LAB 3: WORKING WITH IMAGE DATA

University of Washington

ECE 241

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OUTLINE

Part 1: Image formats

- How are images represented in a computer
- Grayscale image
- Color image
- Reading and Writing images in Python
- Converting Color to Grayscale

Part 2: Basic Operations on images: Grayscale

- Analyzing an image with pixel histogram
- Manipulating image pixels
- Image flipping
- Image down-sampling
- Image blending

Part 3: Basic Operations on images: Color

- Indexing 3D image arrays
- Constructing 3D image from 2D arrays
- Expanding image operations to color

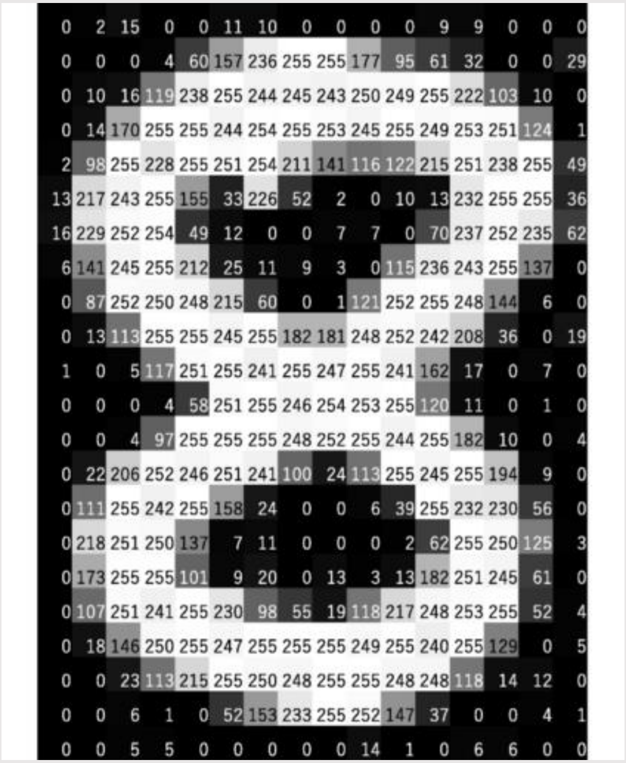
Part 4: Lab Assignments

- Exercise 1 – 5

IMAGE FORMATS

HOW ARE IMAGES REPRESENTED IN A COMPUTER

Original Image



Pixels as Numbers

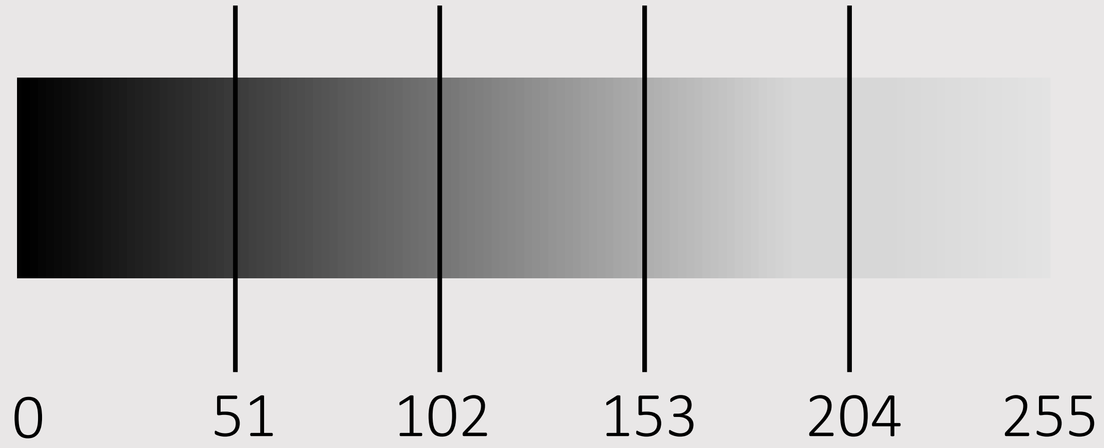
0	2	15	0	0	11	10	0	0	0	0	9	9	0	0	0
0	0	0	4	60	157	236	255	255	177	95	61	32	0	0	29
0	10	16	119	238	255	244	245	243	250	249	255	222	103	10	0
0	14	170	255	255	244	254	255	253	245	255	249	253	251	124	1
2	98	255	228	255	251	254	211	141	116	122	215	251	238	255	49
13	217	243	255	155	33	226	52	2	0	10	13	232	255	255	36
16	229	252	254	49	12	0	0	7	7	0	70	237	252	235	62
6	141	245	255	212	25	11	9	3	0	115	236	243	255	137	0
0	87	252	250	248	215	60	0	1	121	252	255	248	144	6	0
0	13	113	255	255	245	255	182	181	248	252	242	208	36	0	19
1	0	5	117	251	255	241	255	247	255	241	162	17	0	7	0
0	0	0	4	58	251	255	246	254	253	255	120	11	0	1	0
0	0	4	97	255	255	255	248	252	255	244	255	182	10	0	4
0	22	206	252	246	251	241	100	24	113	255	245	255	194	9	0
0	111	255	242	255	158	24	0	0	6	39	255	232	230	56	0
0	218	251	250	137	7	11	0	0	0	2	62	255	250	125	3
0	173	255	255	101	9	20	0	13	3	13	182	251	245	61	0
0	107	251	241	255	230	98	55	19	118	217	248	253	255	52	4
0	18	146	250	255	247	255	255	255	249	255	240	255	129	0	5
0	0	23	113	215	255	250	248	255	255	248	248	118	14	12	0
0	0	6	1	0	52	153	233	255	252	147	37	0	0	4	1
0	0	5	5	0	0	0	0	0	14	1	0	6	6	0	0

Array form of the image

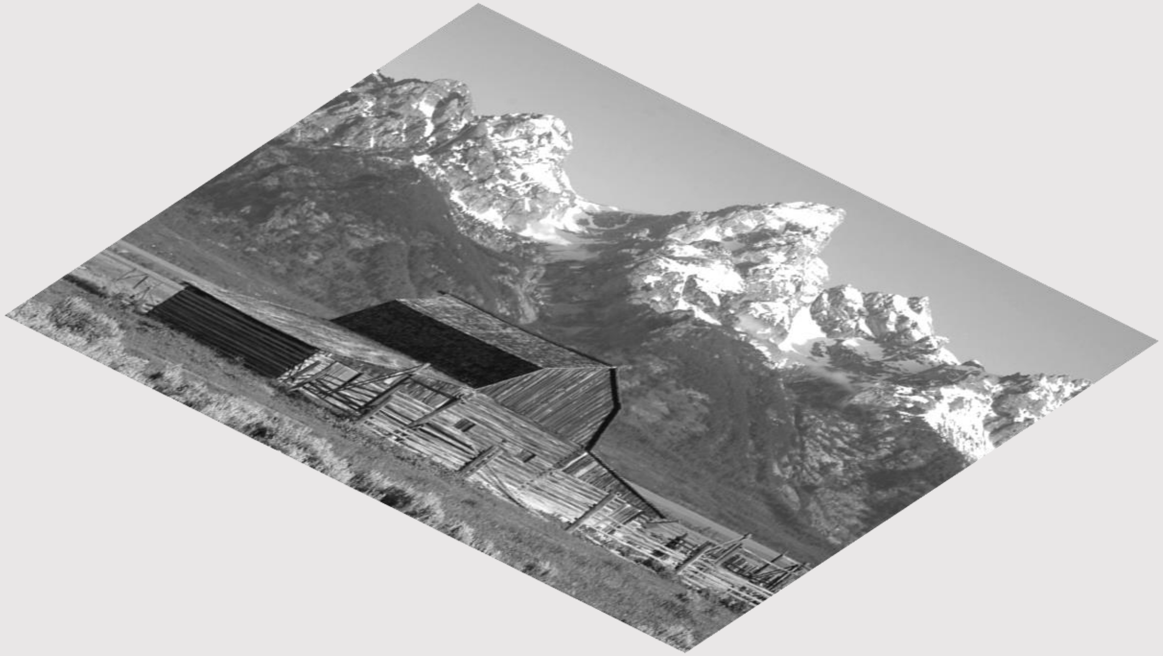
Image = Set of 2D array(s)

Image credit: MNIST dataset

GRAYSCALE IMAGES

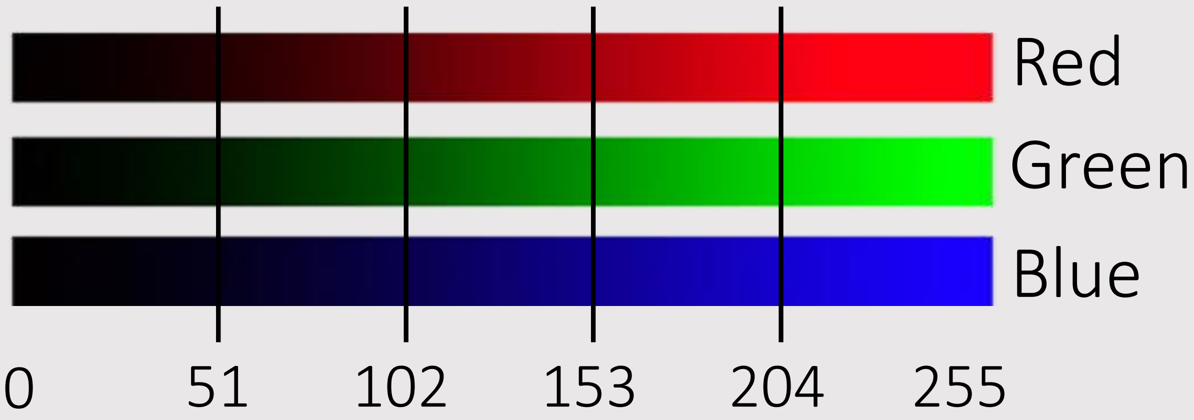


8-bit scale

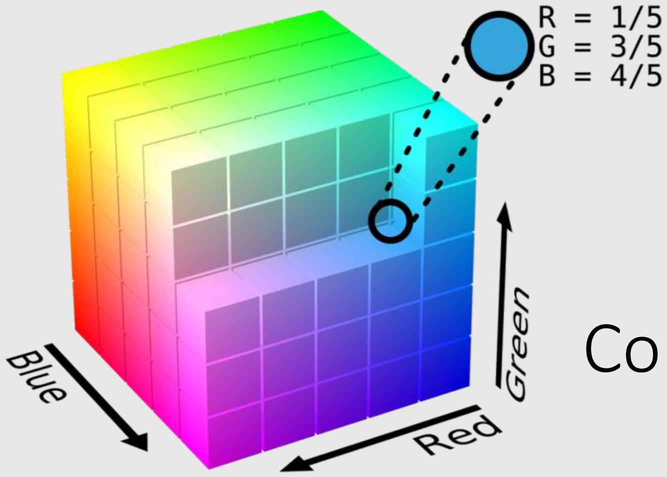


Grayscale image example

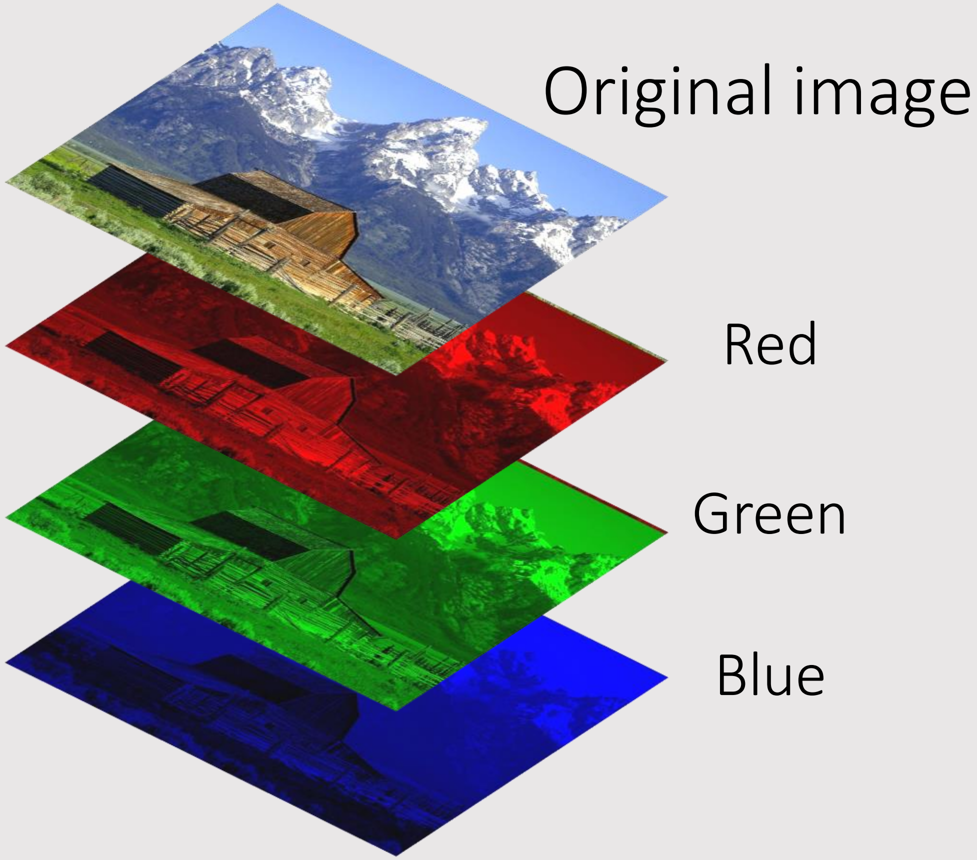
COLOR IMAGES



RGB 8-bit scale

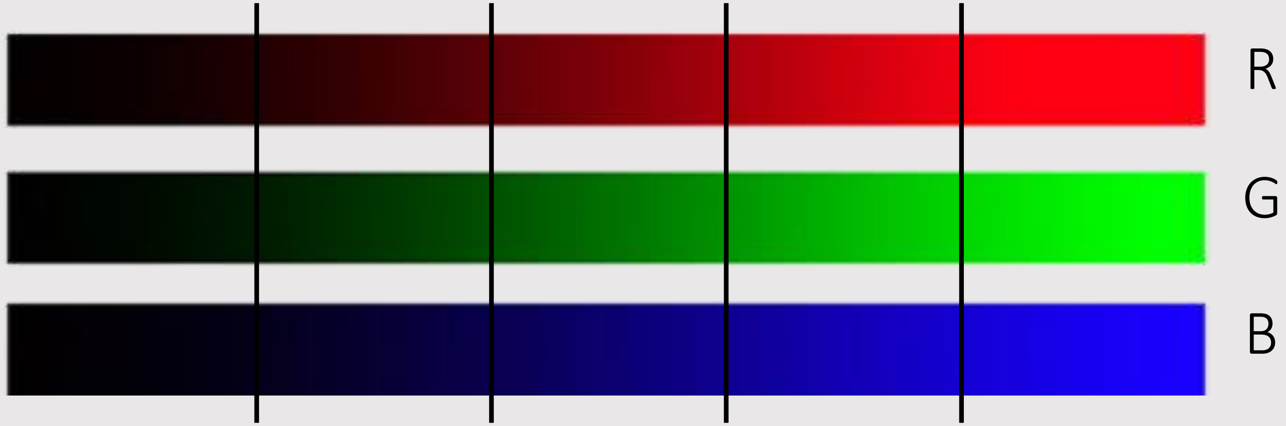


Color spectrum of RGB



Color image example

COMMONLY USED UNITS OF COLOR DEPTH



8-bit color	0	51	102	153	204	255
Normalized 8-bit color	0	0.2	0.4	0.6	0.8	1.0
HEX	#000000	#333333	#666666	#999999	#cccccc	#ffffff

R G B

LOADING IMAGES IN PYTHON WITH matplotlib

```
import matplotlib.pyplot as plt
import matplotlib.image as mpimg
```

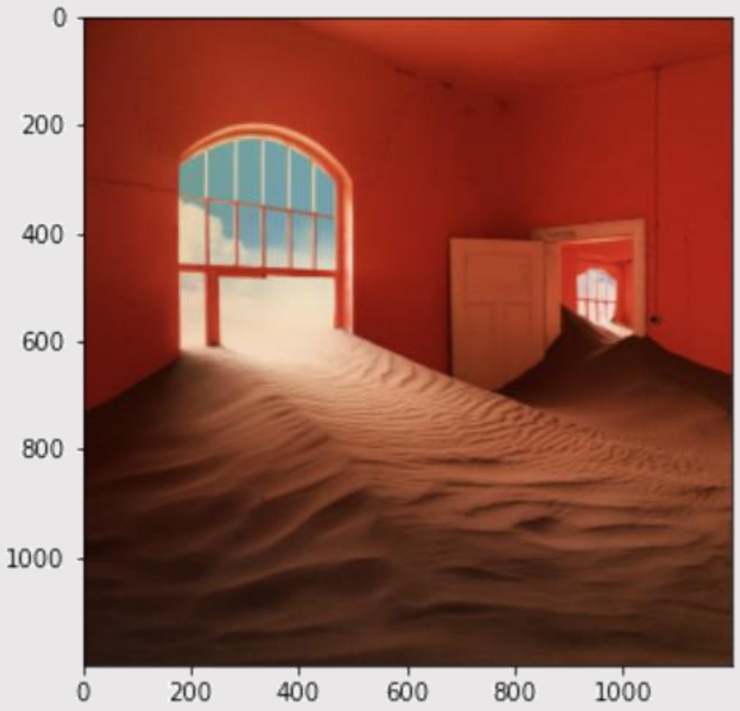
Import matplotlib.pyplot and matplotlib.image

```
img = mpimg.imread('TSR.jpg')
```

Load the image with imread()

```
fig = plt.figure(figsize=(5, 5))

imgplot = plt.imshow(img)
```

Plot the image with imshow()



NOTE: When using imread, make sure you have your image in the **same directory** as ipynb OR Have a **correct directory path** to the image.

NOTE: plt.imshow() automatically normalizes the pixel values between 0 – 1 or 0 - 255. Explicitly set vmin and vmax parameters to 0, 1 or 0, 255 to force standard normalization.

Image credit: Tame Impala Official Instagram

READING IMAGES AS NUMPY ARRAYS

```
img.shape
```

```
(1200, 1200, 3)
```

Typical images have (Height, Width, 3)

```
img_red = img[:, :, 0]
img_green = img[:, :, 1]
img_blue = img[:, :, 2]
```

Extract Red (Top) Channel

Green (Middle)

Blue (Bottom)

```
print(img_red, img_red.shape)
```

```
[[107 108 107 ... 163 165 167]
 [110 111 110 ... 165 164 163]
 [109 110 109 ... 165 162 160]
 ...
 [ 42  41  41 ...  91  88  86]
 [ 43  43  42 ...  89  87  85]
 [ 44  43  43 ... 100  98  96]] (1200, 1200)
```

Extracted channel is a Numpy 2D array of 8-bit color values with shape (W, H).

NOTE: some images may use normalized 8-bit color instead of standard values.

WRITING IMAGE WITH matplotlib EXAMPLE: Write Red channel of an image into a .png file

```
import numpy as np
```

Import Numpy

```
img_redonly = np.zeros((1200, 1200, 3), dtype = 'int')
```

Create an empty 3D array that has same dimension as original image

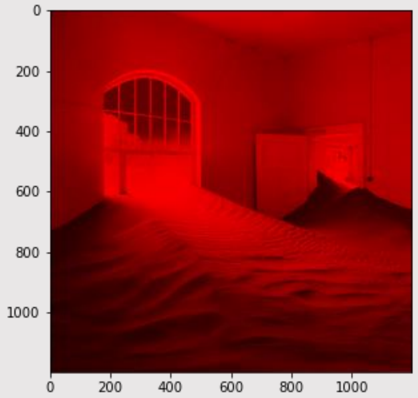
```
img_redonly[:, :, 0] = img[:, :, 0]
```

Populate the first layer of channel axis with Red channel of the image.

```
fig = plt.figure(figsize=(5, 5))

imgplot_redonly = plt.imshow(img_redonly)

plt.savefig('imgplot_redonly.png')
```

Plot the new image with imshow()

Save the image with savefig('filename.xyz')



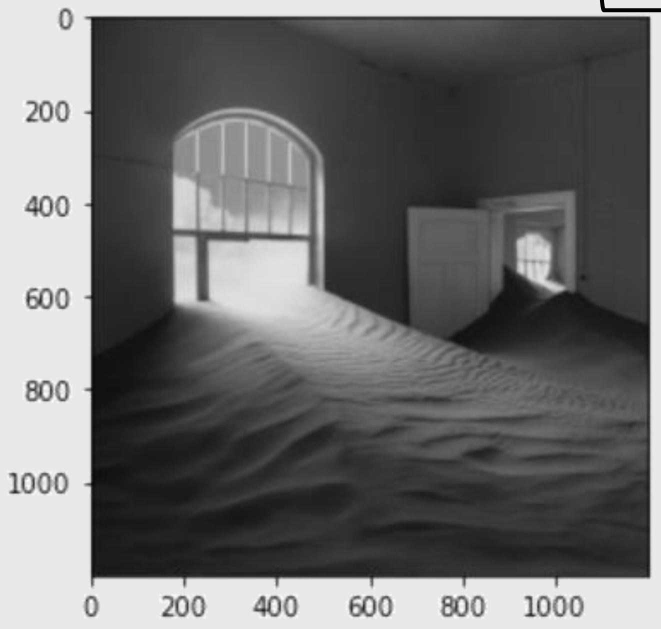
imgplot_redonly.png

NOTE: The empty array must be of type 'int' to correctly represent 8-bit color depth

CONVERTING COLOR IMAGE TO GRAYSCALE

```
from skimage import color
from skimage import io

img_gray = color.rgb2gray(io.imread('TSR.jpg'))
```

```
imgplot = plt.imshow(img_gray, cmap = 'gray')
```

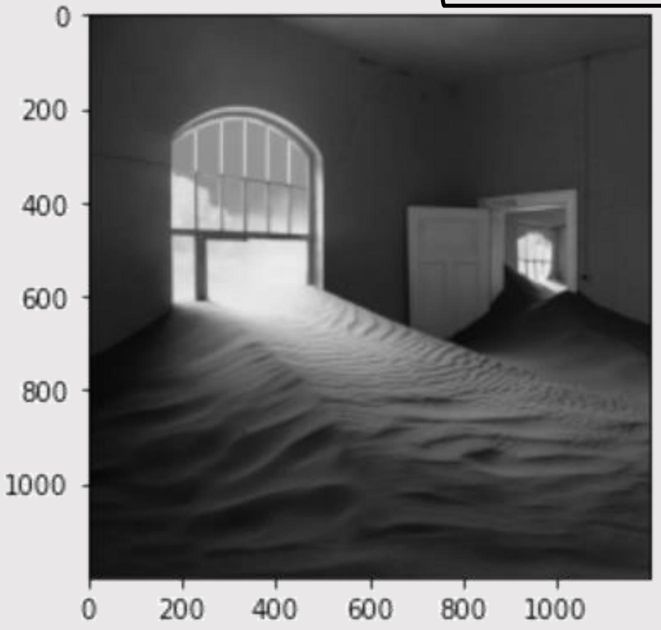


Need this line to tell imshow you are plotting grayscale

Using skimage

```
from PIL import Image
img_gray = Image.open('TSR.jpg').convert('L')
```

```
imgplot = plt.imshow(np.array(img_gray), cmap = 'gray')
```



Need this line to tell imshow you are plotting grayscale

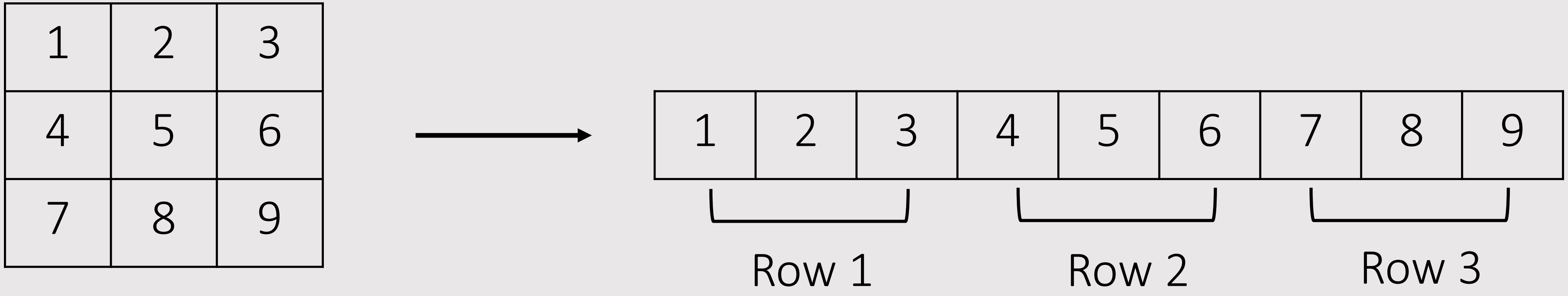
Need to cast into np.array() to turn image into numpy array

Using Pillow

NOTE: skimage uses normalized 8-bit scale and pillow uses standard 8-bit (0 - 255)

OPERATIONS ON IMAGE (GRAYSCALE)

CONVERTING 2D ARRAY INTO 1D ARRAY WITH np.ndarray.flatten()




```python
sample_2d = np.vstack([np.arange(3), np.arange(3,6), np.arange(6,9)])
```

Construct sample_2d

```python
print(sample_2d)
```

```
[[0 1 2]
 [3 4 5]
 [6 7 8]]
```

```python
print(np.ndarray.flatten(sample_2d))
```

```
[0 1 2 3 4 5 6 7 8]
```

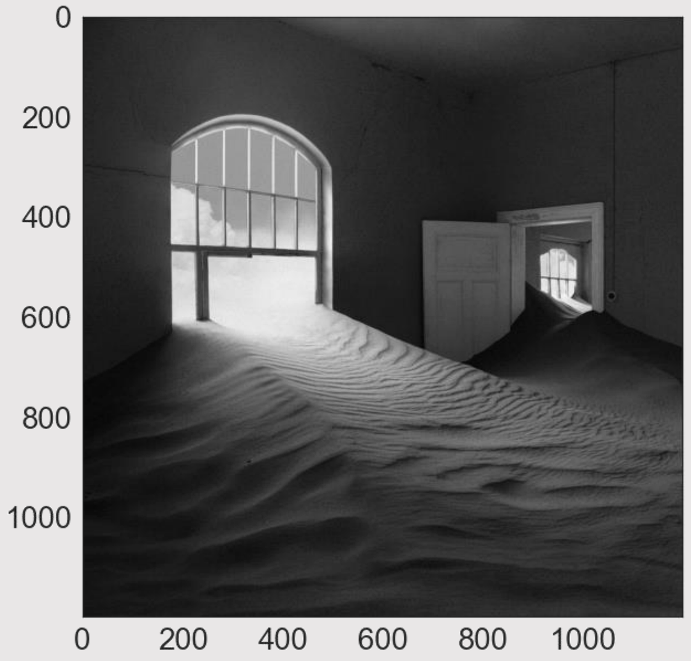
Use np.ndarray.flatten() to convert 2D array to 1D

ANALYZING AN IMAGE WITH PIXEL HISTOGRAM

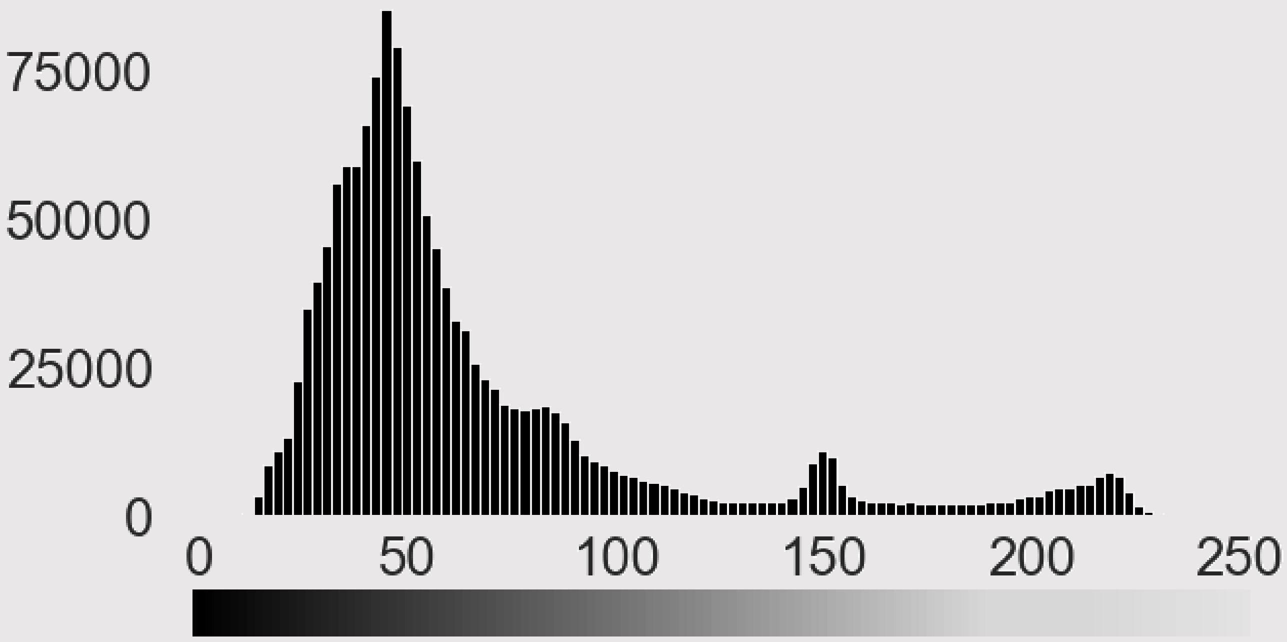
```
flattened_2D_arr = np.ndarray.flatten(img_gray)

fig = plt.figure(figsize=(10, 5))

plt.hist(flattened_2D_arr, bins = 100, color = 'black')
```

Flatten img_gray 2D array (slide 11) -> 1D array

Plot the histogram of the pixel values

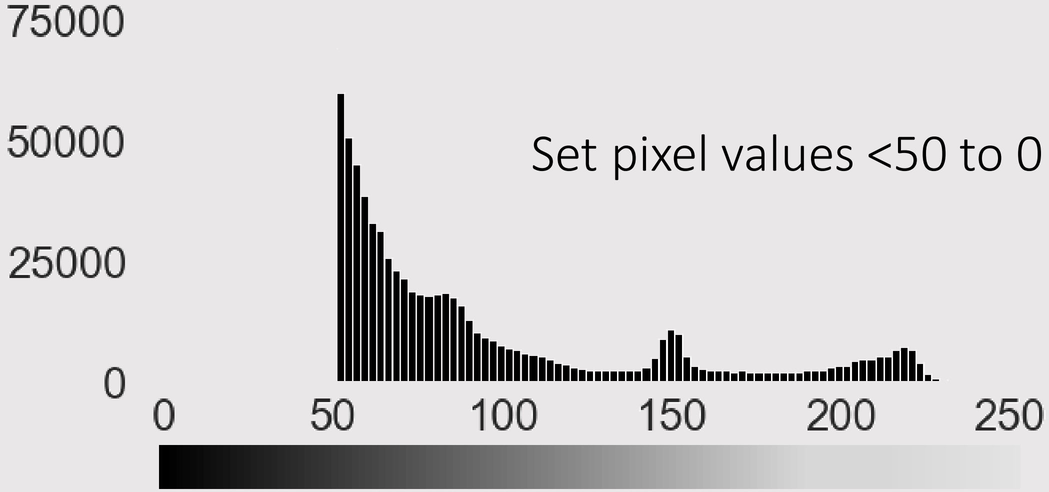


Original Greyscale image

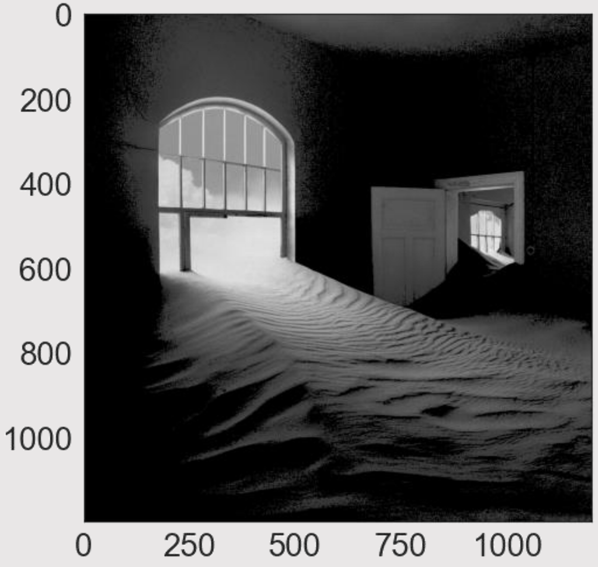


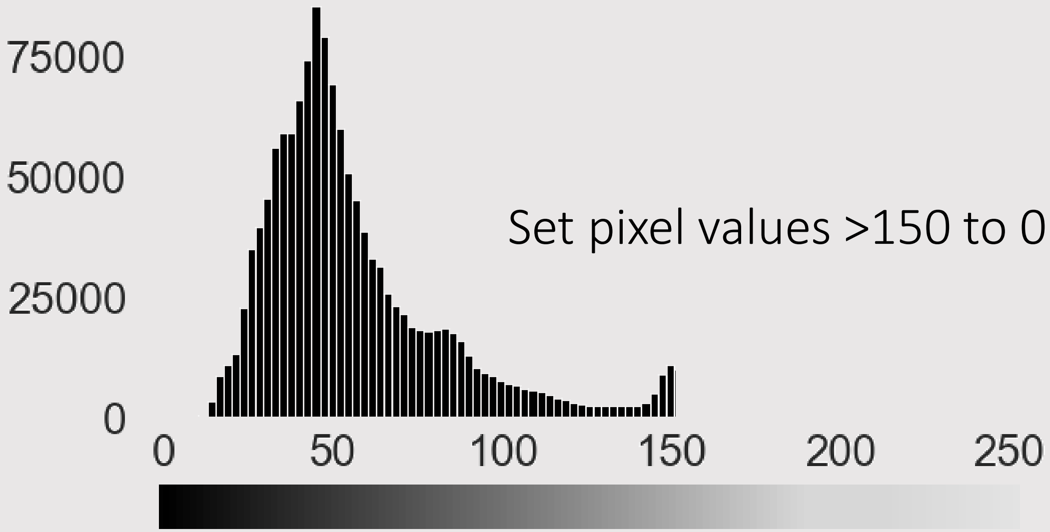
Pixel value histogram

MANIPULATING IMAGE PIXELS WITH HISTOGRAM

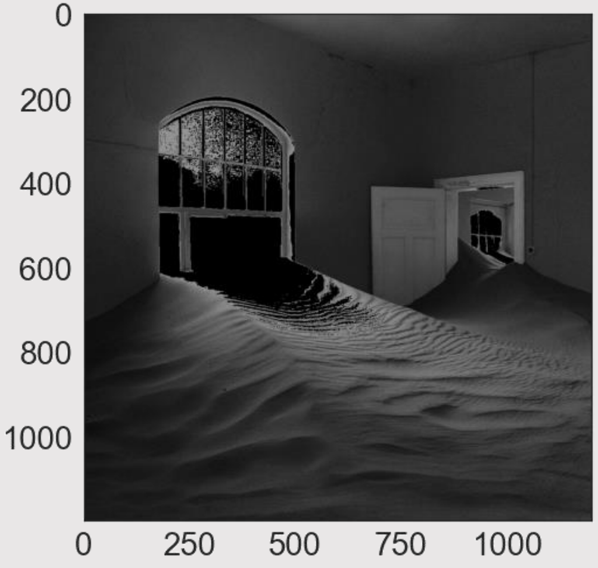


Set pixel values <50 to 0





Set pixel values >150 to 0



MANIPULATING IMAGE PIXELS WITH HISTOGRAM: BOOLEAN MASK METHOD

Original 2D array

1	2	3	4	5
6	7	8	9	10
11	12	13	14	15
16	17	18	19	20
21	22	23	24	25

array2d

Boolean mask

T	T	T	T	T
T	T	T	T	T
T	T	T	T	F
F	F	F	F	F
F	F	F	F	F

array2d < 15

T = True, F = False

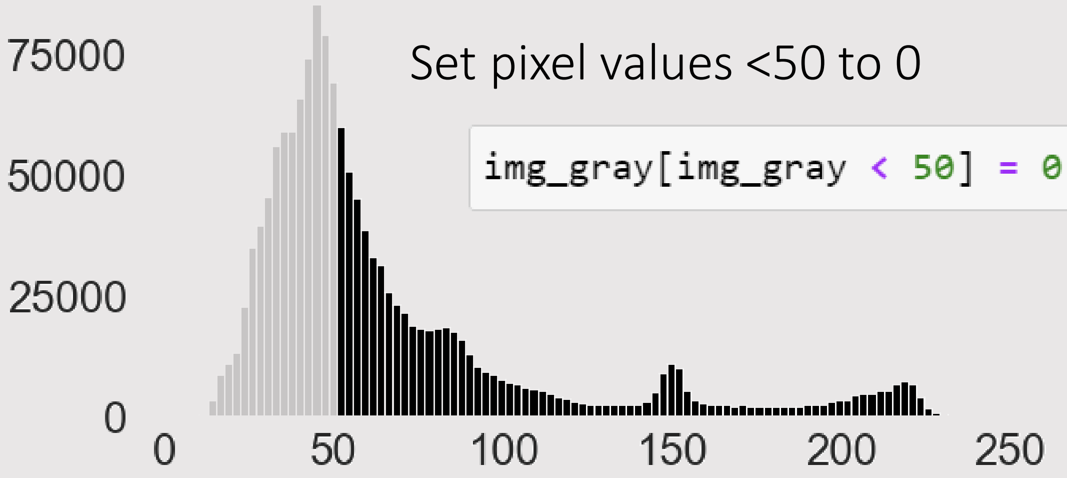
Applying the mask

n	n	n	n	n
n	n	n	n	n
n	n	n	n	15
16	17	18	19	20
21	22	23	24	25

array2d[array2d < 15] = n

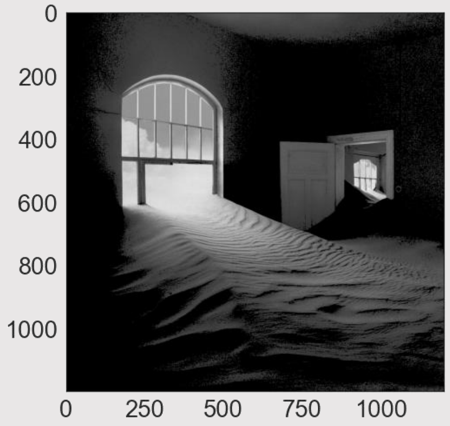
MANIPULATING IMAGE PIXELS WITH HISTOGRAM: BOOLEAN MASK METHOD

plt.imshow(img_gray, cmap = ‘gray’, vmin = 0, vmax = 255)

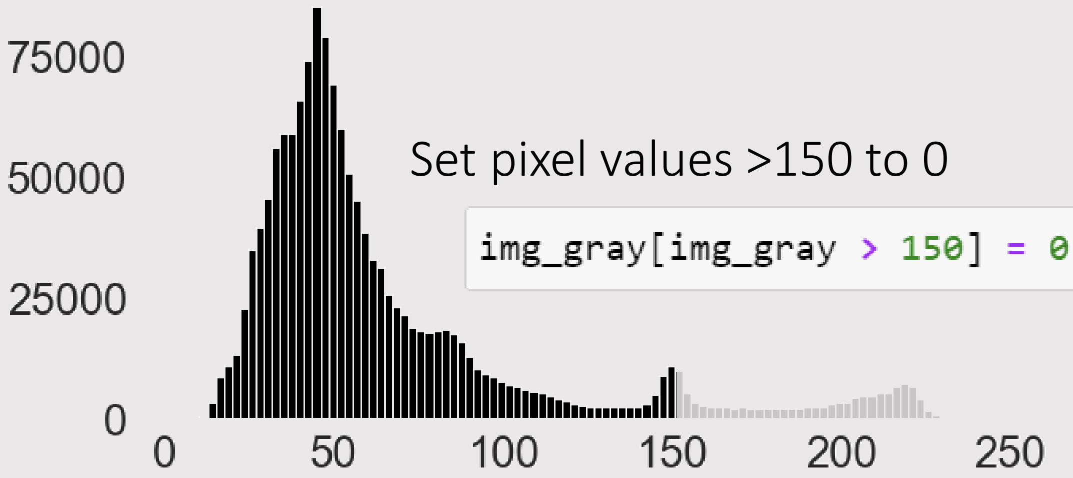


Set pixel values <50 to 0

```
img_gray[img_gray < 50] = 0
```



NOTE:
Set vmin = 0, vmax = 255 in imshow() to properly normalize the image



Set pixel values >150 to 0

```
img_gray[img_gray > 150] = 0
```

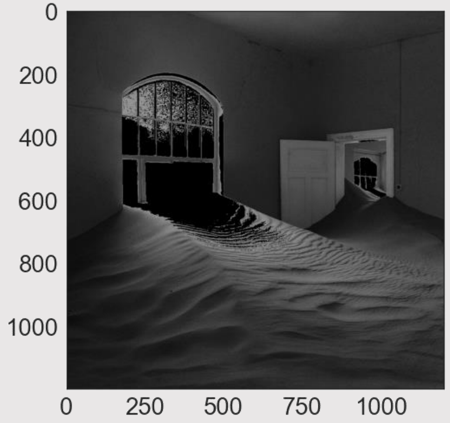


IMAGE FLIPPING WITH NUMPY FLIP FUNCTIONS

Original Image

Horizontal Flip

Vertical Flip

IMAGE FLIPPING WITH NUMPY FLIP FUNCTIONS

Horizontal Flip

1	2	3
4	5	6
7	8	9

arr

→

3	2	1
6	5	4
9	8	7

np.fliplr(arr)

Vertical Flip

1	2	3
4	5	6
7	8	9

arr

→

7	8	9
4	5	6
1	2	3

np.flipud(arr)

IMAGE FLIPPING WITH NUMPY FLIP FUNCTIONS

Original Image

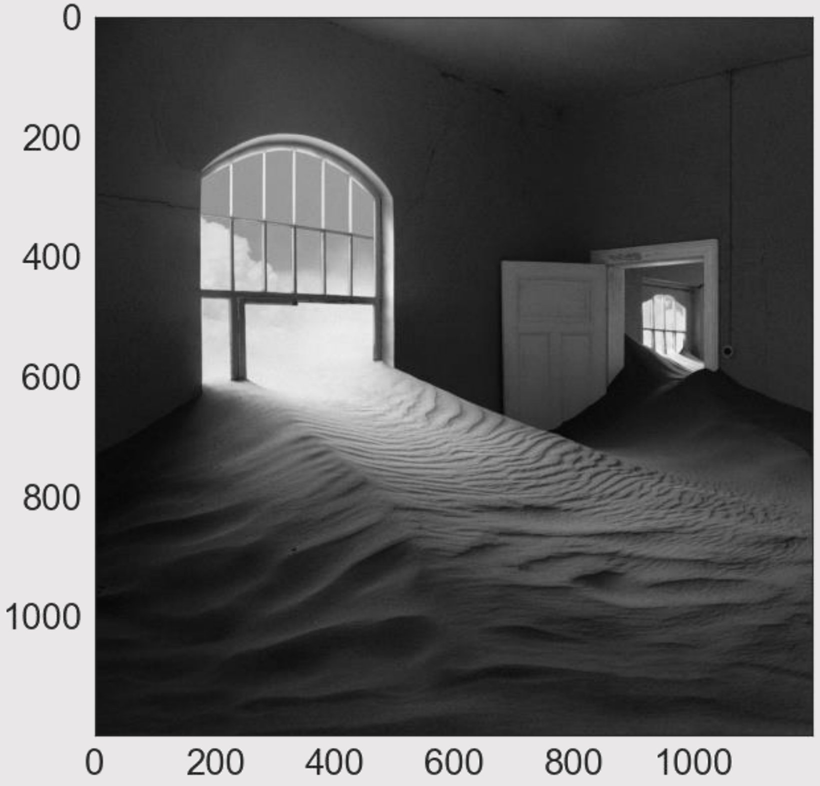
Horizontal Flip

np.fliplr(img)

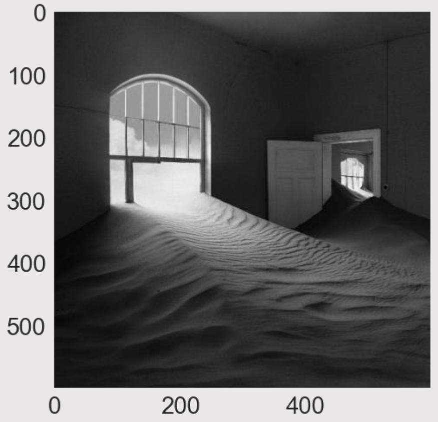
Vertical Flip

np.flipud(img)

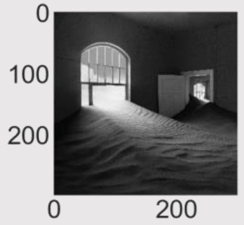
IMAGE DOWNSAMPLING



Original image
(1200 x 1200)



Downsampled by x2
(600 x 600)



Downsampled by x4
(300 x 300)

IMAGE DOWNSAMPLING WITH SIMPLE INDEXING (Pick one Method)

Original 2D array

1	2	3	4	5
6	7	8	9	10
11	12	13	14	15
16	17	18	19	20
21	22	23	24	25

array2d

Downsampling via indexing

1	2	3	4	5
6	7	8	9	10
11	12	13	14	15
16	17	18	19	20
21	22	23	24	25

→

1	3	5
11	13	15
21	23	25

array2d[::2, ::2]

IMAGE DOWNSAMPLING BY SEGMENT AVERAGING

Original 2D array

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16

array2d

Downsampling via averaging

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16

Split the array into segments

→

(1+2+5+6)/4

4	6
12	14

Downsampling rate = x2

Average each segment + rounding

SIMPLE INDEXING VS SEGMENT AVERAGING

Original Image

Downsample factor: x5 | Downsample factor: x10

Pick one method

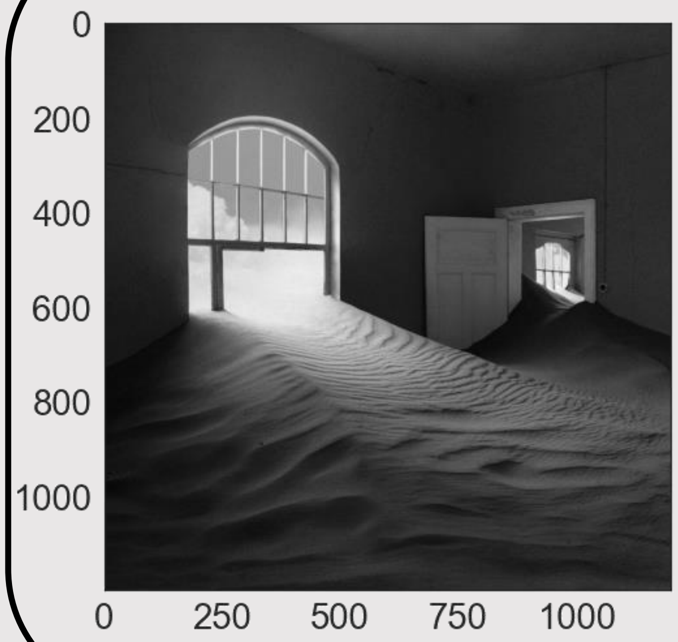
Segment averaging method

Images are magnified to scale

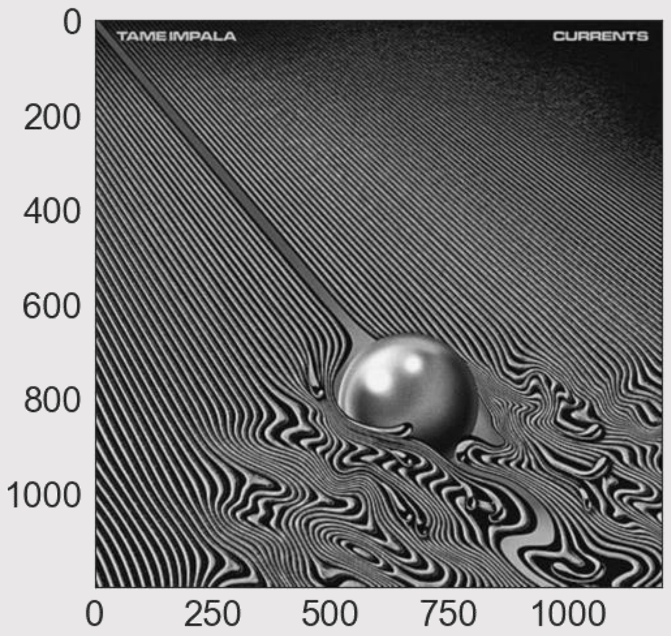
Smoother images

IMAGE BLENDING

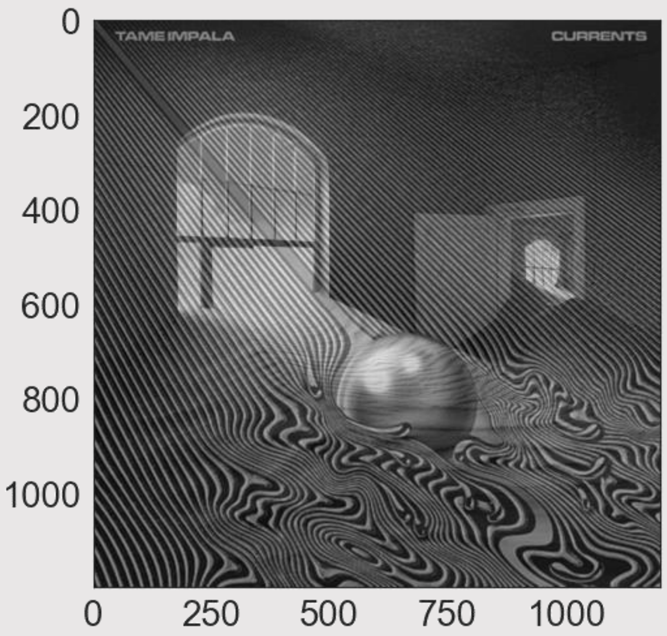
$\times 1/2$



$+$



$=$



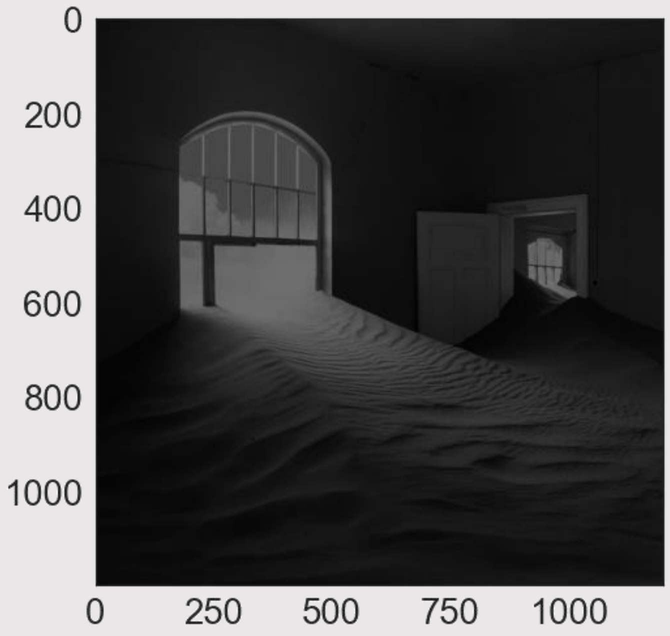
Img_A

Img_B

Blended Image

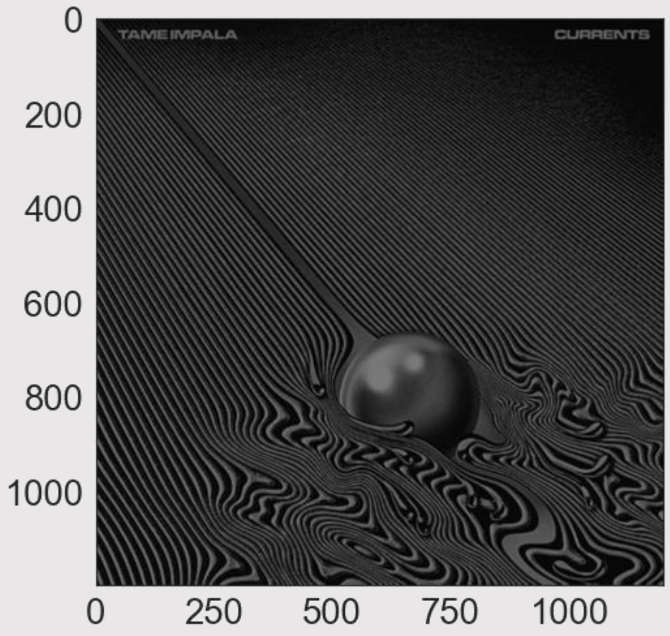
Image credit: Tame Impala Official Instagram

IMAGE BLENDING



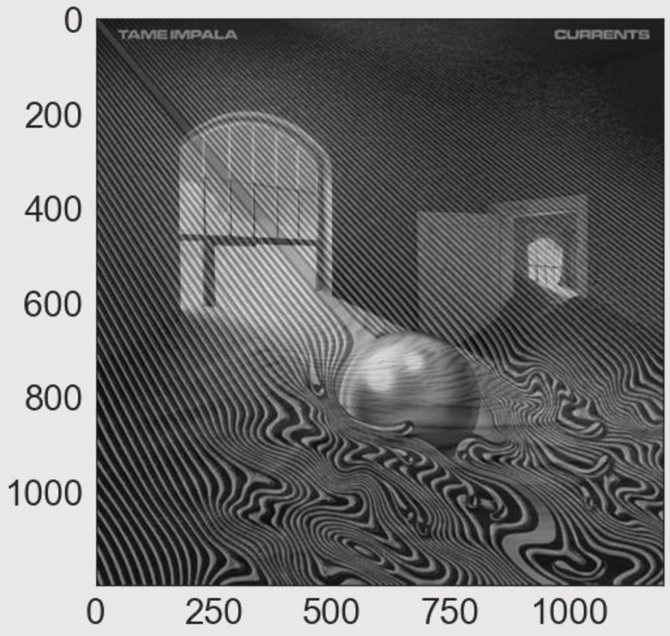
0.5*Img_A

+



0.5* Img_B

=



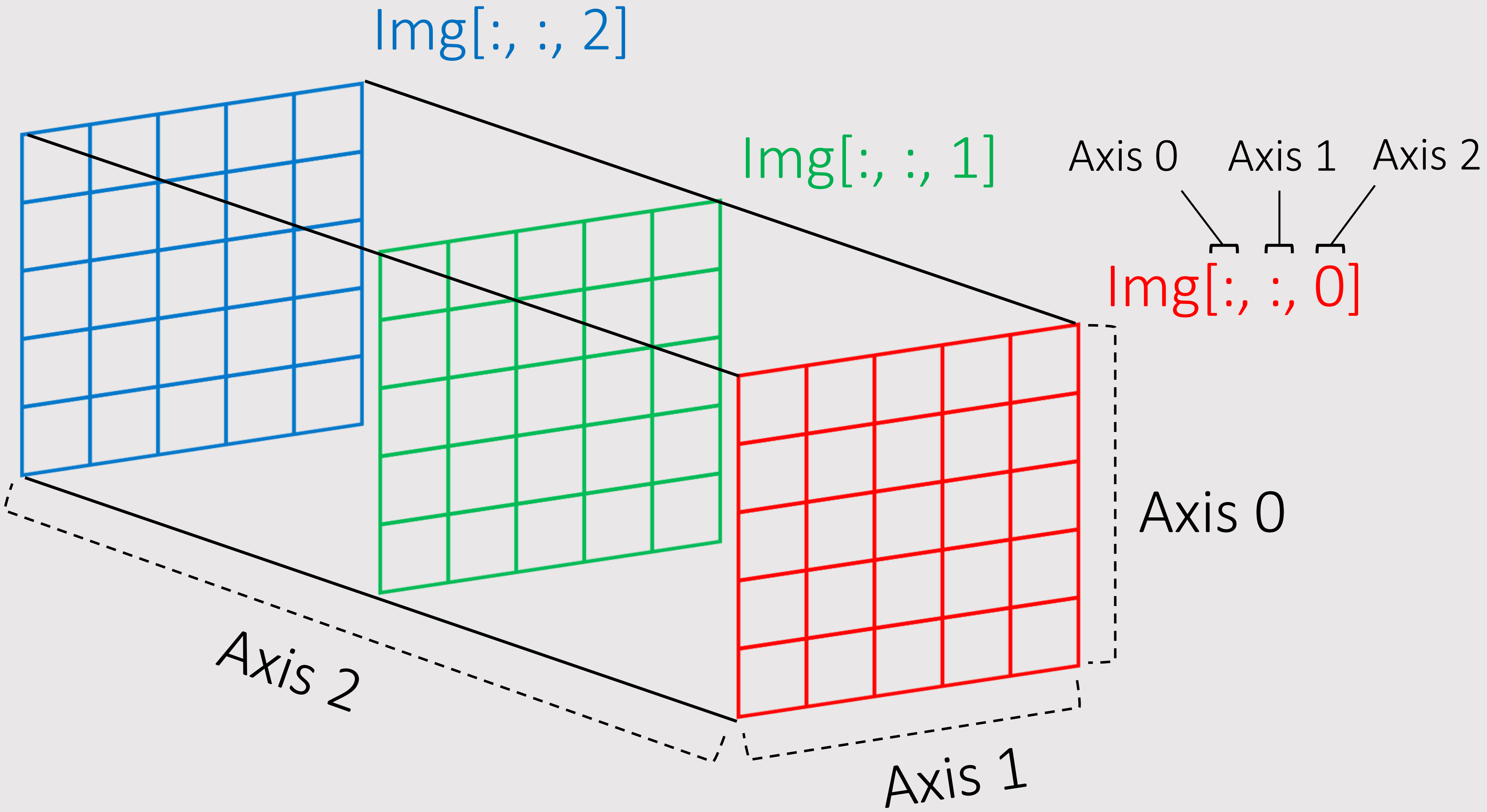
0.5* Img_A + 0.5* img_B

Question:

What would be the effects of using different weights - e.g. 0.3*img_A + 0.7*img_B?

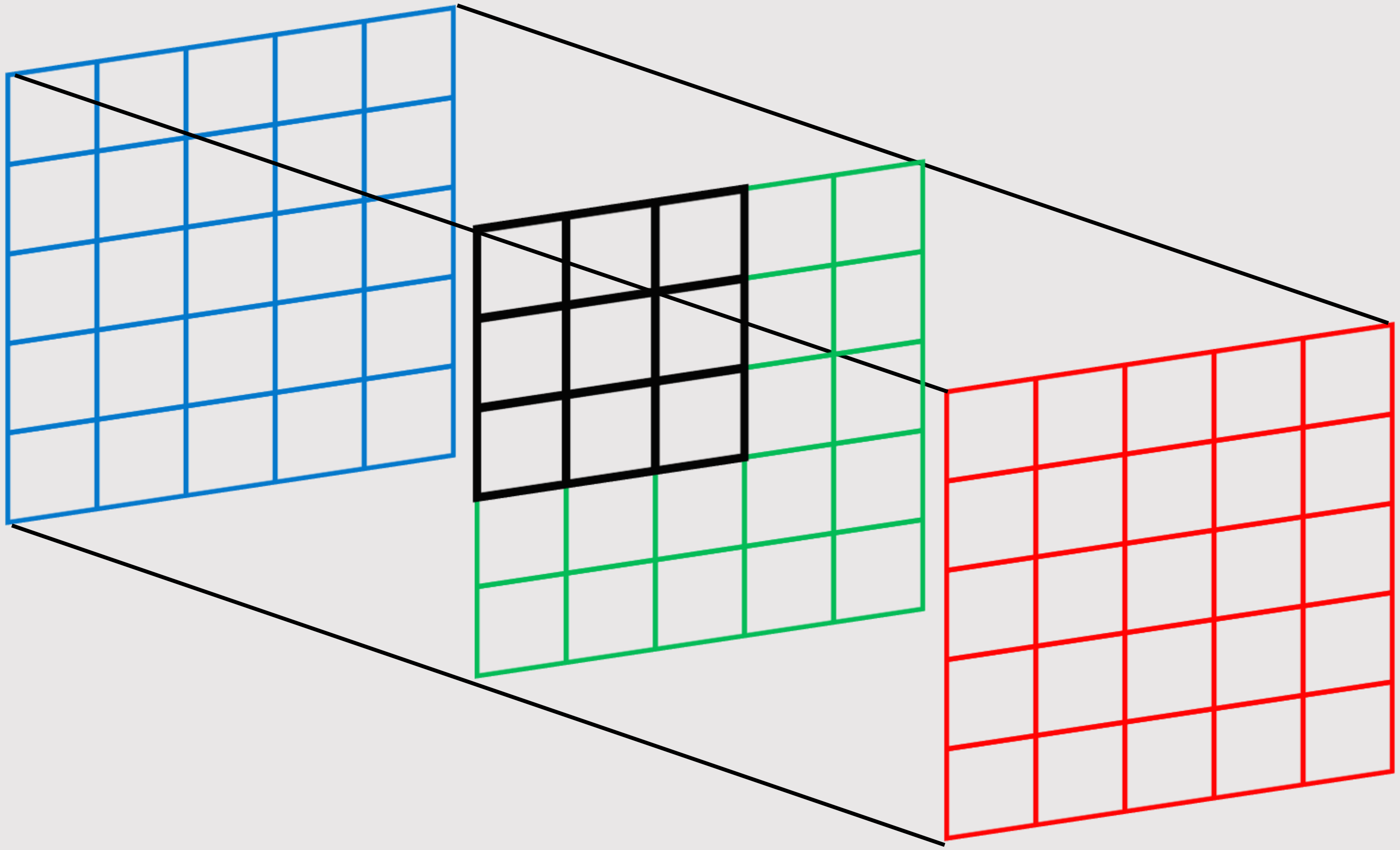
OPERATIONS ON IMAGE (COLOR)

WORKING WITH 3D ARRAYS: COLOR IMAGE ARRAY STRUCTURE



WORKING WITH COLOR IMAGE ARRAY: INDEXING

Desired array subset



Code

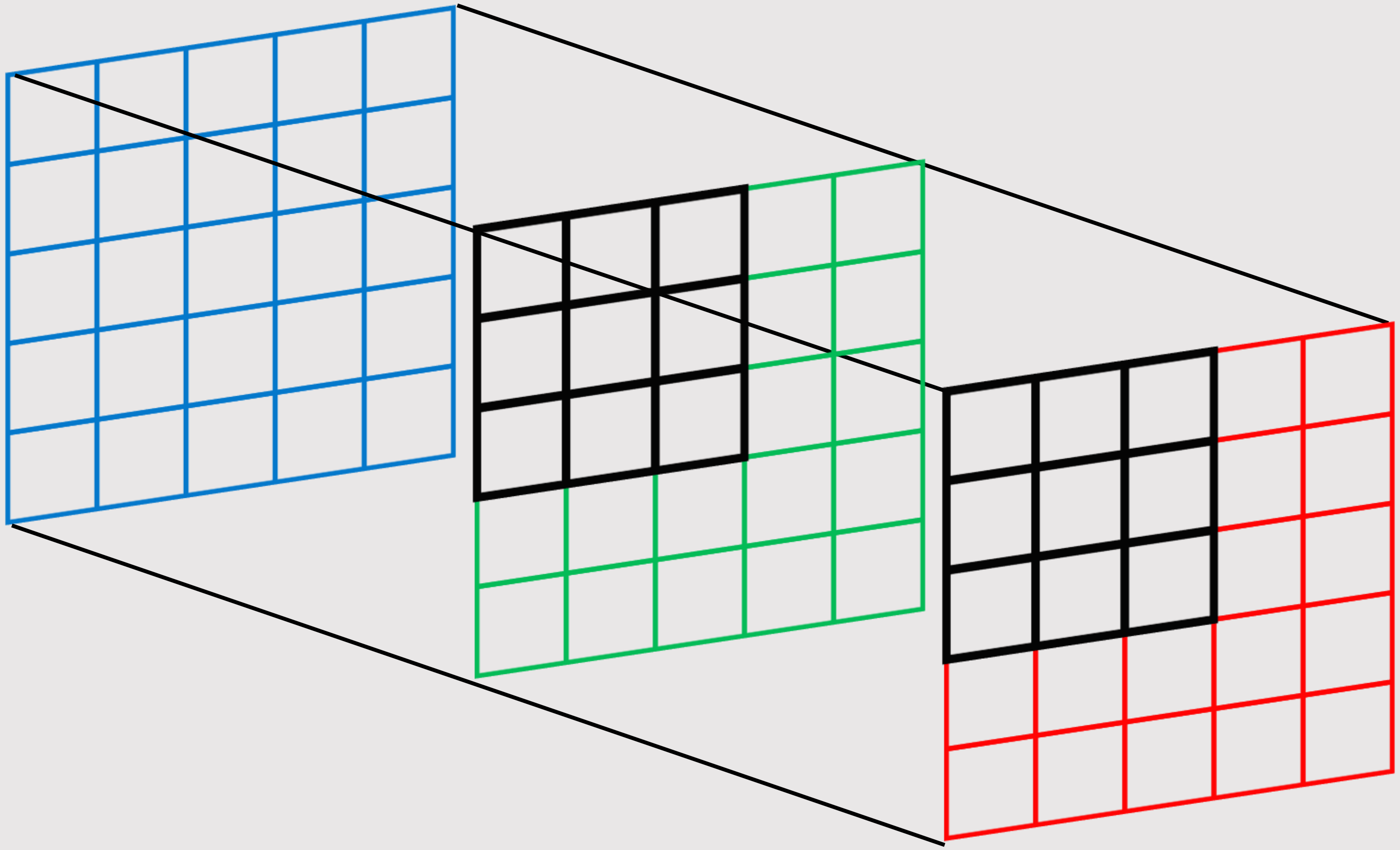
Img[:3, :3, 1]

Output array shape

(3, 3)

WORKING WITH COLOR IMAGE ARRAY: INDEXING

Desired array subset



Code

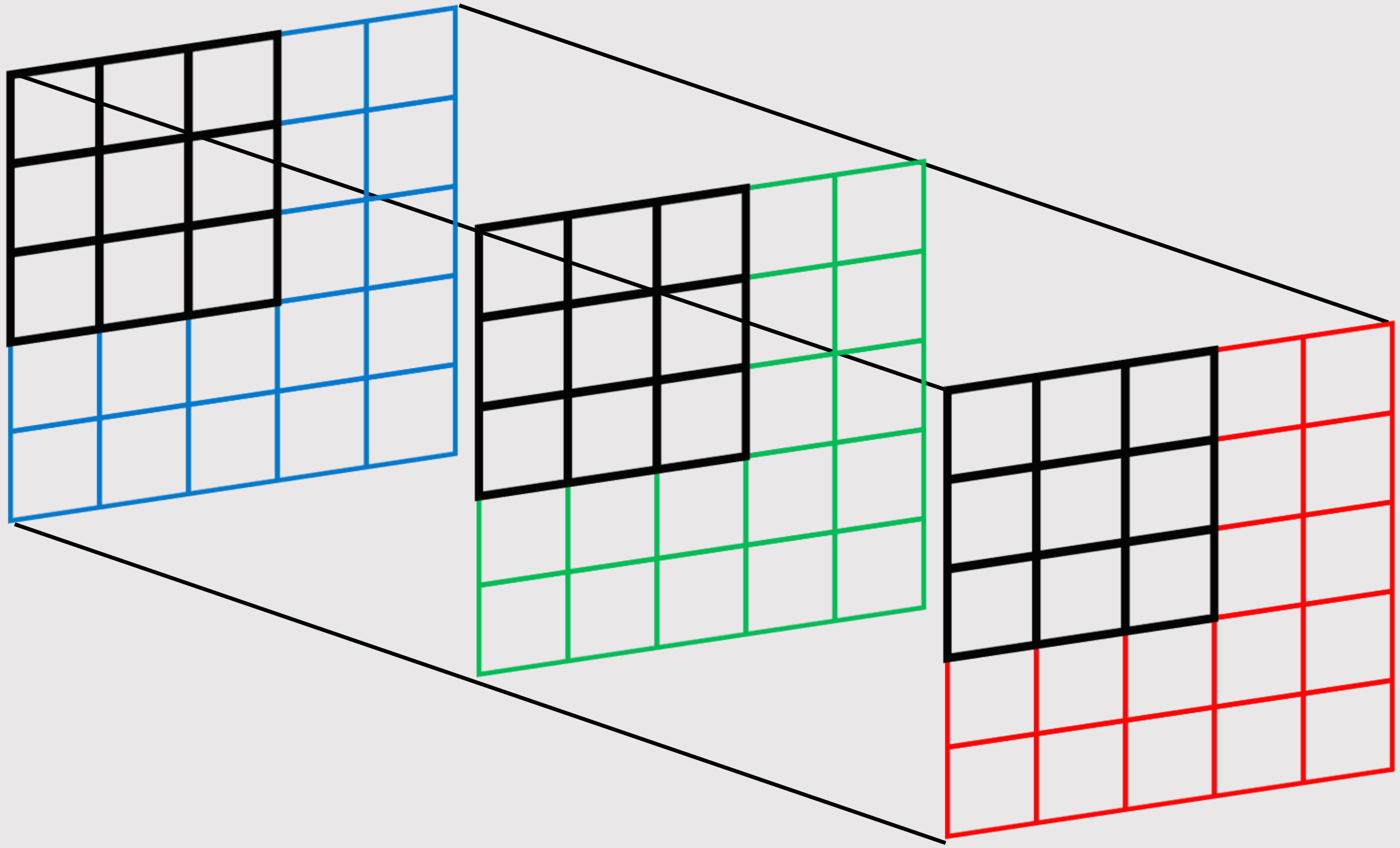
Img[:3, :3, :2]

Output array shape

(3, 3, 2)

WORKING WITH COLOR IMAGE ARRAY: INDEXING

Desired array subset



Code

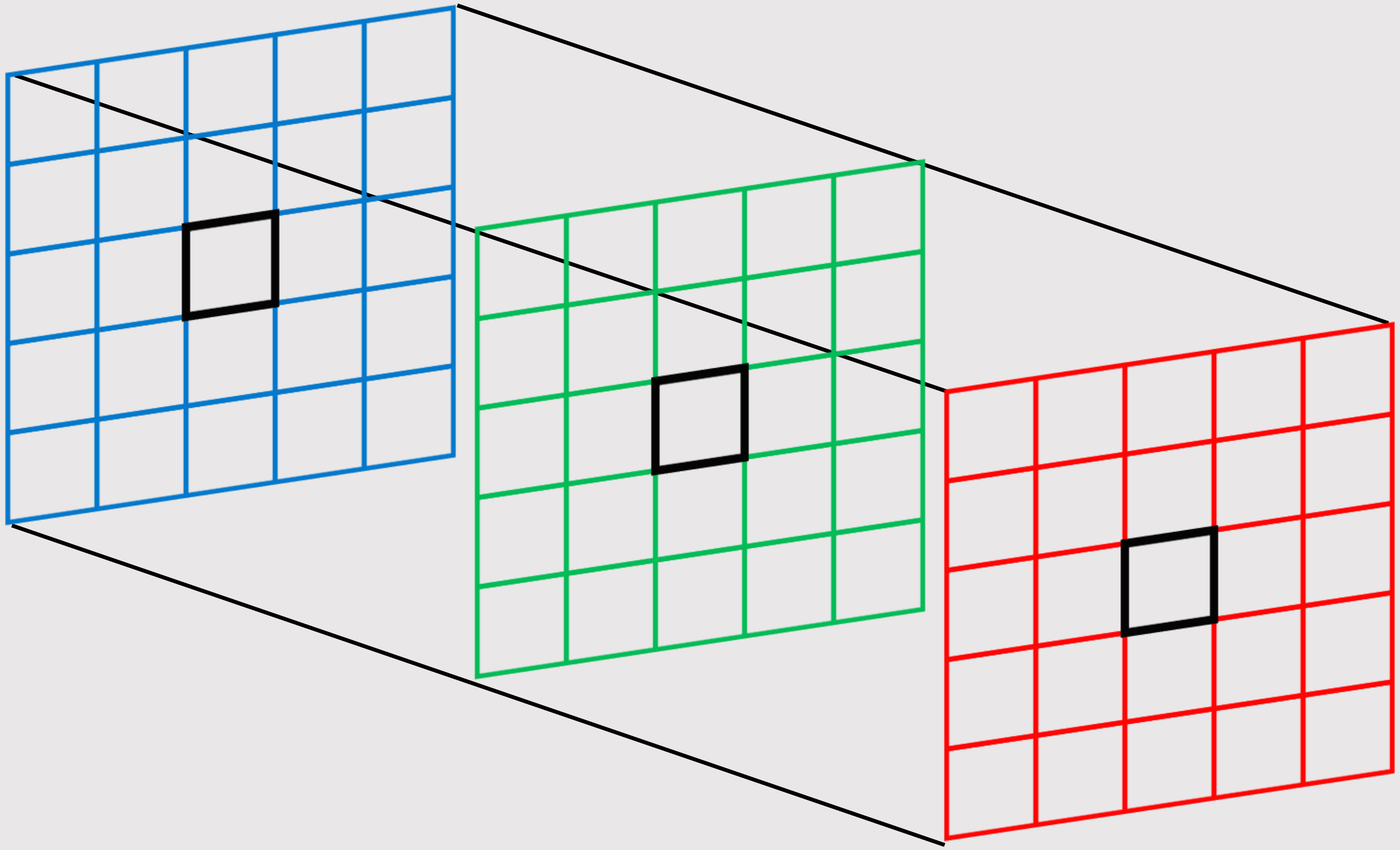
Img[:3, :3, :]

Output array shape

(3, 3, 3)

WORKING WITH COLOR IMAGE ARRAY: INDEXING

Desired array subset



Code

Img[2, 2, :]

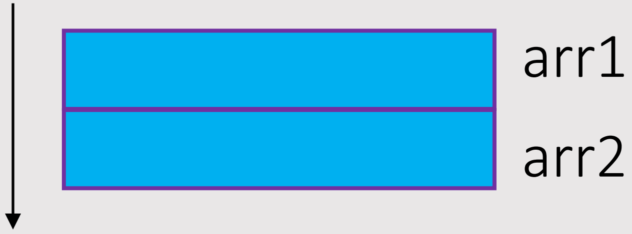
Output array shape

(3,)

CONSTRUCTING 3D ARRAYS FROM 2D ARRAYS

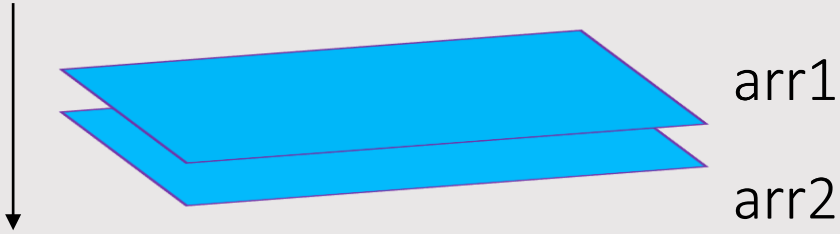
Recall np.stack() can be used to stack arrays alongside new dimension

New dimension



1D -> 2D

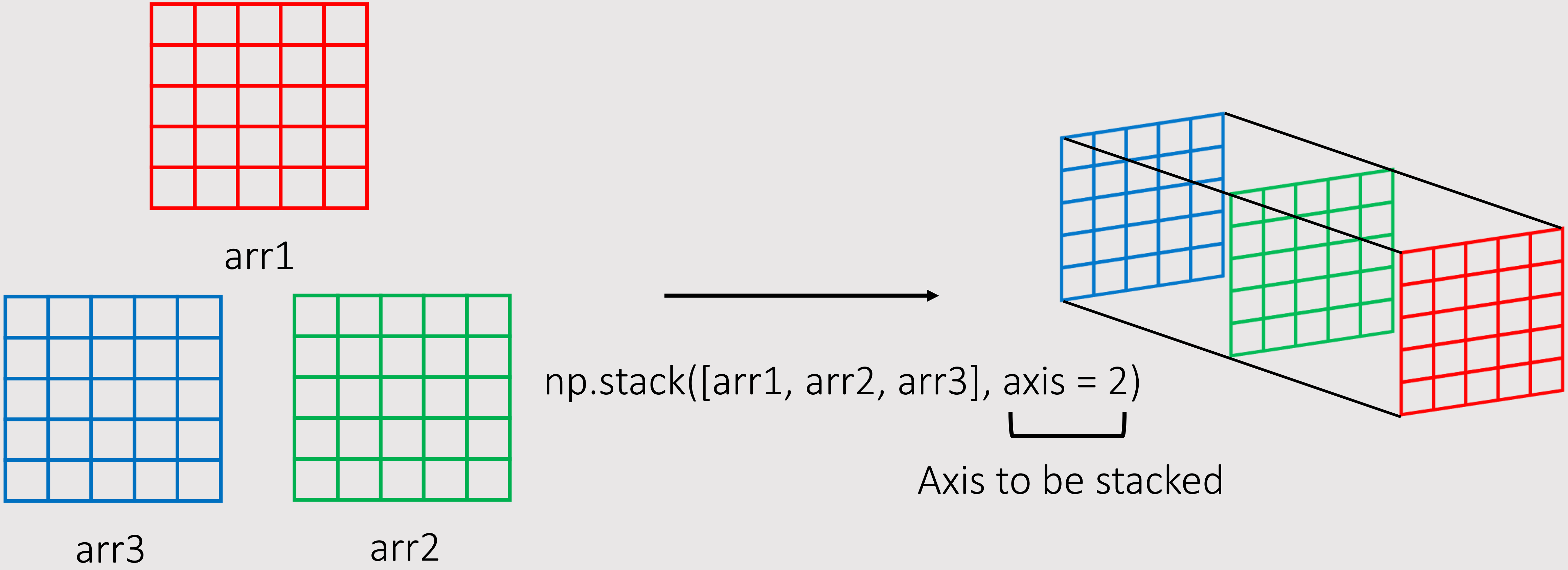
New dimension



2D -> 3D

We can use np.stack() to construct RGB image from 2D arrays

CONSTRUCTING 3D ARRAYS FROM 2D ARRAYS



EXPANDING IMAGE OPERATIONS TO COLOR: Image Flipping

```
img = mpimg.imread('TSR.jpg')
img = img.copy()
```

Load a color image

```
img_red = img[:, :, 0]
img_green = img[:, :, 1]
img_blue = img[:, :, 2]
```

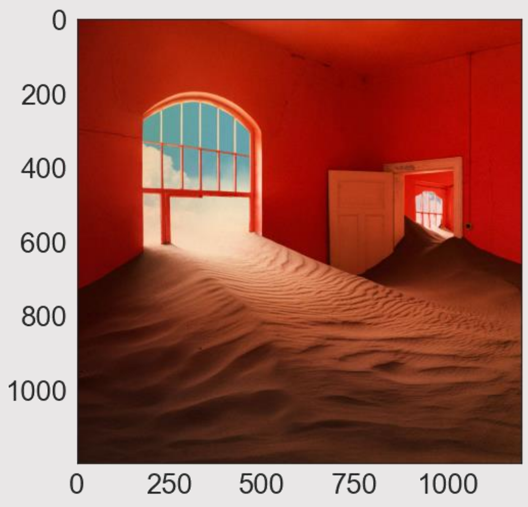
Extract Red, Green, Blue channels

```
img_red_flipped = np.fliplr(img_red)
img_green_flipped = np.fliplr(img_green)
img_blue_flipped = np.fliplr(img_blue)
```

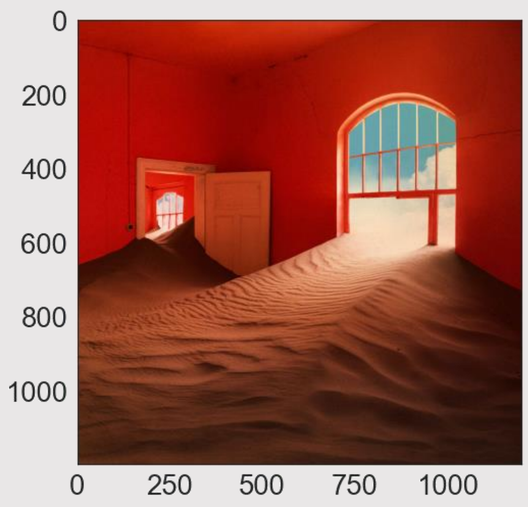
Apply flip on each channel

```
flipped_img = np.stack([img_red_flipped, img_green_flipped, img_blue_flipped], axis = 2)
```

Reconstruct the RGB image



Original image



Flipped image (Horizontal)

EXPANDING IMAGE OPERATIONS TO COLOR: Image Flipping (Partial)

```
img = mpimg.imread('TSR.jpg')
img = img.copy()
```

Load a color image

```
img_red = img[:, :, 0]
img_green = img[:, :, 1]
img_blue = img[:, :, 2]
```

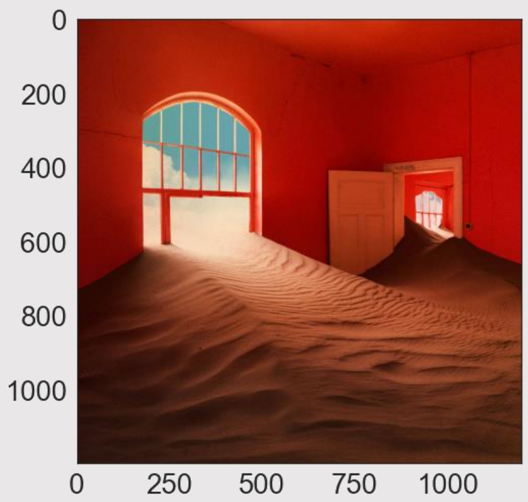
Extract Red, Green, Blue channels

```
img_green_flipped = np.fliplr(img_green)
```

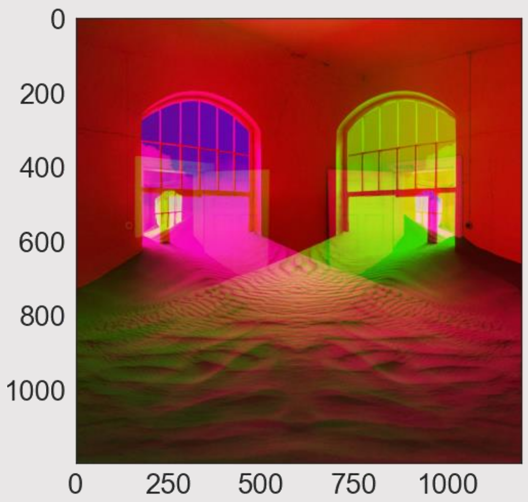
Apply flip on subset of channels

```
flipped_img = np.stack([img_red, img_green_flipped, img_blue], axis = 2)
```

Reconstruct the RGB image



Original image



Partially Flipped image (Horizontal)

EXPANDING IMAGE OPERATIONS TO COLOR: Image Downsampling

```
img = mpimg.imread('TSR.jpg')
img = img.copy()
```

Load a color image

```
img_red = img[:, :, 0]
img_green = img[:, :, 1]
img_blue = img[:, :, 2]
```

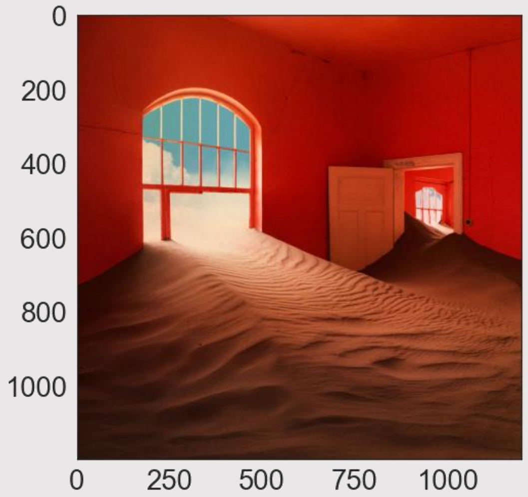
Extract Red, Green, Blue channels

```
img_red_DS = img_red[::10, ::10]
img_green_DS = img_green[::10, ::10]
img_blue_DS = img_blue[::10, ::10]
```

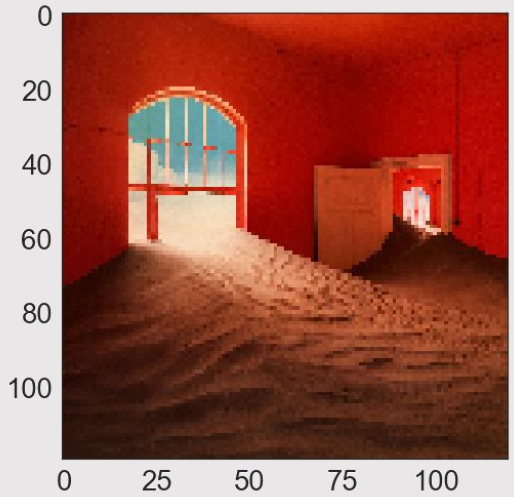
Down sample each channel

```
downsampled_img = np.stack([img_red_DS, img_green_DS, img_blue_DS], axis = 2)
```

Reconstruct the RGB image



Original image



Downsampled image (x10)

EXPANDING IMAGE OPERATIONS TO COLOR: Image Blending

```
img1 = mpimg.imread('TSR.jpg')
img1 = img1.copy()

img2 = mpimg.imread('currents.jpg')
img2 = img2.copy()
```

Load 2 images to be blended

```
img1_red, img2_red = img1[:, :, 0], img2[:, :, 0]
img1_green, img2_green = img1[:, :, 1], img2[:, :, 1]
img1_blue, img2_blue = img1[:, :, 2], img2[:, :, 2]
```

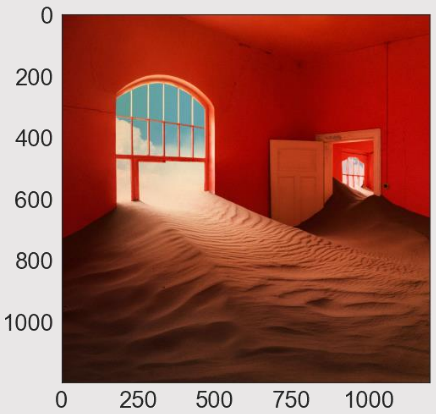
Extract channels from each image

```
blended_img_red = 0.5 * img1_red + 0.5 * img2_red
blended_img_green = 0.5 * img1_green + 0.5 * img2_green
blended_img_blue = 0.5 * img1_blue + 0.5 * img2_blue
```

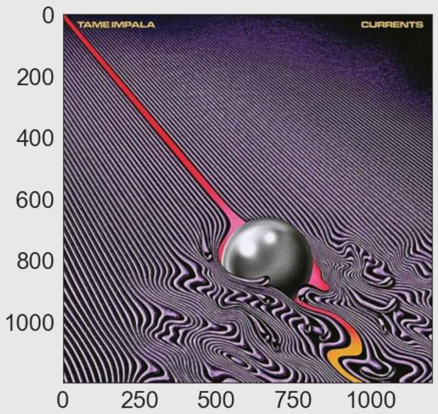
Add each channel with weights

```
blended_img = np.stack([blended_img_red, blended_img_green, blended_img_blue], axis = 2)
blended_img = blended_img.astype('int')
```

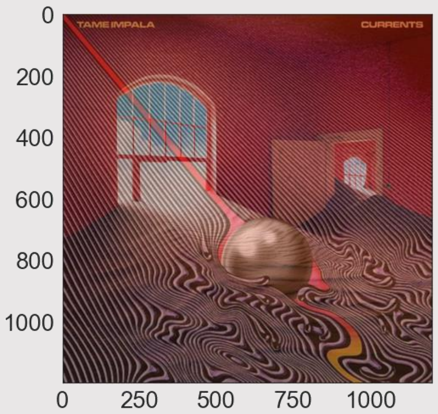
Reconstruct the image - Make sure to convert the pixel values into integers



Original image 1



Original image 2

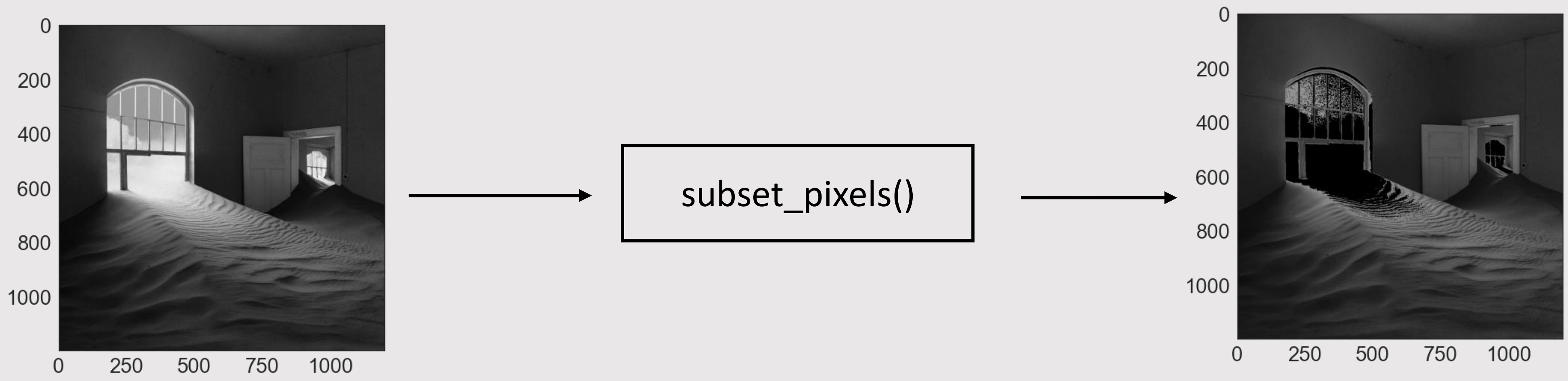


Blended image

LAB ASSIGNMENTS

Download ipynb template in Canvas page:
Assignments/Lab 3 report -> click “Lab 3 Report Templates”

EXERCISE 1: Generalized function for subsetting pixels



- Create a function **subset_pixels()** which takes a grayscale image as an input, and outputs the image with subsetted pixels according to minimum and maximum pixel values.

- The function should accept following parameters
  - Image – 2D array corresponding to input image
  - min_pixel_depth – minimum pixel depth value
  - max_pixel_depth – maximum pixel depth value
  - replacement_val – a pixel depth value to mask pixels that fall outside of min and max_pixel_depth

- Your function should mask the pixels s.t. values that fall outside of min and max values are set to replacement_val.
- Test your function against 3 provided parameter sets on a single grayscale image, and save them as e1_output1.png, e1_output2.png, e1_output3.png.

EXERCISE 2: Thumbnail generator function

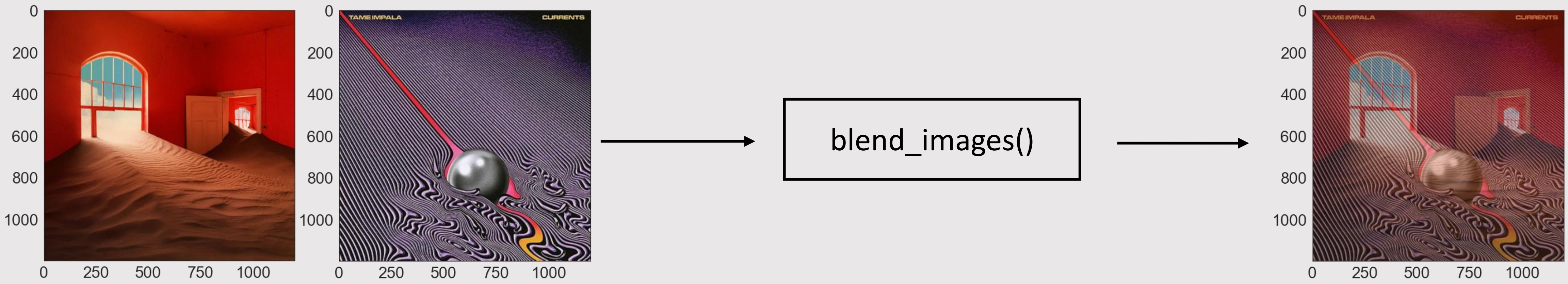
- Create a function **create_thumbnail()** which takes an RGB image as an input, and outputs the downsampled RGB image according to given compression rate using the **segment averaging technique (slide 23)**.

- The function should accept following parameters
  - image – 3D array corresponding to input image
  - downsampling_rate - an integer corresponding to the ratio between dimensions of original vs downsampled image. e.g. 10, 5, 3.

- Test your function against a provided color image with following downsampling rate: 5x, 10x, 20x. Save your outputs as e2_output1.png, e2_output2.png, e2_output3.png.

- You can assume the function only handles square images and the downsampling rate divides both the height and width of the image
- NOTE: **DO NOT USE** pre-existing downsampling function from a Python package

EXERCISE 3: Generalized image blender function



- Create a function **blend_images()** which takes multiple RGB images as an input, and outputs a blended image.

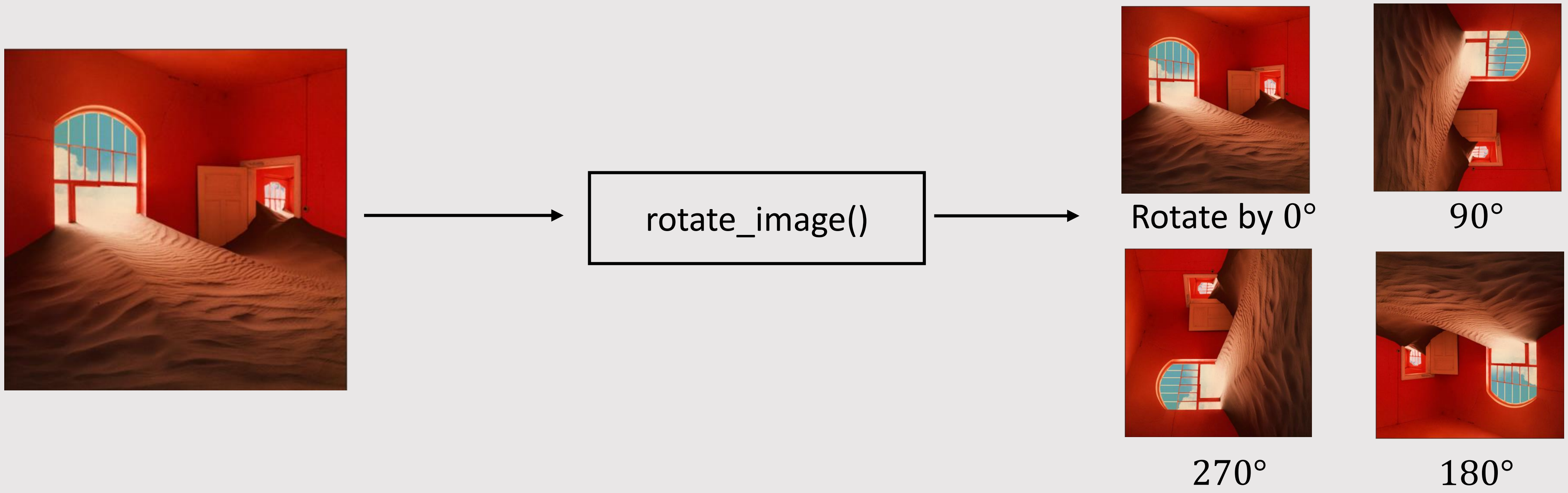
- The function should accept following parameters
  - image_list - A Python list of 3D arrays where each 3D array corresponds to an RGB image
  - weight_list – A Python list of float values between (0, 1) corresponding to the pixel weight to be given to each image – e.g. [0.2, 0.3, 0.1, 0.4] for 4 images. The sum of the weights should be equal to 1.

- Test your function against a provided list of 5 images with following weight_lists (i.e. 2 blended images)
  - [0.2, 0.2, 0.2, 0.2, 0.2] – blend all 5 images
  - [0.2, 0.3, 0.5] – blend first 3 images

- NOTE: **DO NOT USE** pre-existing image blending functions.

- Save your outputs as e3_output1.png, e3_output2.png.

EXERCISE 4: Image rotation function



- Create a function **rotate_images()** which takes a color image as an input, and outputs a rotated image by multiples of 90° in a **clockwise** direction.

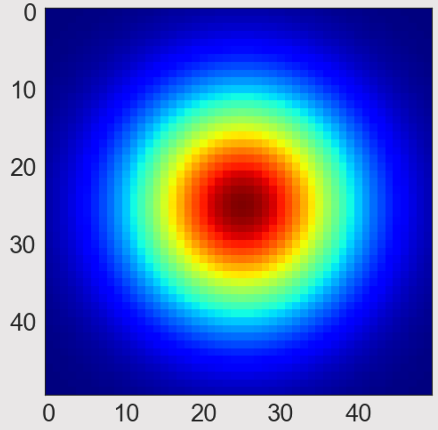
- The function should accept following parameters
  - Image - A 3D array corresponding to a color image
  - rotate angle – Angle to rotate the image. Takes one of 4 values [0°, 90°, 180°, 270°].

- Test your function against a provided image with 0°, 90°, 180° and 270° rotations (i.e. generate 4 images). Save your outputs as e4_output1.png, e4_output2.png, e4_output3.png, e4_output4.png.

- NOTE: **DO NOT USE** pre-existing rotation function from a Python package

EXERCISE 5: 2D Gaussian image generator

$[\vec{X}, \vec{Y}, \sigma_x, \sigma_x, x_0, y_0, A, cmap] \longrightarrow$ vis_2d_gaussian() $\longrightarrow$



- 2D Gaussian function is provided by an equation: $f(x,y) = A\exp\left(-\left(\frac{(x-x_o)^2}{2\sigma_X^2} + \frac{(y-y_o)^2}{2\sigma_Y^2}\right)\right)$
- You will implement a function **vis_2d_gaussian()** which creates an 2D array of $f(x,y)$ for given x, y-domains and outputs visualization of the function using plt.imshow().

- The function should accept following parameters:
  - $\vec{X}, \vec{Y}$ - 2D numpy arrays of floats corresponding to grids of x and y-coordinates respectively (more detail in template).
  - σ_X, σ_Y - standard deviations in x, y directions
  - x_0, y_0 - x center and y center coordinates
  - A – Scaling factor of the function. Set this to **255** so that $f(x,y) \in (0, 255)$ thus consistent with 8-bit color code
  - cmap – color spectrum to be used for the plotting function

- Test your function against 2 sets of parameters provided by the lab template. For each parameter set, produce 2 plots one using **cmap = 'gray' (grayscale)** and other one using **cmap = 'jet' (blue to red color spectrum).** Save your outputs as e5_output1.png, e5_output2.png, e5_output3.png, e5_output4.png.

SUPPLEMENTARY: DEBUGGING YOUR CODE VIA LOGGING & COMMON ARRAY MISTAKES

GENERAL TIPS ON MINIMIZING ERRORS

Do not panic when you get errors

Outline your code structure ahead of time

Keep your code organized

Test your code often

More tips on avoiding errors by Berkeley online textbook
https://pythonnumericalmethods.berkeley.edu/notebooks/chapter10.00-Errors-Practices-Debugging.html

BASIC DEBUGGING WITH PRINT()

Code block 1

print("done running block 1") → Runs when code block 1 doesn't produce an error

Code block 2

print("done running block 2") → Runs when code block 2 doesn't produce an error

Code block 3

.
.
.

print("done running block 3")

BASIC DEBUGGING WITH PRINT()

Original code

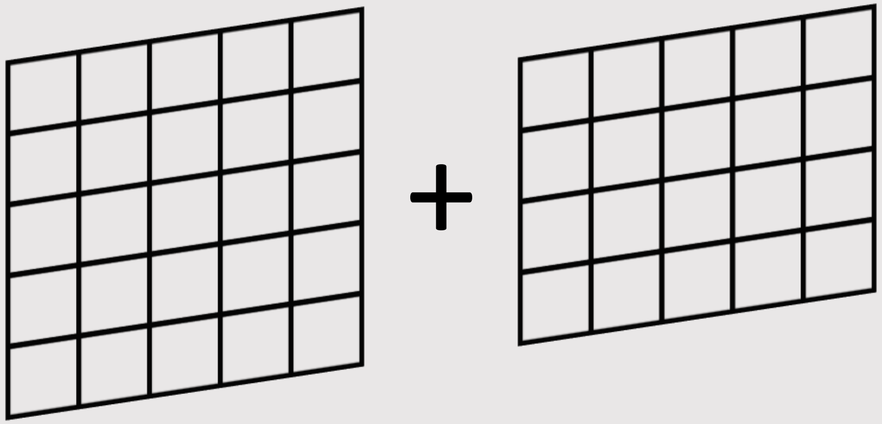
```
x = …

Code that processes x
Produces y

y = …

Code that processes y
Produces z

z = …
```

Debugging each step with print()

```
x = …
print(x)        → Check if x value is correct

Code that processes x
Produces y

y = …
print(y)        → Check if y value is correct

Code that processes y
Produces z

z = …
print(z)        → Check if z value is correct
```

COMMON ARRAY MISTAKES – ARRAY ARITHMETIC

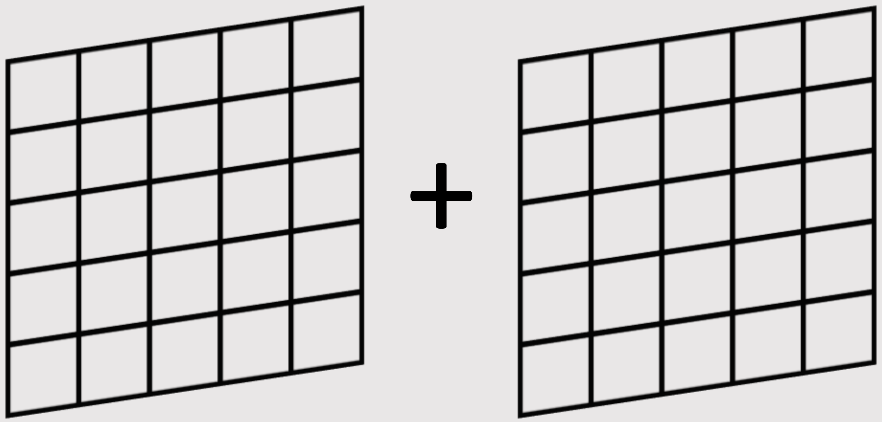
Dimension mismatch example during array addition



arr_1.shape = (5, 5)   arr_2.shape = (4, 5)

```
---------------------------------------------------------------------------
ValueError                                Traceback (most recent call last)
<ipython-input-14-926f132f2a32> in <module>
      1 arr_1 = np.ones((5,5))
      2 arr_2 = np.ones((4,5))
----> 3 np.add(arr_1, arr_2)

ValueError: operands could not be broadcast together with shapes (5,5) (4,5)
```

Correct operation



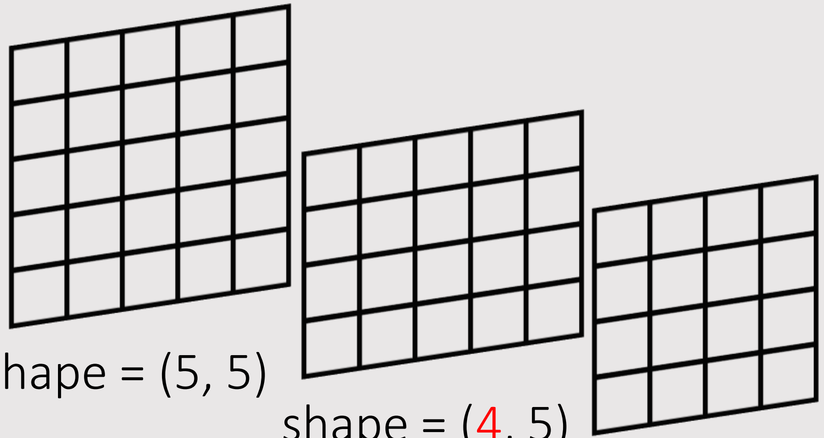
arr_1.shape = (5, 5)   arr_2.shape = (5, 5)

```
arr_1 = np.ones((5,5))
arr_2 = np.ones((5,5))

np.add(arr_1, arr_2)
```

```
array([[2., 2., 2., 2., 2.],
       [2., 2., 2., 2., 2.],
       [2., 2., 2., 2., 2.],
       [2., 2., 2., 2., 2.],
       [2., 2., 2., 2., 2.]])
```

COMMON ARRAY MISTAKES – ARRAY STACKING

Dimension mismatch example during array stacking



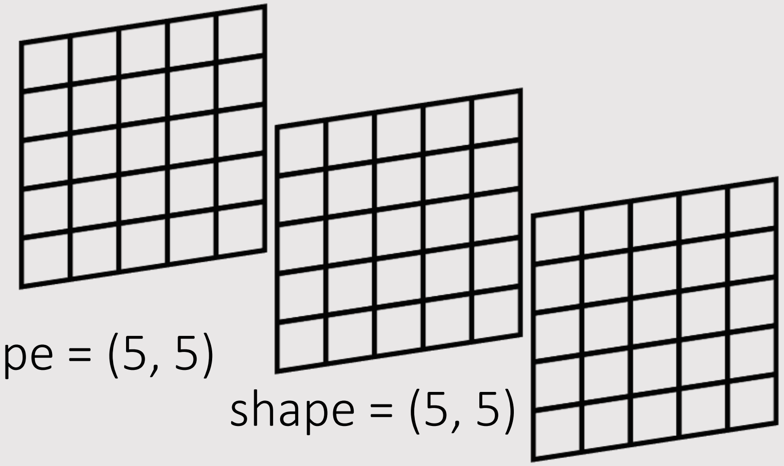
shape = (5, 5)

shape = (4, 5)

shape = (4, 4)

```
---------------------------------------------------------------------------
ValueError                                Traceback (most recent call last)
<ipython-input-16-328819f5fe4c> in <module>
      3 arr_3 = np.ones((4,4))
      4 
----> 5 np.stack([arr_1, arr_2, arr_3], axis = 2)

<__array_function__ internals> in stack(*args, **kwargs)

~\anaconda3\lib\site-packages\numpy\core\shape_base.py in stack(arrays, axis, out)
    425     shapes = {arr.shape for arr in arrays}
    426     if len(shapes) != 1:
--> 427         raise ValueError('all input arrays must have the same shape')
    428 
    429     result_ndim = arrays[0].ndim + 1

ValueError: all input arrays must have the same shape
```

Correct operation



shape = (5, 5)

shape = (5, 5)

shape = (5, 5)

```
arr_1 = np.ones((5,5))
arr_2 = np.ones((5,5))
arr_3 = np.ones((5,5))

arr_combined = np.stack([arr_1, arr_2, arr_3], axis = 2)
print(arr_combined.shape)
```

```
(5, 5, 3)
```