Slides and example codes are available:
https://github.com/mint-lab/cv_tutorial

# Image Editing:
# Learning OpenCV

Sunglok Choi, Assistant Professor, Ph.D.
Computer Science and Engineering Department, SEOULTECH
sunglok@seoultech.ac.kr | https://mint-lab.github.io/

## OpenCV: Open-source Computer Vision Library

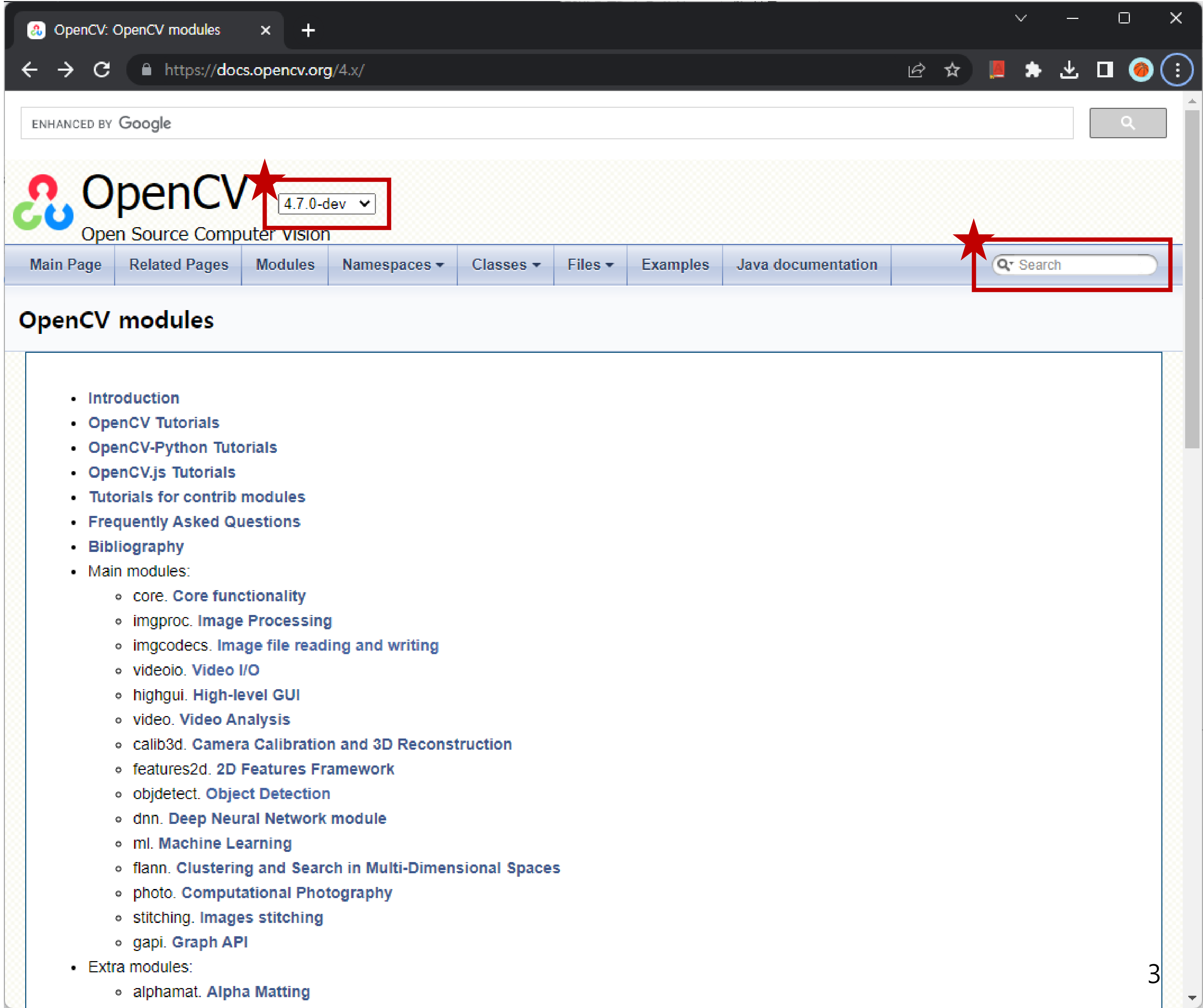
- OpenCV is the most popular open-source library for real-time computer vision.
  - It includes many basic functionalities (e.g. `cv::Mat`, `cv::imread()`, `cv::VideoCapture`, `cv::FileStorage`) and useful algorithms (e.g. `cv::solvePnP()`, `cv::SIFT`, `cv::ml::SVM`, `cv::dnn::DetectionModel`)
  - Its codes are written in C++ and highly optimized (for real-time operation) with Intel IPP, Intel TBB, NVIDIA CUDA, OpenCL, OpenMP, and more.
  - Cross-platform: C++, Python, Java, MATLAB @ Windows, Linux, MacOS, iOS, Android
  - License: Apache 2 (free for commercial use)
- References: **Documentation** (tutorials and APIs), Github, Cheatsheet (by Antonio Anjos)
- Installation in Python
  - Installation

```
pip install opencv-python opencv-contrib-python
```

  - Check the installation and its version

```
import cv2 as cv
print(cv.__version__) # 4.7.0
```

## OpenCV Documentation



OpenCV modules

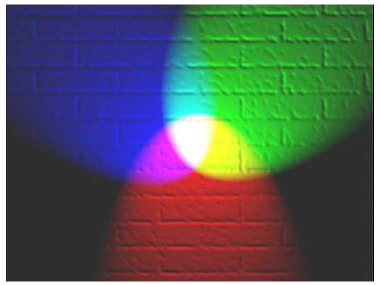
- Introduction
- OpenCV Tutorials
- OpenCV-Python Tutorials
- OpenCV.js Tutorials
- Tutorials for contrib modules
- Frequently Asked Questions
- Bibliography
- Main modules:
  - core. Core functionality
  - imgproc. Image Processing
  - imgcodecs. Image file reading and writing
  - videoio. Video I/O
  - highgui. High-level GUI
  - video. Video Analysis
  - calib3d. Camera Calibration and 3D Reconstruction
  - features2d. 2D Features Framework
  - objdetect. Object Detection
  - dnn. Deep Neural Network module
  - ml. Machine Learning
  - flann. Clustering and Search in Multi-Dimensional Spaces
  - photo. Computational Photography
  - stitching. Images stitching
  - gapi. Graph API
- Extra modules:
  - alphamat. Alpha Matting

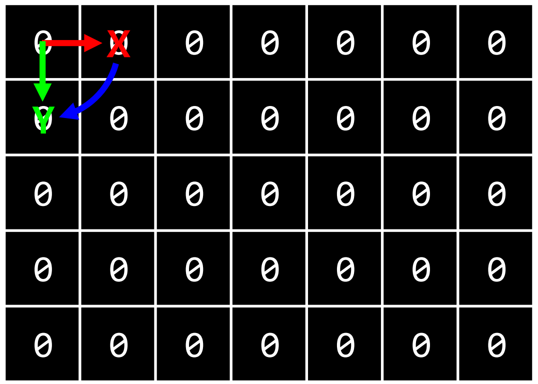
## Table of Contents

# OpenCV Image Representation

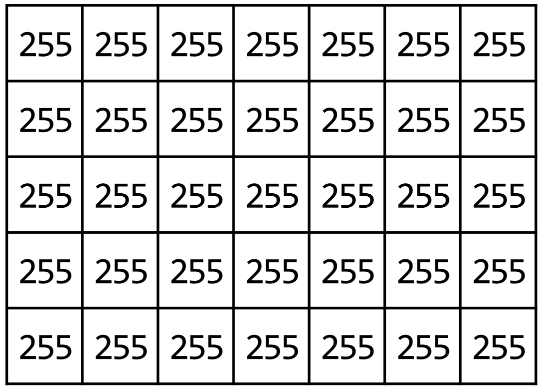
- An image is represented by the **multi-dimensional array of NumPy** (`np.array`) in Python.
  - Note) An image is represented by the `cv::Mat` class in C++.
  - The shape of NumPy array is `(height, width, channel)`, not `(width, height, channel)`.
    - A pixel at (x, y) is accessed through `image[y,x]`, not `image[x,y]`.
    - The channel of a **gray** image: **1**
    - The channel of a **color** image: **3** (or 4 with alpha channel)
      - The order of color channels is **Blue**-**Green**-**Red** (**BGR**), not RGB.
  - The data type of NumPy array is `np.uint8` (size: 8 bits) whose range is 0 to 255.
  - Examples) 8-by-5 images (width: 8, height: 5)

Why? Additive color

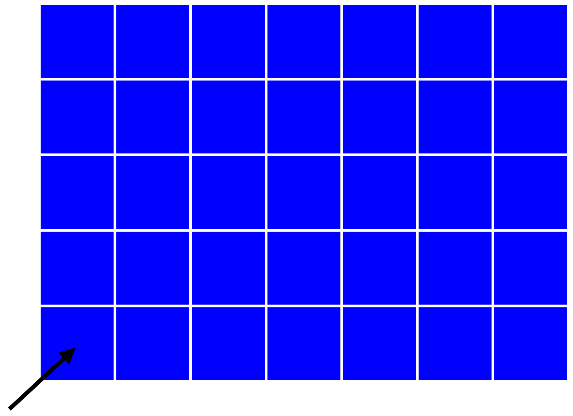




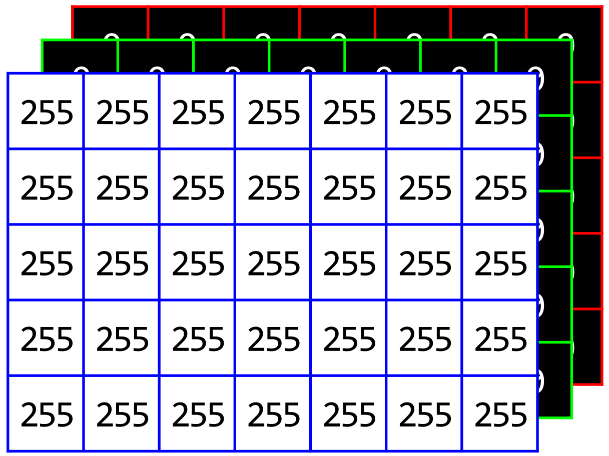
| | | | | | | |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |



| | | | | | | |
|---|---|---|---|---|---|---|
| 255 | 255 | 255 | 255 | 255 | 255 | 255 |
| 255 | 255 | 255 | 255 | 255 | 255 | 255 |
| 255 | 255 | 255 | 255 | 255 | 255 | 255 |
| 255 | 255 | 255 | 255 | 255 | 255 | 255 |
| 255 | 255 | 255 | 255 | 255 | 255 | 255 |



(255, 0, 0)



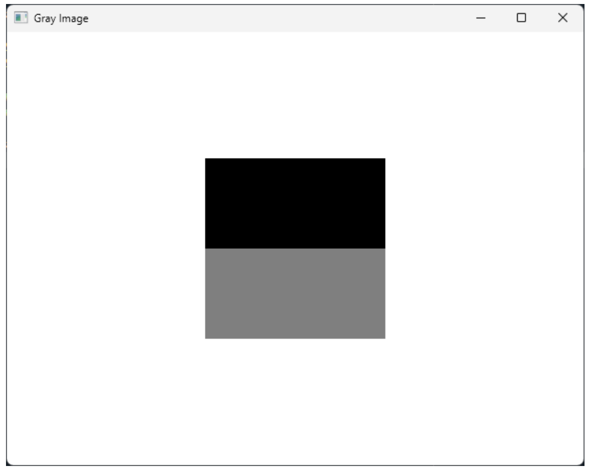
| | | | | | | |
|---|---|---|---|---|---|---|
| 255 | 255 | 255 | 255 | 255 | 255 | 255 |
| 255 | 255 | 255 | 255 | 255 | 255 | 255 |
| 255 | 255 | 255 | 255 | 255 | 255 | 255 |
| 255 | 255 | 255 | 255 | 255 | 255 | 255 |
| 255 | 255 | 255 | 255 | 255 | 255 | 255 |

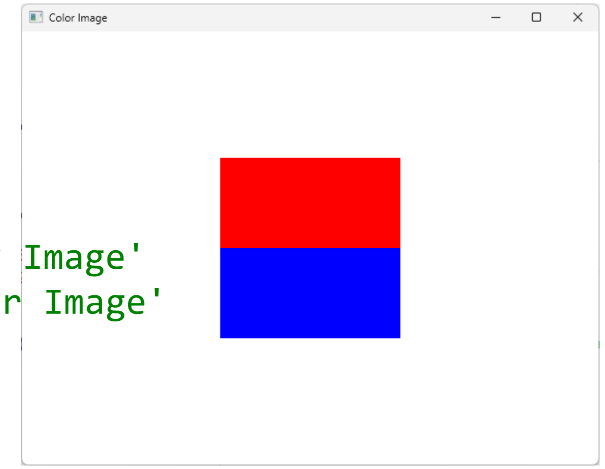
Image: Wikipedia

## OpenCV Image Representation

- Example) Image creation

```
import numpy as np
import cv2 as cv

img_gray = np.full((480, 640), 255, dtype=np.uint8) # Create a gray image (white)
img_gray[140:240, 220:420] = 0                      # Draw the black box
img_gray[240:340, 220:420] = 127                    # Draw the gray box

img_color = np.zeros((480, 640, 3), dtype=np.uint8) # Create a color image (black)
img_color[:] = 255                                  # Make the color image white
img_color[140:240, 220:420, :] = (0, 0, 255)        # Draw the red box
img_color[240:340, 220:420, :] = (255, 0, 0)        # Draw the blue box

cv.imshow('Gray Image',  img_gray)  # Show 'img_gray'  on a new window named as 'Gray Image'
cv.imshow('Color Image', img_color) # Show 'img_color' on a new window named as 'Color Image'
cv.waitKey()                        # Wait until a user press any key
cv.destroyAllWindows()              # It is necessary only for Spyder IDE.
```





## OpenCV Image Representation

- Note) Image visualization functions in OpenCV High-level GUI module
  - `cv.imshow(winname, mat) → None`
    - Displays an image (`mat`) in the specified window.
  - `cv.waitKey([, delay]) → keycode or -1`
    - Waits for a pressed key and return the key code.
      - `delay`: Delay in milliseconds. 0 is the special value that means "forever".
      - `keycode`: ASCII code of the pressed key (e.g. 27 for ESC key code)
    - Note) `cv.waitKeyEx()` can return full key code including arrow keys.
      - However, its additional key codes are different according to its GUI backend (e.g. Win32/QT/GTK).
  - `cv.destroyAllWindows() → None`
    - Destroys all of the HighGUI windows.
    - Note) `cv.destroyWindow(winname)` can destroy the specific window.

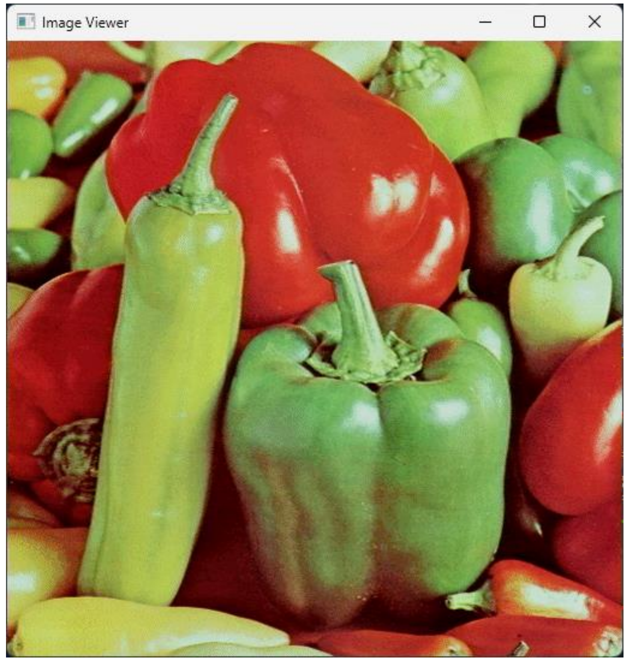
## OpenCV Image and Video Input/Output

- **Image files**
  - `cv.imread(filename[, flags]) → image or None`
    - Loads an image from a file.
  - `cv.imwrite(filename, img[, params]) → retval`
    - Saves an image to a specified file.
- **Video files and cameras**
  - `cv.VideoCapture`
    - A class for video capturing from video files, image sequences or cameras.
    - The member function, `get()` and `set()`, can access and modify video properties.
      - Note) Flags for Video I/O (e.g. `cv.CAP_PROP_FPS`)
  - `cv.VideoWriter`
    - A class for video writing.

## OpenCV Image Input/Output

- Example) Image file viewer

```python
import cv2 as cv

img_file = 'data/peppers_color.tif'

# Read the given image file
img = cv.imread(img_file)

# Check whether the image is valid or not
if img is not None:
    # Show the image
    cv.imshow('Image Viewer', img)
    cv.waitKey()
    cv.destroyAllWindows()
```



## OpenCV Image Input/Output

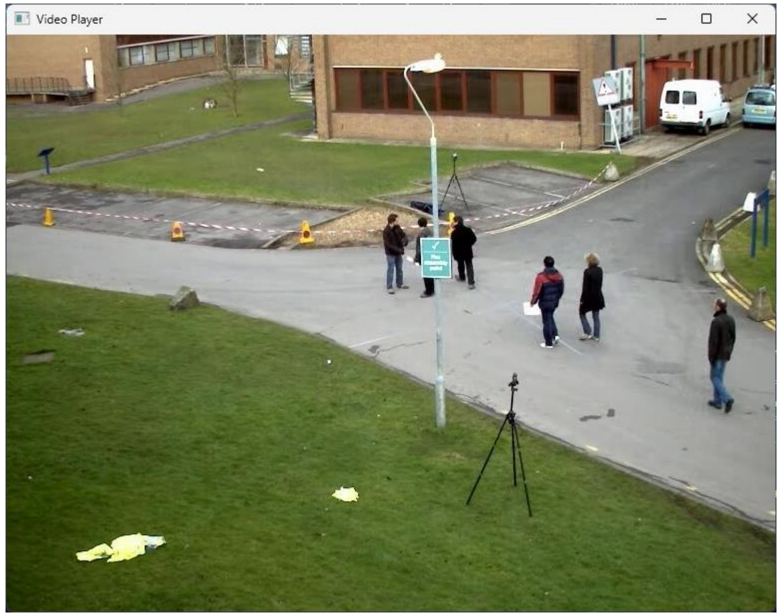
- Example) Image format converter

```
import cv2 as cv

img_file = 'data/peppers_color.tif'
target_format = 'png'

# Read the given image file
img = cv.imread(img_file)

# Check whether the image is valid or not
if img is not None:
    # Write 'img' as a file named 'target_file'
    target_file = img_file[:img_file.rfind('.')] + '.' + target_format
    cv.imwrite(target_file, img)
```

## OpenCV Video Input/Output

- Example) Video file player

```
video_file = 'data/PETS09-S2L1-raw.webm'

# Read the given video file
# Note) Additional argument examples
# - Image sequence: video_file = 'data/PETS09-S2L1-raw_%04d.png'
# - Camera        : video_file = 0 (Note: The camera index)
video = cv.VideoCapture(video_file)

if video.isOpened():
    # Get FPS and calculate the waiting time in millisecond
    fps = video.get(cv.CAP_PROP_FPS)
    wait_msec = int(1 / fps * 1000)

    while True:
        # Read an image from 'video'
        valid, img = video.read()
        if not valid:
            break

        # Show the image
        cv.imshow('Video Player', img)

        # Terminate if the given key is ESC
        key = cv.waitKey(wait_msec)
        if key == 27: # ESC
            break

    cv.destroyAllWindows()
```



## OpenCV Video Input/Output

- Example) Video format converter

```
video_file = 'data/PETS09-S2L1-raw.webm'
target_format = 'avi'
target_fourcc = 'XVID' # Note) FourCC: https://learn.microsoft.com/en-us/windows/win32/medfound/video-fourccs

# Read the given video file
video = cv.VideoCapture(video_file)

if video.isOpened():
    target = cv.VideoWriter()
    while True:
        # Get an image from 'video'
        valid, img = video.read()
        if not valid:
            break

        if not target.isOpened():
            # Open the target video file
            target_file = video_file[:video_file.rfind('.')] + '.' + target_format
            fps = video.get(cv.CAP_PROP_FPS)
            h, w, *_ = img.shape
            is_color = (img.ndim > 2) and (img.shape[2] > 1)
            target.open(target_file, cv.VideoWriter_fourcc(*target_fourcc), fps, (w, h), is_color)

        # Add the image to 'target'
        target.write(img)

    target.release()
```

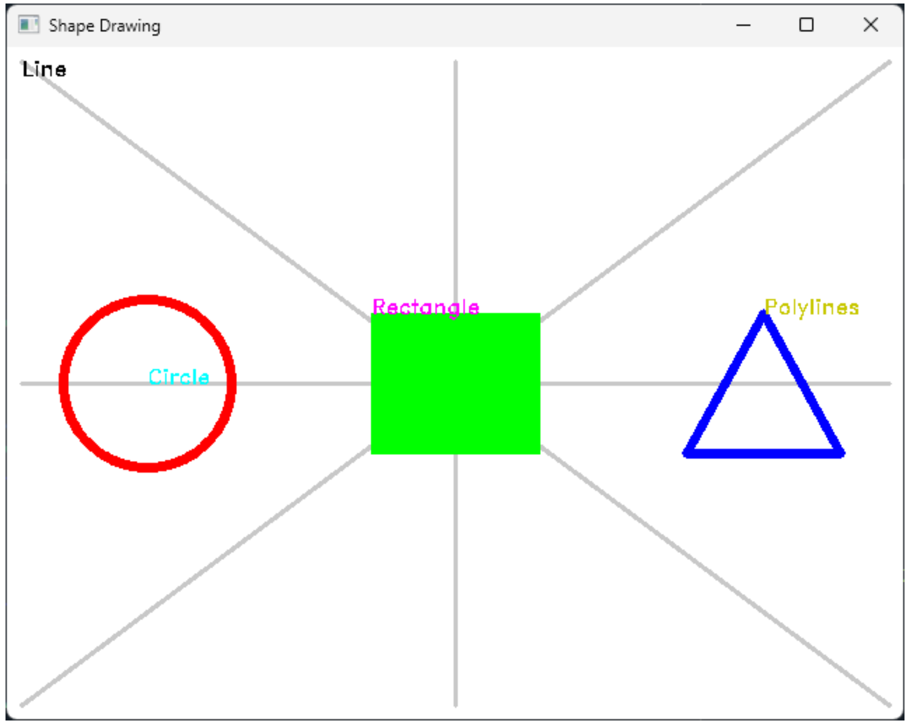
## OpenCV Drawing Functions

- Drawing functions in OpenCV Image Processing module
  - `cv.line(img, pt1, pt2, color, [thickness, …]) → img`
    - Draw a line segment connecting two points.
    - Note) `img` is modified as call-by-reference. `pt1` and `pt2` should be integers, not real numbers.
  - `cv.circle(img, center, radius, color [, thickness, …]) → img`
    - Draw a circle.
    - Note) Negative values of `thickness` draws a circle filled with the given `color`.
  - `cv.rectangle(img, pt1, pt2, color [, thickness, …]) → img`
    - Draw a rectangle.
  - `cv.polylines(img, pts, isClosed, color [, thickness, …]) → img`
    - Draw a multiple connected lines or a polygon (if `isClosed` is True).
  - `cv.fillPoly(img, pts, color [, …]) → img`
    - Draw a polygon filled with the given `color`.
  - `cv.putText(img, text, org, fontFace, fontScale, color [, thickness, …]) → img`
    - Draw a `text` at the given point, `org`. (Note: The top left of the `text` is aligned at `org` by default.)

## OpenCV Drawing Functions

- Examples) Shape drawing

```python
# Prepare a canvas
canvas = np.full((480, 640, 3), 255, dtype=np.uint8)

# Draw lines with its label
cv.line(canvas, (10, 10), (640-10, 480-10), color=(200, 200, 200), thickness=2)
cv.line(canvas, (640-10, 10), (10, 480-10), color=(200, 200, 200), thickness=2)
cv.line(canvas, (320, 10), (320, 480-10), color=(200, 200, 200), thickness=2)
cv.line(canvas, (10, 240), (640-10, 240), color=(200, 200, 200), thickness=2)
cv.putText(canvas, 'Line', (10, 20), cv.FONT_HERSHEY_DUPLEX, 0.5, (0, 0, 0))

# Draw a circle with its label
center = (100, 240)
cv.circle(canvas, center, radius=60, color=(0, 0, 255), thickness=5)
cv.putText(canvas, 'Circle', center, cv.FONT_HERSHEY_DUPLEX, 0.5, (255, 255, 0))

# Draw a rectangle with its label
pt1, pt2 = (320-60, 240-50), (320+60, 240+50)
cv.rectangle(canvas, pt1, pt2, color=(0, 255, 0), thickness=-1)
cv.putText(canvas, 'Rectangle', pt1, cv.FONT_HERSHEY_DUPLEX, 0.5, (255, 0, 255))

# Draw a polygon (triangle) with its label
pts = np.array([(540, 240-50), (540-55, 240+50), (540+55, 240+50)])
cv.polylines(canvas, [pts], True, color=(255, 0, 0), thickness=5)
cv.putText(canvas, 'Polylines', pts[0].flatten(), cv.FONT_HERSHEY_DUPLEX, 0.5, (0, 200, 200))

# Show the canvas
cv.imshow('Shape Drawing', canvas)
cv.waitKey()
cv.destroyAllWindows()
```



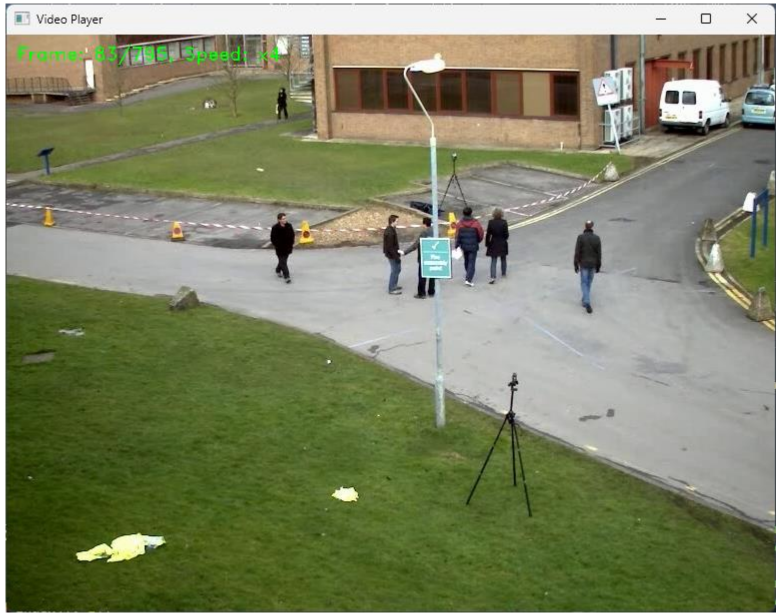
## OpenCV High-level GUI

- OpenCV high-level GUI provides **common interface** for image visualization and minimal user interaction regardless of operating systems and GUI backends (e.g. Win32, Qt, GTK).
  - `cv.namedWindow(winname[, flags]) → None`
    - Creates a window.
  - `cv.setMouseCallback(winname, event_handler, userdata) → None`
    - Sets mouse handler for the specified window.
      - `event_handler`: Callback function for mouse events.
      - `userdata`: The optional parameter passed to the callback (for information sharing).
  - `cv.imshow(winname, mat) → None`
    - Displays an image (`mat`) in the specified window.
  - `cv.waitKey([, delay]) → keycode or -1`
    - Waits for a pressed key and return the key code.
  - `cv.destroyAllWindows() → None`
    - Destroys all of the HighGUI windows.

## OpenCV High-level GUI: Handling Keyboard Events

- Example) Video file player with frame navigation

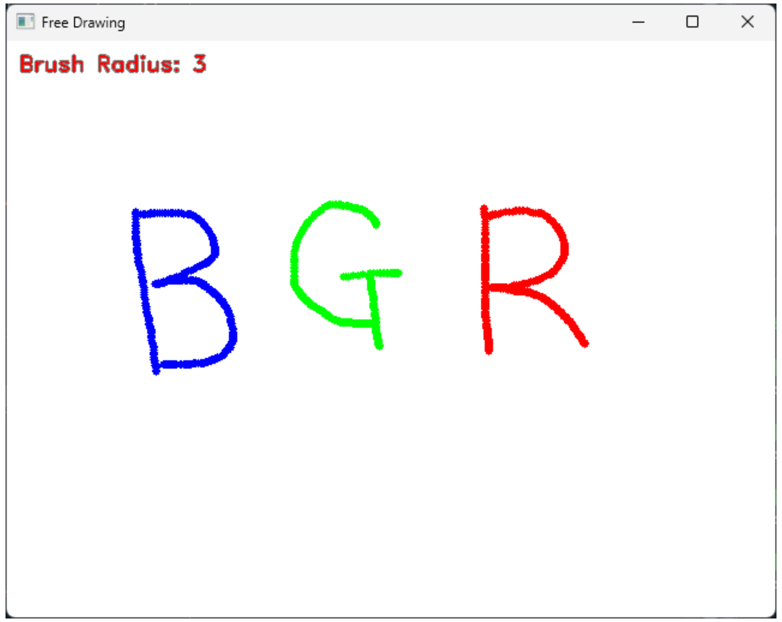
```python
if video.isOpened():
    # Configure the frame navigation
    frame_total = int(video.get(cv.CAP_PROP_FRAME_COUNT))
    frame_shift = 10
    speed_table = [1/10, 1/8, 1/4, 1/2, 1, 2, 3, 4, 5, 8, 10]
    speed_index = 4

    while True:
        # Get an image from 'video'
        ...

        # Show the image
        ...

        # Process the key event
        key = cv.waitKey(max(int(wait_msec / speed_table[speed_index]), 1))
        if key == ord(' '):
            key = cv.waitKey()
        if key == 27: # ESC
            break
        elif key == ord('\t'):
            speed_index = 4
        elif key == ord('>') or key == ord('.'):
            speed_index = min(speed_index + 1, len(speed_table) - 1)
        elif key == ord('<') or key == ord(','):
            speed_index = max(speed_index - 1, 0)
        elif key == ord(']') or key == ord('}'):
            video.set(cv.CAP_PROP_POS_FRAMES, frame + frame_shift)
        elif key == ord('[') or key == ord('{'):
            video.set(cv.CAP_PROP_POS_FRAMES, max(frame - frame_shift, 0))
```



# OpenCV High-level GUI: Handling Mouse Events

- Example) Free drawing

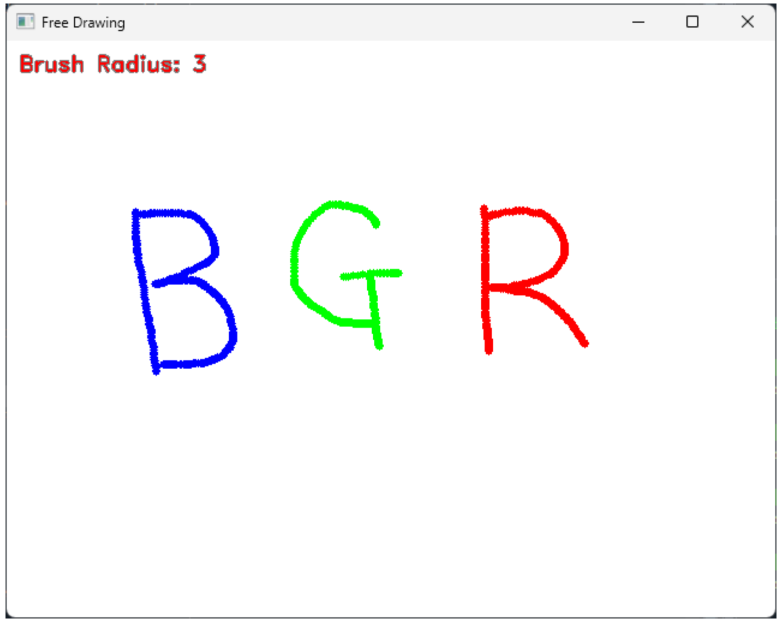
```
def mouse_event_handler(event, x, y, flags, param):
    # Change 'mouse_state' (given as 'param') according to the mouse 'event'
    if event == cv.EVENT_LBUTTONDOWN:
        param[0] = True
        param[1] = (x, y)
    elif event == cv.EVENT_LBUTTONUP:
        param[0] = False
    elif event == cv.EVENT_MOUSEMOVE and param[0]:
        param[1] = (x, y)

def free_drawing(canvas_width=640, canvas_height=480, init_brush_radius=3):
    # Prepare a canvas and palette
    canvas = np.full((canvas_height, canvas_width, 3), 255, dtype=np.uint8)
    palette = [(0, 0, 0), (255, 255, 255), (0, 0, 255), (0, 255, 0), (255, 0, 0), (255, 255, 0), (255, 0, 255), (0, 255, 255)]

    # Initialize drawing states
    mouse_state = [False, (-1, -1)] # Note) [mouse_left_button_click, mouse_xy]
    brush_color = 0
    brush_radius = init_brush_radius

    # Instantiate a window and register the mouse callback function
    cv.namedWindow('Free Drawing')
    cv.setMouseCallback('Free Drawing', mouse_event_handler, mouse_state)

    while True:
        # Draw a point if necessary
        mouse_left_button_click, mouse_xy = mouse_state
        if mouse_left_button_click:
            cv.circle(canvas, mouse_xy, brush_radius, palette[brush_color], -1)

        # Show the canvas
```



# OpenCV High-level GUI: Handling Mouse Events

- Example) Free drawing

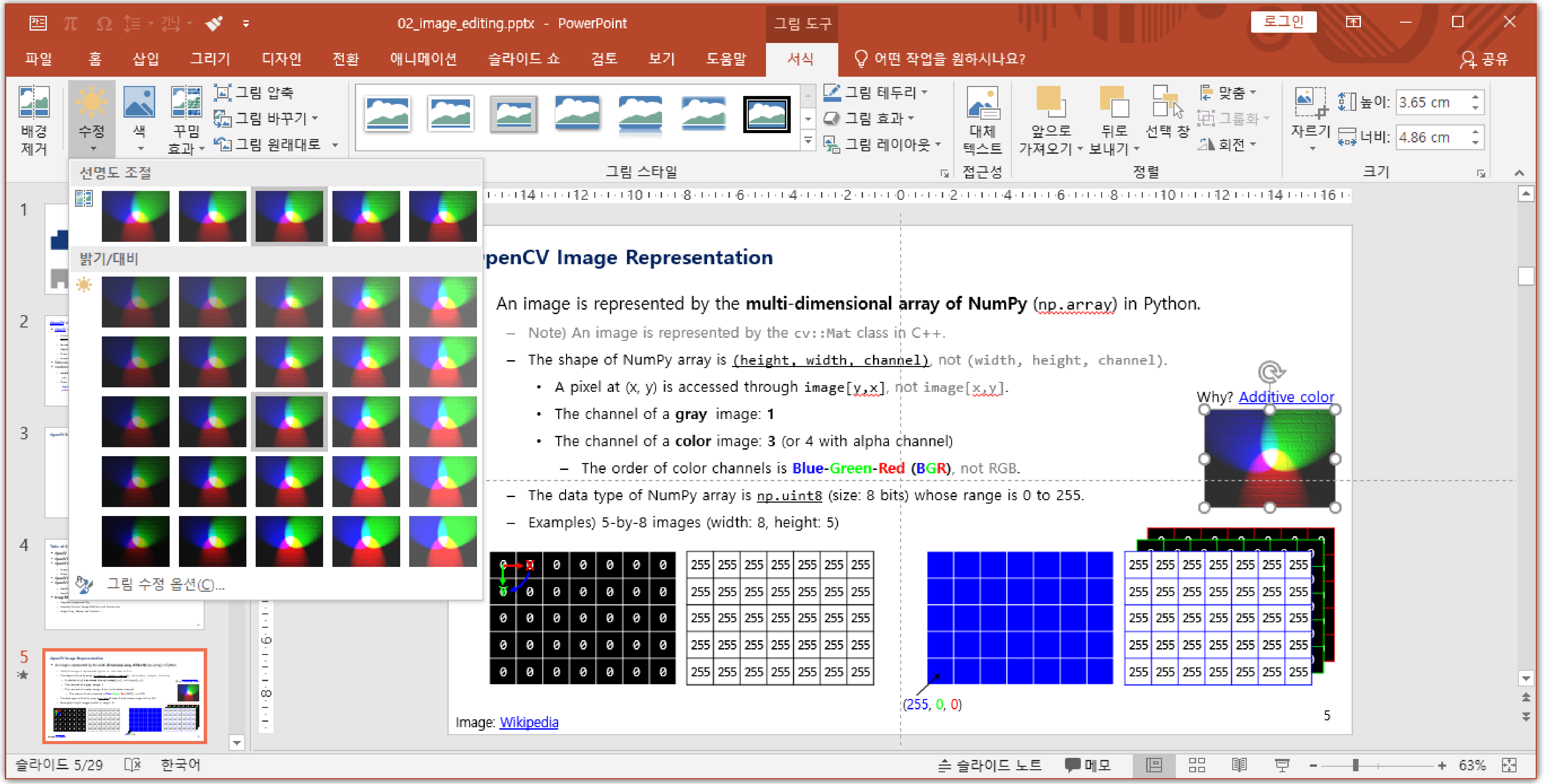
```python
def free_drawing(canvas_width=640, canvas_height=480, init_brush_radius=3):
    ...
    while True:
        # Draw a point if necessary
        mouse_left_button_click, mouse_xy = mouse_state
        if mouse_left_button_click:
            cv.circle(canvas, mouse_xy, brush_radius, palette[brush_color], -1)

        # Show the canvas
        canvas_copy = canvas.copy()
        info = f'Brush Radius: {brush_radius}'
        cv.putText(canvas_copy, info, (10, 25), cv.FONT_HERSHEY_DUPLEX, 0.6, (127, 127, 127), thickness=2)
        cv.putText(canvas_copy, info, (10, 25), cv.FONT_HERSHEY_DUPLEX, 0.6, palette[brush_color])
        cv.imshow('Free Drawing', canvas_copy)

        # Process the key event
        key = cv.waitKey(1)
        if key == 27: # ESC
            break
        elif key == ord('\t'):
            brush_color = (brush_color + 1) % len(palette)
        elif key == ord('+') or key == ord('='):
            brush_radius += 1
        elif key == ord('-') or key == ord('_'):
            brush_radius = max(brush_radius - 1, 1)

    cv.destroyAllWindows()

if __name__ == '__main__':
    free_drawing()
```



## Table of Contents

# Image Editing

- Mission) Learn and implement common image editing techniques available in many applications



OpenCV Image Representation

An image is represented by the **multi-dimensional array of NumPy** (`np.array`) in Python.

– Note) An image is represented by the `cv::Mat` class in C++.

– The shape of NumPy array is `(height, width, channel)`, not `(width, height, channel)`.

  • A pixel at (x, y) is accessed through `image[y,x]`, not `image[x,y]`.

  • The channel of a **gray** image: **1**

  • The channel of a **color** image: **3** (or 4 with alpha channel)

    – The order of color channels is **Blue**-**Green**-**Red** (**BGR**), not RGB.

– The data type of NumPy array is `np.uint8` (size: 8 bits) whose range is 0 to 255.

– Examples) 5-by-8 images (width: 8, height: 5)

Why? Additive color

| | | | | | | |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 255 | 255 | 255 | 255 | 255 | 255 | 255 |
| 255 | 255 | 255 | 255 | 255 | 255 | 255 |
| 255 | 255 | 255 | 255 | 255 | 255 | 255 |
| 255 | 255 | 255 | 255 | 255 | 255 | 255 |
| 255 | 255 | 255 | 255 | 255 | 255 | 255 |

(255, 0, 0)

| | | | | | | |
|---|---|---|---|---|---|---|
| 255 | 255 | 255 | 255 | 255 | 255 | 255 |
| 255 | 255 | 255 | 255 | 255 | 255 | 255 |
| 255 | 255 | 255 | 255 | 255 | 255 | 255 |
| 255 | 255 | 255 | 255 | 255 | 255 | 255 |
| 255 | 255 | 255 | 255 | 255 | 255 | 255 |

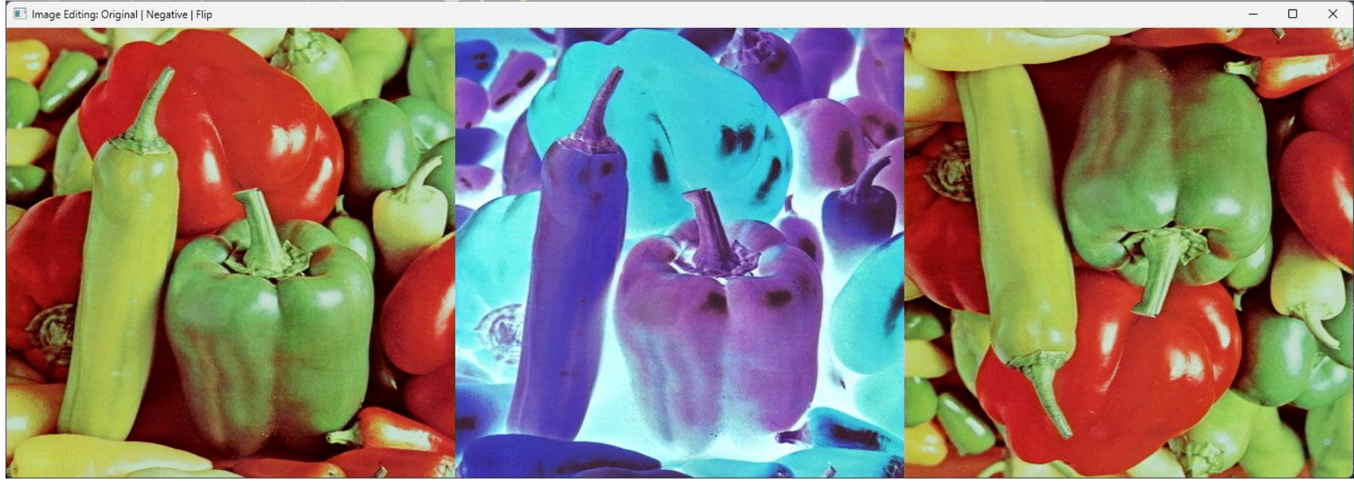
Image: Wikipedia

5

## Image Editing: Negative Image and Flip

- Example) Negative image and vertical flip

```
import cv2 as cv
import numpy as np

# Read the given image
img = cv.imread('data/peppers_color.tif')

if img is not None:
    # Get its negative image
    img_nega = 255 - img                        # Alternative) cv.bitwise_xor()

    # Get its vertically flipped image
    img_flip = img[::-1,:,:]                    # Alternative) cv.flip()

    # Show all images
    merge = np.hstack((img, img_nega, img_flip)) # Alternative) cv.hconcat()
    cv.imshow('Image Editing: Original | Negative | Flip', merge)
    cv.waitKey()
    cv.destroyAllWindows()
```

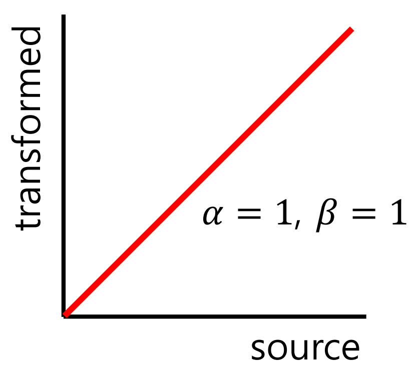


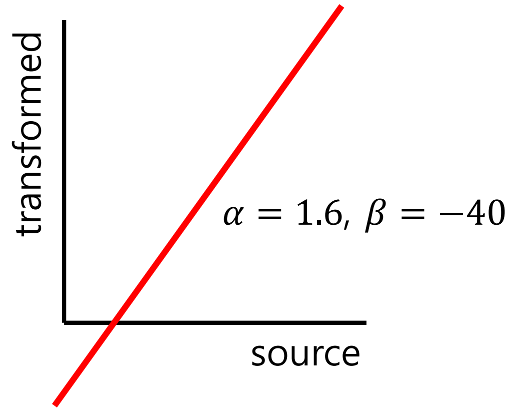
Photometric editing
(e.g. negative image)

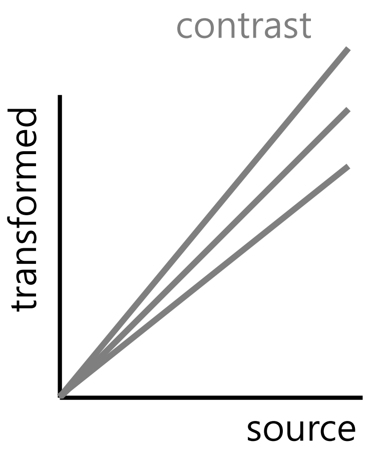
Geometric editing
(e.g. flipped image)

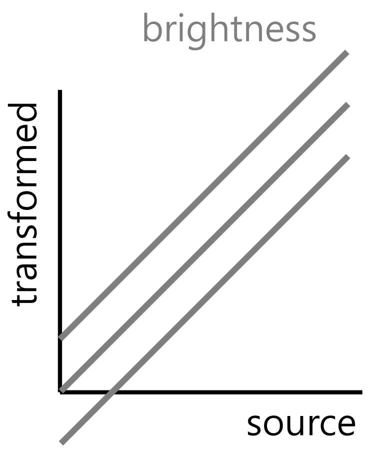
## Image Editing: Intensity Transformation

- Example) Intensity transformation with contrast and brightness
  - *Contrast* (대비 in Korean) is the property that makes an object (or its representation in an image or display) distinguishable.
  - *Brightness* (명암 in Korean) is the strength of overall luminance.
  - A simple formulation: $I' = \alpha I + \beta$
    - $\alpha$: contrast (slope)
    - $\beta$: brightness (Y intercept)









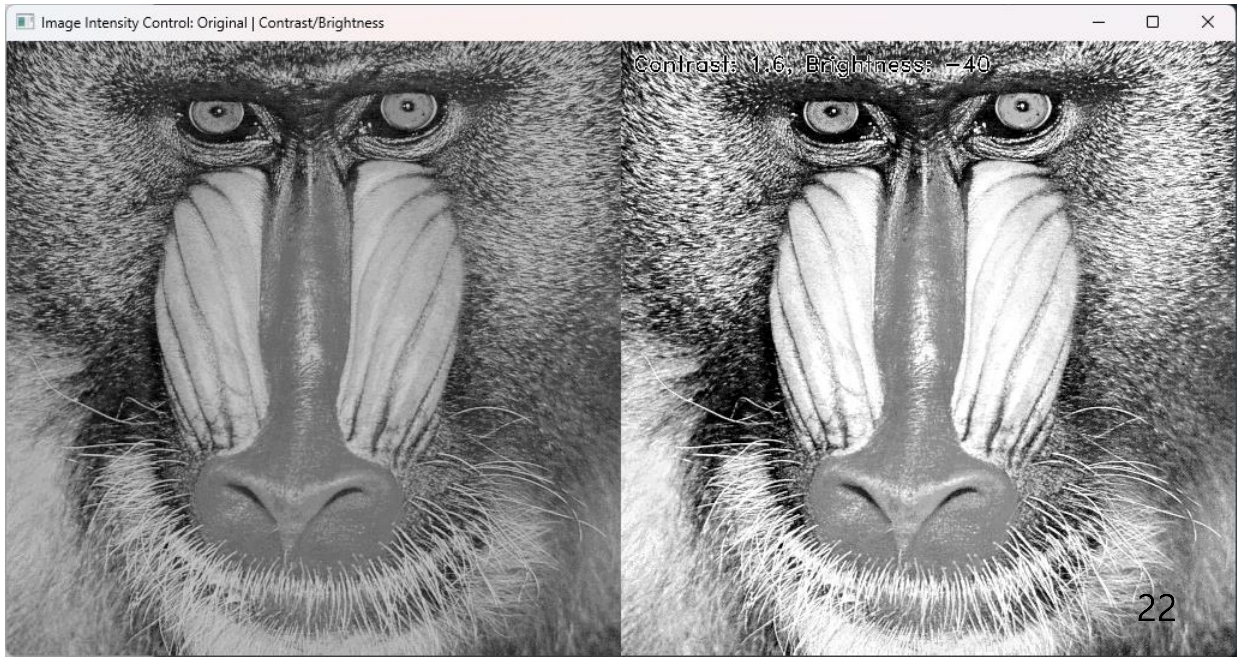


Image Intensity Control: Original | Contrast/Brightness
Contrast: 1.6, Brightness: -40

## Image Editing: Intensity Transformation

- Example) Intensity transformation with contrast and brightness

```
# Read the given image as gray scale
img = cv.imread('data/mandril_color.tif', cv.IMREAD_GRAYSCALE)

if img is not None:
    # Configure the intensity control
    contrast = 1.6
    contrast_step = 0.1
    brightness = -40
    brightness_step = 1

    while True:
        # Apply contrast and brightness
        img_tran = contrast * img + brightness # Alternative) cv.equalizeHist(), cv.intensity_transform
        img_tran[img_tran < 0] = 0
        img_tran[img_tran > 255] = 255          # Saturate values
        img_tran = img_tran.astype(np.uint8)

        # Show all images
        ...

        # Process the key event
        key = cv.waitKey()
        if key == 27: # ESC
            break
        elif key == ord('+') or key == ord('='):
            contrast += contrast_step
        elif key == ord('-') or key == ord('_'):
            contrast -= contrast_step
        elif key == ord(']') or key == ord('}'):
            brightness += brightness_step
        elif key == ord('[') or key == ord('{'):
```

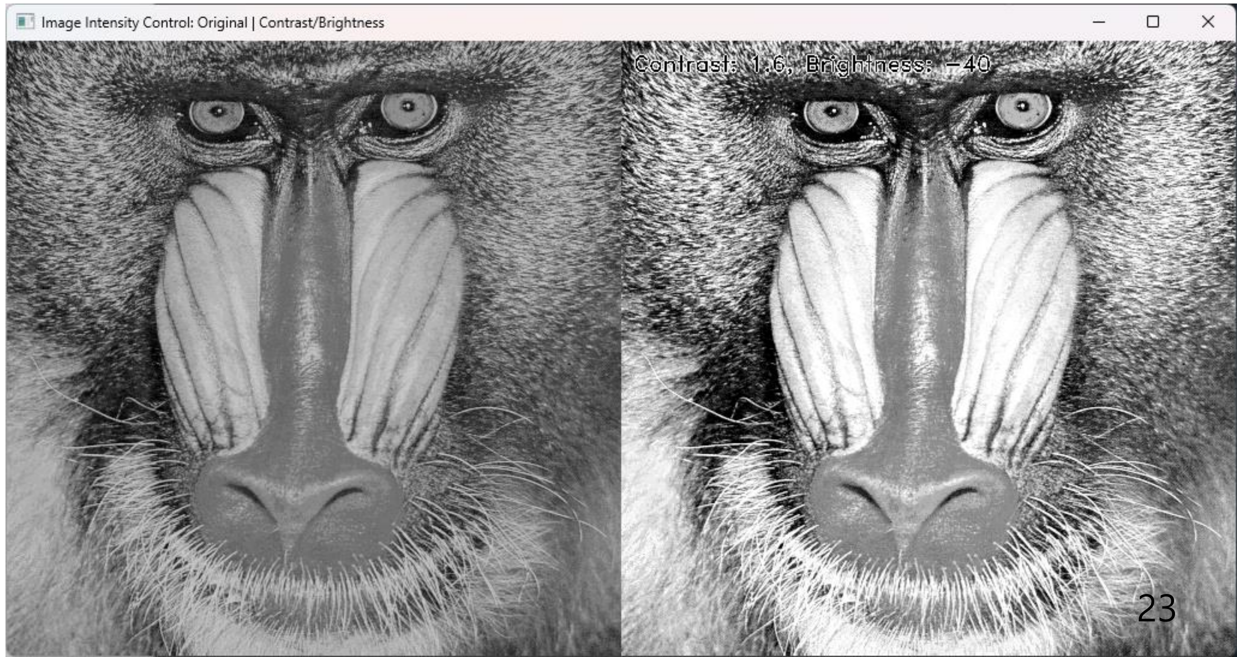


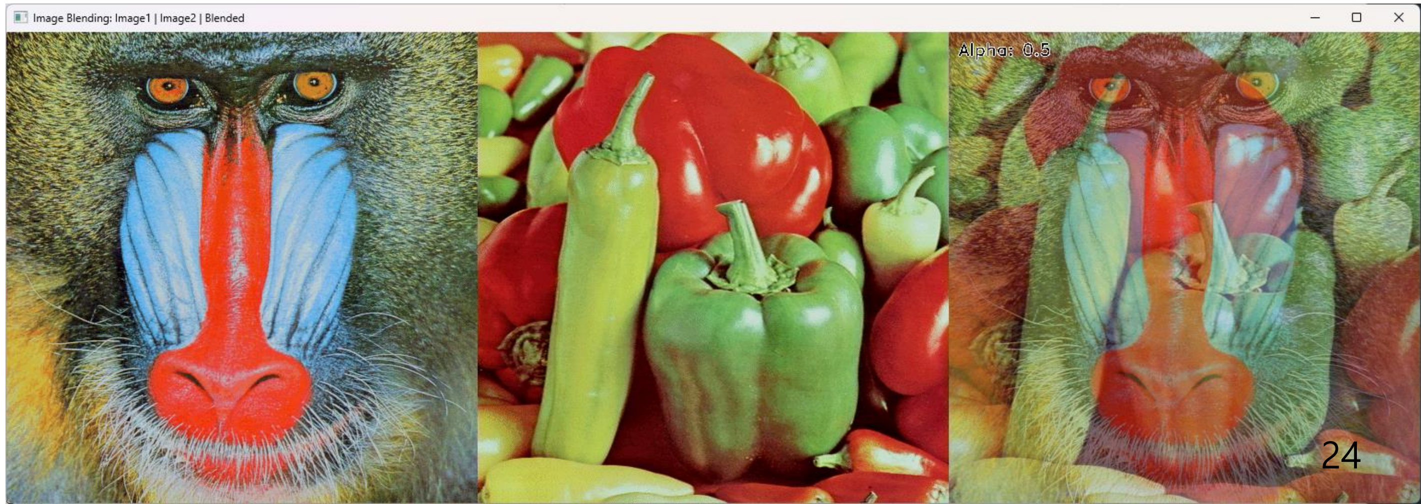
Image Intensity Control: Original | Contrast/Brightness
Contrast: 1.6, Brightness: -40

## Image Editing: Image Addition

- Example) Alpha blending: $I_b = \alpha I_1 + (1 - \alpha) I_2$

```python
# Read the given images
img1 = cv.imread('data/mandril_color.tif')
img2 = cv.imread('data/peppers_color.tif')

if img1 is not None and img2 is not None:
    alpha = 0.5

    while True:
        # Apply alpha blending
        blend = (alpha * img1 + (1 - alpha) * img2).astype(np.uint8) # Alternative) cv.addWeighted()

        # Show all images
        info = f'Alpha: {alpha:.1f}'
        cv.putText(blend, info, (10, 25), cv.FONT_HERSHEY_DUPLEX, 0.6, (255, 255, 255), thickness=2)
        cv.putText(blend, info, (10, 25), cv.FONT_HERSHEY_DUPLEX, 0.6, (0, 0, 0))
        merge = np.hstack((img1, img2, blend))
        cv.imshow('Image Blending: Image1 | Image2 | Blended', merge)

        # Process the key event
        key = cv.waitKey()
        if key == 27: # ESC
            break
        elif key == ord('+') or key == ord('='):
            alpha = min(alpha + 0.1, 1)
        elif key == ord('-') or key == ord('_'):
            alpha = max(alpha - 0.1, 0)

    cv.destroyAllWindows()
```

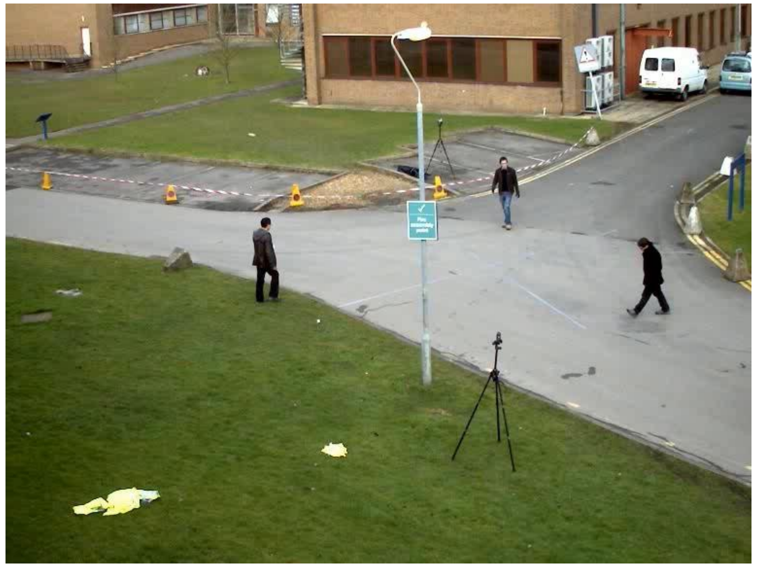
Transparent effect



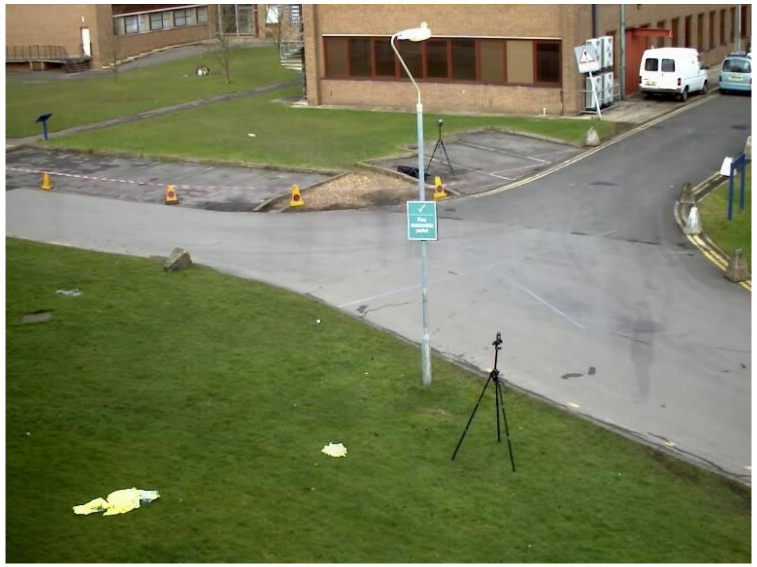
## Image Editing: Image Addition

- Example) Background extraction: $\mathrm{I}_b = \frac{1}{N}\sum_{i=1}^{N}\mathrm{I}_i$

```
# Read the given video
video = cv.VideoCapture('../data/PETS09-S2L1-raw.webm')

frame_count = 0
img_back = None
while True:
    # Get an image from 'video'
    valid, img = video.read()
    if not valid:
        break
    frame_count += 1

    # Show progress
    if frame_count % 100 == 0:
        print(f'Frame: {frame_count}')

    # Add the image to the averaged image (the background image)
    # Alternative) cv.createBackgroundSubtractorMOG2(), cv::bgsegm
    if img_back is None:
        img_back = np.zeros_like(img, dtype=np.float64)
    img_back += img.astype(np.float64)
img_back = img_back / frame_count
img_back = img_back.astype(np.uint8)

# Save and show the background image
cv.imwrite('../data/PETS09-S2L1-raw_back.png', img_back)
cv.imshow('Background Extraction', img_back)
cv.waitKey()
cv.destroyAllWindows()
```



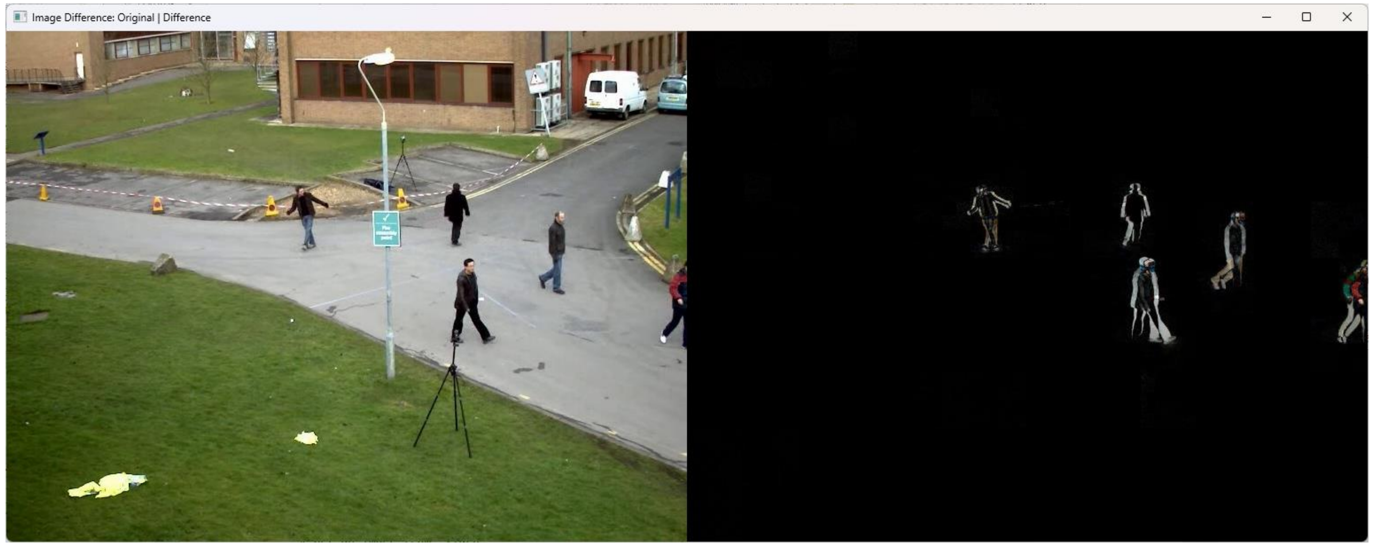
Averaging

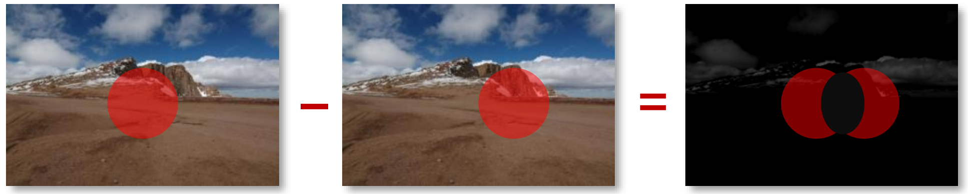


# Image Editing: Image Subtraction

- Example) Image difference: $I_d = |I_t - I_{t-1}|$

```
# Read the given video
video = cv.VideoCapture('data/PETS09-S2L1-raw.webm')

if video.isOpened():
    img_prev = None
    while True:
        # Get an image from 'video'
        valid, img = video.read()
        if not valid:
            break

        # Get the image difference
        if img_prev is None:
            img_prev = img.copy()
            continue
        img_diff = np.abs(img.astype(np.int32) - img_prev).astype(np.uint8) # Alternative) cv.absdiff()
        img_prev = img.copy()

        # Show all images
        merge = np.hstack((img, img_diff))
        cv.imshow('Image Difference: Original | Difference', merge)

        # Process the key event
        key = cv.waitKey(1)
        if key == ord(' '):
            key = cv.waitKey()
        if key == 27: # ESC
            break

cv.destroyAllWindows()
```



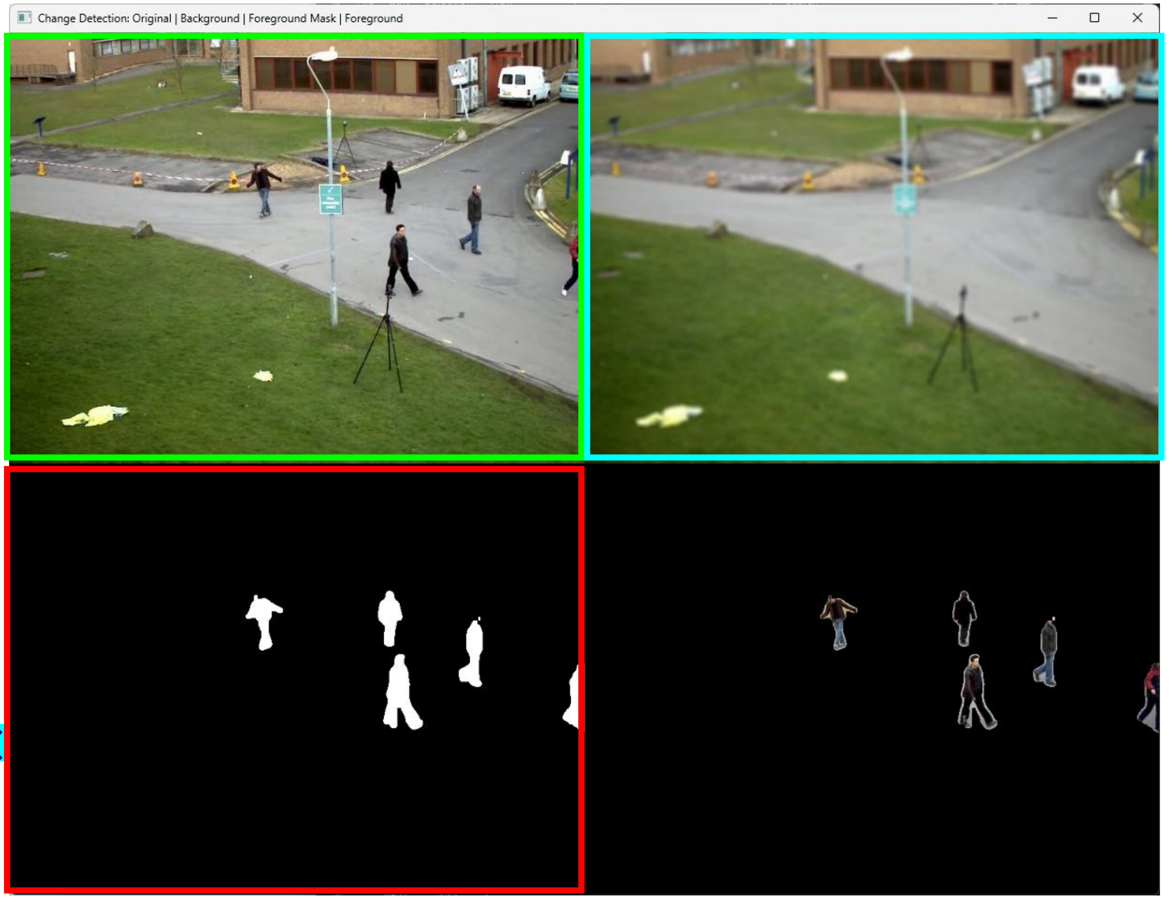


Change detection

# Image Editing: Image Subtraction

- Example) Background subtraction: $I_d = \|I_t - I_b\|_2$

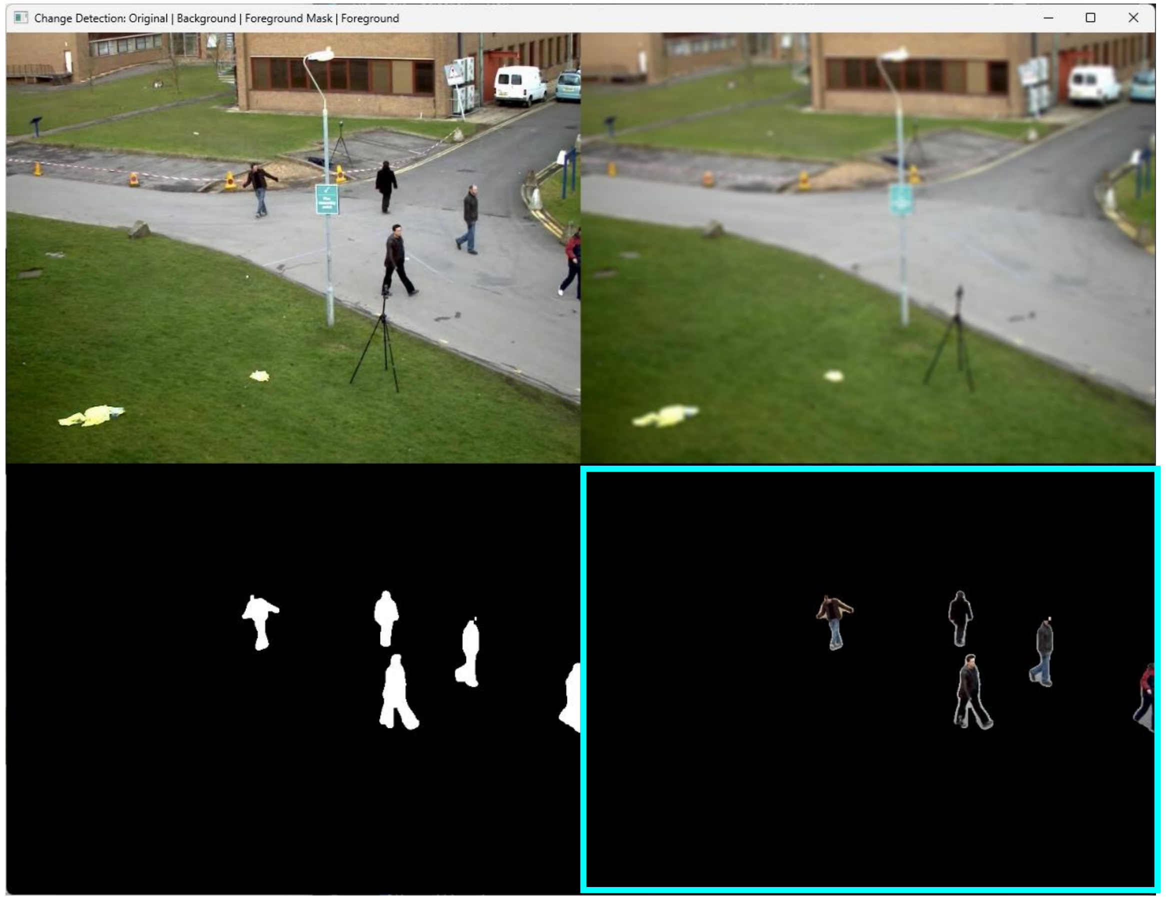
```
# Read the given video
video = cv.VideoCapture('../data/PETS09-S2L1-raw.webm')

# Initialize control parameters
blur_ksize = (9, 9)
blur_sigma = 3
diff_threshold = 50
bg_update_rate = 0.05
fg_update_rate = 0.001
zoom_level = 0.8

# Read the background image
img_back = cv.imread('../data/PETS09-S2L1-raw_back.png')
img_back = cv.GaussianBlur(img_back, blur_ksize, blur_sigma).astype(

box = lambda ksize: np.ones((ksize, ksize), dtype=np.uint8)
while True:
    # Get an image from 'video'
    valid, img = video.read()
    if not valid:
        break

    # Get the difference between the current image and background
    img_blur = cv.GaussianBlur(img, blur_ksize, blur_sigma)
    img_diff = img_blur - img_back

    # Apply thresholding
    img_norm = np.linalg.norm(img_diff, axis=2)
    img_bin = np.zeros_like(img_norm, dtype=np.uint8)
    img_bin[img_norm > diff_threshold] = 255
```


Change Detection: Original | Background | Foreground Mask | Foreground

## Image Editing: Image Subtraction

- Example) Background subtraction: $I_d = \|I_t - I_b\|_2$

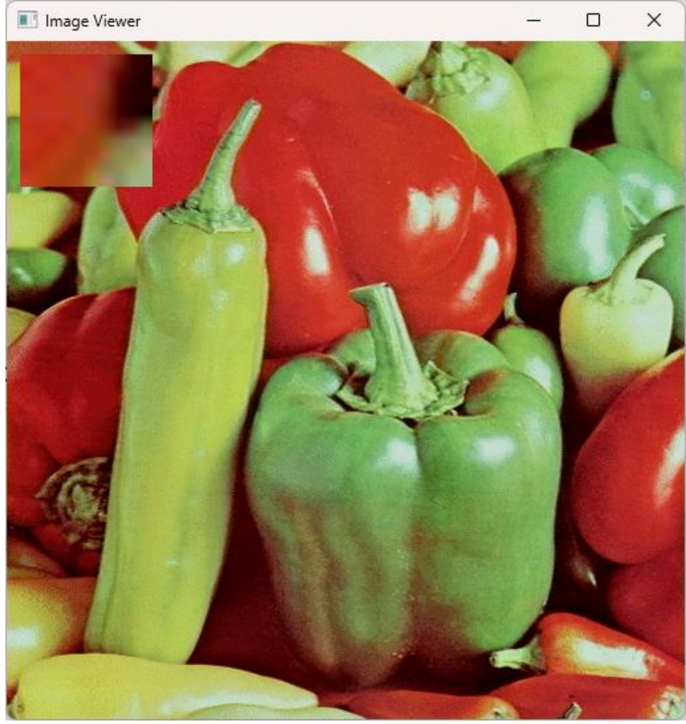
```
# Initialize control parameters
...
bg_update_rate = 0.05
fg_update_rate = 0.001
...

while True:
    # Get the difference between the current image and background
    img_blur = cv.GaussianBlur(img, blur_ksize, blur_sigma)
    img_diff = img_blur - img_back

    # Apply thresholding
    img_norm = np.linalg.norm(img_diff, axis=2)
    img_bin = np.zeros_like(img_norm, dtype=np.uint8)
    img_bin[img_norm > diff_threshold] = 255

    # Apply morphological operations
    img_mask = img_bin.copy()
    ...
    fg = img_mask == 255                                # Keep the (thick) foreground mask

    # Update the background
    # Alternative) cv.createBackgroundSubtractorMOG2(), cv.bgsegm
    bg = ~fg
    img_back[bg] = (bg_update_rate * img_blur[bg] + (1 - bg_update_rate) * img_back[bg]) # With the higher weight
    img_back[fg] = (fg_update_rate * img_blur[fg] + (1 - fg_update_rate) * img_back[fg]) # With the lower weight

    # Get the foreground image
    img_fore = np.zeros_like(img)
    img_fore[fg] = img[fg]
```


Change Detection: Original | Background | Foreground Mask | Foreground

## Image Editing: Image Crop

- Example) Image file viewer with the zoom window

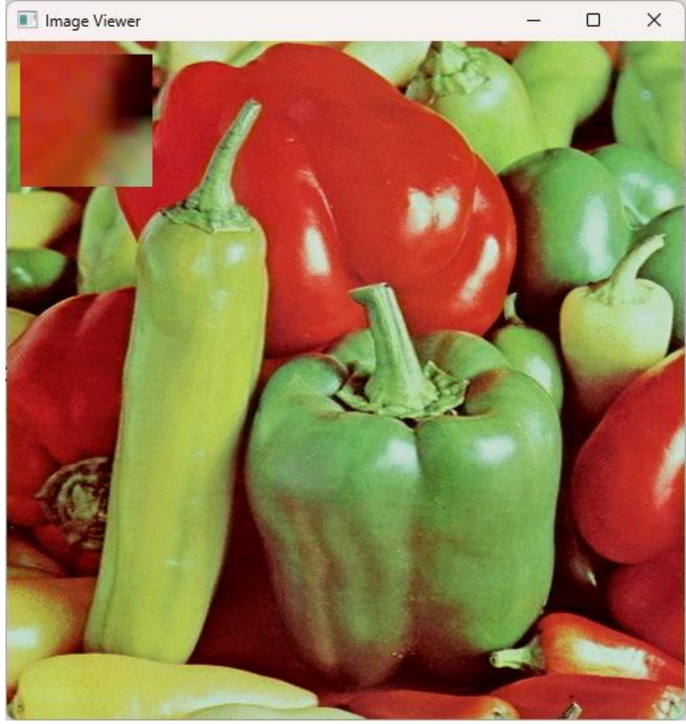
```
def mouse_event_handler(event, x, y, flags, param):
    # Catch the mouse position when it moves
    if event == cv.EVENT_MOUSEMOVE:
        param[0] = x # Note) Please do not use 'param = [x, y]'
        param[1] = y

def image_viewer(img_file, zoom_level=10, zoom_box_radius=5, zoom_box_margin=10):
    # Read the given image file
    img = cv.imread(img_file)
    if img is None:
        return False
    img_height, img_width, *_ = img.shape

    # Instantiate a window and register the mouse callback function
    cv.namedWindow('Image Viewer')
    mouse_xy = [-1, -1]
    cv.setMouseCallback('Image Viewer', mouse_event_handler, mouse_xy)

    while True:
        # Paste 'zoom_box' on 'img_copy'
        img_copy = img.copy()
        if mouse_xy[0] >= zoom_box_radius and mouse_xy[0] < (img_width  - zoom_box_radius) and \
           mouse_xy[1] >= zoom_box_radius and mouse_xy[1] < (img_height - zoom_box_radius):
            # Crop the target region
            img_crop = img[mouse_xy[1]-zoom_box_radius:mouse_xy[1]+zoom_box_radius, \
                               mouse_xy[0]-zoom_box_radius:mouse_xy[0]+zoom_box_radius, :]

            # Get the zoomed (resized) image
            zoom_box = cv.resize(img_crop, None, None, zoom_level, zoom_level)

            # Paste the zoomed image on 'img_copy'
```



# Image Editing: Image Crop

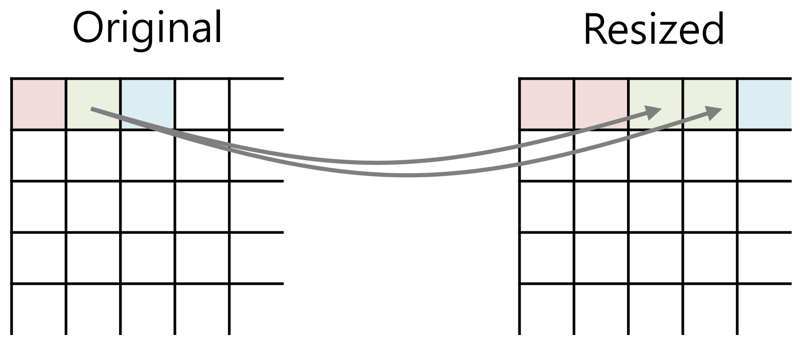
- Example) Image file viewer with the zoom window

```
def image_viewer(img_file, zoom_level=10, zoom_box_radius=5, zoom_box_margin=10):
    ...
    while True:
        # Paste 'zoom_box' on 'img_copy'
        img_copy = img.copy()
        if mouse_xy[0] >= zoom_box_radius and mouse_xy[0] < (img_width  - zoom_box_radius) and \
           mouse_xy[1] >= zoom_box_radius and mouse_xy[1] < (img_height - zoom_box_radius):
            # Crop the target region
            img_crop = img[mouse_xy[1]-zoom_box_radius:mouse_xy[1]+zoom_box_radius, \
                           mouse_xy[0]-zoom_box_radius:mouse_xy[0]+zoom_box_radius, :]

            # Get the zoomed (resized) image
            zoom_box = cv.resize(img_crop, None, None, zoom_level, zoom_level)

            # Paste the zoomed image on 'img_copy'
            s = zoom_box_margin
            e = zoom_box_margin + len(zoom_box)
            img_copy[s:e,s:e,:] = zoom_box

        # Show the image with the zoom
        cv.imshow('Image Viewer', img_copy)
        ...

    cv.destroyAllWindows()
    return True

if __name__ == '__main__':
    img_file = 'data/peppers_color.tif'
    if not image_viewer(img_file):
        print(f'Cannot open the given file, {img_file}.')
```

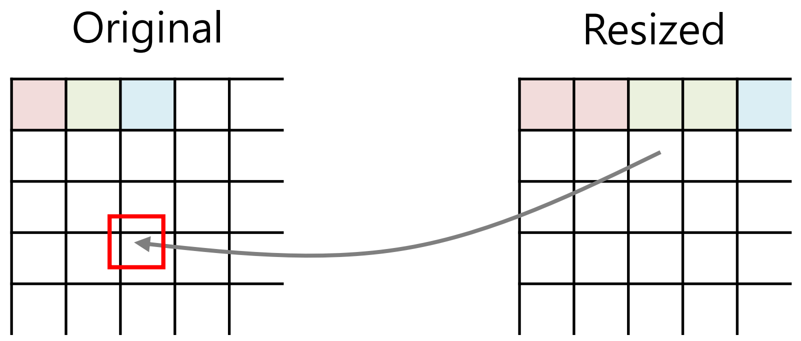


## Image Editing: Image Resize

- Image resize
  - **Forward value copy**
    - For every $(x, y)$ @ the original image:
      - Find its **all** $(x_r, y_r)$ @ the resized image
      - For every $(x_r, y_r)$ @ the resized image:
        - $\mathrm{I}_r(x_r, y_r) = \mathrm{I}(x, y)$
    - Issue) How about resize scale of 0.5 or 3.29? The target pixels are not clear!



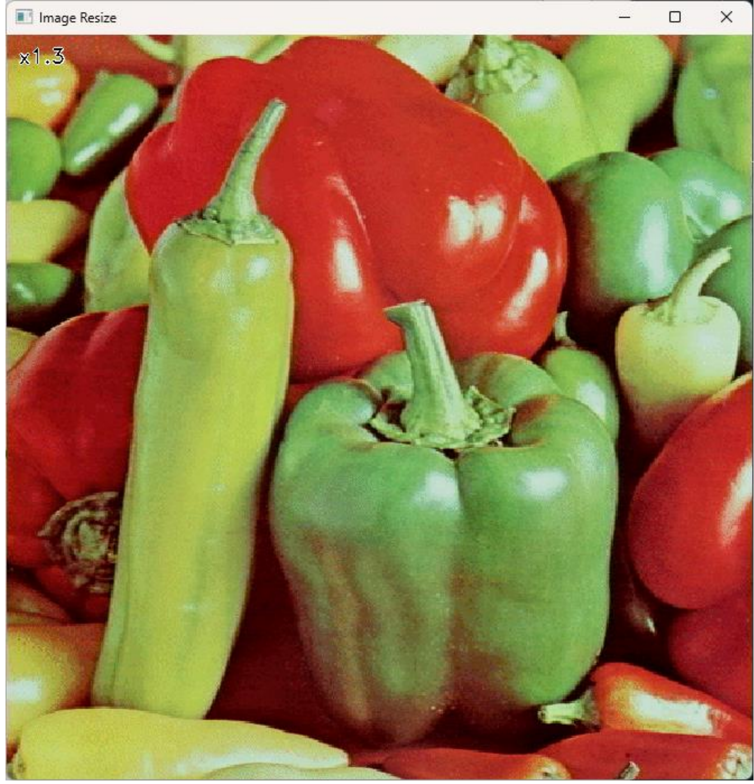
  - **Backward value copy**
    - For every $(x_r, y_r)$ @ the resized image:
      - Find its **single** $(x, y)$ @ the original image
      - $\mathrm{I}_r(x_r, y_r) = \mathrm{I}(x, y)$
    - Issue) $(x, y)$ can be real numbers, not integer numbers.
      - Solutions) The nearest pixel (rounding), (bi)linear **interpolation**, …



## Image Editing: Image Resize

- Example) Image resize with backward value copy

```
def resize(img, scale):
    # Prepare the (empty) resized image
    img_shape = list(img.shape)
    img_shape[0] = int(img_shape[0] * scale)
    img_shape[1] = int(img_shape[1] * scale)
    img_resize = np.zeros(img_shape, dtype=np.uint8)

    # Copy each pixel from the given image
    for ry in range(img_shape[0]):
        y = ry / scale
        for rx in range(img_shape[1]):
            x = rx / scale
            img_resize[ry, rx, :] = img[int(y+0.5), int(x+0.5), :] # Note) Rounding: int(x+0.5)
    return img_resize
```



Discussion) Why is resizing process quite slow?

## Image Editing: Image Rotation

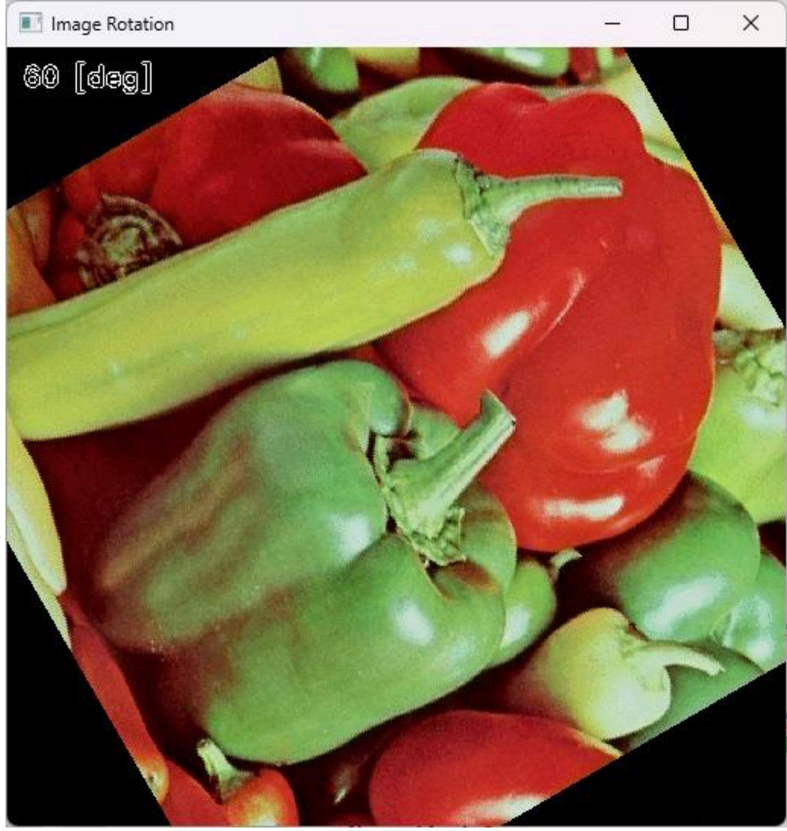
- Image rotation
  - **Forward value copy**
    - For every $(x, y)$ @ the original image:
      - Find its **rotated point** $(x_r, y_r)$ @ the resized image
        - $\begin{bmatrix} x_r \\ y_r \end{bmatrix} = \mathrm{R}(\theta) \begin{bmatrix} x \\ y \end{bmatrix}$ where $\mathrm{R}(\theta) = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}$
      - $\mathrm{I}_r(x_r, y_r) = \mathrm{I}(x, y)$
  - **Backward value copy**
    - For every $(x_r, y_r)$ @ the resized image:
      - Find its **original point** $(x, y)$ @ the original image
        - $\begin{bmatrix} x \\ y \end{bmatrix} = \mathrm{R}^{-1}(\theta) \begin{bmatrix} x_r \\ y_r \end{bmatrix}$ where $\mathrm{R}^{-1}(\theta) = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}$
      - $\mathrm{I}_r(x_r, y_r) = \mathrm{I}(x, y)$

Discussion) What is better? Why?

## Image Editing: Image Rotation

- Example) Image rotation with backward value copy

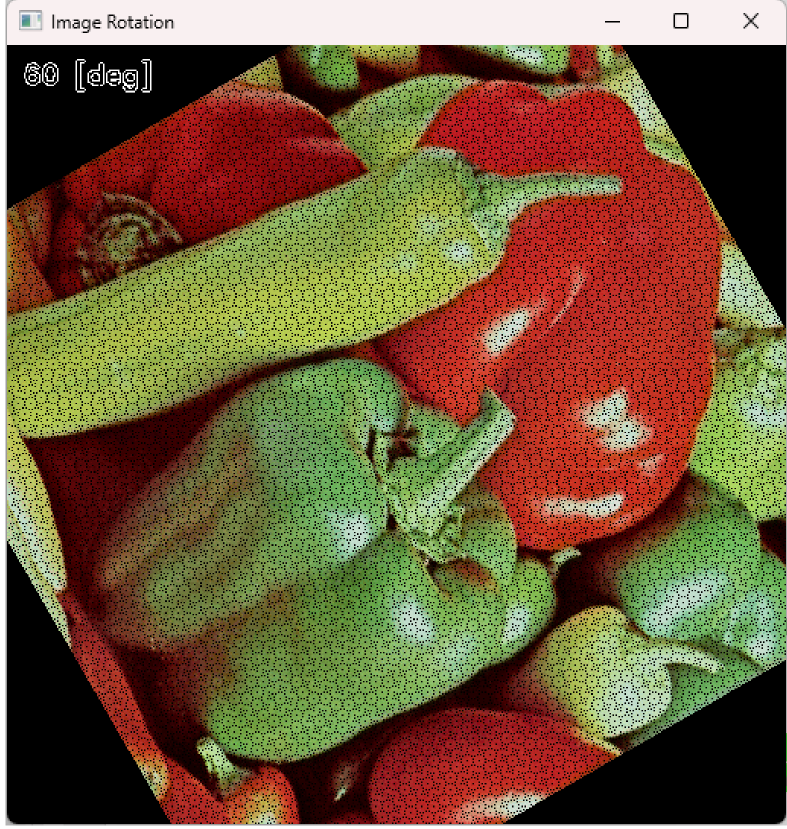
```
def rotate(img, degree):
    # Prepare the (empty) rotated image
    img_rotate = np.zeros(img.shape, dtype=np.uint8)

    # Prepare the inverse transformation
    c, s = np.cos(np.deg2rad(degree)), np.sin(np.deg2rad(degree))
    R = np.array([[c, -s], [s, c]]).T # Note) Transpose is the inverse.
    h, w, *_ = img.shape
    cx = (w - 1) / 2
    cy = (h - 1) / 2

    # Copy each pixel from the given image
    for ry in range(h):
        for rx in range(w):
            dx, dy = R @ [rx - cx, ry - cy]
            x, y = int(dx + cx + 0.5), int(dy + cy + 0.5) # The nearest pixel
            if x >= 0 and y >= 0 and x < w and y < h:
                img_rotate[ry, rx, :] = img[y, x, :]
    return img_rotate

def rotate_forward(img, degree):
    # Prepare the (empty) rotated image
    img_rotate = np.zeros(img.shape, dtype=np.uint8)

    # Prepare the forward transformation
    c, s = np.cos(np.deg2rad(degree)), np.sin(np.deg2rad(degree))
```



# Image Editing: Image Rotation

- Example) Image rotation with backward/forward value copy

```
def rotate(img, degree):
    ...
    R = np.array([[c, -s], [s, c]]).T # Note) Transpose is the inverse.
    ...
    for ry in range(h):
        for rx in range(w):
            dx, dy = R @ [rx - cx, ry - cy]
            x, y = int(dx + cx + 0.5), int(dy + cy + 0.5) # The nearest pixel
            ...

def rotate_forward(img, degree):
    ...
    R = np.array([[c, -s], [s, c]])
    h, w, *_ = img.shape
    cx = (w - 1) / 2
    cy = (h - 1) / 2

    # Copy each pixel from the given image
    for x in range(h):
        for y in range(w):
            dx, dy = R @ [x - cx, y - cy]
            rx, ry = int(dx + cx + 0.5), int(dy + cy + 0.5) # The nearest pixel
            if rx >= 0 and ry >= 0 and rx < w and ry < h:
                img_rotate[ry, rx, :] = img[y, x, :]
    return img_rotate
```



Discussion) Why does forward copy generate black dots?

## Summary

- **OpenCV Image Representation**
  - Be careful
    - OpenCV: (x, y) vs. NumPy: [y, x]
    - OpenCV: (width, height) vs. NumPy: (height, width)
    - OpenCV: BGR vs. Others: RGB
- **OpenCV Image and Video Input/Output**
  - Image files / video files and cameras
- **OpenCV Drawing Functions**
  - Common errors (mistakes) of OpenCV in Python
    - Argument types: e.g. `list/tuple` or `np.array` or …, `np.int32` (`CV_32S`) or `np.float64` (`CV_64F`) or …
    - Argument shapes: e.g. 2D points `(n, 2)` or `(n, 1, 2)`
- **OpenCV High-level GUI**
  - Handling keyboard/mouse events
- **Image Editing**
  - Photometric: Negative image, intensity transformation, image addition, and subtraction
  - Geometric: Flip, image crop, resize, and rotation