CSCI 136
Data Structures & Advanced Programming

Lecture 12

Fall 2019

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Last Time

- Merge sort and quicksort

Today

- Abstract classes and inheritance
- Lists
- Implementing Lists with linked structures
  - Singly Linked Lists
    - See Lecture 11 slides
  - Circularly & Doubly Linked Lists
- The structure5 hierarchy so far

Class Specialization

- Classes can *extend* other classes
  - Inherit fields and **method bodies**
- By extending other classes, we can create specialized sub-classes
- Java supports class extension/specialization
- Java enforces *type-safety*: Objects behave according to their type
  - Some checks are made at compile-time
  - Some checks are made at run-time
- We'll first use this feature to factor out code

Abstract Classes

- Note: All of our Card implementations code `toString()` in identical fashion.
- It's good to be able to "factor out" common code so that it only has to be maintained in one place
- *Abstract classes* to the rescue….
- An abstract class allows for a *partial* implementation
- We can then *extend* it to a complete implementation
- Let's do this with our cards.
  - Examine CardAbstract.java....
- As with interfaces, can't use "new" with abstract types!

Abstract Classes

Notes from `CardAbstract` class example

- `CardAbstract` *implements* `Card` (partially)
- `CardAbstract` is declared to be *abstract*
  - It contains the implementation of `toString(), equals(), and compareTo()` [Note: We made our cards comparable!]

How do the full implementations (`CardRankSuit`, etc) change?

- They are declared to *extend* `CardAbstract`
- They don't need to say "`implements Card`"
- They don't contain the `toString()` method
  - They *inherit* that method from `CardAbstract`
  - But could *override* that method if desired

Extending Concrete Classes

Let's call a class *concrete* if it is not abstract

We can extend concrete classes

Example: Adding a point count to a `Card`

- Suppose we wanted to add a point value to each of the playing cards in `CardRankSuit`
- We *extend* that class

```
class CardRankSuitPoints extends CardRankSuit {… }
```

- This new class can now contain additional instance variables and methods
- Let's look at the code for CardRankSuitPoints.java….

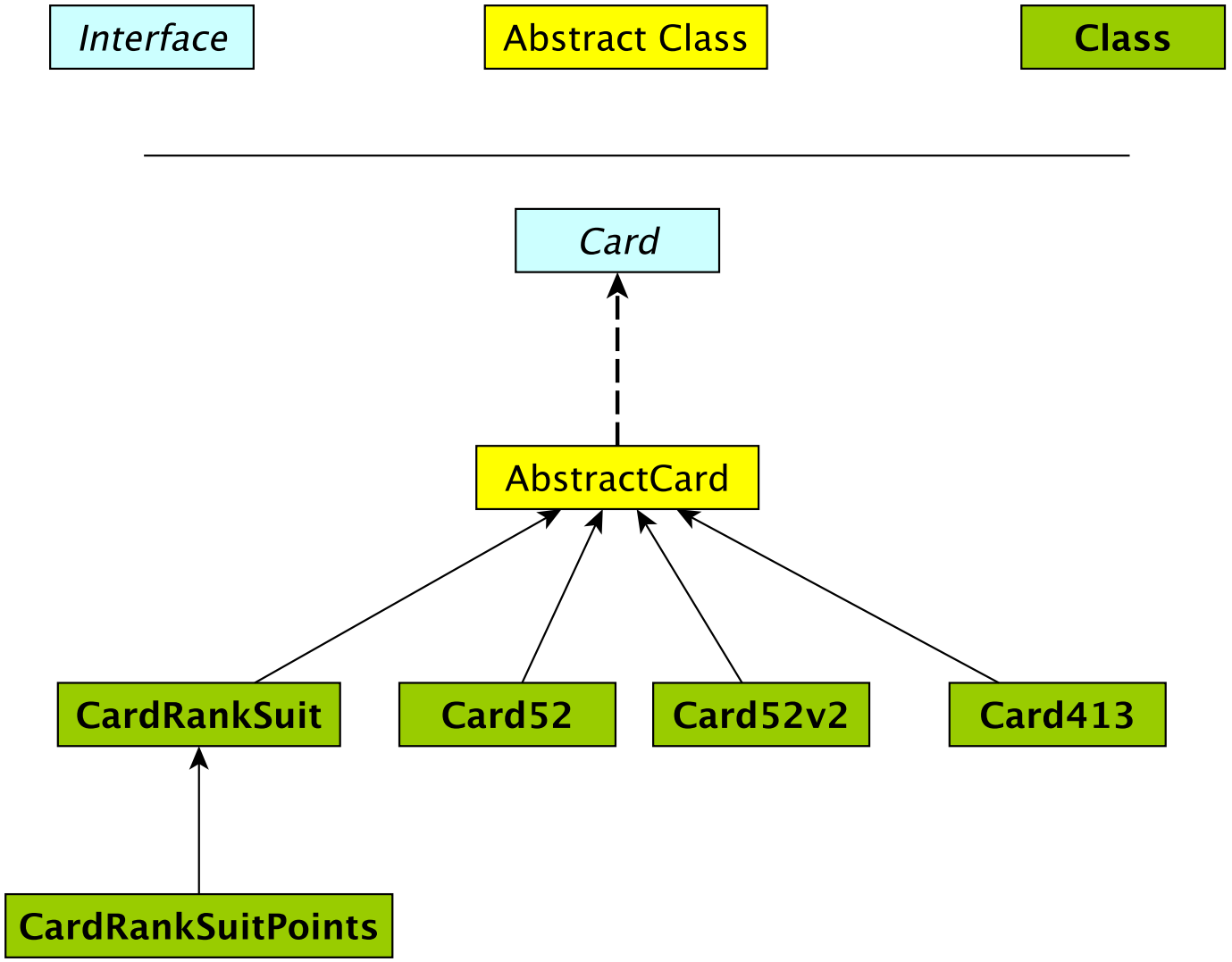
CardRankSuitPoints Notes

- Constructor calls `CardRankSuit` constructor using *super*
- We can override methods---e.g., `toString()`
- Can use a `CardRankSuitPoints` object wherever we use a `Card`
  - But! Can only use new features (`getPoints()`) if the object is declared to be of type `CardRankSuitPoints`

```
CardRankSuitPoints c1 = new CardRankSuitPoints(
    Rank.ACE, Suit.CLUBS, 4);
int p1 = c1.getPoints(); // Legal
Card c2 = new CardRankSuitPoints(Rank.ACE,
    Suit.CLUBS, 4);
int p2 = c2.getPoints(); // Bad! c2 is of type Card
int p3 = ((CardRankSuitPoints) c2).getPoints(); // Legal
```

- Java enforces *type-safety*: An variable of type X can only be assigned a value of type X or of a type that extends X

The Card Classes Hierarchy



Pros and Cons of Vectors

Pros

- Good general purpose list
- Dynamically Resizeable
- Fast access to elements
  - vec.get(387425) finds item 387425 in the same number of operations regardless of vec's size

Cons

- Slow updates to front of list (why?)
- Hard to predict time for add (depends on internal array size)
- Potentially wasted space

Today we look at another way to store data: Linked Lists

But First : List Interface

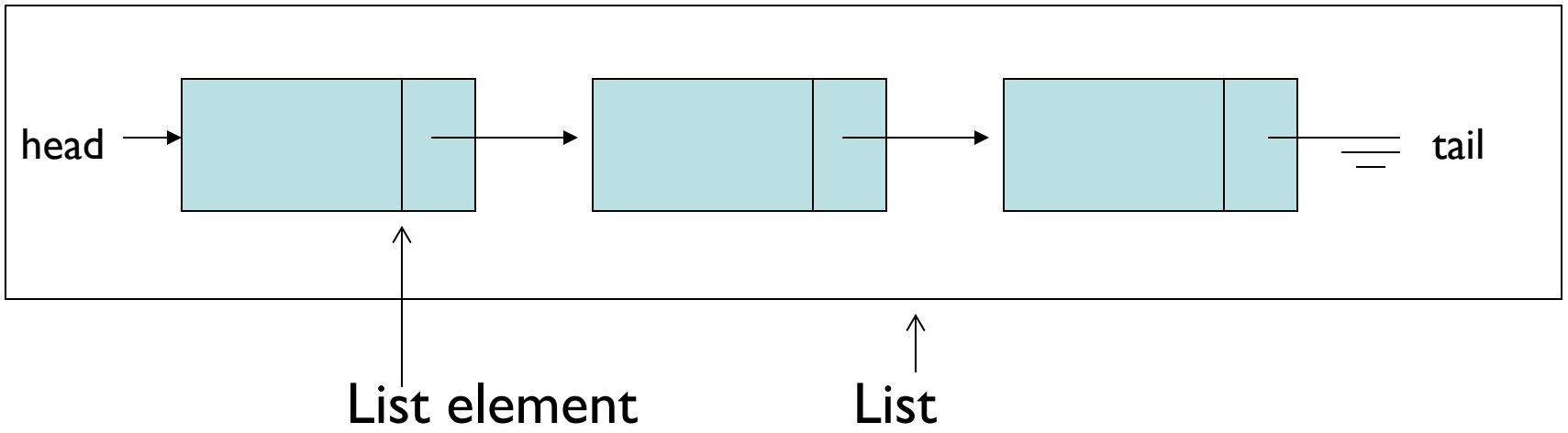
```
interface List {
    size()
    isEmpty()
    contains(e)
    get(i)
    set(i, e)
    add(i, e)
    remove(i)
    addFirst(e)
    getLast()
    .
    .
    .
}
```

- Flexible interface
- Can be used to describe many different types of lists
- It's an interface…therefore it provides no implementation
- Vector implements List
- Other implementations are possible
  - SinglyLinkedList
  - CircularlyLinkedList
  - DoublyLinkedList

Linked List Basics

- There are two key aspects of Lists
  - Elements of the list
  - The list itself

- Visualizing lists

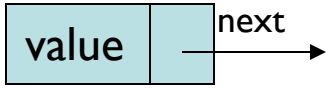


Linked List Basics

- List nodes are recursive data structures
- Each "node" has:
  - A data value
  - A "next" value that identifies the next element in the list
  - Can also have "previous" that identifies the previous element ("doubly-linked" lists)
- What methods does Node class need?

SinglyLinkedLists

- Terminology alert!
  - SinglyLinkedListNode = SLLN in these notes
  - SLLN = Node in structure5 (and in Ch 9)
  - Let's look at SLLN.java
  - How about SinglyLinkedList?
  - SinglyLinkedList = SLL in my notes



- What would addFirst(E d) look like?
- getFirst()?
- addLast(E d)? (more interesting)
- getLast()?

More SLL Methods

- How would we implement:
  - get(int index), set(E d, int index)
  - add(E d, int index), remove(int index)
- Left as an exercise:
  - contains(E d)
  - clear()
- Note: E is value type

Get and Set

```
public E get(int index) {
   Assert.pre(index < size() - 1, "Index out of range");
   // or should we return null in above case?
   SLLN finger = head;
   for (int i=0; i<index; i++){
        finger = finger.next();
   }
   return finger.value();
}

public E set(E d, int index) {
   Assert.pre(index < size() - 1, "Index out of range");
   // Same question!
   SLLN finger = head;
   for (int i=0; i<index; i++){
        finger = finger.next();
   }
   E old = finger.value();
   finger.setValue(d);
   return old;
}
```

Remove

```
public E remove(int index) {
   if(index >= size()) return null;

   E old;

   if (index == 0) return removeFirst();
   else if (index == size()-1) return removeLast();

   else {
        SLLN finger = head;
        for (int i=0; i<index - 1; i++) { //stop one before index
                finger = finger.next();
        }
        old = finger.next.value();
        finger.setNext(finger.next().next());
        count--;
        return old;
   }
}
```

Add

```
public void add(E d, int index) {
   if(index > size()) return null;
   E old;

   if (index==0) { addFirst(d); }

   else if (index==size()) { addLast(d); }

   else {
        SLLN finger = head;
        SLLN previous = null;
        for (int i=0; i<index; i++) {
            previous = finger;
            finger = finger.next();
        }
        SLLN elem = new SLLN(d, finger);
        previous.setNext(elem); // new “ith” item added after i-1
        count++;
   }
}
```

Linked Lists Summary

- Recursive data structures used for storing data
- More control over space use than Vectors
- Easy to add objects to front of list
- Components of SLL (SinglyLinkedList)
  - head, elementCount
- Components of SLLN (Node):
  - next, value

Vectors vs. SLL

- Compare performance of
  - size
  - addLast, removeLast, getLast
  - addFirst, removeFirst, getFirst
  - get(int index), set(E d, int index)
  - remove(int index)
  - contains(E d)
  - remove(E d)

SLL Summary

- SLLs provide methods for efficiently modifying front of list
  - Modifying tail/middle of list is not quite as efficient
- SLL runtimes are consistent
  - No hidden costs like Vector.ensureCapacity()
  - Avg and worst case are always the same
- Space usage
  - No empty slots like vectors
  - But keep extra reference for each value
    - overhead proportial to list length
      - (but this is constant and predictable)

Food for Thought: SLL Improvements to Tail Ops

- In addition to Node head and int elementCount, add Node tail reference to SLL
- Result
  - addLast and getLast are fast
  - removeLast is not improved
    - We need to know element before tail so we can reset tail pointer
- Side effects
  - We now have three cases to consider in method implementations: empty list, head == tail, head != tail
  - Think about addFirst(E d) and addLast(E d)

CircularlyLinkedLists

- Use *next* reference of last element to reference head of list
- Replace ***head*** reference with ***tail*** reference
- Access head of list via *tail.next*
- ALL operations on head are fast!
- addLast() is still fast
- Only modest additional complexity in implementation
- Can "cyclically reorder" list by changing *tail* node
- Question: What's a circularly linked list of size 1?

DoublyLinkedLists

- Keep reference/links in **both** directions
  - previous and next
- DoublyLinkedListNode instance variables
  - DLLN next, DLLN prev, E value
- Space overhead is proportional to number of elements
- ALL operations on tail (including removeLast) are fast!
- Additional work in each list operation
  - Example: add(E d, int index)
  - Four cases to consider now: empty list, add to front, add to tail, add in middle

```
public class DoublyLinkedNode<E>
{
        protected E data;
        protected DoublyLinkedNode<E> nextElement;
        protected DoublyLinkedNode<E> previousElement;

// Constructor inserts new node between existing nodes
public DoublyLinkedNode(E v,
                DoublyLinkedNode<E> next,
                DoublyLinkedNode<E> previous)
{
        data = v;
        nextElement = next;
        if (nextElement != null)  // point next back to me
                nextElement.previousElement = this;
        previousElement = previous;
        if (previousElement != null) // point previous to me
                previousElement.nextElement = this;
}
```

DoublyLinkedList Add Method

```
public void add(int i, E o) {
        Assert.pre((0 <= i) && (i <= size()),
                "Index in range.");
        if (i == 0) addFirst(o);
        else if (i == size()) addLast(o);
        else {
                // Find items before and after insert point
                DoublyLinkedNode<E> before = null;
                DoublyLinkedNode<E> after = head;
                // search for ith position
                while (i > 0) {
                   before = after;
                   after = after.next();
                   i--;
                }
        // before, after refer to items in slots i-1 and i
        // continued on next slide
```

DoublyLinkedList Add Method

```
            // Note: Still in "else" block!
            // before, after refer to items in slots i-1 and i

            // create new value to insert in correct position
            // Use DLN constructor that takes parameters
            // to set its next and previous instance variables
            DoublyLinkedNode<E> current =
                  new DoublyLinkedNode<E>(o,after,before);

            count++; // adjust size
      }
}
```

```
public E remove(E value) {
        DoublyLinkedNode<E> finger = head;
        while ( finger != null &&
                !finger.value().equals(value) )
                finger = finger.next();
        if (finger == null) return null;

        // fix next field of previous element
        if (finger.previous() != null)
                finger.previous().setNext(finger.next());
        else head = finger.next();

        // fix previous field of next element
        if (finger.next() != null)
                finger.next().setPrevious(finger.previous());
        else tail = finger.previous();
        count--;
        return finger.value();
}
```

Duane's Structure Hierarchy

The structure5 package has a hierarchical structure

- A collection of *interfaces* that describe---but do not implement---the functionality of one or more data structures
- A collection of *abstract classes* provide partial implementations of one or more data structures
  - To factor out common code or instance variables
- A collection of concrete (fully implemented) classes to provide full functionality of a data structure

AbstractList Superclass

```
abstract class AbstractList<E> implements List<E> {
    public void addFirst(E element) { add(0, element); }
    public E getLast() { return get(size()-1);}
    public E removeLast() { return remove(size()-1); }
}
```

- AbstractList provides *some* of the list functionality
  - Code is shared among all sub-classes (see Ch. 7 for more info)

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

  - Concrete classes (SLL, DLL) can override the code implemented in AbstractList
- Abstract classes in general do not implement every method
  - For example, size() is not defined although it is in the List interface
- Can't create an "AbstractList" directly
- Other lists extend AbstractList and implement missing functionality as needed

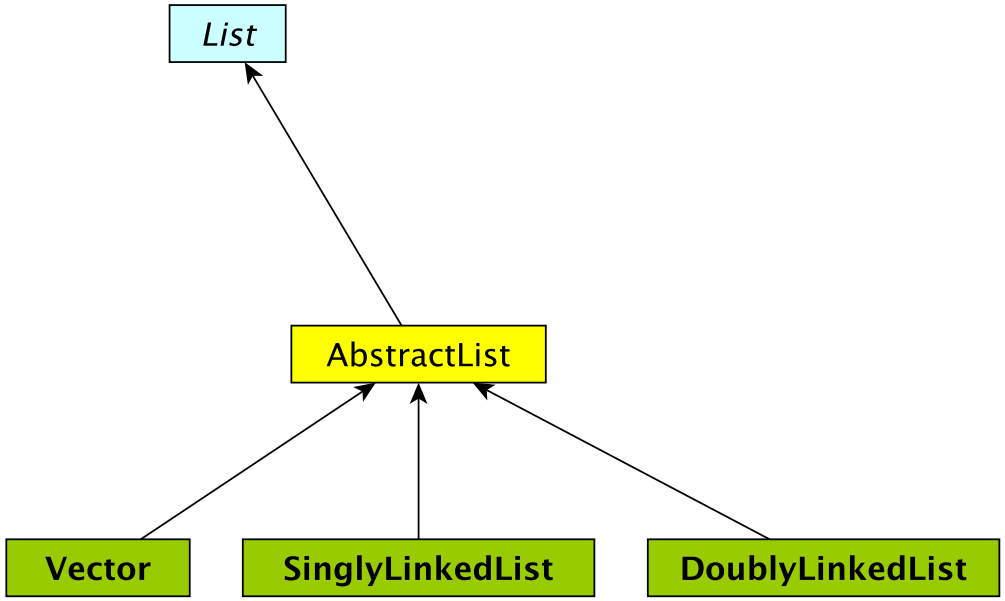
```
class Vector extends AbstractList {
    public int size() { return elementCount; }
}
```

The Structure5 Universe (almost)

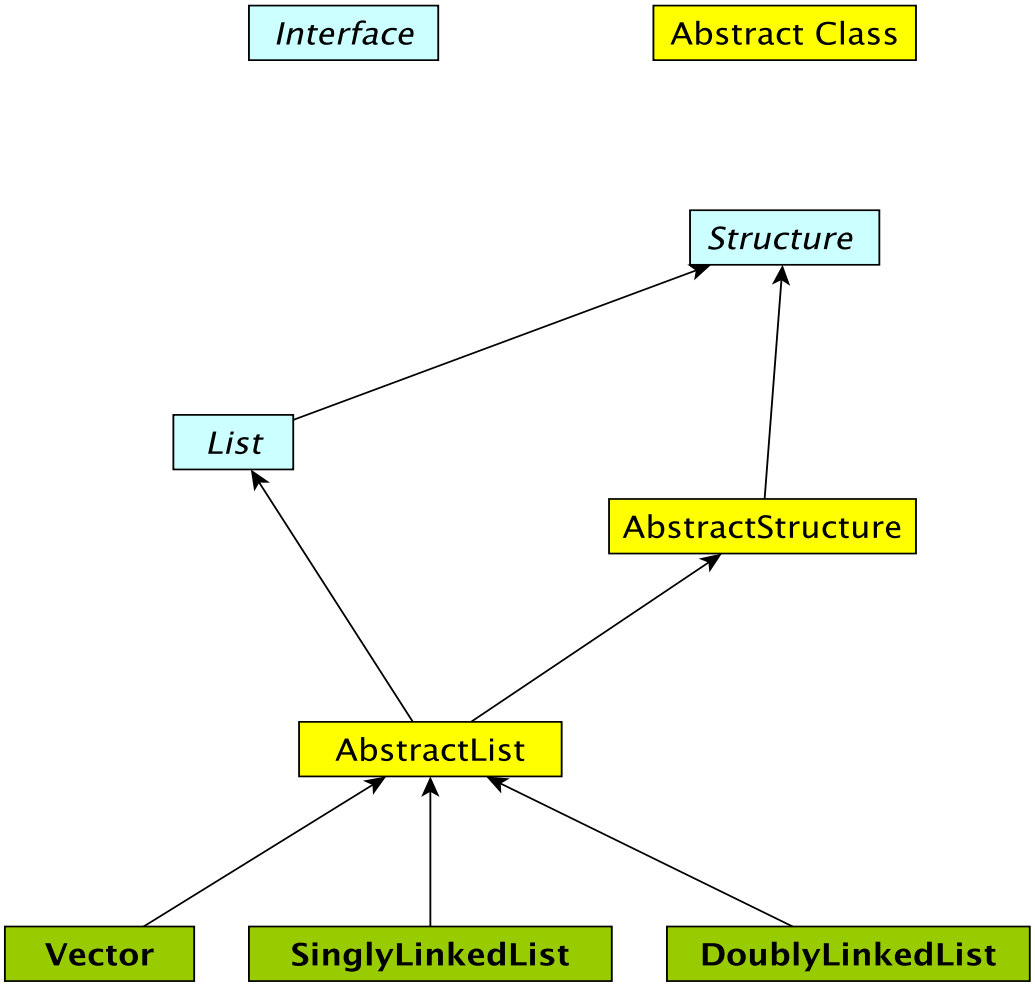
Interface

Abstract Class

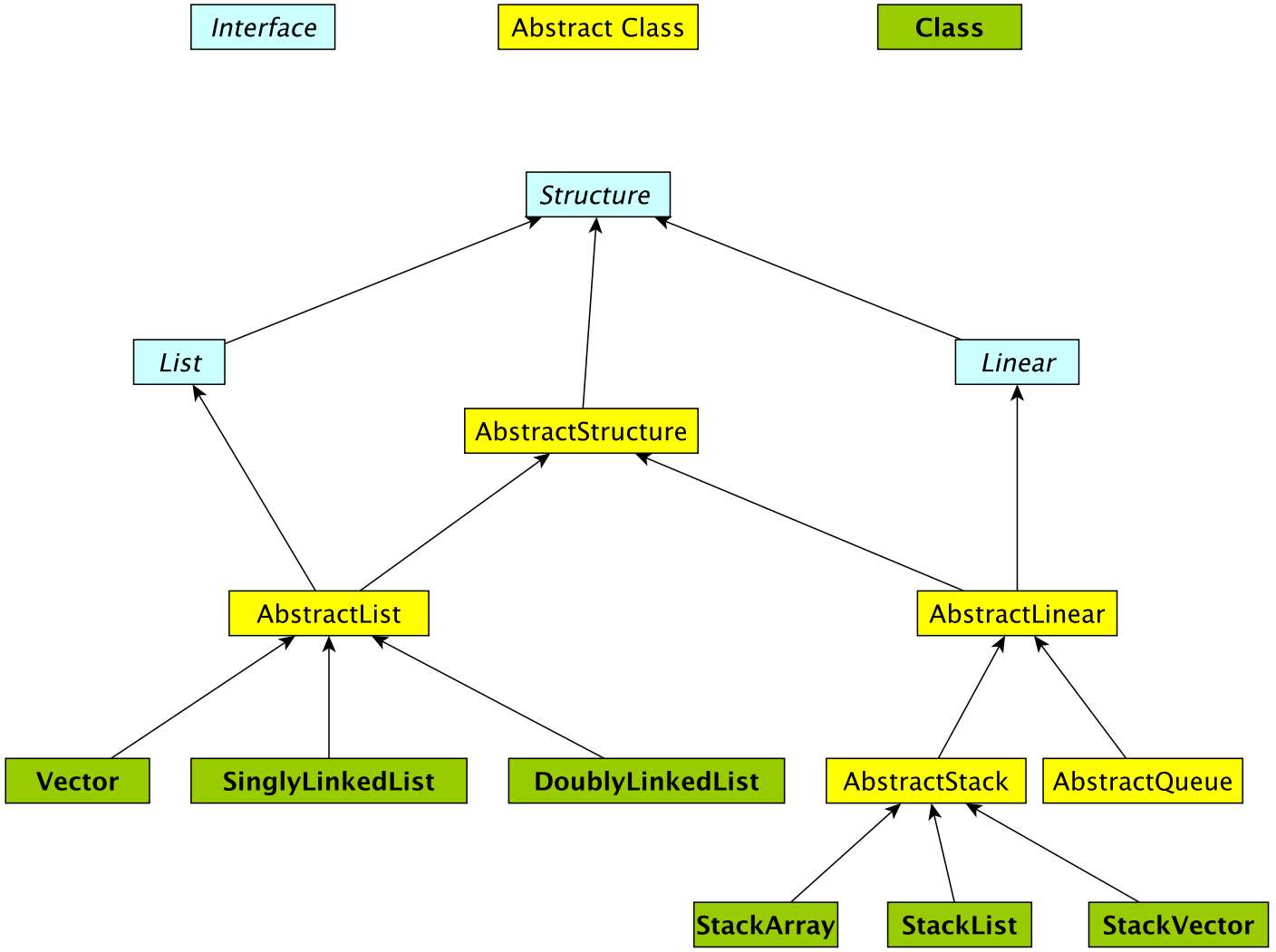
Class



The Structure5 Universe (so far)



The Structure5 Universe (soon)



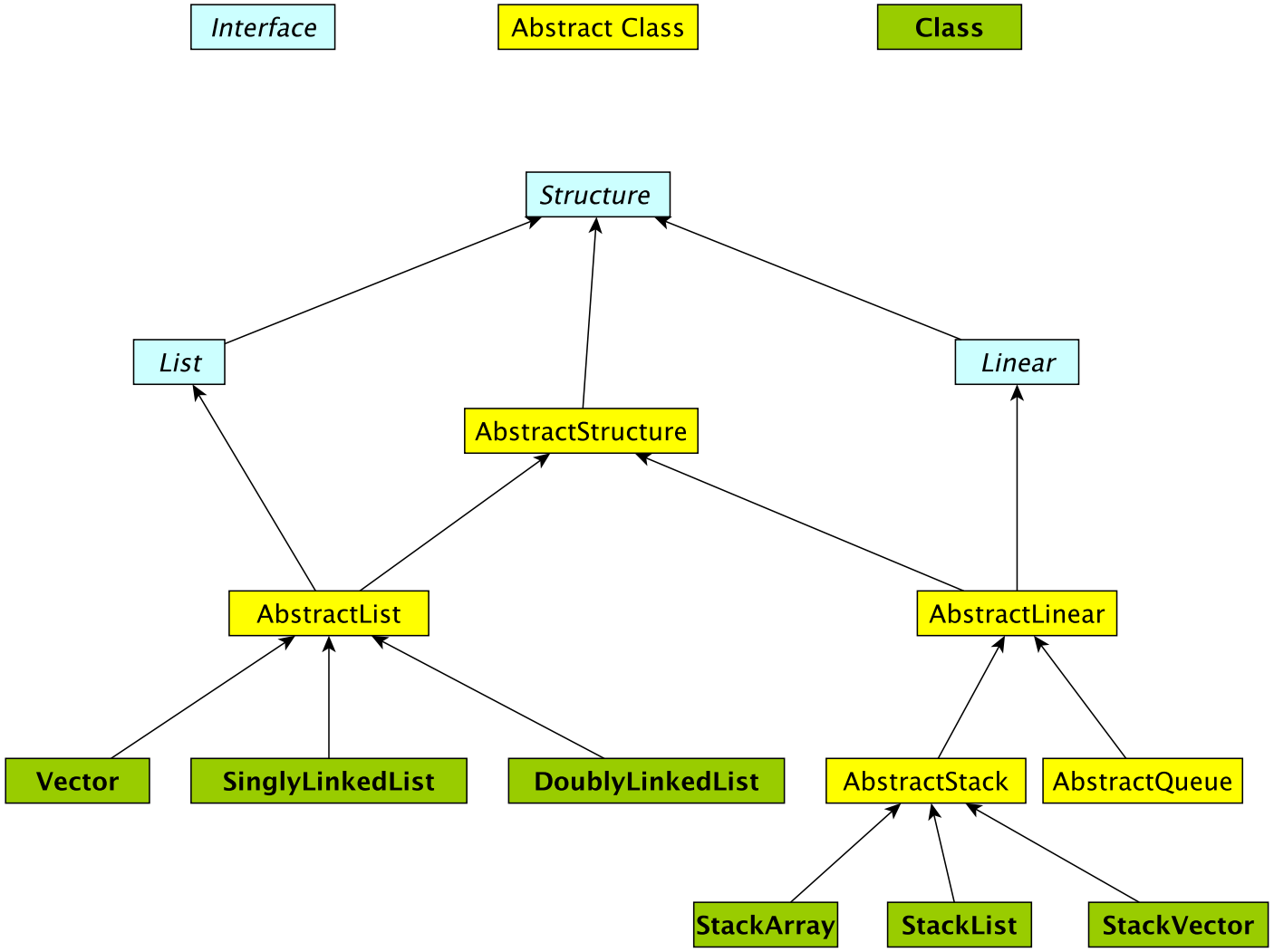
Linear Structures

- What if we want to impose *access restrictions* on our lists?
  - I.e., provide only one way to add and remove elements from list
  - No longer provide access to middle
- Key Examples: Order of removal depends on order elements were added
  - LIFO: Last In First Out
  - FIFO: First In First Out

Examples

- FIFO: First In – First Out (Queue)
  - Line at dining hall
  - Data packets arriving at a router
- LIFO: Last In – First Out (Stack)
  - Stack of trays at dining hall
  - Java Virtual Machine stack

The Structure5 Universe (next)



Linear Interface

- How should it differ from List interface?
  - Should have fewer methods than List interface since we are limiting access …
- Methods:
  - Inherits all of the Structure interface methods
    - add(E value) – Add a value to the structure.
    - E remove(E o) – Remove value o from the structure.
      - But this is awkward---why?
    - int size(), isEmpty(), clear(), contains(E value), …
  - Adds
    - E get() – Preview the next object to be removed.
    - E remove() – Remove the *next* value from the structure.
    - boolean empty() – same as isEmpty()

Linear Structures

- Why no "random access"?
  - I.e., no access to middle of list
- More restrictive than general List structures
  - Less functionality can result in
    - Simpler implementation
    - Greater efficiency
- Approaches
  - Use existing structures (Vector, LL), or
  - Use underlying organization, but simplified

Stacks

- Examples: stack of trays or cups
  - Can only take tray/cup from top of stack
- What methods do we need to define?
  - Stack interface methods
- New terms: push, pop, peek
  - Only use push, pop, peek when talking about stacks
  - Push = add to top of stack
  - Pop = remove from top of stack
  - Peek = look at top of stack (do not remove)

Notes about Terminology

- When using stacks:
  - pop = remove
  - push = add
  - peek = get
- In Stack interface, pop/push/peek methods call add/remove/get methods that are defined in Linear interface
- But "add" is not mentioned in Stack interface (it is inherited from Linear)
- Stack interface **extends** Linear interface
  - Interfaces *extend* other interfaces
  - Classes *implement* interfaces

Stack Implementations

- Array-based stack
  - int top, Object data[ ]
  - Add/remove from index top

  \+ all operations are O(1)

  – wasted/run out of space

- Vector-based stack
  - Vector data
  - Add/remove from tail

  +/– most ops are O(1) (add is O(n) in worst case)

  – potentially wasted space

- List-based stack
  - SLL data
  - Add/remove from *head*

  \+ all operations are O(1)

  +/– O(n) space overhead (no "wasted" space)

Stack Implementations

- structure5.StackArray
  - int top, Object data[ ]
  - Add/remove from index top

  \+ all operations are O(1)

  – wasted/run out of space

- structure5.StackVector
  - Vector data
  - Add/remove from tail

  +/– most ops are O(1) (add is O(n) in worst case)

  – potentially wasted space

- structure5.StackList
  - SLL data
  - Add/remove from head

  \+ all operations are O(1)

  +/– O(n) space overhead (no "wasted" space)

Summary Notes on The Hierarchy

- Linear interface *extends* Structure
  - add(E val), empty(), get(), remove(), size()
- AbstractLinear (partially) implements Linear
- AbstractStack class (partially) *extends* AbstractLinear
  - Essentially introduces "stack-ish" names for methods
  - push(E val) is add(E val), pop() is remove(), peek() is get()
- Now we can extend AbstractStack to make "concrete" Stack types
  - StackArray<E>: holds an array of type E; add/remove at high end
  - StackVector<E>: similar, but with a vector for dynamic growth
  - StackList<E>: A singly-linked list with add/remove at head
  - We implement add, empty, get, remove, size directly
    - push, pop, peek are then indirectly implemented

The Structure5 Universe (so far)