Solving Problems Recursively

- Recursion is an indispensable tool in a programmer’s toolkit
  - Allows many complex problems to be solved simply
  - Elegance and understanding in code often leads to better programs: easier to modify, extend, verify (and sometimes more efficient!)
  - Sometimes recursion isn’t appropriate, when it’s bad it can be very bad—every tool requires knowledge and experience in how to use it

- The basic idea is to get help solving a problem from coworkers (clones) who work and act like you do
  - Ask clone to solve a simpler but similar problem
  - Use clone’s result to put together your answer

- Need both concepts: call on the clone and use the result

Print words entered, but backwards

- Can use an ArrayList, store all the words and print in reverse order
  - Probably the best approach, recursion works too
    ```java
    public void printReversed(Scanner s){
        if (s.hasNext()){ // reading succeeded?
            String word = s.next(); // store word
            printReversed(s); // print rest
            System.out.println(word); // print the word
        }
    }
    ```

- The function printReversed reads a word, prints the word only after the clones finish printing in reverse order
  - Each clone has own version of the code, own word variable
  - Who keeps track of the clones?
  - How many words are created when reading N words?
    - What about when ArrayList<String> used?

Exponentiation

- Computing $x^n$ means multiplying n numbers (or does it?)
  - What’s the easiest value of n to compute $x^n$?
  - If you want to multiply only once, what can you ask a clone?
    ```java
    public static double power(double x, int n){
        if (n == 0){
            return 1.0;
        }
        return x * power(x, n-1);
    }
    ```

- What about an iterative version?

Faster exponentiation

- How many recursive calls are made to compute $2^{1024}$?
  - How many multiplies on each call? Is this better?
    ```java
    public static double power(double x, int n){
        if (n == 0) {
            return 1.0;
        }
        double semi = power(x, n/2);
        if (n % 2 == 0) {
            return semi*semi;
        }
        return x * semi * semi;
    }
    ```

- What about an iterative version of this function?
Back to Recursion

- Recursive functions have two key attributes
  - There is a base case, sometimes called the exit case, which does not make a recursive call
    - See print reversed, exponentiation
  - All other cases make a recursive call, with some parameter or other measure that decreases or moves towards the base case
    - Ensure that sequence of calls eventually reaches the base case
      - “Measure” can be tricky, but usually it’s straightforward

- Example: sequential search in an array
  - If first element is search key, done and return
  - Otherwise look in the “rest of the array”
  - How can we recurse on “rest of array”?

Thinking recursively

- Problem: find the largest element in an array
  - Iteratively: loop, remember largest seen so far
  - Recursive: find largest in [1..n), then compare to 0th element

```java
public static double max(double[] a) {
    double maxSoFar = a[0];
    for(int k=1; k < a.length; k++) {
        maxSoFar = Math.max(maxSoFar, a[k]);
    }
    return maxSoFar;
}
```

- In a recursive version what is base case, what is measure of problem size that decreases (towards base case)?

Recursive Max

```java
public static double recMax(double[] a, int index) {
    if (index == a.length-1) {
        // last element, done
        return a[index];
    }
    double maxAfter = recMax(a, index+1);
    return Math.max(a[index], maxAfter);
}
```

- What is base case (conceptually)?
- Do we need variable maxAfter?
- We can use recMax to implement arrayMax as follows
  ```java
  return recMax(a, 0);
  ```

Recognizing recursion:

```java
public static void change(String[] a, int first, int last) {
    if (first < last) {
        String temp = a[first]; // swap a[first], a[last]
        a[first] = a[last];
        a[last] = temp;
        change(a, first+1, last-1);
    }
}
```

- What is base case? (no recursive calls)
- What happens before recursive call made?
- How is recursive call closer to the base case?
More recursion recognition

```java
public static int value(int[] a, int index) {
    if (index < a.length) {
        return a[index] + value(a, index + 1);
    }
    return 0;
}
```

// original call: int v = value(a, 0);

- What is base case, what value is returned?
- How is progress towards base case realized?
- How is recursive value used to return a value?
- What if a is array of doubles, does anything change?