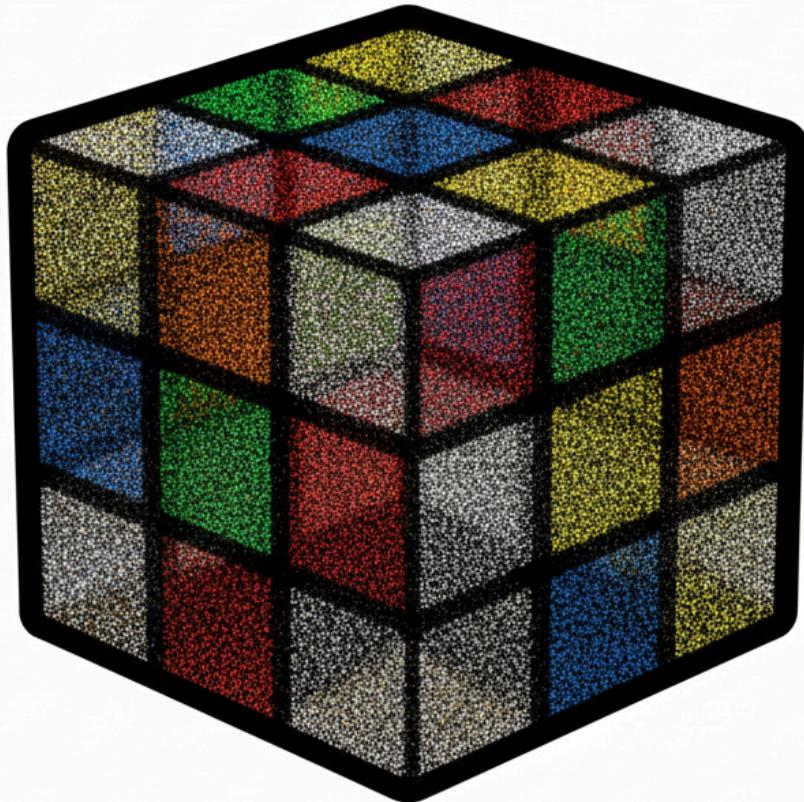


# Assignment 3 – Rubik's Cube + PointNet



## Task 1 - Rubik's Cube

### Overview:

In this task you will render a dynamic Rubik's cube using **OpenGL** in C++.

### Part 1 – building the Rubik's cube scene:

1. Create a **Perspective View Camera** with a **FOV Angle** of 45.
2. Build a **Cube** mesh with the **plane.png Texture** to render a single cube.  
See what happens when you translate and rotate the cube.
3. For building the Rubik's cube you will need to duplicate the cube 26 or 27 times and translate each cube to its initial position.

### Part 2 – data structures:

1. Build data structures that will hold information about the current position of each cube on the full cube based on their shape index.  
You will need to know which of the cube you need to rotate each time you rotate a wall of the Rubik's cube.
2. You may build other data structures to hold for each cube its current rotations and translation.  
This data structure will save the transformations you did for each cube.  
(But it is possible to solve this task without them).
3. Build data structure (class) to hold all the Rubik's cube data.  
(It is also possible to store all the data on the available classes in the engine if you find it easier).

### Part 3 – rotations in a row (the difficult part):

1. Keyboard keys callback function:
  - a. "R" – press state for **right** wall rotation (90 degrees clockwise).
  - b. "L" – press state for **left** wall rotation (90 degrees clockwise).
  - c. "U" – press state for **up** wall rotation (90 degrees clockwise).
  - d. "D" – press state for **down** wall rotation (90 degrees clockwise).
  - e. "B" – press state for **back** wall rotation (90 degrees clockwise).
  - f. "F" – press state for **front** wall rotation (90 degrees clockwise).
  - g. " " (Space) – press state for **flipping** rotation direction.  
(from clockwise to counterclockwise or vice versa).
  - h. "Z" – press state: dividing rotation angle by 2 (until minimum of 90).
  - i. "A" – press state: multiply rotation angle by 2 (until maximum of 180).
  - j. **Notice:** The rotation directions are only relative to the cube **initial** camera view.
2. Mouse keys callback function:
  - a. Moving while holding **left button** will **show** rotation of the whole **Rubik's cube**:  
Left to right movement will rotate the cube around the **global Y** axis and up to down movement will rotate it around **global X** axis.
  - b. Moving while holding the **right button** will move the **camera** up, down, left or right.
  - c. **Scrolling** up and down will move the camera along the **Z axis** backward and forward  
(Make sure that the cube is moving backward and forward from the current view).
  - d. **Notice:** Implementing all the transformations above can be done by updating the **View Matrix** only.
3. Color Picking:
  - a. The Picking Mode should get enabled and disabled by pressing the "P" key.
  - b. Picking a **specific** cube with the mouse, to **translate** and **rotate** it, should be possible.
  - c. When translating the picked cube with the mouse **right** click, the cube should stay under the mouse.  
(Implement the **Z-Buffer** formula to make it work).
  - d. When rotating the picked cube with the mouse left click, the cube should be rotated according to the current camera view.
  - e. **Notice:** Implementing all of the transformations above should be done on a cube's **Model Matrix**.

### Part 4 – cube functionality:

- The cube structure should never "**break**" after multiple different wall rotations.
- In the "Color Picking" mode, breaking the cube is **required**, and when exiting this mode, you are allowed to reload your whole program.

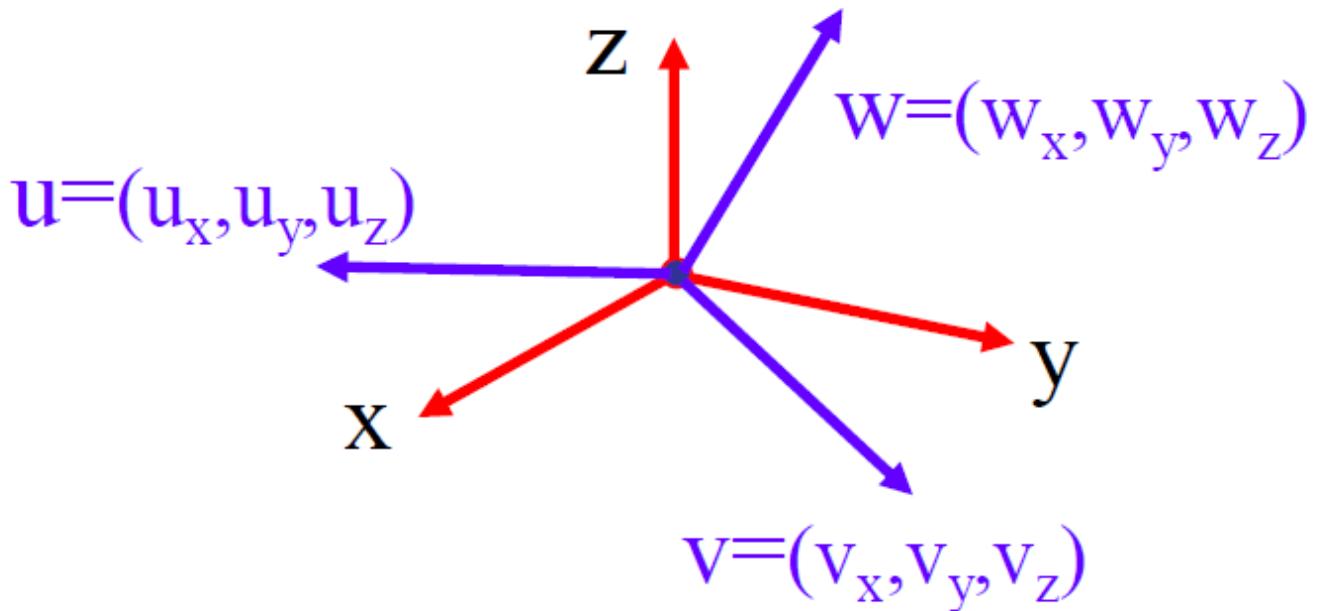
## Color Picking Guidance:

You may choose in which way you want to implement the Color Picking method, but here are some suggested steps to do it: by modifying the MouseButtonCallback:

1. Modify the **Shaders** to support Picking Mode, so that in this mode the shape will get their colors only from the uniform **u\_Color** parameter.
2. Modify the **MouseButtonCallback** to do as follows:
  - a. Clear the window.
  - b. Get the: VBO, VAO, Shader and the MVP matrices of all the cubes you created.
  - c. Bind the: VBO, VAO and the Shader.
  - d. Draw each one of the cubes with a unique color in **u\_Color** that will be passed to the Shader.
  - e. Use the **glReadPixels** function to read the **color** in the selected pixel and convert the color to the relevant cube index and keep it.
  - f. Use the **glReadPixels** function to read the depth in the selected pixel (to use for the Z-Buffer) and keep it.
3. Modify the **CursorPosCallback** to check if a cube was selected, and supported the Translate and Rotate operation based on the selected Mouse Button.

## General tips:

1. When calculating the Model Matrix per cube, set the Translate, Scale and Rotate Matrices as you see fit:
  - a.  $rot \times trans \times scl$  – For rotations around the global center. (Better for this task)
  - b.  $trans \times rot \times scl$  – For rotations around the object center.
2. First, try to implement one wall rotation in the Rubik's cube.
3. Plan where each cube supposes to be after every rotation and how you can follow each cube (hint: use index array).
4. Then try to implement a support for multiple different rotations in a row.  
Remember that after each wall rotation the rotated cubes' coordinate system is getting changed.  
Use the equations for **Changing Coordinate Systems** to handle that:



## Task 2 - PointNet + ShapeNet

### Overview:

In this task you will analyze the AI Model **PointNet**, set up the 3D Dataset **ShapeNet** (of shapes in point cloud), and run a **Jupyter Notebook** in Python.

### Part 1 – Project setup:

1. Create a new folder in the project (for example: “PointNet”) and download the following files from Kaggle:
  - a. <https://www.kaggle.com/code/jeremy26/pointnet-shapenet-dataset> - PointNet AI Model  
(Put in path: “/PointNet/pointnet-shapenet-dataset.ipynb”)
  - b. <https://www.kaggle.com/datasets/jeremy26/shapenet-core-seg> - ShapeNet Dataset  
(Put in path: “/PointNet/shapenet-core-seg/<unzipped-content>”)
  - c. <https://www.kaggle.com/datasets/jeremy26/lidar-od-scripts> - Utility Scripts  
(Put in path: “/PointNet/lidar-od-scripts/<unzipped-content>”)
2. Install **VS Code** extensions for: **Python** and **Jupyter**.
3. Create a Python environment (Suggest version: **Python 3.10.x**)  
(See the following guide to setup a python environment: <https://www.youtube.com/watch?v=D2cwvpJSBX4>)
4. Download the following requirements libraries to your Python environment:

Python

```
numpy>=1.21.0
torch>=1.9.0
matplotlib>=3.4.0
plotly>=5.0.0
tqdm>=4.62.0
```

5. Update the paths on the notebook to the paths on your computer.

### Part 2 – Dataset preparation:

Training on the full ShapeNet Dataset requires a strong GPU, and on CPU it might take forever.

So instead of training the PointNet on the whole Dataset, to select a subset of data from the Dataset so that you will be able to run it on your computers.

To do that:

1. Select 5 to 6 categories of shapes from the dataset.  
(The file: “synsetoffset2category.txt” contains the mapping of “folder names” to “shape types”)
2. From each category select around 100 to 150 samples.
3. **Notice:** Increase the number of “epochs” to increase the model accuracy on this task.

After you finish, train the PointNet and view its results.

### Part 3 – Analysis tasks:

Select 2 out of the 3 following task:

- **3.1. Task:** Understand **ShapeNet features importance for PointNet**
  1. Test the effectiveness of modifying the data dimensions and features:
    - Clone 2 times the ShapeNet subset you have created.
    - In Subset 1: For each sample randomly drop a single dimension (e.g., **Orthographic Projection** on  $(x, y)$  or  $(y, z)$ ).
    - In Subset 2: For each sample, apply a random rotation and then apply **Perspective Projection** on a random dimension ([See video](#) for example).
    - Train the original PointNet architecture on each subset separately.
    - Compare the 2 approaches results.
- **3.2. Task:** Understand **PointNet architecture modifications**
  1. Analyze the **impact of architecture on feature learning** by implementing the following changes:
    - Observe **Global pooling (max)** vs **Local aggregation (avg)**
    - Original PointNet uses **MLPs (64, 128, 1024)** → max pooling → fully connected classifier.
      - Change **number of neurons** (e.g., 32, 64, 512)
      - Add **extra hidden layer**
      - Replace **ReLU** with **LeakyReLU**
      - Change **pooling** from max to average
  2. Analyze the T-Net learned transformations:
    - Choose a class and 3 (or more) different samples from it.
    - Display for each sample its original transformation vs the 2 PointNets' T-Net transformations (**Original vs Original PointNet vs Modified PointNet**).
    - **Notice:** You need to apply the transformations on the shapes and then display them.
- **3.3. Task:** Understand **PointNet's analysis w.r.t. sampling**
  1. **Notice:** For this task you must choose the classes: **chairs**, **airplanes** and **tables**.
  2. Observe limits of robustness for **sparse/thin shapes**
    - Clone 2 times the ShapeNet subset you have created ([See Downsampling](#) on the next page).
    - In Subset 1: **Drop 10%, 30%, 50% of points** using **Voxel Downampling (\*)**.
    - In Subset 2: **Drop 10%, 30%, 50% of points** by **Uniform Downampling (\*\*)**.
    - Train the original PointNet architecture and/or test pre-trained the model on each subset separately.
    - Compare the 2 approaches results.
  3. **Pooling analysis**
    - Compare **max pooling** vs **average pooling** for handling missing points.
    - PointNet uses **global max-pooling** over points.
    - You can:
      - Replace with **average pooling**
      - Replace with **top-k max pooling** (e.g., top 5 points)
    - Evaluate accuracy on **chairs** vs **airplanes** vs **tables**.

**(\*) Voxel Downsampling:** A technique to reduce the number of points on a selected shape in point cloud format with minimal structural loss.

The key idea is to:

1. Setup a 3D grid on the points world and mark each occupied cell (voxel) by a point with a bit of 1.
2. Convert the grid back to points by converting each occupied cell (i,j,k) indices to (x,y,z) point coordinates.  
(Notice: This idea resembles the “Minification” algorithm as you will learn in the “Textures” lecture).

To implement this correctly you need to perform the following steps:

1. Translate all the points so that their coordinates will be positive.
2. Apply the Grid on the points and mark occupied cells (voxels).
3. Convert back the occupied cells to 3D point coordinates.
4. Translate back the points to their original center (by applying the opposite Translation from step 1).

**(\*\*) Uniform Downsampling:** A technique to reduce the number of points on a selected shape in point cloud format by randomly selecting which points to keep (structural loss can be high).

Common approaches are:

1. Selecting every K point (to drop or to keep) - For example K=2 will drop 50% of the points.
2. Random selection - Count the number of points and randomly select how many points to drop.

You may choose either way you like.

### **Assignment Score:**

#### **Rubik's Cube (50 points):**

- **Sanity** - Rendering the Rubik's cube with a Perspective Camera: **10 points**
- Full support for multiple wall rotations (Clockwise/Counterclockwise) of the Rubik's cube: **10 points**
- Option to 180 degrees rotations: **5 points**
- **(Full Rubik's Cube)** Rotation according to camera view: **5 points**
- **(Full Rubik's Cube)** Translation up/down/left/right according to camera view: **5 points**
- **(Full Rubik's Cube)** Scroll in and out according to camera view: **5 point**
- **(Color Picking)** Z-Buffer translations for a selected cube: **5 points**
- **(Color Picking)** Rotations for a selected cube: **5 points**

#### **PointNet (50 points):**

- **Sanity** - Project setup and notebook run: **10 points**
- Dataset preparation: **10 points**
- Analyze tasks: **30 points**

### **Submission:**

Submit zip file with the following files:

1. Link to your [GitHub](#) repository.
2. **(Optional)** Text, Doc or PDF file with short explanation about the changes you did in the engine (files you change and functions you modify).

This file will help you and us to understand what changes you have made in the engine to complete the assignment 😊

The zip file name must include your ID numbers as follows: **ID1\_ID2.zip**.