Assignment 1

CSE471: Computer Graphics

Fall 2022

Computer Science and Engineering

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Objectives

- The purpose of this assignment is to learn:
  - OpenGL primitives
  - Coordinate systems (local ↔ world ↔ screen)
  - GLUT event handler
  - Basic geometric transformations

- You will create your own interactive tool
  - You will keep building up your tool for all the upcoming assignments

Introduction

OpenGL

- **Open G**raphics **L**ibrary
  - 2D, 3D computer graphics API
  - Cross-platform (hardware-independent)
  - Developed by Silicon Graphics Inc. in 1992
  - Managed by a non-profit technology consortium, the Khronos Group

  - Latest stable version: 4.6 (released in 2017)

OpenGL

- Graphic library for rendering primitives
  - Drawing geometric objects
  - Viewing transformation
  - Color / Lighting
  - Blending, Antialiasing, and Fog
  - Display List
  - Drawing pixels, Bitmaps, Fonts, and Images
  - Texture Mapping
  - Frame Buffer
  - Evaluators and NURBS
  - Selection and Feedback

- No high-level modeling commands

OpenGL-related Libraries

- GLU (OpenGL Utility Library)
  - additional high-level routines
- GLUT (OpenGL Utility Toolkit)
- GLUI (OpenGL User Interface Library)
- GLEE, GLEW …

Important Concepts

- OpenGL Context
  - The context contains all of the information that will be used by the OpenGL system to render, when the system is given a rendering command. A context effectively is OpenGL, because OpenGL cannot be used without one.
- State
  - The OpenGL context contains information used by the rendering system. This information is called State, which has given rise to the saying that OpenGL is a "state machine".
  - Your computation (transformations, colors, etc.) is stored as “global” in a context
- See https://www.khronos.org/opengl/wiki/Portal:OpenGL_Concepts

A Simple OpenGL Program

- Example 1

```
glClearColor(0.0, 0.0, 0.0, 0.0)  # clear background
glClear(GL_COLOR_BUFFER_BIT)      # clear color buffer
glBegin(GL_TRIANGLE)              # begin primitive
glColor3f(1.0,0.0,0.0)            # current state -> red
glVertex2f(0, 1)                  # vertex 0
glColor3f(0.0,1.0,0.0)            # current state -> green
glVertex2f(-1, 1)                 # vertex 1
glColor3f(0.0,0.0,1.0)            # current state -> blue
glVertex2f(1, -1)                 # vertex 2
glEnd()                           # end primitive
```

There are several ways to draw triangles without glBegin/glEnd as it is deprecated in modern OpenGL.
We will see some other ways later but follow the above example at this moment for simplicity.

A Simple OpenGL Program

- Example

```
def draw():
  glBegin(GL_TRIANGLE)
  glColor3f(1.0,0.0,0.0)
  glVertex2f(0, 1)
  glColor3f(0.0,1.0,0.0)
  glVertex2f(-1, 1)
  glColor3f(0.0,0.0,1.0)
  glVertex2f(1, -1)
  glEnd()
```

```
draw()  # original triangle appears
mat = some transform
glMultMatrixf(mat) # global state: mat
draw() # a transformed triangle by mat
draw() # a transformed triangle by mat
glMultMatrixf(mat) # global state: mat * mat
draw() # a transformed triangle by mat * mat
glLoadIdentity()   # global state: Identity
draw()  # original triangle appears
```

Command Syntax

- Function : gl~
- Constant : GL_~
- Type indicating suffix
  - b : signed char (GLbyte)
  - s : short (GLshort)
  - I : long (GLint, GLsizei)
  - f : float (GLfloat)
  - d : double (GLdouble)
  - ub : unsigned char (GLubyte, GLboolean)
  - us : unsigned short (GLushort)
  - ui : unsigned int (GLuint, GLenum, GLbitfield)
  - v : vector type

```
glColor3f(1.0, 0.0, 0.0)
color_array=[1.0, 0.0, 0.0]
glColor3fv(color_array)
```

GLUT

- The OpenGL Utility Toolkit (from its official site)
  - GLUT (pronounced like the glut in gluttony) is the OpenGL Utility Toolkit, a window system independent toolkit for writing OpenGL programs.
  - It implements a simple windowing application programming interface (API) for OpenGL.
  - GLUT makes it considerably easier to learn about and explore OpenGL programming.
  - GLUT provides a portable API so you can write a single OpenGL program that works on both Win32 PCs and X11 workstations.

GLUT

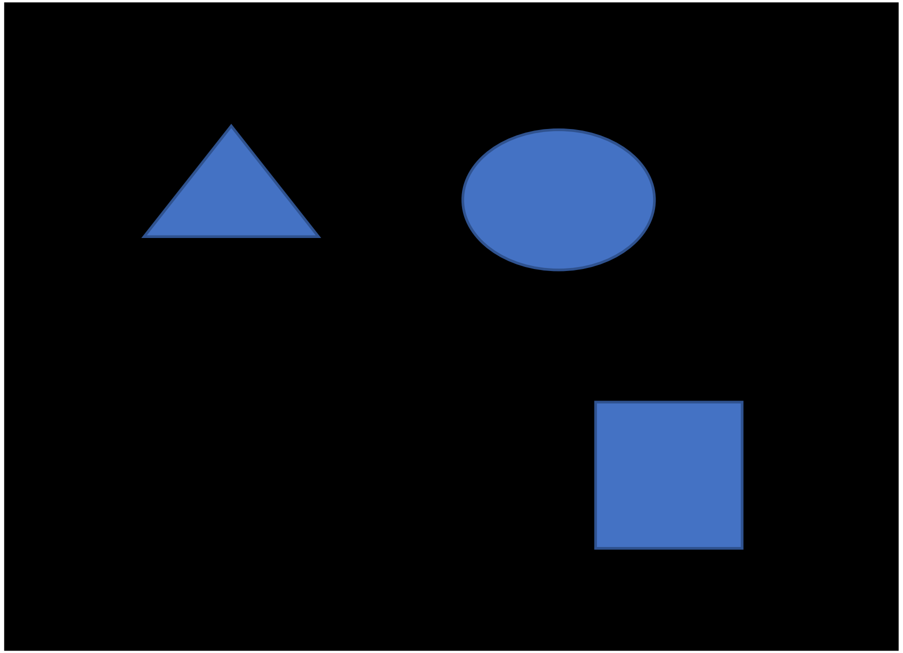
- GLUT is based on call-back routines
  - You will bind your function to each built-in call-back function
  - Example: glutDisplayFunc(display) # you implement "display" function and GLUT will call this when events occur

  - You can customize your interface window like
    - glutInit() # init OpenGL context
    - glutInitDisplayMode(GLUT_DOUBLE | GLUT_RGB | GLUT_DEPTH) # display mode
    - glutInitWindowSize(800, 600) # window size
    - glutInitWindowPosition(0, 0) # window position
    - glutCreateWindow("title goes here") # window title

Assignment 1

Specifications

- Simple 2D interactive tool
  - You will add/remove predefined solid (filled) polygons (triangle, rectangle, and ellipse) as many as you want on your screen
  - You will manipulate global/local transformations

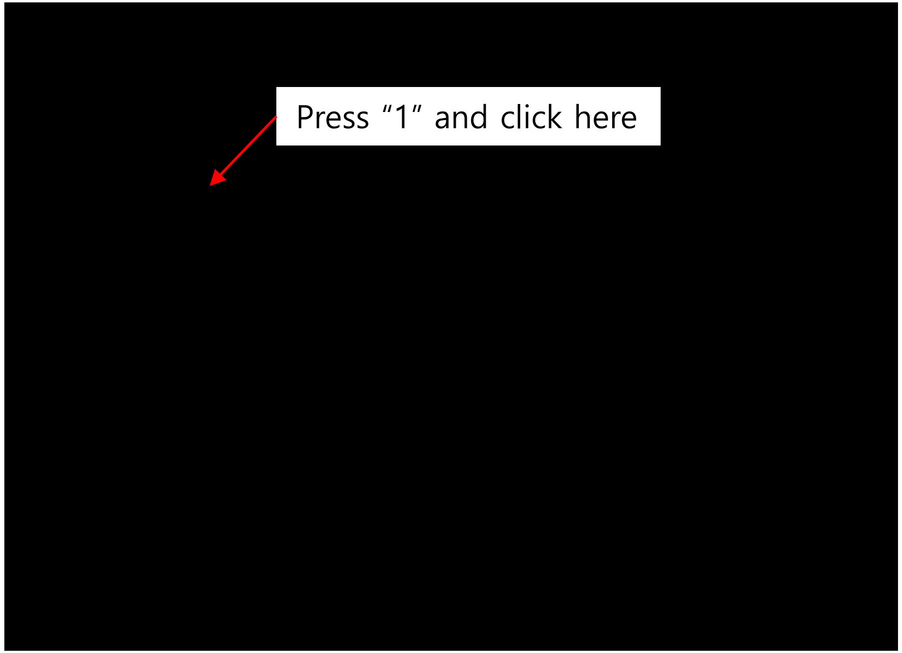


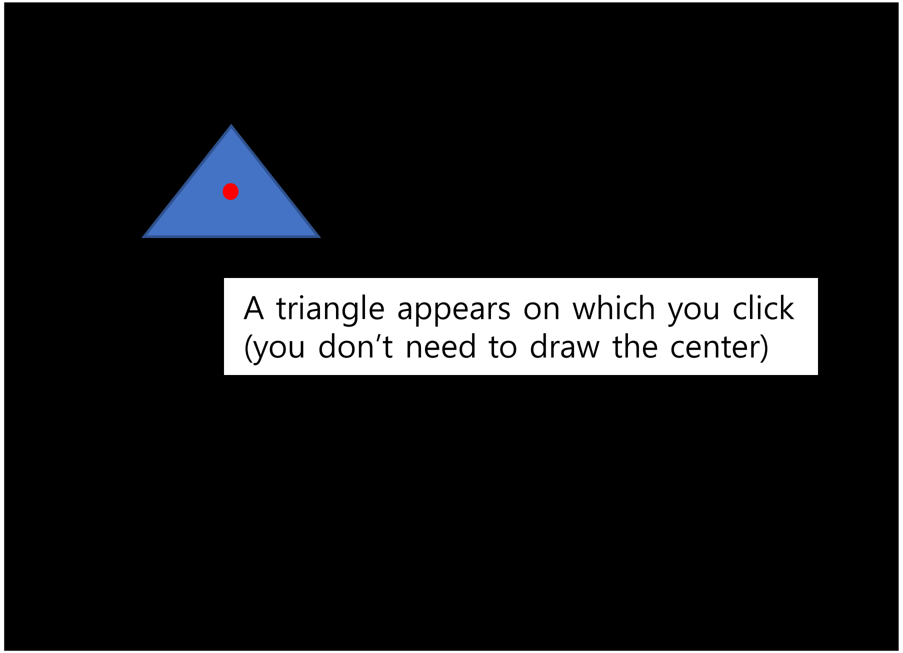
Specifications

- Polygons deployment

  1. Choose a polygon type by pressing a key (1: triangle, 2: rectangle, 3: ellipse, esc: cancellation of polygon drawing mode)
  2. Click a desirable location of your screen, where a polygon will be located
  3. The center of the polygon should appear at the location you click
  4. A user can add as many polygons as possible

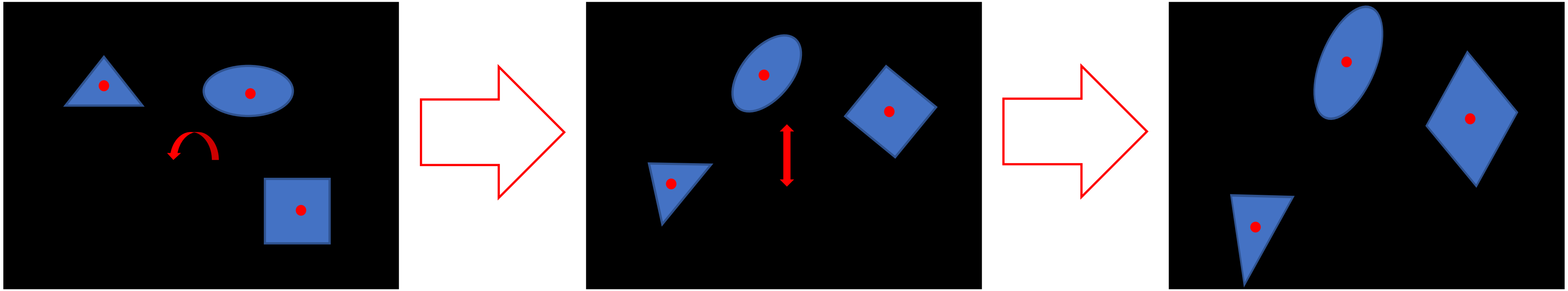
Example


Press “1” and click here


A triangle appears on which you click
(you don’t need to draw the center)

Specifications

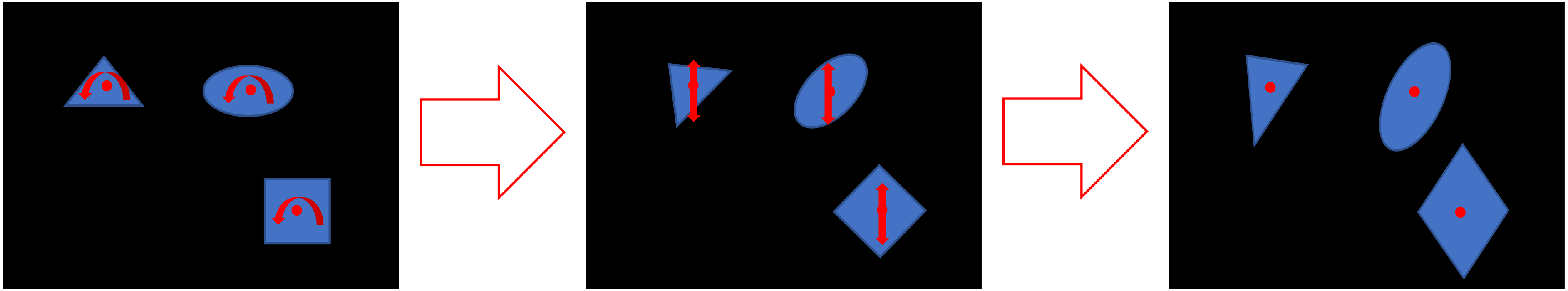
- Polygon manipulation
  - Global transformation occurs at the center of your screen



Example: rotation and scaling; polygon centers change

Specifications

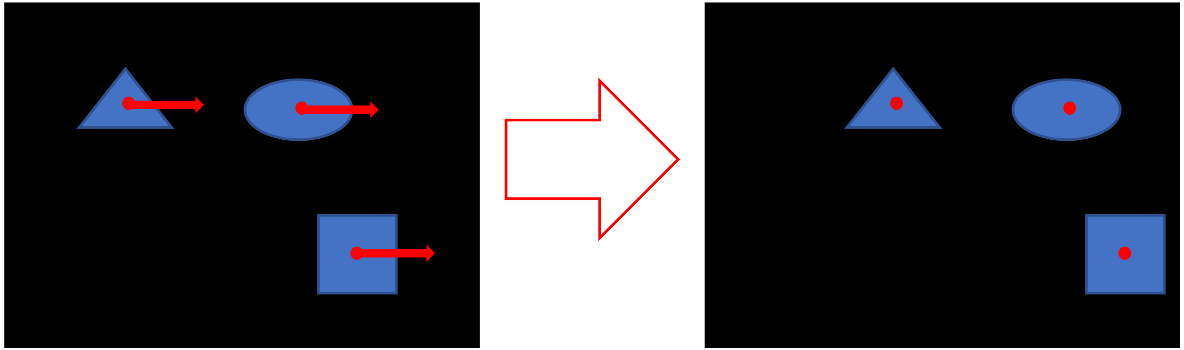
- Polygon manipulation
  - Local transformation occurs at the center of each polygon



Example: rotation and scaling; polygon centers stay same

Specifications

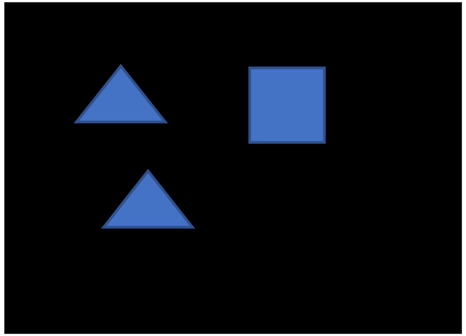
- A local translation will move the origin to keep the center as origin

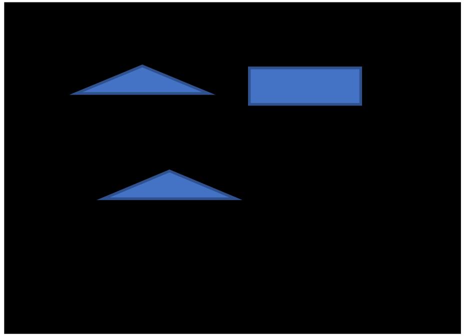


Example: local translation; the polygon centers move

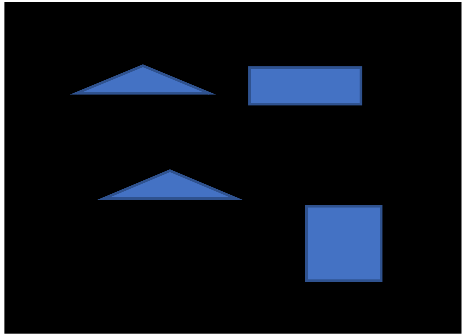
Specifications

- Transformations should be accumulated
  - For example, if you scale down your polygons and place a new polygon, the new polygon should have a default scale





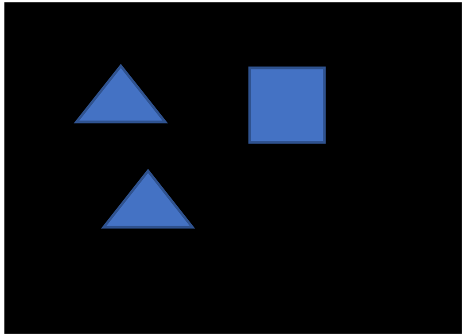
Scale down

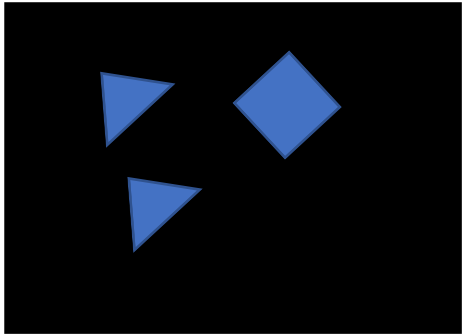


Place a new polygon

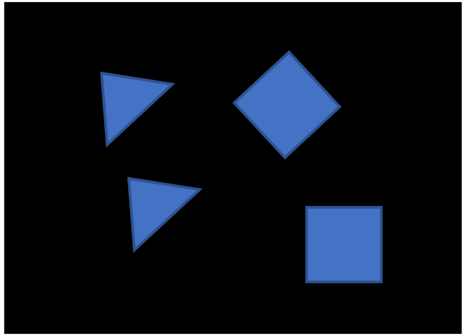
Specifications

- Transformations should be accumulated
  - For example, if you rotate your polygons and place a new polygon, the new polygon should have a default orientation





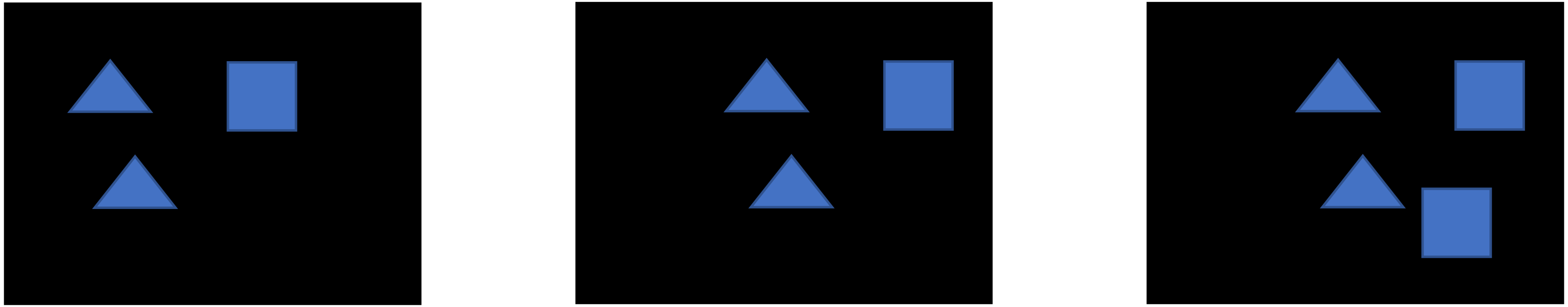
Rotation



Place a new polygon

Specifications

- Transformations should be accumulated
  - For example, if you translate your polygons and place a new polygon, the new polygon should appear exactly where you click



Translation

Place a new polygon

Task 1

- Implement primitive polygons in your draw function

- In the skeleton code, create a subclass of "Polygon" and implement draw() function
  - Triangle: (0, 0.1, 0), (-0.1, -0.1, 0), (0.1, -0.1, 0)
  - Rectangle: (-0.1, 0.1, 0), (0.1, 0.1, 0), (0.1, -0.1, 0), (-0.1, -0.1, 0)
  - Ellipse: vertical radius=0.05, horizontal radius=0.1 (for ellipse drawing, you can sample as many points as you want)
  - You can assign whichever colors you like

  - Use GL_TRIANGLES for triangles, GL_QUADS for rectangles, GL_TRIANGLE_FAN for ellipses

Task 2

- Implement keyboard/mouse event handlers

- You will need:
  - Conversion between window coordinates (i.e., screen size, origin=top-left corner) and world coordinates (i.e., [-1,1] x [-1,1], origin=window center)
    - Use this conversion when you compute the amount of each transformation
    - Example: window width = 800 px, 80 px difference becomes 1/10
  - Keyboard event handler
    - 1: triangle, 2: rectangle, 3: ellipse, esc: cancellation of polygon drawing mode

Task 3-1

- Implement basic transformation functions

- Scale
  - scale(sx, sy):
    - Inputs: sx: double, sy: double
    - Returns 4-by-4 matrix
  - You will need to update only first two columns & rows
  - Use numpy's eye(4) to make an identity matrix
  - Use the coordinate conversion you implement in Task 2
  - You may want to adjust "sx"&"sy" if transformation is too slow/fast

$$\begin{bmatrix} ? & ? & 0 & 0 \\ ? & ? & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Task 3-2

- Implement basic transformation functions

- Rotation
  - rotation(degree):
    - Inputs: degree: double
    - Returns 4-by-4 matrix
  - You will need to update only first two columns & rows
  - Use numpy's eye(4) to make an identity matrix
  - Use the coordinate conversion you implement in Task 2
  - You may want to adjust "degree" if transformation is too slow/fast

$$\begin{bmatrix} ? & ? & 0 & 0 \\ ? & ? & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Task 3-3

- Implement basic transformation functions

- Translation
  - translation(dx, dy):
    - Inputs: dx: double, dy: double
    - Returns: 4-by-4 matrix
  - You will need to update only last column's first two rows
  - Use numpy's eye(4) to make an identity matrix
  - Use the coordinate conversion you implement in Task 2
  - Note: we will learn why translation has the above matrix form later

$$\begin{bmatrix} 1 & 0 & 0 & dx \\ 0 & 1 & 0 & dy \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Task 3-1, 3-2, 3-3

- Hints
  - Use @ operator for matrix multiplication in numpy (do not be confused with *, which is for element-wise multiplication)
  - OpenGL uses a column-major format for matrix whereas a row-major format in numpy by default. You will thus need to transpose your numpy matrix to feed transformations to OpenGL (Use .T for transpose in numpy)

Task 4

You can bind different keys/mouse behaviors, but if so, you must describe how to operate your tool

- Implement polygon manipulation (see event handlers in the skeleton code)
  - Press “g” to toggle global/local transformations
  - Rotation: drag mouse
    - left→right or down→up: increase rotation degree (counterclockwise)
    - right→left or up→down: decrease rotation degree (clockwise)
  - Scaling: ctrl+drag mouse
    - left→right / right→left: increase/decrease scale along local/world x-axis
    - down→up / up→down: increase/decrease scale along local/world y-axis
  - Translation: arrow keys
    - Move along local/world axes

Local axes: polygon’s coordinates (origin: polygon center)

Task 4

- Implement polygon manipulation (see event handlers in the skeleton code)
    - Implement draw() and add relevant functions in your polygon classes to handle transformations

- Hints
    - You may need to call glLoadIdentity() followed by glMultMatrixf() to place your polygons properly – remember OpenGL is a “state” language
    - Or you can call glLoadMatrixf() to load a matrix from an array directly

Task 5

- Implement visualization of your polygons

- Rendering
  - Implement display() of Viewer and draw() of your polygon classes
  - You may need to maintain a list of polygon instances internally as they are added on the fly during runtime

Be Aware

- Please DO (you will otherwise lose your credits):
  - The default coordinates of the primitive polygons (i.e., contents of glVertex) never change during runtime as the purpose of this assignment is to learn transformations (if modified, no credits)
  - Instead, your polygon's coordinates should be changed via glMultMatrixf() or glLoadMatrixf()
  - Try to reduce calling glMultMatrixf() / glLoadMatrixf() (i.e., make your transformations composite)
  - Provide sufficient comments on what you implement; also, put Task # in your code
  - Provide user instructions to run your program
  - Do not make multiple files for your implementation – a single source file will be enough
  - Make window size 800-by-800

Submission

- What to submit
  - Your implementation and user manual
- Where to submit
  - Blackboard
- When to submit by
  - September 30th by midnight, 10 days from now (no extension – start as soon as possible)

Questions?

- Use Blackboard (Discussions → Course Board)
- Email/call the instructor
- Useful resources:
  - https://www.opengl.org/
  - http://www.songho.ca/opengl/index.html
  - http://pyopengl.sourceforge.net/context/tutorials/index.html