Sequential search revisited

- What does the code below do? How would it be called initially?
  - Another overloaded function `search` with 2 parameters?

```java
boolean bsearch(String[] a, int index, String target)
{
    if (index >= a.length) return false;
    else if (a[index].equals(target))
        return true;
    else return bsearch(a, index+1, target);
}
```

- What is complexity (big-Oh) of this function?

Recursion and Recurrences

```java
boolean occurs(String s, String x)
{   // post: returns true iff x is a substring of s
    if (s.equals(x)) return true;
    if (s.length() <= x.length()) return false;
    return occurs(s.substring(1, s.length()), x) ||
           occurs(s.substring(0, s.length()-1), x);
}
```

- In worst case, both calls happen
- Say T(N) is the worst case cost of occurs(s, x), N == s.length()
  - T(N) = 1 if N < x.length()
  - T(N) = 2T(N-1) + O(1) if N >= x.length()
  - T(N) = O(1) if N <= x.length()
  - T(N) = O(1) if s == x

- What is T(N)?
  - T(N) = 2T(N-1) + O(1) = 2(2T(N-2) + O(1)) + O(1) = 4T(N-2) + 3O(1)
  - 4T(N-3) + O(1) = 8T(N-3) + 7O(1) = ...
  - = 2^NT(1) + (2^N - 1)O(1) = N x length() = 0 T(0) = O(1)

Why we study recurrences/complexity?

- Tools to analyze algorithms
- Machine-independent measuring methods
- Familiarity with good data structures/algorithms

- What is CS person: programmer, scientist, engineer?
  - scientists build to learn, engineers learn to build

- Mathematics is a notation that helps in thinking, discussion, programming
The Power of Recursion: Brute force

- Consider the TypingJob APT problem: What is minimum number of minutes needed to type n term papers given page counts and three typists typing one page/minute? (assign papers to typists to minimize minutes to completion)
  - Example: (3, 3, 5, 9, 10, 10) as page counts

- How can we solve this in general? Suppose we're told that there are no more than 10 papers on a given day.
  - How does this constraint help us?
  - What is complexity of using brute-force?

Recasting the problem

- Instead of writing this function, write another and call it

```java
// @return min minutes to type papers in pages
int bestTime(int[] pages)
{
    return best(pages, 0, 0, 0, 0);
}
```

- What cases do we consider in function below?

```java
int best(int[] pages, int index, int t1, int t2, int t3)
// returns min minutes to type papers in pages
// starting with index-th paper and given
// minutes assigned to typists, t1, t2, t3
{
}
```

Data Structures revisited

- Linked lists and arrays and ArrayLists and ...
  - Linear structures, operations include insert, delete, traverse, ...
  - Advantages and trade-offs include ...

- We want to move toward structures that support very efficient insertion and lookup, lists can't do better than O(n) for one of these: consider binary search and insert for arrays, or insert and lookup for linked lists

- Interlude: two linear structures that facilitate certain algorithms: Stack and Queue
  - Restricted access linear structures

Stack: What problems does it solve?

- Stacks are used to avoid recursion, a stack can replace the implicit/actual stack of functions called recursively
- Stacks are used to evaluate arithmetic expressions, to implement compilers, to implement interpreters
  - The Java Virtual Machine (JVM) is a stack-based machine
  - Postscript is a stack-based language
  - Stacks are used to evaluate arithmetic expressions in many languages
- Small set of operations: LIFO or last in is first out access
  - Operations: push, pop, top, create, clear, size
  - More in postscript, e.g., swap, dup, rotate, ...
Simple stack example

- Stack is part of java.util.Collections hierarchy
  - It's an OO abomination, extends Vector (like ArrayList)
    - Should be implemented using Vector
    - Doesn't model "is-a" inheritance
  - what does pop do? What does push do?

```java
Stack<String> s = new Stack<String>();
s.push("panda");
s.push("grizzly");
s.push("brown");
System.out.println("size = " + s.size());
System.out.println(s.peek());
String str = s.pop();
System.out.println(s.peek());
System.out.println(s.pop());
```

Implementation is very simple

- Extends Vector, so simply wraps Vector/ArrayList methods in better names
  - push=add, pop=remove (also peek and empty)
  - Note: code below for ArrayList, Vector is used
    - Stack is generic, so Object replaced by generic reference
      (see next slide)

```java
public Object push(Object o){
    add(o);
    return o;
}
public Object pop(){
    return remove(size()-1);
}
```

Uses rather than "is-a"

- Suppose there's a private ArrayList myStorage
  - Doesn't extend Vector, simply uses Vector/ArrayList
  - Disadvantages of this approach?
    - Synchronization issues

```java
public class Stack<E> {  
    public E push(E o){
        add(o);
        return o;
    }
    public E pop(Object o){
        return remove(size()-1);
    }
    public class Stack<E> {
    private ArrayList<E> myStorage;
    public E push(E o){
        myStorage.add(o);
        return o;
    }
    public E pop(){
        return myStorage.remove(size()-1);
    }
```
Postfix, prefix, and infix notation

- Postfix notation used in some HP calculators
  - No parentheses needed, precedence rules still respected
    \[ 3 5 + 4 2 * 7 + 3 - 9 7 + * \]
  - Read expression
    - For number/operand: push
    - For operator: pop, pop, operate, push
- See Postfix.java for example code, key ideas:
  - Use StringTokenizer, handy tool for parsing
  - Note: Exceptions thrown, what are these?
- What about prefix and infix notations, advantages?

Exceptions

- Exceptions are raised or thrown in exceptional cases
  - Bad indexes, null pointers, illegal arguments, ...
  - File not found, URL malformed, ...
- Runtime exceptions aren't meant to be handled or caught
  - Bad index in array, don't try to handle this in code
  - Null pointer stops your program, don't code that way!
- Other exceptions must be caught or rethrown
  - See FileNotFoundException and IOException in Scanner class implementation
- RuntimeException extends Exception, catch not required

Prefix notation in action

- Scheme/LISP and other functional languages tend to use a prefix notation

```scheme
(define (square x) (* x x))

(define (expt b n)
  (if (= n 0)
    1
    (* b (expt b (- n 1)))))
```

Postfix notation in action

- Practical example of use of stack abstraction
- Put operator after operands in expression
  - Use stack to evaluate
    - operand: push onto stack
    - operator: pop operands push result
- PostScript is a stack language mostly used for printing
  - drawing an X with two equivalent sets of code

```postscript
%!
200 200 moveto
100 100 rlineto
200 300 moveto
100 -100 rlineto
stroke showpage
```
Queue: another linear ADT

- FIFO: first in, first out, used in many applications
  - Scheduling jobs/processes on a computer
  - Tenting policy?
  - Computer simulations

- Common operations: add (back), remove (front), peek ??
  - java.util.Queue is an interface (jdk5)
    - offer(E), remove(), peek(), size()
  - java.util.LinkedList implements the interface
    - add(), addLast(), getFirst(), removeFirst()

- Downside of using LinkedList as queue
  - Can access middle elements, remove last, etc. why?

Stack and Queue implementations

- Different implementations of queue (and stack) aren’t really interesting from an algorithmic standpoint
  - Complexity is the same, performance may change (why?)
  - Use ArrayList, growable array, Vector, linked list, ...
    - Any sequential structure

- As we’ll see java.util.LinkedList is good basis for all
  - In Java 5, LinkedList implements the Queue interface,
    low-level linked lists facilitate (circular list!)

- ArrayList for queue is tricky, ring buffer implementation, add but wrap-around if possible before growing
  - Tricky to get right (exercise left to reader)

Using linear data structures

- We’ve studied arrays, stacks, queues, which to use?
  - It depends on the application
  - ArrayList is multipurpose, why not always use it?
    - Make it clear to programmer what’s being done
    - Other reasons?

- Other linear ADTs exist
  - List: add-to-front, add-to-back, insert anywhere, iterate
    - Alternative: create, head, tail, Lisp or
    - Linked-list nodes are concrete implementation
  - Deque: add-to-front, add-to-back, random access
    - Why is this “better” than an ArrayList?
    - How to implement?

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Klawe’s personal interests include painting, long distance running, hiking, kayaking, juggling and playing electric guitar. She describes herself as “crazy about mathematics” and enjoys playing video games.

“I personally believe that the most important thing we have to do today is use technology to address societal problems, especially in developing regions”
Queue applications

- Simulation, discrete-event simulation
  - How many toll-booths do we need? How many express lanes or self-checkout at grocery store? Runway access at airport?
  - Queues facilitate simulation with mathematical distributions governing events, e.g., Poisson distribution for arrival times

- Shortest path, e.g., in flood-fill to find path to some neighbor or in word-ladder
  - How do we get from "white" to "house" one-letter at a time?
    - white, while, whale, shale, shake, ...

Queue for shortest path (see APT)

```java
public boolean ladderExists(String[] words, String from, String to) {
    Queue<String> q = new LinkedList<String>();
    Set<String> used = new TreeSet<String>();
    for (String s : words) {
        if (oneAway(from, s)) {
            add(s);
            used.add(s);
        }
    }
    while (q.size() != 0) {
        String current = q.remove();
        if (oneAway(current, to)) return true;
        // add code here, what?
    }
    return false;
}
```

Shortest Path reprised

- How does use of Queue ensure we find shortest path?
  - Where are words one away from start?
  - Where are words two away from start?

- Why do we need to avoid revisiting a word, when?
  - Why do we use a set for this? Why a TreeSet?
  - Alternatives?

- What if we want the ladder, not just whether it exists
  - What's path from white to house? We know there is one.
  - Ideas? Options?

Blob Finding with Queues

```java
myGrid[row][col] = fillWith; // mark pixel
size++;
myQueue.add(myPairGrid[row][col]);
myGrid[row][col] = fillWith;
size++;
```

```java
while (myQueue.size() != 0) {
    Pair p = myQueue.remove();
    for (int k = 0; k < rowDelta.length; k++) {
        row = p.row + rowDelta[k];
        col = p.col + colDelta[k];
        if (inRange(row, col) &&
            myGrid[row][col] == lookFor) {
            myQueue.add(myPairGrid[row][col]);
            myGrid[row][col] = fillWith;
            size++;
        }
    }
}
```