HW2 Camera Relocalization

Due: 2022/10/25 11:59 AM

3DCV 2022

Email: 3dcv@csie.ntu.edu.tw

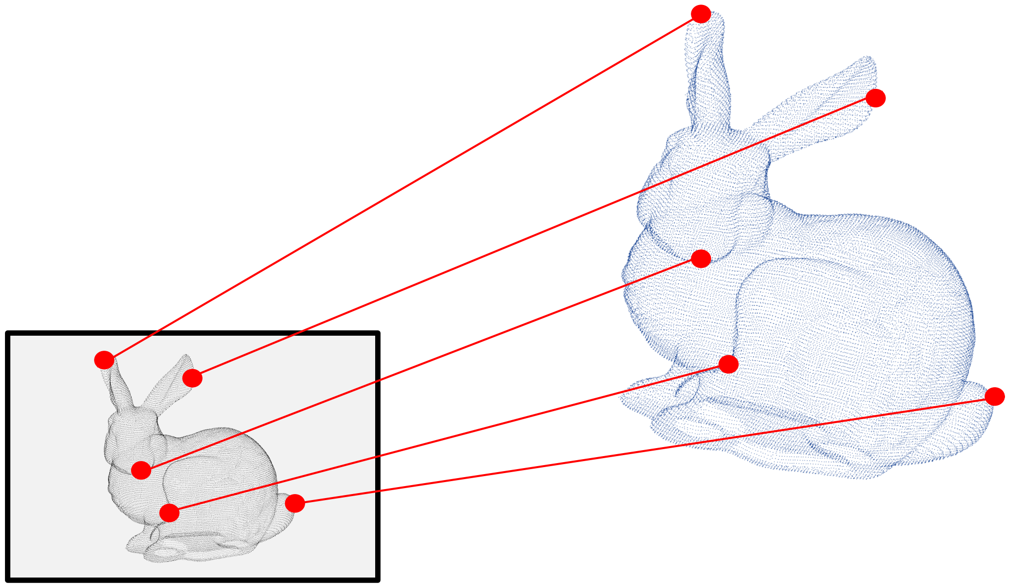
GitHub Classroom: https://classroom.github.com/a/9Y9x2XTS

GitHub Registration: https://forms.gle/ikNyfxXJUw7krcG88

Outline

The goal of this homework is to realize how a camera re-localization system works.

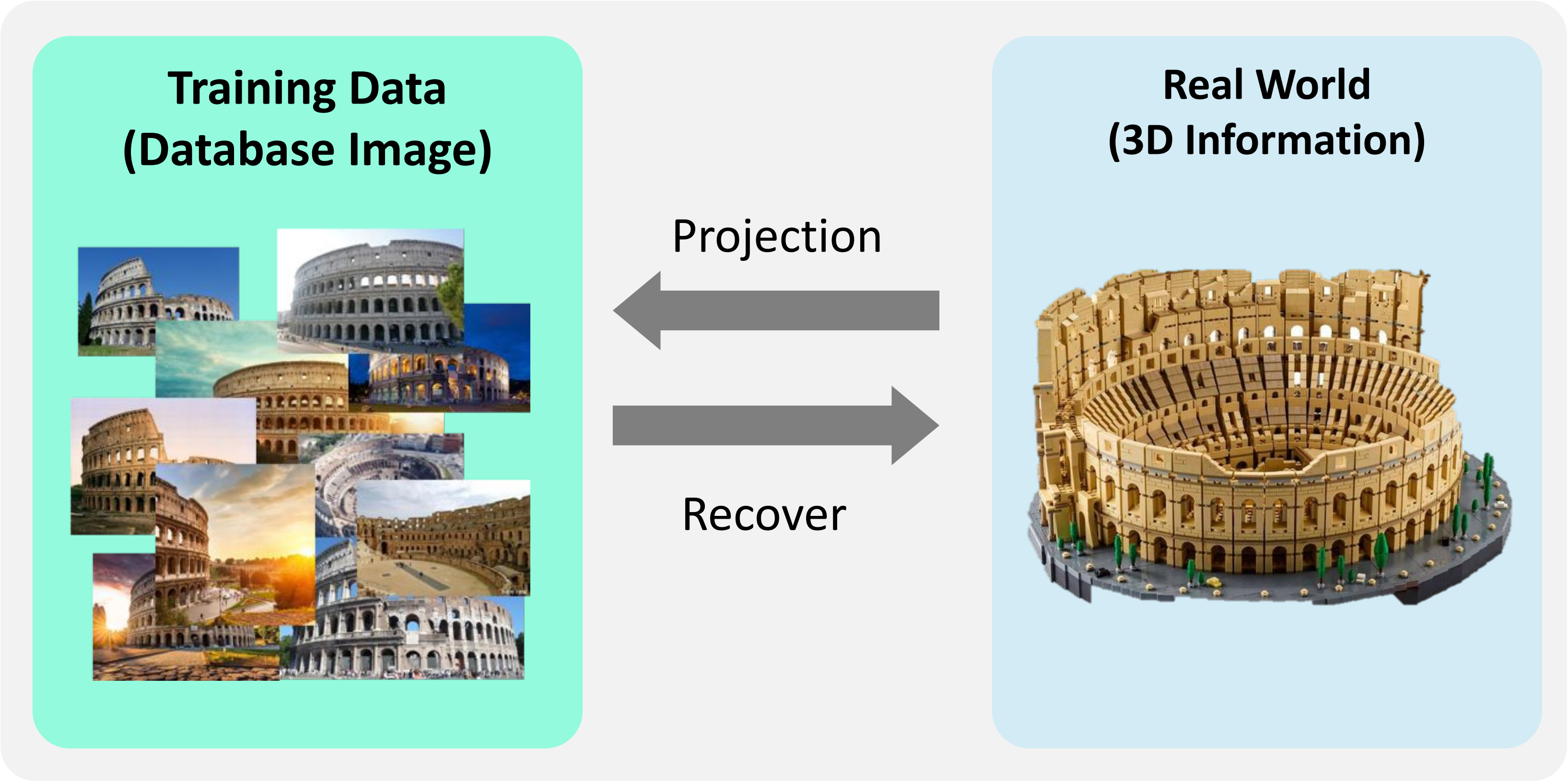
- Introduction
- Dataset
- Problem 1: 2D-3D Matching (Q1-1 ~ Q1-3)
- Problem 2: Augmented Reality (Q2-1 ~ Q2-2)
- Bonus List
- Grading Policy



Introduction

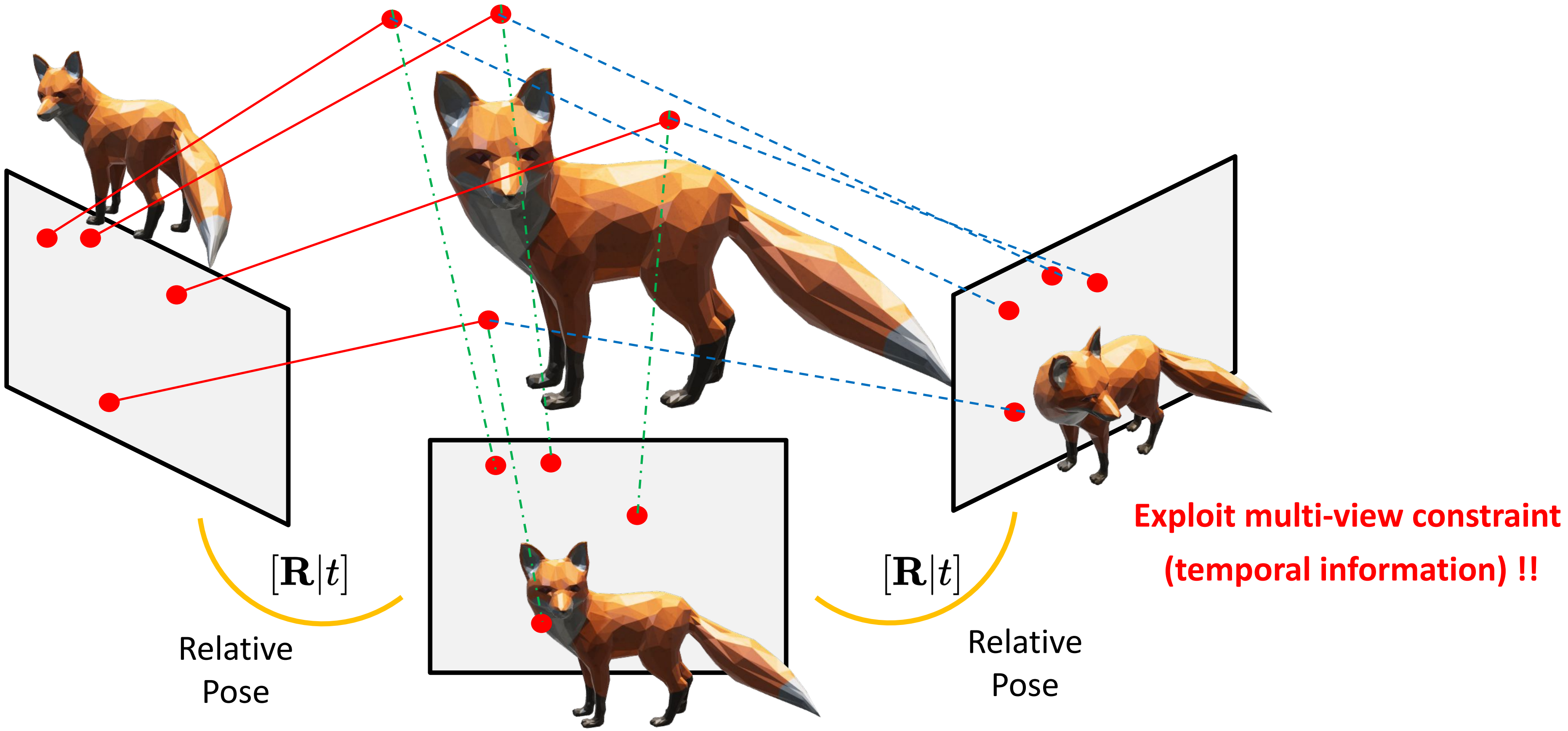
- **Camera Relocalization**: Determine the camera pose from the visual scene representation. In other words, the scene is **seen** (and modeled) **beforehand**. Now, given a query image that is taken is this environment, we are able to find out where this image is taken.

Query Image



Introduction

- **One-shot relocalization**: focus on a finding the pose of still image.
- **Temporal camera relocalization**: estimates the poses of every frame in the video sequence

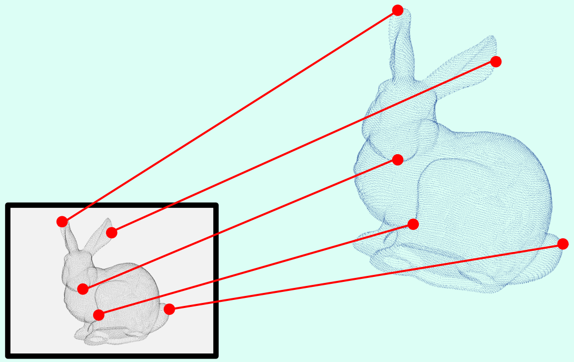


Methodology

- Common strategies for camera relocalization. Note that there are some approaches utilize hybrid models to increase the efficiency and robustness.
- Metric localization can only be achieved by machine (or deep) learning models.

2D-3D Matching Localization

3D scene models with local feature descriptors



Metric Localization (Absolute Pose Regression)

regresses the position and orientation of the camera

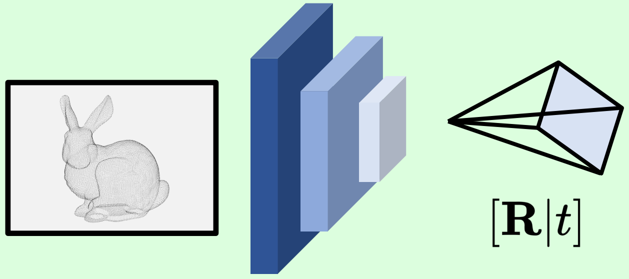
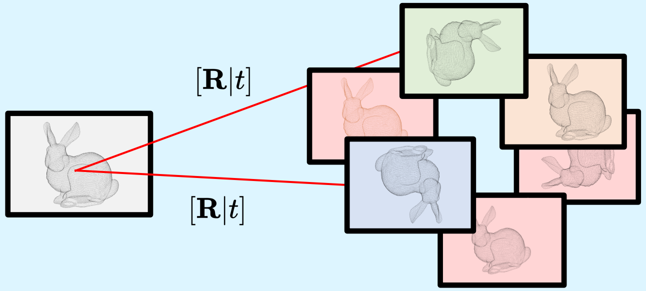


Image Retrieval Localization

pose approximation from top-k similar images



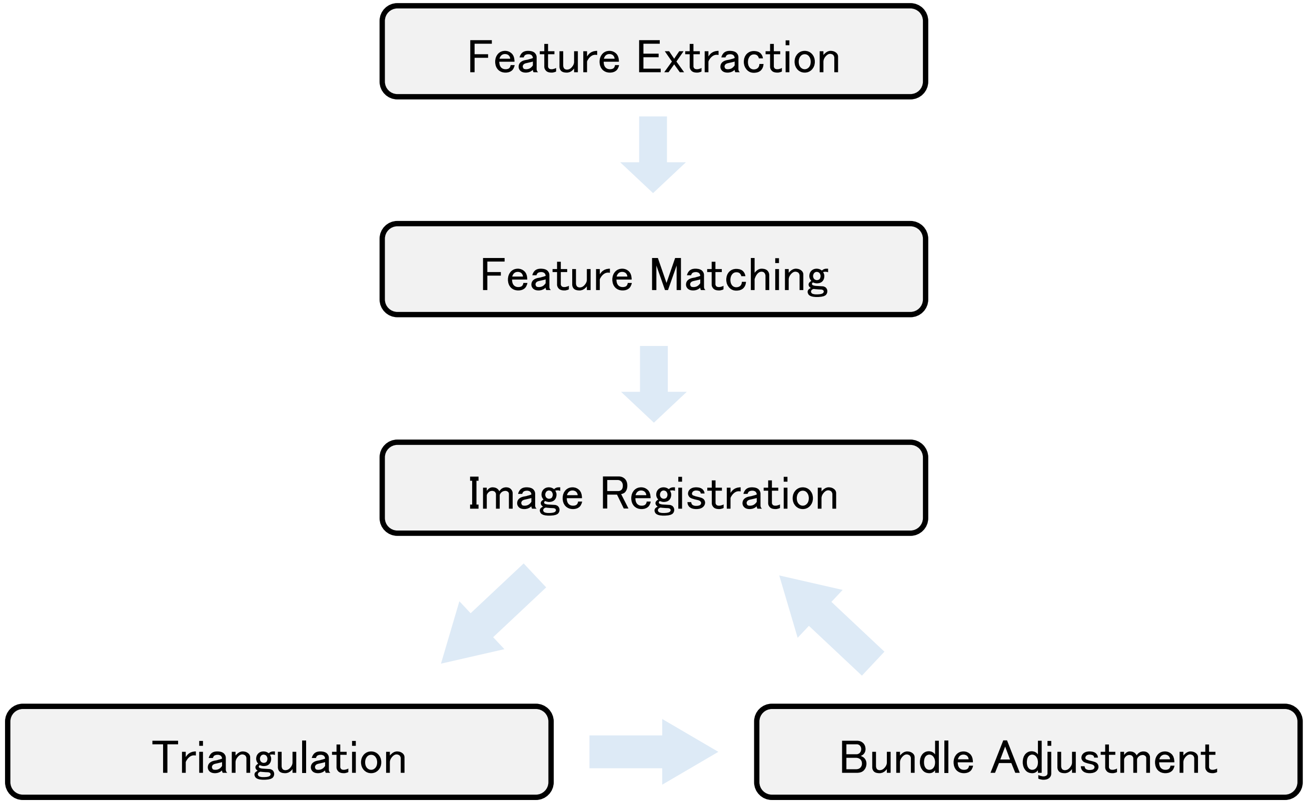
Welcome to the NTU Front Gate

- We collect multiple images of the NTU front gate, and reconstruct its 3D point cloud model via structure from motion.

About Dataset

- 293 color images (1920x1080x3): 163 images for training, 130 images for testing
- 111,518 points (in world coordinate) with 682,467 local image descriptors

Dataset images



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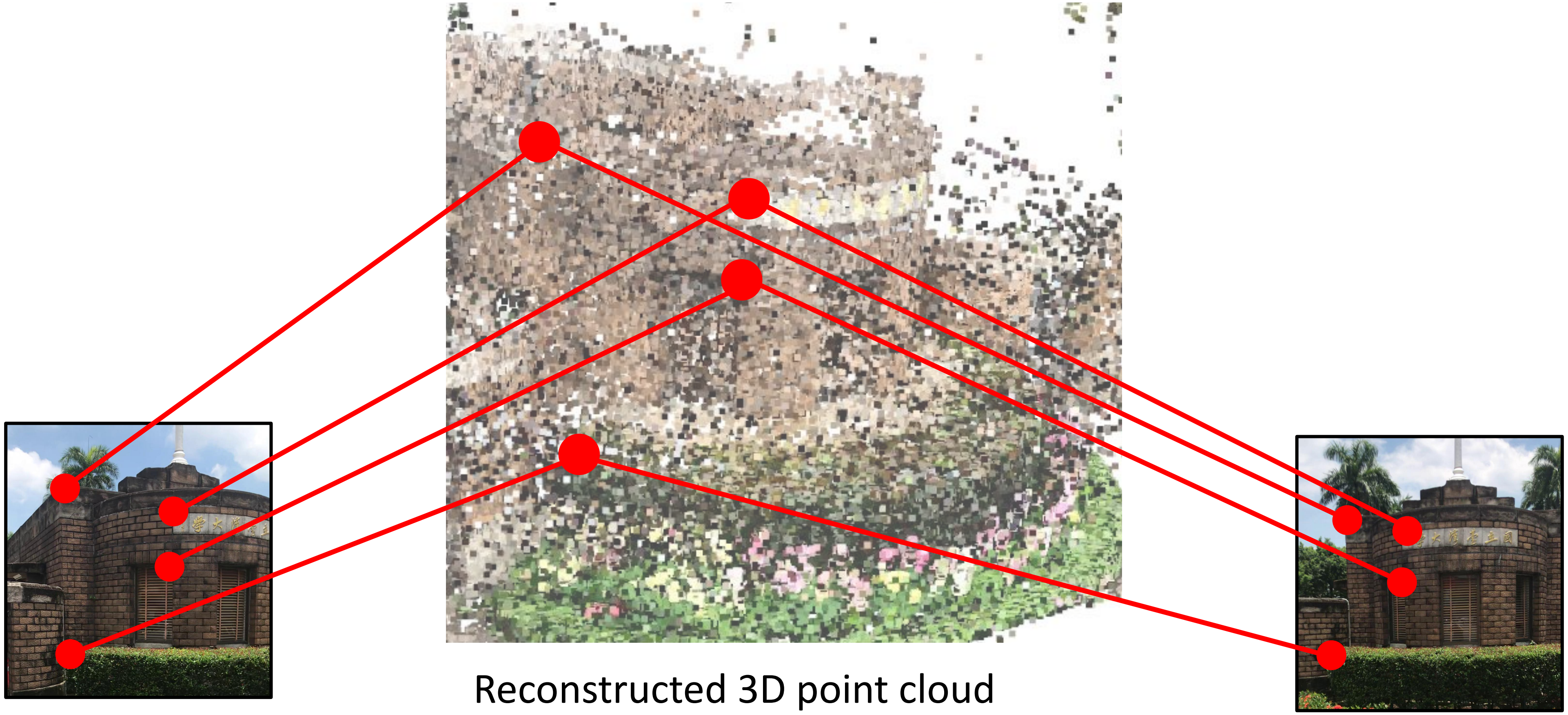


Reconstructed 3D point cloud

Data/image.pkl

⚠️ The pose of an image is represented as the projection **from world to the camera** coordinate system. That is, p=K[R|T]X.

Camera Position(x,y,z)

Rotation (in quaternion)

	IMAGE_ID	NAME	TX	TY	TZ	QW	QX	QY	QZ
0	1	train_img100.jpg	-3.12923	-0.273371	3.17218	0.969363	-0.003488	0.244797	0.019927
1	2	train_img104.jpg	-3.10598	-0.264036	3.12049	0.972423	-0.005048	0.232322	0.019880
2	3	train_img108.jpg	-3.06986	-0.270274	3.08285	0.975032	-0.004203	0.221007	0.021220
3	4	train_img112.jpg	-3.02027	-0.290710	3.07195	0.976940	-0.003627	0.212336	0.022091
4	5	train_img116.jpg	-2.98028	-0.307973	3.05439	0.979017	-0.002989	0.202524	0.022389
...	...	...	...	...	...	...	...	...	...
288	289	valid_img75.jpg	-2.86676	-0.366566	3.79563	0.931094	0.002295	0.363172	0.034118
289	290	valid_img80.jpg	-2.86618	-0.323873	3.72239	0.937160	-0.001973	0.347476	0.031431
290	291	valid_img85.jpg	-2.91426	-0.300918	3.59808	0.945271	-0.004261	0.325035	0.028210
291	292	valid_img90.jpg	-2.99320	-0.267023	3.46717	0.954254	-0.004443	0.298019	0.023733
292	293	valid_img95.jpg	-3.08001	-0.259334	3.30072	0.962891	-0.003862	0.269045	0.021006

293 rows × 9 columns

⚠️ Note that the order is (QW, QX, QY, QZ)

Data/point_desc.pkl

- point_desc.pkl

Source Info

128D Descriptors

	POINT_ID	IMAGE_ID	XY	DESCRIPTORS
0	1	1	[94.94650268554688, 284.02899169921875]	[46, 43, 12, 11, 10, 5, 19, 37, 24, 16, 8, 9, ...
1	1	2	[99.05780029296875, 290.6889953613281]	[39, 42, 34, 14, 15, 12, 13, 31, 29, 11, 8, 7,...
2	1	3	[110.51899719238281, 291.7560119628906]	[47, 57, 39, 12, 12, 11, 9, 20, 43, 26, 13, 7,...
3	1	4	[131.70199584960938, 286.4880065917969]	[38, 58, 39, 12, 11, 11, 13, 16, 35, 20, 12, 8...
4	1	7	[156.52499389648438, 279.2149963378906]	[32, 38, 31, 19, 15, 6, 11, 32, 28, 14, 6, 10,...
...	...	...	...	...
1234453	129081	276	[816.5590209960938, 353.6910095214844]	[28, 20, 11, 16, 23, 18, 22, 25, 42, 11, 8, 24...
1234454	129081	278	[892.0490112304688, 384.6050109863281]	[30, 30, 15, 22, 28, 14, 15, 23, 47, 13, 10, 2...
1234455	129081	279	[965.5770263671875, 397.2950134277344]	[29, 22, 12, 18, 28, 16, 20, 30, 40, 12, 9, 27...
1234456	129081	280	[1039.56005859375, 405.864990234375]	[27, 24, 14, 15, 26, 16, 25, 33, 45, 12, 10, 2...
1234457	129081	280	[1045.989990234375, 404.6090087890625]	[23, 38, 24, 33, 28, 7, 3, 7, 52, 12, 12, 26, ...

⚠️ If Point_ID is -1, then its 3D position is not available.

Data/train.pkl

- train.pkl 3D Point Position(x,y,z) Source Info 128D Descriptors

	POINT_ID	XYZ	RGB	IMAGE_ID	XY	DESCRIPTORS
0	1	[1.6093346, -1.1848674, 1.610395]	[87, 87, 77]	1	[94.94650268554688, 284.02899169921875]	[46, 43, 12, 11, 10, 5, 19, 37, 24, 16, 8, 9, ...
1	1	[1.6093346, -1.1848674, 1.610395]	[87, 87, 77]	2	[99.05780029296875, 290.6889953613281]	[39, 42, 34, 14, 15, 12, 13, 31, 29, 11, 8, 7,...
2	1	[1.6093346, -1.1848674, 1.610395]	[87, 87, 77]	3	[110.51899719238281, 291.7560119628906]	[47, 57, 39, 12, 12, 11, 9, 20, 43, 26, 13, 7,...
3	1	[1.6093346, -1.1848674, 1.610395]	[87, 87, 77]	4	[131.70199584960938, 286.4880065917969]	[38, 58, 39, 12, 11, 11, 13, 16, 35, 20, 12, 8...
4	1	[1.6093346, -1.1848674, 1.610395]	[87, 87, 77]	7	[156.52499389648438, 279.2149963378906]	[32, 38, 31, 19, 15, 6, 11, 32, 28, 14, 6, 10,...
...	...	...	...	...	...	...
682463	129081	[0.66382873, -1.3121917, 5.433149]	[33, 30, 28]	141	[834.9459838867188, 363.7510070800781]	[32, 26, 15, 19, 28, 14, 18, 30, 37, 12, 11, 2...
682464	129081	[0.66382873, -1.3121917, 5.433149]	[33, 30, 28]	142	[867.6019897460938, 366.8039855957031]	[33, 16, 6, 11, 25, 16, 18, 36, 41, 10, 7, 23,...
682465	129081	[0.66382873, -1.3121917, 5.433149]	[33, 30, 28]	144	[981.5599975585938, 398.8039855957031]	[25, 14, 7, 12, 27, 21, 24, 28, 50, 13, 8, 24,...
682466	129081	[0.66382873, -1.3121917, 5.433149]	[33, 30, 28]	145	[1039.56005859375, 405.864990234375]	[27, 24, 14, 15, 26, 16, 25, 33, 45, 12, 10, 2...
682467	129081	[0.66382873, -1.3121917, 5.433149]	[33, 30, 28]	145	[1045.989990234375, 404.6090087890625]	[23, 38, 24, 33, 28, 7, 3, 7, 52, 12, 12, 26, ...

682468 rows × 6 columns

About Dataset: Camera Parameters

- Review the Pinhole camera model:

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} \approx \begin{bmatrix} f_x & s & o_x \\ 0 & f_y & o_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} R & t \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

- Intrinsic Parameters:

$$K = \begin{bmatrix} f_x & s & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1868.27 & 0 & 540 \\ 0 & 1869.18 & 960 \\ 0 & 0 & 1 \end{bmatrix}$$

- Distortion Parameters (Brown-Conrady Model):

$$D = \begin{bmatrix} k_1 & k_2 & p_1 & p_2 \end{bmatrix} = [0.0847023, -0.192929, -0.000201144, -0.000725352]$$

Problem1

Q1-1 For each validation image, compute its camera pose with respect to world coordinate. Find the 2D-3D correspondence by descriptor matching, and solve the camera pose. Implement at least one kind of algorithm that solves a PnP problem. Briefly explain your implementation and write down the pseudo code in your report.

Notes:

- Expected Solution: P3P + RANSAC. You have to implement RANSAC by yourself.
- You cannot use calib3d module in OpenCV. That is, solvePnP and solvePnPRansac is forbidden. However, you are encouraged to try them beforehand.
- You may also try DLT, EPnP, AP3P, or any kinds of solutions.

Problem1

<u>Q1-2</u> For each camera pose you calculated, compute the median pose error (translation, rotation) with respect to ground truth camera pose. Provide some discussion.

Notes:

- Translation: median of all absolute pose differences (Euclidean Distance).

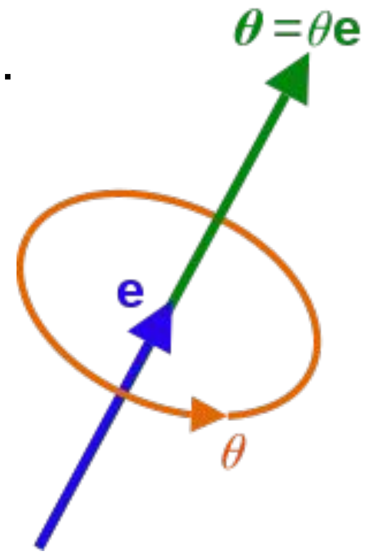
$$t_e = \|\mathbf{t} - \hat{\mathbf{t}}\|_2$$

- Rotation: median of relative rotation angle between estimation and ground-truth.

  (1. Find out the relative rotation and represent it as axis angle representation.

  2. Report the median of angles.)

$$\mathcal{R} = R_e \widehat{\mathcal{R}}$$

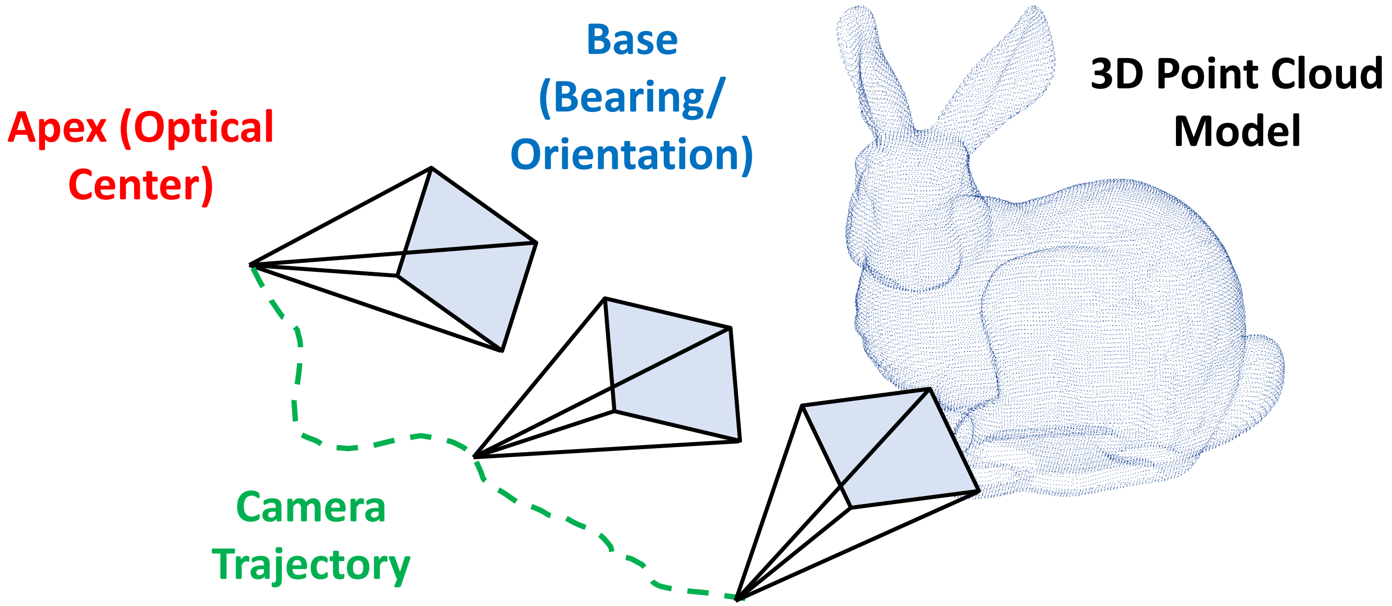


Problem1

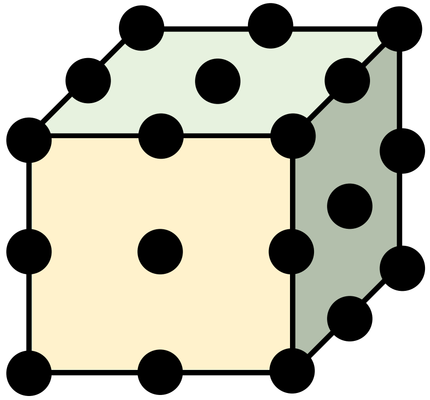
<u>Q1-3</u> For each camera pose you calculated, plot the trajectory and camera poses along with 3d point cloud model using Open3D. Explain how you draw and provide some discussion.

Notes:

- Draw the camera pose as a quadrangular pyramid, where the apex is the position of the optical center, and the normal of base is the bearing (orientation) of the camera.



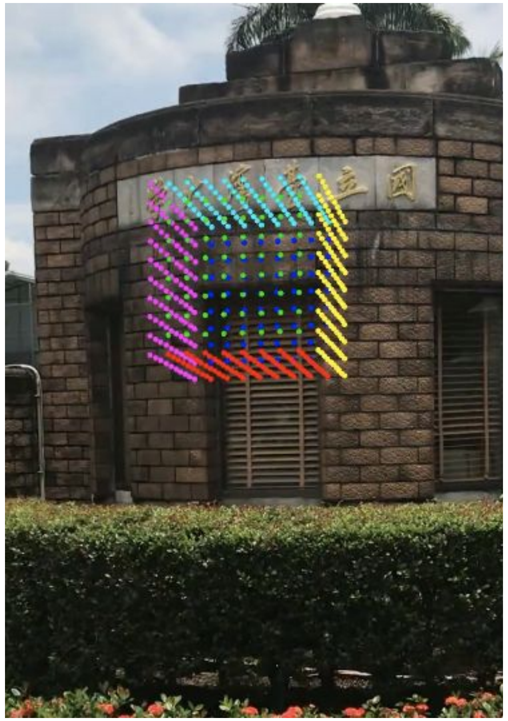
Problem2



<u>Q2-1</u> With camera intrinsic and extrinsic parameters, place a virtual cube in the the validation image sequences to create an Augmented Reality video. Draw the virtual cube as a point set with different colors on its surface. Implement a simply but efficient painter's algorithm to determine the order of drawing.

Notes:

- You don't have to consider whether virtual cube will be occluded.
- Manually select the location, orientation, and scale of the virtual cube. (We provide a code that allows you to adjust the cube by keyboard.)
- Painter's Algorithm:
  1. Sort each voxel by depth
  2. Place each voxel from the furthest to the closest



Sample Code

- You should read the pickle files with **pandas**.

```
>>> import pandas as pd
>>> images_df = pd.read_pickle("dataframes/images.pkl")
```

- You may use **Scipy** to deal with 3D rotation representations.

```
>>> from scipy.spatial.transform import Rotation as R
>>> r = R.from_quat([0, 0, np.sin(np.pi/4), np.cos(np.pi/4)])
>>> r.as_rotvec()
array([0. , 0. , 1.57079633])
```

⚠️ Be aware of the order.

Parameters: **quat** : ***array_like, shape (N, 4) or (4,)***

Each row is a (possibly non-unit norm) quaternion in scalar-last (x, y, z, w) format. Each quaternion will be normalized to unit norm.

Returns: **rotation** : ***Rotation instance***

Object containing the rotations represented by input quaternions.

Introduction to Open3D

- Install open3D

```
pip install open3d
```

- Basic manipulation in open3D (Example Drawing):

```
points = [[0, 0, 0], [1, 0, 0], [0, 1, 0], [1, 1, 0],
          [0, 0, 1], [1, 0, 1], [0, 1, 1], [1, 1, 1]]
lines  = [[0, 1], [0, 2], [1, 3], [2, 3], [4, 5], [4, 6],
          [5, 7], [6, 7], [0, 4], [1, 5], [2, 6], [3, 7]]

import open3d as o3d
line_set = o3d.geometry.LineSet()
line_set.points = o3d.utility.Vector3dVector(points)
line_set.lines = o3d.utility.Vector2iVector(lines)

vis = o3d.visualization.Visualizer()
vis.create_window()
vis.add_geometry(line_set) o3d.visualization.ViewControl.set_zoom(vis.get_view_control(), 0.8)
vis.run()
```

⚠️ Please refer to the document to find the property you need.

http://www.open3d.org/docs/latest/tutorial/visualization/visualization.html

Bonus List

To get extra credits, you can try the following things:
(including, but not limited to)

- **Local Features:** Try different kinds of local features (including deep features)
- **Make it faster:** Come up with faster matching or image registration strategy. (prioritized matching, approximate nearest neighbor, coarse-to-fine strategy, image retrieval, …)
- **Make it more accurate**: Make the pose estimation more accurate. (Different PnP solving methods, outlier rejection strategies, …)
- **Absolute Pose Regression:** Train a deep neural network to regress the absolute camera pose. (For example, PoseNet: A Convolutional Network for Real-Time 6-DOF Camera Relocalization, ICCV 2015)

Grading

- We will evaluate both **the functionality of the code** and **the quality of the report**.
- **Functionality**: Can it run? How's the performance?
- **Quality**: theoretical/experimental analysis, observation, discussion, …
- Note that it **might be curved** based on overall performance of students.
- Grade
  - Meet the basic requirement (programming & report) → A
  - Basic requirement + advanced studies (programming & report) → A+

Grading Policies

- Push your code and report to the GitHub classroom.
- Programming Languages: Python (Python>=3.8), (C++)
- Report Format: PDF or Markdown
  (Warning for Markdown users: Latex equations cannot be rendered properly in GitHub)
- Late Submission: **-10% from your score** / day
- Plagiarism: You have to **write your own codes**.
- Discussion: We encourage you to discuss with your classmates, but remember to **mention their names and contributions in the report**.

Thanks

If you have any question, please email 3dcv@csie.ntu.edu.tw