HW2 Objects and Camera

CS 148 Fall 2021-2022
Due Date: Monday, October 4th by 7 pm PT

Follow the instructions carefully. If you encounter any problems in the setup, please do not hesitate to reach out to CAs on Piazza or attend office hours on Nooks.

Be aware of the **Checkpoints** below. Make sure you complete each one since we will do the grading based on them.

I. Objects and Transforms

> 📖 In Blender, we can translate, rotate, and scale objects. We can also parent one object to another to move them around together. The "object space" and "world space" corresponds to "local coordinates" and "global coordinates" in Blender.

First, add a cube to your scene. If you open Blender with the default scene, it should come with a cube already. You can use that cube for this part of the homework.

(Optional Reading) How to transform objects in Blender

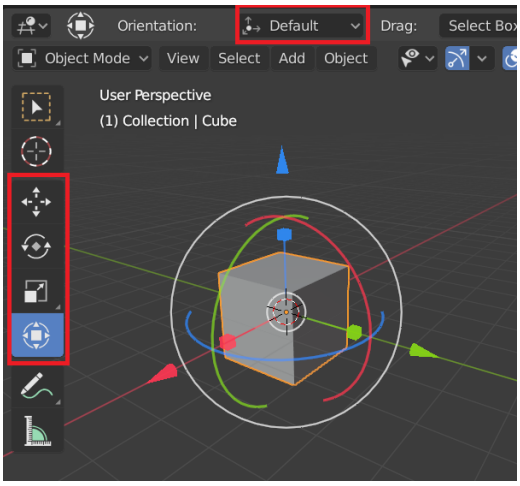
> 📖 If you are new to Blender, we recommend watching this video "Select & Transform" first before proceeding. You can skip this part if you are familiar with Blender.

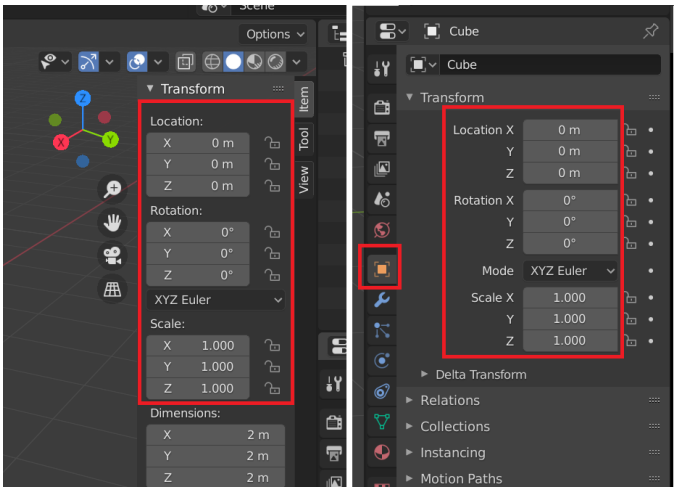
You can use the tools in the Toolbar of the 3D viewport: Move, Rotate, Scale, and Transform Tool to transform the object (fig 1). When you select an object, the orange dot indicates the origin of the object.

The keyboard shortcuts are G (for grab), R (for rotate), and S (for scale). You can press X, Y, or Z afterward to lock the transform to that specific axis. For example, if you press G, then X, then move your mouse, the object will only translate along the X-axis. You can also type in numbers after pressing the keys to specify the exact values you want to move, rotate, or scale. For example, if you press G, Z, 2, then hit Enter, the object will translate 2 units along the Z-axis.

Make sure your cursor is in the 3D viewport area when pressing the keys. Blender uses cursor location to determine which area you want to send your keystrokes to.

You will be able to view/change the local transform of the object in two places: 1) the sidebar of the 3D viewport by pressing N, and 2) Property Editor (bottom right) ▸ Object Properties. Under Transform, you should see the Location, Rotation, and Scale of the active object (fig 2). You can change the values and see how the object changes. You can change the value by clicking on the value and dragging it left or right, or reset the value by hitting backspace. Remember these values specify the local transform, not the global transform.

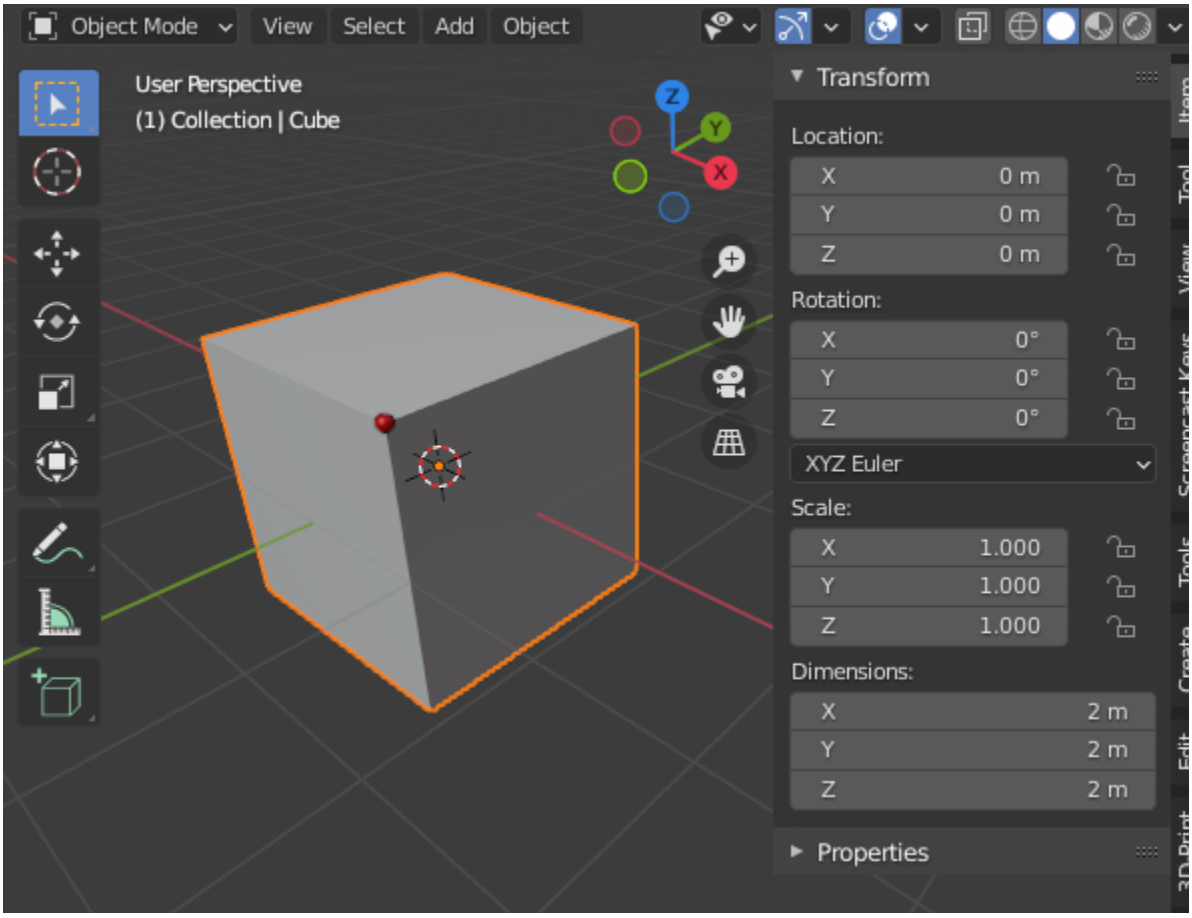




1. Order of Rotations

To explore the ideas we introduced in the lecture, we will first investigate why the order of rotation matters. You will calculate the rotation matrices and verify your result with one of the vertices on the cube.

The default cube in Blender has a size of 2 units, which means its vertices are at locations of positive and negative 1s. We are going to use the vertex v with location $p = \begin{pmatrix} 1 \\ -1 \\ 1 \end{pmatrix}$ (colored in red in fig 1) to see how rotations are constructed. The world (global) axis is shown by the navigation gizmo in the top right corner of the 3D viewport: X-axis points to the bottom right, Y-axis points to the top right, and Z-axis points upward.



First, we rotate the cube along the global X-axis by $+45°$. Then rotate along the global Y-axis by $+45°$ (fig 2). Let p_{xy} denote the world location of vertex v after rotation. (Shortcut: R, X, 45, Enter. R, Y, 45, Enter)

Next, let us go back to the default cube, but this time, we rotate the cube along the global Y-axis first by $+45°$. Then rotate along the global X-axis by $+45°$ (fig 3). Let p_{yx} denote the world location of vertex v after rotation. (Shortcut: R, Y, 45, Enter. R, X, 45, Enter)

Write down the rotation matrices for each step, and then use them to:

- [ ] **Checkpoint 1: Write down p_{xy}.** (be prepared to show your work during grading)
- [ ] **Checkpoint 2: Write down p_{yx}.** (be prepared to show your work during grading)

You are allowed to use a calculator/write your own code to calculate the result.

▼ *Hint*

The final location of vertex p is calculated by multiplying the rotation matrix for each step (be aware of the order!) to the left of $p = \begin{pmatrix} 1 \\ -1 \\ 1 \end{pmatrix}$.

▼ Hint 2

The rotation matrices for rotating along X-axis and Y-axis for 45° are:

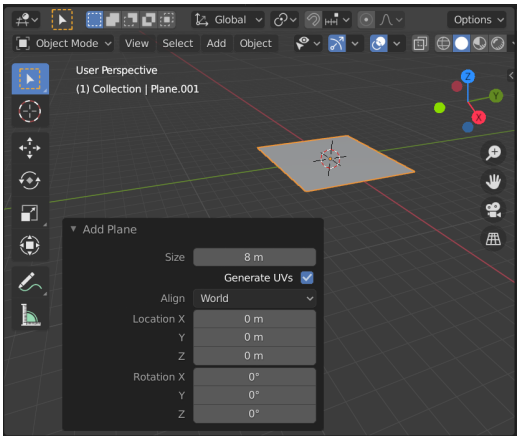
$$R_x = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\frac{\pi}{4} & -\sin\frac{\pi}{4} \\ 0 & \sin\frac{\pi}{4} & \cos\frac{\pi}{4} \end{bmatrix}, R_y = \begin{bmatrix} \cos\frac{\pi}{4} & 0 & \sin\frac{\pi}{4} \\ 0 & 1 & 0 \\ -\sin\frac{\pi}{4} & 0 & \cos\frac{\pi}{4} \end{bmatrix}$$

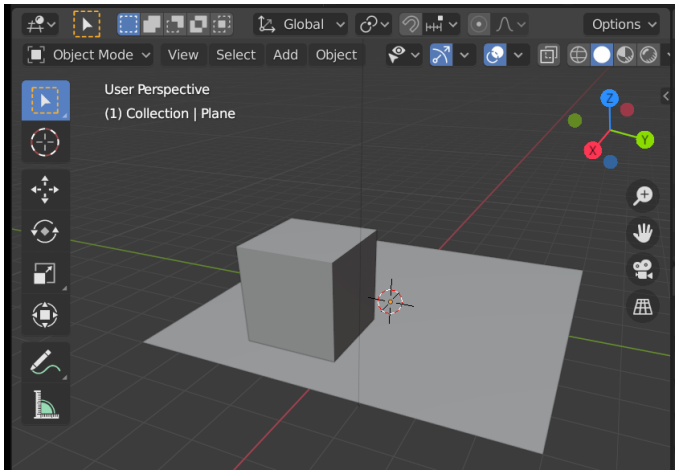
📖 You may notice that you can choose various rotation modes for your object rotation. When you first rotate along Y-axis then X-axis, the rotation shows up as $(54.7, 30, 35.3)$ in XYZ Euler mode instead of $(45, 45, 0)$. If you change the rotation mode to YXZ Euler, the numbers will become $(45, 45, 0)$. This is due to the different order of rotations when defining Euler angles. For more information, see rotation mode in Blender documentation.

2. Parenting Objects

📖 In the lecture, we talked about hierarchical transforms, which can be done in Blender through parenting. Here we will explore how the location of child objects change with their parent.

First, set up the scene. Reset the rotation of the cube (put zeros into the Cube's Rotation, or use Alt/Option R). Set its location to $t_{\text{cube}} = \begin{pmatrix} 3 \\ -1 \\ 1 \end{pmatrix}$. Add a plane (menu bar Add ▸ Mesh ▸ Plane), and in the pop-up panel in the bottom left, change its size to 10 (fig 1). The scene should look like fig 2, with the cube sitting on top of the plane.

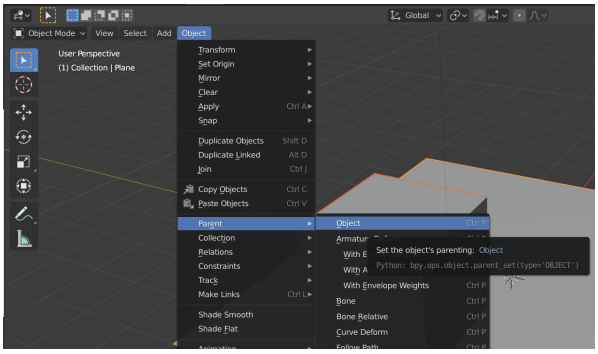


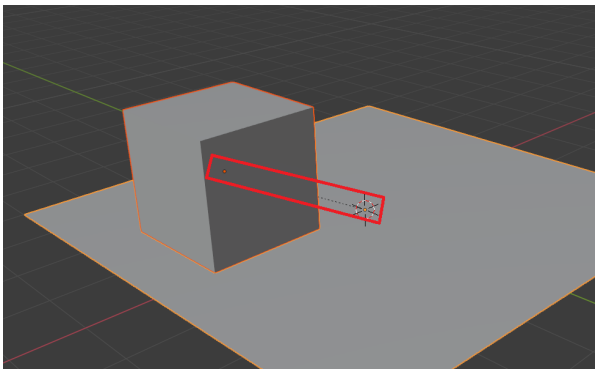


Next, parent the cube to the plane. Select the cube, then hold shift and select the plane. Both objects should be in an orange outline, and the plane should have a lighter orange.

To learn more about multiple selections and active objects, see Blender Documentation.

Then go to the menu bar on top and select Object ▸ Parent ▸ Object (or leave your mouse inside the 3D viewport, and use the shortcut Ctrl/Cmd P) (fig 3). A dotted line should appear between the origin of the cube and the origin of the plane (fig 4), indicating an existing relationship between these two objects. You can verify this relationship by transforming the plane; the cube should follow the exact same transformation and stay on the plane.





After parenting, the translation of the cube relative to the plane is $t_{\text{cube}}^{\text{local}} = \begin{pmatrix} 3 \\ -1 \\ 1 \end{pmatrix}$.

If we set the location of the plane to $t_{\text{plane}}^{\text{world}} = \begin{pmatrix} 0 \\ 2 \\ 1 \end{pmatrix}$ what would the global location of the cube $t_{1\,\text{cube}}^{\text{world}}$ be?

If we **then** rotate the plane along its **local** Y-axis by $+45°$, what would the global location of the cube $t_{2\,\text{cube}}^{\text{world}}$ be?

- [ ] **Checkpoint 3: Write down $t_{1\,\text{cube}}^{\text{world}}$.** (be prepared to show your work during grading)
- [ ] **Checkpoint 4: Write down $t_{2\,\text{cube}}^{\text{world}}$.** (be prepared to show your work during grading)

▼ Hint

Calculate the 4x4 transform matrix for the rotated plane and the 4x1 homogenous coordinate of the cube.

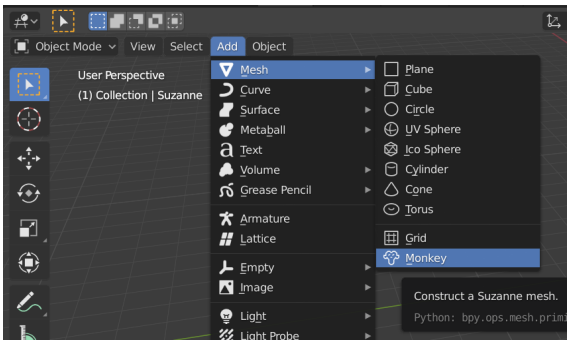
II. Camera

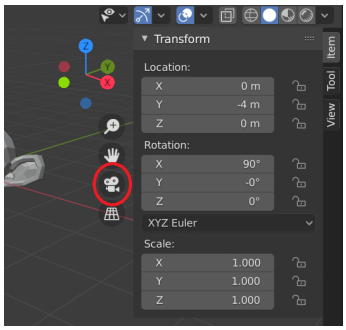
📖 Cameras are crucial to the virtual world. When you render, everything in the scene will be projected onto the camera film (screen space) to create your final image. In this section, we are going to play with the perspective camera and understand the effect of focal length. This is exactly how dolly zoom (or vertigo effect), a famous camera effect, works.

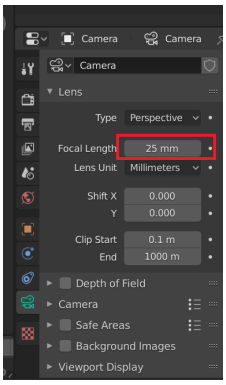
First, we are going to set up the scene. Open a new Blender file, delete the cube. Add a monkey (fig 1). Set the camera location to $(0, -4, 0)$ and rotation to $(90, 0, 0)$.

The scene should look like fig 2. Press the camera icon to go to the camera view.

Select the camera, and change its focal length to 25mm (fig 3).







Set the render engine to Workbench, and render the image.

Change the camera location to $(0, -8, 0)$ and focal length to 50 mm. Render the image.

Change the camera location to $(0, -16, 0)$ and focal length to 100 mm. Render the image.

Here we change the camera location along with focal length to keep the subject the same size.

- [ ] **Checkpoint 5: Save the rendered images under these three camera settings.**
- [ ] **Checkpoint 6: Compare the three images in Checkpoint 5. Discuss the effect of changing the focal length.** (No write-up needed, just get ready to answer this question during the grading session)

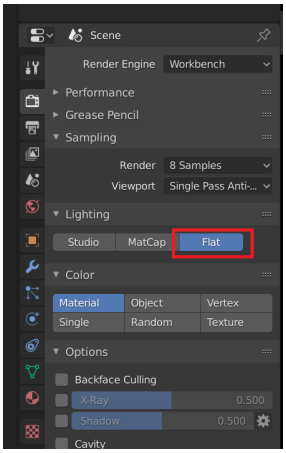
📖 Common focal lengths for real-world cameras (prime lens): 24mm, 35mm, 50mm, 85mm, 105mm.

III. Flat Shading

📖 By default, the Workbench engine uses studio lighting. This assumes a pre-existing lighting environment for the scene, which enables us to better see the shape of the monkey by shading each face with its own color. We will discuss shading and lighting in future lectures. For now, we can change the settings to render the scene without any lighting and see what the render looks like.

Open a new Blender file, add at least two objects in the scene with different colors. (Detailed instructions in HW1/I/3). Transform them so they do not overlap while still being visible through the camera.

Change the lighting of Workbench to flat lighting (fig 1). Render the image.



- [ ] **Checkpoint 7: Save the image with flat lighting.**

IV. Grading (5 pts total)

This assignment will be graded on the following requirements

Complete all the checkpoints (4 pts)

1. (0.5 pt) **Write down p_{xy}.**
2. (0.5 pt) **Write down p_{yx}.**
3. (0.5 pt) **Write down $t_1{}^{\text{world}}_{\text{cube}}$.**

4. (0.5 pt) **Write down $t_2^{\text{world}}_{\text{cube}}$.**
5. (0.5 pt) **Save the rendered images under these three camera settings.**
6. (1 pt) **Compare the three images in Checkpoint 5. Discuss the effect of changing the focal length.**
7. (0.5 pt) **Save the image with flat lighting.**

Quiz Question (1 pt)

The TAs will choose one of the following questions during the grading session. Please be prepared to give a one-minute answer with your partner.

1. Why are homogeneous coordinates advantageous for computing transformations? What kind of matrix transformations preserve the value of w given homogeneous coordinates (x, y, z, w)?
2. Given a single homogeneous matrix transform with both a translation and rotation component, in what order are those two transforms applied? Which ordering of these two transforms is easiest for you to visualize?
3. How is the viewing frustum used to keep objects in the scene in relative perspective for the viewer -- i.e. how does perspective projection work?
4. Why do we use triangles rather than other polygons in rendering? give at least 2 advantages.
5. What is the benefit of applying “bounding boxes” to triangles for rasterization?
6. If we have two adjacent triangles facing the camera with a shared edge between them, what can we say about the 2D normals of this edge for each triangle? How do we use these normal directions to render a shared edge?
7. What are barycentric weights and why are they important?
8. How does the vertex order of a triangle affect how it’s rendered?
9. How do we know whether a 2D point is inside a 2D triangle or not?
10. What is an advantage of using ray tracing instead of scanline rendering?