

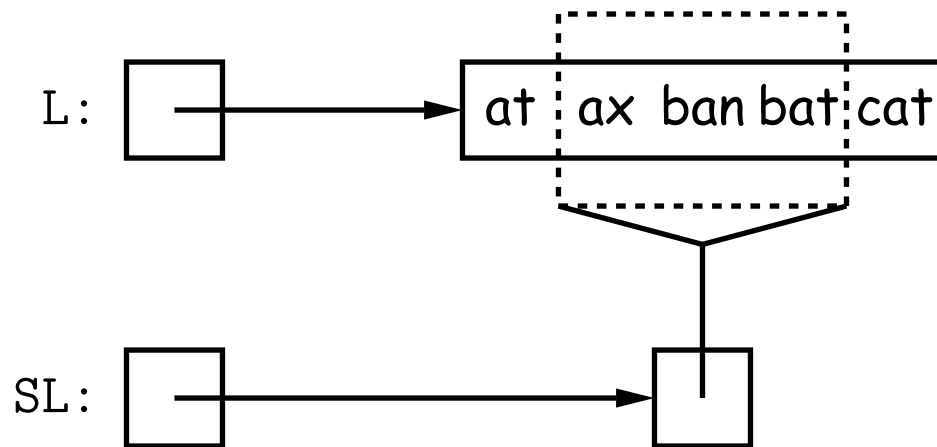
CS61B Lecture #18: Assorted Topics

- Views
- Maps
- More partial implementations
- Array vs. linked: tradeoffs
- Sentinels
- Specialized sequences: stacks, queues, dequeues
- Circular buffering
- Recursion and stacks
- Adapters

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:



```
List<String> L = new ArrayList<String>();  
L.add("at"); L.add("ax"); ...  
List<String> SL = L.sublist(1,4);
```

- 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?!"

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
```

Map Views

```
public interface Map<Key,Value> { // Continuation

    /* Views of Maps */

    /** The set of all keys. */
    Set<Key> keySet();

    /** The multiset of all values that can be returned by get.
     * (A multiset is a collection that may have duplicates). */
    Collection<Value> values();

    /** The set of all(key, value) pairs */
    Set<Map.Entry<Key,Value>> entrySet();
}
```

View Examples

Using example from a previous slide:

```
Map<String,String> f = new TreeMap<String,String>();  
f.put("Paul", "George"); f.put("George", "Martin");  
f.put("Dana", "John");
```

we can take various views of f:

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

// or, more succinctly:

```
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
```

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(PrintStream str) { ... }
}
```

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.
}
```

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?

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: Throws 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.
}
...
```

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 some `AbstractList.this` parts, since meaning is unambiguous.

Example: Using AbstractList

Problem: Want to create a *reversed view* of an existing List (same elements in reverse order). Operations on the original list affect the view, and vice-versa.

```
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); }  
}
```

Getting a View: Sublists

Problem: `L sublist(start, end)` is a `List` that gives a view of part of an existing list. Changes in one must affect the other. How?

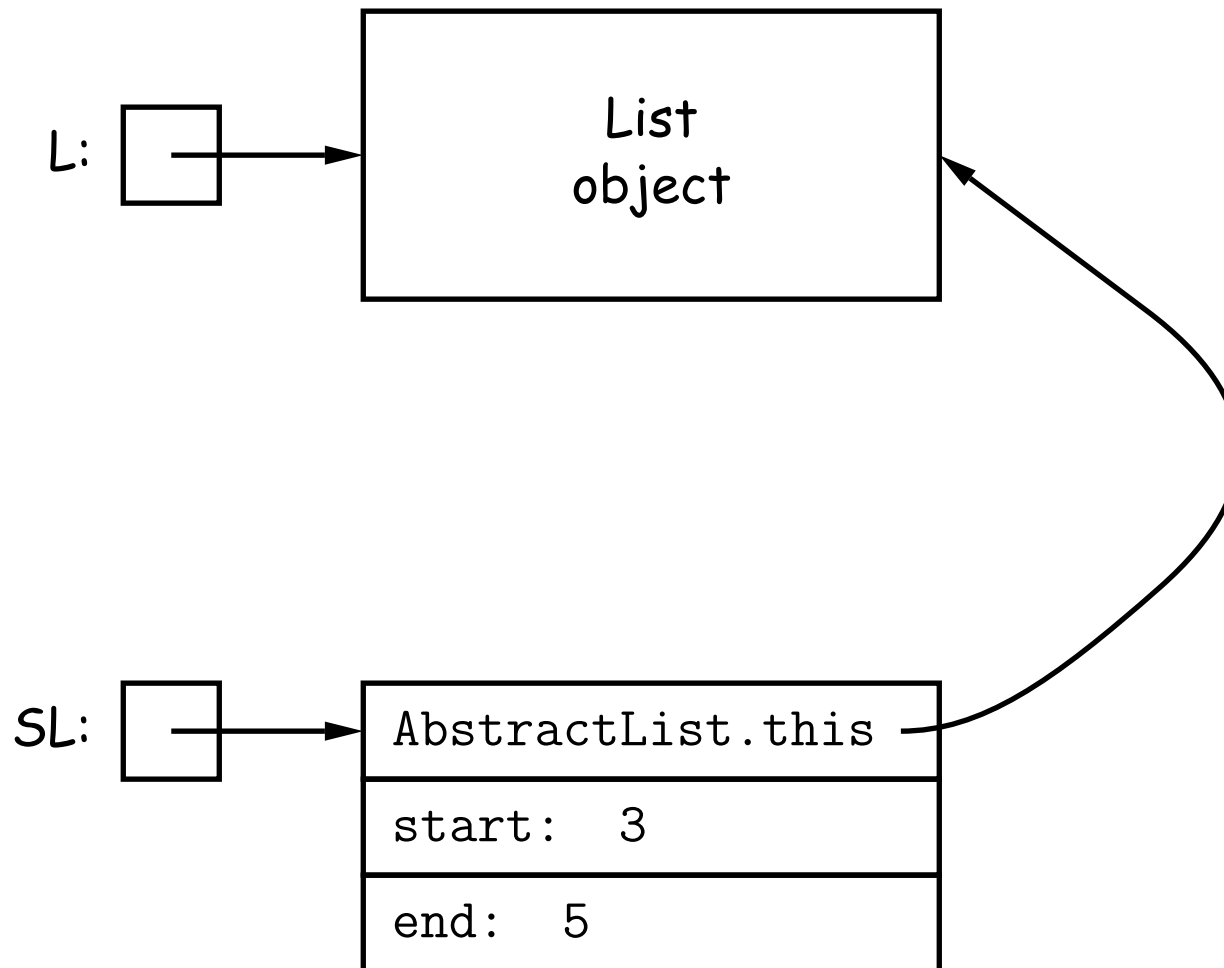
// Continuation of class AbstractList. Error checks not shown.

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

```
private class Sublist extends AbstractList<Item> {  
    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; }  
    ...  
}
```

What Does a Sublist Look Like?

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



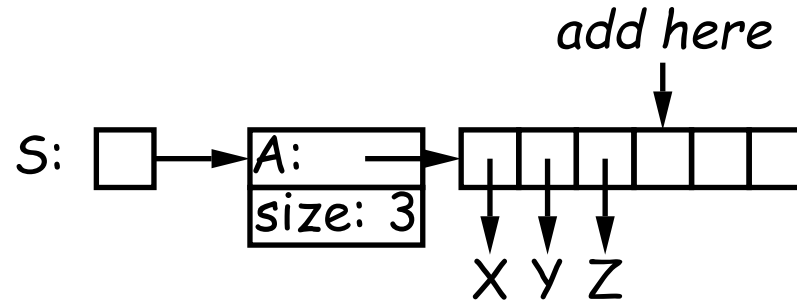
Arrays and Links

- 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.

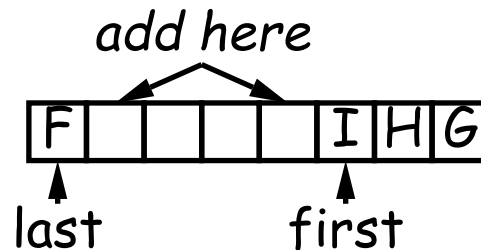
Implementing with Arrays

- 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");
```



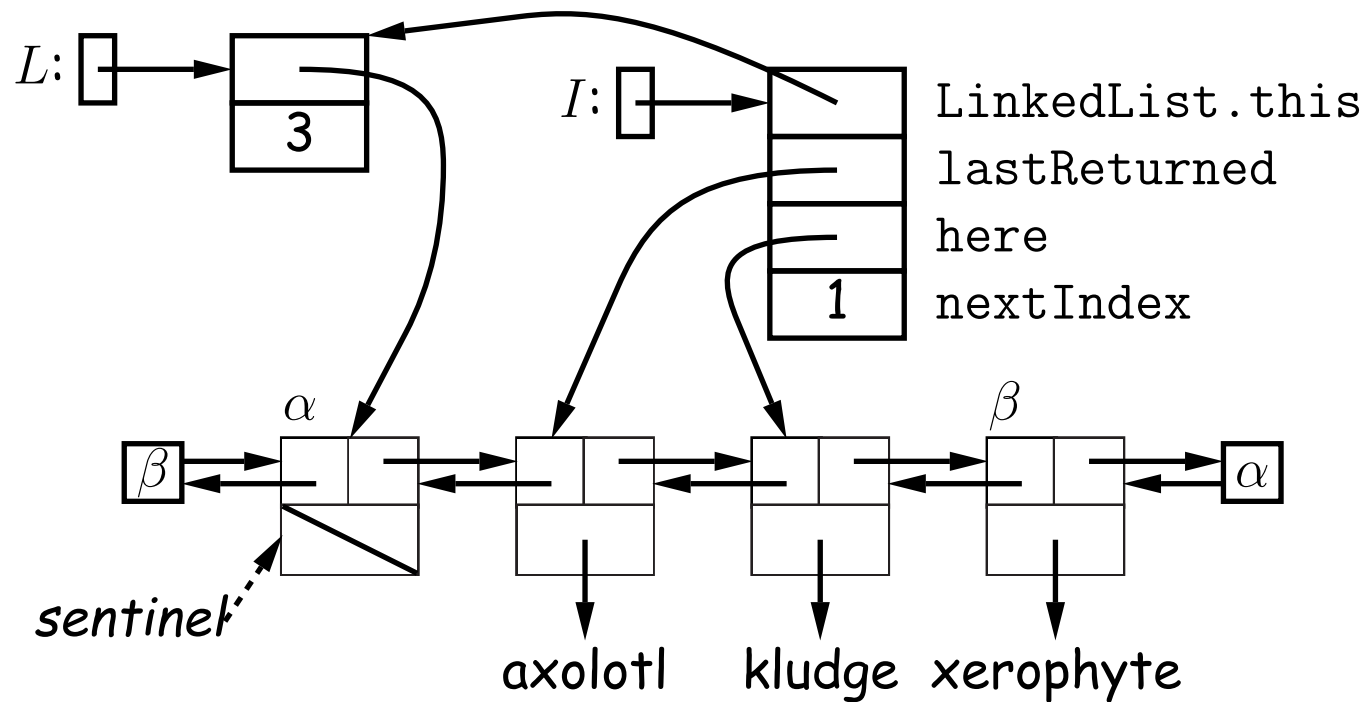
- To allow growth at either end, use *circular buffering*:



- Random access still fast.

Linking

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



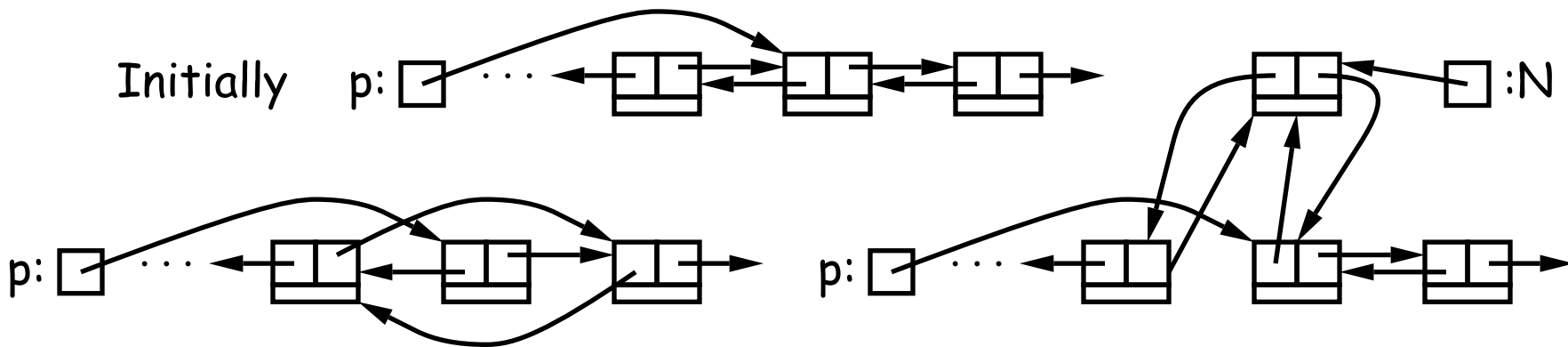
```
L = new LinkedList<String>();  
L.add("axolotl");  
L.add("kludge");  
L.add("xerophyte");
```

```
I = L.listIterator();  
I.next();
```

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;`



Specialization

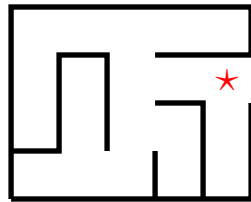
- Traditional special cases of general list:
 - **Stack**: Add and delete from one end (LIFO).
 - **Queue**: Add at end, delete from front (FIFO).
 - **Deque**: Add or delete at either end.
- All of these easily representable by either array (with circular buffering for queue or deque) or linked list.
- 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 are related to recursion. In fact, can convert any recursive algorithm to stack-based (however, generally with 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 legal(start,x) && !isCrumb(x)  
            findExit(x)
```

Call: findExit((0,0))
Exit: (4, 2)



0,0
///

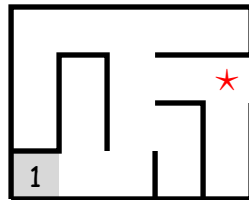
```
findExit(start):  
    S = new empty stack;  
    push start on S;  
    while S not empty:  
        pop S into start;  
        if isExit(start)  
            FOUND  
        else if (!isCrumb(start))  
            leave crumb at start;  
        for each square, x,  
            adjacent to start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

Stacks and Recursion

- Stacks are related to recursion. In fact, can convert any recursive algorithm to stack-based (however, generally with 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 legal(start,x) && !isCrumb(x)  
            findExit(x)
```

Call: findExit((0,0))
Exit: (4, 2)



1, 0
///

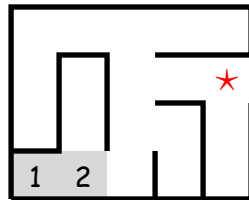
```
findExit(start):  
    S = new empty stack;  
    push start on S;  
    while S not empty:  
        pop S into start;  
        if isExit(start)  
            FOUND  
        else if (!isCrumb(start))  
            leave crumb at start;  
        for each square, x,  
            adjacent to start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

Stacks and Recursion

- Stacks are related to recursion. In fact, can convert any recursive algorithm to stack-based (however, generally with 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 legal(start,x) && !isCrumb(x)  
            findExit(x)
```

Call: findExit((0,0))
Exit: (4, 2)



1, 1
2, 0
///

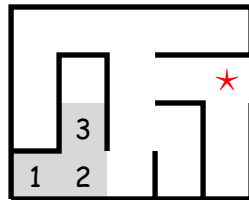
```
findExit(start):  
    S = new empty stack;  
    push start on S;  
    while S not empty:  
        pop S into start;  
        if isExit(start)  
            FOUND  
        else if (!isCrumb(start))  
            leave crumb at start;  
        for each square, x,  
            adjacent to start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

Stacks and Recursion

- Stacks are related to recursion. In fact, can convert any recursive algorithm to stack-based (however, generally with 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 legal(start,x) && !isCrumb(x)
                findExit(x)
```

Call: findExit((0,0))
Exit: (4, 2)



1, 2
2, 0
///

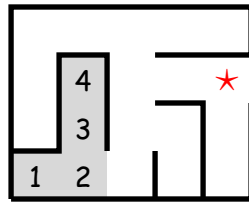
```
findExit(start):
    S = new empty stack;
    push start on S;
    while S not empty:
        pop S into start;
        if isExit(start)
            FOUND
        else if (!isCrumb(start))
            leave crumb at start;
        for each square, x,
            adjacent to start (in reverse):
 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


Stacks and Recursion

- Stacks are related to recursion. In fact, can convert any recursive algorithm to stack-based (however, generally with 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 legal(start,x) && !isCrumb(x)  
            findExit(x)
```

Call: findExit((0,0))
Exit: (4, 2)



2, 0
///

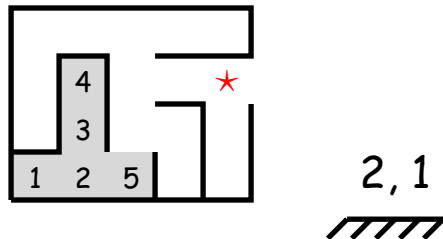
```
findExit(start):  
    S = new empty stack;  
    push start on S;  
    while S not empty:  
        pop S into start;  
        if isExit(start)  
            FOUND  
        else if (!isCrumb(start))  
            leave crumb at start;  
        for each square, x,  
            adjacent to start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

Stacks and Recursion

- Stacks are related to recursion. In fact, can convert any recursive algorithm to stack-based (however, generally with 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 legal(start,x) && !isCrumb(x)  
            findExit(x)
```

Call: findExit((0,0))
Exit: (4, 2)



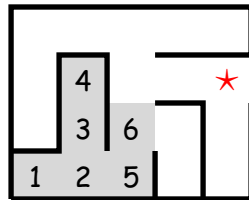
```
findExit(start):  
    S = new empty stack;  
    push start on S;  
    while S not empty:  
        pop S into start;  
        if isExit(start)  
            FOUND  
        else if (!isCrumb(start))  
            leave crumb at start;  
        for each square, x,  
            adjacent to start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

Stacks and Recursion

- Stacks are related to recursion. In fact, can convert any recursive algorithm to stack-based (however, generally with 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 legal(start,x) && !isCrumb(x)  
            findExit(x)
```

Call: findExit((0,0))
Exit: (4, 2)



2, 2
3, 1
///

```
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 legal(start,x) && !isCrumb(x)  
                    push x on S
```

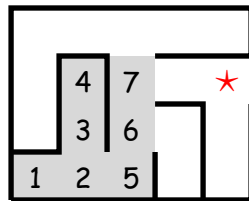
Stacks and Recursion

- Stacks are related to recursion. In fact, can convert any recursive algorithm to stack-based (however, generally with 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 legal(start,x) && !isCrumb(x)
                findExit(x)
```

Call: findExit((0,0))

Exit: (4, 2)



2, 3
3, 2
3, 1



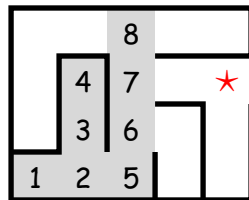
```
findExit(start):
    S = new empty stack;
    push start on S;
    while S not empty:
        pop S into start;
        if isExit(start)
            FOUND
        else if (!isCrumb(start))
            leave crumb at start;
        for each square, x,
            adjacent to start (in reverse):
 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

Stacks and Recursion

- Stacks are related to recursion. In fact, can convert any recursive algorithm to stack-based (however, generally with 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 legal(start,x) && !isCrumb(x)
                    findExit(x)
```

Call: findExit((0,0))
Exit: (4, 2)



```
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 legal(start,x) && !isCrumb(x)
                        push x on S
```

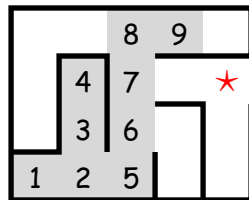
Stacks and Recursion

- Stacks are related to recursion. In fact, can convert any recursive algorithm to stack-based (however, generally with 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 legal(start,x) && !isCrumb(x)
                findExit(x)
```

Call: findExit((0,0))

Exit: (4, 2)



4, 3
1, 3
3, 2
3, 1



```
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 legal(start,x) && !isCrumb(x)
                    push x on S
```

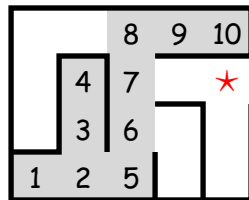
Stacks and Recursion

- Stacks are related to recursion. In fact, can convert any recursive algorithm to stack-based (however, generally with 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 legal(start,x) && !isCrumb(x)
                findExit(x)
```

Call: findExit((0,0))

Exit: (4, 2)



1, 3
3, 2
3, 1



```
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 legal(start,x) && !isCrumb(x)
                    push x on S
```

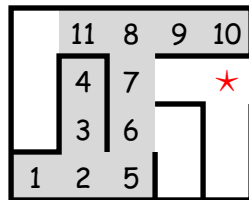
Stacks and Recursion

- Stacks are related to recursion. In fact, can convert any recursive algorithm to stack-based (however, generally with 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 legal(start,x) && !isCrumb(x)
                findExit(x)
```

Call: findExit((0,0))

Exit: (4, 2)



0, 3
3, 2
3, 1



```
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 legal(start,x) && !isCrumb(x)
                    push x on S
```

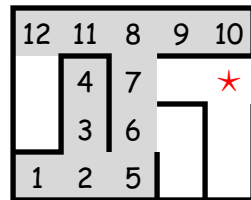

Stacks and Recursion

- Stacks are related to recursion. In fact, can convert any recursive algorithm to stack-based (however, generally with 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 legal(start,x) && !isCrumb(x)
                findExit(x)
```

Call: findExit((0,0))

Exit: (4, 2)



0, 2
3, 2
3, 1



```
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 legal(start,x) && !isCrumb(x)
                    push x on S
```

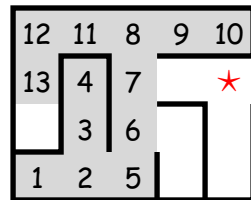
Stacks and Recursion

- Stacks are related to recursion. In fact, can convert any recursive algorithm to stack-based (however, generally with 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 legal(start,x) && !isCrumb(x)
                findExit(x)
```

Call: findExit((0,0))

Exit: (4, 2)



0, 1
3, 2
3, 1



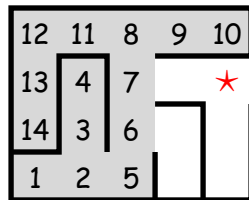
```
findExit(start):
    S = new empty stack;
    push start on S;
    while S not empty:
        pop S into start;
        if isExit(start)
            FOUND
        else if (!isCrumb(start))
            leave crumb at start;
        for each square, x,
            adjacent to start (in reverse):
 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

Stacks and Recursion

- Stacks are related to recursion. In fact, can convert any recursive algorithm to stack-based (however, generally with 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 legal(start,x) && !isCrumb(x)
                findExit(x)
```

Call: findExit((0,0))
Exit: (4, 2)



3, 2
3, 1
///

```
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 legal(start,x) && !isCrumb(x)
                    push x on S
```

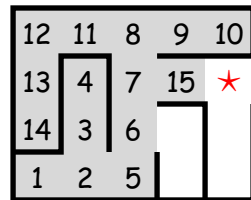
Stacks and Recursion

- Stacks are related to recursion. In fact, can convert any recursive algorithm to stack-based (however, generally with 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 legal(start,x) && !isCrumb(x)
                findExit(x)
```

Call: findExit((0,0))

Exit: (4, 2)



4, 2
3, 1
///

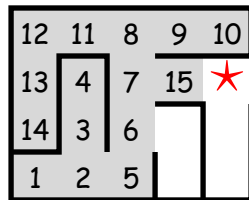
```
findExit(start):
    S = new empty stack;
    push start on S;
    while S not empty:
        pop S into start;
        if isExit(start)
            FOUND
        else if (!isCrumb(start))
            leave crumb at start;
        for each square, x,
            adjacent to start (in reverse):
 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

Stacks and Recursion

- Stacks are related to recursion. In fact, can convert any recursive algorithm to stack-based (however, generally with 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 legal(start,x) && !isCrumb(x)
                findExit(x)
```

Call: findExit((0,0))
Exit: (4, 2)



3, 1
///

```
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 legal(start,x) && !isCrumb(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>()); }  
}
```