Two-Dimensional Arrays

EECS1022 Sections M & N:
Programming for Mobile Computing
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Learning Outcomes

Understand:

- Nested loops
- Two-Dimensional Arrays: Why?
- Two-Dimensional Arrays: Syntax and Semantics
- Two-Dimensional Arrays: Examples

Assumptions

It is assumed that you also complete:

- **Java Tutorial Videos**:
  - ***Weeks 10*** [link]
  - ***Weeks 11*** [link]

Sequential Loops vs. Nested Loops

- *Sequential Loops*:
  Each loop completes an *independent* phase of work.
  e.g., Print an array from left to right, then right to left.

```
System.out.println("Left to right:");
for(int i = 0; i < a.length; i ++) {
  System.out.println(a[i]); }
System.out.println("Right to left:");
for(int i = 0; i < a.length; i ++) {
  System.out.println(a[a.length - i - 1]); }
```

- *Nested Loops*:
  Loop counters form *all combinations* of indices.

```
for(int i = 0; i < a.length; i ++) {
  for(int j = 0; j < a.length; j ++) {
    System.out.println("(" + i + ", " + j + ")");
  } }
```

Nested Loops: Finding Duplicates (1)

- Given an integer array `a`, determine if it contains any duplicates. e.g., Print *false* for $\{1,2,3,4\}$. Print *true* for $\{1,4,2,4\}$.
- **Hint:** When can you conclude that there are duplicates?
  As soon as we find that two elements at difference indices happen to be the same

```
1  boolean hasDup = false;
2  for(int i = 0; i < a.length; i ++) {
3    for(int j = 0; j < a.length; j ++) {
4      hasDup = hasDup || (i != j && a[i] == a[j]);
5    } /* end inner for */ } /* end outer for */
6  System.out.println(hasDup);
```

- **Question:** How do you modify the code, so that we exit from the loops *as soon as* the array is found containing duplicates?
  - **L2**: `for(...; !hasDup && i < a.length; ...)`
  - **L3**: `for(...; !hasDup && j < a.length; ...)`
  - **L4**: `hasDup = (i != j && a[i] == a[j]);`

Nested Loops: Finding Duplicates (2)

```
1  /* Version 1 with redundant scan */
2  int[] a = {1, 2, 3}; /* no duplicates */
3  boolean hasDup = false;
4  for(int i = 0; i < a.length; i ++) {
5    for(int j = 0; j < a.length; j ++) {
6      hasDup = hasDup || (i != j && a[i] == a[j]);
7    } /* end inner for */ } /* end outer for */
8  System.out.println(hasDup);
```

i	j	i != j	a[i]	a[j]	a[i] == a[j]	hasDup
0	0	*false*	1	1	*true*	*false*
0	1	*true*	1	2	*false*	*false*
0	2	*true*	1	3	*false*	*false*
1	0	*true*	2	1	*false*	*false*
1	1	*false*	2	2	*true*	*false*
1	2	*true*	2	3	*false*	*false*
2	0	*true*	3	1	*false*	*false*
2	1	*true*	3	2	*false*	*false*
2	2	*false*	3	3	*true*	*false*

Nested Loops: Finding Duplicates (3)

```
1  /* Version 1 with redundant scan and no early exit */
2  int[] a = {4, 2, 4}; /* duplicates: a[0] and a[2] */
3  boolean hasDup = false;
4  for(int i = 0; i < a.length; i ++) {
5    for(int j = 0; j < a.length; j ++) {
6      hasDup = hasDup || (i != j && a[i] == a[j]);
7    } /* end inner for */ } /* end outer for */
8  System.out.println(hasDup);
```

i	j	i != j	a[i]	a[j]	a[i] == a[j]	hasDup
0	0	false	4	4	true	false
0	1	true	4	2	false	false
0	2	true	4	4	true	true
1	0	true	2	4	false	true
1	1	false	2	2	true	true
1	2	true	2	4	false	true
2	0	true	4	4	true	true
2	1	true	4	2	false	true
2	2	false	4	4	true	true

Nested Loops: Finding Duplicates (4)

```
1  /* Version 2 with redundant scan */
2  int[] a = {1, 2, 3}; /* no duplicates */
3  boolean hasDup = false;
4  for(int i = 0; i < a.length && !hasDup; i ++) {
5    for(int j = 0; j < a.length && !hasDup; j ++) {
6      hasDup = i != j && a[i] == a[j];
7    } /* end inner for */ } /* end outer for */
8  System.out.println(hasDup);
```

i	j	i != j	a[i]	a[j]	a[i] == a[j]	hasDup
0	0	false	1	1	true	false
0	1	true	1	2	false	false
0	2	true	1	3	false	false
1	0	true	2	1	false	false
1	1	false	2	2	true	false
1	2	true	2	3	false	false
2	0	true	3	1	false	false
2	1	true	3	2	false	false
2	2	false	3	3	true	false

Nested Loops: Finding Duplicates (5)

```
1  /* Version 2 with redundant scan and early exit */
2  int[] a = {4, 2, 4}; /* duplicates: a[0] and a[2] */
3  boolean hasDup = false;
4  for(int i = 0; i < a.length &&  !hasDup ; i ++) {
5    for(int j = 0; j < a.length &&  !hasDup ; j ++) {
6      hasDup =  i != j && a[i] == a[j] ;
7    } /* end inner for */ } /* end outer for */
8  System.out.println(hasDup);
```

i	j	i != j	a[i]	a[j]	a[i] == a[j]	hasDup
0	0	*false*	4	4	*true*	*false*
0	1	*true*	4	2	*false*	*false*
0	2	*true*	4	4	*true*	*true*

Nested Loops: Finding Duplicates (6)

The previous two versions scan all pairs of array slots, but with redundancy: e.g., `a[0] == a[2]` and `a[2] == a[0]`.

```
1  /* Version 3 with no redundant scan */
2  int[] a = {1, 2, 3, 4}; /* no duplicates */
3  boolean hasDup = false;
4  for(int i = 0; i < a.length && !hasDup; i ++) {
5    for(int j = i + 1; j < a.length && !hasDup; j ++) {
6      hasDup = a[i] == a[j];
7    } /* end inner for */ } /* end outer for */
8  System.out.println(hasDup);
```

i	j	a[i]	a[j]	a[i] == a[j]	hasDup
0	1	1	2	*false*	*false*
0	2	1	3	*false*	*false*
0	3	1	4	*false*	*false*
1	2	2	3	*false*	*false*
1	3	2	4	*false*	*false*
2	3	3	4	*false*	*false*

Nested Loops: Finding Duplicates (7)

```
1  /* Version 3 with no redundant scan:
2   * array with duplicates causes early exit
3   */
4  int[] a = {1, 2, 3, 2}; /* duplicates: a[1] and a[3] */
5  boolean hasDup = false;
6  for(int i = 0; i < a.length && !hasDup; i ++) {
7    for(int j = i + 1; j < a.length && !hasDup; j ++) {
8      hasDup = a[i] == a[j];
9    } /* end inner for */ } /* end outer for */
10 System.out.println(hasDup);
```

i	j	a[i]	a[j]	a[i] == a[j]	hasDup
0	1	1	2	*false*	*false*
0	2	1	3	*false*	*false*
0	3	1	2	*false*	*false*
1	2	2	3	*false*	*false*
1	3	2	2	*true*	*true*

2-D Arrays: Motivating Example (1)

Consider a table of distances between seven cities:

	Chicago	Boston	New York	Atlanta	Miami	Dallas	Houston
Chicago	0	983	787	714	**1375**	967	1087
Boston	**983**	0	214	1102	1763	1723	1842
New York	787	214	0	888	1549	1548	1627
Atlanta	714	1102	888	0	661	781	810
Miami	1375	1763	1549	661	0	1426	**1187**
Dallas	967	1723	1548	781	1426	0	239
Houston	1087	1842	1627	810	1187	239	0

As part of the program for an airline reservation system, the *distance of a trip* with *multiple stop-overs* is to be calculated in order to accumulate the milage of frequent flyers.

e.g., A trip {`Boston, Chicago, Miami, Houston`} takes 983 (B-to-C) + 1375 (C-to-M) + 1187 (M-to-H) = 3545 miles

Question: How do you manipulate such information in Java?

2-D Arrays: Motivating Example (2.1)

Here is a solution based on what we've learnt so far:

- Fix the "positions" of cities in the table as constants:

```
final int CHICAGO = 0;
final int BOSTON = 1;
final int MIAMI = 4;
```

- Represent each (horizontal) row using a one-dimensional array:

```
int[] fromChicago = {0, 983, 787, 714, 1375, 967, 1087}
int[] fromBoston = {983, 0, 214, 1102, 1763, 1723, 1842}
int[] fromMiami = {1375, 1763, 1549, 661, 0, 1426, 1187}
```

- Given an itinerary {Boston, Chicago, Miami, Houston}, choose the corresponding arrays in the right order:

```
int[] dist = fromBoston[CHICAGO]
           + fromChicago[MIAMI]
           + fromMiami[HUSTON];
```

2-D Arrays: Motivating Example (2.2)

What if cities of an itinerary are read from the user?

```
1  Scanner input = new Scanner(System.in);
2  System.out.println("How many cities?");
3  int howMany = input.nextInt(); input.nextLine();
4  String[] trip = new String[howMany];
5  /* Read cities in the trip from the user. */
6  for(int i = 0; i < howMany; i ++) {
7    System.out.println("Enter a city:");
8    trip[i] = input.nextLine();
9  }
10 /* Add up source-to-destination distances. */
11 int dist = 0;
12 for(int i = 0; i < howMany - 1; i ++) {
13   String src = trip[i];
14   String dst = trip[i + 1];
15   /* How to accumulate the distance between src and dst?  */
16 }
```

2-D Arrays: Motivating Example (2.3)

Given a source and a destination, we need to *explicitly* select:

- The corresponding *source row* [e.g., `fromBoston`]
- The corresponding *destination index* [e.g., `CHICAGO`]

```
13 String src = trip[i];
14 String dst = trip[i + 1];
15 if(src.equals("Chicago")) {
16   if(dst.equals("Boston")) {dist += fromChicago[BOSTON];}
17   else if(dst.equals("New York")) {dist += fromChicago[NY];}
18   ...
19 }
20 else if(src.equals("Boston")) {
21   if(dst.equals("Chicago")) {dist += fromBoston[CHICAGO];}
22   else if(dst.equals("NEW YORK")) {dist += fromBoston[NY];}
23   ...
24 }
25 ...
```

- Drawback? $7 \times (7 - 1)$ possibilities to program!

2-D Arrays: Initialization (1)

A *2D array* is really *an array of arrays*

	[0]	[1]	[2]	[3]	[4]
[0]	0	0	0	0	0
[1]	0	0	0	0	0
[2]	0	0	0	0	0
[3]	0	0	0	0	0
[4]	0	0	0	0	0

```
matrix = new int[5][5];
```

	[0]	[1]	[2]
[0]	1	2	3
[1]	4	5	6
[2]	7	8	9
[3]	10	11	12

```
int[][] array = {
   {1, 2, 3},
   {4, 5, 6},
   {7, 8, 9},
   {10, 11, 12}
};
```

2-D Arrays: Initialization (1)

A *2D array* may be initialized either at the time of declaration, or after declaration.

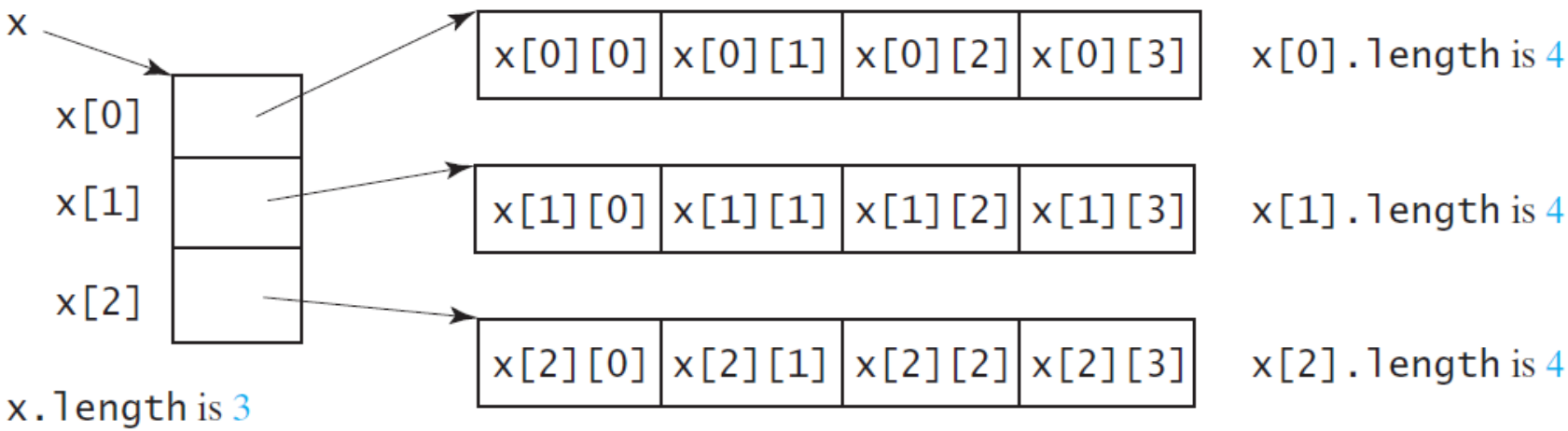
```
int[][] array = {
  {1, 2, 3},
  {4, 5, 6},
  {7, 8, 9},
  {10, 11, 12}
};
```

Same as

```
int[][] array = new int[4][3];
array[0][0] = 1; array[0][1] = 2; array[0][2] = 3;
array[1][0] = 4; array[1][1] = 5; array[1][2] = 6;
array[2][0] = 7; array[2][1] = 8; array[2][2] = 9;
array[3][0] = 10; array[3][1] = 11; array[3][2] = 12;
```

2-D Arrays: Lengths (1)

For a *2D array*, you may query about its *size*, or *sizes* of its component arrays.

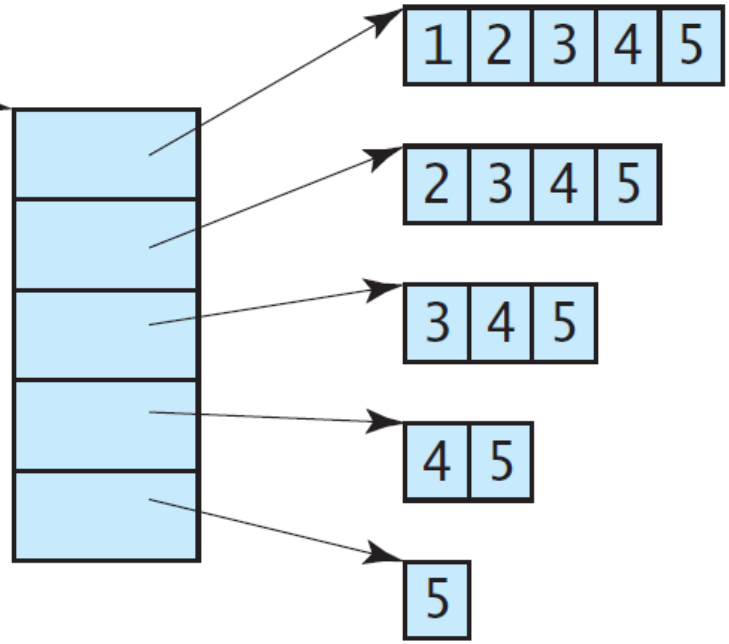


2-D Arrays: Lengths (2)

For a *2D array*, its components may have different *sizes*.

e.g.,

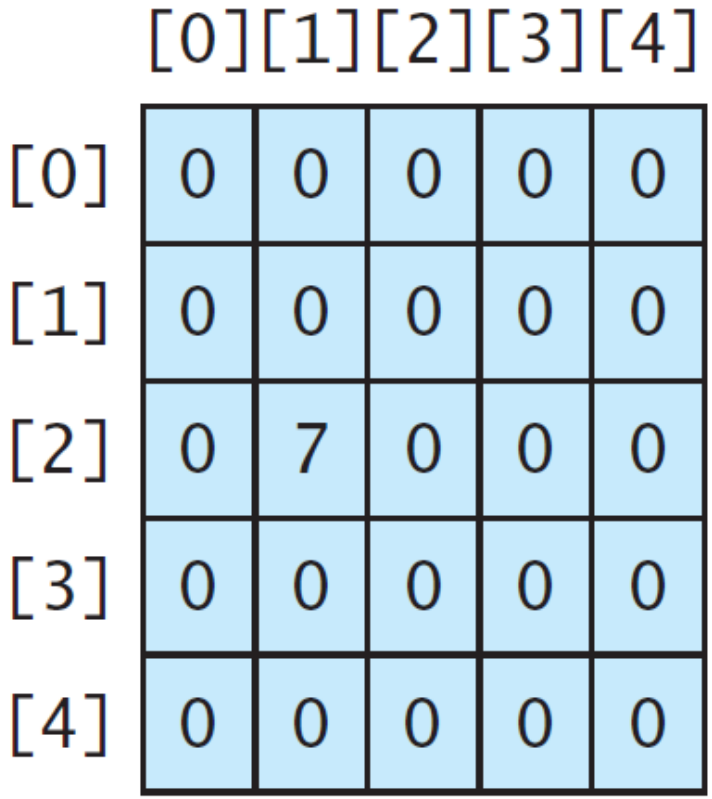
```
int[][] triangleArray = {
  {1, 2, 3, 4, 5},
  {2, 3, 4, 5},
  {3, 4, 5},
  {4, 5},
  {5}
};
```



2-D Arrays: Assignments

For a *2D array*, access a slot via its *row* and *column*.

e.g.,




```
matrix[2][1] = 7;
```

Revisiting the Motivating Example

```
double[][] distances = {
    {0, 983, 787, 714, 1375, 967, 1087},
    {983, 0, 214, 1102, 1763, 1723, 1842},
    {787, 214, 0, 888, 1549, 1548, 1627},
    {714, 1102, 888, 0, 661, 781, 810},
    {1375, 1763, 1549, 661, 0, 1426, 1187},
    {967, 1723, 1548, 781, 1426, 0, 239},
    {1087, 1842, 1627, 810, 1187, 239, 0},
};
```

```
final int CHICAGO = 0;
final int BOSTON = 1;
...
final int HOUSTON = 6;

int MiamiToBoston = distances[MIAMI][BOSTON];
int BostonToNewYork = distances[BOSTON][NEWYORK];
int MiamiToNewYork = MiamiToBoston + BostonToNewYork;
```

Two-Dimensional Arrays: Example (1)

Problem: Given a 2D array `a` of integers, print out all its values: first row, second row, third row, and so on.

```
1  for(int row = 0; row < a.length; row ++) {
2    System.out.print("Row" + row);
3    for(int col = 0; col < a[row].length; col ++) {
4      System.out.print(a[row][col]);
5    }
6    System.out.println(); }
```

- In **L1**, we write *a.length* so that it will print out exactly that many rows in the matrix.
- In **L3**, we write *a[row].length* so that it will print out according to how large the row `a[row]` is.

Two-Dimensional Arrays: Example (2)

Problem: Given a 2D array `a` of integers, calculate the average of its values.

```
int total = 0;
int numOfElements = 0;
for(int row = 0; row < a.length; row ++) {
  for(int col = 0; col < a[row].length; col ++) {
    total += a[row][col];
    numOfElements ++;
  }
}
double average = ((double) total) / numOfElements;
System.out.println("Average is " + average);
```

- Why is the `numOfElements` counter necessary?
- Divide `total` by `a.length * a[0].length` instead?

Two-Dimensional Arrays: Example (3)

Problem: Given a 2D array `a` of integers, find out its *maximum* and *minimum* values.

```
int max = a[0][0];
int min = a[0][0];
for(int row = 0; row < a.length; row ++) {
  for(int col = 0; col < a[row].length; col ++) {
    if (a[row][col] > max) {
      max = a[row][col];
    }
    if (a[row][col] < min) {
      min = a[row][col];
    }
  }
}
System.out.println("Maximum is " + max);
System.out.println("Minimum is " + min);
```

Two-Dimensional Arrays: Example (4)

Problem: Given a 2D array `a` of integers, find out the row which has the *maximum* sum.

```
1  int maxRow = 0; int maxSum = 0;
2  for(int col=0; col < a[0].length; col ++){maxSum += a[ 0 ][col];}
3  for(int row = 1; row < a.length; row ++) {
4    int sum = 0;
5    for(int col = 0; col < a[row].length; col ++) {
6      sum += a[row][col];
7    }
8    if (sum > maxSum) {
9      maxRow = row;
10     maxSum = sum;
11   }
12 }
13 System.out.print("Row at index " + maxRow);
14 System.out.println(" has the maximum sum " + maxSum);
```

Q: What if statement `int sum = 0;` at L4 is moved, outside the for-loop, between L2 and L3?

Two-Dimensional Arrays: Example (5)

Problem: Given a 2D array `a` of integers, determine if all elements are positive.

```
boolean allPos = true;
for(int row = 0; row < a.length; row ++) {
  for(int col = 0; col < a[row].length; col ++) {
    allPos = allPos && a[row][col] > 0;
  } }
if (allPos) { /* print */ } else { /* print */ }
```

Alternatively (with *early exit*):

```
boolean allPos = true;
for(int row = 0; allPos && row < a.length; row ++) {
  for(int col = 0; allPos && col < a[row].length; col ++) {
    allPos = a[row][col] > 0;
  } }
if (allPos) { /* print */ } else { /* print */ }
```

Two-Dimensional Arrays: Example (6)

Problem: Given a 2D array `a` of integers, determine if it is a *rectangle* (i.e., each row has the same number of columns).

```
if(a.length == 0) { /* empty array can't be a rectangle */ }
else { /* a.length > 0 */
  int assumedLength = a[0].length;
  boolean isRectangle = true;
  for(int row = 0; row < a.length; row ++) {
    isRectangle =
      isRectangle && a[row].length == assumedLength;
  }
  if (isRectangle) { /* print */ } else { /* print */ }
}
```

Exercise: Change the above code so that it exits from the loop *as soon as* it is found that the 2-D array is not a rectangle.

Two-Dimensional Arrays: Example (7)

Problem: Given a 2D array `a` of integers, determine if it is a *square* (i.e., each row has the same number of columns, and that number is equal to the number of rows of the 2-D array).

```
if(a.length == 0) { /* empty array can't be a square */ }
else { /* a.length > 0 */
  int assumedLength = a.length;
  boolean isSquare = a[0].length == assumedLength;
  for(int row = 0; row < a.length; row ++) {
    isSquare =
      isSquare && a[row].length == assumedLength;
  }
  if (isSquare) { /* print */ } else { /* print */ }
}
```

Exercise: Change the above code so that it exits from the loop *as soon as* it is found that the 2-D array is not a square.

Two-Dimensional Arrays: Example (8)

- **Problem:** Given a 2D array `a` of integers, print out the *lower-left triangular* area of elements.

  Assumption: The input 2D array is of a *square* shape.

```
for(int row = 0; row < a.length; row ++) {
  for(int col = 0; col <= row; col ++) {
    System.out.print(a[row][col]); }
  System.out.println(); }
```

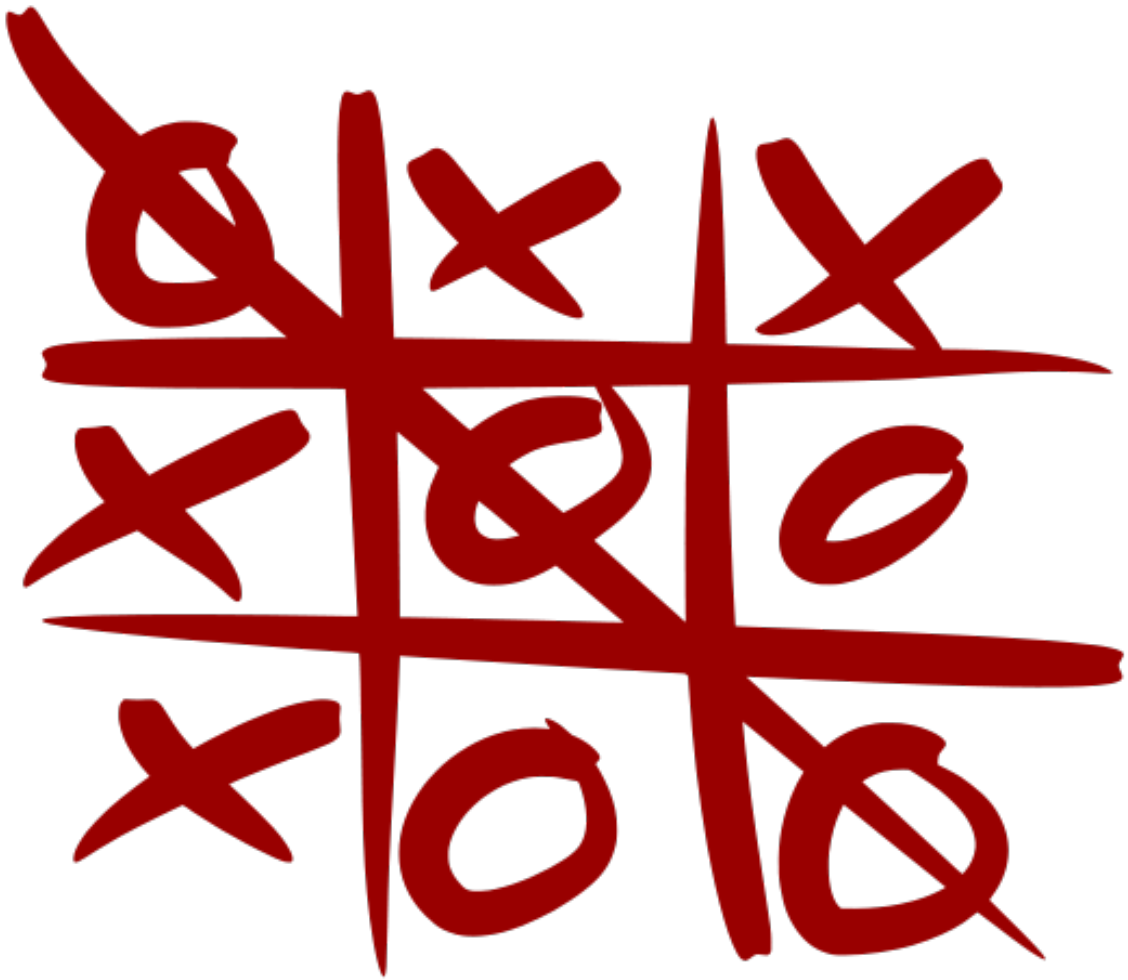
- **Problem:** *upper-left triangular* area?

```
for(int row = 0; row < a.length; row ++) {
  for(int col = 0; col < a[row].length - row; col ++) {
    System.out.print(a[row][col]); }
  System.out.println(); }
```

Exercises: *upper-right triangle*? *lower-right triangle*?

Two-Dimensional Arrays: Example (9)

Consider the tic-tac-toe game:



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