Building Java Programs

Chapter 12

introduction to recursion

reading: 12.1


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Road Map - Quarter

CS Concepts

- Client/Implementer
- Efficiency
- Recursion
- Regular Expressions
- Grammars
- Sorting
- Backtracking
- Hashing
- Huffman Compression

Java Language

- Exceptions
- Interfaces
- References
- Comparable
- Generics
- Inheritance/Polymorphism
- Abstract Classes

Data Structures

- Lists
- Stacks
- Queues
- Sets
- Maps
- Priority Queues

Java Collections

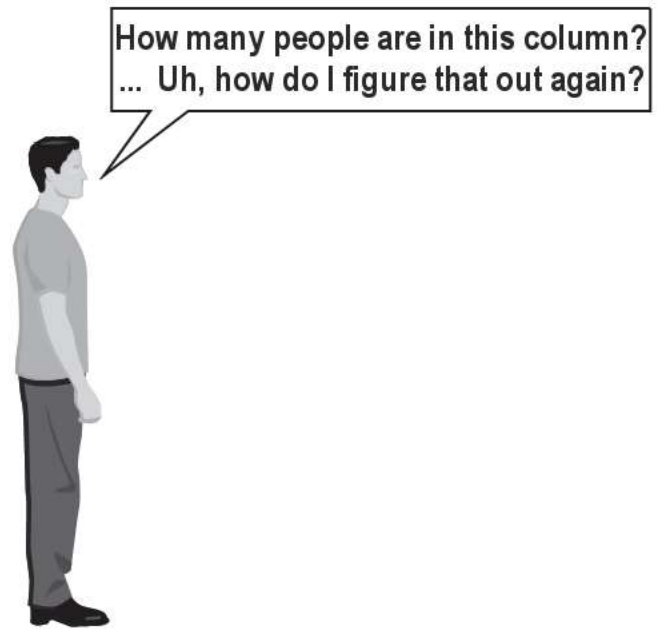
- Arrays
- ArrayList 🛠
- LinkedList 🛠
- Stack
- TreeSet / TreeMap
- HashSet / HashMap
- PriorityQueue

Road Map - Week

- Monday
  - Introduce idea of "recursion"
  - Goal: Understand idea of recursion and read recursive code.
- Tuesday
  - Practice reading recursive code
- Wednesday
  - More complex recursive examples
  - Goal: Identify recursive structure in problem and write recursive code
- Thursday
  - Practice writing recursive code
- Friday
  - Exam logistics
  - Set-up for A5

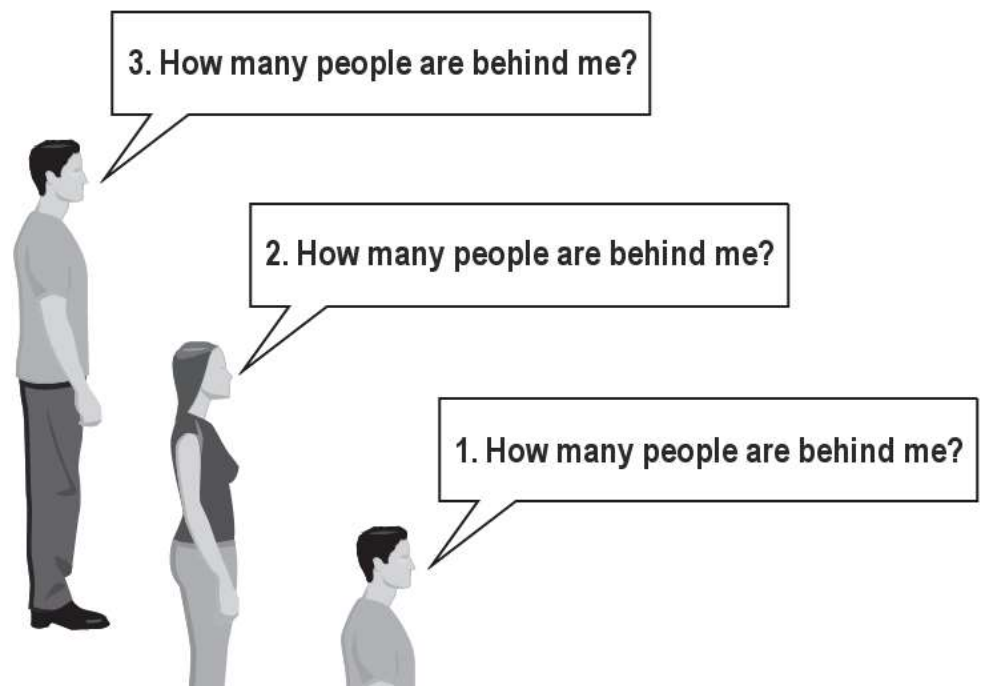
Exercise

- (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 right next to you. So you can't just look back and count.
  - But you are allowed to ask questions of the person next to you.
  - How can we solve this problem? (*recursively*)



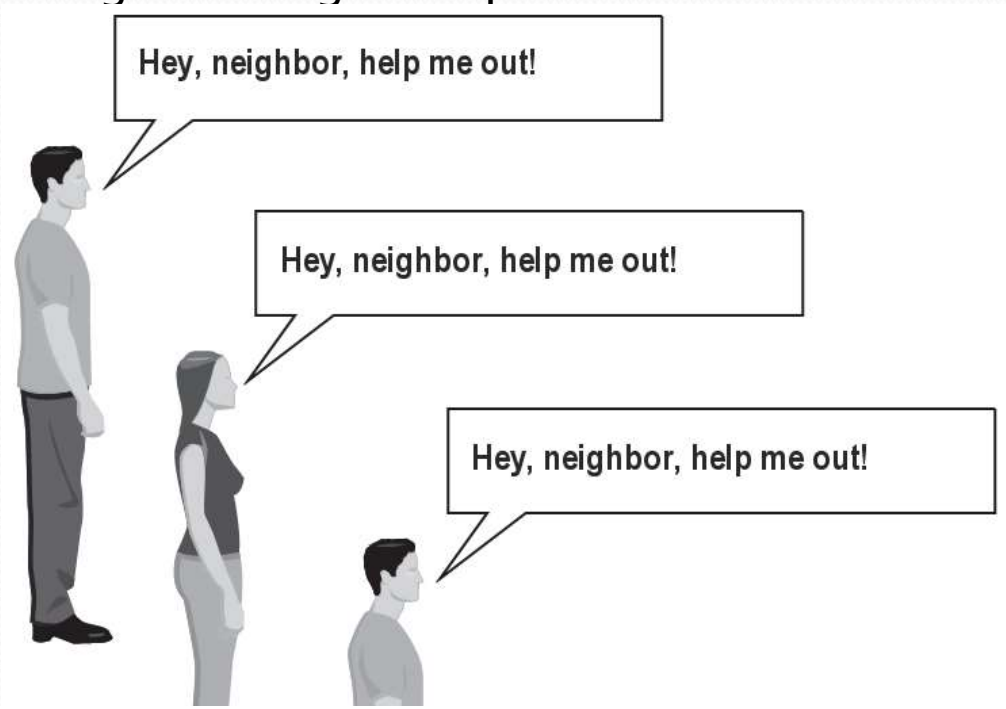
Recursive algorithm

- 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**.



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?



Recursion

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

- **recursive programming**: Writing methods that call themselves to solve problems recursively.

  - An equally powerful substitute for *iteration* (loops)
  - Particularly well-suited to solving certain types of problems

Why learn recursion?

- "Cultural experience" – think differently about problems
- Solves some problems more naturally than iteration
- Can lead to elegant, simplistic, short code (when used well)
- Many programming languages ("functional" languages such as Scheme, ML, and Haskell) use recursion exclusively (no loops)
- A key component of many of our assignments in CSE 143

Getting down stairs

- Need to know two things:
  - Getting down one stair
  - Recognizing the bottom

- Most code will look like:

```
if (simplest case) {
    compute and return solution
} else {
    divide into similar subproblem(s)
    solve each subproblem recursively
    assemble the overall solution
}
```

Recursion and cases

- Every recursive algorithm involves at least 2 cases:
  - **base case**: A simple occurrence that can be answered directly.
  - **recursive case**: A more complex occurrence of the problem that cannot be directly answered, but can instead be described in terms of smaller occurrences of the same problem.
  - Some recursive algorithms have more than one base or recursive case, but all have at least one of each.
  - A crucial part of recursive programming is identifying these cases.

Linked Lists are Self-Similar

- a linked list is:
  - null
  - a node whose `next` field references a list

- **recursive data structure**: a data structure partially composed of smaller or simpler instances of the same data structure

Another recursive task

- How can we remove exactly half of the M&M's in a large bowl, without dumping them all out or being able to count them?
  - What if multiple people help out with solving the problem? Can each person do a small part of the work?
  - What is a number of M&M's that it is easy to double, even if you can't count?
    - (What is a "base case"?)

Recursion in Java

- Consider the following method to print a line of * characters:

```
// Prints a line containing the given number of stars.
// Precondition: n >= 0
public static void printStars(int n) {
    for (int i = 0; i < n; i++) {
        System.out.print("*");
    }
    System.out.println();   // end the line of output
}
```

- Write a recursive version of this method (that calls itself).
  - Solve the problem without using any loops.
  - Hint: Your solution should print just one star at a time.

A basic case

- What are the cases to consider?
  - What is a very easy number of stars to print without a loop?

```
public static void printStars(int n) {
    if (n == 1) {
        // base case; just print one star
        System.out.println("*");
    } else {
        ...
    }
}
```

Handling more cases

- Handling additional cases, with no loops (in a bad way):

```
public static void printStars(int n) {
    if (n == 1) {
        // base case; just print one star
        System.out.println("*");
    } else if (n == 2) {
        System.out.print("*");
        System.out.println("*");
    } else if (n == 3) {
        System.out.print("*");
        System.out.print("*");
        System.out.println("*");
    } else if (n == 4) {
        System.out.print("*");
        System.out.print("*");
        System.out.print("*");
        System.out.println("*");
    } else ...
}
```

Handling more cases 2

- Taking advantage of the repeated pattern (somewhat better):

```
public static void printStars(int n) {
    if (n == 1) {
        // base case; just print one star
        System.out.println("*");
    } else if (n == 2) {
        System.out.print("*");
        printStars(1);    // prints "*"
    } else if (n == 3) {
        System.out.print("*");
        printStars(2);    // prints "**"
    } else if (n == 4) {
        System.out.print("*");
        printStars(3);    // prints "***"
    } else ...
}
```

Using recursion properly

- Condensing the recursive cases into a single case:

```
public static void printStars(int n) {
    if (n == 1) {
        // base case; just print one star
        System.out.println("*");
    } else {
        // recursive case; print one more star
        System.out.print("*");
        printStars(n - 1);
    }
}
```

"Recursion Zen"

- The real, even simpler, base case is an `n` of 0, not 1:

```
public static void printStars(int n) {
    if (n == 0) {
        // base case; just end the line of output
        System.out.println();
    } else {
        // recursive case; print one more star
        System.out.print("*");
        printStars(n - 1);
    }
}
```

  - **Recursion Zen**: The art of properly identifying the best set of cases for a recursive algorithm and expressing them elegantly.

    (A CSE 143 informal term)

Recursion vs Iteration

```
public static void writeStars(int n) {
   while (n > 0) {
      System.out.print("*");
      n--;
   }
   System.out.println();
}

public static void writeStars(int n) {
   if (n == 0) {
      System.out.println();
   } else {
      System.out.print("*");
      writeStars(n - 1);
   }
}
```

Recursion vs Iteration

```
public static void writeStars(int n) {
    while (n > 0) {
        System.out.print("*");
        n--;
    }
    System.out.println(); // base case. assert: n == 0
}

public static void writeStars(int n) {
    if (n == 0) {
        System.out.println(); // base case
    } else {
        System.out.print("*");
        writeStars(n - 1);
    }
}
```

Recursion vs Iteration

```
public static void writeStars(int n) {
    while (n > 0) { // "recursive" case
        System.out.print("*"); // small piece of problem
        n--;
    }
    System.out.println();
}

public static void writeStars(int n) {
    if (n == 0) {
        System.out.println();
    } else { // "recursive" case. assert: n > 0
        System.out.print("*"); // small piece of problem
        writeStars(n - 1);
    }
}
```

Recursion vs Iteration

```
public static void writeStars(int n) {
    while (n > 0) { // "recursive" case
        System.out.print("*");
        n--; // make the problem smaller
    }
    System.out.println();
}

public static void writeStars(int n) {
    if (n == 0) {
        System.out.println();
    } else { // "recursive" case. assert: n > 0
        System.out.print("*");
        writeStars(n - 1); // make the problem smaller
    }
}
```

Recursive tracing

- Consider the following recursive method:

```
public static int mystery(int n) {
    if (n < 10) {
        return n;
    } else {
        int a = n / 10;
        int b = n % 10;
        return mystery(a + b);
    }
}
```

  - What is the result of the following call?

    `mystery(648)`

A recursive trace

mystery(648):

```
int a = 648 / 10;          // 64
int b = 648 % 10;          //  8
return mystery(a + b);     // mystery(72)
```

mystery(72):

```
int a = 72 / 10;           // 7
int b = 72 % 10;           // 2
return mystery(a + b);     // mystery(9)
```

mystery(9):

```
return 9;
```

Recursive tracing 2

- Consider the following recursive method:

```
public static int mystery(int n) {
    if (n < 10) {
        return (10 * n) + n;
    } else {
        int a = mystery(n / 10);
        int b = mystery(n % 10);
        return (100 * a) + b;
    }
}
```

  - What is the result of the following call?

    `mystery(348)`

A recursive trace 2

mystery(348)

- `int a = mystery(34);`
  - `int a = mystery(3);`

    `return (10 * 3) + 3;  // 33`
  - `int b = mystery(4);`

    `return (10 * 4) + 4;  // 44`
  - `return (100 * 33) + 44;  // 3344`
- `int b = mystery(8);`

  `return (10 * 8) + 8;  // 88`
- `return (100 * 3344) + 88;  // 334488`

- What is this method really doing?

Exercise

- Note: We did `reverseDeck` in lecture but they are the **exact same problem**
- Write a recursive method `reverseLines` that accepts a file `Scanner` and prints the lines of the file in reverse order.
  - Example input file:

```
I have eaten
the plums
that were in
the icebox
```


Expected console output:

```
the icebox
that were in
the plums
I have eaten
```

  - What are the cases to consider?
    - How can we solve a small part of the problem at a time?
    - What is a file that is very easy to reverse?

Reversal pseudocode

- Reversing the lines of a file:
  - Read a line L from the file.
  - Print the rest of the lines in reverse order.
  - Print the line L.

- If only we had a way to reverse the rest of the lines of the file....

Reversal solution

```
public static void reverseLines(Scanner input) {
    if (input.hasNextLine()) {
        // recursive case
        String line = input.nextLine();
        reverseLines(input);
        System.out.println(line);
    }
}
```

- Where is the base case?

Tracing our algorithm

- **call stack**: The method invocations currently running

```
reverseLines(new Scanner("poem.txt"));
```

```
public static void reverseLines(Scanner input) {
    if (input.hasNextLine()) {
        String line = input.nextLine();   // "I have eaten"
public static void reverseLines(Scanner input) {
    if (input.hasNextLine()) {
        String line = input.nextLine();   // "the plums"
public static void reverseLines(Scanner input) {
    if (input.hasNextLine()) {
        String line = input.nextLine();   // "that were in"
public static void reverseLines(Scanner input) {
    if (input.hasNextLine()) {
        String line = input.nextLine();   // "the icebox"
public static void reverseLines(Scanner input) {
    if (input.hasNextLine()) {   // false
        ...
    }
}
```

```
I have eaten
the plums
that were in
the icebox
```

```
the icebox
that were in
the plums
I have eaten
```