The Java Collections Framework

Chapters 7.5

Outline

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

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- **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 (currently 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, the best-known examples of collections frameworks are the C++ Standard Template Library (STL) and Smalltalk's collection hierarchy.

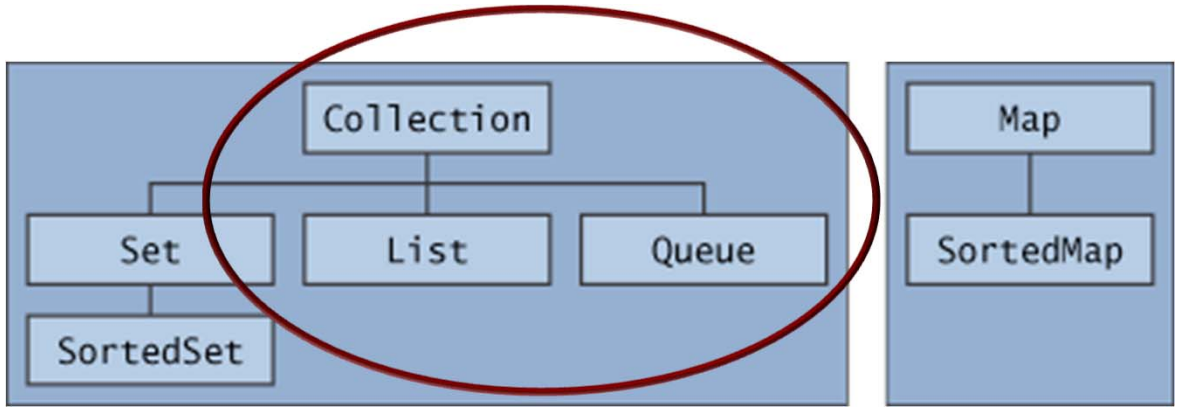
Benefits

- **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



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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);

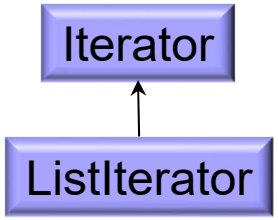
  prints each element of the collection on a separate line.
- This code is just shorthand: it compiles to use o.iterator().

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.

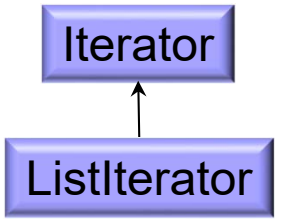
ListIterators

- 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 (before implicit cursor)
  - **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

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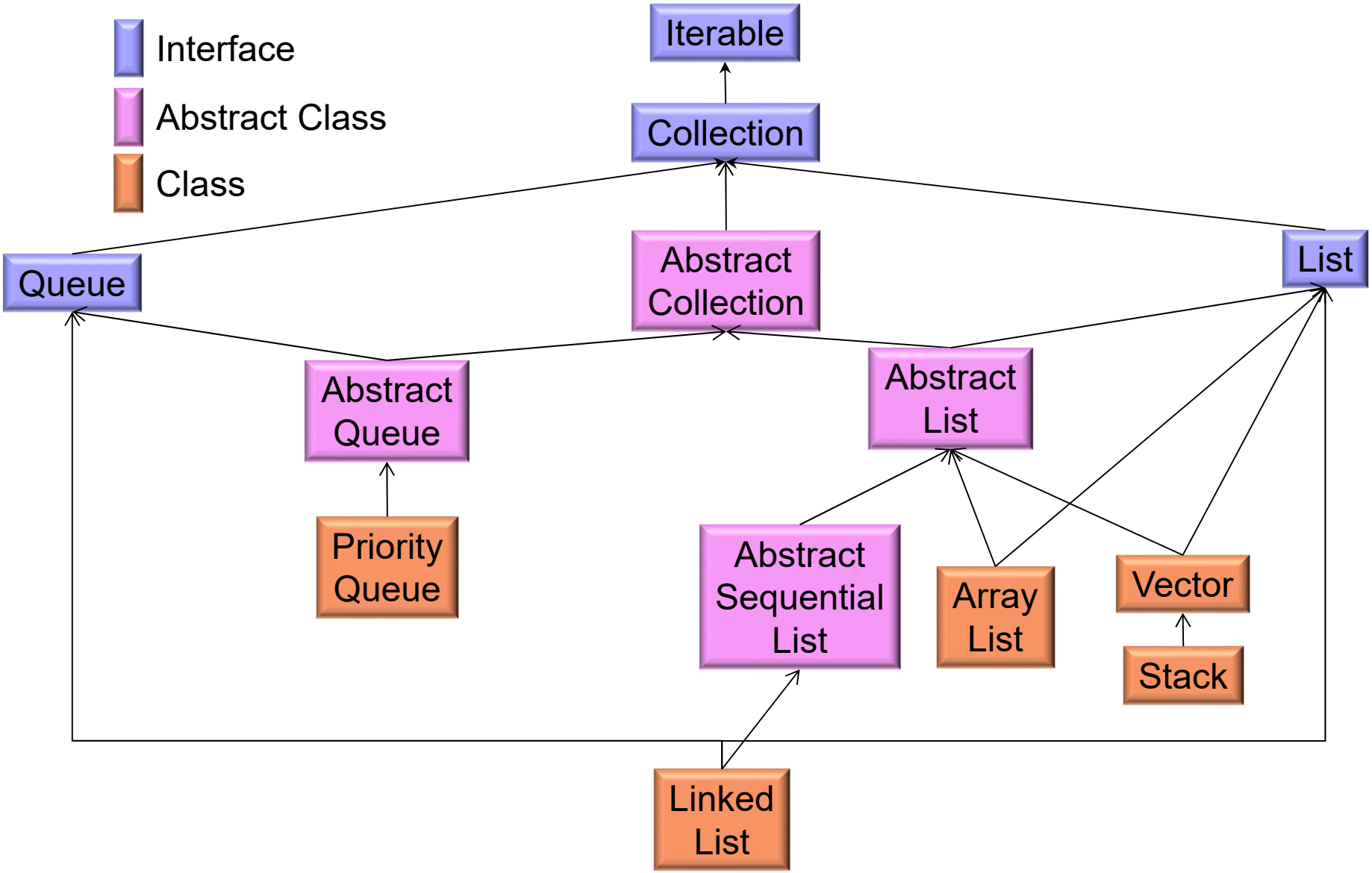
- **Interfaces, Abstract Classes and Classes of the Java Collections Framework**

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) Classes**
    - 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

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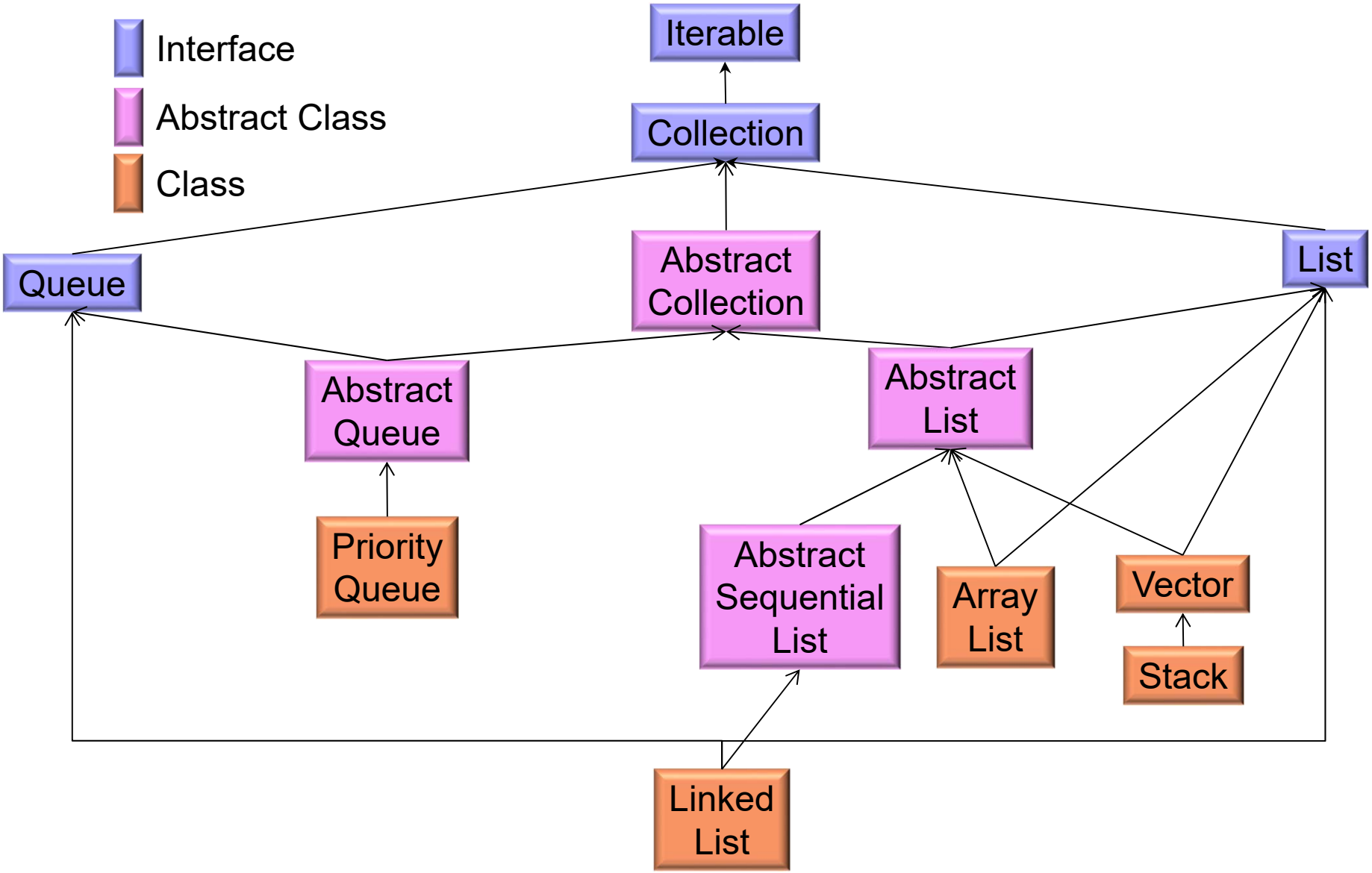
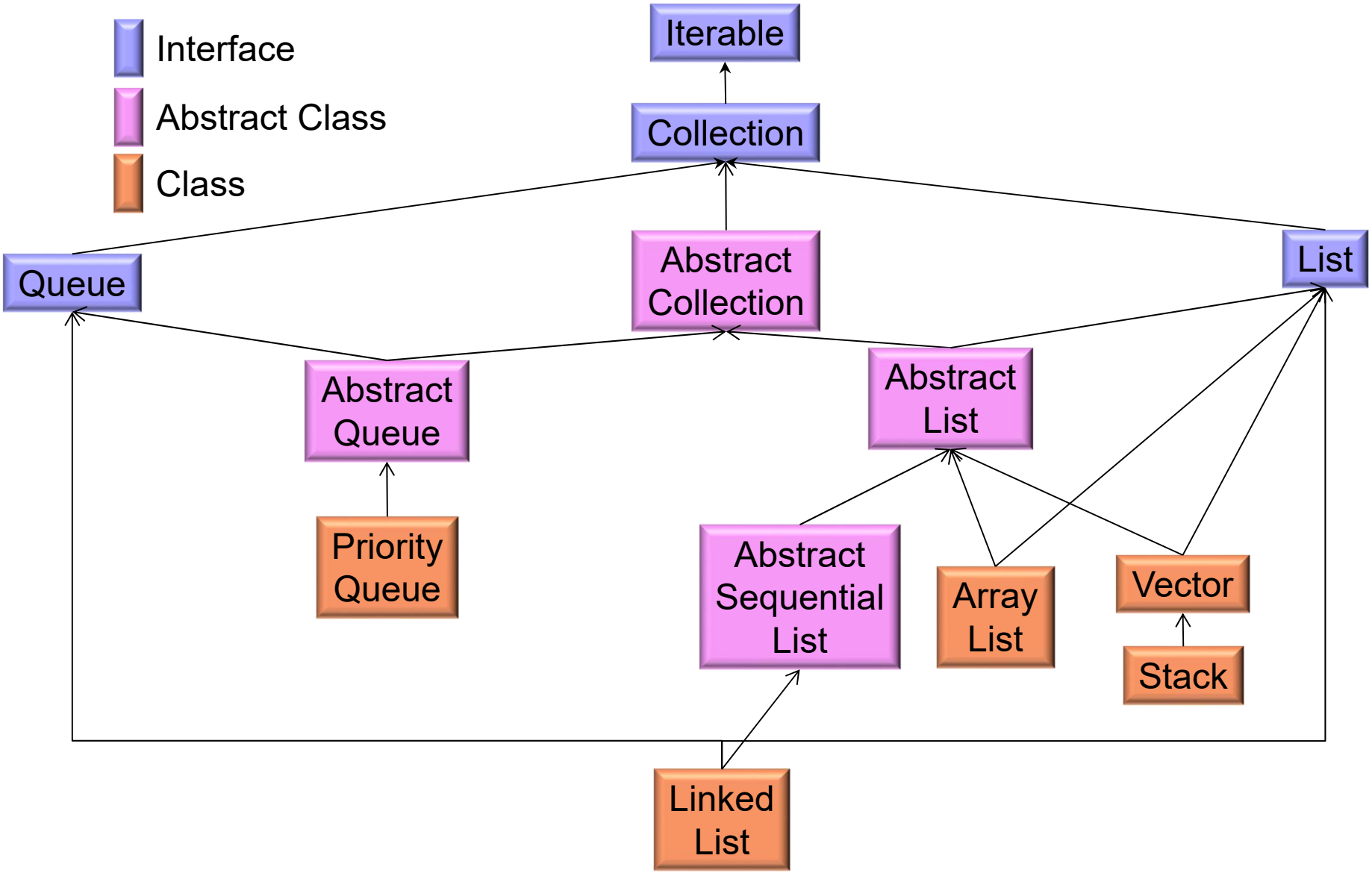


The **Collection** Interface

- 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(e)**
  - Modifying the data structure
    - **remove(e)**
    - **removeAll(c)**
    - **retainAll(c)**
    - **clear()**

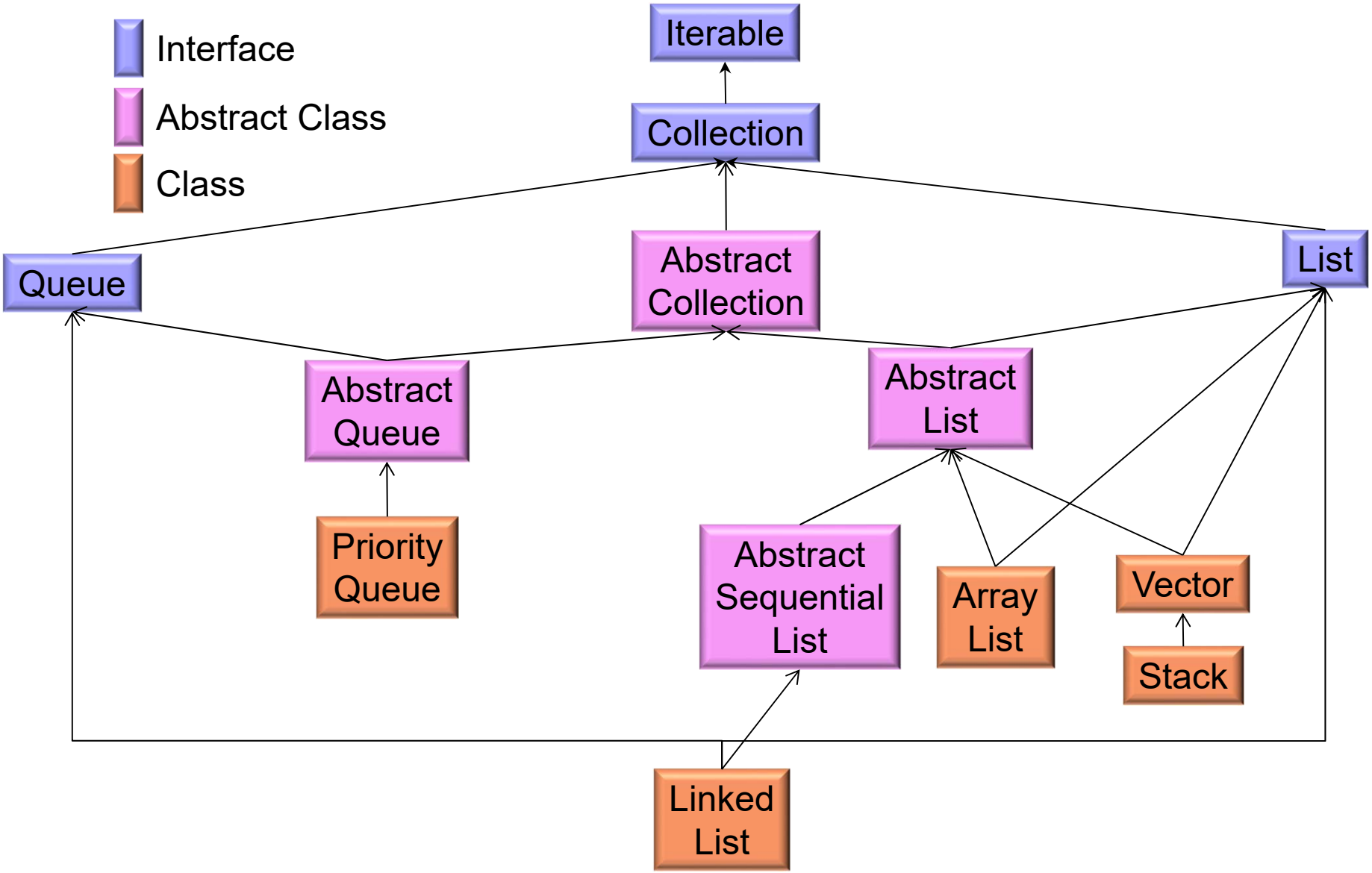
The Java Collections Framework (Ordered Data Types)



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**

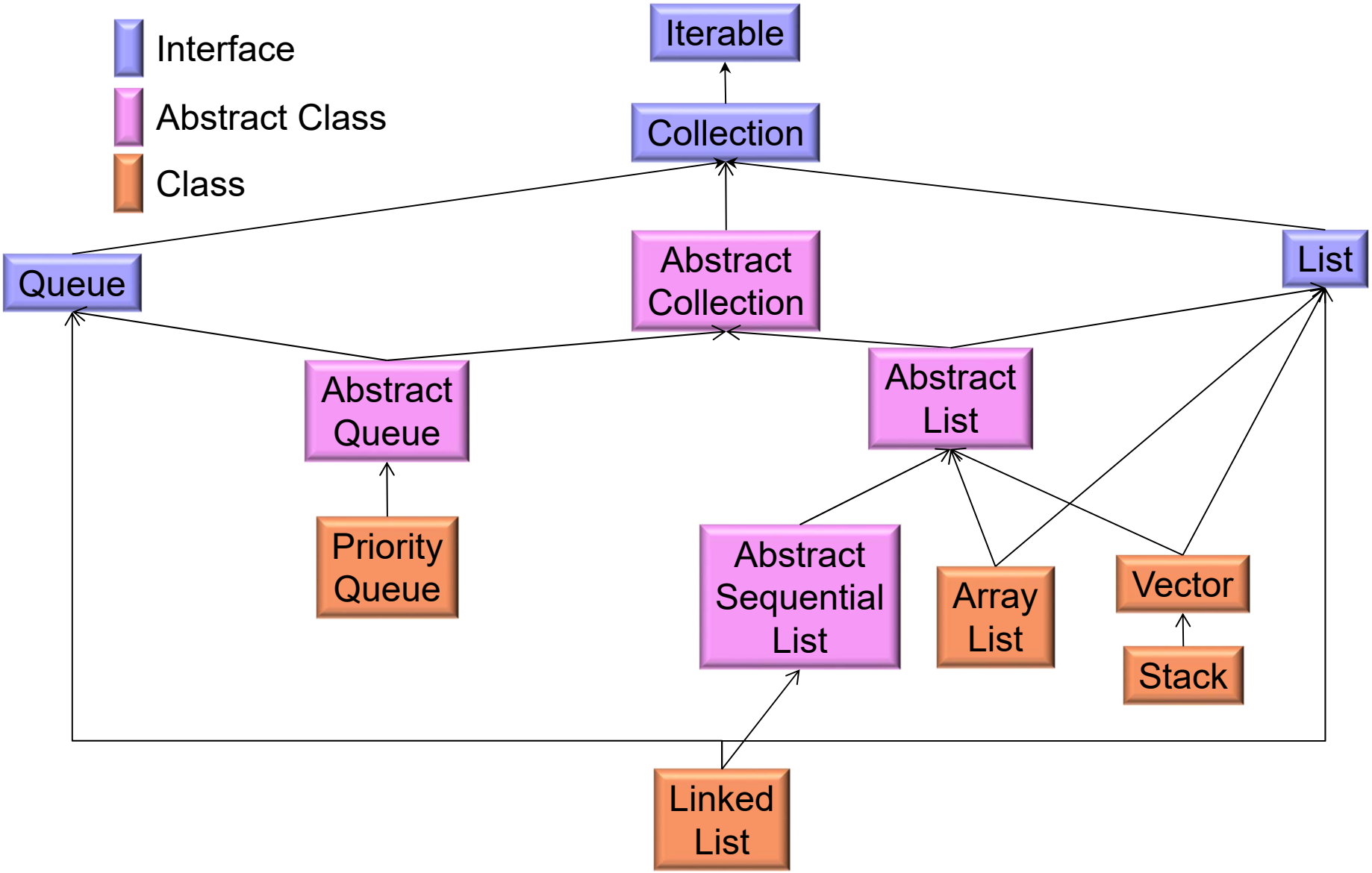
The Java Collections Framework (Ordered Data Types)



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

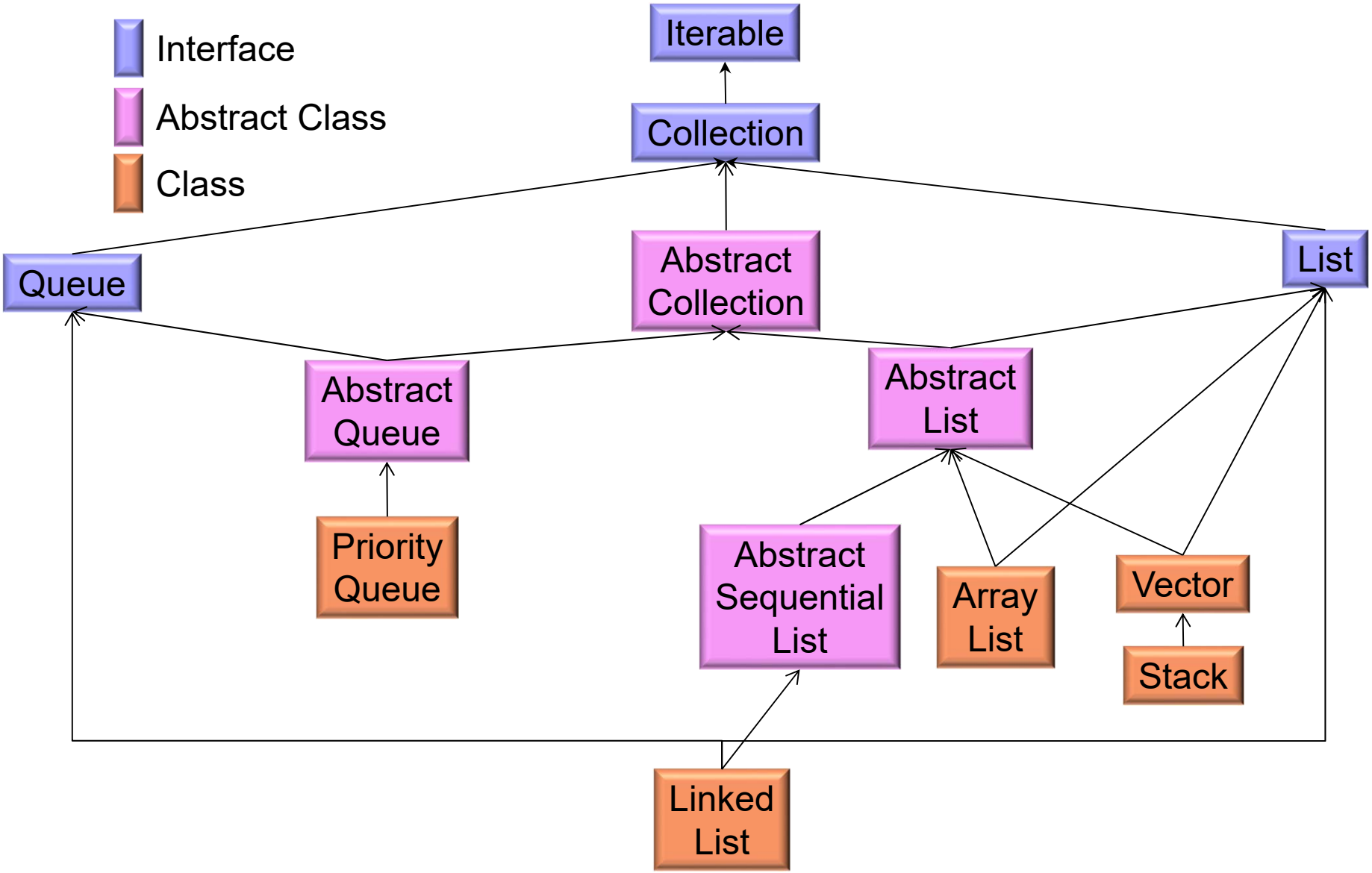
The Java Collections Framework (Ordered Data Types)



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**

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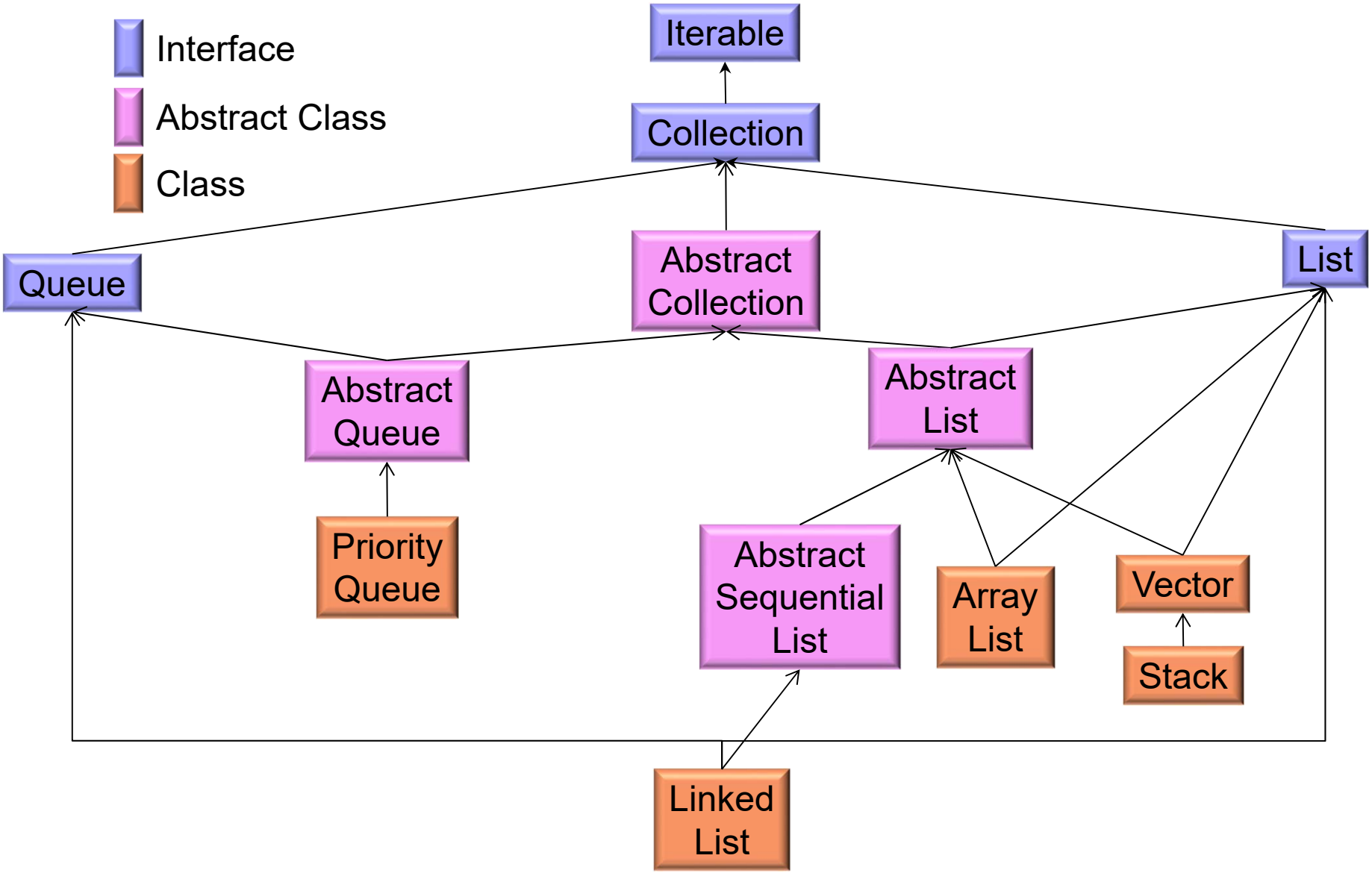
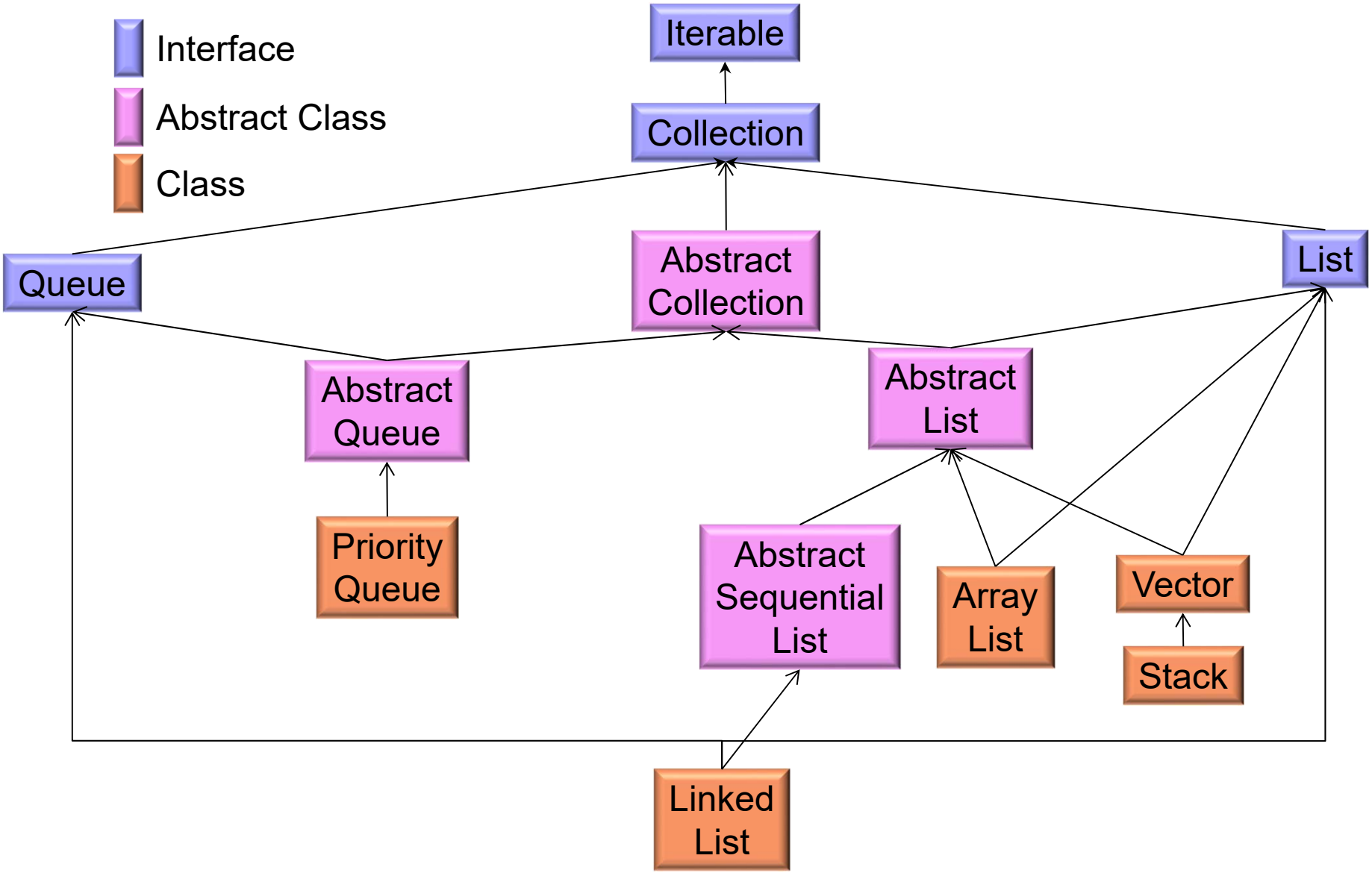


The **Vector** Class

- 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).

The Java Collections Framework (Ordered Data Types)



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.

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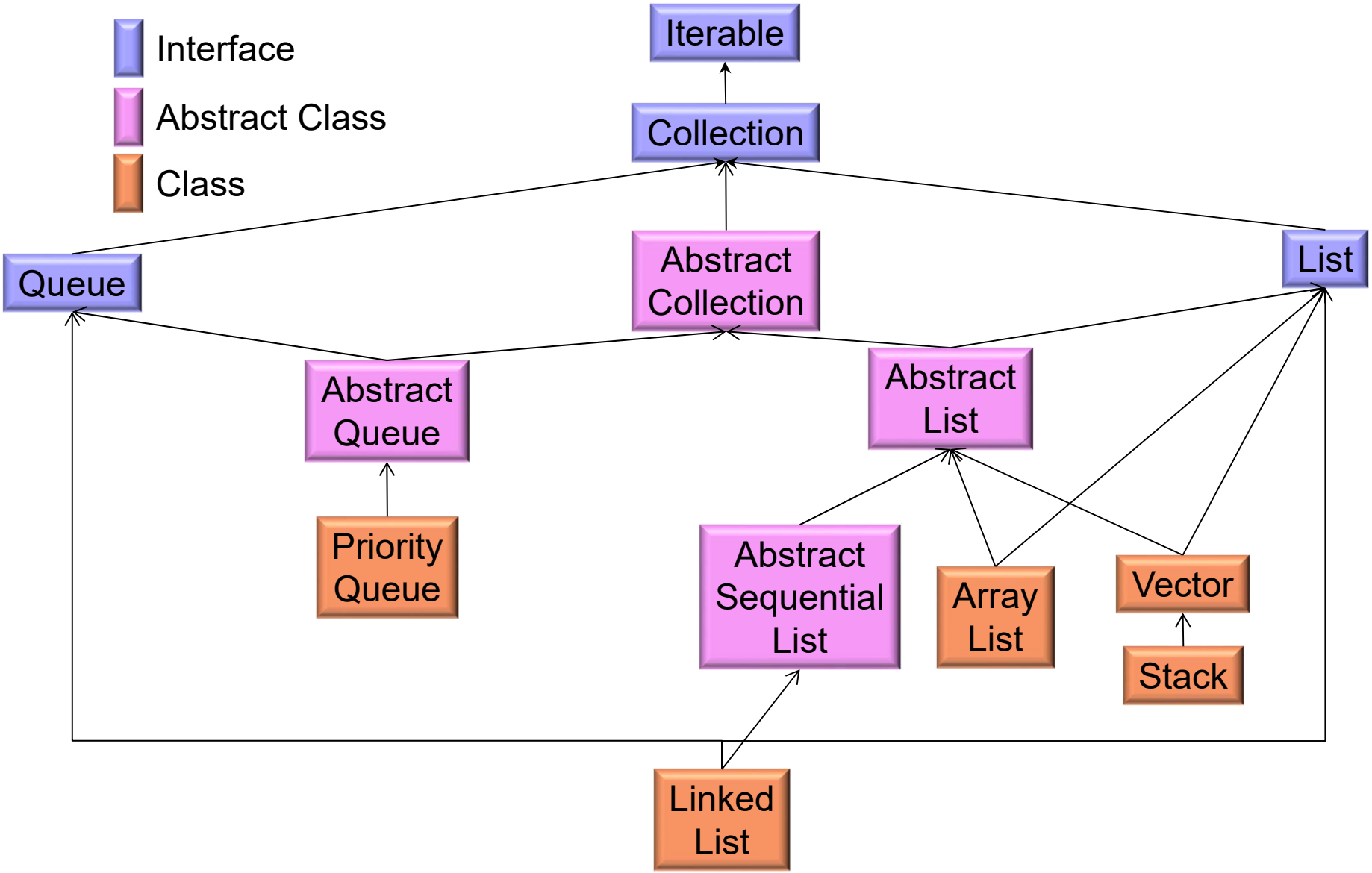
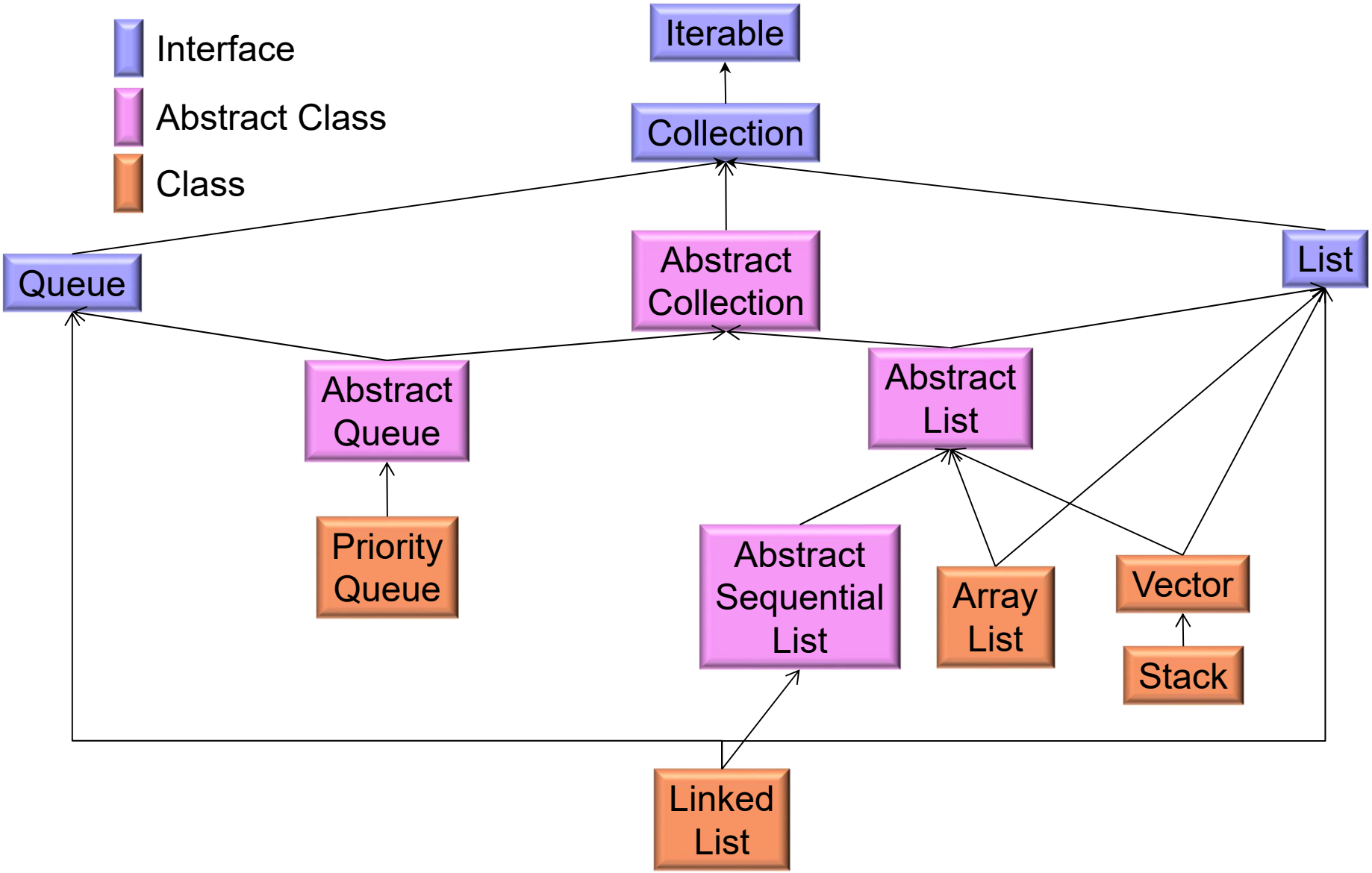


The **Abstract Sequential List** Class

- 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()**

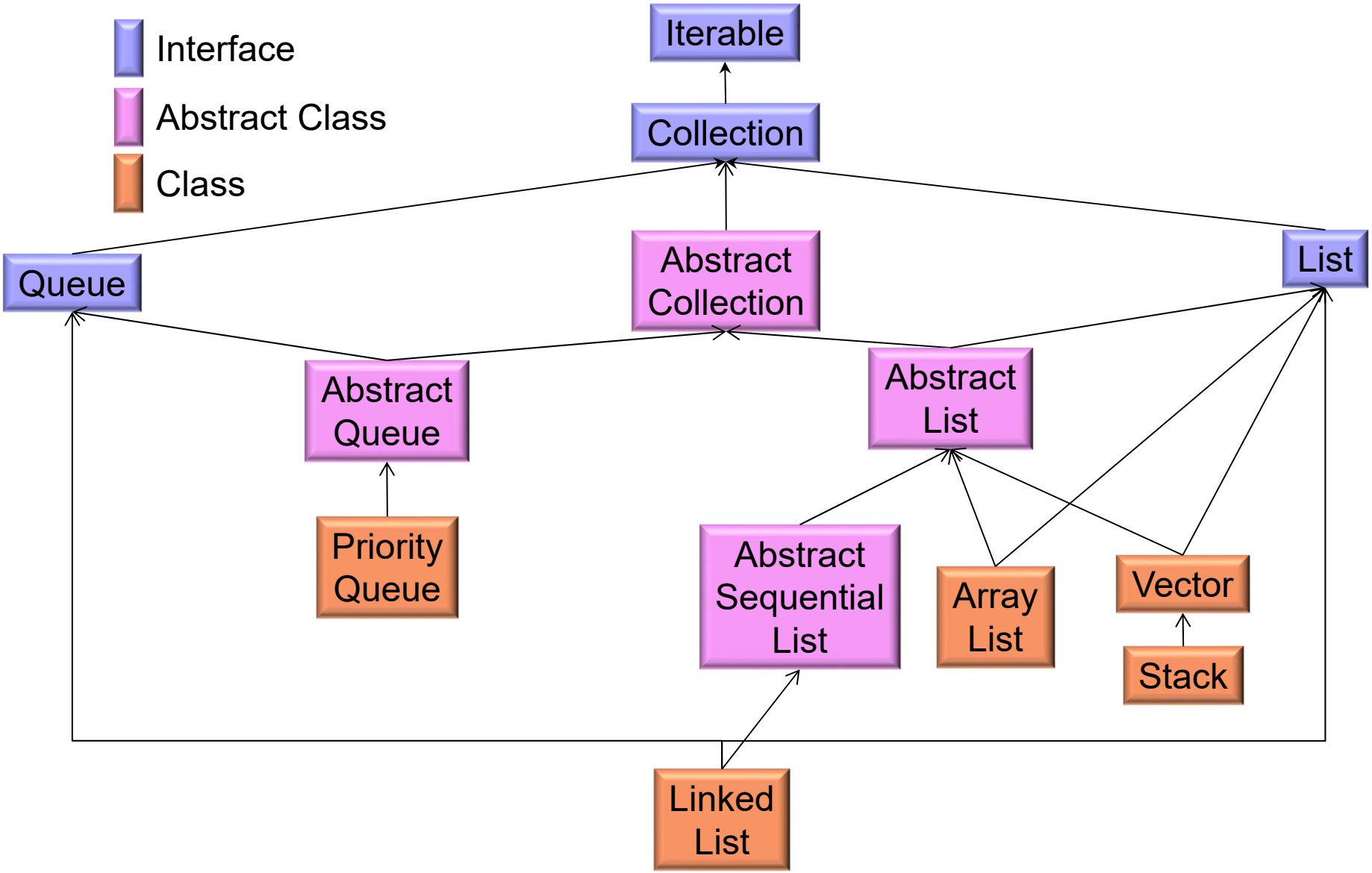
The Java Collections Framework (Ordered Data Types)



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)



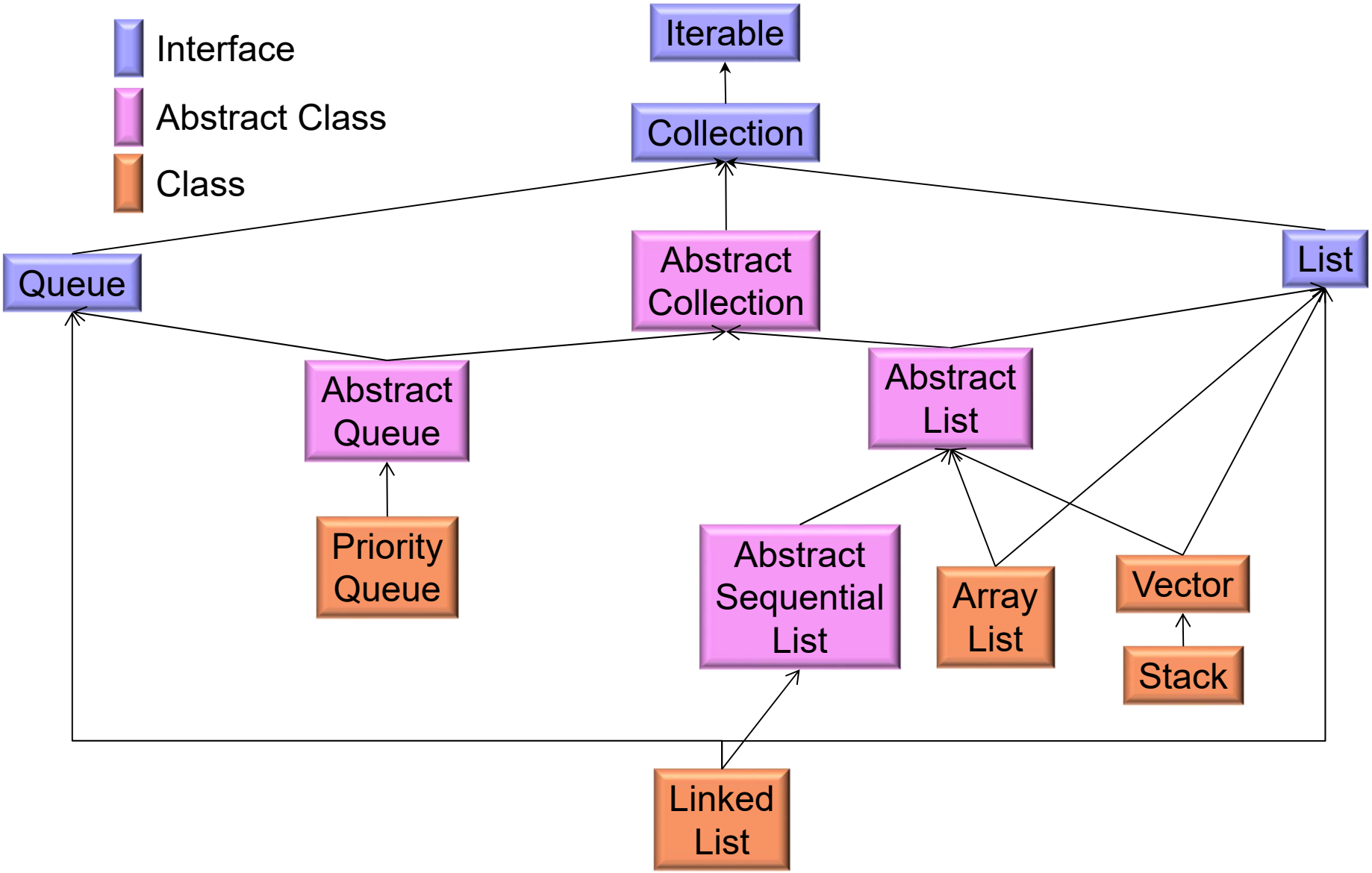
The **LinkedList** Class

- Implements the **List** and **Queue** 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.

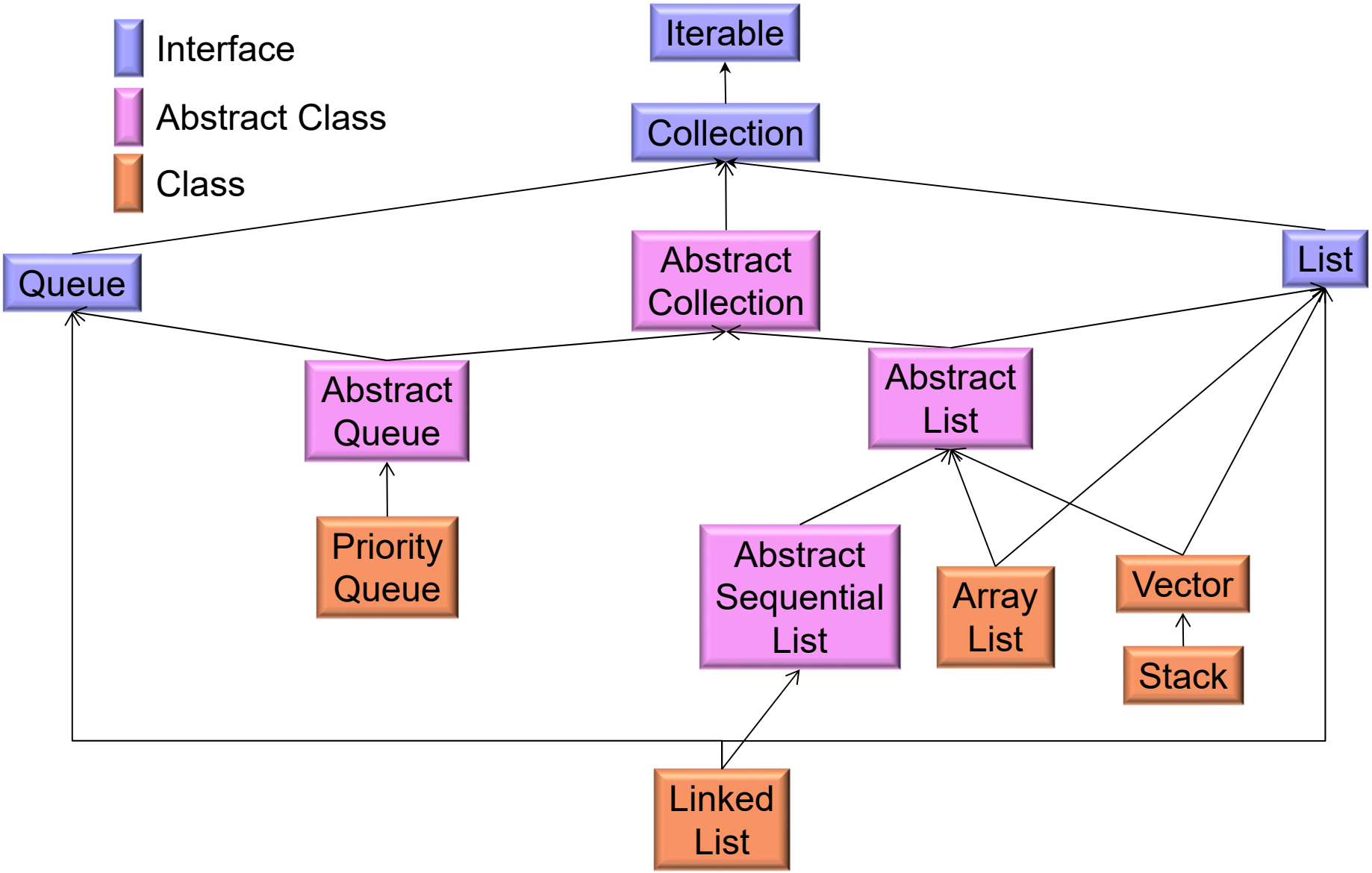
The Java Collections Framework (Ordered Data Types)



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)

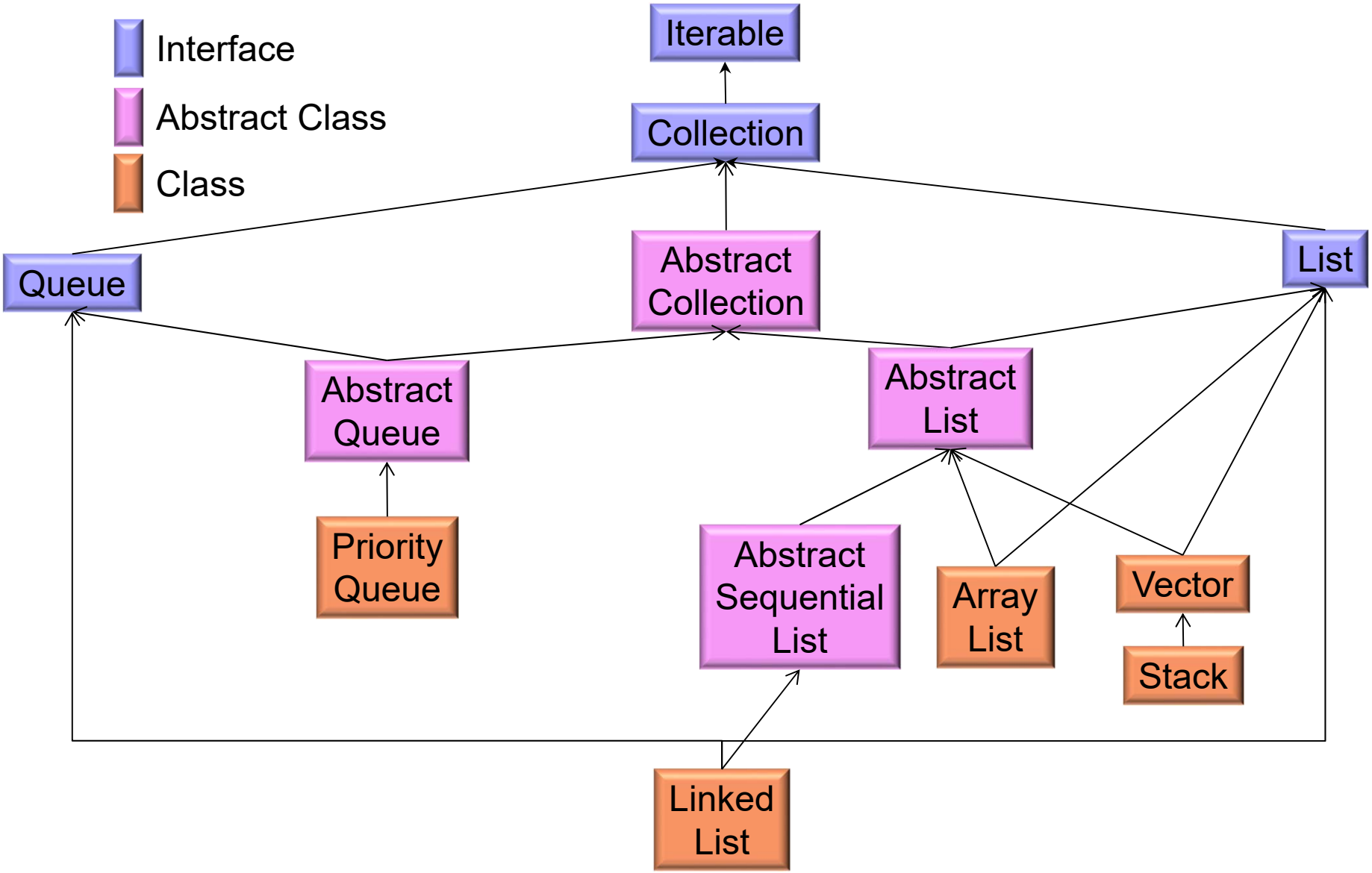


The **Priority Queue** Class

- 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)



Summary

- 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