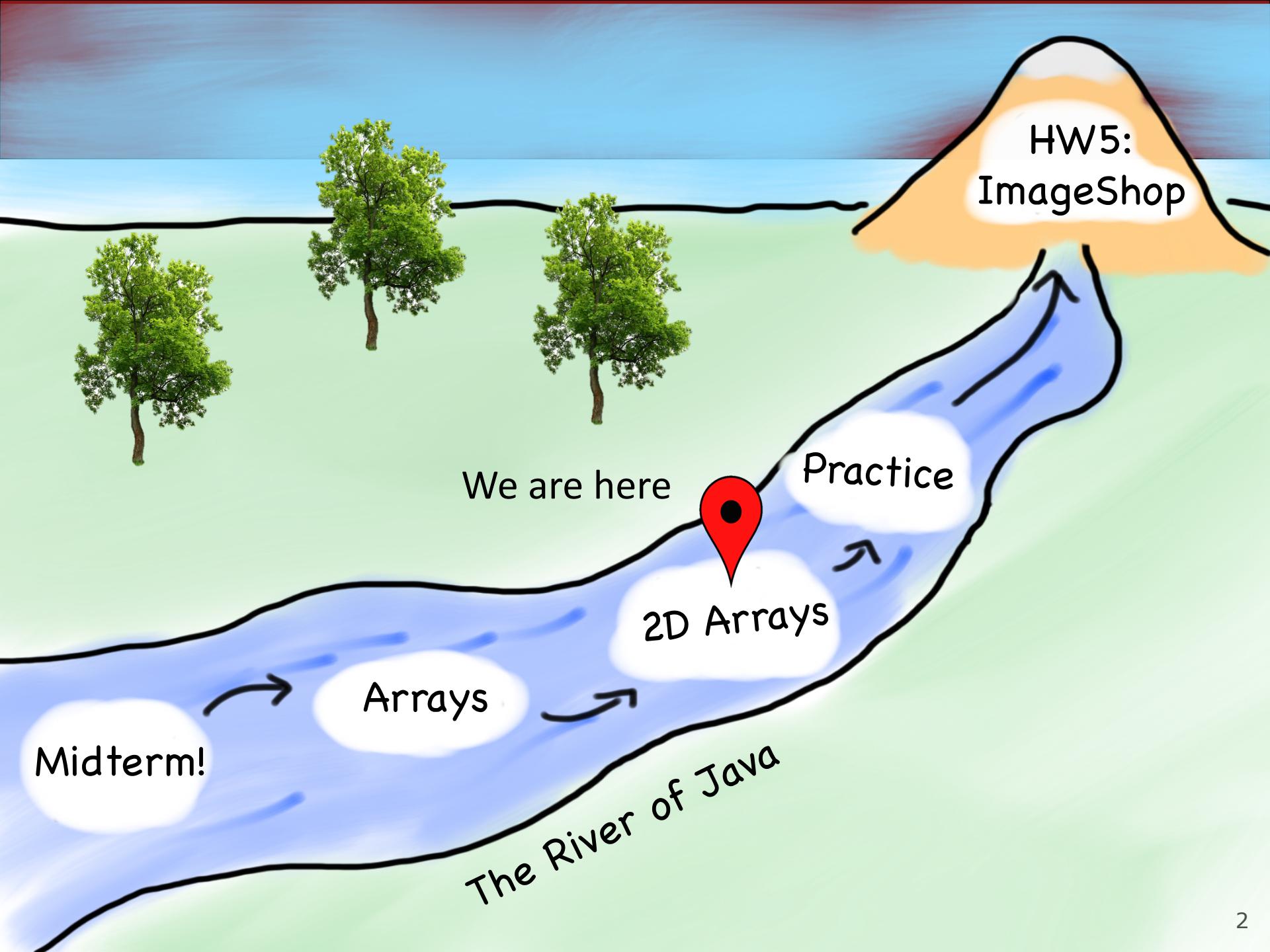


# CS 106A, Lecture 17

## 2D Arrays and Images

suggested reading:

*Java Ch. 11.6-11.7*



# Plan for Today

- Recap: Arrays
- 2D Arrays
- Images as 2D Arrays
- Announcements
- Modifying Images
- Practice: Brighten, Grayscale

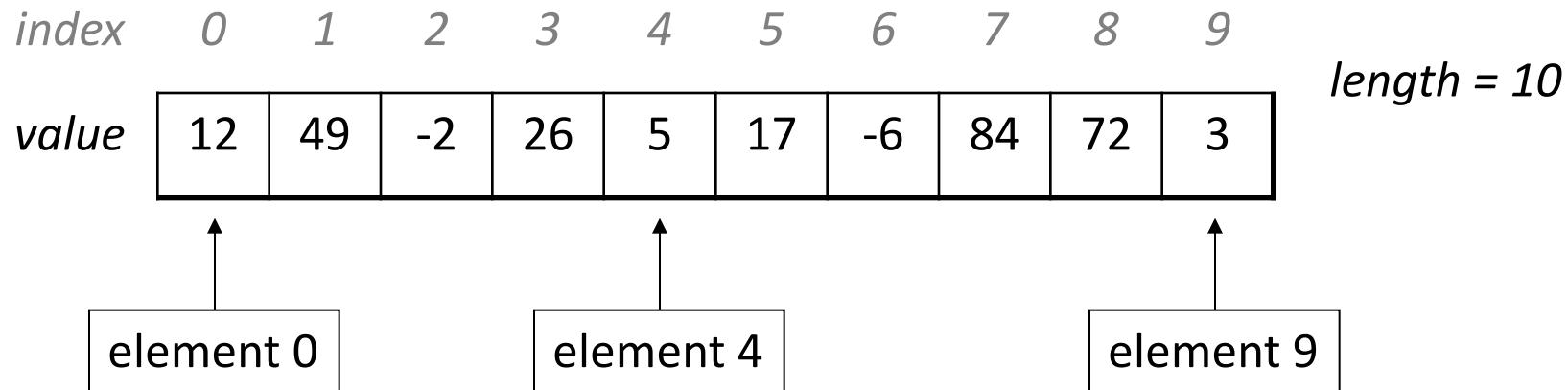
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# From Last Time: Arrays

A new variable type that is an **object** that represents an ordered, homogeneous list of data.

- Arrays have many *elements* that you can access using *indices*



# Creating an Array

```
type[ ] name = new type[length];
```

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

| <i>index</i> | 0 | 1 | 2 | 3 | 4 |
|--------------|---|---|---|---|---|
| <i>value</i> | 0 | 0 | 0 | 0 | 0 |

# Creating an Array

Sometimes, we want to hardcode the elements of an array. Luckily, Java has a special syntax for initializing arrays to hardcoded numbers.

*type[] name = { elements };*

```
// Java infers the array length
int[] numbers = {5, 32, 12, 2, 1, -1, 9};
```

# Accessing Data In An Array

*name*[*index*] // get element at *index*

- Like Strings, indices go from **0** to the array's **length - 1**.

```
for (int i = 0; i < 7; i++) {  
    println(numbers[i]);  
}  
println(numbers[9]); // exception  
println(numbers[-1]); // exception
```

| <i>index</i> | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|--------------|---|---|---|---|---|---|---|
| <i>value</i> | 0 | 1 | 2 | 3 | 4 | 5 | 6 |

# Putting Data In An Array

```
name[index] = value; // set element at index
```

- Like Strings, indices go from **0** to the **array's length - 1**.

```
int[] numbers = new int[7];
for (int i = 0; i < 7; i++) {
    numbers[i] = i;
}
numbers[8] = 2; // exception
numbers[-1] = 5; // exception
```

| <i>index</i> | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|--------------|---|---|---|---|---|---|---|
| <i>value</i> | 0 | 1 | 2 | 3 | 4 | 5 | 6 |

# Array Length

Similar to a String, you can get the length of an array by saying

*myArray.length*

Note that there are *no parentheses* at the end!

# Arrays + For Loops = ❤

Just like with Strings, we can use an array's length, along with its indices, to perform cool operations.

For instance, we can read in numbers from the user:

```
int length = readInt("# of numbers? ");
int[] numbers = new int[length];
for (int i = 0; i < numbers.length; i++) {
    numbers[i] = readInt("Elem " + i + ": ");
}
```

# Arrays + For Loops = ❤

Just like with Strings, we can use an array's length, along with its indices, to perform cool operations.

For instance, we can *sum up* all of an array's elements.

```
int sum = 0;  
for (int i = 0; i < numbers.length; i++) {  
    sum += numbers[i];  
}  
println(sum);
```

# Limitations of Arrays

- An array's length is **fixed**. You cannot resize an existing array:

```
int[] a = new int[4];  
a.length = 10; // error
```

- You cannot compare arrays with == or equals :

```
int[] a1 = {42, -7, 1, 15};  
int[] a2 = {42, -7, 1, 15};  
if (a1 == a2) { ... } // false!  
if (a1.equals(a2)) { ... } // false!
```

- An array does not know how to print itself:

```
println(a1); // [I@98f8c4]
```

# Arrays Methods To The Rescue!

- The class `Arrays` in package `java.util` has useful methods for manipulating arrays:

| Method name                                    | Description   |
|--|---|
| <code>Arrays.binarySearch(array, value)</code> | returns the index of the given value in a <i>sorted</i> array (or < 0 if not found) |
| <code>Arrays.copyOf(array, length)</code>      | returns a new copy of array of given length   |
| <code>Arrays.equals(array1, array2)</code>     | returns true if the two arrays contain same elements in the same order              |
| <code>Arrays.fill(array, value);</code>        | sets every element to the given value   |
| <code>Arrays.sort(array);</code>               | arranges the elements into sorted order   |
| <code>Arrays.toString(array)</code>            | returns a string representing the array, such as "[10, 30, -25, 17]"                |

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# The Matrix



Image used under "fair use" for educational purposes.

Source: <https://www.themarysue.com/decoding-the-transgender-matrix-the-matrix-as-a-transgender-coming-out-story/>

# 2D Arrays (“Matrices”)



WELCOME .... TO  
THE MATRIX!!!!!!

# 2D Arrays

```
type[ ][] name = new type[rows][columns];
```

```
int[][] a = new int[3][5];
```

|   | 0       | 1       | 2       | 3       | 4       |
|---|---------|---------|---------|---------|---------|
| 0 | a[0][0] | a[0][1] | a[0][2] | a[0][3] | a[0][4] |
| 1 | a[1][0] | a[1][1] | a[1][2] | a[1][3] | a[1][4] |
| 2 | a[2][0] | a[2][1] | a[2][2] | a[2][3] | a[2][4] |

# Manipulating 2D Arrays

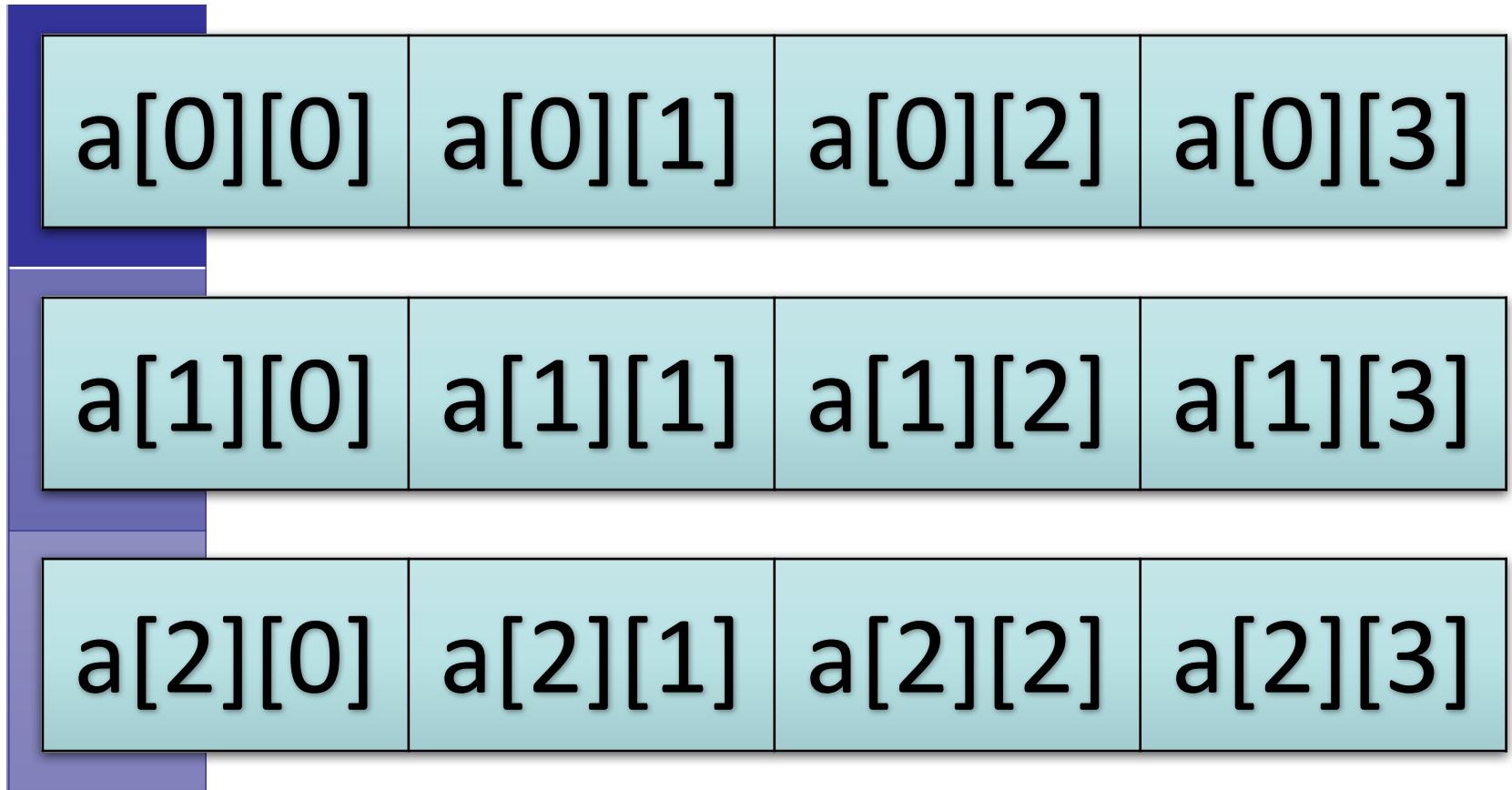
*name*[*row*][*col*] // get element at *row*,*col*

*name*[*row*][*col*] = *value*; // set element at *row*,*col*

2D arrays are  
arrays *of arrays*!

# 2D Arrays = Arrays of Arrays!

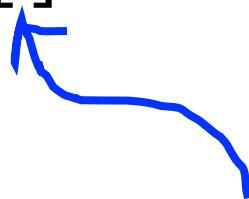
```
int[][] a = new int[3][4];
```



# 2D Arrays = Arrays of Arrays!

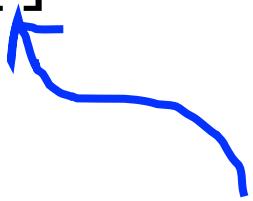
A 2D array is an array where every element is *itself* an array.

```
int[] a = new int[3];
```



“array of” **int**

```
int[][] a = new int[3][4];
```



“array of” **int[]**

# 2D Arrays = Arrays of Arrays!

A 2D array is an array where every element is *itself* an array.

```
int[][] a = new int[3][4];
```

```
...
```

```
int x = a[1][1]; // int at position (1, 1)
```

```
int[] firstRow = a[0]; // 1D array!
```

```
// NOTE: no way to get a single column ☹
```

# 2D Array Dimensions

How do we get the number of rows of a 2D array using the **length** property? How about the number of columns?

|         |         |         |         |
|---------|---------|---------|---------|
| a[0][0] | a[0][1] | a[0][2] | a[0][3] |
| a[1][0] | a[1][1] | a[1][2] | a[1][3] |
| a[2][0] | a[2][1] | a[2][2] | a[2][3] |

# 2D Array Dimensions

You can get the number of rows in a 2D array by saying:

```
arr.Length // # rows in our 2D array
```

Since the length of each row is the same, you can get the number of columns in a 2D array by saying:

```
arr[0].Length // # entries in row 0 ( = # cols)
```

# 2D Arrays + For Loops = ❤

We can use **double for-loops** to loop over each row, and then each column, in a 2D array.

```
int[][] arr = ...
for (int row = 0; row < arr.length; row++) {
    for (int col = 0; col < arr[0].length; col++) {
        // do something with arr[row][col];
    }
}
```

|   | 0  | 1  | 2  | 3  |
|---|----|----|----|----|
| 0 | 75 | 61 | 83 | 71 |
| 1 | 94 | 89 | 98 | 91 |
| 2 | 63 | 54 | 51 | 49 |

“row-major” order

# Practice: 2D Arrays

- Q: What is the array state after the code below?

```
int[] a = new int[4][3];
...    // fill with data at right
for (int r = 1; r < 4; r++) {
    for (int c = 0; c < 3; c++) {
        a[r][c] += a[r - 1][c];
    }
} //
```

A.

|   | 0 | 1 | 2 |
|---|---|---|---|
| 0 | 1 | 3 | 5 |
| 1 | 1 | 3 | 5 |
| 2 | 1 | 3 | 5 |
| 3 | 1 | 3 | 5 |

B.

|   | 0 | 1 | 2 |
|---|---|---|---|
| 0 | 1 | 3 | 6 |
| 1 | 1 | 3 | 6 |
| 2 | 1 | 3 | 6 |
| 3 | 1 | 3 | 6 |

C.

|   | 0 | 1 | 2 |
|---|---|---|---|
| 0 | 1 | 2 | 3 |
| 1 | 2 | 4 | 6 |
| 2 | 2 | 4 | 6 |
| 3 | 2 | 4 | 6 |

D.

|   | 0 | 1 | 2  |
|---|---|---|----|
| 0 | 1 | 2 | 3  |
| 1 | 2 | 4 | 6  |
| 2 | 3 | 6 | 9  |
| 3 | 4 | 8 | 12 |

| r\c | 0 | 1 | 2 |
|-----|---|---|---|
| 0   | 1 | 2 | 3 |
| 1   | 1 | 2 | 3 |
| 2   | 1 | 2 | 3 |
| 3   | 1 | 2 | 3 |

# Limitations of 2D Arrays

- Unlike 1D arrays, you *cannot compare 2D arrays with `Arrays.equals`.* You must use `Arrays.deepEquals`.

```
int[][] a1 = ...
int[][] a2 = ...
if (Arrays.deepEquals(a1, a2)) { ... }
```

- A 2D array does not know how to print itself:

```
int[][] a = new int[rows][cols];
println(a); // [[I@8cf420
println(Arrays.toString(a)); // [[I@6b3f44,[I@32c2a8]...
// [[0, 1, 2, 3, 4], [1, 2, ...
println(Arrays.deepToString(a));
```

# Summary: 2D Arrays

- Make a new 2D array

```
type[][] name = new type[rows][columns];
```

- Get and set values using bracket notation

```
name[row][col]           // get elem at row,col
```

```
name[row][col] = value; // set elem at row,col
```

- Get the number of rows and columns

```
arr.length   // # rows
```

```
arr[0].length // # columns
```

- Iterate over a 2D array using a double for-loop

```
for (int row = 0; row < arr.length; row++) {  
    for (int col = 0; col < arr[0].length; col++) {  
        // do something with arr[row][col];  
    }  
}
```

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# Images



Images are just grids (2D arrays!) of pixels! Pixels are just integer values from 0-255.



# Images as 2D Arrays

We can get a GImage as a 2D array of pixels.

```
GImage img = new GImage("res/daisy.jpg");
int[][] pixels = img.getPixelArray();
int pixel = pixels[0][0]; // top-left pixel
```

# Example: Pointillism

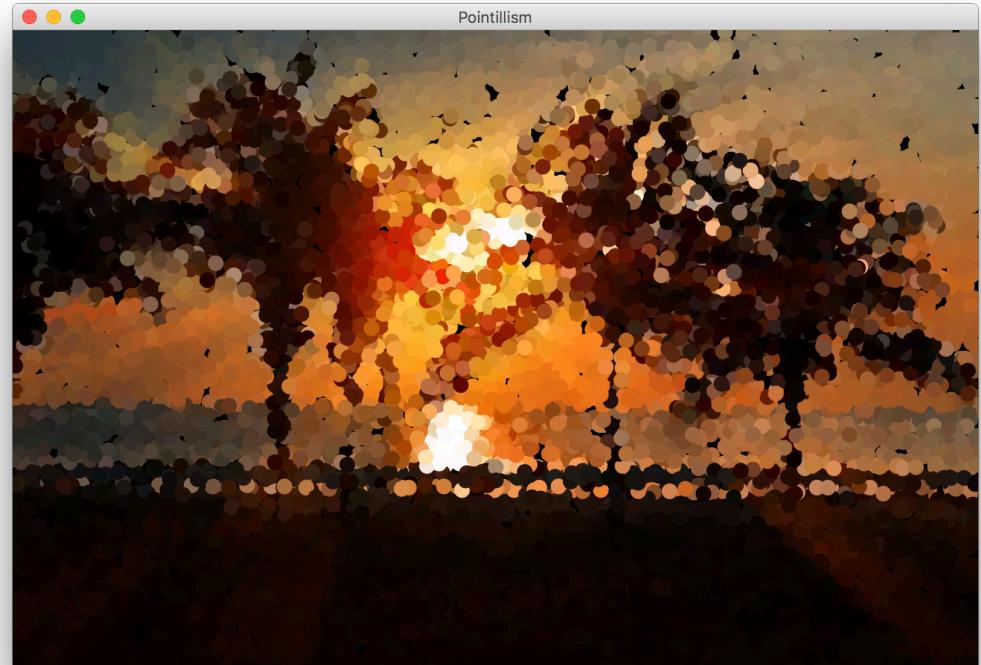
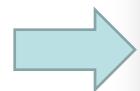
Pointillism is an art style where many small dots of color are combined to make a larger image.



*A Sunday on La Grande Jatte, Georges Seurat*

# Example: Pointillism

Pointillism is an art style where many small dots of color are combined to make a larger image.



# Example: Pointillism

Pointillism is an art style where many small dots of color are combined to make a larger image.



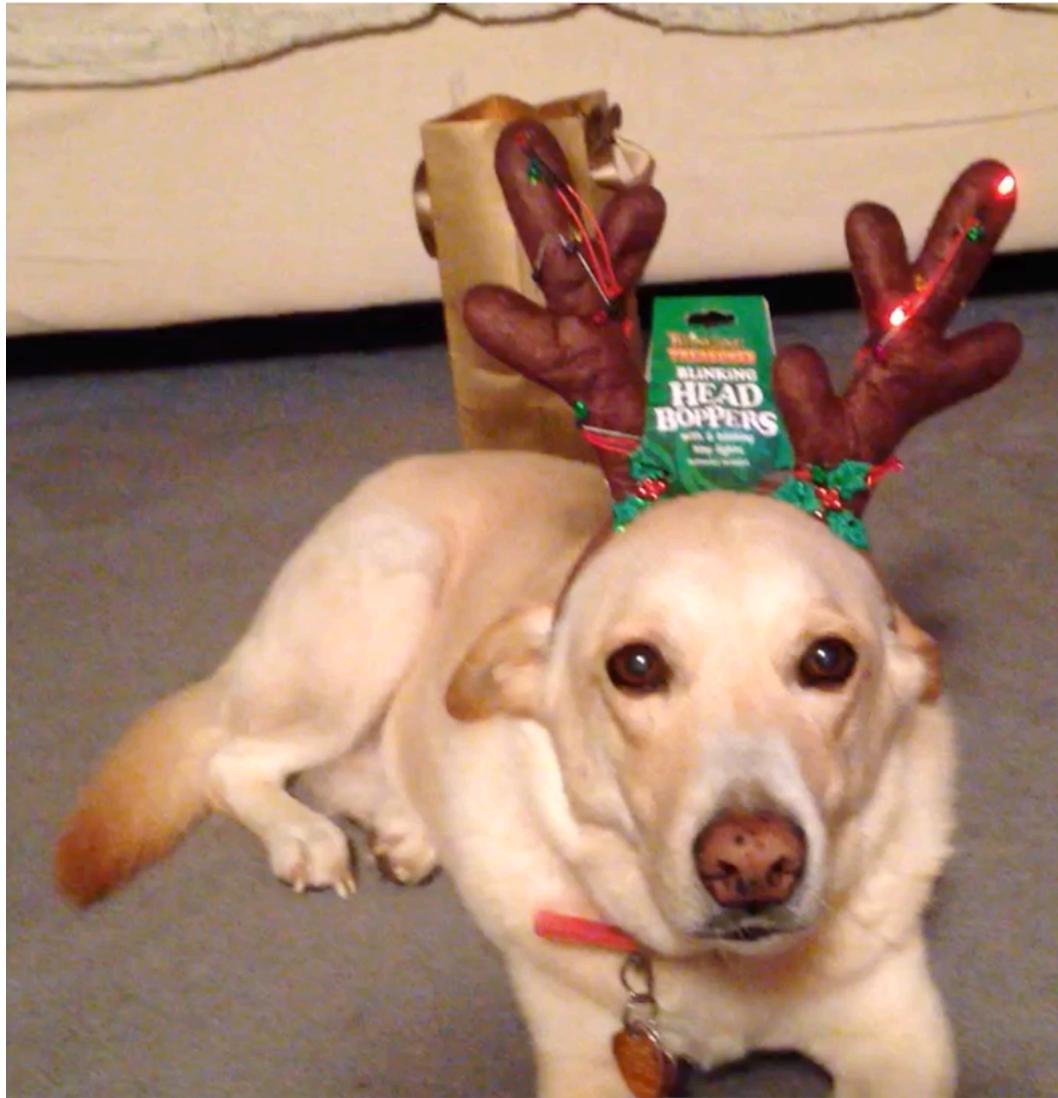
# Example: Pointillism

Pointillism is an art style where many small dots of color are combined to make a larger image.

Repeat many times:

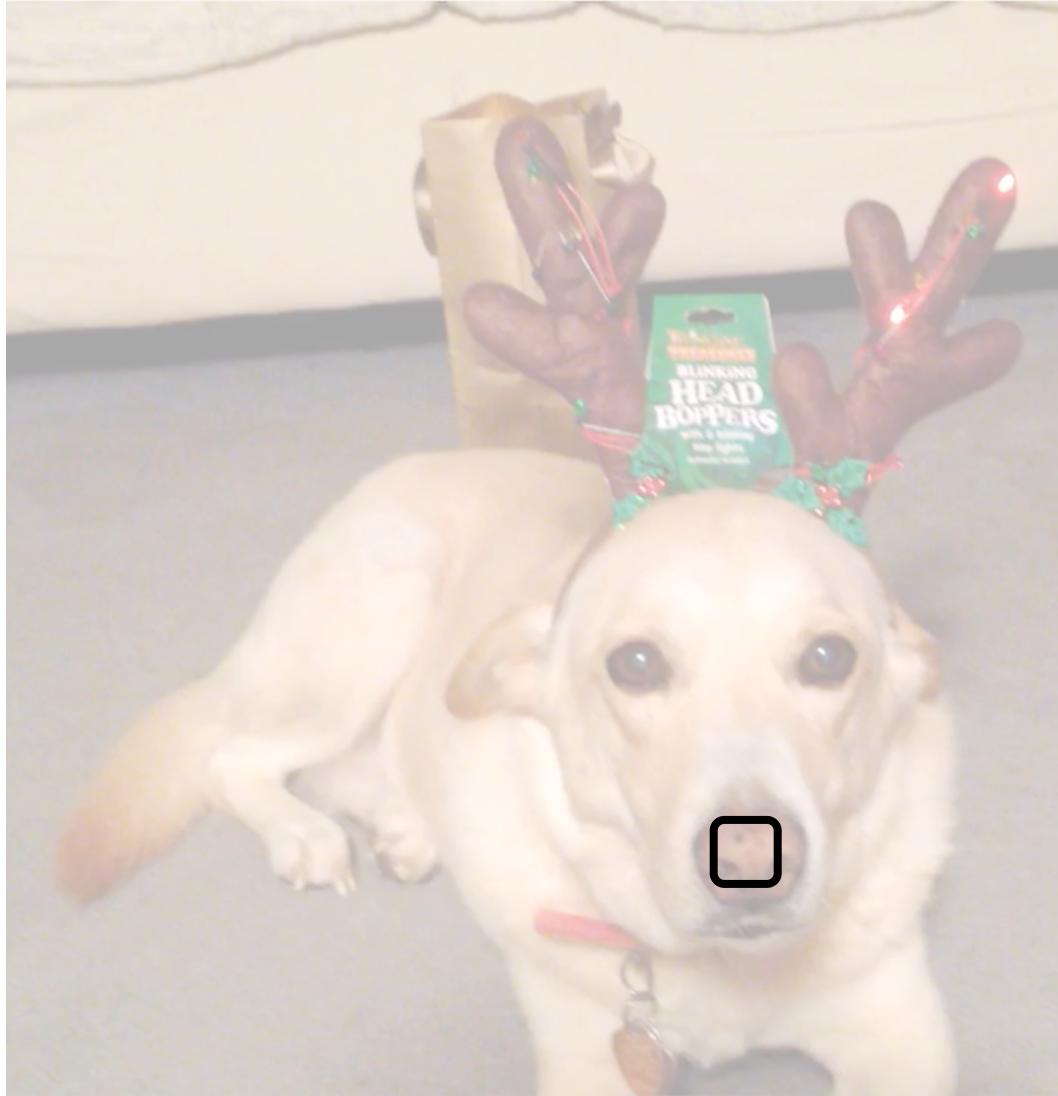
1. Pick a random pixel from an image
2. Find the pixel's color
3. “Paint” a large brush stroke of that color in the corresponding location

# Example: Pointillism



# Example: Pointillism

c = 36



r = 46

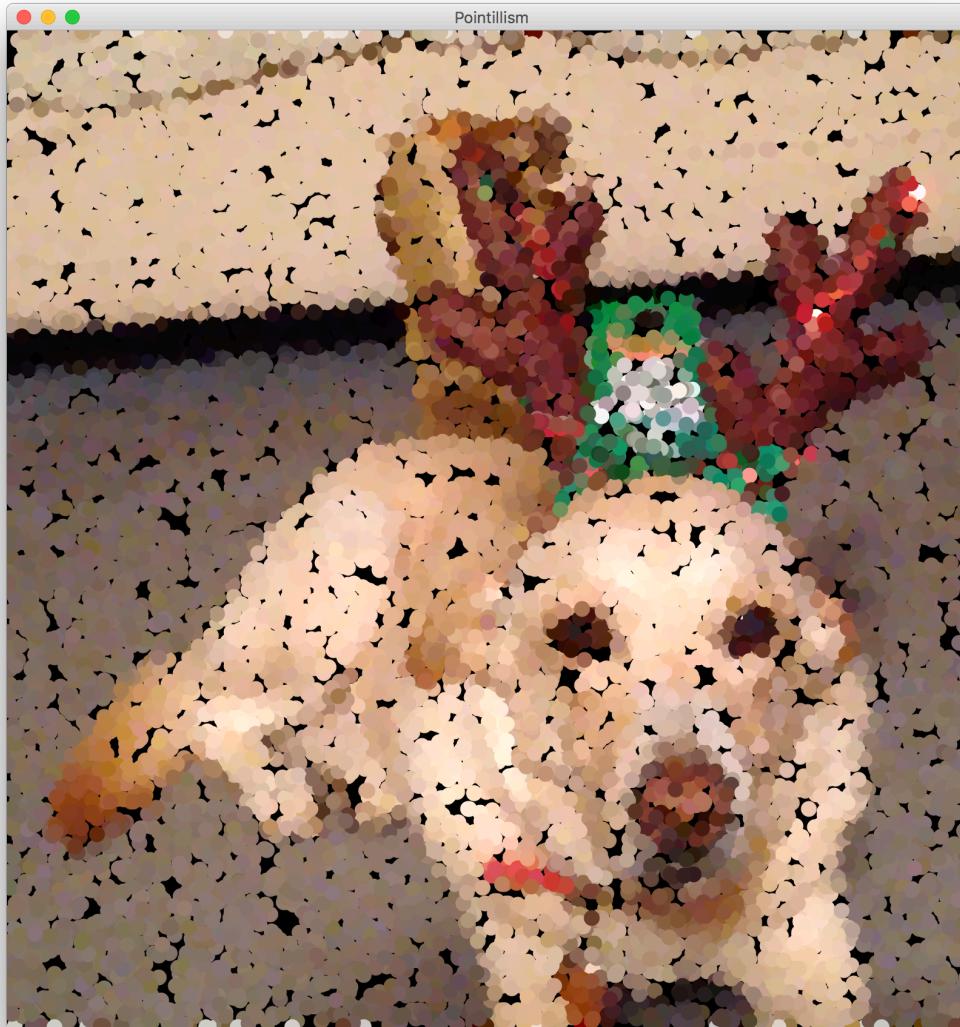
# Example: Pointillism

c = 36

r = 46



# Example: Pointillism



# Example: Pointillism

```
GImage daisy = new GImage("res/daisy.jpg");
int[][] pixels = daisy.getPixelArray();
int rows = pixels.length;
int cols = pixels[0].length;

for (int i = 0; i < NUM_SAMPLES; i++) {
    int c = RandomGenerator.getInstance().nextInt(cols);
    int r = RandomGenerator.getInstance().nextInt(rows);
    int pixel = pixels[r][c];
    Color color = new Color(pixel);
    addColoredCircle(r, c, color);
}
```

# Example: Pointillism

```
GImage daisy = new GImage("res/daisy.jpg");
int[][] pixels = daisy.getPixelArray();
int rows = pixels.length;
int cols = pixels[0].length;

for (int i = 0; i < NUM_SAMPLES; i++) {
    int c = RandomGenerator.getInstance().nextInt(cols);
    int r = RandomGenerator.getInstance().nextInt(rows);
    int pixel = pixels[r][c];
    Color color = new Color(pixel);
    addColoredCircle(r, c, color);
}
```

# Example: Pointillism

```
GImage daisy = new GImage("res/daisy.jpg");
int[][] pixels = daisy.getPixelArray();
int rows = pixels.length;
int cols = pixels[0].length;

for (int i = 0; i < NUM_SAMPLES; i++) {
    int c = RandomGenerator.getInstance().nextInt(cols);
    int r = RandomGenerator.getInstance().nextInt(rows);
    int pixel = pixels[r][c];
    Color color = new Color(pixel);
    addColoredCircle(r, c, color);
}
```

# Example: Pointillism

```
GImage daisy = new GImage("res/daisy.jpg");
int[][] pixels = daisy.getPixelArray();
int rows = pixels.length;
int cols = pixels[0].length;

for (int i = 0; i < NUM_SAMPLES; i++) {
    int c = RandomGenerator.getInstance().nextInt(cols);
    int r = RandomGenerator.getInstance().nextInt(rows);
    int pixel = pixels[r][c];
    Color color = new Color(pixel);
    addColoredCircle(r, c, color);
}
```

# Example: Pointillism

```
GImage daisy = new GImage("res/daisy.jpg");
int[][] pixels = daisy.getPixelArray();
int rows = pixels.length;
int cols = pixels[0].length;

for (int i = 0; i < NUM_SAMPLES; i++) {
    int c = RandomGenerator.getInstance().nextInt(cols);
    int r = RandomGenerator.getInstance().nextInt(rows);
    int pixel = pixels[r][c];
    Color color = new Color(pixel);
    addColoredCircle(r, c, color);
}
```

# Example: Pointillism

```
GImage daisy = new GImage("res/daisy.jpg");
int[][] pixels = daisy.getPixelArray();
int rows = pixels.length;
int cols = pixels[0].length;

for (int i = 0; i < NUM_SAMPLES; i++) {
    int c = RandomGenerator.getInstance().nextInt(cols);
    int r = RandomGenerator.getInstance().nextInt(rows);
    int pixel = pixels[r][c];
    Color color = new Color(pixel);
    addColoredCircle(r, c, color);
}
```

# Example: Pointillism

```
GImage daisy = new GImage("res/daisy.jpg");
int[][] pixels = daisy.getPixelArray();
int rows = pixels.length;
int cols = pixels[0].length;

for (int i = 0; i < NUM_SAMPLES; i++) {
    int c = RandomGenerator.getInstance().nextInt(cols);
    int r = RandomGenerator.getInstance().nextInt(rows);
    int pixel = pixels[r][c];
    Color color = new Color(pixel);
    addColoredCircle(r, c, color);
}
```

# Example: Pointillism

```
// Assume canvas is exactly image size
private void addColoredCircle(int r, int col, Color c) {
    double size = CIRCLE_RADIUS * 2;
    G0val circle = new G0val(size, size);
    circle.setFilled(true);
    circle.setColor(c);
    add(oval, col - CIRCLE_RADIUS, r - CIRCLE_RADIUS);
}
```

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# Anonymous Questions

- Out of curiosity, do you also happen to like broccoli?
- Can I see more Daisy?
- A slingshot may help you with candy delivery (your accuracy tends to drop off after ~10 rows). Make sure its a low-powered slingshot, though, as I don't think students would appreciate being pelted with candy at high speeds.

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# Red, Green and Blue in one int?

Images *encode* the R, G, and B values of a pixel into a single integer between 0 and 255. You can convert between this **pixel value** and the individual **RGB values**.

```
int[][] pixels = image.getPixelArray();
int px = pixels[0][0];
int red = GImage.getRed(px);
int green = GImage.getGreen(px);
int blue = GImage.getBlue(px);
```

# Creating New Pixels

Images *encode* the R, G, and B values of a pixel into a single integer between 0 and 255. You can convert between this **pixel value** and the individual **RGB values**.

You can also create pixels with your own RGB values.

```
int r = ...  
int g = ...  
int b = ...  
int pixel = GImage.createRGBPixel(r, g, b);
```

# Images as 2D Arrays

We can get a GImage as a 2D array of pixels, and modify it any way we want. Then, we can create a new GImage with the modified pixels.

```
GImage img = new GImage("res/daisy.jpg");
int[][][] pixels = img.getPixelArray();
... (modify pixels)
img.setPixelArray(pixels); // update image

// or make a new GImage
GImage newImg = new GImage(pixels);
```

# Modifying Image Pixels

- There are many cool image algorithms based around modifying individual pixels in an image: grayscale, brighten, normalize, remove red-eye...

*grayscale*



*zoom*



# GImage Pixel Methods

```
GImage img = new GImage("res/daisy.jpg");
```

| Method name   | Description   |
|---|---|
| <code>img.getPixelArray()</code>  | returns pixels as 2D array of ints, where each int in the array contains all 3 of Red, Green, and Blue merged into a single integer |
| <code>img.setPixelArray(array);</code>  | updates pixels using the given 2D array of ints   |
| <code>GImage.createRGBPixel(r, g, b)</code>   | returns an int that merges the given amounts of red, green and blue (each 0-255)  |
| <code>GImage.getRed(px)</code><br><code>GImage.getGreen(px)</code><br><code>GImage.getBlue(px)</code> | returns the redness, greenness, or blueness of the given pixel as an integer from 0-255   |

# Recap: Modifying Pixels

- **Extract** pixel RGB colors with `GImage.getRed/Blue/Green`.

```
int red    = GImage.getRed(pixels[0][0]);      // 0-255  
int green = GImage.getGreen(pixels[0][0]);     // 0-255  
int blue   = GImage.getBlue(pixels[0][0]);     // 0-255
```

- **Modify** the color components for a given pixel.

```
red = 0;    // remove redness
```

- **Combine** the RGB back together into a single int.

```
pixels[0][0] = GImage.createRGBPixel(red, green, blue);
```

- **Update** the image with your modified pixels when finished.

```
image.setPixelArray(pixels);
```

# Changing Image Size

- Destination image is same size → often modify array in place.
- Destination image is different size → need a new array.
- Example: **Half the size** of an image.

```
int[][] pixels = img.getPixelArray();
int[][] smaller = new int[pixels.length / 2]
                  [pixels[0].length / 2];
...
// set to be the pixels of 'smaller'
img.setPixelArray(smaller);
```

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# Recap

- Recap: Arrays
  - 2D Arrays
  - Images as 2D Arrays
  - Announcements
  - Modifying Images
  - Practice: Brighten, Grayscale
- Next time:** more practice with arrays