Group Name : Unfiltered Commentary

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```
import numpy as np
import imageio.v2 as imageio
from glob import glob
from skimage import img_as_float32
from natsort import natsorted
import matplotlib.pyplot as plt
import cv2
from typing import Tuple
import json
from collections import defaultdict
from sklearn.neighbors import NearestNeighbors
import networkx as nx
import random
import math

path_pairs = list(zip(
natsorted(glob('./puzzle_corners_1024x768/images-1024x768/*.png')),
natsorted(glob('./puzzle_corners_1024x768/masks-1024x768/*.png')),
))
imgs = np.array([img_as_float32(imageio.imread(ipath)) for ipath, _ in path_pairs])
msks = np.array([img_as_float32(imageio.imread(mpath)) for _, mpath in path_pairs])
```

Part 1 Finding Contours

1.1 `get_puzzle_contour`

1.2

```
def get_clockwise_contour(contours):
    if cv2.contourArea(contours,oriented=True)<0:
        return contours[::-1]
    return contours
```

1.1

```
def get_puzzle_contour(mask):
    mask_uint8 = cv2.convertScaleAbs(mask)
    contours, _ = cv2.findContours(mask_uint8, cv2.RETR_LIST, cv2.CHAIN_APPROX_SIMPLE)
```

```
    contours = [c.reshape(-1, 2) for c in contours]

    # since we assume the contour closed has the largest area.
    max_contour = max(contours, key=cv2.contourArea)
    max_contour = get_clockwise_contour(max_contour.reshape(-1, 2))
    # some plots are not closed
    if not np.array_equal(max_contour[0], max_contour[-1]):
        # adding the first point to close the contour
        max_contour = np.vstack([max_contour, max_contour[0]])
    return max_contour
```

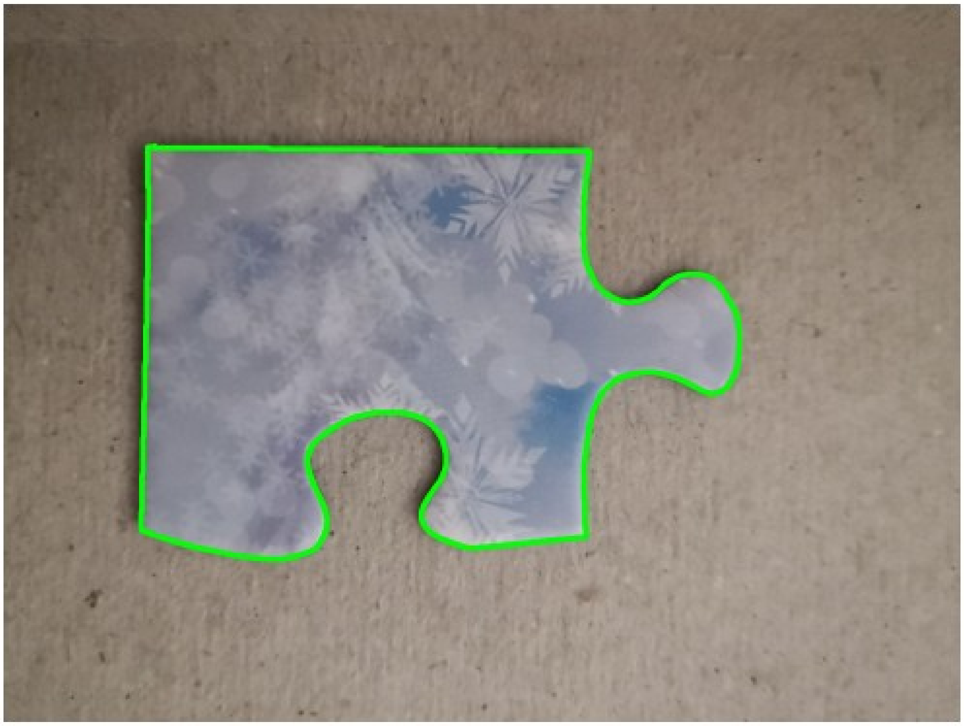
1.3 **how does `cv2.findContours` work and ow the oriented=True version

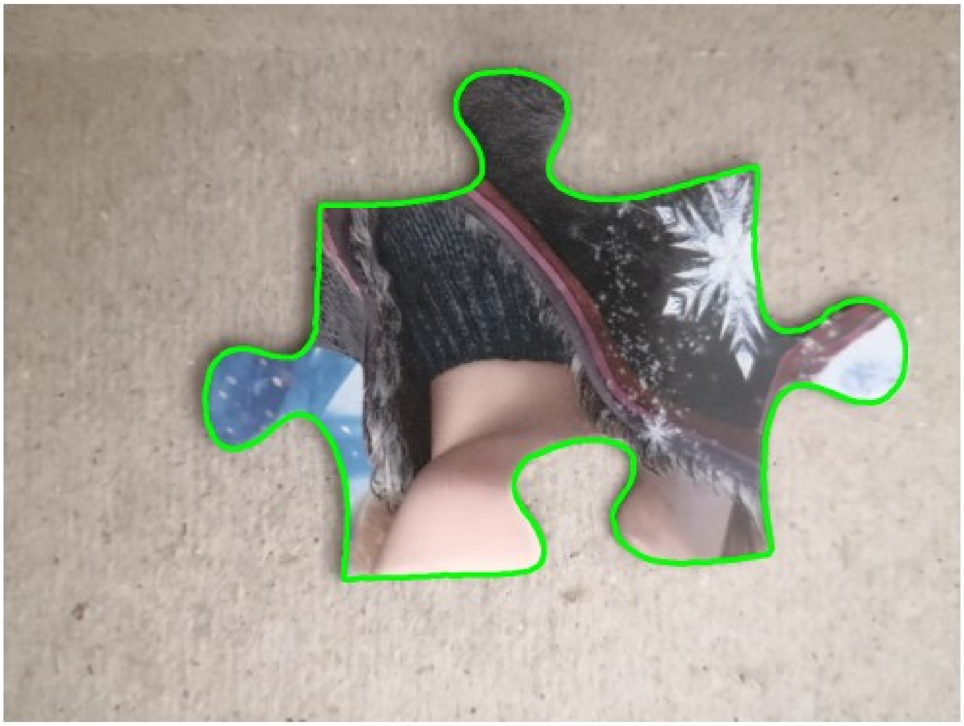
of cv2.contourArea detects orientation :**

\

1.4 plot of the any 3 contours

```
#Show Contours
for i in range(3):
    contour = get_puzzle_contour(msks[i])


    fig, ax = plt.subplots()

    #  image
    ax.imshow(imgs[i], cmap='gray')

    # contours
    x_coords, y_coords = zip(*contour)
    ax.plot(x_coords, y_coords, c='lime', linewidth=2)
    ax.axis('off')
    plt.show()
```





Shape models

2.1.1

```
with open("./puzzle_corners_1024x768/corners.json", mode="r") as f:
    names, corner_ratios = json.load(f)

#Convert Ratios to coordinates
for picture in range(len(corner_ratios)):
    for points in range(len(corner_ratios[picture])):
        corner_ratios[picture][points]=[corner_ratios[picture][points]
[0]*1024,corner_ratios[picture][points][1]*768]
```

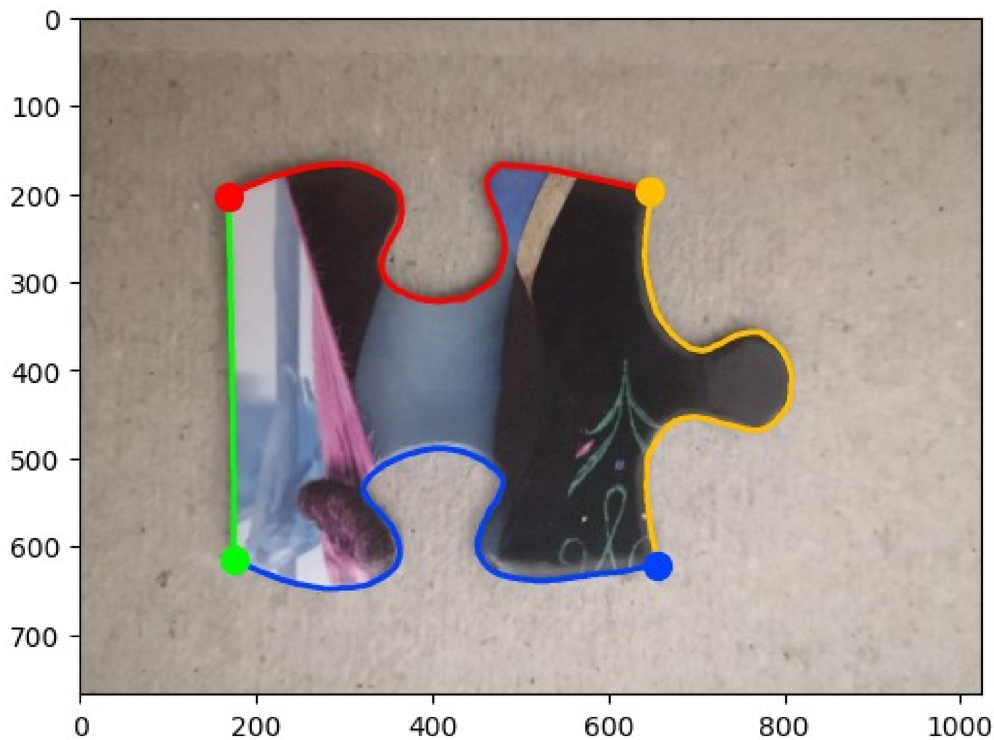
2.1.2

NOTE: Using `cv2.CHAIN_APPROX_SIMPLE` is helpful since it only stores the endpoints of the lines that form the contour - this is what we need if we want to find the nearest point in the contour to the corner. makes finding the nearest contour easier.

```
def extract_sides(contour, corners):
    corner_indices=[]
    for corner in corners:
        #get distance
        corner_dists = np.linalg.norm(contour - corner, axis=-1)
        # using argmin to get the closest points since smaller
distance
```

```
        nearest_idx = np.argmin(corner_dists)
        corner_indices.append(nearest_idx)

    corner_indices = sorted(corner_indices)




    side_contours = []
    for i in range(4):
        start_idx = corner_indices[i]
        end_idx = corner_indices[(i + 1) % 4]
        if start_idx < end_idx:
            side_contour = contour[start_idx:end_idx + 1]
        else:
            side_contour = np.concatenate([contour[start_idx:],
contour[:end_idx + 1]])

        side_contours.append(side_contour)

    return side_contours



### 2.1.3

### helper to plot the contours
def plot_puzzle_piece(img,contour, corners, sides):
    corners = np.array(corners)
    # colors of quad and sides
    quad_color = (1.0, 1.0, 1.0)
    side_colors = [(1.0, 0.75, 0.0),

                   (0.0, 0.25, 1.0),
                    (0.0, 1.0, 0.0),
                    (1.0, 0.0, 0.0),]


    plt.figure(figsize=(6, 6))
    plt.imshow(img)

    # contour for each side with different colors
    for i, side in enumerate(sides):
        # ide contour in its color
        plt.plot(side[:, 0], side[:, 1], color=side_colors[i],
linewidth=2)

        # colored dot at the start of each side
        plt.scatter(side[0, 0], side[0, 1], color=side_colors[i],
zorder=6, s=100)
```

```
        # white dots along the side
        # num_points = 10
        # sparse_indices = np.linspace(0, len(side) - 1, num_points,
dtype=int)


        # plt.scatter(side[sparse_indices, 0], side[sparse_indices,
1], color='white', zorder=5, s=20)






    plt.show()

def plot_side(img_index):
    contour = get_puzzle_contour(msks[img_index])
    # print("contours\n",contours)

    sides = extract_sides(contour,corner_ratios[img_index])

    plot_puzzle_piece(imgs[img_index],contour,
corner_ratios[img_index], sides)

plot_side(1)
```



NOTE

had to comment out the plot in this function because it was messing the the plot for the ijnterpolation!!!

2.2.1

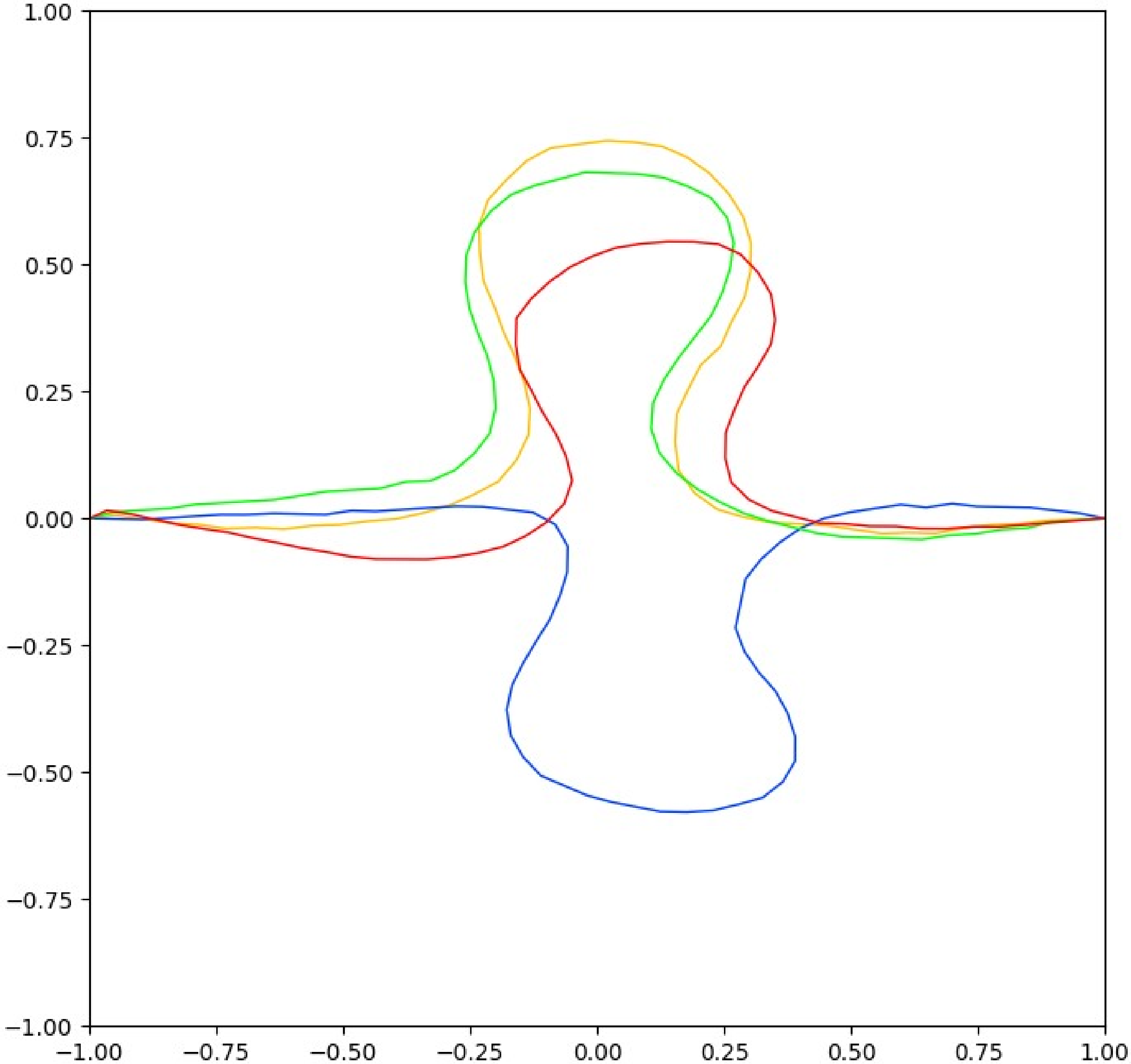
```
def transform_puzzle_side(contour): # contour is a side
    point1 = np.array(contour[0])
    point2 = np.array(contour[-1])
    line = np.array([point1,point2])

    midpoint = (point1 + point2)/2
    #print(midpoint)

    #Do translation
    translated_contour = contour - midpoint

    #scale
    length = np.linalg.norm(point2 - point1)
    scale_factor = 2.0/length
    scaled_contour = (translated_contour)* scale_factor

    #Do Rotation
    theta =np.arctan2(translated_contour[0][1],translated_contour[0]
[0])
    #print(theta)
    rotation_matrix = np.array([[np.cos(-theta), -np.sin(-theta)],
                                [np.sin(-theta),  np.cos(-theta)]])

    rotated_contour = (rotation_matrix @ scaled_contour.T).T

    # x_coords = rotated_contour[:, 0]
    # y_coords = rotated_contour[:, 1]

    # # Create the scatter plot
    # plt.scatter(x_coords, y_coords)

    # # Optional: Add titles and labels
    # plt.title('Scatter Plot of Points')
    # plt.xlabel('X-axis')
    # plt.ylabel('Y-axis')
    # plt.show()
    return rotated_contour
    # Show the plot
contour = get_puzzle_contour(msks[1])


sides = extract_sides(contour,corner_ratios[1])
side_0 = transform_puzzle_side(sides[0])
```

2.2.2

```
def even_spaced_contour(contour, num_points=64):
    #distance between consecutive points
    diffs = np.diff(contour, axis=0)
    segment_lengths = np.sqrt((diffs**2).sum(axis=1)) #just the 
euclidean

    #cumultive len init to 0
    cumulative_lengths = np.insert(np.cumsum(segment_lengths),0,0)

    #normalisation of len
    total_length = cumulative_lengths[-1] #since cumulative las it 
total
    cumulative_ratios = cumulative_lengths/ total_length

    #to space evenly
    spacing = np.linspace(0,1,num_points)

    #interpolation
    x_new = np.interp(spacing, cumulative_ratios, contour[:,0])
    y_new = np.interp(spacing, cumulative_ratios, contour[:,1])

    new_contour = np.vstack((x_new,y_new)).T

    return new_contour

new_side = even_spaced_contour(side_0)

def plot_normalised(contour, corners, num_sides=4):
    sides = extract_sides(contour,corners)

    plt.figure(figsize=(8, 8))
    plt.xlim(-1, 1)
    plt.ylim(-1, 1)

    side_colors = [(1.0, 0.75, 0.0),
                   (0.0, 0.25, 1.0),
                    (0.0, 1.0, 0.0),
                    (1.0, 0.0, 0.0),]
    for i in range(num_sides):
        side = transform_puzzle_side(sides[i])
        simplified_side = even_spaced_contour(side, 64) #said to use 
10 points for a simplified plot
        plt.plot(simplified_side[:, 0], simplified_side[:, 1], 
color=side_colors[i], linestyle='-', linewidth=1, marker=None)

    plt.gca().set_aspect('equal', adjustable='box')
    plt.show()
```

2.2.3

```
contour = get_puzzle_contour(msks[2])
plot_normalised(contour, corner_ratios[2])
```



3 Match Shape Models

3.1 Before we can apply these rules, we need to know which sides of pieces are flat so we can determine if they should be matched or not, and so that we can determine if a piece is an interior piece (no flat sides), edge piece (1 flat side), corner piece (2 flat sides) or invalid piece (3 or 4 flat sides). Note that with side information, you could solve for possible the widths and heights of the puzzle in terms of pieces. Taking into account the number of pieces along the perimeter and the total area. Code is_flat_side(contour, min_ratio=0.9) that checks if the distance cont_dist between the two endpoints of a non-closed contour is approximately equal to the entire length cont_len of the contour. If cont_dist/cont_len >= min_ratio then the side should be considered flat. Hint: np.linalg.norm and cv2.arcLength7 called with closed=False may come in handy.

3.1

```
def is_flat_side(contour, min_ratio=0.9):
    contour = contour.reshape((-1, 1, 2))
    contour = contour.astype(np.float32)
    point_to_point = np.array([contour[0], contour[-1]])
    point_to_point_length = cv2.arcLength(point_to_point,closed=False)
    total_length = cv2.arcLength(contour,closed=False)

    #print("Straight:",point_to_point_length)
    #print("Curve:",total_length)
    if(point_to_point_length/total_length <min_ratio):
        return False

    return True


def flat_sides(contour, corners, num_sides=4):
    sides = extract_sides(contour,corners)

    for i in range(num_sides):
        side = transform_puzzle_side(sides[i])
        simplified_side = even_spaced_contour(side, 64) #said to use
10 points for a simplified plot
        is_flat_side(simplified_side)

contour = get_puzzle_contour(msks[1])


flat_sides(contour,corner_ratios[1])

class Piece:
    """
    A class for each piece
        Attributes:
        contour
        corners
        sides : extracted sides normalized and translated.
        sides_objects : list of objects of type Side
        num_flat (int) : the number of flat sides
        interior_piece : if is interior piece

    """
    def __init__(self,mask,corners) -> None:
        self.contour = get_puzzle_contour(mask)
        self.corners = corners
        self.sides = extract_sides(self.contour,corners)
        self.sides_objects:Side = [Side]*4
```

```
        # normalize,translate sides, determine flat and not flat sides
        for i in range(4):
            side = transform_puzzle_side(self.sides[i])
            self.sides[i] = even_spaced_contour(side, 64) #said to use
10 points for a simplified plot
            self.sides_objects[i] = Side(self,self.sides[i])

        self.interior_piece =
self.is_interior_piece(self.sides_objects)

        # set flags if the piece is anticlockwise or clockwise from an
flat edge
        for i in range(len(self.sides_objects)):
            before_index = (i - 1) % len(self.sides_objects)
            after_index = (i + 1) % len(self.sides_objects)
            # is this piece after a flat edge
            if(self.sides_objects[before_index].is_flat):
                self.sides_objects[i].after_flat = True
            elif(self.sides_objects[after_index].is_flat):
                self.sides_objects[i].before_flat = True




    def is_interior_piece(self,side_objects):
        interior:bool = True
        for x in (side_objects):
            if(x.is_flat == True):
                interior = False
                return interior
        return interior

class Side :
    """
    A class for each side
        Attributes:
        Piece : A refrence to the parent piece class.
        Side : contour of the side.
        is_flat (bool) : Boolean flag for if the side is flat.
        protruding (bool) :
        after_flat : if the edge is clockwise after a flat edge.
        before_flat : if the edge is anticlockwise from a flat edge.
    """
    def __init__(self,piece,contour):
        self.piece = piece
        self.contour = contour
        self.rotated_side = self.rotate_side(self.contour)
        self.is_flat = is_flat_side(self.contour)
        self.protruding = self.determine_protruding(self.contour,-
0.25)
```

```
        self.after_flat = False
        self.before_flat = False
        pass

    def plot_side(self):
        plt.figure(figsize=(3,3))
        plt.plot(self.contour[:, 0], self.contour[:, 1],
linestyle='-', linewidth=1, marker=None)
        plt.ylim(-1, 1)
        plt.show()

    def determine_protruding(self,contour,threshold):
        if(np.min(contour[:,1])<threshold):
            return False
        else:
            return True
    def rotate_side(self,contour):
        reversed_side = (contour * -1)[::-1]
        return reversed_side

    def __str__(self):
        return f"Side(is_flat={self.is_flat},
protruding={self.protruding},
after_flat={self.after_flat},before_flat={self.before_flat})"

def get_nearest_neighbour_model(rotated_sides):
    knn = NearestNeighbors(n_neighbors=192,algorithm="brute")
    return knn.fit(rotated_sides)

def plot_graph(V, E, seed=42):
    random.seed(seed) # graphs are randomly plotted
    np.random.seed(seed) # graphs are randomly plotted
    G = nx.DiGraph()
    G.add_nodes_from(V)
    G.add_edges_from(E)
    nx.draw_kamada_kawai(G, with_labels=True)
    plt.show()

def plot_all_connections(indeces,pieces_array):
    V = [i for i in range(len(pieces_array))]
    E = []

    for side in range(len(indeces)):

        #Check if side is flat
        if not(pieces_array[math.floor(side/4)].sides_objects[side
%4].is_flat):
            index = 0
            while(pieces_array[math.floor(side/4)].sides_objects[side
%4].after_flat and not pieces_array[math.floor(indeces[side]
```

```
[index]/4)].sides_objects[indeces[side][index]%4].before_flat) or
(pieces_array[math.floor(side/4)].sides_objects[side%4].before_flat
and not pieces_array[math.floor(indeces[side]
[index]/4)].sides_objects[indeces[side][index]%4].after_flat):
                index+=1

            E.append((math.floor(side/4),math.floor(indeces[side]
[index]/4)))

    plot_graph(V,E)

def plot_double_connections(indeces,pieces_array):
    V = [i for i in range(len(pieces_array))]

    double_indicies = []
    for i in range(len(indeces)):
        index = 0
        while(pieces_array[math.floor(i/4)].sides_objects[i
%4].after_flat and not pieces_array[math.floor(indeces[i]
[index]/4)].sides_objects[indeces[i][index]%4].before_flat) or
(pieces_array[math.floor(i/4)].sides_objects[i%4].before_flat and not
pieces_array[math.floor(indeces[i][index]/4)].sides_objects[indeces[i]
[index]%4].after_flat):
            index+=1

        check = indeces[i][index]
        if(indeces[check][index]==i):
            double_indicies.append([math.floor(i/4),i%4,indeces[i]
[index]])

    E = []

    for side in double_indicies:
        #Check if side is flat
        if not(pieces_array[side[0]].sides_objects[side[1]].is_flat):
            E.append((side[0],math.floor(side[2]/4)))

    plot_graph(V,E)

def plot_edge_connections(indeces,pieces_array):
    V = []

    for i in range(len(pieces_array)):
        if not(pieces_array[i].interior_piece):
            V.append(i)


    double_indicies = []
    for i in range(len(indeces)):
        index = 0
        while(pieces_array[math.floor(i/4)].sides_objects[i
```

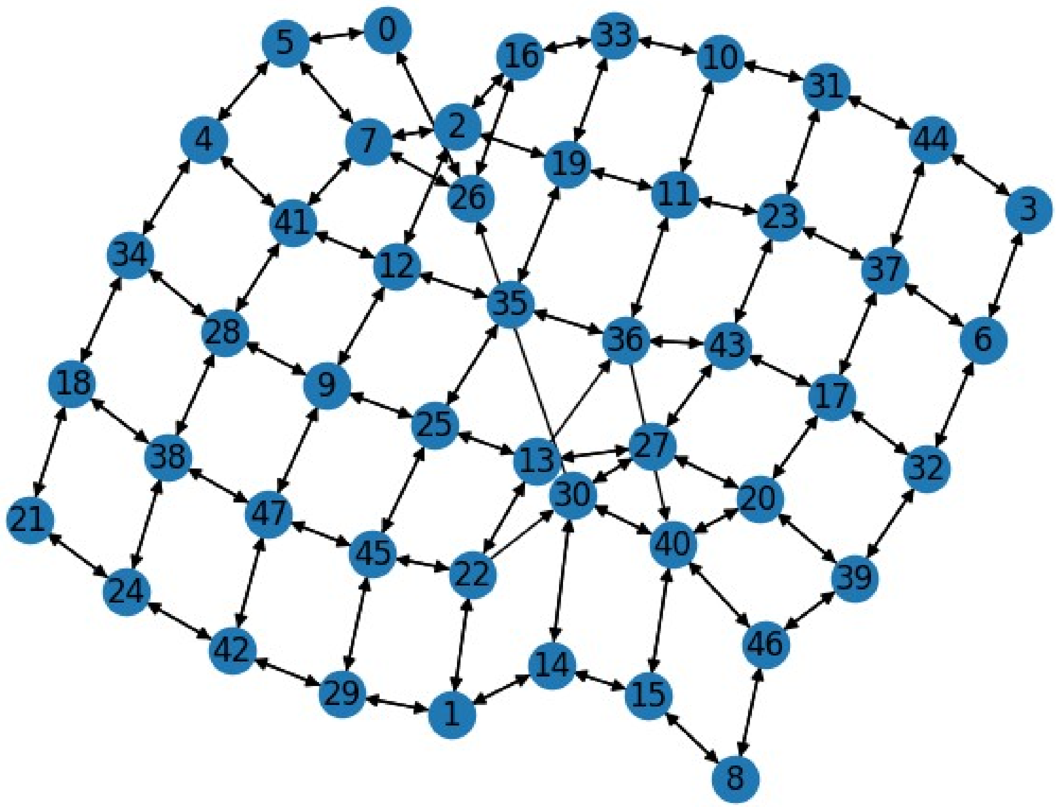
```
%4].after_flat and not pieces_array[math.floor(indeces[i]
[index]/4)].sides_objects[indeces[i][index]%4].before_flat) or
(pieces_array[math.floor(i/4)].sides_objects[i%4].before_flat and not
pieces_array[math.floor(indeces[i][index]/4)].sides_objects[indeces[i]
[index]%4].after_flat):
            index+=1

        check = indeces[i][index]
        if(indeces[check][index]==i):
            double_indicies.append([math.floor(i/4),i%4,indeces[i]
[index]])

    E = []
    for side in double_indicies:


        if pieces_array[side[0]].interior_piece or
pieces_array[math.floor(side[2]/4)].interior_piece:
            continue

        #Check if side is flat
        if not(pieces_array[side[0]].sides_objects[side[1]].is_flat):
            E.append((side[0],math.floor(side[2]/4)))

    plot_graph(V,E)
```

3.2 , 3.3

```
pieces_array = []
rotated_sides = []
side_features = []
for image in range(len(imgs)):
    piece = Piece(msks[image],corner_ratios[image])
    pieces_array.append(piece)
    for i in piece.sides_objects:
        side_features.append(i.contour.flatten()) ##Flatten to give a
1D feature array
        rotated_sides.append(i.rotated_side.flatten()) ##Flatten to
give a 1D feature array

knn = get_nearest_neighbour_model(rotated_sides)

distances , indeces = knn.kneighbors(side_features)
```

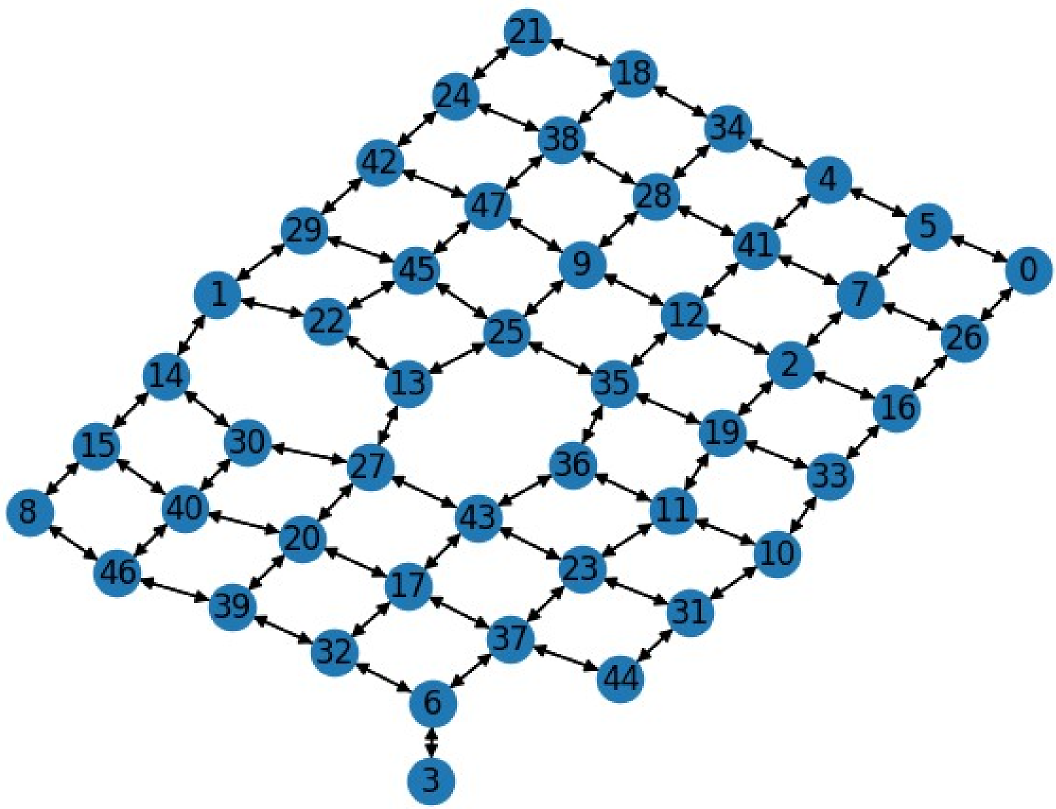
3.4

```
plot_all_connections(indeces,pieces_array)
```

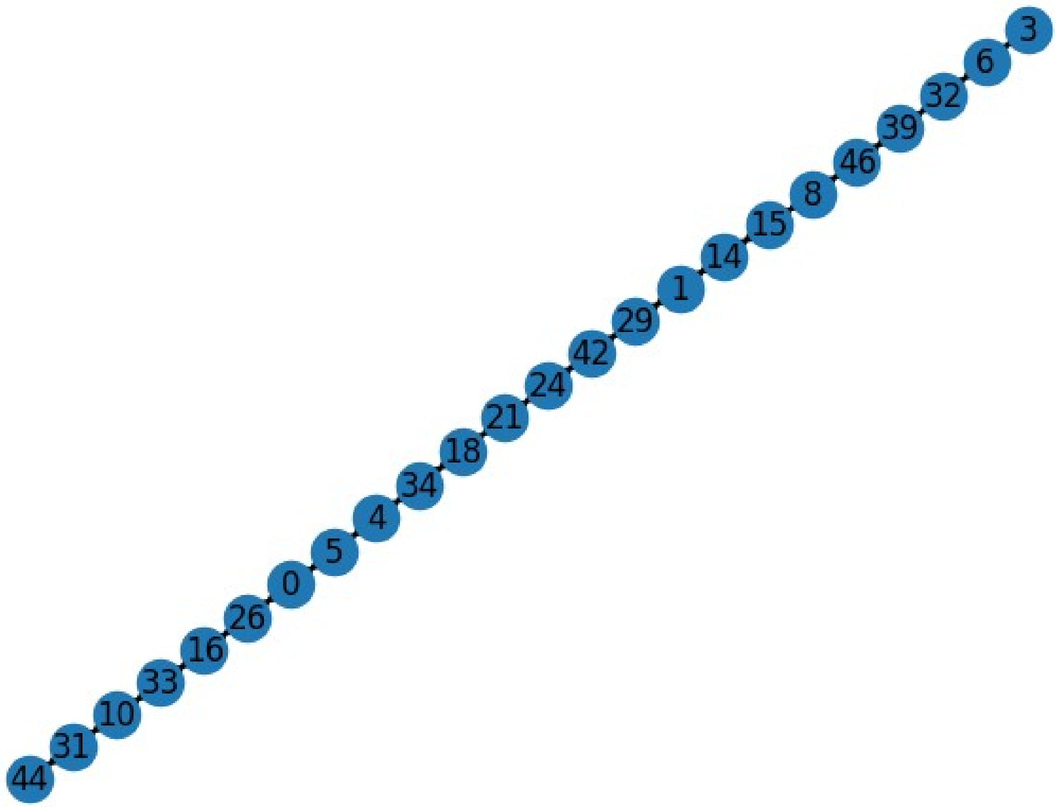


3.5

```
plot_double_connections(indeces,pieces_array)
```



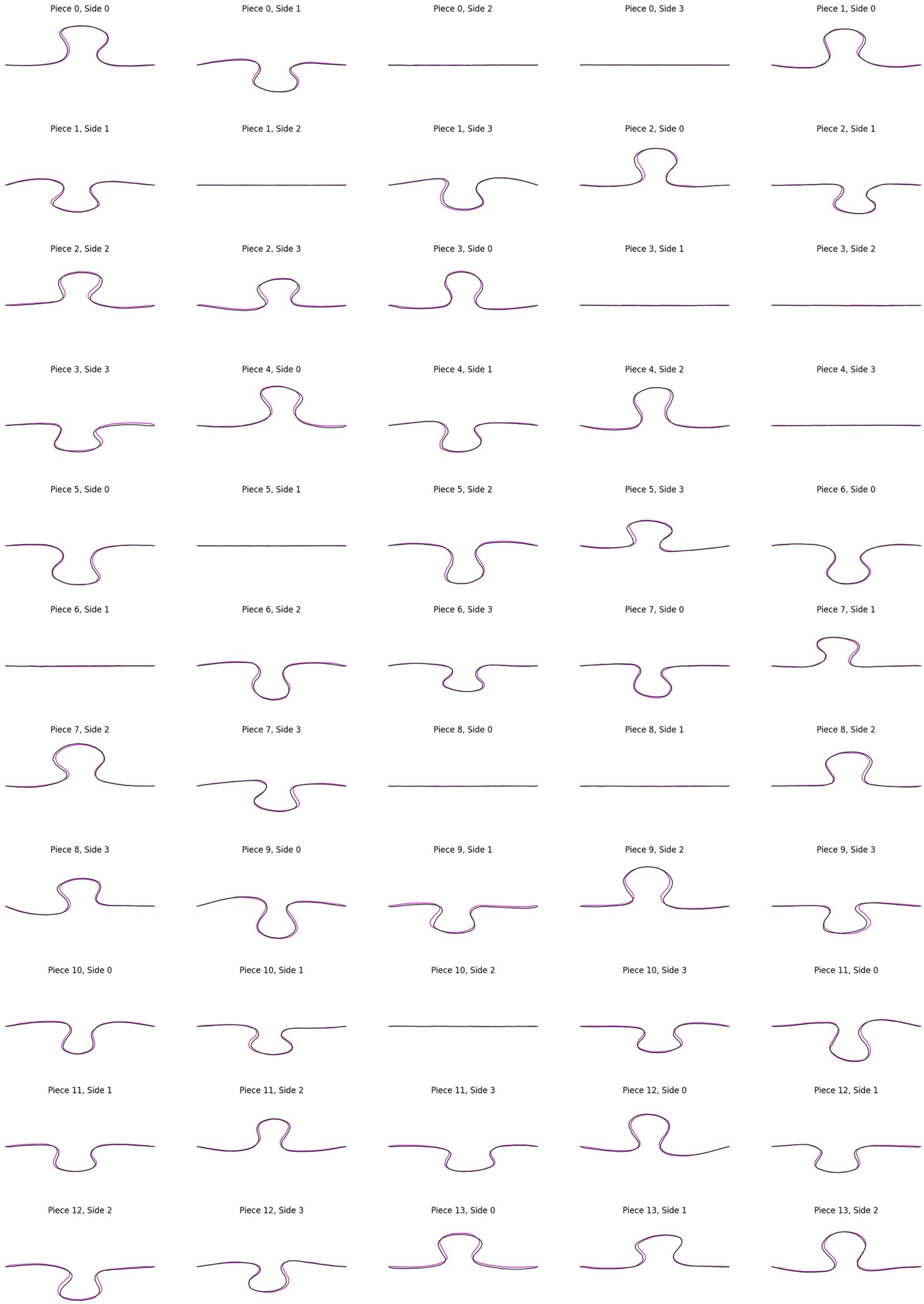

```
### 3.6

plot_edge_connections(indeces,pieces_array)
```



3.7

```
def plot_all_matches(indecies,pieces_array):
    rows = 40
    cols = 5

    # Create a figure with the specified rows and columns
    fig, axes = plt.subplots(rows, cols, figsize=(20, 100))  # Adjust
size as needed
    for i in range(len(indecies)):

        piece_idx = math.floor(i / 4)  # Get the piece index
        side_idx = i % 4
        piece = pieces_array[piece_idx]
        side = piece.sides_objects[side_idx]

        row = i // cols
        col = i % cols
        axes[row, col].plot(side.contour[:, 0], side.contour[:, 1],
linestyle='-',color='m', linewidth=1, marker=None)
        axes[row, col].set_title(f"Piece {piece_idx}, Side
{side_idx}")
```

```
        axes[row, col].set_ylim(-1, 1)
        matched_sides = [indeces[i][0]]
        for x in matched_sides:
            piece_idx = math.floor(x / 4)  # Get the piece index
            side_idx = x % 4
            piece = pieces_array[piece_idx]
            side = piece.sides_objects[side_idx]
            axes[row, col].plot(side.rotated_side[:, 0],
side.rotated_side[:, 1], linestyle='-',color='black', linewidth=1,
marker=None)


        axes[row, col].axis('off')
    plt.tight_layout()
    plt.show()

plot_all_matches(indeces,pieces_array)
```


Piece 0, Side 0
Piece 0, Side 1
Piece 0, Side 2
Piece 0, Side 3
Piece 1, Side 0
Piece 1, Side 1
Piece 1, Side 2
Piece 1, Side 3
Piece 2, Side 0
Piece 2, Side 1
Piece 2, Side 2
Piece 2, Side 3
Piece 3, Side 0
Piece 3, Side 1
Piece 3, Side 2
Piece 3, Side 3
Piece 4, Side 0
Piece 4, Side 1
Piece 4, Side 2
Piece 4, Side 3
Piece 5, Side 0
Piece 5, Side 1
Piece 5, Side 2
Piece 5, Side 3
Piece 6, Side 0
Piece 6, Side 1
Piece 6, Side 2
Piece 6, Side 3
Piece 7, Side 0
Piece 7, Side 1
Piece 7, Side 2
Piece 7, Side 3
Piece 8, Side 0
Piece 8, Side 1
Piece 8, Side 2
Piece 8, Side 3
Piece 9, Side 0
Piece 9, Side 1
Piece 9, Side 2
Piece 9, Side 3
Piece 10, Side 0
Piece 10, Side 1
Piece 10, Side 2
Piece 10, Side 3
Piece 11, Side 0
Piece 11, Side 1
Piece 11, Side 2
Piece 11, Side 3
Piece 12, Side 0
Piece 12, Side 1
Piece 12, Side 2
Piece 12, Side 3
Piece 13, Side 0
Piece 13, Side 1
Piece 13, Side 2

3.7

Having plotted all of the pieces and their matches, we can see that the sunken sides are always smaller than the protruding sides. This shows a human bias to mark beyond the edge, inflating the object (which makes holes smaller and extremeties bigger).

How can this be remedied? Post matching we can find the average distance between the matched pieces and adjust all pieces using dilation on sunknen and erosion on protruding sides. And then rematch all of the pieces.

3.8

Computational Complexity:

As the number of puzzle pieces increases, the computational complexity of k-nearest neighbors matching will grow quadratically. For very large puzzles (e.g., 1000+ pieces), this could become a significant bottleneck.

Memory Usage:

Storing shape models and match data for each piece will require increasing amounts of memory as the puzzle size grows. With our current methods it will be quadratic, as we find 192 neighbors to each 192 sides. An improvement would be to find the relationsip between number of pieces and number of perimiter pieces. With more pieces, there's a higher chance of accumulating matching errors, potentially leading to incorrect solutions for larger puzzles.

A stable marriage matching algorithm would solve many of these problems.

How well it performs? Considering with what we were expected to do (example baseline). Even though not all of the pieces are matched to their exact neighbours, as long as there is 1 correct match , the puzzle will be solved. So the high but not perfect accuracy of the model will suffice.