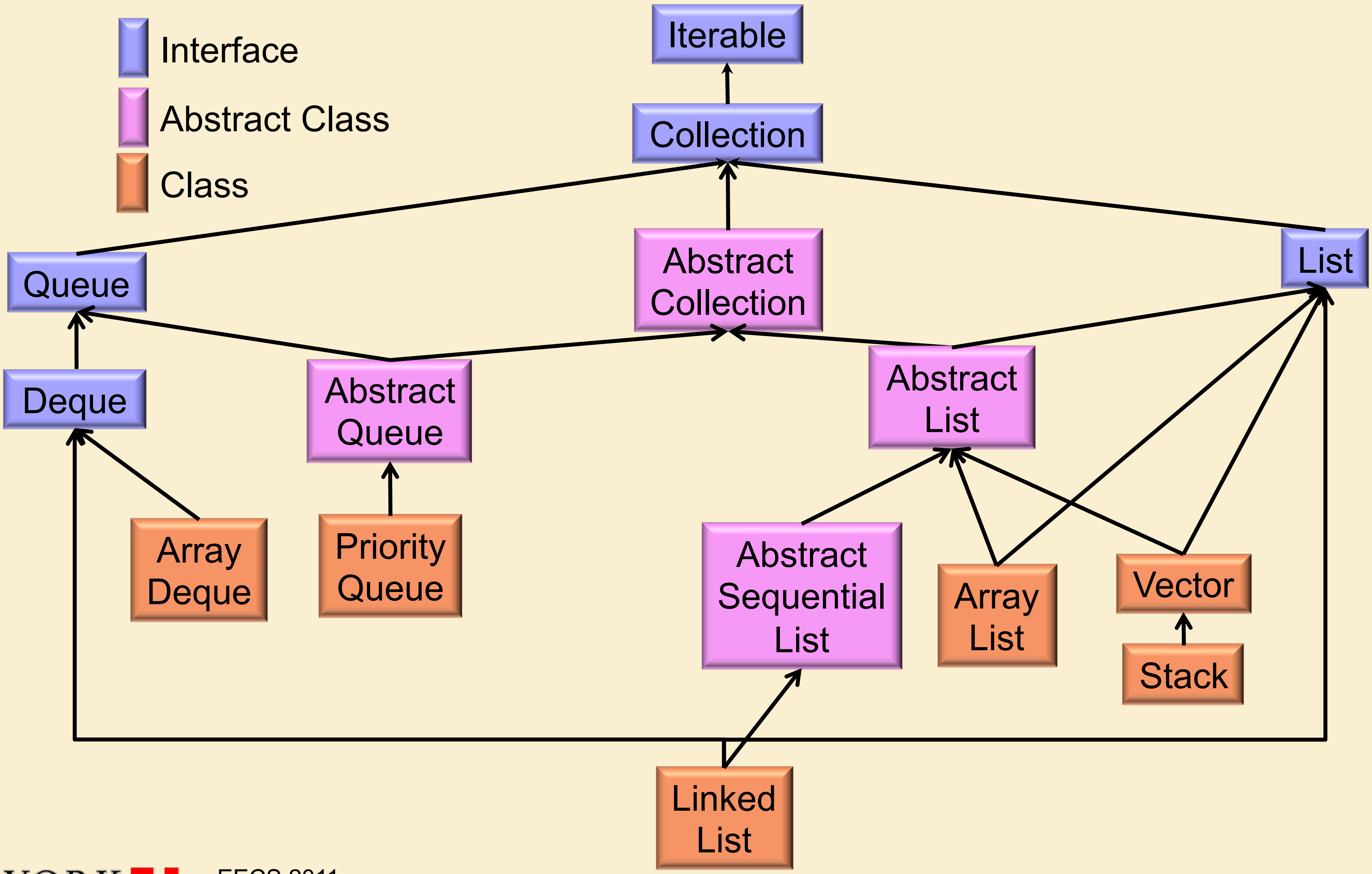
The Java Collections Framework (Ordered Data Types)



The **Abstract List** Class

- Skeletal implementation of the **List** interface.
- For **unmodifiable** list, programmer needs to implement methods:
  - **get**
  - **size**
- For **modifiable** list, need to implement
  - **set**
- For **variable-size** modifiable list, need to implement
  - **add**
  - **remove**

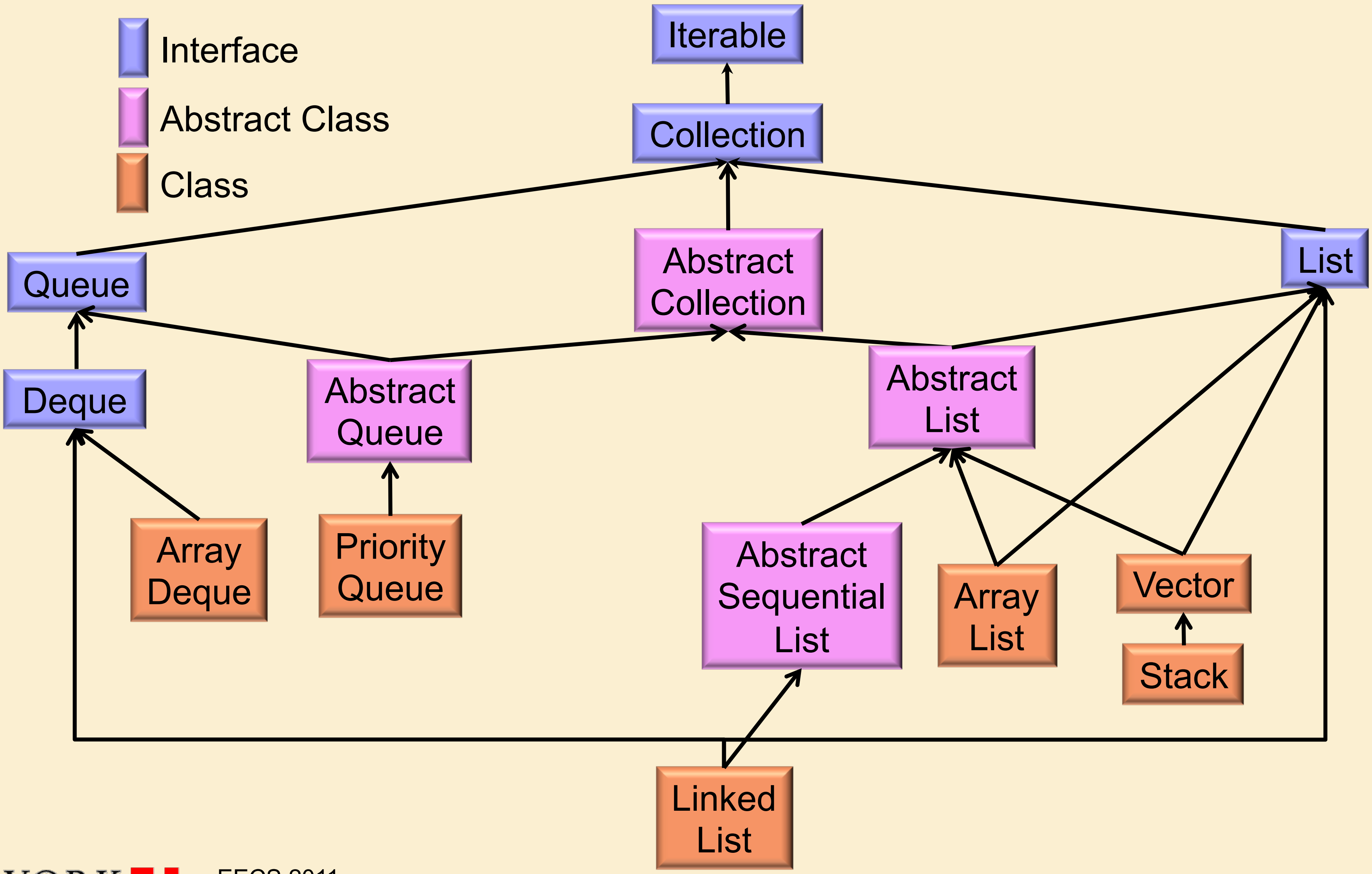
The Java Collections Framework (Ordered Data Types)



The **ArrayList** Class

- **Random access** data store implementation of the **List** interface
- Uses an **array** for storage.
- Supports automatic array-resizing
- Adds methods
  - **trimToSize()** – Trims capacity to current size
  - **ensureCapacity(n)** **–** Increases capacity to at least n
  - **clone()** – Create copy of list
  - **removeRange(i1, i2)** – Remove elements at positions i1 to i2
  - **RangeCheck(i):** throws exception if i not in range
  - **writeObject(s):** writes out list to output stream **s**
  - **readObject(s):** reads in list from input stream **s**

The Java Collections Framework (Ordered Data Types)



🟦 Interface

🟪 Abstract Class

🟧 Class

Iterable

Collection

Queue

Abstract Collection

List

Deque

Abstract Queue

Abstract List

Array Deque

Priority Queue

Abstract Sequential List

Array List

Vector

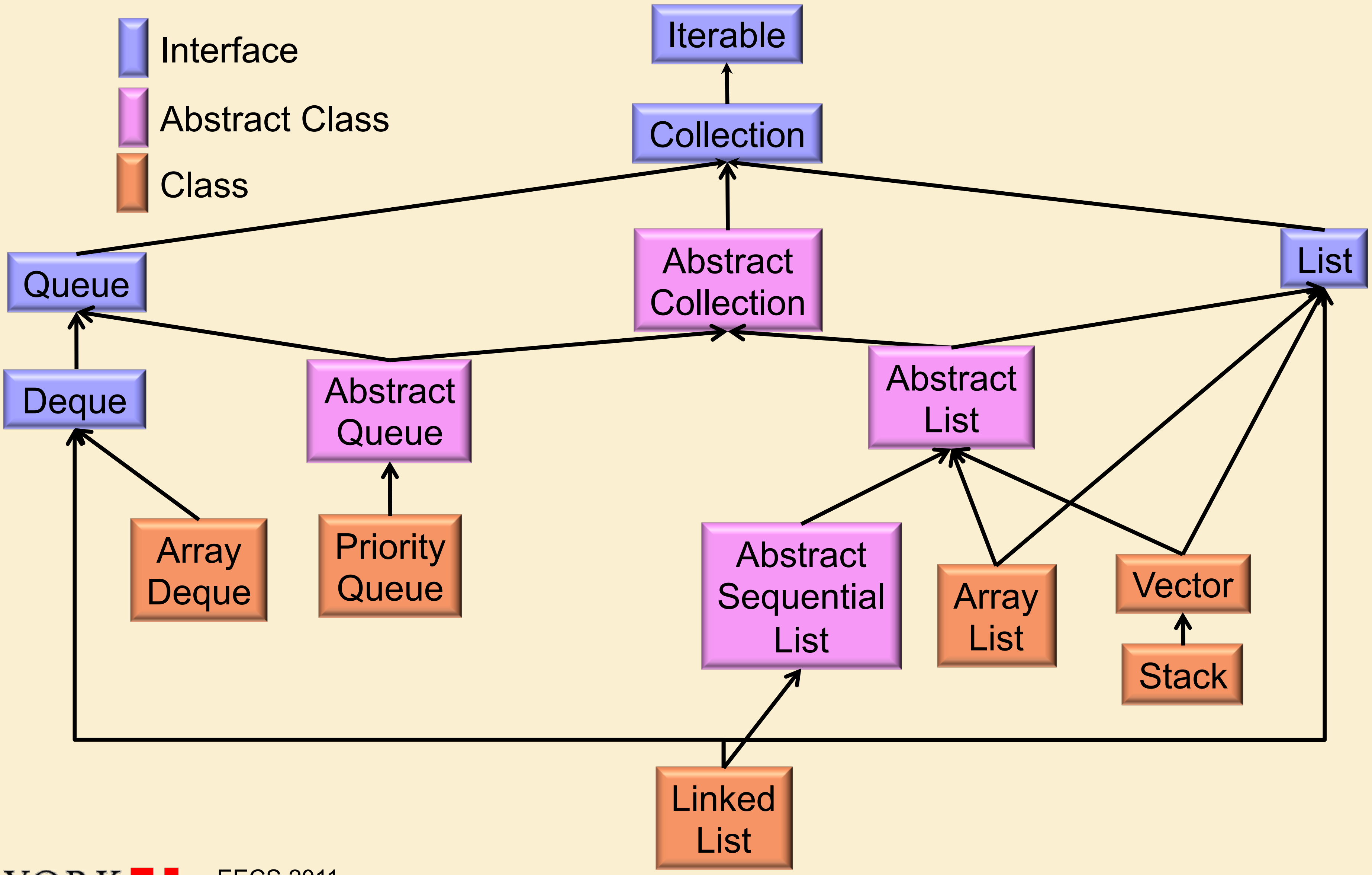
Stack

Linked List

The **Vector** Class

- Similar to ArrayList.
- But all methods of Vector are synchronized.
  - Uses an internal lock to prevent multiple threads from concurrently executing methods for the same vector object .
  - Other threads trying to execute methods of the object are suspended until the current thread completes.
  - Helps to prevent conflicts and inconsistencies in multi-threaded code
- Vector is a so-called **legacy class**: no longer necessary for new applications, but still in widespread use in existing code.
- Synchronization can be achieved with ArrayLists and other classes of the Collections framework using **synchronization wrappers** (we will not cover this).

The Java Collections Framework (Ordered Data Types)



🟦 Interface

🟪 Abstract Class

🟧 Class

Iterable

Collection

Queue

Abstract Collection

List

Deque

Abstract Queue

Abstract List

Array Deque

Priority Queue

Abstract Sequential List

Array List

Vector

Stack

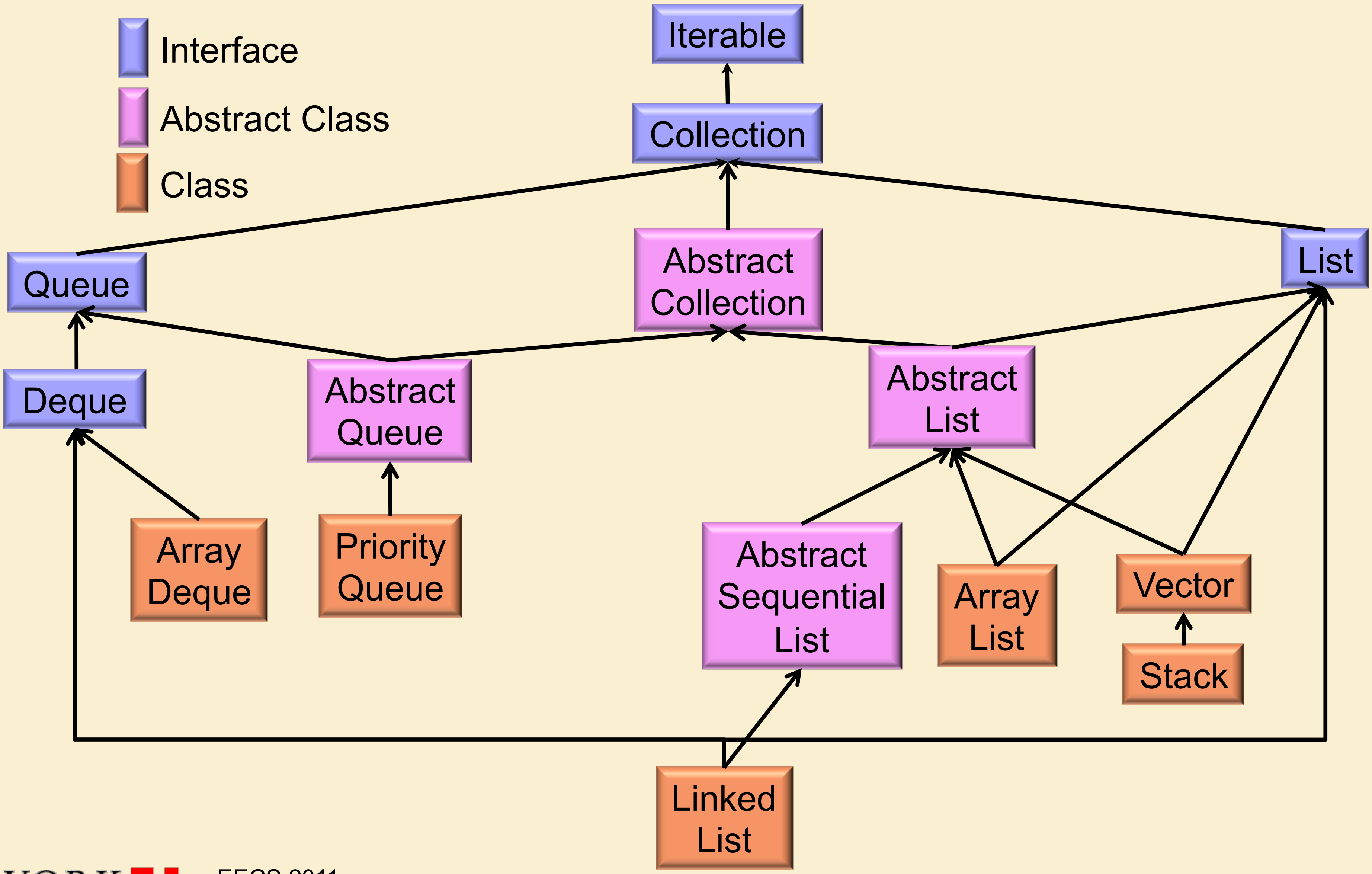
Linked List

The **Stack** Class

- Represents a last-in, first-out (LIFO) stack of objects.
- Adds 5 methods:
  - **push()**
  - **pop()**
  - **peek()**
  - **empty()**
  - **search(e):** return the 1-based position of where an object is on the stack.

- **Note:** it is now recommended that LIFO functionality be implemented using double-ended queues **(java.util.Deque)** instead of **java.util.Stack**.
  - Java.util.Stack needlessly exposes positions through search
  - Java.util.stack has no interface, requiring an early commitment to a concrete class.

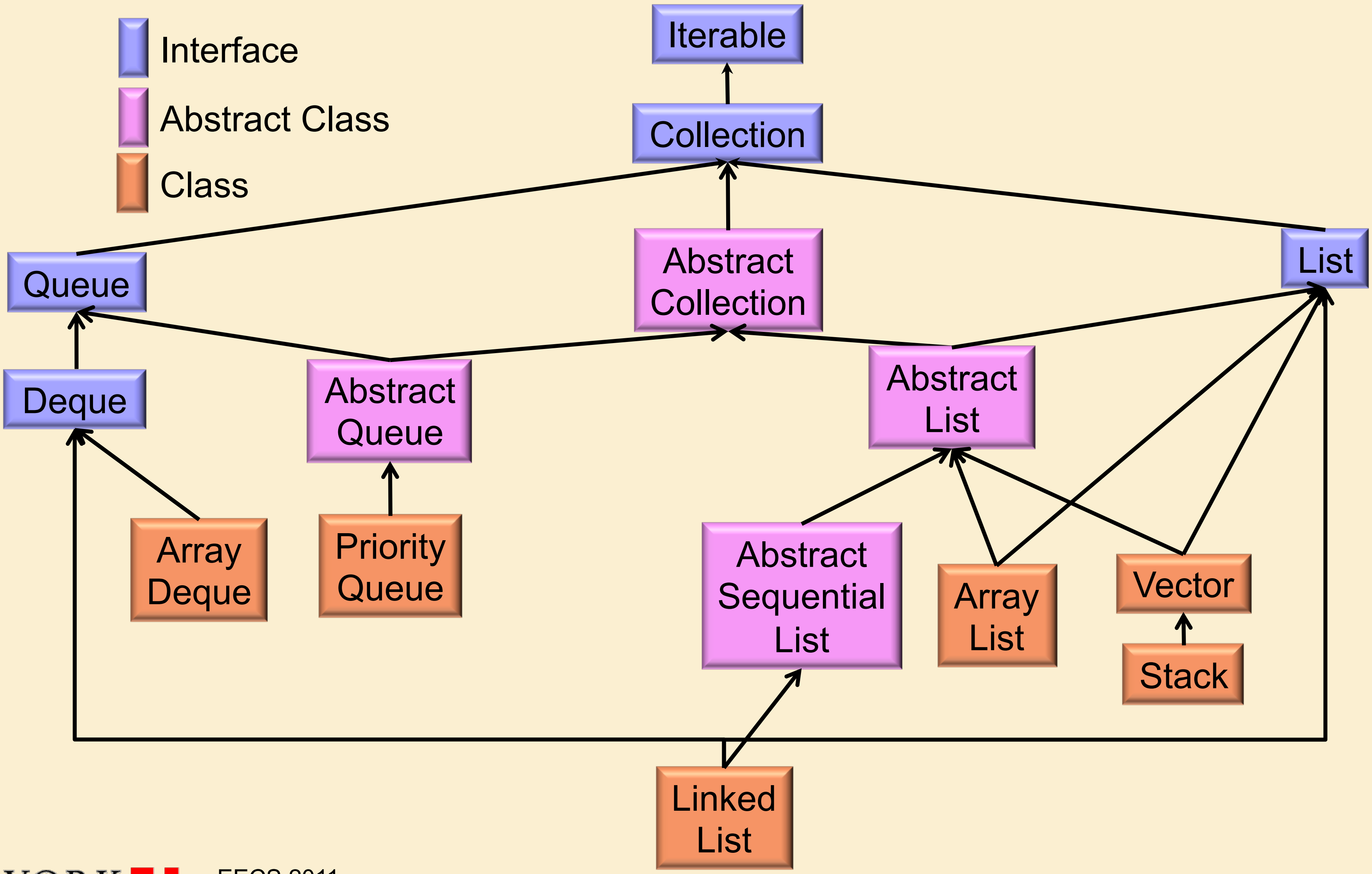
The Java Collections Framework (Ordered Data Types)



The **Abstract Sequential List** Class

- Skeletal implementation of the **List** interface.
- Assumes a **sequential** access data store (e.g., **linked list**)
- Programmer needs to implement methods
  - **listIterator()**
  - **size()**
- For **unmodifiable** list, programmer needs to implement list iterator's methods:
  - **hasNext()**
  - **next()**
  - **hasPrevious()**
  - **previous()**
  - **nextIndex()**
  - **previousIndex()**
- For **modifiable** list, need to also implement list iterator's
  - **set(e)**
- For **variable-size** modifiable list, need to implement list iterator's
  - **add(e)**
  - **remove()**

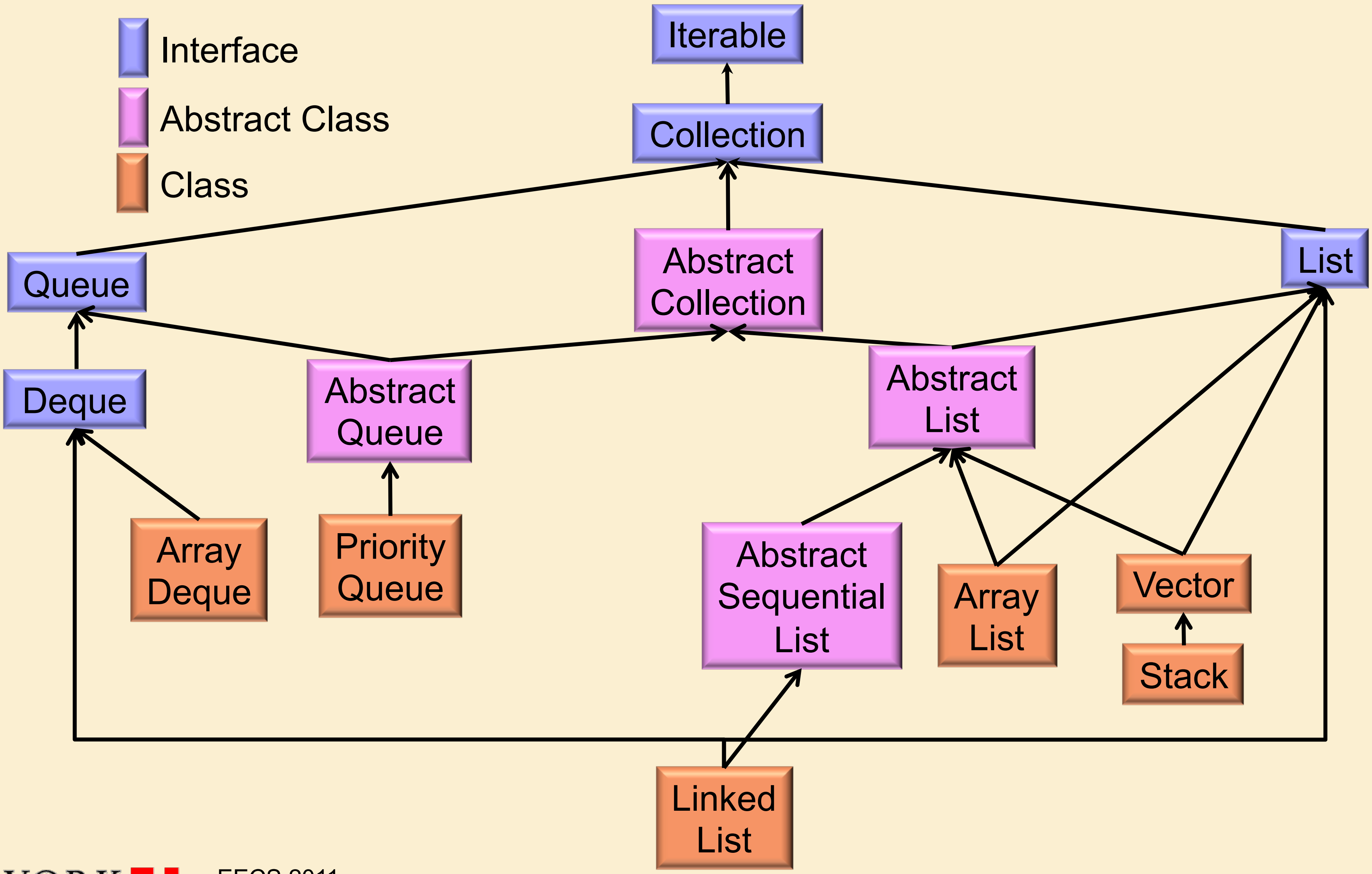
The Java Collections Framework (Ordered Data Types)



The **Queue** Interface

- Designed for holding elements prior to processing.
- Could be used for first-in first-out (FIFO) or last-in first-out (LIFO) functionality.
- Defines a head position, which is the next element to be removed.
- Provides additional insertion, extraction and inspection operations.
- Extends the **Collection** interface to provide interfaces for:
  - **offer(e):** add **e** to queue if there is room (return false if not)
  - **poll():** return and remove head of queue (return null if empty)
  - **remove():** return and remove head of queue (throw exception if empty)
  - **peek():** return head of queue (return null if empty**)**
  - **element():** return head of queue (throw exception if empty)

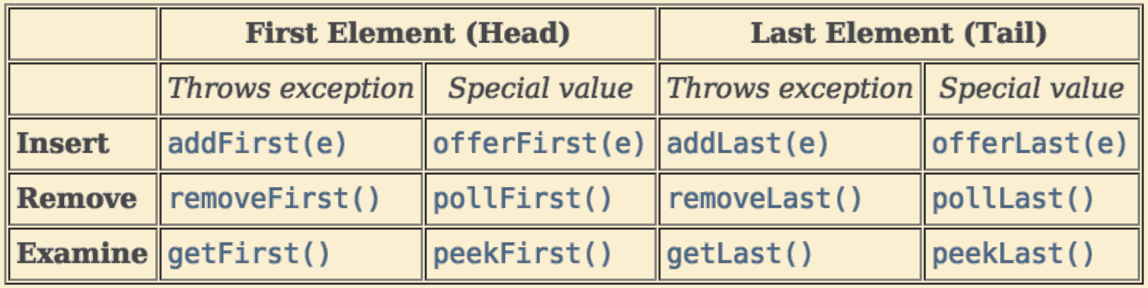
The Java Collections Framework (Ordered Data Types)



The **Deque** Interface

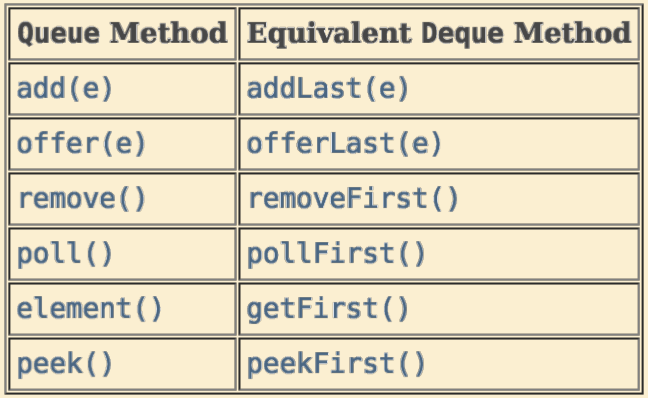
- Supports element insertion and removal at both ends
- First-in first-out (FIFO) or last-in first-out (LIFO) functionality

Deque Methods



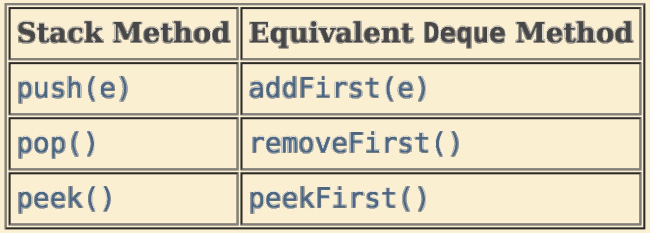
	First Element (Head)		**Last Element (Tail)**	
	Throws exception	*Special value*	*Throws exception*	*Special value*
Insert	`addFirst(e)`	`offerFirst(e)`	`addLast(e)`	`offerLast(e)`
Remove	`removeFirst()`	`pollFirst()`	`removeLast()`	`pollLast()`
Examine	`getFirst()`	`peekFirst()`	`getLast()`	`peekLast()`

Deque Equivalent of Queue



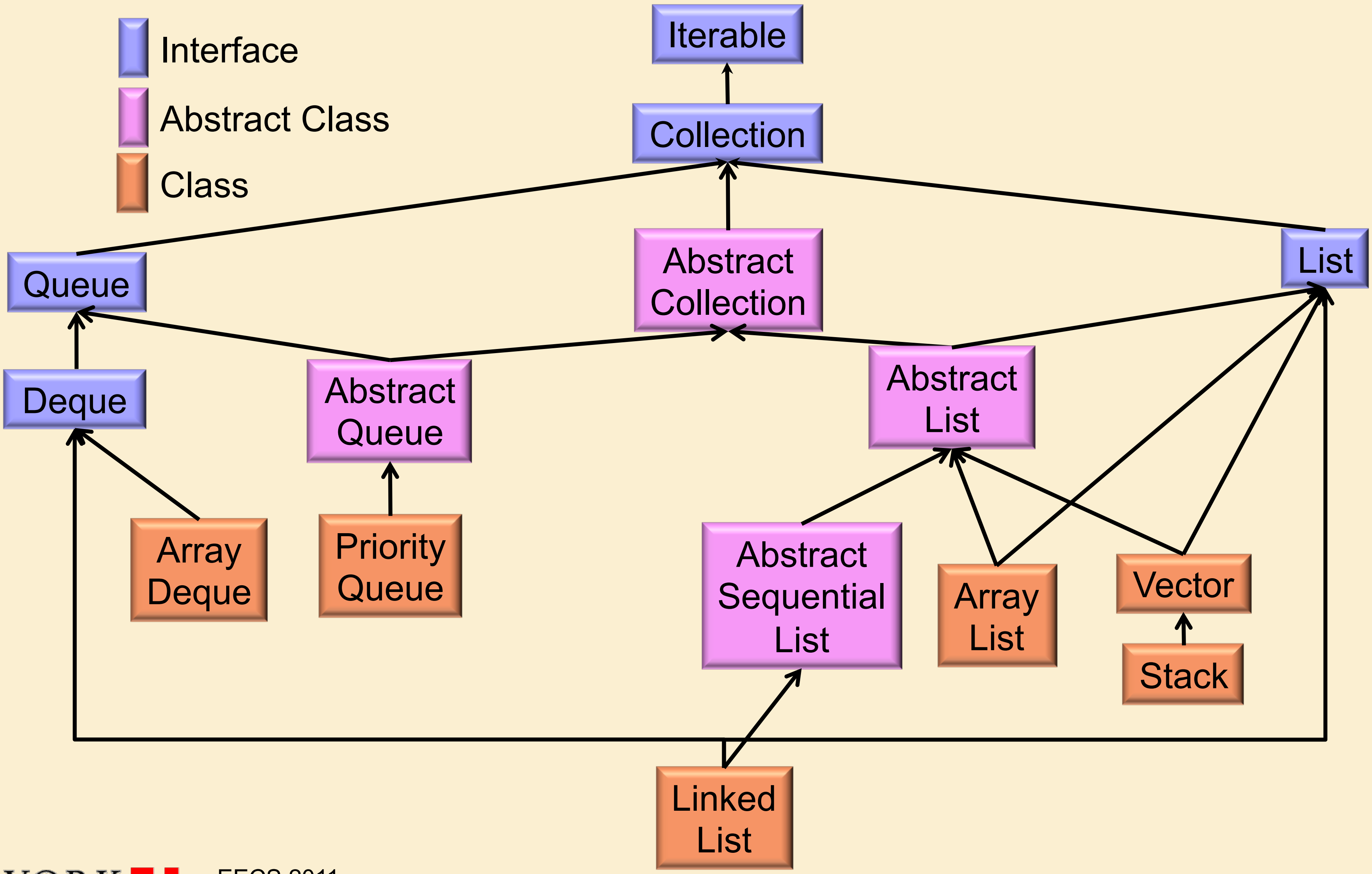
Queue Method	**Equivalent Deque Method**
`add(e)`	`addLast(e)`
`offer(e)`	`offerLast(e)`
`remove()`	`removeFirst()`
`poll()`	`pollFirst()`
`element()`	`getFirst()`
`peek()`	`peekFirst()`

Deque Equivalent of Stack



Stack Method	**Equivalent Deque Method**
`push(e)`	`addFirst(e)`
`pop()`	`removeFirst()`
`peek()`	`peekFirst()`

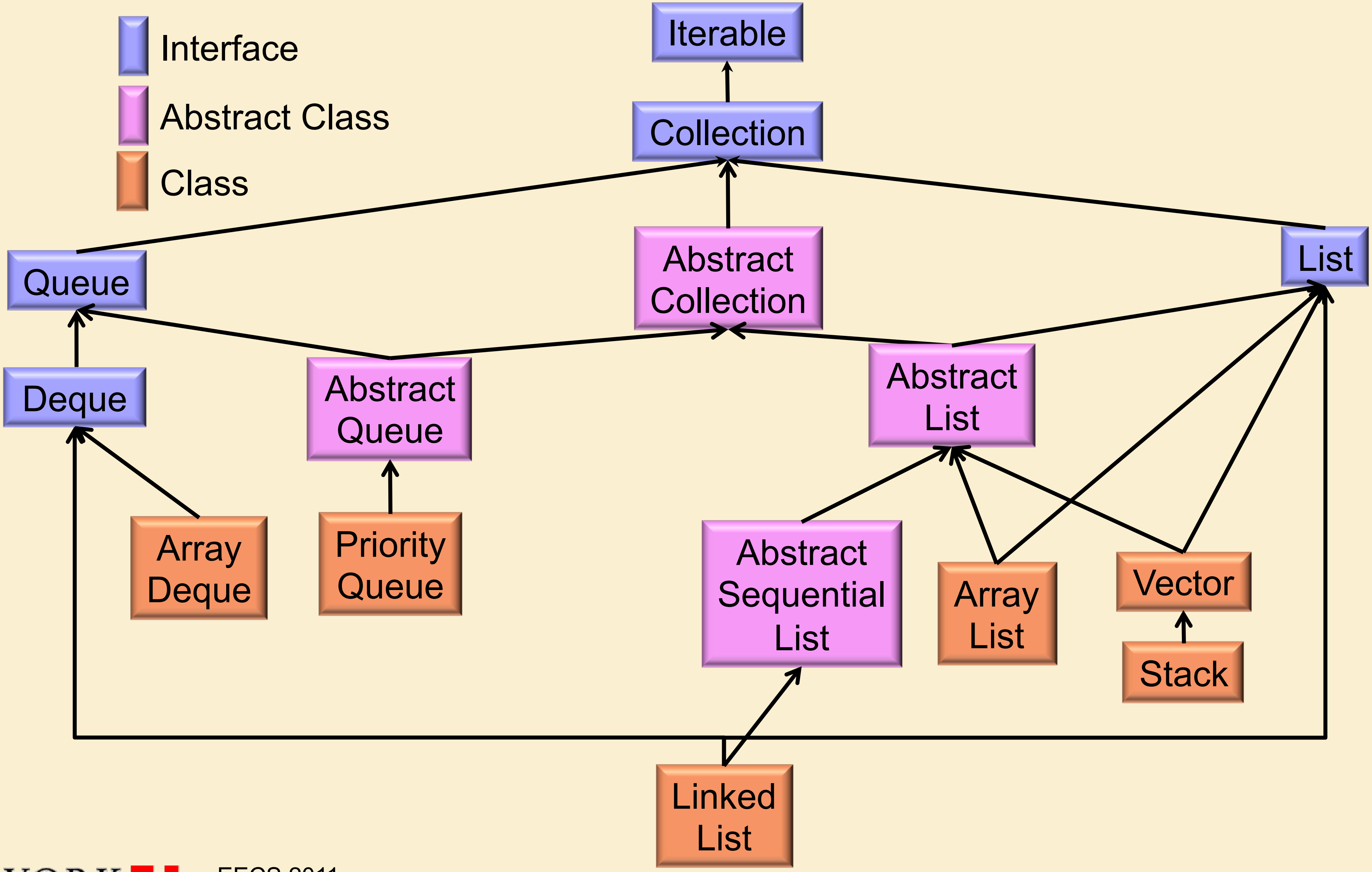
The Java Collections Framework (Ordered Data Types)



ArrayDeque Class

- Resizable array implementation of the **Deque** interface.
- ArrayDeque objects are **not** synchronized by default.
- However, the iterator is **fail-fast**: if the deque is structurally modified at any time after the iterator is created, in any way except through the Iterator's own remove or add methods, the iterator will throw a **ConcurrentModificationException**.
- This is detected at the first execution of one of the iterator’s methods after the modification.
- In this way the iterator will hopefully fail quickly and cleanly, rather than risking arbitrary, non-deterministic behavior at an undetermined time in the future.

The Java Collections Framework (Ordered Data Types)



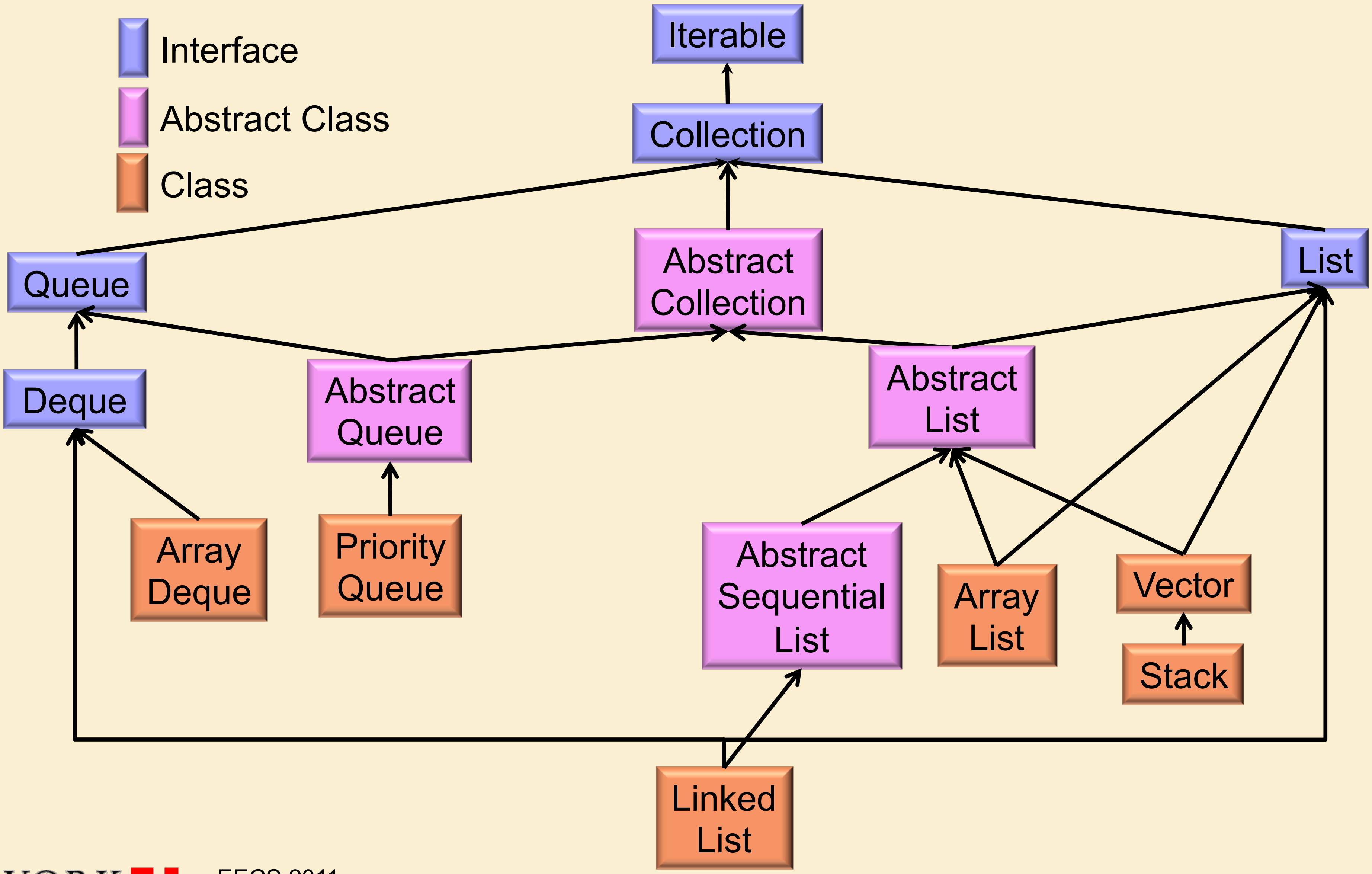
The **LinkedList** Class

- Implements the **List**, **Queue** and **Deque** interfaces.
- Uses a **doubly-linked list** data structure.
- Extends the **List** interface with additional methods:
  - **getFirst()**
  - **getLast()**
  - **removeFirst()**
  - **removeLast()**
  - **addFirst(e)**
  - **addLast(e)**
- These make it easier to use the LinkedList class to create stacks, queues and deques (double-ended queues).

The **LinkedList** Class

- LinkedList objects are **not** synchronized by default.
- However, the LinkedList iterator is **fail-fast**: if the list is structurally modified at any time after the iterator is created, in any way except through the Iterator's own remove or add methods, the iterator will throw a **ConcurrentModificationException**.
- This is detected at the first execution of one of the iterator’s methods after the modification.
- In this way the iterator will hopefully fail quickly and cleanly, rather than risking arbitrary, non-deterministic behavior at an undetermined time in the future.

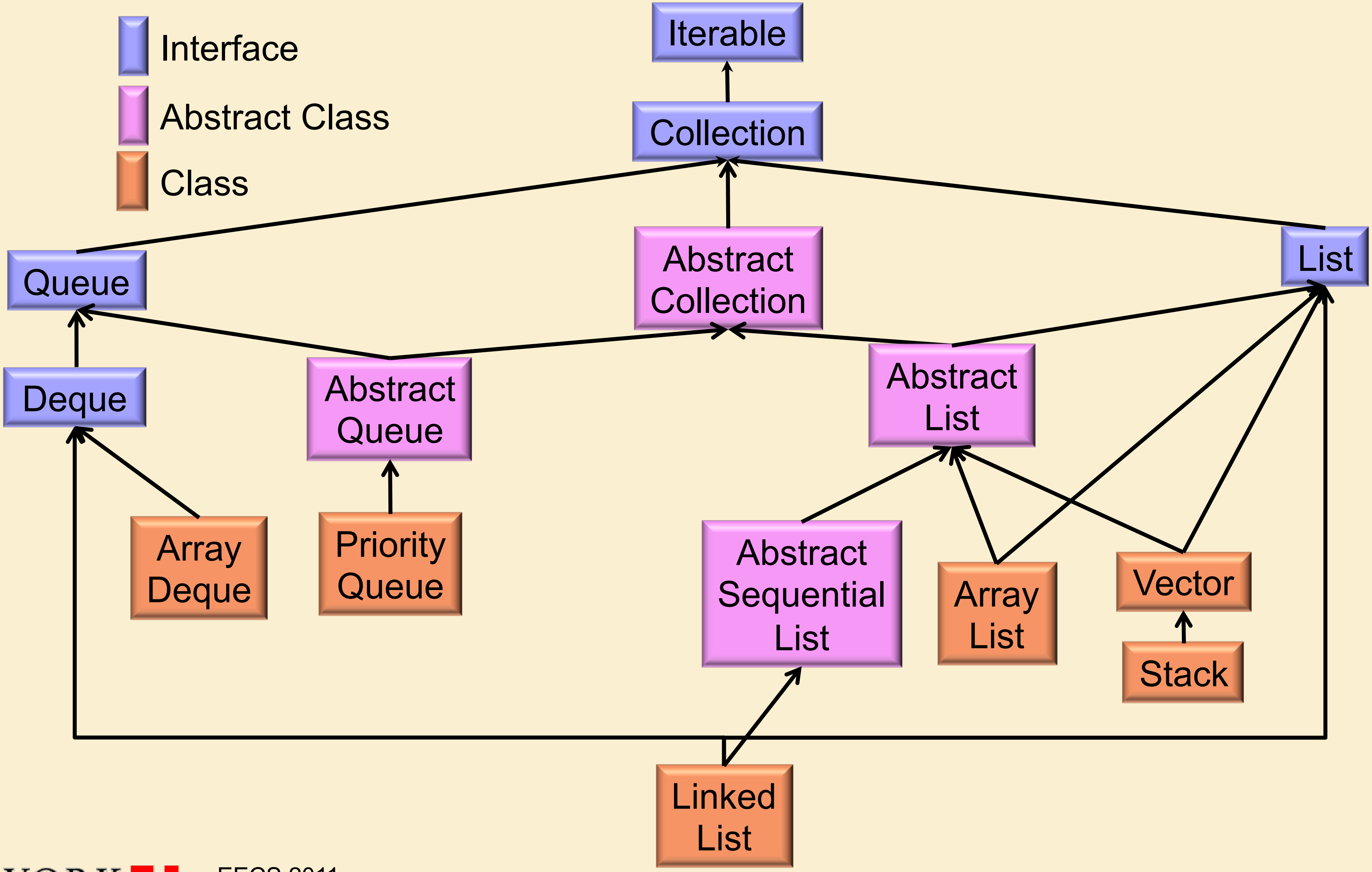
The Java Collections Framework (Ordered Data Types)



The **Abstract Queue** Class

- Skeletal implementation of the **Queue** interface.
- Provides implementations for
  - **add(e)**
  - **remove()**
  - **element()**
  - **clear()**
  - **addAll(c)**

The Java Collections Framework (Ordered Data Types)

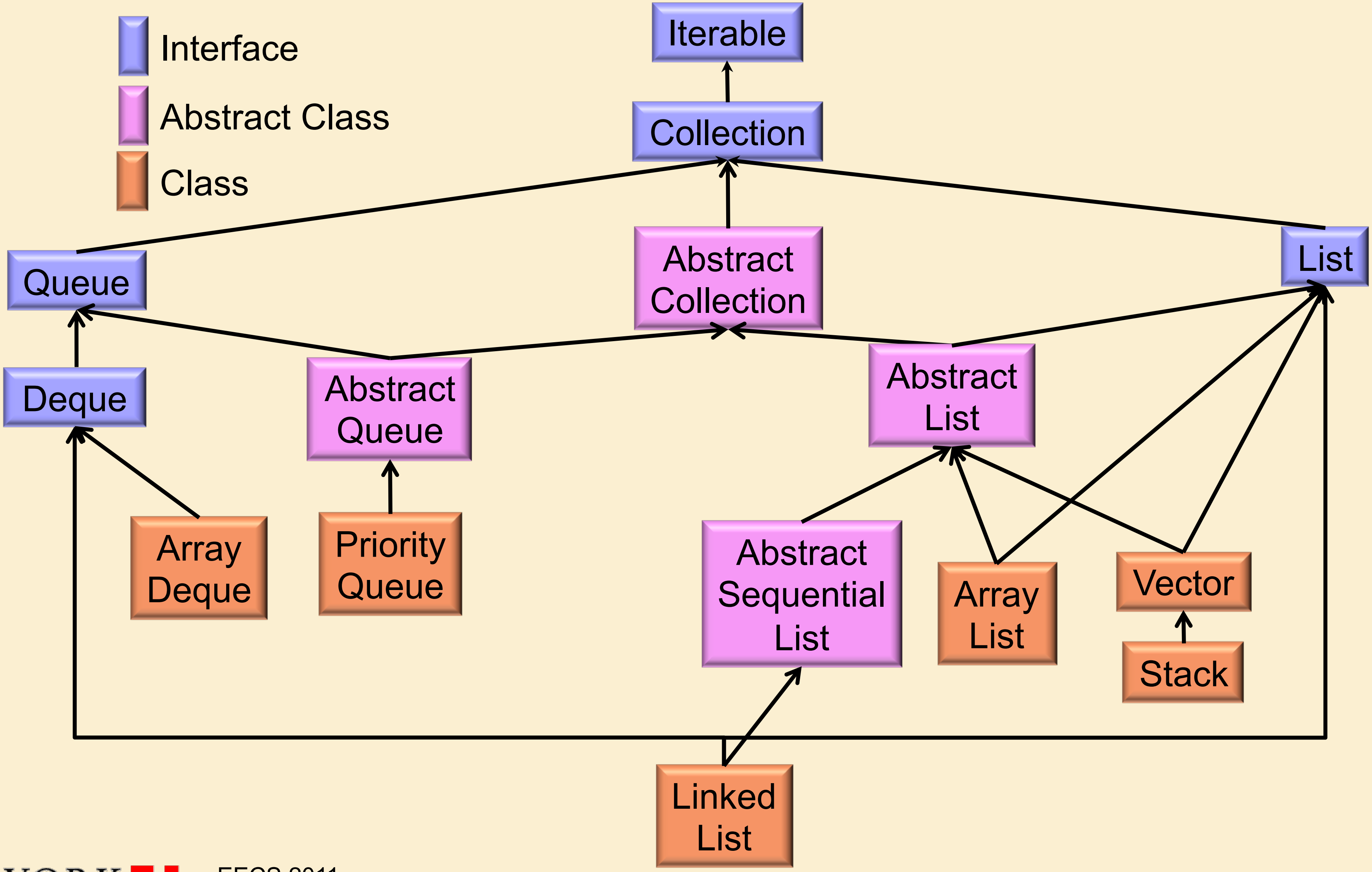


The **Priority Queue** Class

- Based on priority heap
- Elements are prioritized based either on
  - natural order
  - a **comparator**, passed to the constructor.
- **Provides an iterator**

- **We will study this in detail when we get to heaps!**

The Java Collections Framework (Ordered Data Types)



Interface

Abstract Class

Class

Iterable

Collection

Queue

Abstract Collection

List

Deque

Abstract Queue

Abstract List

Array Deque

Priority Queue

Abstract Sequential List

Array List

Vector

Stack

Linked List

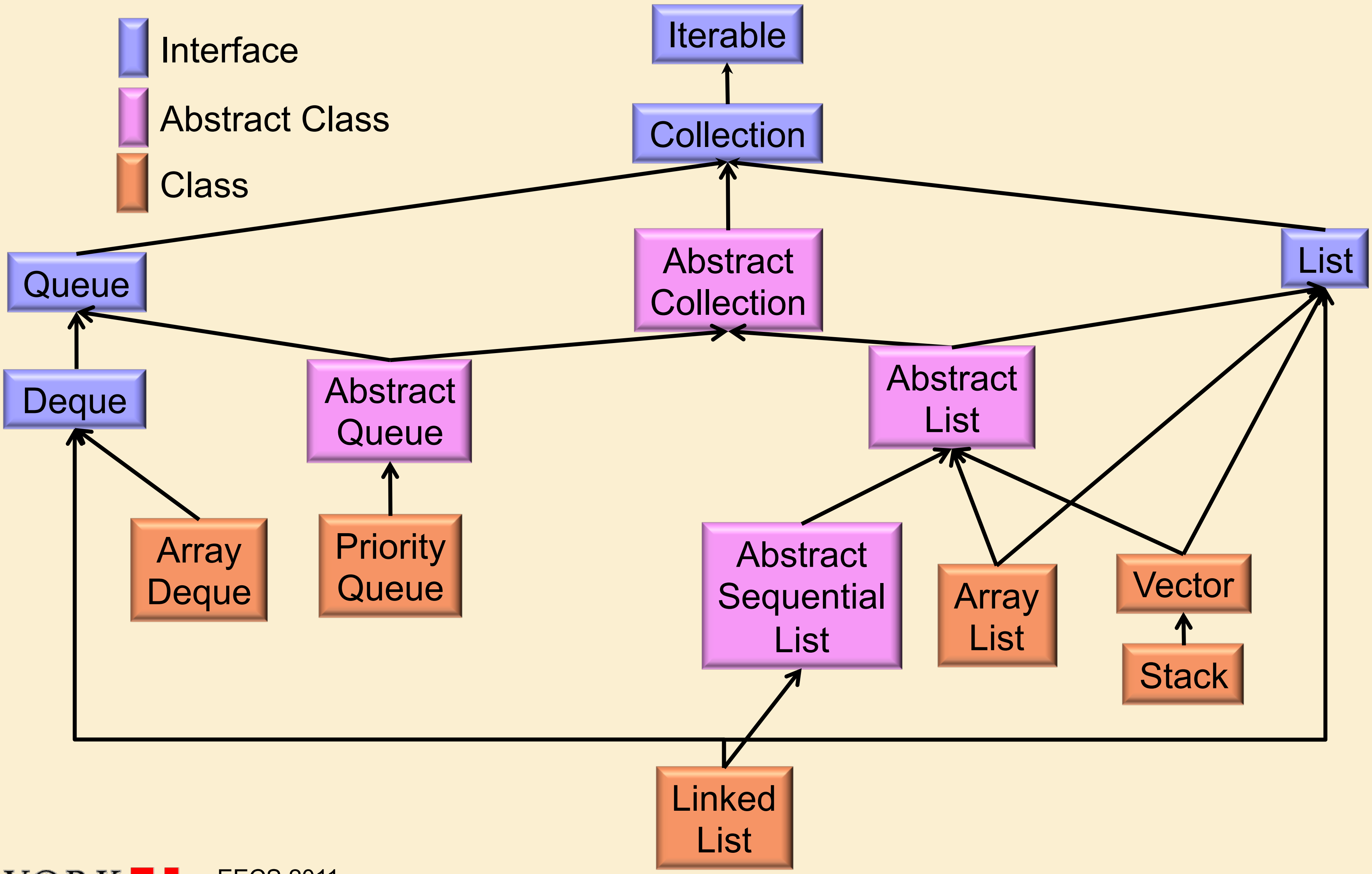
Learning Outcomes

- From this lecture you should understand:
  - The purpose and advantages of the Java Collections Framework
  - How interfaces, abstract classes and classes are used hierarchically to achieve some of the key goals of object-oriented software engineering.
  - The purpose of iterators, and how to create and use them.
  - How the Java Collections Framework can be used to develop code using general collections, lists, array lists, stacks and queues.

For More Details

- **Javadoc**, provided with your java distribution.
- **Comments and code in the specific java.util.*.java files**, provided with your java distribution.
- **The Collections Java tutorial**, available at http://docs.oracle.com/javase/tutorial/collections/index.html
- Chan et al, The Java Class Libraries, Second Edition

The Java Collections Framework (Ordered Data Types)


Interface
Abstract Class
Class
Iterable
Collection
Queue
Abstract Collection
List
Deque
Abstract Queue
Abstract List
Array Deque
Priority Queue
Abstract Sequential List
Array List
Vector
Stack
Linked List