CS61B Lecture #18

Announcements:

• Programming Contest Saturday! See
  
  http://inst.eecs.berkeley.edu/~ctest/contest/

  for details and registration.
Topics

- Views
- Generic Implementation
- Array vs. linked: tradeoffs
- Sentinels
- Specialized sequences: stacks, queues, deques
- 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:

```java
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:”

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

```java
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
```
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.
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

```java
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;
    }
    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.
}
...
Example: Using AbstractList

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

```java
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:

```java
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.
**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:

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

```java
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; }
    ...
}
```
What Does a Sublist Look Like?

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

```
L: List object

SL: AbstractList.this
    start: 3
    end: 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:

    ```
    add here
    add here
    ```

    - 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:

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

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

\[ L: \quad I: \quad \text{LinkedList.this}
\]
\[ \text{lastReturned} \quad \text{here} \quad \text{nextIndex} \]

```
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;
  ```

Initially [Diagram 1]

![Diagram 1](image1)

After deletion, addition [Diagram 2]

![Diagram 2](image2)
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.”

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

Call: findExit(0)
Exit: 16

```plaintext
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) && !isCrumb(x)
            push x on S
```

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.”

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

Call: findExit(0)
Exit: 16

```plaintext
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) && !isCrumb(x)
          push x on S
```

1, 0
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.”

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

Call: findExit(0)
Exit: 16

```python
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) && !isCrumb(x)
                        push x on S
```

```python
1, 1
2, 0
1 2
```
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.”

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

Call: findExit(0)
Exit: 16

```python
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) && !isCrumb(x)
                        push x on S
```

1, 2
2, 0
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.”

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

Call: `findExit(0)`
Exit: 16

```python
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) && !isCrumb(x)
                    push x on S
```
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.”

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

Call: `findExit(0)`
Exit: 16

```python
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) && !isCrumb(x)
                    push x on S
```
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.”

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

```
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) && !isCrumb(x)
                        push x on S
```

Call: findExit(0)
Exit: 16

```
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) && !isCrumb(x)
          findExit(x)
```

```
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) && !isCrumb(x)
            push x on S
```

Call: findExit(0)
Exit: 16
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.”

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

```
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) && !isCrumb(x)
                        push x on S
```

Call: findExit(0)
Exit: 16
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) && !isCrumb(x)
        findExit(x)
```

Call: findExit(0)
Exit: 16

```
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) && !isCrumb(x)
          push x on S
```

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

Call: findExit(0)
Exit: 16
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.”

\[
\text{findExit}(\text{start}): \\
\text{if isExit}(\text{start})  \\
\hspace{1em} \text{FOUND}  \\
\text{else if (!isCrumb}(\text{start}))  \\
\hspace{1em} \text{leave crumb at start;}  \\
\hspace{2em} \text{for each square, x,}  \\
\hspace{3em} \text{adjacent to start:}  \\
\hspace{4em} \text{if legalPlace}(x) \land \text{!isCrumb}(x)  \\
\hspace{5em} \text{findExit}(x)
\]

\[
\text{findExit}(\text{start}): \\
\text{S = new empty stack;}  \\
\text{push start on S;}  \\
\text{while S not empty:}  \\
\hspace{1em} \text{pop S into start;}  \\
\hspace{2em} \text{if isExit}(\text{start})  \\
\hspace{3em} \text{FOUND}  \\
\hspace{2em} \text{else if (!isCrumb}(\text{start}))  \\
\hspace{3em} \text{leave crumb at start;}  \\
\hspace{4em} \text{for each square, x,}  \\
\hspace{5em} \text{adjacent to start (in reverse):}  \\
\hspace{6em} \text{if legalPlace}(x) \land \text{!isCrumb}(x)  \\
\hspace{7em} \text{push x on S}
\]

Call: findExit(0)
Exit: 16
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.”

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

```
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) && !isCrumb(x)
            push x on S
```

Call: findExit(0)
Exit: 16
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.”

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

Call: `findExit(0)`
Exit: 16
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) && !isCrumb(x)
                findExit(x)

Call: findExit(0)
Exit: 16
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.”

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

```plaintext
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) && !isCrumb(x)
        push x on S
```

Call: findExit(0)
Exit: 16
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) && !isCrumb(x)
          findExit(x)
```

```
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) && !isCrumb(x)
            push x on S
```

Call: findExit(0)
Exit: 16
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.”

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

Call: findExit(0)
Exit: 16

```python
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) && !isCrumb(x)
                        push x on S
```

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

Call: findExit(0)
Exit: 16
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.”

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

Call: findExit(0)
Exit: 16

```plaintext
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) && !isCrumb(x)
            push x on S
```
Design Choices: Extension, Delegation, Adaptation

• The standard `java.util.Stack` type `extends` Vector:

```java
class Stack<Item> extends Vector<Item> { void push(Item x) { add(x); } ...
}
```

• Could instead have `delegated` to a field:

```java
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:

```java
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); } ...
}
```

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