

A large, two-story, light-colored building with a red-tiled roof and a central tower, surrounded by green grass and trees under a clear blue sky.

# MAHARISHI UNIVERSITY of MANAGEMENT

*Engaging the Managing Intelligence of Nature*

## Computer Science Department

**CS390 Fundamental Programming  
Practices (FPP)  
Professor Anne McCollum**

# 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, such as traversing a tree.)



# Why Recursion?

- 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

- The definition of factorial is that for any positive integer  $n$ :

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

$$0! = 1$$

Example:  $5! = 5 \times 4 \times 3 \times 2 \times 1$

- 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);  
}
```

See lesson7.fibfactorial package, class Factorial for an example of factorial.

# Factorial continued

We can trace the computation of factorial the same as any sequence of function calls.

```
factorial(5)
  factorial(4)
    factorial(3)
      factorial(2)
        factorial(1)
          return 1
        return 2*1 = 2
      return 3*2 = 6
    return 4*6 = 24
  return 5*24 = 120
```



# Recursion in Java

- In order for a self-calling method 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.

Hmmm how many behind me?

# Example



- You are standing in line, waiting to get into an event (like a movie or a concert). You are at the front of the line. You wonder "How many people are in line behind me?" The line is long, so there is no way for you to count the number of people in line yourself. You decide to use recursion.
- For this task, we make the following rule: Each person in line is allowed to ask the person directly behind him one question.
- What question should you, and the person behind you, and the person behind him,... ask? How can the answers lead to a solution to the problem?

# The idea

- With recursion, you break up a big problem into smaller occurrences of that same problem.
- In this 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?

# Recursive Solution

The question to ask: "How many people are behind you?"

Suppose Person C is behind Person B and person B is behind Person A. If Person C answers "There are  $N$  people behind me", then Person B knows there are  $N+1$  persons behind *him*. Then, when person A asks the question to Person B, Person B will answer " $N+1$ ".

The last person in line has no one behind him, so he will answer "0".



# Recursive Solution In Code (optional)

```
public class Person {  
    String name;  
    Person behind;  
    Person(String n) {  
        name = n;  
    }  
    int answerToQuestion() {  
        if(behind == null) return 0 ;  
        else return behind.answerToQuestion() + 1;  
    }  
}
```

```
public class PersonLine {  
    private Person[] personLine;  
    PersonLine(Person[] persons) {  
        personLine = persons;  
    }  
    public int howManyInLine() {  
        return personLine[0].answerToQuestion() + 1;  
    }  
}
```

# Exercise 7.0

Simple Task: Write a recursive solution to printout a String in reverse order.

To develop a valid recursion for this, ask yourself:

- What is the base case?
- What is the self call (parameters, etc.)?
- How is the problem reduced with each self call?



# Exercise 7.0 continued

Write a recursive solution to calculate the product of an array of numbers which is given as input.

Base case:

No more characters to display

Self call parameters:

The string characters that have not yet been printed

Problem reduced with each self call:

Print one character

Return a substring that does not include the character that was printed.

# Exercise 7.0 – Solution

```
void reverseStr(String str) {  
    if (str.length() == 0)  
        return;  
    int lastIdx = str.length()-1;  
    System.out.print(str.charAt(lastIdx));  
    reverseStr(str.substring(0, lastIdx));  
}
```

# Another Example of Recursion

The Fibonacci numbers are defined as follows:

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

The next number is found by adding up the two numbers before it.

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

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`

# Redundant Recursion

Why is calculating the nth Fibonacci number using recursion redundant?

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

Hint: List the calls for  $n = 5$ .

# 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.

Extra method calls in recursive iterations can also be inefficient. (Method variables are stored on stack...)

Example: 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 7.2

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

```
public class Fib {  
  
    public int fib(int n) {  
        //implement  
        return 0;  
    }  
  
    public static void main(String[] args) {  
        Fib f = new Fib();  
        System.out.println(f.fib(10));  
    }  
}
```

# Solution

```
public class Fib {  
    int[] store;  
  
    public int fib(int n) {  
        store = new int[n+1];  
        store[0] = 0;  
        store[1] = 1;  
  
        for(int i = 2; i <= n; i++) {  
            store[i] = store[i-1] + store[i-2];  
        }  
        return store[n];  
    }  
}
```

# 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).

# 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

# 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 first or 0<sup>th</sup> character `ch` from the input string and name the modified string `t`.
- Reverse `t` and append `ch`.

*Thinking recursively.* Assume the recursive produces the expected output, and find a way to combine the base case output with the output from the recursive step.



# 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  $\text{charS}$  be the 0<sup>th</sup> character of  $s$  and  $\text{charT}$  be the 0<sup>th</sup> character of  $t$ .
2. Merge action:
  - If  $\text{charS}$  comes before  $\text{charT}$  alphabetically, store  $\text{charS}$  in a buffer,
  - otherwise place  $\text{charT}$  in a buffer;
  - 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, and in the third step we are calling that procedure. The way to think about it is: After you have done something with the 0<sup>th</sup> 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 && t == null) return null;
        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 0<sup>th</sup> character `ch` from the string and call the resulting string `t`.
- Find (recursively) the minimum character in `t` -- call it `min`.
- If `min < ch`, return `min`; otherwise, return `ch`.

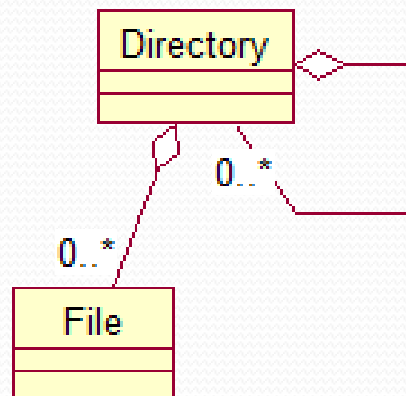
*Thinking recursively.* After processing the 0<sup>th</sup> character, assume the `findMin` operation works correctly on the remaining elements.

# 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 prevMin = rmin(str.substring(1));  
        return (ch < prevMin ? ch : prevMin);  
    }  
}
```

# 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 problem is naturally solved by 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.
- 
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.

