CSCI 136
Data Structures & Advanced Programming

Lecture 15

Fall 2019

Instructor: Bill & Sam

Announcements

- Mid-Term Review Session
  - Monday Oct. 14 from 9:00-11:00 am
  - No prepared remarks, so bring questions!
- Mid-term exam is Wednesday, October17
  - During your normal lab session
  - You'll have 1 hour & 45 minutes (if you come on time!)
  - Closed-book
  - Covers Chapters 1-7 & 9 and all topics up through Linked Lists
  - A "sample" mid-term and study sheet are available online
    - See Handouts & Problem Sets

Announcements: Office Hours

- New hours available on GLOW
- Change in TA hours (see email)
- No TA hours from Wednesday-Sunday next week after midterm

Announcements

- Lab 2 back (check), PS1 back now
- Lab 3 back soon (just finishing up)
- Lab 4 back with time to review before midterm
- PS2 hopefully back soon
  - may need to pick up from my office if Mountain Day

Last Time : Linear Structures

- Stack applications
  - Arithmetic Expressions
  - Postscript
  - Mazerunning (Depth-First-Search)

Today: Linear Structures

- Stacks
  - (Implicit) program call stack
- Queues
  - Implementations Details
  - Applications
- Iterators

Mazes

- How can we use a stack to solve a maze?
  - http://www.primaryobjects.com/maze/
- Properties of mazes:
  - We model a maze as a rectangular grid of cells
  - There is a *start* cell and one or more *finish* cells
  - Goal: Find path of *adjacent* free cells from *start* to *finish*
- Strategy: Consider unvisited cells as "potential tasks"
  - Use linear structure (stack) to keep track of current path being explored

Solving Mazes

- We'll use two objects to solve our maze:
  - Position: Info about a single cell
  - Maze: Grid of Positions
- General strategy:
  - Use stack to keep track of path from start
  - If we hit a dead end, backtrack by popping location off stack
  - Mark discarded cells to make sure we don't visit the same paths twice

Backtracking Search

- Try one way (favor north and east)
- If we get stuck, go back and try a different way
- We will eventually either find a solution or exhaust all possibilities
- Also called a "depth first search"

- Lots of other algorithms that we will not explore: http://www.astrolog.org/labyrnth/algrithm.htm

A “Pseudo-Code” Sketch

```
// Initialization
Read cell data (free/blocked/start/finish) from file data
Mark all free cells as unvisited
Create an empty stack S
Mark start cell as visited and push it onto stack S

While (S isn't empty && top of S isn't finish cell)
    current ← S.peek()                          // current is top of stack
    If (current has an unvisited neighbor x)
        Mark x as visited ; S.push(x)           // x is explored next
    Else S.pop()
If finish is on top of S then success else no solution
```

Is Pseudo-Code Correct?

- Tools
  - Concepts: *adjacent cells; path; simple path; path length; shortest path; distance between cells*; *reachable from cell*
  - Solving a maze: is *finish* reachable from *start*?
- Theorem: The pseudo-code will either visit *finish* or visit every free cell reachable from *start*
- Proof: Prove that if algorithm does *not* visit *finish* then it *does* visit every free cell reachable from *start*
  - Do this by induction on distance of free cell from *start*
  - Base case: distance 0. Easy
  - Induction: Assume every reachable free cell of distance at most $k \geq 0$ from *start* is visited. Prove for k+1

Is Pseudo-Code Correct?

- Induction Hyp: Assume every reachable free cell of distance at most $k \geq 0$ from *start* is visited.
- Induction Step: Prove that every reachable free cell of distance $k+1$ from *start* is visited.
  - Let *c* be a free cell of distance $k+1$ reachable from *start*
  - Then *c* has a free neighbor *d* that is distance k from *start* and reachable from *start*
  - But then by induction, *d* is visited, so it was put on stack
  - So each free neighbor of *d* is visited by algorithm
- Done!

Recursive "Pseudo-Code" Sketch

Boolean RecSolve(Maze m, Position current)

If (current equals <u>finish</u>) return true

Mark current as visited

next ← some unvisited neighbor of current (or null if none left)

While (next does not equal null && recSolve(m, next) is false)

next← an unvisited neighbor of current (null if none left)

Return next != null

- To solve maze, call: *Boolean recSolve(*m, start*)*
- To prove correct: Induction on distance from *current* to *finish*
- How could we generate the actual solution?

Implementing A Maze Solver

- Iteratively: Maze.java
- Recursively: RecMaze.java
  - Recursive method keeps an implicit stack
    - The method call stack
  - Each recursive call adds to the stack

Implementation: Position class

- Represent position in maze as (x,y) coordinate
- class Position has several relevant methods:
  - Find a neighbor
    - `Position getNorth(), getSouth(), getEast(), getWest()`
  - `boolean equals()`
  - Check states of position
    - `boolean isVisited(), isOpen()`
  - Set states of position
    - `void visit(), setOpen(boolean b)`

Maze class

- Relevant Maze methods:
  - `Maze(String filename)`
    - Constructor; takes file describing maze as input
  - `void visit(Position p)`
    - Visit position p in maze
  - `boolean isVisited(Position p)`
    - Returns true iff p has been visited before
  - `Position start(), finish()`
    - Return start /finish positions
  - `Position nextAdjacent(Position p)`
    - Return next unvisited neighbor of p---or null if none
  - `boolean isClear(Position p)`
    - Returns true iff p is a valid move and is not a wall

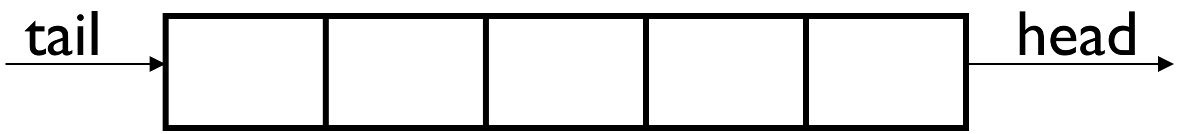
Method Call Stacks

- In JVM, need to keep track of method calls
- JVM maintains stack of method invocations (called frames)
- Stack of frames
  - Receiver object, parameters, local variables
- On method call
  - Push new frame, fill in parameters, run code
- Exceptions print out stack
- Example: StackEx.java
- Recursive calls recurse too far: StackOverflowException
  - Overflow.java

Stacks vs. Queues

- Stacks are LIFO (Last In First Out)
  - Methods: push, pop, peek, empty
  - Sample Uses:
    - Evaluating expressions (postfix)
    - Solving mazes
    - Evaluating postscript
    - JVM method calls
- Queues are FIFO (First In First Out)
  - Another linear data structure (implements Linear interface)
  - Queue interface methods: enqueue (add), dequeue (remove), getFirst (get), peek (get)

Queues



- Examples:
  - Lines at movie theater, grocery store, etc
  - OS event queue (keeps keystrokes, mouse clicks, etc, in order)
  - Printers
  - Routing network traffic (more on this later)

Queue Interface

```
public interface Queue<E> extends Linear<E> {
  public void enqueue(E item);
  public E dequeue();
  public E getFirst(); //value not removed
  public E peek();  //same as getFirst()
}
```

Implementing Queues

As with Stacks, we have three options:

QueueArray

```
class QueueArray<E> implements Queue<E> {
  protected Object[] data; //can't declare E[]
  int head;
  int count; // better than storing tail...
}
```

QueueVector

```
class QueueVector<E> implements Queue<E> {
  protected Vector<E> data;
}
```

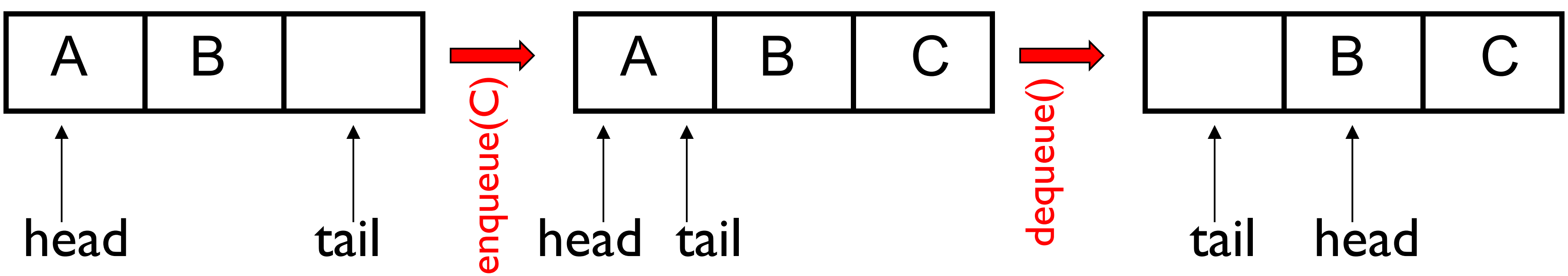
QueueList

```
class QueueList<E> implements Queue<E> {
  protected List<E> data; //uses a CircularList
}
```

All three of these also extend AbstractQueue

QueueArray

- Let's look at an example…
- How to implement?
  - enqueue(item), dequeue(), size()



head points to front of queue; tail points to next empty space (where next item will be added)

head and tail "wrap around" array; when queue is full, head == tail

After wrap around, head > tail in some cases!

```
public class queueArray<E> {

    protected Object[] data;       // Must use object because...
    protected int head;
    protected int count;

   public queueArray(int size) {
        data = new Object[size];  // ... can’t say “new E[size]”
   }

   public void enqueue(E item) {
       Assert.pre(count<data.length,”Queue is full.");
       int tail = (head + count) % data.length;
       data[tail] = item;
       count++;
   }

   public E dequeue() {
        Assert.pre(count>0,"The queue is empty.");
        E value = (E)data[head];
        data[head] = null;
        head = (head + 1) % data.length;
        count--;
        return value;
   }

    public boolean empty() {
        return count>0;
    }
```

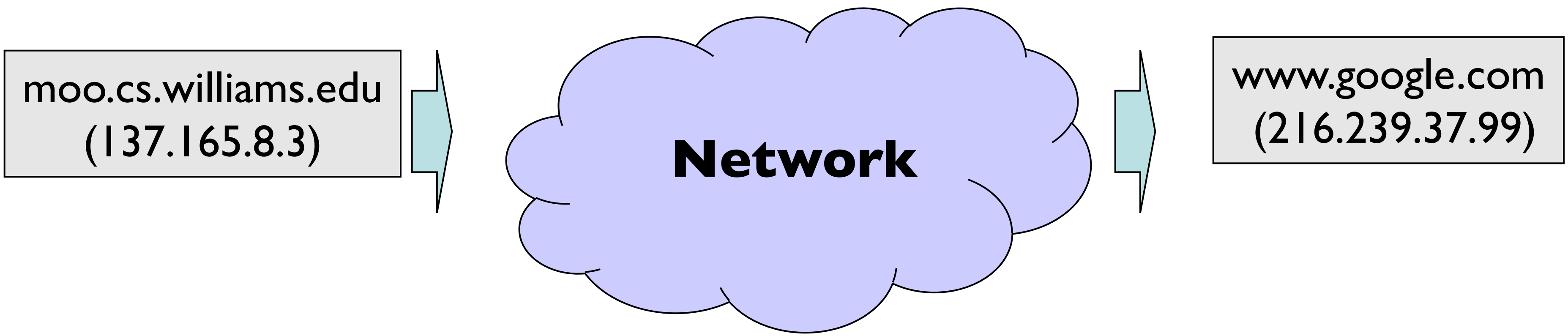
Tradeoffs:

- QueueArray:
  - enqueue is O(1)
  - dequeue is O(1)
  - Faster operations, but limited size
- QueueVector:
  - enqueue is O(1) (but O(n) in worst case - ensureCapacity)
  - dequeue is O(n)
- QueueList:
  - enqueue is O(1) (addLast)
  - dequeue is O(1) (CLL removeFirst)

Routing With Queues

Slides by Stephen Freund

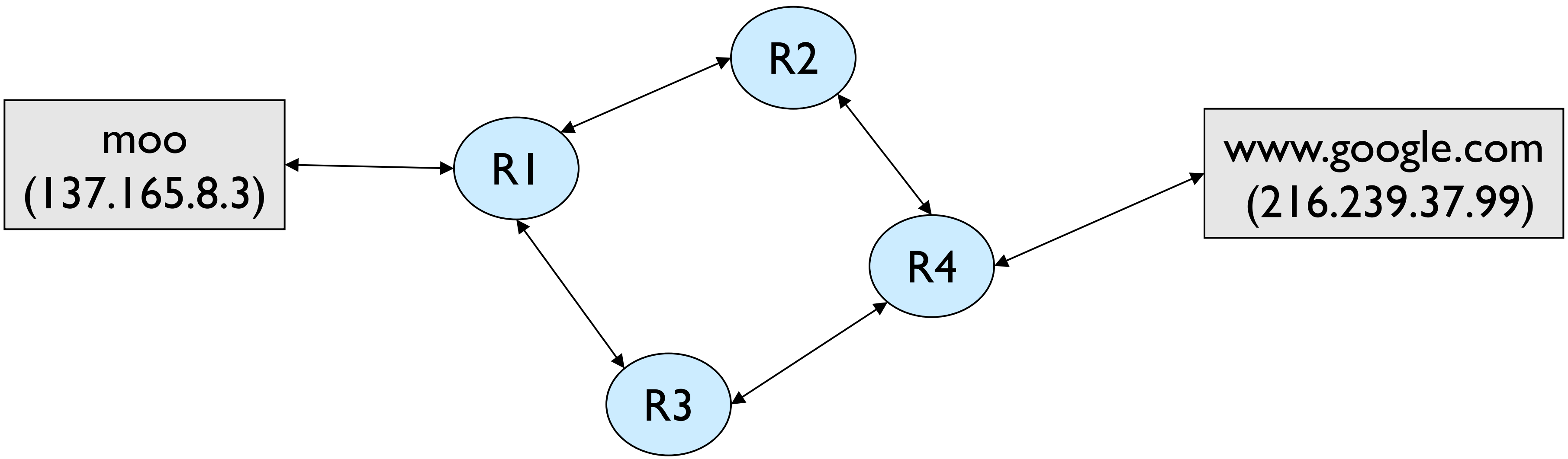
The Network



Message:

137.165.8.3	216.239.37.99	"Search for ..."

Routers



Message:

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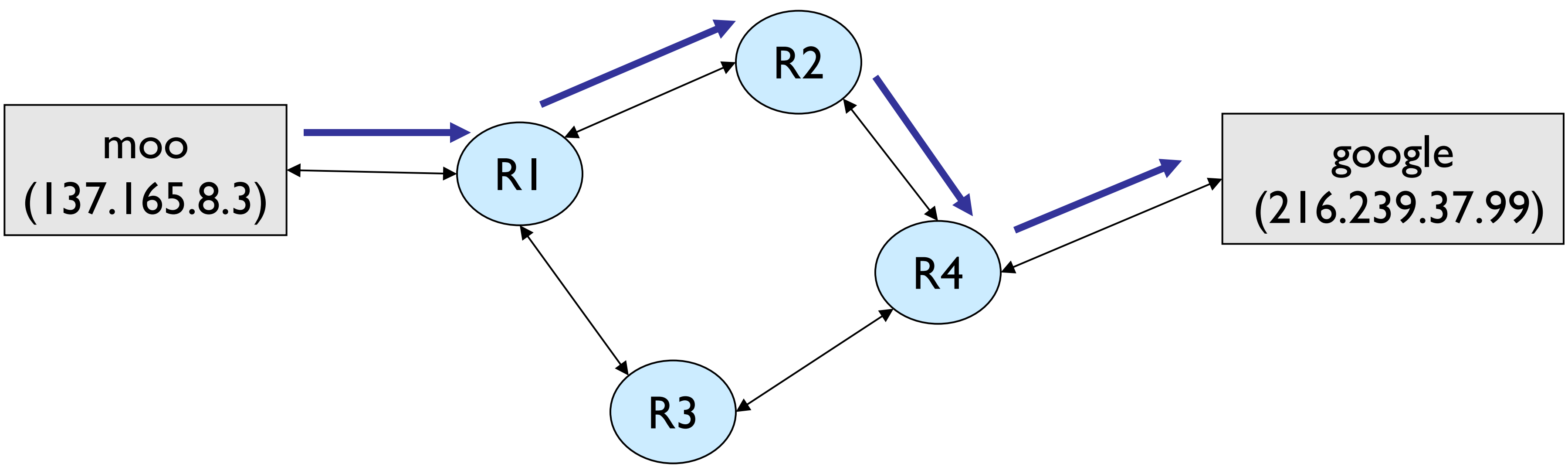
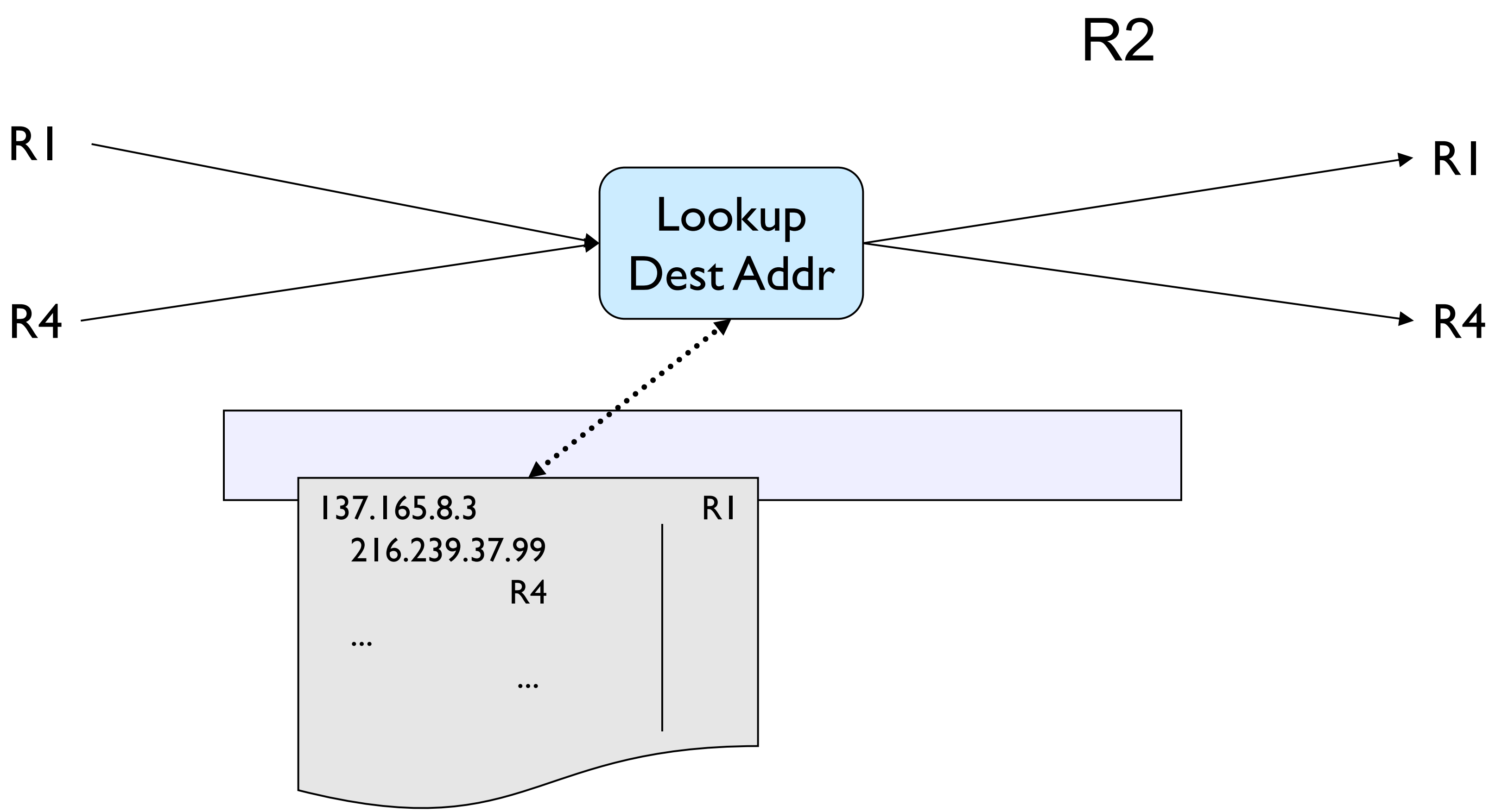
Routers



Routing Algorithm

1. Receive message
2. Look up Destination Address
   a) Deliver message to Dest
   b) Forward to next Router

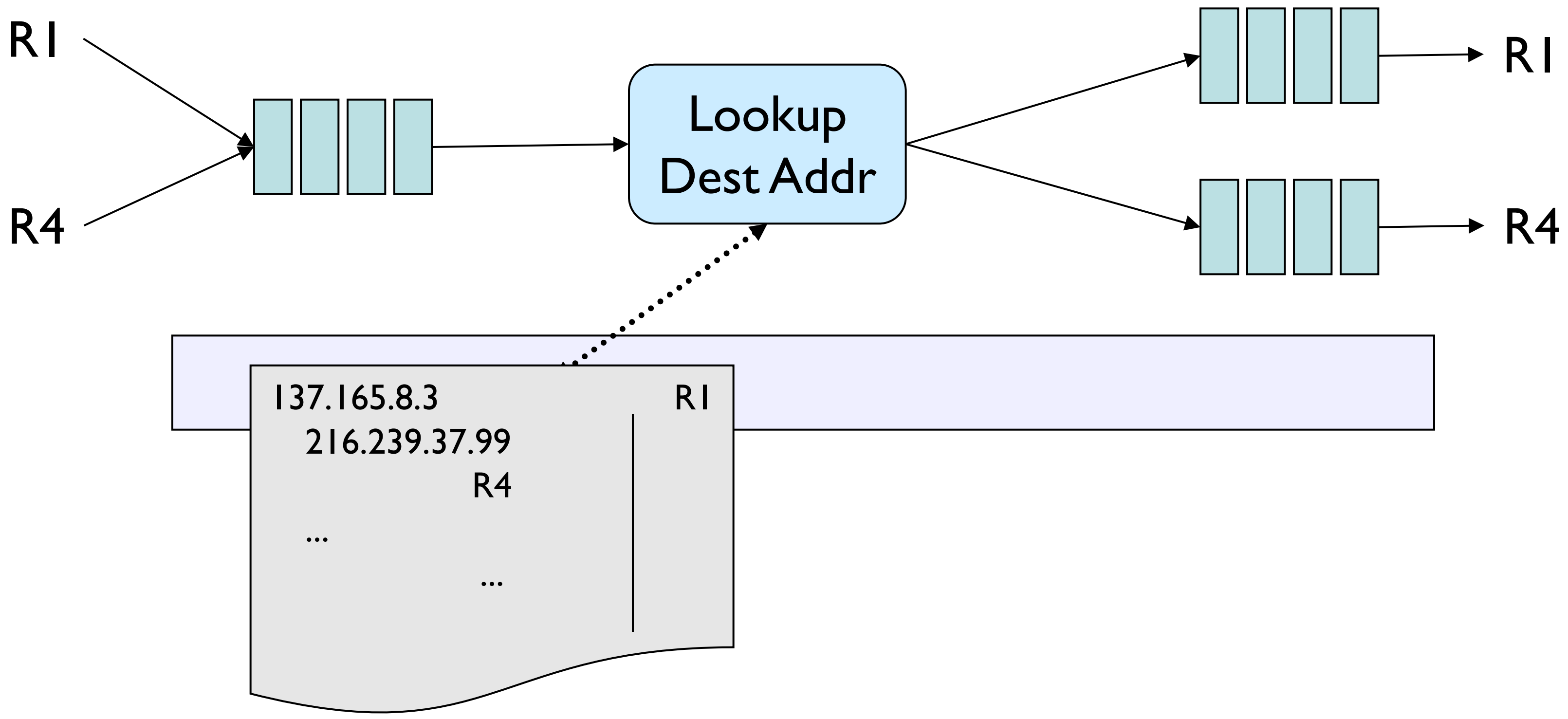
Router Internals



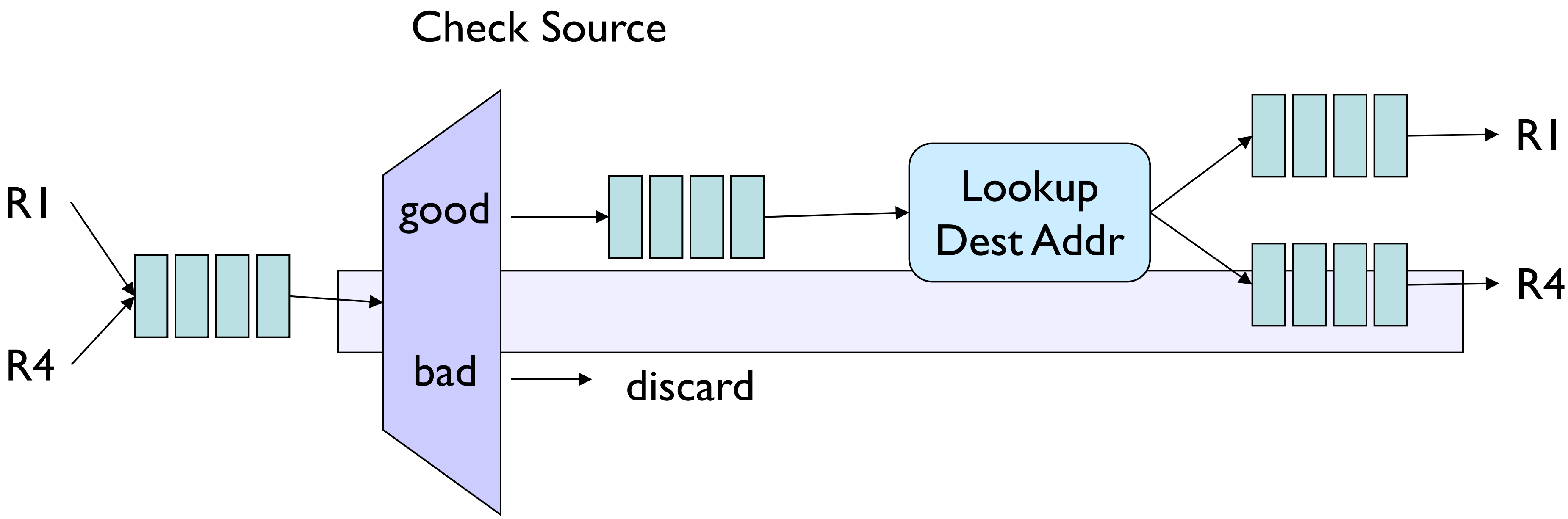
Buffering Messages

- There may be delays
  - Router receives messages faster than it can process and send
  - Some links are slower than others
    - Common speeds: 10 Mbs, 100Mbs, 1Gbs.
    - Wireless, satellite, infra-red, telephone line, ...
  - Hardware problems
- Want to be able to handle short-term congestion problems

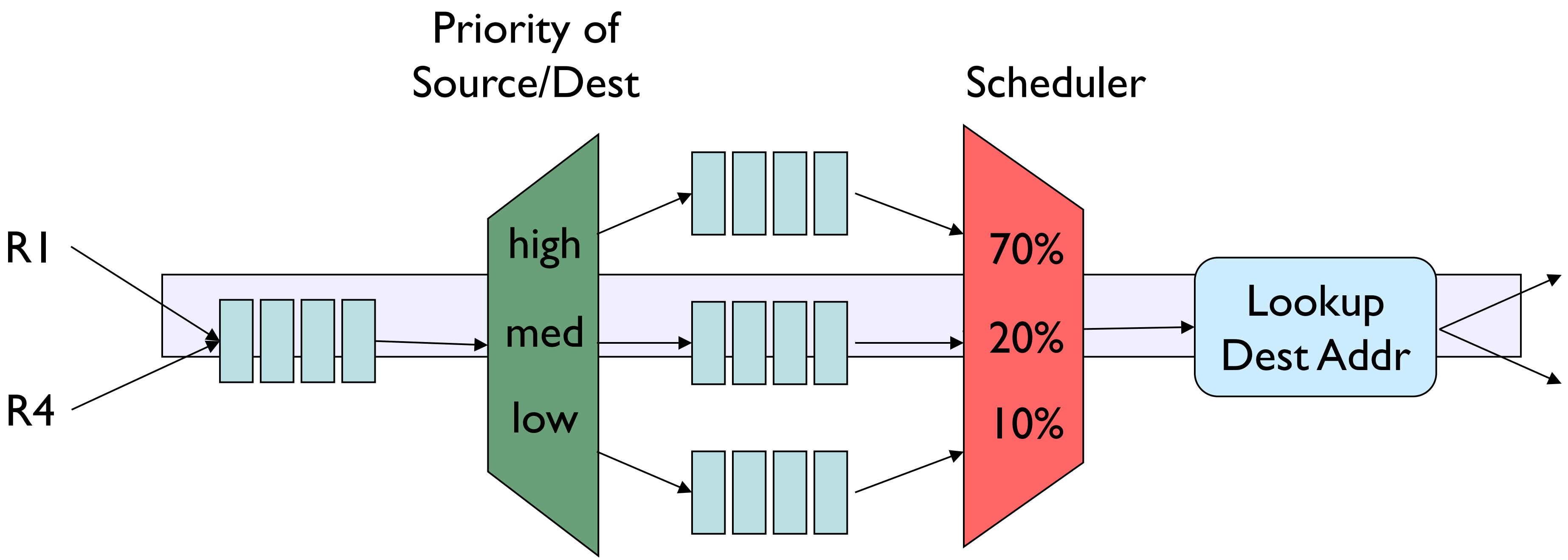
Router Internals



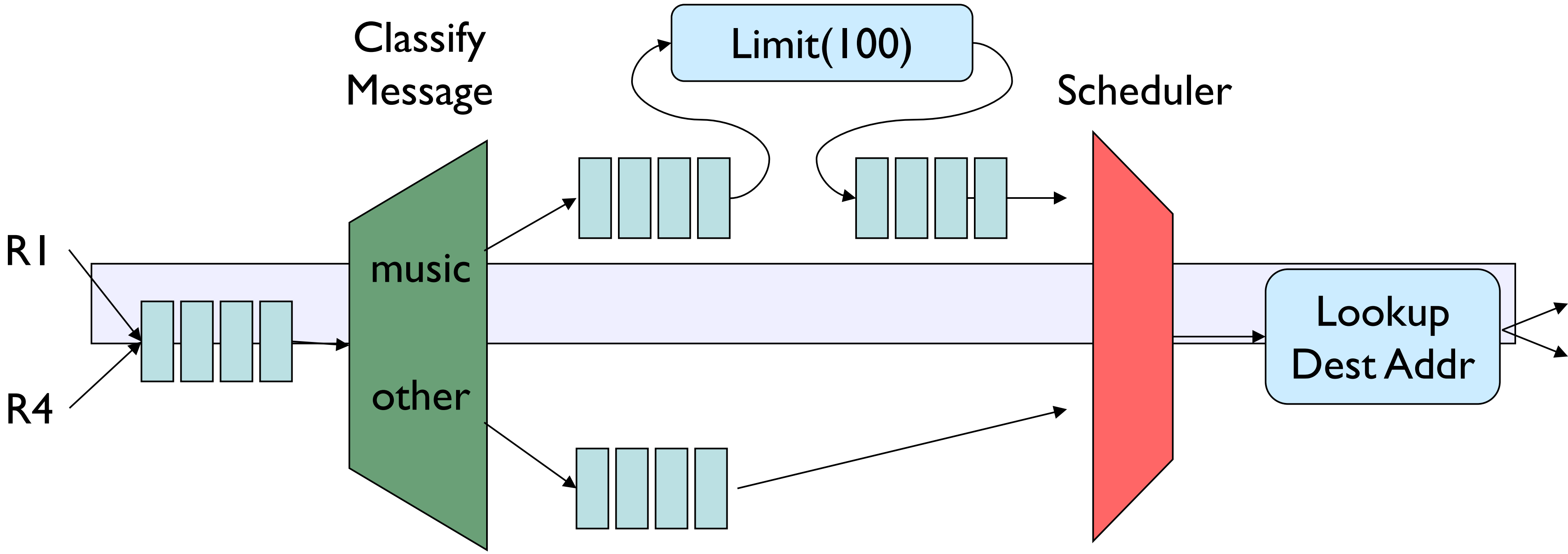
Firewalls



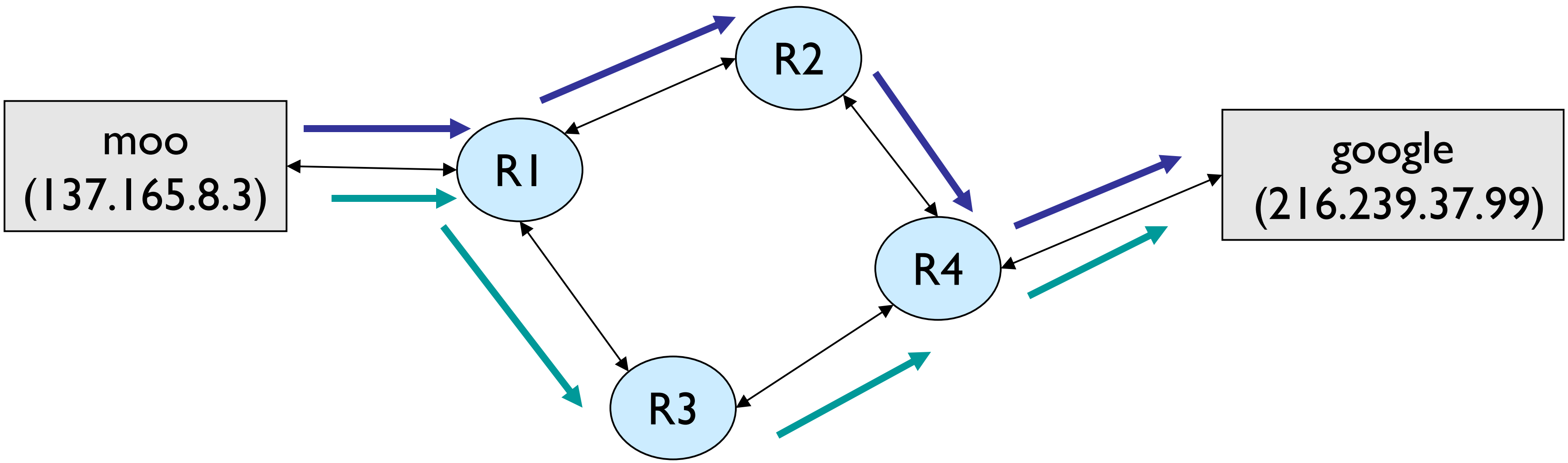
Priority Scheduling



Bandwidth Shaper



Choosing The Best Route



Choosing Routes

- Routers exchange information periodically
  - Attempt to route on "best" path to destination
  - Not easy to determine:
    - Network congestion varies (evening vs. morning)
    - Hardware added/removed or failures
- Dijkstra's algorithm (later)

Visiting Data from a Structure

- Write a method (numOccurs) that counts the number of times a particular Object appears in a structure

```
public int numOccurs (List data, E o) {
     int count = 0;
     for (int i=0; i<data.size(); i++) {
          E obj = data.get(i);
          if (obj.equals(o)) count++;
     }
     return count;
}
```

- Does this work on all structures (that we have studied so far)?

Problems

- get(int) not defined on Linear structures (i.e., stacks and queues)
- get(int) is "slow" on some structures
  - O(n) on SLL (and DLL)
  - So numOccurs = $O(n^2)$ for linked lists
- How do we traverse data in structures in a general, efficient way?
  - Goal: data structure-specific for efficiency
  - Goal: use same interface to make general

Recall : Structure Operations

- `size()`
- `isEmpty()`
- `add()`
- `remove()`
- `clear()`
- `contains()`

- But also
  - Method for efficient data traversal
    - `iterator()`

Iterators

- **Iterators** provide support for *efficiently* visiting all elements of a data structure
- An Iterator:
  - Provides generic methods to dispense values
    - Traversal of elements : *Iteration*
    - Production of values : *Generation*
  - Abstracts away details of how elements are retrieved
  - Uses different implementations for each structure

```
public interface Iterator<E> {
   boolean hasNext() – are there more elements in iteration?
   E next() – return next element
   default void remove() – removes most recently returned value
```

- Default : Java provides an implementation for remove
  - It throws an UnsupportedOperationException exception

Iterators Of Structures

Goal: Have data structures produce iterators that return the values of the structure in some order.

How?

- Define an iterator class for the structure, e.g.

```
public class VectorIterator<E>
        implements Iterator<E>;
public class SinglyLinkedListIterator<E>
        implements Iterator<E>;
```

- Provide a method in the structure that returns an iterator

```
public Iterator<E> iterator(){ … }
```

Iterators Of Structures

The details of hasNext() and next() depend on the specific data structure, e.g.

- VectorIterator holds an array reference and index of next element
  - A reference to the data array of the Vector
  - The index of the next element whose value to return
- SinglyLinkedListIterator holds
  - a reference to the head of the list
  - A reference to the next node whose value to return

Iterator Use : numOccurs

```
public int numOccurs (List<E> data, E o) {
      int count = 0;
      Iterator<E> iter = data.iterator();
      while (iter.hasNext())
            if(o.equals(iter.next())) count++;
      return count;
}
// Or...

public int numOccurs (List<E> data, E o) {
       int count = 0;
       for(Iterator<E> i = data.iterator()); i.hasNext();)
              if(o.equals(i.next())) count++;
       return count;
}
```

Implementation Details

- We use both an Iterator interface and an AbstractIterator class
- All concrete classes in structure5 extend AbstractIterator
  - AbstractIterator partially implements Iterator
- Importantly, AbstractIterator *adds* two methods
  - get() – peek at (but don't take) next element, and
  - reset() – reinitialize iterator for reuse
- Methods are specialized for each data structure

Iterator Use : numOccurs

Using an AbstractIterator allows more flexible coding
(but requiring a cast to AbstractIterator)

Note: It has the form of a standard 3-part for statement

```
public int numOccurs (List<E> data, E o) {
      int count = 0;
      for(AbstractIterator<E> i =
            (AbstractIterator<E>) data.iterator();
                  i.hasNext(); i.next())
            if(o.equals(i.get())) count++;
      return count;
}
```

Implementation : SLLIterator

```
public class SinglyLinkedListIterator<E> extends AbstractIterator<E> {

    protected Node<E> head, current;

    public SinglyLinkedListIterator(Node<E> head) {
        this.head = head;
        reset();
    }

    public void reset() { current = head;}

    public E next() {
        E value = current.value();
        current = current.next();
        return value;
    }

    public boolean hasNext() { return current != null; }

    public E get() { return current.value(); }
}
```

In SinglyLinkedList.java:

```
public Iterator<E> iterator() {
    return new SinglyLinkedListIterator<E>(head);
}
```

More Iterator Examples

- How would we implement VectorIterator?
- How about StackArrayIterator?
  - Do we go from bottom to top, or top to bottom?
  - Doesn't matter! We just have to be consistent…

- We can also make "specialized" iterators
  - Another SLL Example: SkipIterator.java
  - ReverseIterator.java

Iterators and For-Each

Recall: with arrays, we can use a simplified form of the for loop

```
for( E elt : arr) {System.out.println( elt );}
```

Or, for example

```
// return number of times o appears in data
public int numOccurs (E[] data, E o) {
      int count = 0;
      for(E current : data)
            if(o.equals(current)) count++;
      return count;
}
```

We can do this with classes that provide an iterator() method…

The Iterable Interface

We can use the "for-each" construct…

```
for( E elt : boxOfStuff ) { ... }
```

…as long as `boxOfStuff` implements the *Iterable* interface

```
public interface Iterable<T> {
        public Iterator<T> iterator();
}
```

Since Structure<E> extends Iterable<E>, we can write

```
public int numOccurs (List<E> data, E o) {
        int count = 0;
        for(E current : data)
                if(o.equals(current)) count++;
        return count;
}
```

General Rules for Iterators

1. Understand order of data structure
2. **Always call hasNext() before calling next()!!!**
3. Use remove with caution!

   ** Don’t use remove….

4. Don’t add to structure while iterating: TestIterator.java

- Take away messages:
  - Iterator objects capture state of traversal
  - They have access to internal data representations
  - They should be fast and easy to use

A Fun Use of Iterators

- Example: FibonacciNumbers

```
public class FibonacciNumbers implements Iterator<Integer> {
    private int next= 1, current = 1;
    private int length= 10;  // Default

    public FibonacciNumbers() {}
    public FibonacciNumbers(int n) {length= n;}
    public boolean hasNext() { return length>=0;}
    public Integer next() {
            length--;
            int temp = current;
            current = next;
            next = temp + current;
            return temp;
    }
}
```

Why Is This Cool? (it is)

- We could calculate the i^{th} Fibonacci number each time, but that would be slow
  - Observation: to find the n^{th} Fib number, we calculate the previous n-1 Fib numbers…
  - But by storing some state, we can easily generate the next Fib number in O(1) time
- Knowledge about the structure of the problem helps us traverse the Fib space *efficiently* one element at a time
  - Let's do the same for data structures