

## Administrative:

- Need alternative test time? Make sure you send me mail.
- Monday: TAs will conduct a review. There will also be a review session on Sunday (see Piazza).
- HKN will be holding a review session this weekend for the upcoming CS61B test. Place: HP Auditorium (306 Soda). Time: Saturday October 6, 4-6PM.
- OccupyWoz:

"Come to Wozniak Lounge anytime from 1000 Saturday (10/6) to 1300 Sunday (10/7) to camp out against stress and lack of food. For more than 30 hours, Woz will be the stress-free, food-ful haven you've always dreamed of, filled with acclaimed HKN tutors sporting pillows, study groups for all your EECS classes (CS61A, CS61B, and CS61C especially)."

## Topics

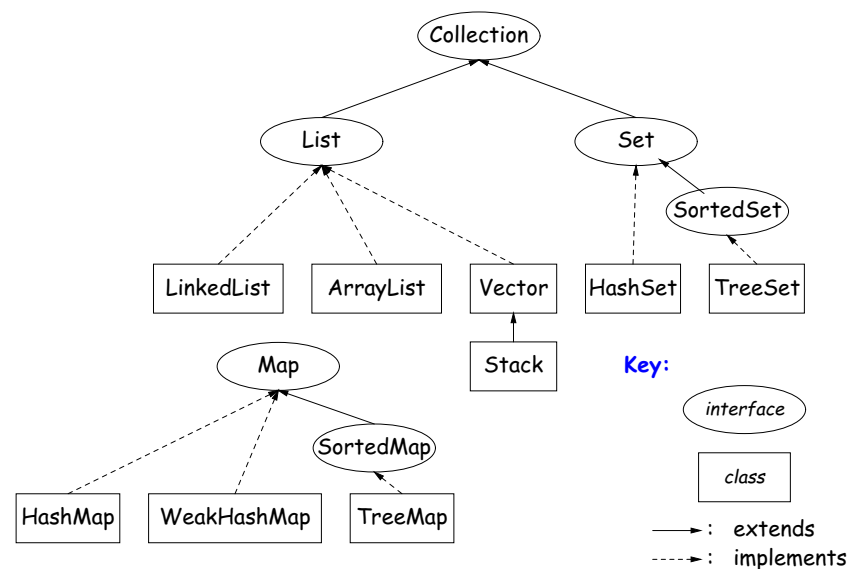
- Overview of standard Java Collections classes.
  - Iterators, ListIterators
  - Containers and maps in the abstract
  - Views
- Generic Implementation
- Array vs. linked: tradeoffs
- Sentinels
- Specialized sequences: stacks, queues, dequeues
- Circular buffering
- Recursion and stacks
- Adapters

**Readings:** *Data Structures*, Chapter 2, 3 (for today), and 4 (Friday).

## Data Types in the Abstract

- Most of the time, should *not* worry about implementation of data structures, search, etc.
- What they do for us—their specification—is important.
- Java has several standard types (in `java.util`) to represent collections of objects
  - Six interfaces:
    - \* Collection: General collections of items.
    - \* List: Indexed sequences with duplication
    - \* Set, SortedSet: Collections without duplication
    - \* Map, SortedMap: Dictionaries (key  $\mapsto$  value)
  - Concrete classes that provide actual instances: `LinkedList`, `ArrayList`, `HashSet`, `TreeSet`.
  - To make change easier, purists would use the concrete types only for **new**, interfaces for parameter types, local variables.

## Collection Structures in java.util



## The Collection Interface

- Collection interface. Main functions promised:
  - Membership tests: contains ( $\in$ ), containsAll ( $\subseteq$ )
  - Other queries: size, isEmpty
  - Retrieval: iterator, toArray
  - *Optional* modifiers: add, addAll, clear, remove, removeAll (set difference), retainAll (intersect)

- Design point (a side trip): Optional operations may throw

UnsupportedOperationException

- An alternative design would have separate interfaces:

```
interface Collection { contains, containsAll, size, iterator, ... }
interface Expandable { add, addAll }
interface Shrinkable { remove, removeAll, difference, ... }
interface ModifiableCollection
    extends Collection, Expandable, Shrinkable { }
...
```

You'd soon have lots of interfaces. Perhaps that's why they didn't do it that way.)

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## The List Interface

- Extends Collection
- Intended to represent *indexed sequences* (generalized arrays)
- Adds new methods to those of Collection:
  - Membership tests: indexOf, lastIndexOf.
  - Retrieval: get(*i*), listIterator(), sublist(*B*, *E*).
  - Modifiers: add and addAll with additional index to say *where* to add. Likewise for removal operations. set operation to go with get.
- Type ListIterator<Item> extends Iterator<Item>:
  - Adds previous and hasPrevious.
  - add, remove, and set allow one to iterate through a list, inserting, removing, or changing as you go.
  - **Important Question:** What advantage is there to saying List *L* rather than LinkedList *L* or ArrayList *L*?

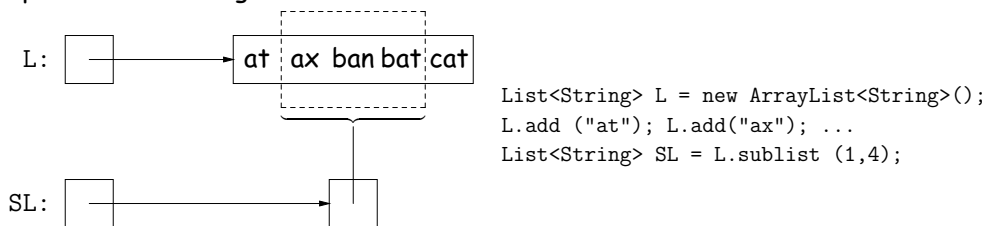
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## Views

**New Concept:** A *view* is an alternative presentation of (interface to) an existing object.

- For example, the sublist method is supposed to yield a "view of" part of an existing list:



- Example: after *L.set*(2, "bag"), value of *SL.get*(1) is "bag", and after *SL.set*(1, "bad"), value of *L.get*(2) is "bad".
- Example: after *SL.clear*(), *L* will contain only "at" and "cat".
- Small challenge: "How do they do that?!"

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## Maps

- A Map is a kind of "modifiable function:"

```
package java.util;
public interface Map<Key,Value> {
    Value get (Object key);           // Value at KEY.
    Object put (Key key, Value value); // Set get(KEY) -> VALUE
    ...
}

-----
Map<String,String> f = new TreeMap<String,String> ();
f.put ("Paul", "George"); f.put ("George", "Martin");
f.put ("Dana", "John");
// Now f.get ("Paul").equals ("George")
//      f.get ("Dana").equals ("John")
//      f.get ("Tom") == null
```

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## Map Views

```
public interface Map<Key,Value> { // Continuation
    /* VIEWS */
    /** The set of all keys. */
    Set<Key> keySet ();
    /** The multiset of all values */
    Collection<Value> values ();
    /** The set of all (key, value) pairs */
    Set<Map.Entry<Key,Value>> entrySet ();
}
```

Using example from previous slide:

```
for (Iterator<String> i = f.keySet ().iterator (); i.hasNext ();)
    i.next () ==> Dana, George, Paul
// or, just:
for (String name : f.keySet ())
    name ==> Dana, George, Paul

for (String parent : f.values ())
    parent ==> John, Martin, George
for (Map.Entry<String,String> pair : f.entrySet ())
    pair ==> (Dana,John), (George,Martin), (Paul,George)
f.keySet ().remove ("Dana"); // Now f.get("Dana") == null
```

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## Simple Banking I: Accounts

**Problem:** Want a simple banking system. Can look up accounts by name or number, deposit or withdraw, print.

### Account Structure

```
class Account {
    Account (String name, String number, int init) {
        this.name = name; this.number = number;
        this.balance = init;
    }
    /** Account-holder's name */
    final String name;
    /** Account number */
    final String number;
    /** Current balance */
    int balance;

    /** Print THIS on STR in some useful format. */
    void print (PrintWriter str) { ... }
}
```

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## Simple Banking II: Banks

```
class Bank {
    /* These variables maintain mappings of String -> Account. They keep
    * the set of keys (Strings) in "compareTo" order, and the set of
    * values (Accounts) is ordered according to the corresponding keys. */
    SortedMap<String,Account> accounts = new TreeMap<String,Account> ();
    SortedMap<String,Account> names = new TreeMap<String,Account> ();

    void openAccount (String name, int initBalance) {
        Account acc =
            new Account (name, chooseNumber (), initBalance);
        accounts.put (acc.number, acc);
        names.put (name, acc);
    }

    void deposit (String number, int amount) {
        Account acc = accounts.get (number);
        if (acc == null) ERROR(...);
        acc.balance += amount;
    }
    // Likewise for withdraw.
```

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## Banks (continued): Iterating

### Printing out Account Data

```
/** Print out all accounts sorted by number on STR. */
void printByAccount (PrintStream str) {
    // accounts.values () is the set of mapped-to values. Its
    // iterator produces elements in order of the corresponding keys.
    for (Account account : accounts.values ())
        account.print (str);
}

/** Print out all bank accounts sorted by name on STR. */
void printByName (PrintStream str) {
    for (Account account : names.values ())
        account.print (str);
}
```

**A Design Question:** What would be an appropriate representation for keeping a record of all transactions (deposits and withdrawals) against each account?

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## Partial Implementations

- Besides interfaces (like `List`) and concrete types (like `LinkedList`), Java library provides abstract classes such as `AbstractList`.
- Idea is to take advantage of the fact that operations are related to each other.
- Example: once you know how to do `get(k)` and `size()` for an implementation of `List`, you can implement all the other methods needed for a *read-only* list (and its iterators).
- Now throw in `add(k,x)` and you have all you need for the additional operations of a growable list.
- Add `set(k,x)` and `remove(k)` and you can implement everything else.

## Example: The `java.util.AbstractList` helper class

```
public abstract class AbstractList<Item> implements List<Item> {
    /** Inherited from List */
    // public abstract int size ();
    // public abstract Item get (int k);
    public boolean contains (Object x) {
        for (int i = 0; i < size (); i += 1) {
            if ((x == null && get (i) == null) ||
                (x != null && x.equals (get (i))))
                return true;
        }
        return false;
    }
    /* OPTIONAL: By default, throw exception; override to do more. */
    void add (int k, Item x) {
        throw new UnsupportedOperationException ();
    }
    Likewise for remove, set
}
```

## Example, continued: `AListIterator`

```
// Continuing abstract class AbstractList<Item>:
public Iterator<Item> iterator () { return listIterator (); }
public ListIterator<Item> listIterator () { return new AListIterator (this); }

private static class AListIterator implements ListIterator<Item> {
    AbstractList<Item> myList;
    AListIterator (AbstractList<Item> L) { myList = L; }
    /** Current position in our list. */
    int where = 0;

    public boolean hasNext () { return where < myList.size (); }
    public Item next () { where += 1; return myList.get (where-1); }
    public void add (Item x) { myList.add (where, x); where += 1; }
    ... previous, remove, set, etc.
}
...
```

## Example: Using `AbstractList`

**Problem:** Want to create a *reversed view* of an existing `List` (same elements in reverse order).

```
public class ReverseList<Item> extends AbstractList<Item> {
    private final List<Item> L;

    public ReverseList (List<Item> L) { this.L = L; }

    public int size () { return L.size (); }

    public Item get (int k) { return L.get (L.size ()-k-1); }

    public void add (int k, Item x)
        { L.add (L.size ()-k, x); }

    public Item set (int k, Item x)
        { return L.set (L.size ()-k-1, x); }

    public Item remove (int k)
        { return L.remove (L.size () - k - 1); }
}
```

## Aside: Another way to do AListIterator

It's also possible to make the nested class non-static:

```
public Iterator<Item> iterator () { return listIterator (); }
public ListIterator<Item> listIterator () { return this.new AListIterator (); }

private class AListIterator implements ListIterator<Item> {
    /** Current position in our list. */
    int where = 0;

    public boolean hasNext () { return where < AbstractList.this.size (); }
    public Item next () { where += 1; return AbstractList.this.get (where-1); }
    public void add (Item x) { AbstractList.this.add (where, x); where += 1; }
    ... previous, remove, set, etc.
}
...
```

- Here, `AbstractList.this` means "the `AbstractList` I am attached to" and `X.new AListIterator` means "create a new `AListIterator` that is attached to `X`."
- In this case you can abbreviate `this.new` as `new` and can leave off the `AbstractList.this` parts, since meaning is unambiguous.

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## Getting a View: Sublists

**Problem:** `L.sublist(start, end)` is a full-blown `List` that gives a view of part of an existing list. Changes in one must affect the other. **How?** Here's part of `AbstractList`:

```
List<Item> sublist (int start, int end) {
    return new this.Sublist (start, end);
}

private class Sublist extends AbstractList<Item> {
    // NOTE: Error checks not shown
    private int start, end;
    Sublist (int start, int end) { obvious }

    public int size () { return end-start; }

    public Item get (int k)
    { return AbstractList.this.get (start+k); }

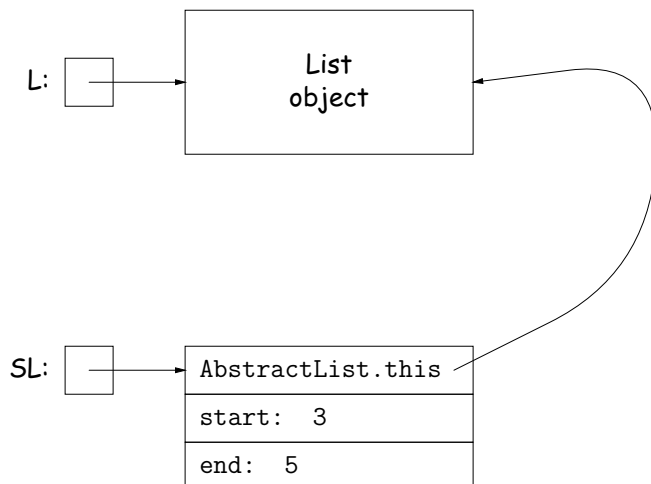
    public void add (int k, Item x) {
        { AbstractList.this.add (start+k, x); end += 1; }
        ...
    }
}
```

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## What Does a Sublist Look Like?

- Consider `SL = L.sublist (3, 5);`



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## Arrays and Links

- Two main ways to represent a sequence: array and linked list
- In Java Library: `ArrayList` and `Vector` vs. `LinkedList`.
- Array:
  - Advantages: compact, fast ( $\Theta(1)$ ) random access (indexing).
  - Disadvantages: insertion, deletion can be slow ( $\Theta(N)$ )
- Linked list:
  - Advantages: insertion, deletion fast once position found.
  - Disadvantages: space (link overhead), random access slow.

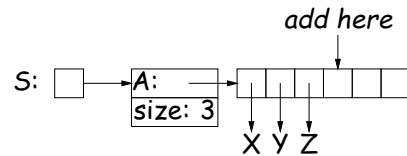
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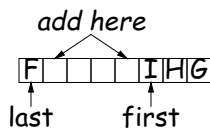
## Implementing with Arrays

- Biggest problem using arrays is insertion/deletion in the *middle* of a list (must shove things over).
- Adding/deleting from ends can be made fast:
  - Double array size to grow; amortized cost constant (Lecture #15).
  - Growth at one end really easy; classical stack implementation:

```
S.push ("X");
S.push ("Y");
S.push ("Z");
```



- To allow growth at either end, use *circular buffering*:



- Random access still fast.

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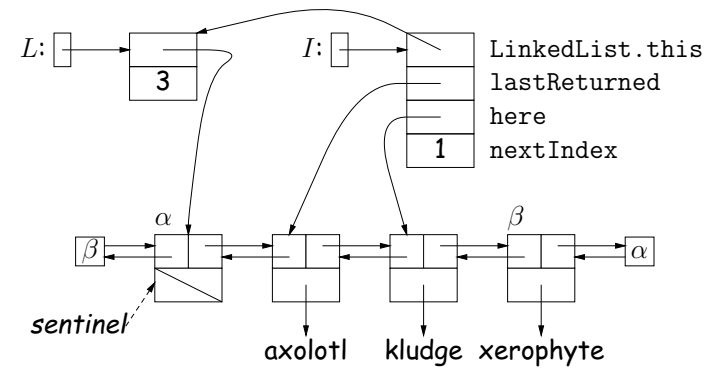
```
I.next();
```

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## Linking

- Essentials of linking should now be familiar
- Used in Java `LinkedList`. One possible representation for linked list and an iterator object over it:



```
L = new LinkedList<String>();
L.add("axolotl");
L.add("kludge");
L.add("xerophyte");
I = L.listIterator();
```

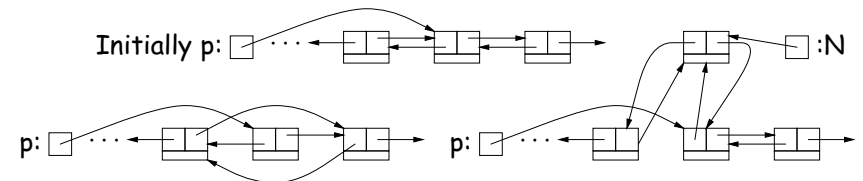
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## Clever trick: Sentinels

- A *sentinel* is a dummy object containing no useful data except links.
  - Used to eliminate special cases and to provide a fixed object to point to in order to access a data structure.
  - Avoids special cases ('if' statements) by ensuring that the first and last item of a list always have (non-null) nodes—possibly sentinels—before and after them:
- ```
// To delete list node at p:
p.next.prev = p.prev;
p.prev.next = p.next;

// To add new node N before p:
N.prev = p.prev; N.next = p;
p.prev.next = N;
p.prev = N;
```



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## Specialization

- Traditional special cases of general list:
  - **Stack:** Add and delete from one end (LIFO).
  - **Queue:** Add at end, delete from front (FIFO).
  - **Dequeue:** Add or delete at either end.
- All of these easily representable by either array (with circular buffering for queue or deque) or linked list.
- Java has the List types, which can act like any of these (although with non-traditional names for some of the operations).
- Also has `java.util.Stack`, a subtype of List, which gives traditional names ("push", "pop") to its operations. There is, however, no "stack" interface.

## Stacks and Recursion

- Stacks related to *recursion*. In fact, can convert any recursive algorithm to stack-based (however, generally no great performance benefit):
  - Calls become "push current variables and parameters, set parameters to new values, and loop."
  - Return becomes "pop to restore variables and parameters."

```
findExit(start):  
  if isExit(start)  
    FOUND  
  else if (! isCrumb(start))  
    leave crumb at start;  
    for each square, x,  
      adjacent to start:  
        if legalPlace(x)  
          findExit(x)
```

Call: findExit(0)  
Exit: 16

|    |    |   |    |    |
|----|----|---|----|----|
| 12 | 11 | 8 | 9  | 10 |
| 13 | 4  | 7 | 15 | 16 |
| 14 | 3  | 6 |    |    |
| 1  | 2  | 5 |    |    |

```
findExit(start):  
  S = new empty stack;  
  push start on S;  
  while S not empty:  
    pop S into start;  
    if isExit(start)  
      FOUND  
    else if (! isCrumb(start))  
      leave crumb at start;  
      for each square, x,  
        adjacent to start (in reverse):  
          if legalPlace(x)  
            push x on S
```

## Design Choices: Extension, Delegation, Adaptation

- The standard `java.util.Stack` type *extends* Vector:  

```
class Stack<Item> extends Vector<Item> { void push (Item x) { add (x); } ... }
```
- Could instead have *delegated* to a field:  

```
class ArrayStack<Item> {  
  private ArrayList<Item> repl = new ArrayList<Item> ();  
  void push (Item x) { repl.add (x); } ...  
}
```
- Or, could generalize, and define an *adapter*: a class used to make objects of one kind behave as another:

```
public class StackAdapter<Item> {  
  private List repl;  
  /** A stack that uses REPL for its storage. */  
  public StackAdapter (List<Item> repl) { this.repl = repl; }  
  public void push (Item x) { repl.add (x); } ...  
}
```

```
class ArrayStack<Item> extends StackAdapter<Item> {  
  ArrayStack () { super (new ArrayList<Item> ()); }  
}
```