Lecture 7:
Recursion in Java

Creation Through Self-Referral Dynamics

Wholeness of the Lesson

Computation of a function by recursion involves repeated self-calls of the function. Recursion is implicit also at the design level when a reflexive association is present. Recursion mirrors the self-referral dynamics of consciousness, the unified field, on the basis of which all creation emerges.

Outline of Topics

- Recursion Defined and two examples: Factorial and Fibonacci
- Recursive Utility Functions
  - Reversing characters in a string
  - Merging sorted Strings
  - Finding the minimum element in an array
  - Searching for a file in a directory system

Recursion – Basic Idea

- **Recursion**: The definition of an operation in terms of itself.
  - Solving a problem using recursion depends on solving smaller occurrences of the same problem.

- A Java method is **recursive**, or exhibits recursion, if in its body it calls itself.
  - An equally powerful substitute for *iteration* (loops)
  - Particularly well-suited to solving certain types of problems (problems which can naturally be broken down into sub-problems.)

Why Recursion?

- "cultural experience" - A different way of thinking of problems
- Can solve some kinds of problems better than iteration
- Leads to elegant and simple code (when used well)
- Many programming languages ("functional" languages such as Scheme, ML, and Haskell) use recursion exclusively (no loops)

First Example: factorial

- Definition of factorial:

  For any positive integer n:

  $n! = n \times (n-1) \times (n-2) \times \ldots \times 3 \times 2 \times 1$

  $0! = 1$

- Another way of defining factorial using recursion.

  $n! = n \times (n-1)!$

  $0! = 1.$

```
int factorial(int n) {
    //base case
    if(n == 0 || n == 1) {
        return 1;
    }
    return n * factorial(n-1);
}
```

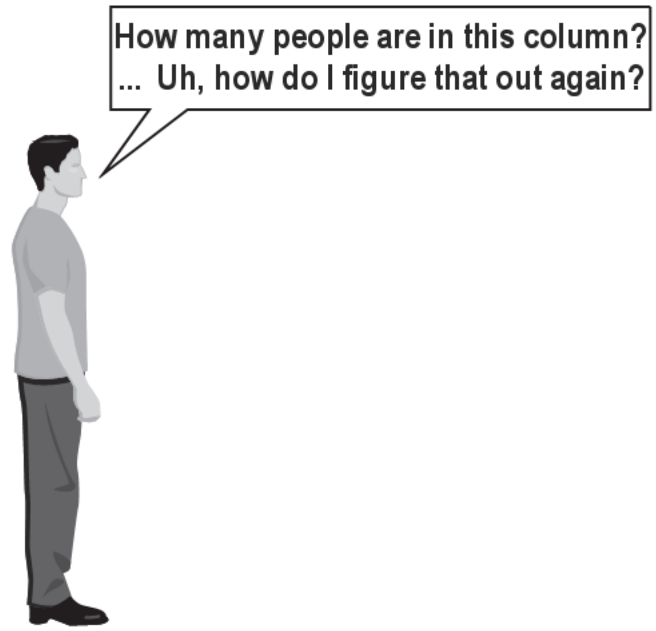
Demo: Observe the sequence of self-calls in executing `factorial` on input 12.
See package `lesson7.fibfactorial`.

Recursion in Java

- In order to be a *valid recursion* (one that eventually terminates), the following criteria must be met:
  - *Base Case Exists.* The method must have a base case which returns a value without making a self-call.
  - *Self-calls Lead to Base Case.* For every input to the method, the sequence of self-calls must eventually lead to a self-call in which the base case is accessed.

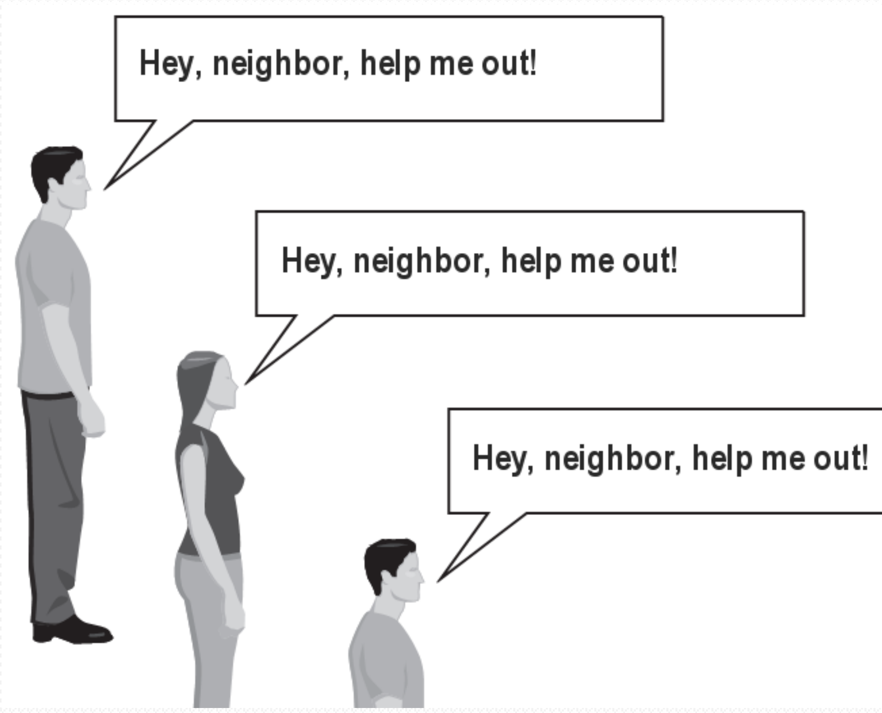
In-Class Exercise

- (To a student in the front row)
How many students total are directly behind you in your "column" of the classroom?
  - You have poor vision, so you can see only the people one seat away from you. So you can't just look back and count.
  - But you are allowed to ask questions of a person one seat away from you.
  - How can we solve this problem? (*recursively*)



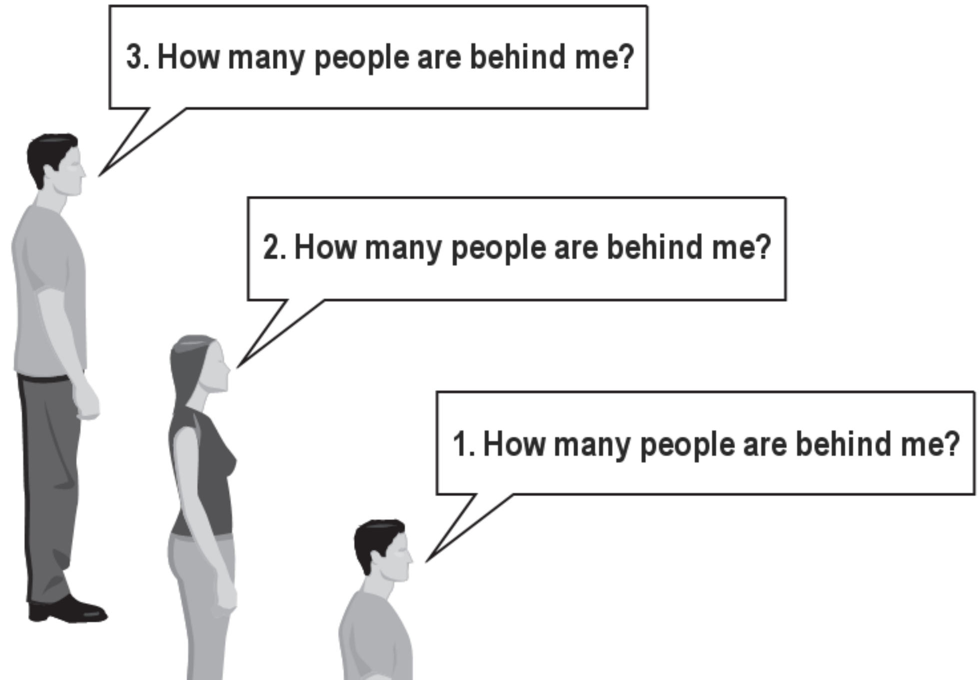
The idea

- Recursion is all about breaking a big problem into smaller occurrences of that same problem.
  - Each person can solve a small part of the problem.
    - What is a small version of the problem that would be easy to answer?
    - What information from a neighbor might help me?



Recursive Solution

- Number of people behind me:
  - If there is someone behind me,
    ask him/her how many people are behind him/her.
    - When they respond with a value **N**, then I will answer **N + 1**.
  - If there is nobody behind me, I will answer **0**.



Another Example of Recursion

The Fibonacci numbers are defined as follows:

$$F_0 = 0,\ F_1 = 1,\ F_2 = 1,\ F_3 = 2,\ F_4 = 3,\ F_5 = 5, \ldots,$$

$$F_n = F_{n-1} + F_{n-2}, \ldots$$

The nth Fibonacci number can be computed by:

```
int fib(int n) {
   //base case
    if(n == 0 || n == 1) {
       return n;
    }
    return fib(n-1) + fib(n-2);
}
```

Demo: Observe the sequence of self-calls – package `lesson7.fibfactorial`

Design Guideline

> *No recursion should involve a large amount of redundant computation.*

Usually, if a recursion *does* involve redundant computations, it can be rewritten as a loop or by using a more efficient recursive strategy.

<u>Example</u>: We have seen how there is a great deal of redundant computation in the recursive computation of Fibonacci numbers.

Example: Implementing `factorial` Iteratively

```
int factorial(int n) {
    if(n == 0 || n == 1) {
        return 1;
    }

    int result = 1;
    for(int i = 1; i <= n; ++i ) {
        result *= i;
    }
    return result;
}
```

Exercise: Rewrite the function that computes the nth fibonacci number iteratively (using a loop instead of recursion).

Main Point

Java supports the creation of recursive methods, characterized by the fact that they call themselves in their method body. A self-calling method is a *valid* recursive function if it contains a *base case* – a branch of code that exits the method under certain conditions but does not involve a self-call – and if the sequence of self-calls, on any input to the method, always converges to the base case. Likewise, a quest for self-knowledge not based in the direct experience of the "Self" is endless (and baseless).

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Recursive Implementations of a Utility Method

- Sorting, searching, and other manipulations of characters in a string or elements in arrays or lists are often done recursively. Sometimes (but not always), an implementation of such a utility provides a public method

```
public <return-value-type> thePublicMethod(params)
```

whose signature and return type make sense to potential users, and a private recursive method

```
private <ret-value-type> privateRecurMethod(otherParams)
```

which does the real work and is designed to call itself.

We first consider simpler examples that do not require this separation

Example of a Recursive Utility: Reversing a String

Attempt to reverse the order of the characters in an input String by using the following strategy:

- Remove the 0th character `ch` from the input string and name the modified string `t`.
- Reverse `t` and append `ch`.

Thinking recursively. After processing the 0th character, assume the reverse method works on the remaining elements.

Implementation

```
static String reverse(String s) {
  if(s == null || s.length() == 0) return s;
  String first = "" + s.charAt(0);
  return reverse(s.substring(1)) + first;
}
```

Example of a Recursive Utility: Merging Sorted Char Arrays (Strings)

Problem: Merge two strings `s`, `t` consisting of characters in the range a-z that are each in sorted order, to produce a new string whose characters are also in sorted order. Try the following recursive strategy:

1. Let `chs` be the 0^{th} character of `s` and `cht` be the 0^{th} character of `t`.
2. If `chs` comes before `cht` alphabetically, store `chs`, otherwise place `cht` in a buffer and remove the stored character from its original string
3. Merge the remaining strings (recursively) and insert the result in the buffer, placed after the stored character.

Thinking recursively: We are specifying a Merge procedure, yet in the third step we are calling that procedure. The way to think about it is: After you have done something with the 0^{th} character of one of the two Strings, *assume* the recursive step works as specified.

Implementation

```
public class MergeStrings {
     StringBuilder ret = new StringBuilder();
     public String merge(String s, String t) {
       if(s == null || s.isEmpty()) {
          ret.append(t);
          return ret.toString();
       }
       if(t == null || t.isEmpty()) {
          ret.append(s);
          return ret.toString();
       }
       if(s.charAt(0) <= t.charAt(0)) {
          ret.append(s.charAt(0));
          return merge(s.substring(1), t);
       } else {
          ret.append(t.charAt(0));
          return merge(s, t.substring(1));
       }
    }
}
//sample usage
MergeStrings ms = new MergeStrings();
System.out.println(ms.merge("ace", "bd"));
"abcde" //output
```

Example of a Recursive Utility: Finding the Minimum Value

Attempt to find the minimum (alphabetically) character in a String of characters in the range a-z, but using the following strategy:

- Remove the 0th character `ch` from the string, call the resulting string `t`.
- Find the minimum character min in `t`.
- If `min` < `ch`, return min; otherwise, return `ch`.

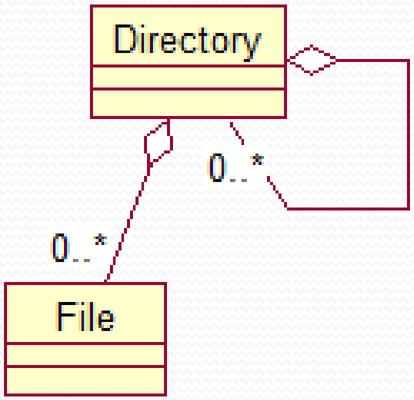
Thinking recursively. After processing the 0th character, assume the `findMin` operation works correctly on the remaining elements.

Implementation

```
public class RecursiveMin {
  public Character rmin(String str) {
    if(str == null || str.length() == 0) {
      return null;
    }
    char ch = str.charAt(0);
    if(str.length() == 1) return ch;
    char c = rmin(str.substring(1));
    return (ch < c ? ch : c);
  }
}
```

Object-based Recursion

- In Java, one can work with files and directories – each is represented by a particular Java class (to be discussed later). Suppose we want to write a Java method that searches for a particular file. This task will require recursion. To see what is involved, we represent the structure of a directory in the following class diagram:



Strategy

To search for a given file *file* in a given directory *dir,* the recursive strategy is:

- Get all the files and other directories that lie in the given directory *dir*
- For each of these files, compare with the given file *file* – if the same, return true
- For each directory *d* among the directories found in *dir*, recursively search for *file*
- Return false

Implementation

Rather than discuss the implementation of Directory and File in Java, we give higher level description to show how such a search is to be done. (See Lesson 13 for more details on File.)

```
//this is not Java code
boolean searchForFile(Object file, Object startDir) {

      Object[] fileSystemObjects = startDir.getContents();

      for(Object o: fileSystemObjects) {
            //base case
            if(isFile(o) && isSameFile(o,file)) {
                  return true;
            }

            if(isDirectory(o)) {
                  searchForFile(file, o);
            }
      }
      //file not found in startDir
      return false;
}
```

Summary

- A Java method is ***recursive***, or exhibits recursion, if in its body it calls itself.
- A recursion is ***valid*** if the following criteria are met:
  - The method must have a base case which returns a value without making a self-call.
  - For every input to the method, the sequence of self-calls eventually leads to a self-call in which the base case is accessed.
- Sometimes recursion leads to redundant computations, which lead to slow running times (like Fibonacci). In such cases, an implementation using iteration instead of recursion should be done.
- When recursion is used to provide utility function support, the public method signature that is exposed to the client reveals only the parameters that are relevant for the client – not the special parameters that may be needed to implement the recursion.

Connecting the Parts of Knowledge With the Wholeness of Knowledge

Recursion creates from self-referral activity

1. In Java, it is possible for a method to call itself.
2. For a self-calling method to be a legitimate recursion, it must have a base case, and whenever the method is called, the sequence of self-calls must converge to the base case.

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3. **Transcendental Consciousness:** TC is the self-referral field of existence, at the basis of all manifest existence.
4. **Wholeness moving within itself**: In Unity Consciousness, one sees that all activity in the universe springs from the self-referral dynamics of wholeness. The "base case" – the reference point – is always the Self, realized as Brahman.