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1 EECS 442 PS3: Panoramic Stitching

Please provide the following information (e.g. Drew Scheffer, drewskis):

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2 Brief Overview

In this problem set, you will implement panoramic stitching. Given two input images, we will "stitch" them together to create a simple panorama. To construct the image panorama, we will use concepts learned in class such as keypoint detection, local invariant descriptors, RANSAC, and perspective warping.

3.1 You are given a npy file consisting the original points and target points. You want to find the homography transformation that map the original points to the destination points. Please generate 3 plots: original points, destination points, and mapped points for visualization

3.2 The panoramic stitching algorithm consists of four main steps which we ask you to implement in individual functions:

1. Detect keypoints and extract local invariant descriptors (we will be using ORB) from two input images.
2. Match the descriptors between the two images.
3. Apply RANSAC to estimate a homography matrix between the extracted features.
4. Apply a perspective transformation using the homography matrix to merge image into a panorama.

Functions to implement (refer to function comments for more detail):

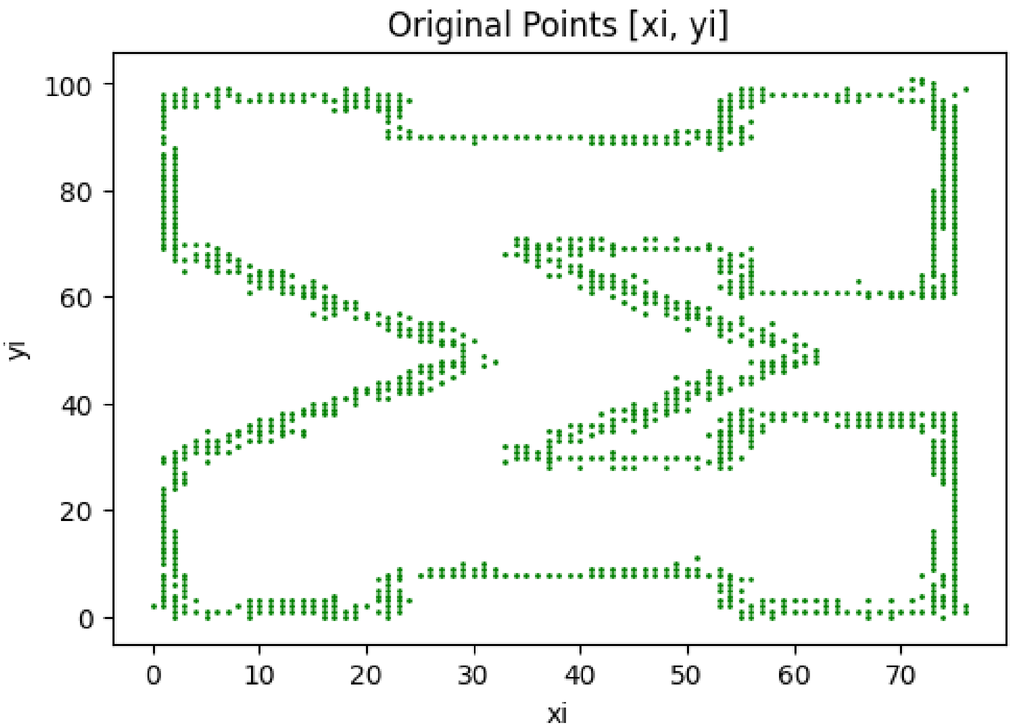
1. **fit_homography** (2 points)
2. **apply_homography** (2 points)
3. **get_orb_features** (2 points)
4. **match_keypoints** (2 points)
5. **transform_ransac** (2 points)
6. **panoramic_stitching** (2 points)

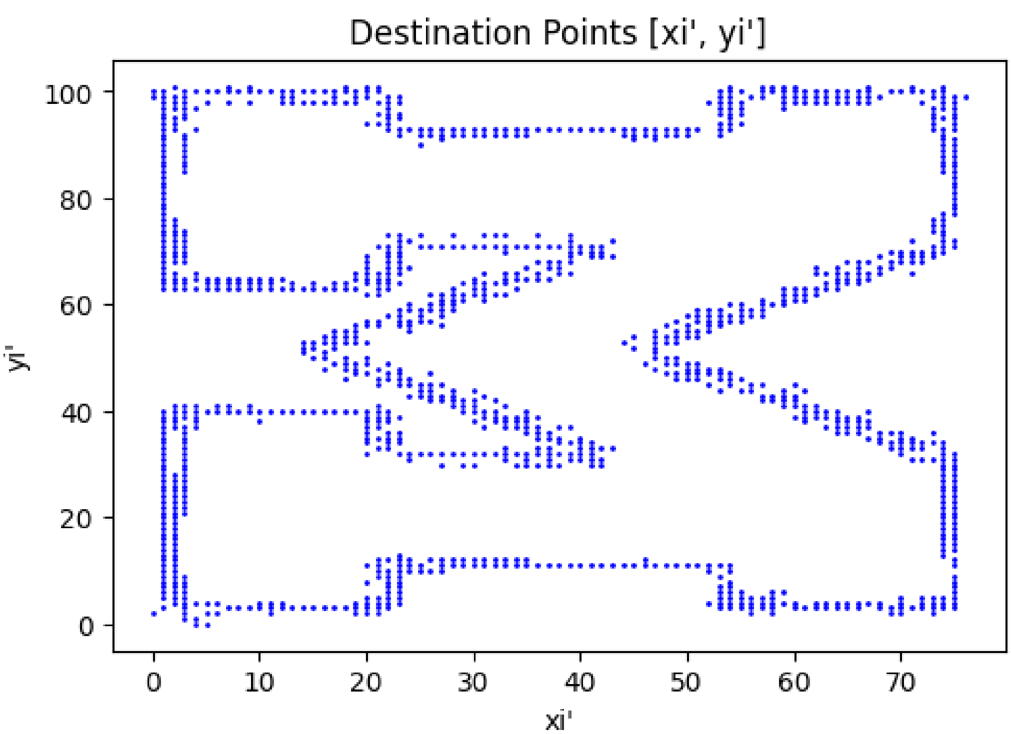
Retreive the npy file online and convert to np array

[16]:
```
%%capture
!wget -O file1.npy 'https://drive.google.com/uc?
↪export=download&id=1WuDd_SKDXnCJkZb6EzNCX6Wn_dWF8w4A'
```

[17]:
```
import numpy as np
import matplotlib.pyplot as plt
data = np.load("file1.npy")
print(data.shape)

plt.figure(figsize=(6, 4))
plt.scatter(data[:, 0], data[:, 1], s=1, c='green')
plt.title('Original Points [xi, yi]')
plt.xlabel("xi")
plt.ylabel("yi")
plt.show()

# Plot for [xi', yi']
plt.figure(figsize=(6, 4))
plt.scatter(data[:, 2], data[:, 3], s=1, c='blue')
plt.title('Destination Points [xi\', yi\']')
plt.xlabel("xi'")
plt.ylabel("yi'")
plt.show()
```

```
(1205, 4)
```


Original Points [xi, yi]
yi
xi
0
20
40
60
80
100
0
10
20
30
40
50
60
70


Destination Points [xi', yi']
yi'
xi'
0
20
40
60
80
100
0
10
20
30
40
50
60
70

#3.1 Homography estimation

Your first task is to implement a function fit_homography(pts1, pts2) that computes the homography matrix from a set of point correspondences.

This should fit a homography mapping between the two given points. You will use it to map the original points to the destination points.

[18]:
```
def fit_homography(pts1, pts2):
        '''
        Given a set of N correspondences of the form [x,y], [x',y'],
        fit a homography that maps [x',y',1] to [x,y,1].

        Input - pts1, pts2: (N, 2) matrices representing N corresponding points␣
↪[x, y] and [x', y']
        Output - H: a (3,3) homography matrix that (if the correspondences can␣
↪be
                                                described by a homography) satisfies␣
↪[x,y,1] === H [x',y',1]

        Use either nonlinear least squares or direct linear transform
        to find a homography that estimates the transformation mapping from pts2
        to pts1.
        e.g. If u = pts1[i] and v = pts2[i], then u = H * v in homogeneous␣
↪coordinates

        Hint if using nonlinear least square:
                The objective function to optimize here is:
                \\sum_i ||pts1[i] - cart(H*homog(pts2[i]))||^2 where homog(x)␣
↪converts x into
                homogeneous coordinates and cart(x) converts x to cartesian␣
↪coordinates.
                You can use scipy.optimize.least_squares for this.

        Hint if using direct linear transform:
                The solution is given by the right-singular vector with the␣
↪smallest singular value in the singular vector decomposition.
                You can use np.linalg.svd for this.

        Input:
                pts1, pts2: (N, 2) matrix
        Return:
                H: the resulting homography matrix (3 x 3)

        '''
        ################################################################################
        #                                           TODO                               ␣
↪   #
```

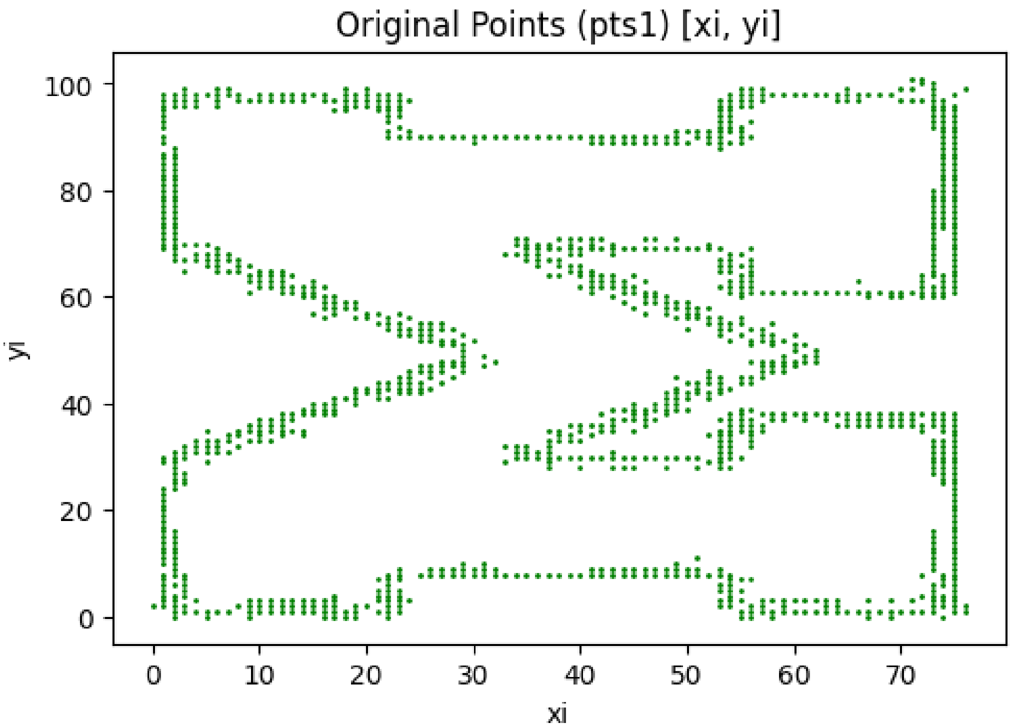
```
        ###########################################################################
        from scipy.optimize import least_squares

        def homog(x):
                # Convert (N,2) to (N,3) homogeneous coordinates
                return np.hstack([x, np.ones((x.shape[0], 1))])

        def cart(x):
                # Convert (N,3) homogeneous to (N,2) cartesian coordinates
                return (x[:, :2].T / x[:, 2]).T

        def cost_fn(H0, pts1, pts2):
                H = H0.reshape(3, 3)
                pts2_h = homog(pts2)
                pts2_proj = (H @ pts2_h.T).T
                pts2_proj_cart = cart(pts2_proj)
                r = (pts1 - pts2_proj_cart).reshape(-1)
                return r

        H0 = np.ones(9) # Initial guess for homography
        res = least_squares(cost_fn, H0, args=(pts1, pts2))
        H = res.x.reshape(3, 3)
        return H
        ###########################################################################
        #                               END OF YOUR CODE                          ␣
↪       #
        ###########################################################################

        return None
```

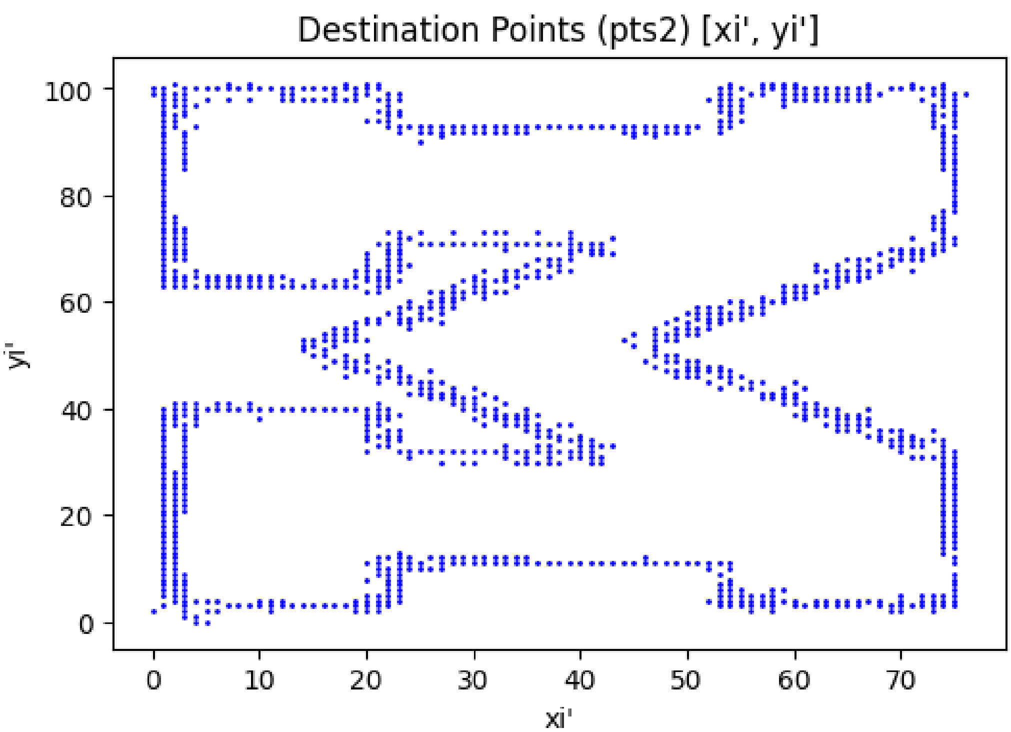
Visualize the original points, target points and points after applying a homography transform in three separate figures: original points, destination points, and mapped points

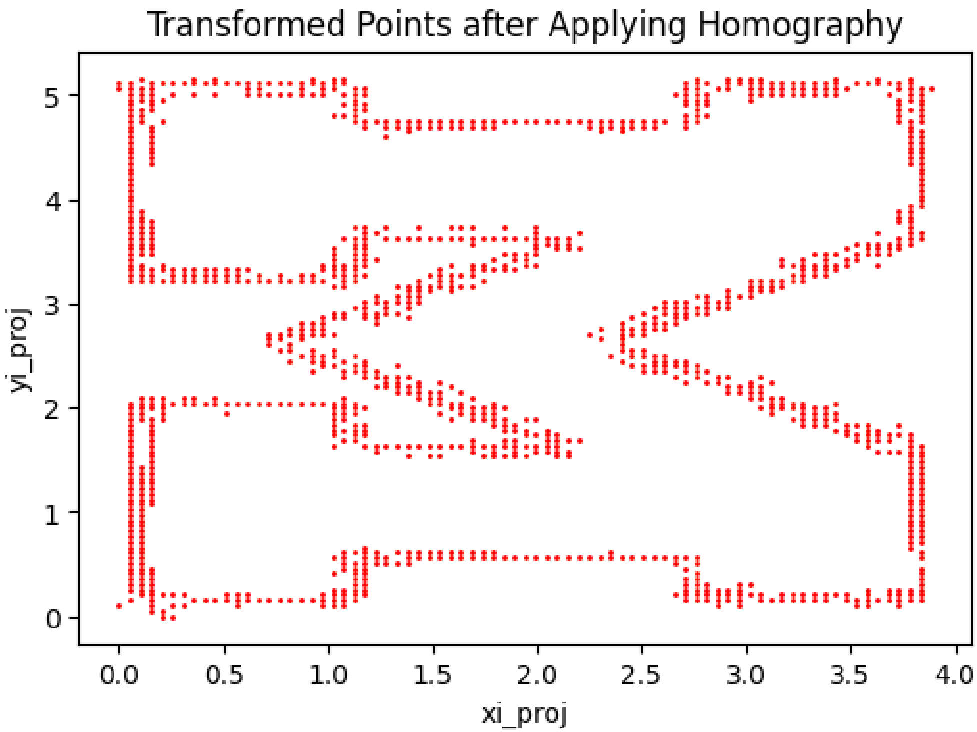
plt.scatter may be useful here

```
[19]: def apply_homography(data):
        '''
        Given loaded file1.npy, which is data, apply the transformation. data␣
↪is in the
        form [x1,y1,x2,y2]

        Steps:
        1. Find the homography matrix
        2. Transform the data to homogeneous coordinates, then apply the␣
↪transformation
        3. Transform the data back to Euclidean coordinates
        '''
        ###########################################################################
```

```
        #                                       TODO                                   ␣
    ↪   #
        ##############################################################################

        # Find homography matrix
        pts1 = data[:, :2]          # original points
        pts2 = data[:, 2:]          # destination points
        H = fit_homography(pts2, pts1)          # H maps pts1 to pts2

        # Transform pts1 to homogeneous coordinates
        pts1_h = np.hstack([pts1, np.ones((pts1.shape[0], 1))])

        # Apply the homography to project pts1 to pts2 coordinates
        pts1_proj_cart = (H @ pts1_h.T).T

        # Plot 1: Original points (pts1) [xi, yi]
        plt.figure(figsize=(6, 4))
        plt.scatter(pts1[:, 0], pts1[:, 1], s=1, c='green')
        plt.title('Original Points (pts1) [xi, yi]')
        plt.xlabel("xi")
        plt.ylabel("yi")
        plt.show()

        # Plot 2: Destination points (pts2) [xi', yi']
        plt.figure(figsize=(6, 4))
        plt.scatter(pts2[:, 0], pts2[:, 1], s=1, c='blue')
        plt.title('Destination Points (pts2) [xi\', yi\']')
        plt.xlabel("xi'")
        plt.ylabel("yi'")
        plt.show()

        # Plot 3: Transformed points (pts1_proj_cart) after applying homography
        plt.figure(figsize=(6, 4))
        plt.scatter(pts1_proj_cart[:, 0], pts1_proj_cart[:, 1], s=1, c='red')
        plt.title('Transformed Points after Applying Homography')
        plt.xlabel("xi_proj")
        plt.ylabel("yi_proj")
        plt.show()
        return None

        ##############################################################################
        #                                 END OF YOUR CODE                             ␣
    ↪   #
        ##############################################################################

apply_homography(data)
```


Original Points (pts1) [xi, yi]
yi
xi
0
20
40
60
80
100
0
10
20
30
40
50
60
70


Destination Points (pts2) [xi', yi']
yi'
xi'
0
20
40
60
80
100
0
10
20
30
40
50
60
70



3 3.2 Panoramic stitching

Run the following code to import the modules you'll need. After your finish the assignment, remember to run all cells and save the note book to your local machine as a .ipynb file for Canvas submission.

[20]:
```
%matplotlib inline
import cv2
import random
import numpy as np
import matplotlib.pyplot as plt
from google.colab.patches import cv2_imshow
```

[21]:
```
%%capture
! wget -O img1.jpg "https://drive.google.com/uc?
↪export=download&id=1vHN5rBWj-sco8tcymzLkeu-DoMS1I8vi"
! wget -O img2.jpg "https://drive.google.com/uc?
↪export=download&id=1A26taOJAjhhEp_HJVsH3zvvFKtWMpaFe"
```

4 Visualize Input Images

[22]:
```
img1 = plt.imread('img1.jpg')
img2 = plt.imread('img2.jpg')

def plot_imgs(img1, img2):
        fig, ax = plt.subplots(1, 2, figsize=(15, 20))
        for a in ax:
                a.set_axis_off()
        ax[0].imshow(img1)
        ax[1].imshow(img2)

plot_imgs(img1, img2)
```

5 (a) Feature Extraction

5.1 (i) Compute ORB Features

[23]:
```
def get_orb_features(img):
        '''
        Compute ORB features using cv2 library functions.
        Use default parameters when computing the keypoints.
        Hint: you will need cv2.ORB_create() and some related functions
        Input:
                img: cv2 image
        Returns:
                keypoints: a list of cv2 keypoints
                descriptors: a list of ORB descriptors
        '''
        #############################################################################
        #                                  TODO                                      ␣
↪       #
```

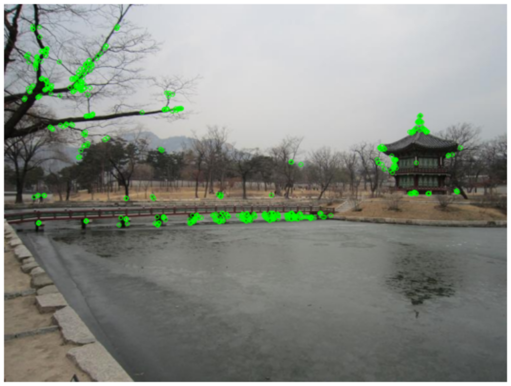
```
        ###########################################################################
        orb = cv2.ORB_create()
        keypoints, descriptors = orb.detectAndCompute(img, None)
        ###########################################################################
        #                              END OF YOUR CODE                            ␣
 ↪    #
        ###########################################################################
        return keypoints, descriptors
```

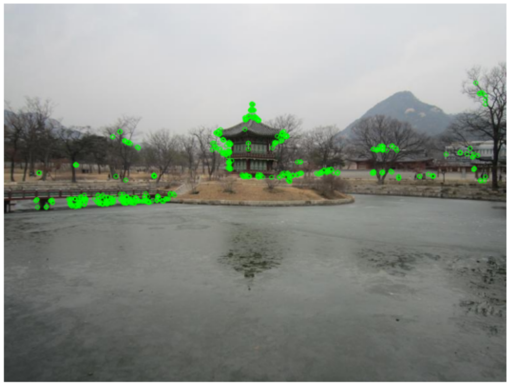
5.2 (ii) Match Keypoints

[24]:
```
def match_keypoints(desc_1, desc_2, ratio=0.75):
        '''
        Compute matches between feature descriptors of two images using
        Lowe's ratio test. You may use cv2 library functions.
        Hint: you may need to use cv2.DescriptorMatcher_create or cv2.BFMatcher
        and some related functions
        Input:
                desc_1, desc_2: list of feature descriptors
        Return:
                matches: list of feature matches
        '''
        ###########################################################################
        #                                    TODO                                  ␣
 ↪    #
        ###########################################################################
        matcher = cv2.BFMatcher(cv2.NORM_HAMMING, crossCheck=True)
        matches = matcher.match(desc_1, desc_2)
        matches = sorted(matches, key=lambda x: x.distance)
        ###########################################################################
        #                              END OF YOUR CODE                            ␣
 ↪    #
        ###########################################################################

        return matches
```

[25]:
```
kp_1, desc_1 = get_orb_features(img1)
kp_2, desc_2 = get_orb_features(img2)

kp_img1 = cv2.drawKeypoints(img1, kp_1, None, color=(0,255,0), flags=0)
kp_img2 = cv2.drawKeypoints(img2, kp_2, None, color=(0,255,0), flags=0)

print('keypoints for img1 and img2')
plot_imgs(kp_img1, kp_img2)
```

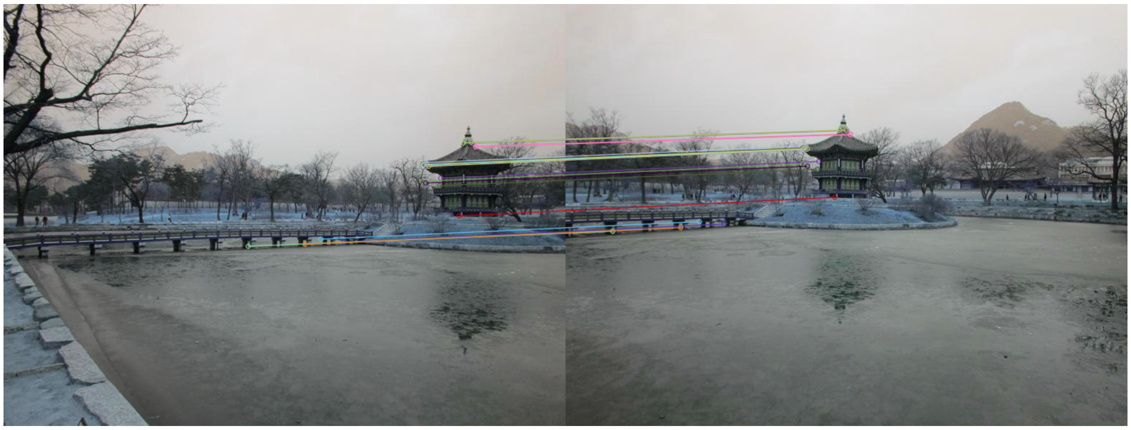
```
keypoints for img1 and img2
```





[26]:
```
matches = match_keypoints(desc_1, desc_2)
match_plot = cv2.drawMatches(img1, kp_1, img2, kp_2, matches[:20], None,␣
 ↪flags=2)
print("orb feature matches")
cv2_imshow(match_plot)
```

orb feature matches



6 (b) Implement RANSAC

[27]:
```
def transform_ransac(x1, x2, verbose=False):
        '''
        Implements RANSAC to estimate homography matrix.
        Hint: Follow the RANSAC steps outlined in the lecture slides.
        Input:
                pts_1, pts_2: (N, 2) matrices
        Return:
```

```
            best_model: homography matrix with most inliers
        '''
        ############################################################################
        #                                   TODO                                   ␣
↪     #
        ############################################################################

        # RANSAC parameters
        max_iter = 100
        threshold = 3
        n_samples = 4
        best_inliers_idx = []
        best_model = None
        N = x1.shape[0]

        # Main RANSAC loop
        for i in range(max_iter):
                idx = np.random.choice(N, n_samples, replace=False)
                pts1_sample = x1[idx]
                pts2_sample = x2[idx]
                try:
                        H = fit_homography(pts1_sample, pts2_sample)
                except Exception:
                        continue
                # Project all x2 to x1 using H
                x2_h = np.hstack([x2, np.ones((N, 1))])
                x2_proj = (H @ x2_h.T).T
                x2_proj = x2_proj[:, :2] / x2_proj[:, 2][:, None]
                # Compute distances
                dists = np.linalg.norm(x1 - x2_proj, axis=1)
                inliers_idx = np.where(dists < threshold)[0]
                if len(inliers_idx) > len(best_inliers_idx):
                        best_inliers_idx = inliers_idx
                        best_model = H

        # Re-estimate H with all inliers
        if best_model is not None and len(best_inliers_idx) >= n_samples:
                best_model = fit_homography(x1[best_inliers_idx],␣
↪x2[best_inliers_idx])
        ############################################################################
        #                             END OF YOUR CODE                             ␣
↪     #
        ############################################################################
        return best_model
```

7 (c) Panoramic Stitching

[28]:
```
def panoramic_stitching(img1, img2):
        '''
                Given a pair of overlapping images, generate a panoramic image.
                Hint: use the functions that you've written in the previous␣
 ↪parts.
                Input:
                        img1, img2: images
                Return:
                        final_img: image of panorama
        '''
        #############################################################################
        #                                    TODO                                  ␣
 ↪    #
        # 1. detect keypoints and extract orb feature descriptors                  ␣
 ↪    #
        # 2. match features between two images                                     ␣
 ↪    #
        # 3. compute homography matrix H transforming points from pts_2 to␣
 ↪pts_1.   #
        # Note the order here (not pts_1 to pts_2)!                                ␣
 ↪    #
        #############################################################################
        # 1. Get keypoints and descriptors from img1 and img2
        kp_1, desc_1 = get_orb_features(img1)
        kp_2, desc_2 = get_orb_features(img2)

        # 2. Match features between the two images
        matches = match_keypoints(desc_1, desc_2)

        # 3. transform_ransac
        pts1 = np.array([kp_1[m.queryIdx].pt for m in matches])
        pts2 = np.array([kp_2[m.trainIdx].pt for m in matches])
        H = transform_ransac(pts1, pts2)

        #############################################################################
        #                              END OF YOUR CODE                            ␣
 ↪    #
        #############################################################################
        # apply perspective wrap to stitch images together
        final_img = cv2.warpPerspective(img2, H, (img2.shape[1] + img1.
 ↪shape[1], img2.shape[0] * 2))
        final_img[0:img1.shape[0], 0:img1.shape[1]] = img1

        return final_img
```

[29]:
```
result = panoramic_stitching(img1, img2)
cv2_imshow(result)
```

8 (d) Observe that in Figure 1, there is border artifacts in the stiched panorama. Describe methods that can remove the border artifacts for a smooth blending.

A: For my implementation to solve this problem, it will take the following 3 steps. 1. Crop the images so that so black boarder exists. 2. Adjust brightness and saturation of two images to reduce discrepency. 3. Utilize Gaussian and Laplacian pyramid and mask to blend the two images.

9 Convert to PDF

Before converting to pdf, please get rid of the **funuction points declaration text** starts with "Functions to implement (refer to function comments for more detail)" of the brief overview section at the top. That part of text requires specific latex libaraies for conversion and may affect your pdf conversion process.

This may be important if you have failed converting to pdf.

[ ]:
```python
# generate pdf
# Please provide the full path of the notebook file below
# Important: make sure that your file name does not contain spaces!
import os
notebookpath = '/content/drive/My Drive/EECS 442 - Computer Vision/Hw/hw3/
↪pohsun_40183452.ipynb' # Ex: notebookpath = '/content/drive/My Drive/Colab␣
↪Notebooks/drewskis_31415926.ipynb'
drive_mount_point = '/content/drive/'
from google.colab import drive
drive.mount(drive_mount_point)
file_name = notebookpath.split('/')[-1]
get_ipython().system("apt update && apt install texlive-xetex␣
↪texlive-fonts-recommended texlive-generic-recommended")
get_ipython().system("pip install pypandoc")
get_ipython().system("apt-get install texlive texlive-xetex texlive-latex-extra␣
↪pandoc")
get_ipython().system("jupyter nbconvert --to PDF {}".format(notebookpath.
↪replace(' ', '\\ ')))
from google.colab import files
files.download(notebookpath.split('.')[0]+'.pdf')
```

```
Drive already mounted at /content/drive/; to attempt to forcibly remount, call
drive.mount("/content/drive/", force_remount=True).
Hit:1 https://cloud.r-project.org/bin/linux/ubuntu jammy-cran40/ InRelease
Hit:2 https://cli.github.com/packages stable InRelease
Hit:3 https://developer.download.nvidia.com/compute/cuda/repos/ubuntu2204/x86_64
InRelease
Hit:4 http://archive.ubuntu.com/ubuntu jammy InRelease
Hit:5 http://archive.ubuntu.com/ubuntu jammy-updates InRelease
Hit:6 http://security.ubuntu.com/ubuntu jammy-security InRelease
Hit:7 http://archive.ubuntu.com/ubuntu jammy-backports InRelease
0% [Waiting for headers] [Waiting for headers]
```