

Building Java Programs

Chapter 12
introduction to recursion

reading: 12.1

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Road Map

CS Concepts

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


Data Structures

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

Java Language

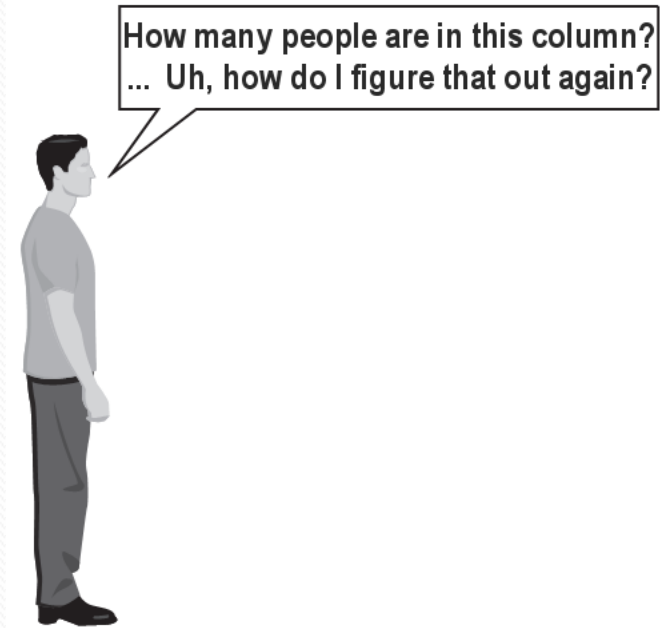
- Exceptions
- Interfaces
- References
- Comparable
- Generics
- Inheritance/Polymorphism
- Abstract Classes

Java Collections

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

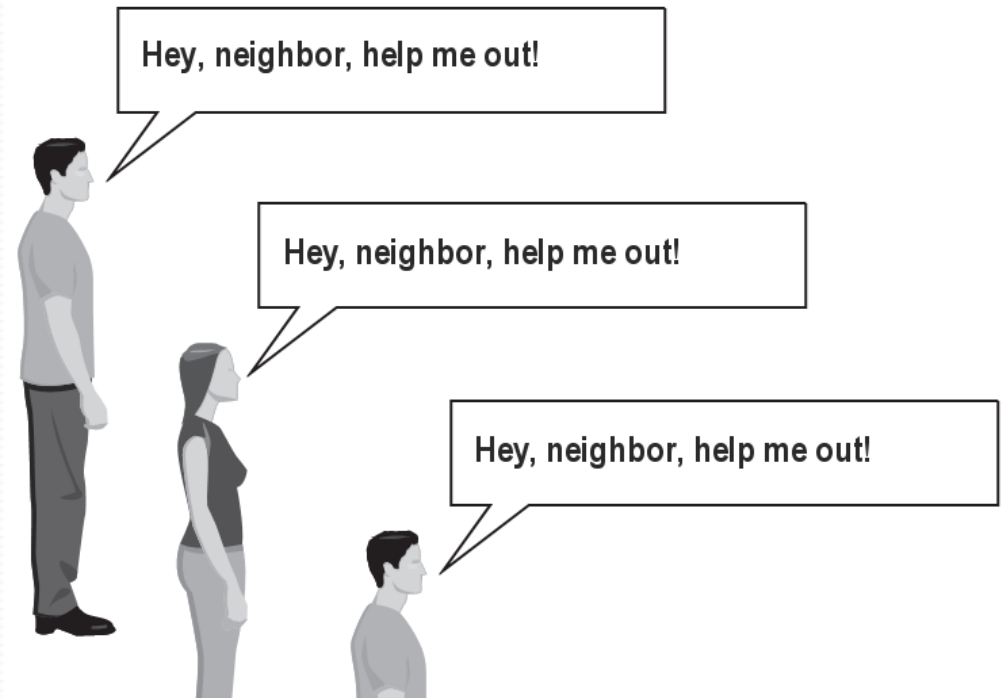
Exercise

- (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*)



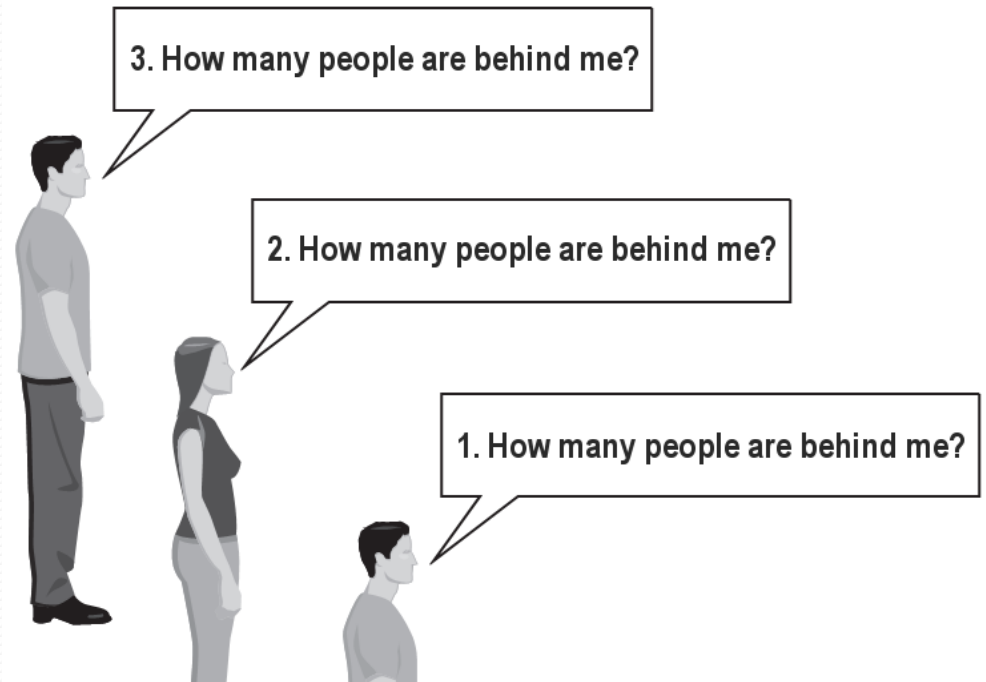
The idea

- 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 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**.



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  
}
```

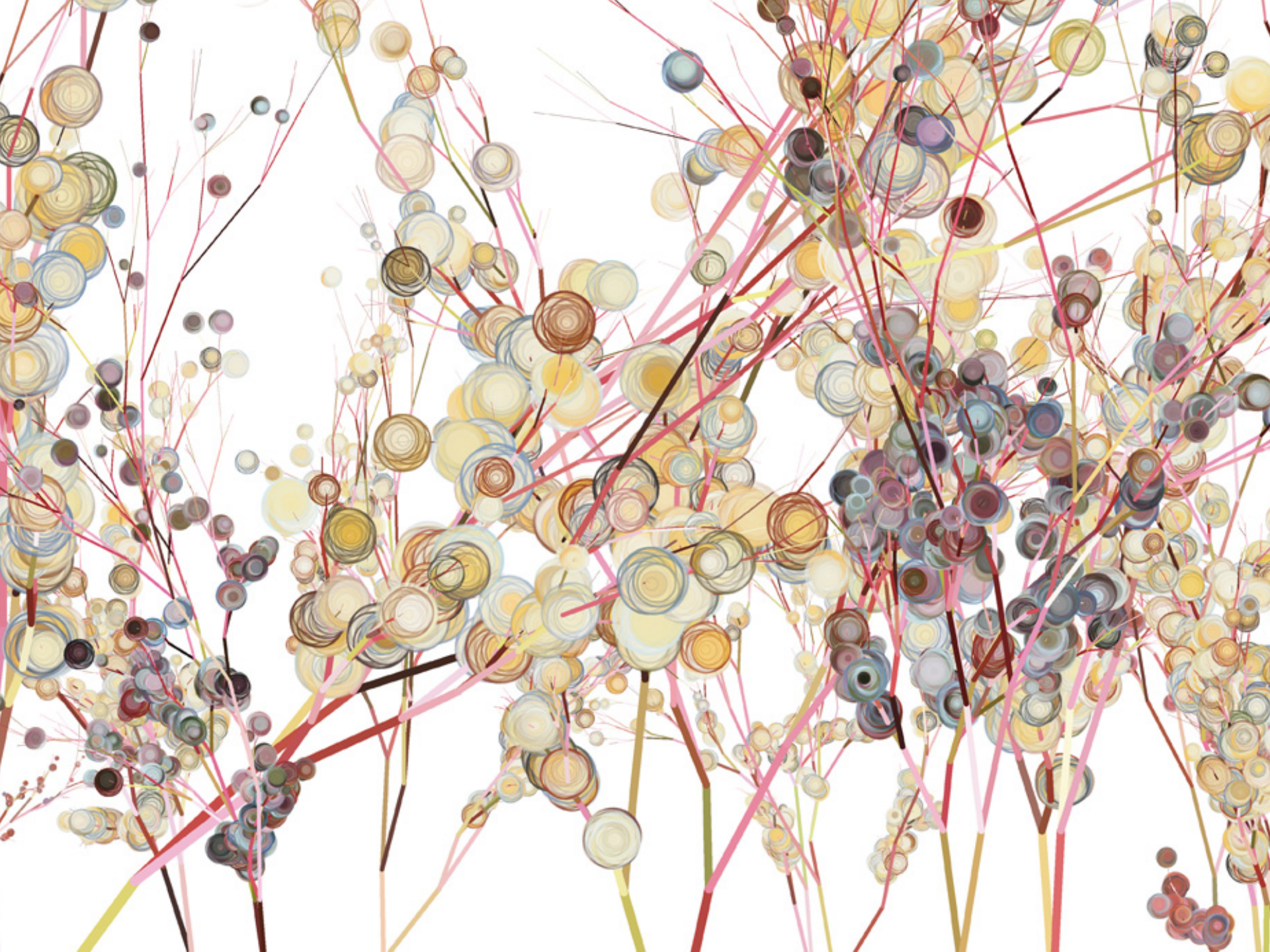
Recursion and cases

- 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 `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