

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.

History

- Apart from the Java Collections Framework, well-known examples of collections frameworks include the C++ Standard Template Library (STL) and Smalltalk's collection hierarchy.

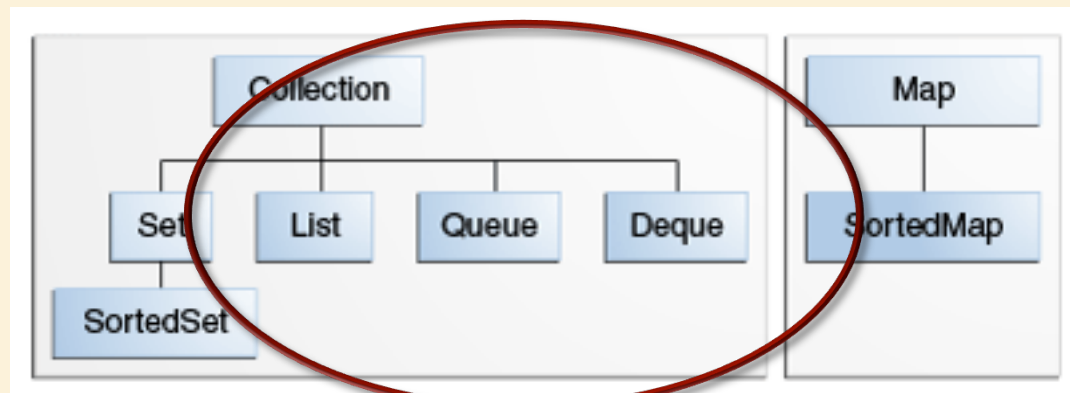
Benefits

- **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 unrelated APIs:** APIs can interoperate seamlessly, even though they were written independently.
- **Reduces effort to learn and to use new APIs**
- **Reduces effort to design new APIs**
- **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

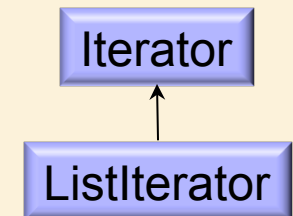
- Suppose **collection** is an instance of a **Collection**. Then
for (Object o : collection)
 System.out.println(o);
prints each element of the collection on a separate line.
- This code is just shorthand: it compiles to use o.iterator().

The Generality of Iterators

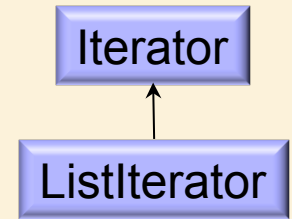
- Note that iterators are general in that they apply to any collection.
 - Could represent a sequence, set or map.
 - Could be implemented using arrays or linked lists.

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



- 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

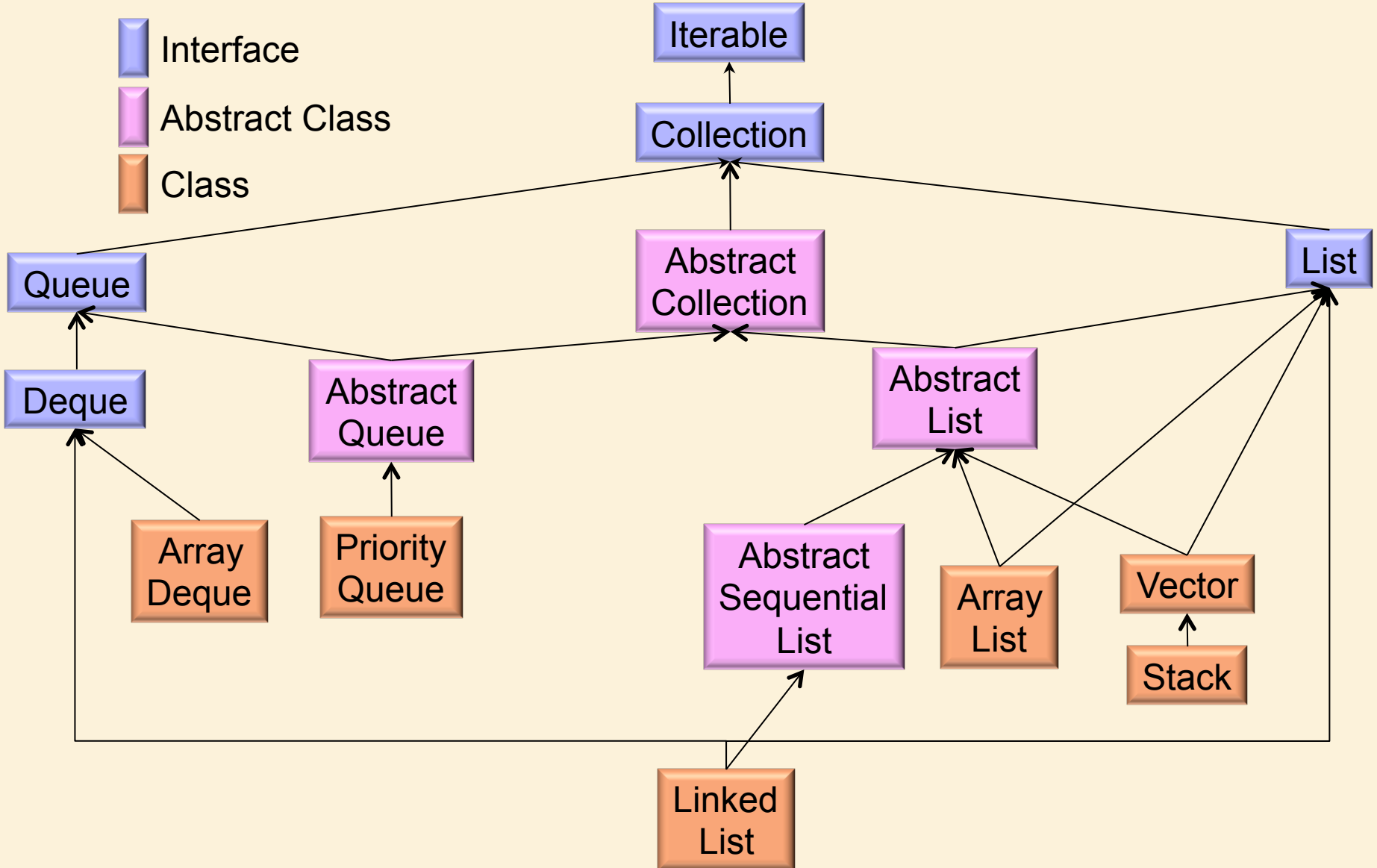
Outline

- 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.

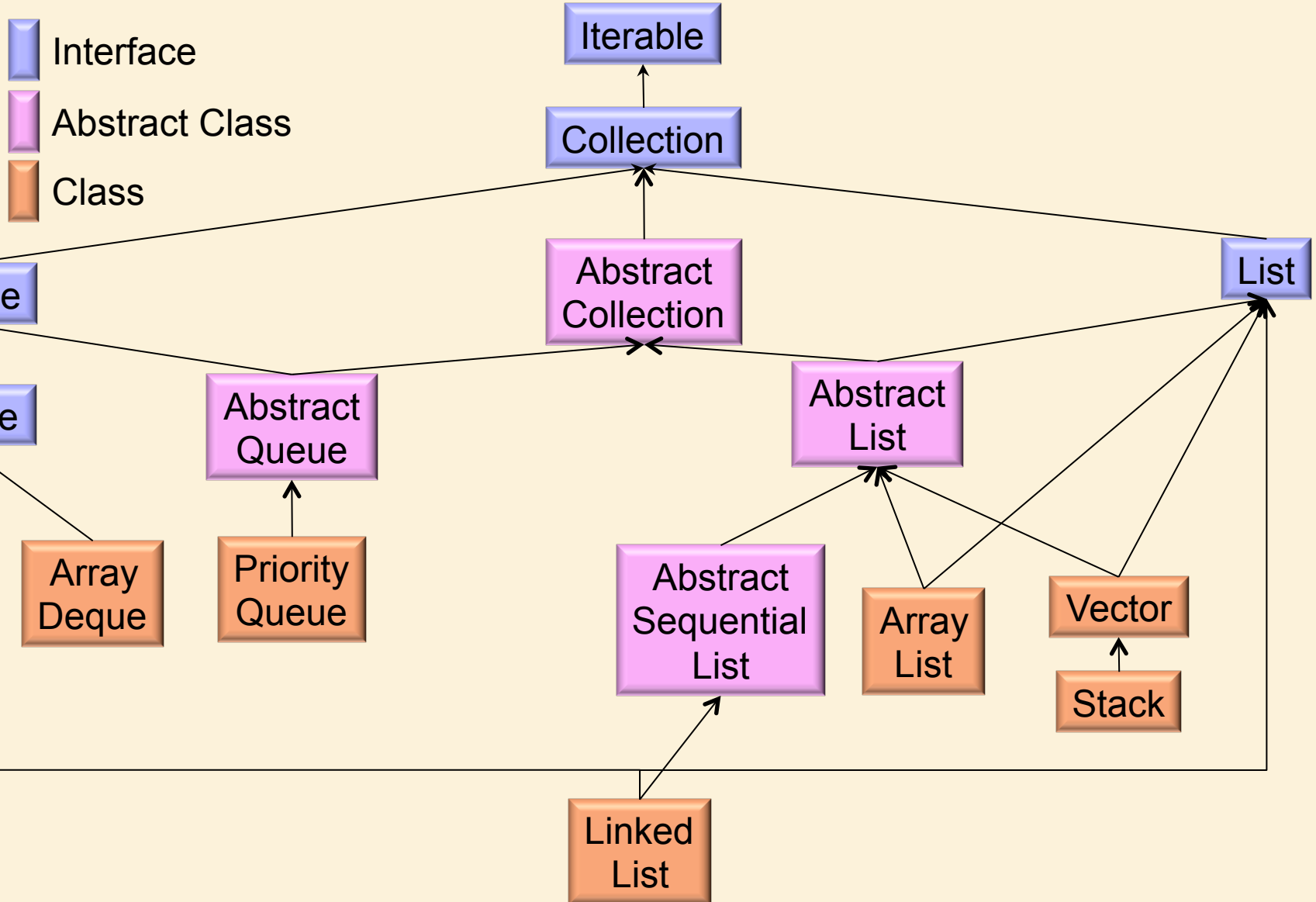
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The **Iterable** Interface

- 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

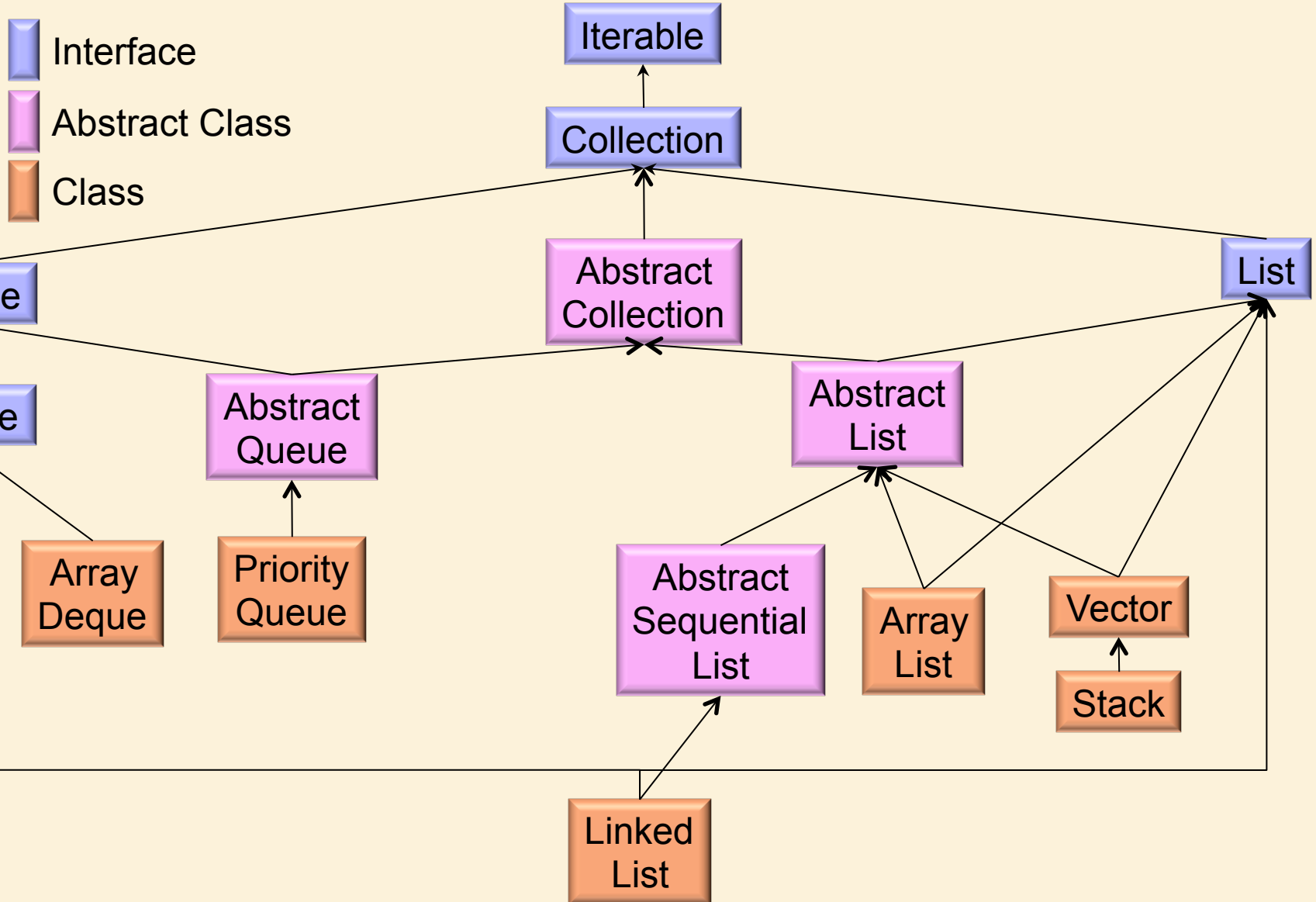
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The **Collection** Interface

- 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()**

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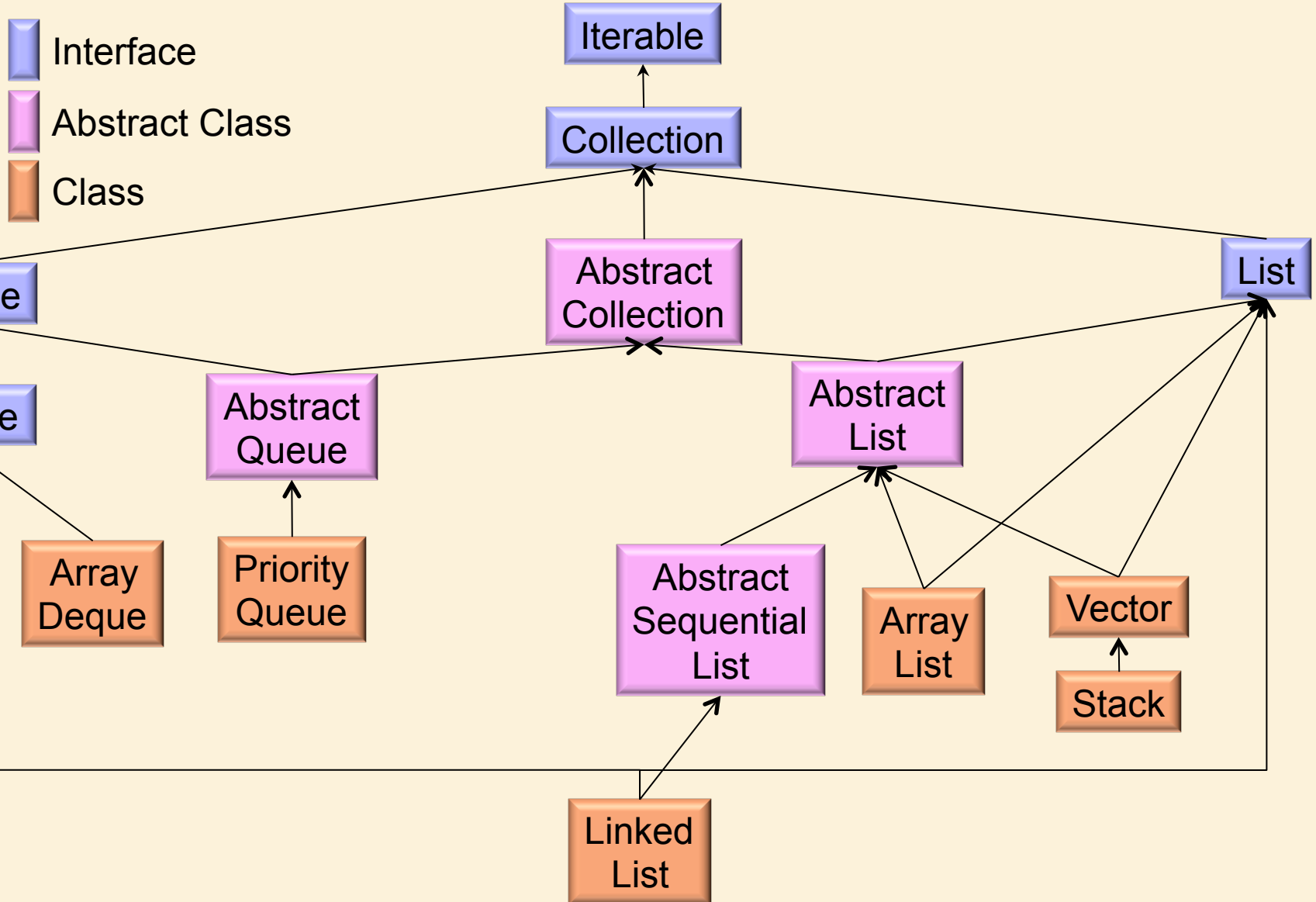
The **Abstract Collection** Class

- 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**

October 1, 2015

End of Lecture

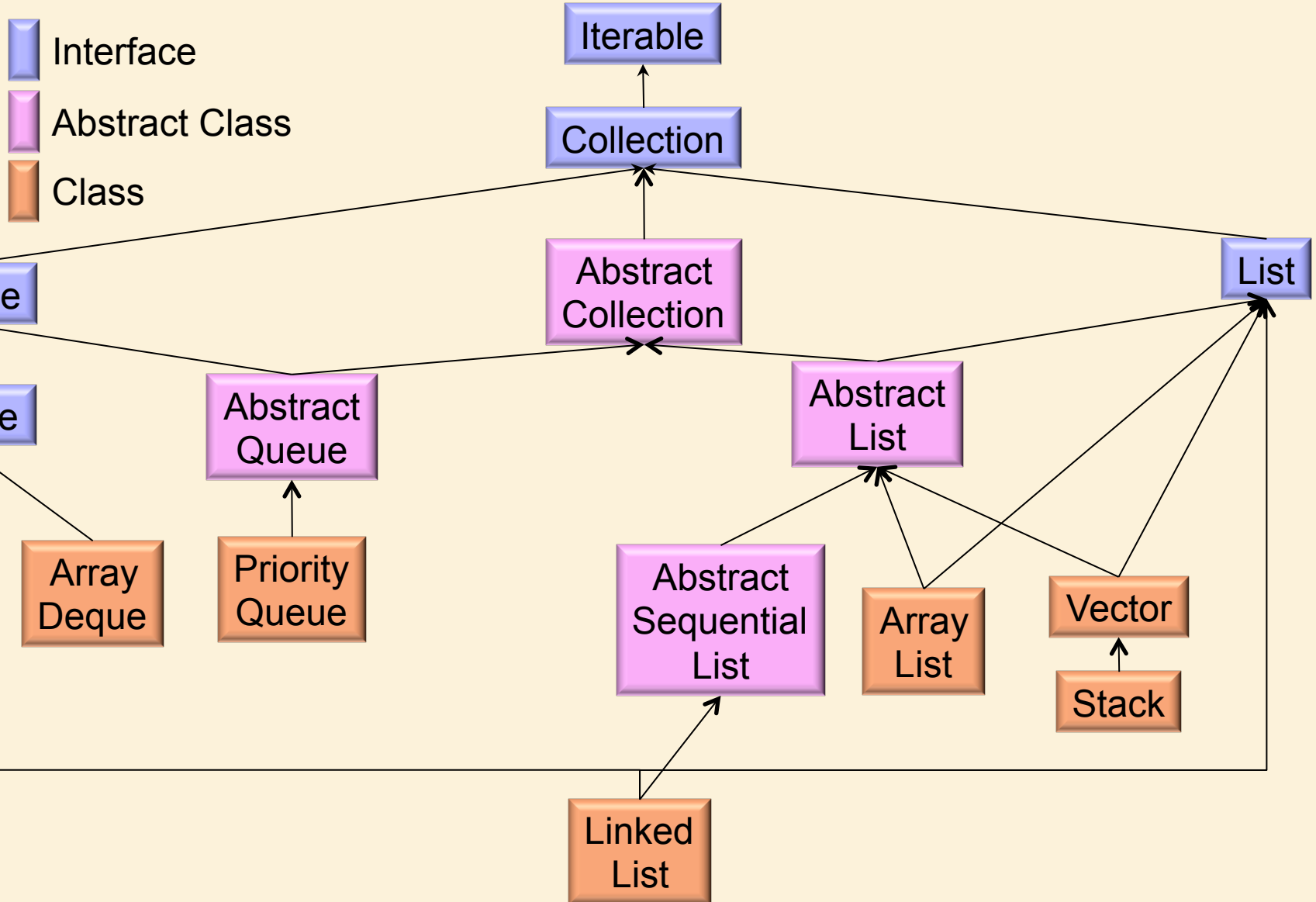
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The **List** Interface

- 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

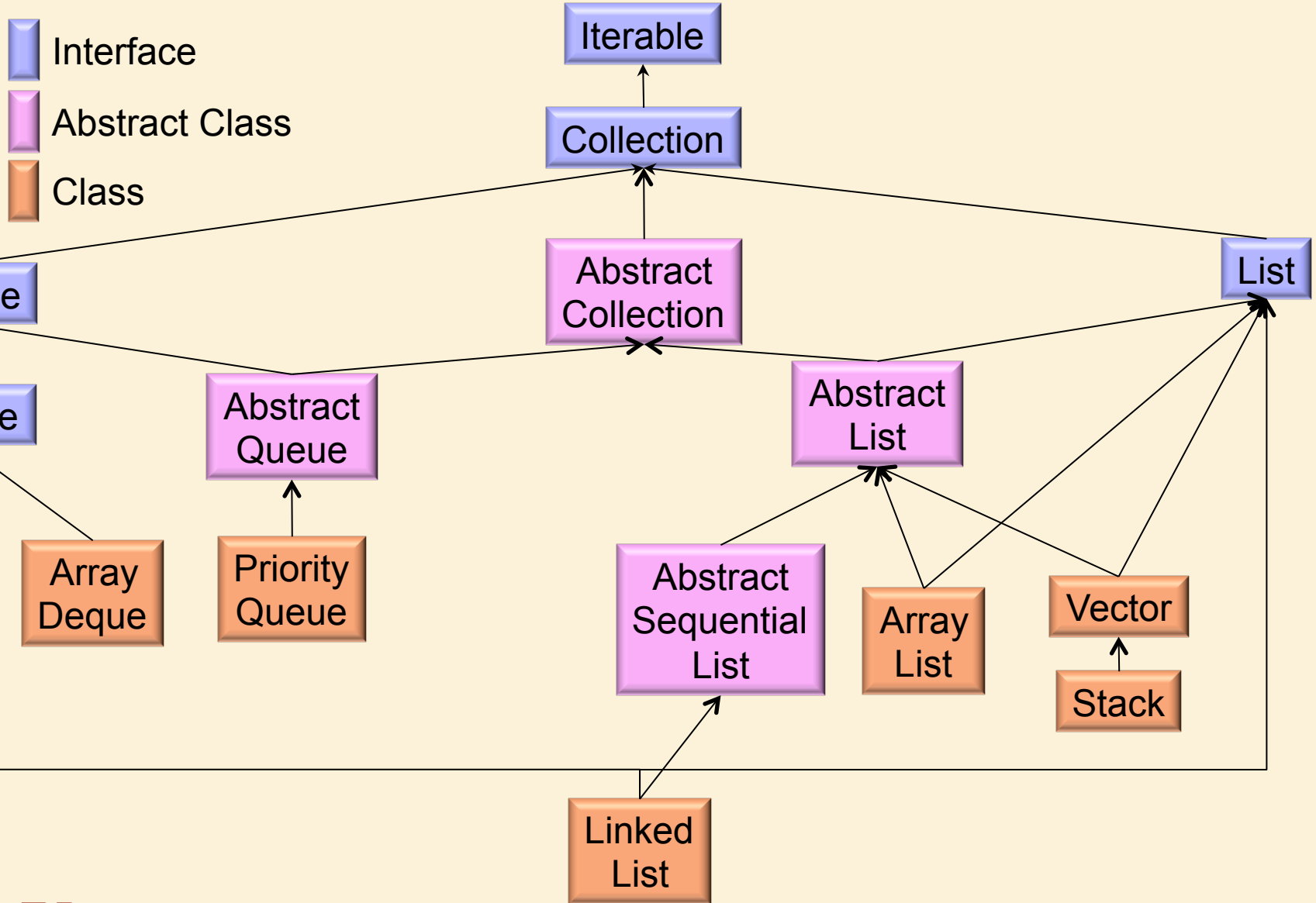
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The **Abstract List** Class

- 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**

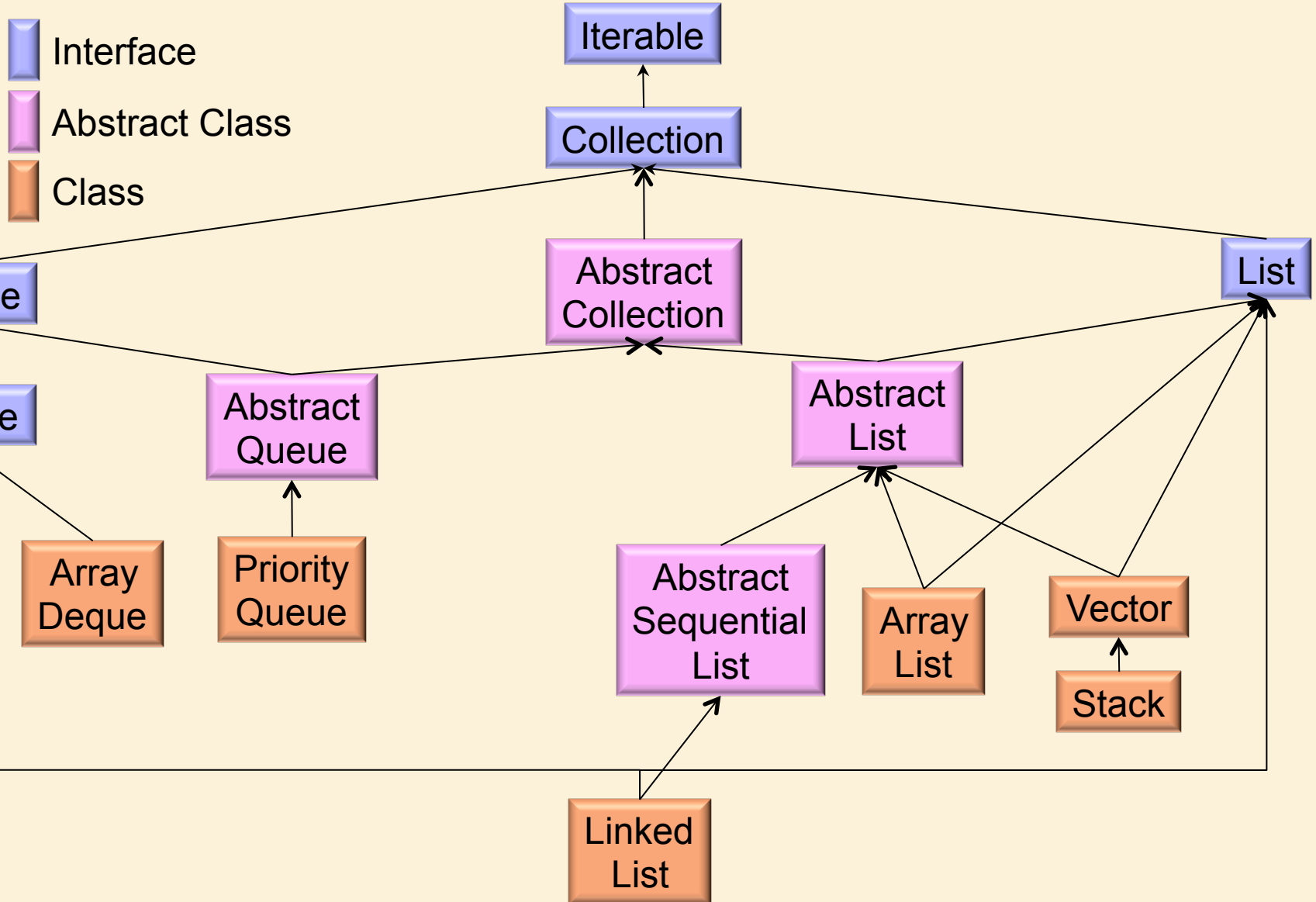
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The **ArrayList** Class

- **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**

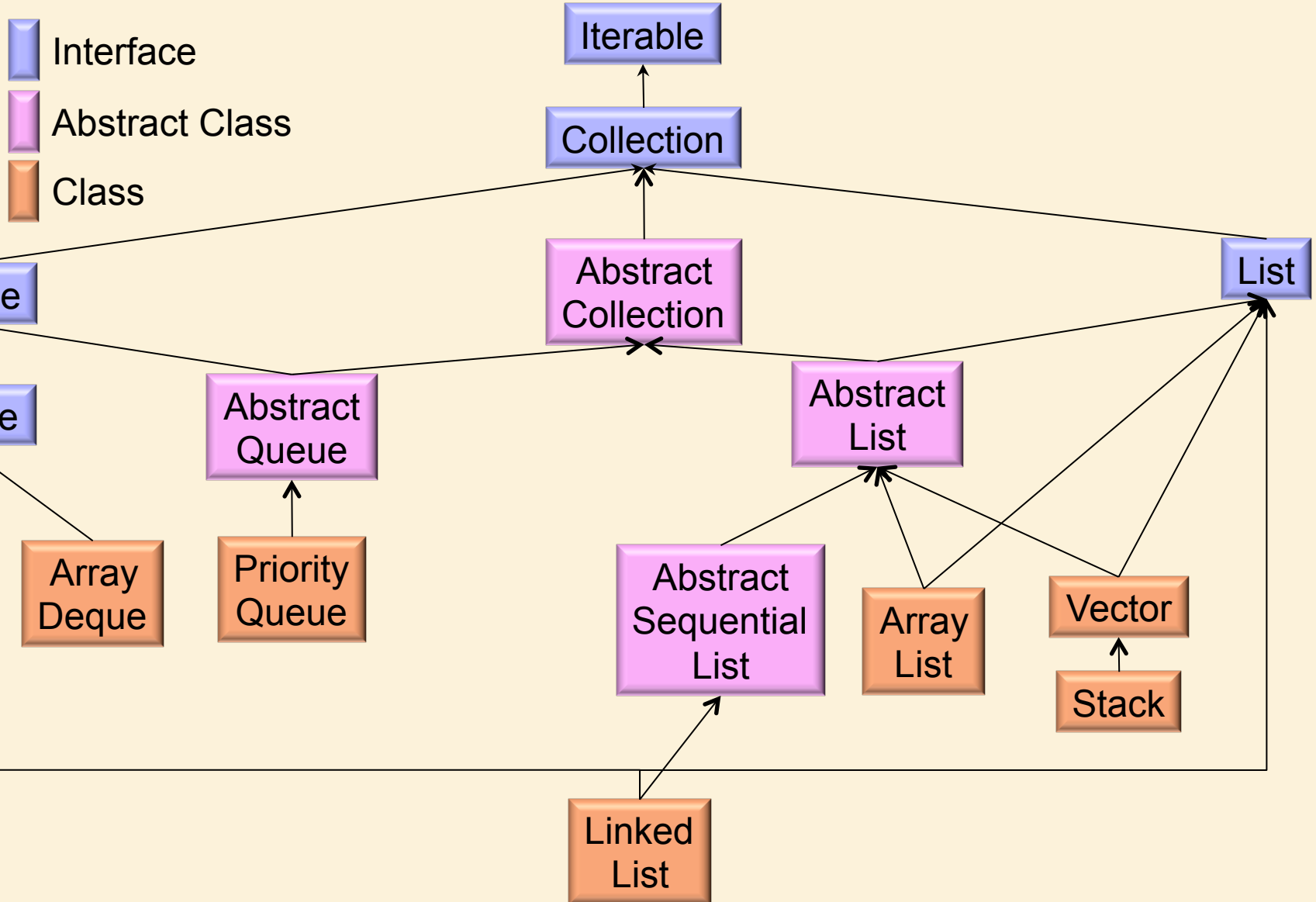
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The **Vector** Class

- 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).

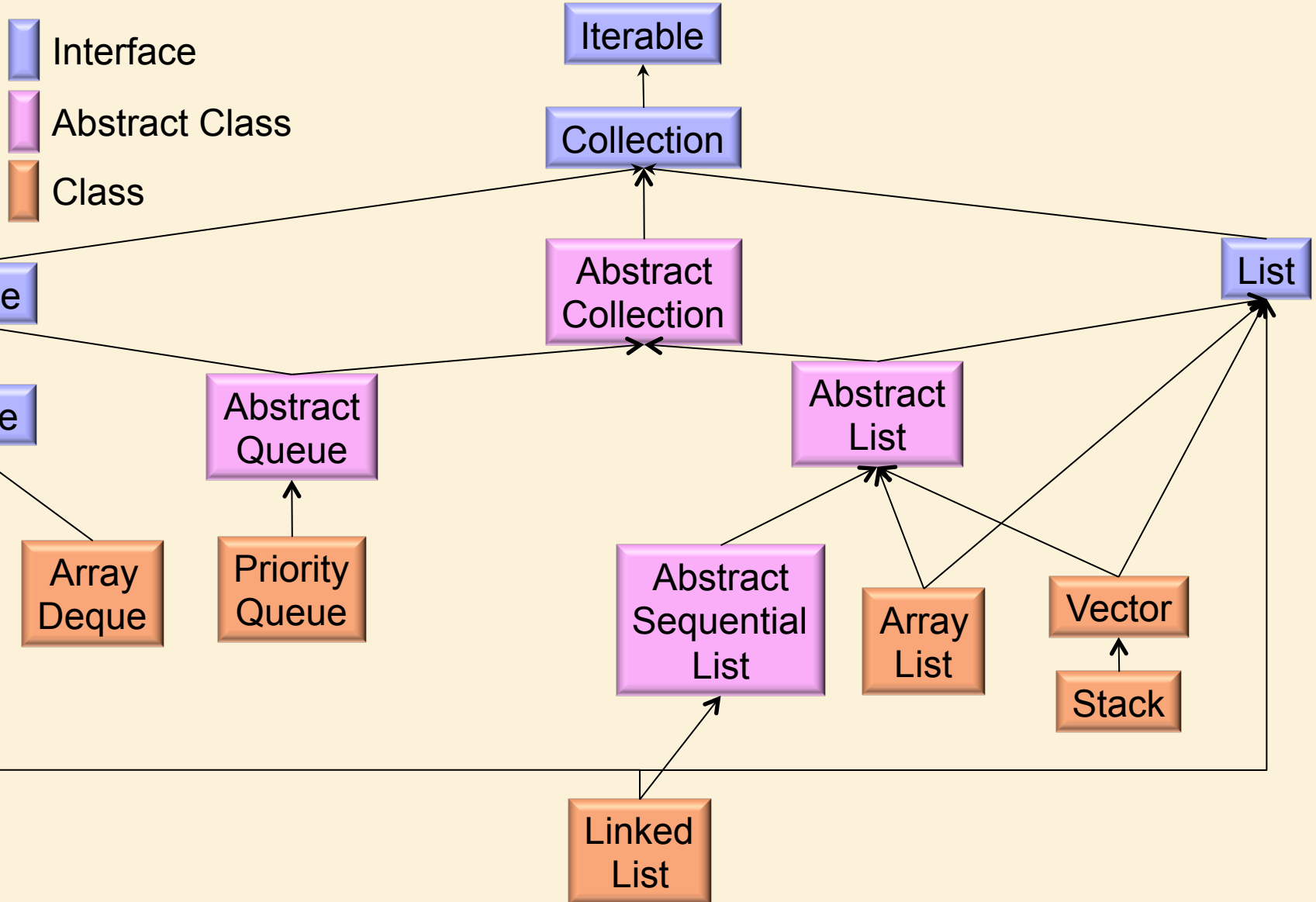
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The **Stack** Class

- 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**.

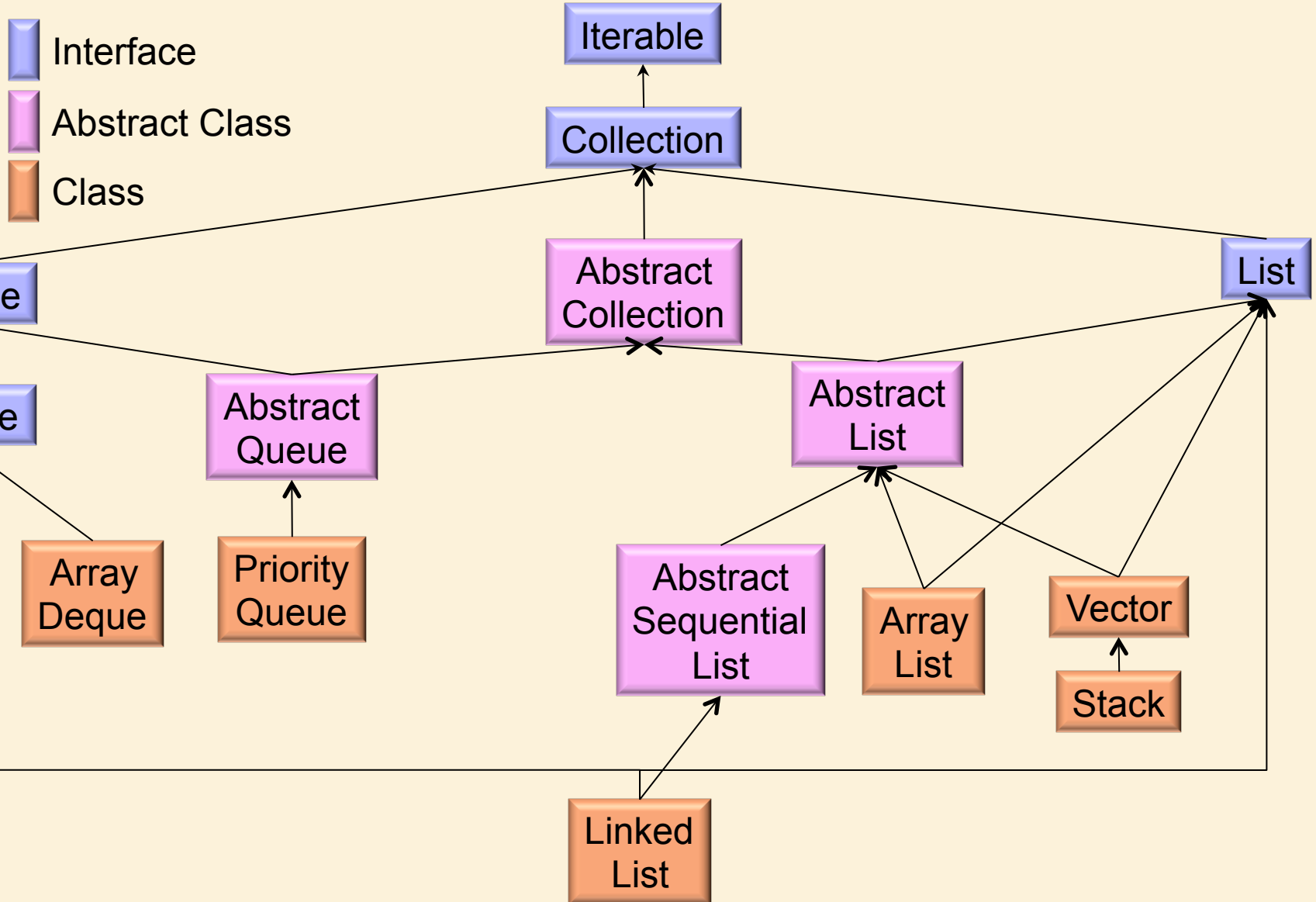
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The **Abstract Sequential List** Class

- 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()**

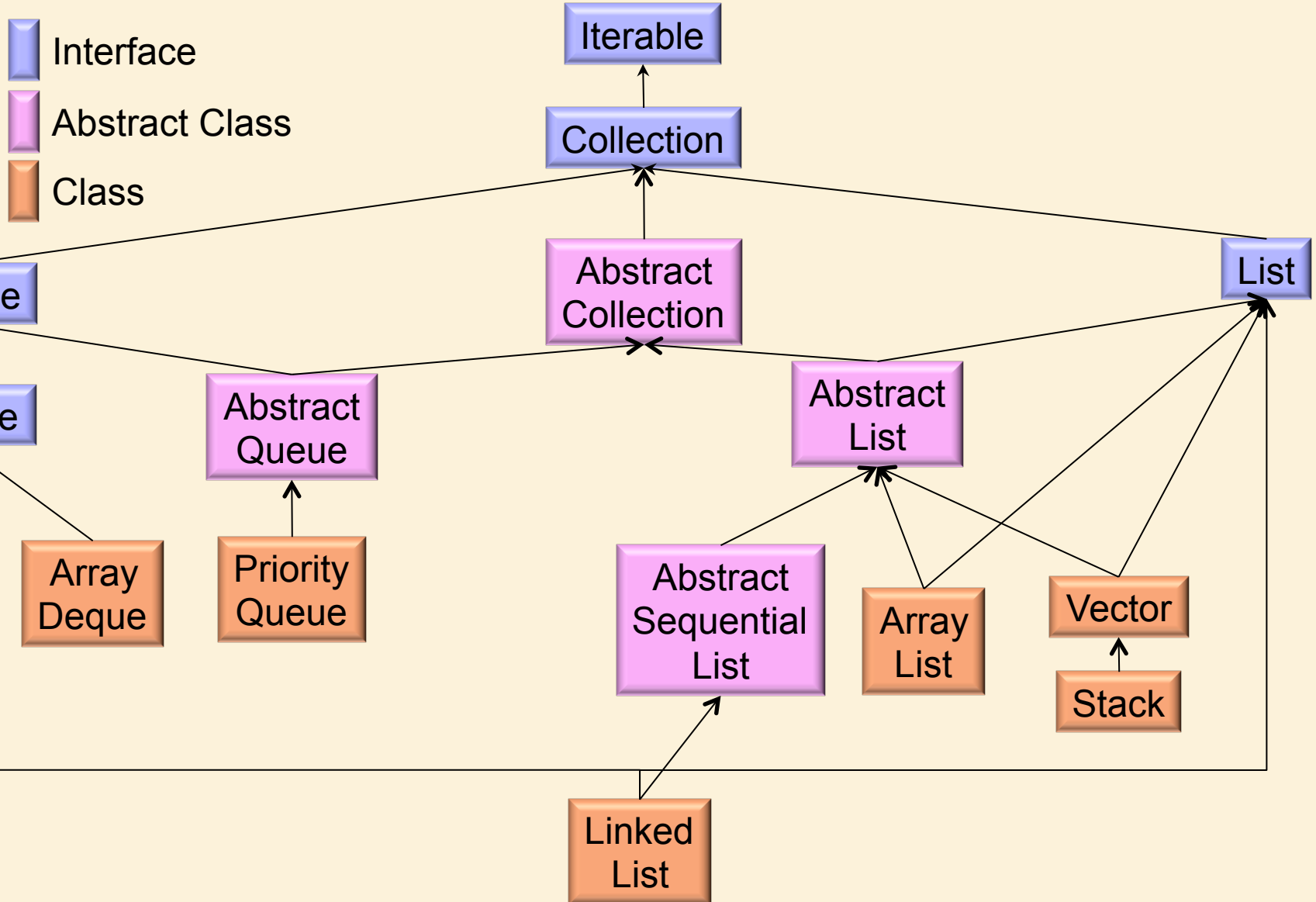
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The **Queue** Interface

- Designed for holding elements prior to processing
- Typically first-in first-out (FIFO)
- 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)	
	<i>Throws exception</i>	<i>Special value</i>	<i>Throws exception</i>	<i>Special value</i>
Insert	<code>addFirst(e)</code>	<code>offerFirst(e)</code>	<code>addLast(e)</code>	<code>offerLast(e)</code>
Remove	<code>removeFirst()</code>	<code>pollFirst()</code>	<code>removeLast()</code>	<code>pollLast()</code>
Examine	<code>getFirst()</code>	<code>peekFirst()</code>	<code>getLast()</code>	<code>peekLast()</code>

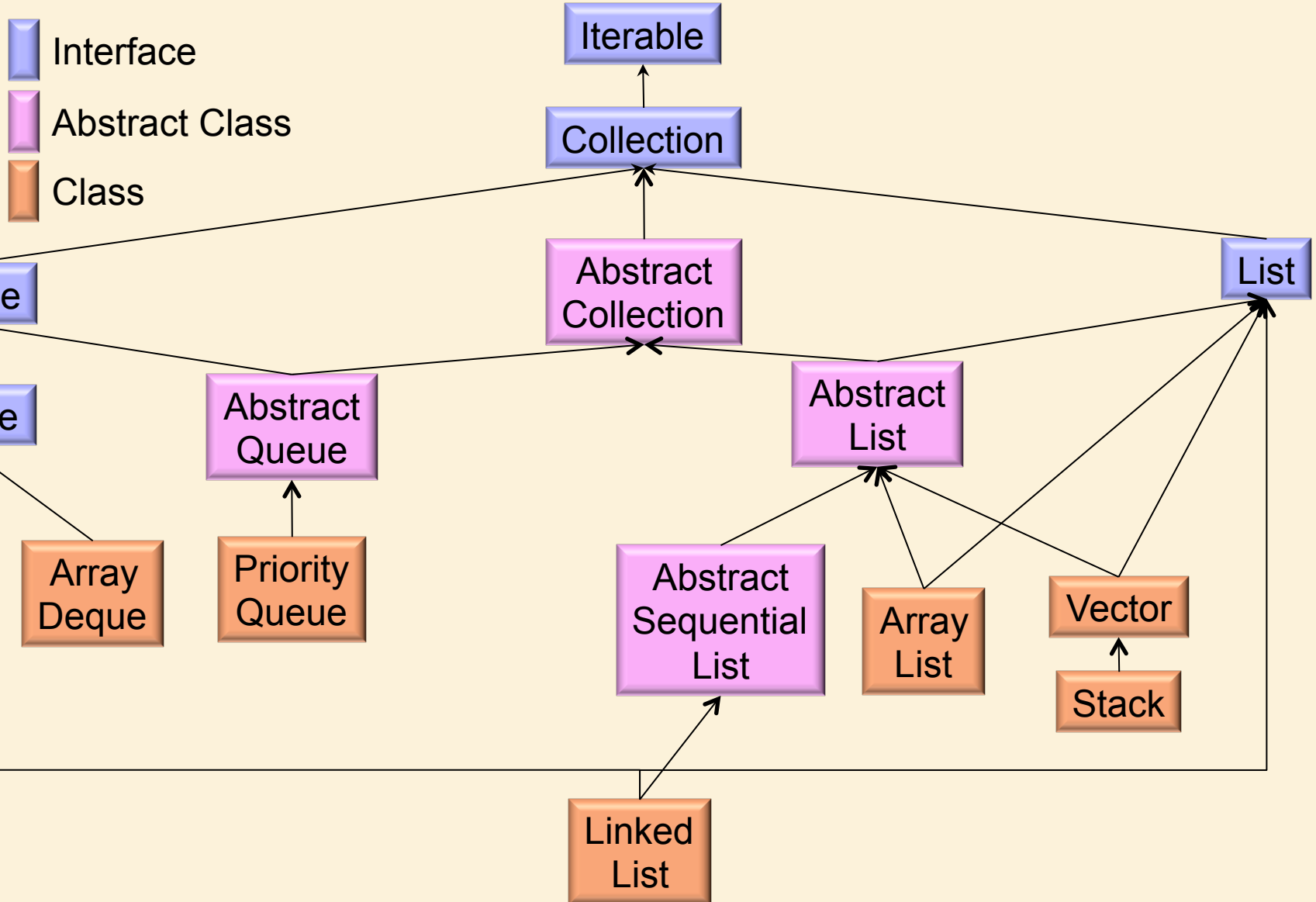
Deque Equivalent of Queue

Queue Method	Equivalent Deque Method
<code>add(e)</code>	<code>addLast(e)</code>
<code>offer(e)</code>	<code>offerLast(e)</code>
<code>remove()</code>	<code>removeFirst()</code>
<code>poll()</code>	<code>pollFirst()</code>
<code>element()</code>	<code>getFirst()</code>
<code>peek()</code>	<code>peekFirst()</code>

Deque Equivalent of Stack

Stack Method	Equivalent Deque Method
<code>push(e)</code>	<code>addFirst(e)</code>
<code>pop()</code>	<code>removeFirst()</code>
<code>peek()</code>	<code>peekFirst()</code>

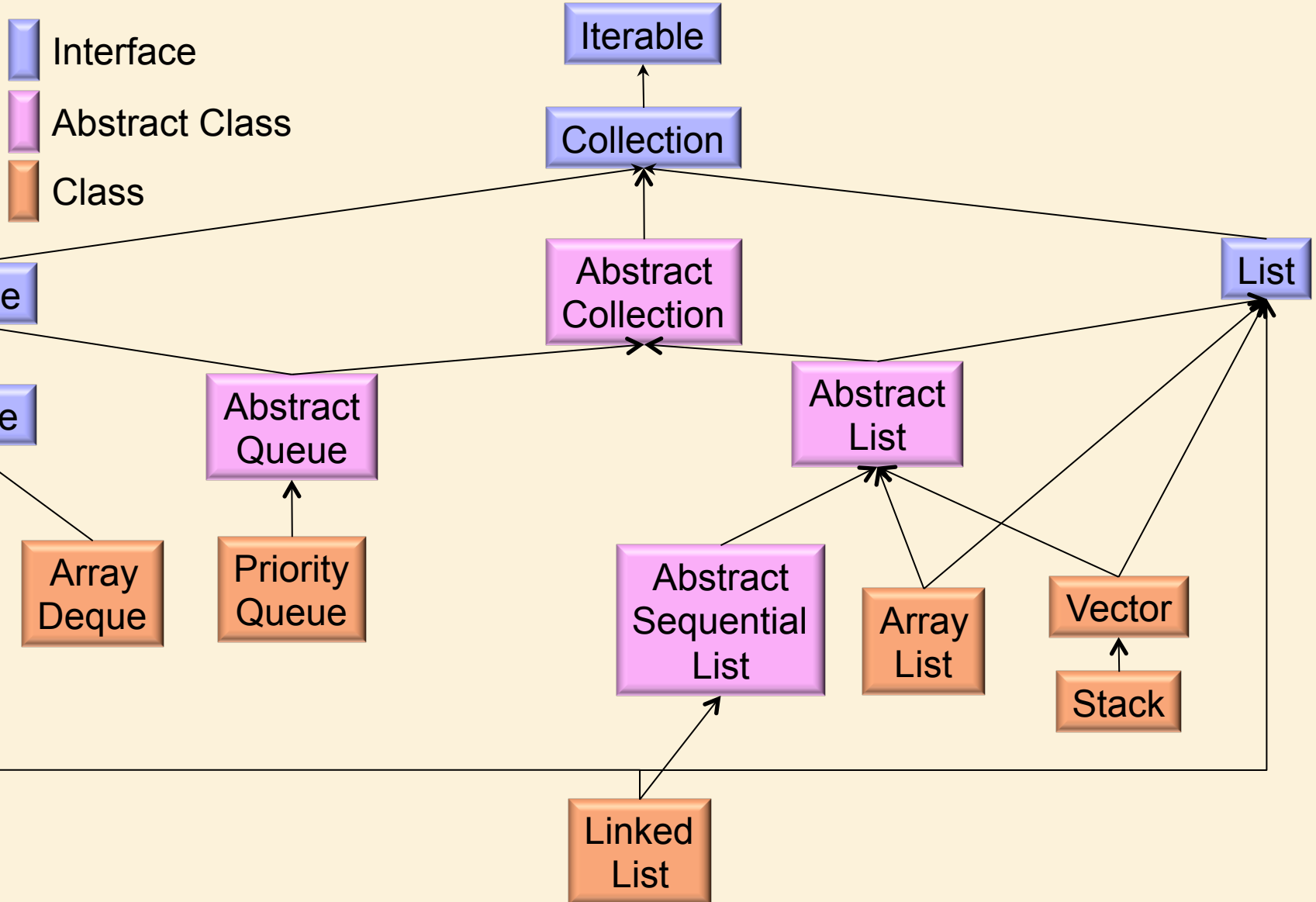
The Java Collections Framework (Ordered Data Types)



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)



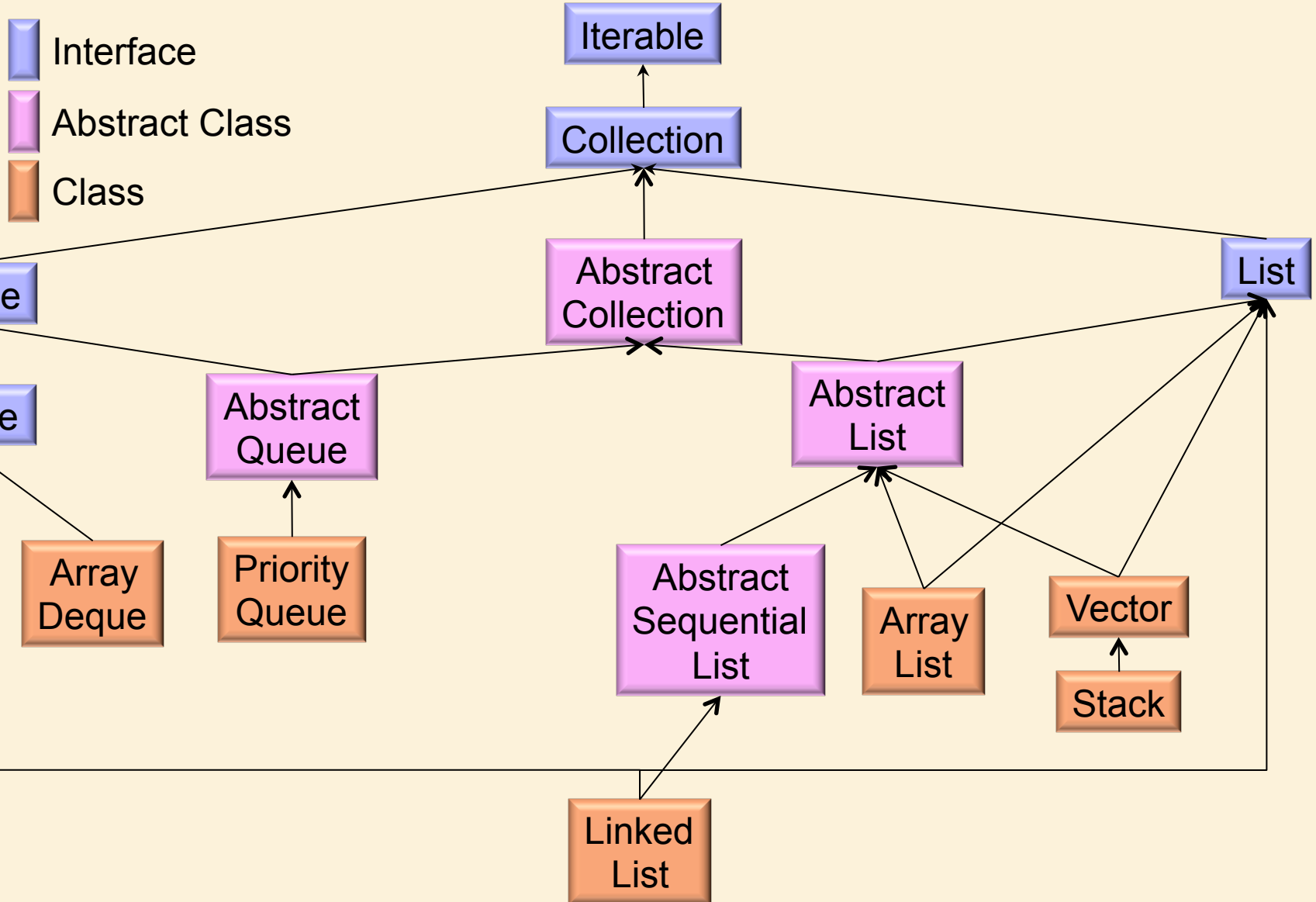
The **LinkedList** Class

- 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**.
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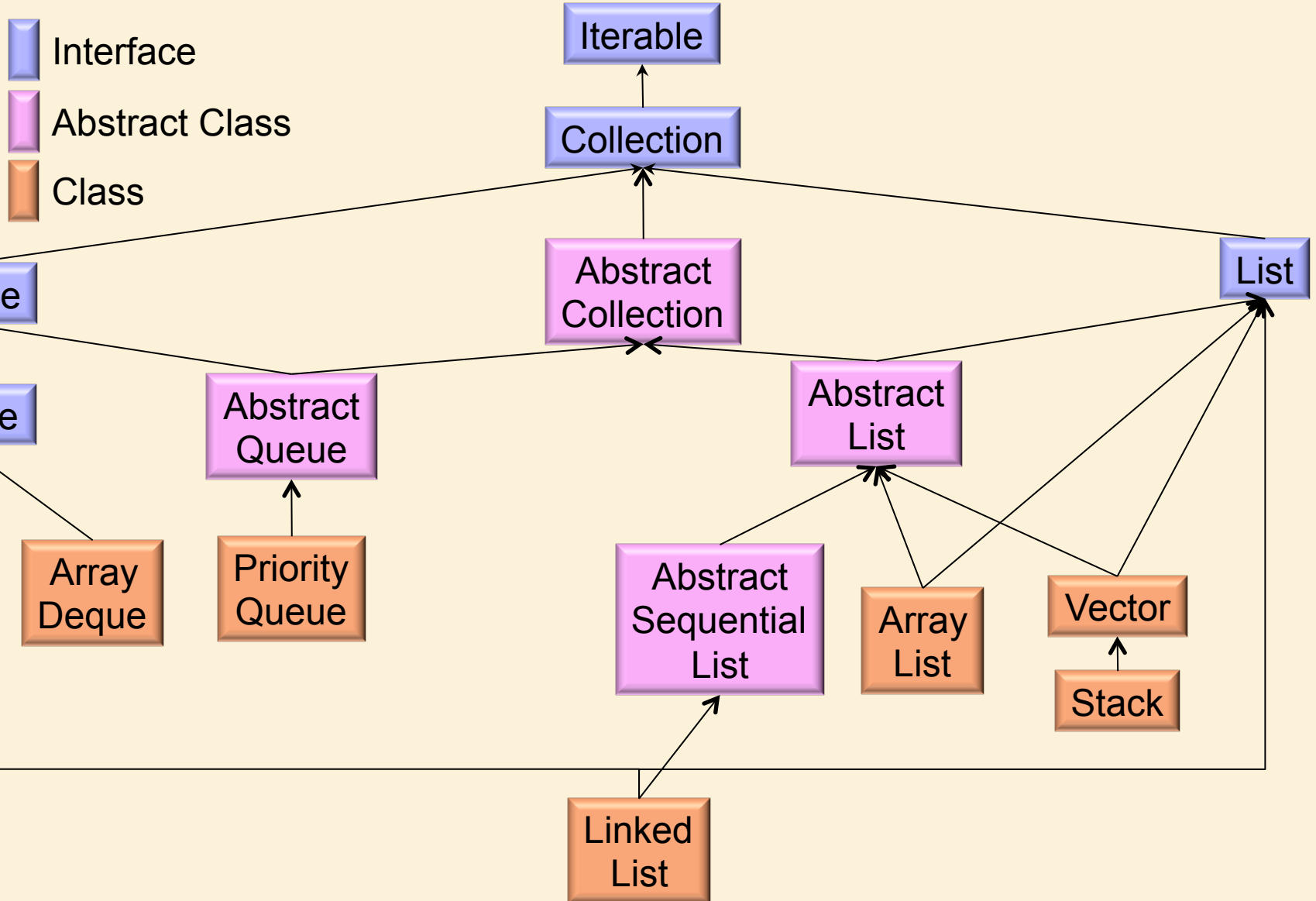
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The **Abstract Queue** Class

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

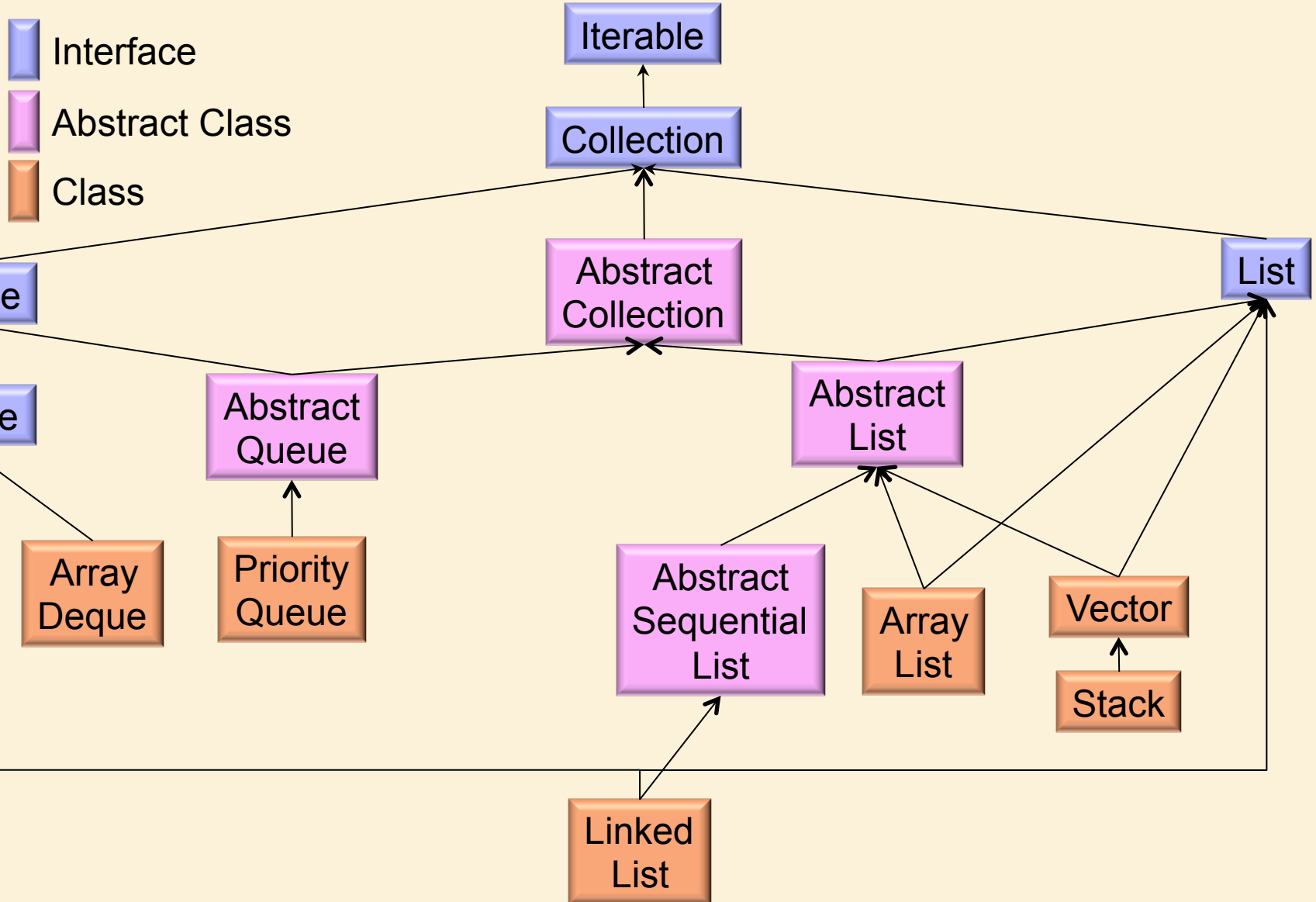
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The Priority Queue Class

- 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)



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

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