Department of CSE
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UCS 1712 - Graphics And Multimedia Lab

Exercise 8: 3D Transformations in C++ using OpenGL

Aim:

To apply the following 3D transformations on objects and to render the final output along with the original object.

- Translation
- Rotation
- Scaling
- Reflection
- Shearing

Display the original and the transformed object.

Code: 3D Transformations:

```
/*
3D Transformations - Translation, Rotation, Scaling, Reflection and
    Shearing
*/

#include <stdio.h>
#include <math.h>
#include <GL/glut.h>
#include <iostream>     //for cin, cout
#include <cstring>      //for memcpy

using namespace std;

enum Axes {xAxis = 0, yAxis = 1, zAxis = 2};
enum Planes {xyPlane = 0, yzPlane = 1, zxPlane = 2};

const int WINDOW_HEIGHT = 800;
const int WINDOW_WIDTH = 800;
const int FPS = 60;

class Face{     //wrapper class for a face of a 3D object
    private:
        GLfloat r = 1, g = 1, b = 1, a = 1; //black
        GLfloat vertices[4][4];     // V * (x, y, z, h)
        int vertexCount = 4;        // V

    public:
        Face(){
            r = g = b = a = 1;  //black
            vertexCount = 4;
        }

        Face(GLfloat R, GLfloat G, GLfloat B, GLfloat A){
            //Set colors
            Face();
            r = R;
            g = G;
            b = B;
            a = A;
        }

        void setColor(GLfloat R, GLfloat G, GLfloat B, GLfloat A){
            //Set colors
            r = R;
            g = G;
            b = B;
            a = A;
```

```
47          }
48
49          void setIthVertex(int i, GLfloat x, GLfloat y, GLfloat z, GLfloat
    h = 1){
50              //Set the ith vertex coordinates
51              vertices[i][0] = x;
52              vertices[i][1] = y;
53              vertices[i][2] = z;
54              vertices[i][3] = h;
55          }
56
57          void drawFace(){
58              glColor4f(r, g, b, a);
59
60              glBegin(GL_POLYGON);
61
62              for(int i = 0; i < vertexCount; i++){
63                  glVertex3f(vertices[i][0], vertices[i][1], vertices[i][2])
    ;
64              }
65
66              glEnd();
67          }
68
69          Face transform(double transformationMatrix[4][4]){
70              Face fDash(r, g, b, a - 0.5);
71              double values[4];
72
73              // [V x 4] x [4 x 1] = [V x 1] matrix
74              for(int i = 0; i < vertexCount; i++){
75                  for(int j = 0; j < 4; j++){
76                      values[j] = transformationMatrix[j][0] * vertices[i
    ][0] +
77                                  transformationMatrix[j][1] * vertices[i
    ][1] +
78                                  transformationMatrix[j][2] * vertices[i
    ][2] +
79                                  transformationMatrix[j][3] * vertices[i
    ][3];
80                  }
81
82                  fDash.setIthVertex(i, values[0], values[1], values[2],
    values[3]);
83                  //cout << "\nVertex" << values[0] << " " << values[1] << "
     " << values[2] << " " << values[3];
84
85              }
86
87              return fDash;
88          }
89  };
```

```
90
91  class Object3D{     //wrapper class for a 3D object with multiple faces
92      private:
93          Face *faces;
94          int numFaces;
95
96      public:
97          Object3D(){
98              numFaces = 0;
99          }
100
101         Object3D(int noFaces){
102             numFaces = noFaces;
103             faces = new Face[numFaces];
104         }
105
106         void setIthFace(int i, Face face){
107             faces[i] = face;
108         }
109
110         void drawObject3D(){
111             for(int i = 0; i < numFaces; i++){
112                 faces[i].drawFace();
113             }
114         }
115
116         Object3D translateObject3D(GLfloat tx, GLfloat ty, GLfloat tz){
117             //To translate the 3D object wrt. a translation vector
118
119             double translationMatrix[4][4] = {  {1, 0, 0, tx},
120                                                 {0, 1, 0, ty},
121                                                 {0, 0, 1, tz},
122                                                 {0, 0, 0, 1}};
123
124             Object3D transformedObject(numFaces);
125
126             for(int i = 0; i < numFaces; i++){
127                 Face fDash = faces[i].transform(translationMatrix);
128                 transformedObject.setIthFace(i, fDash);
129             }
130
131             return transformedObject;
132         }
133
134         Object3D scaleObject3D(GLfloat sx, GLfloat sy, GLfloat sz){
135             //To scale the 3D object wrt. the given scaling factors
136
137             double scalingMatrix[4][4] = {  {sx, 0, 0, 0},
138                                             {0, sy, 0, 0},
139                                             {0, 0, sz, 0},
140                                             {0, 0, 0, 1}};
```

```
141
142             Object3D transformedObject(numFaces);
143
144             for(int i = 0; i < numFaces; i++){
145                 Face fDash = faces[i].transform(scalingMatrix);
146                 transformedObject.setIthFace(i, fDash);
147             }
148
149             return transformedObject;
150         }
151
152         Object3D rotateObject3D(int axis, double rotationAngle){
153             //To rotate the 3D object about an axis and an angle
154
155             double rotationAngleInRadians = rotationAngle * 3.14159 / 180;
156             double cosAngle = cos(rotationAngleInRadians);
157             double sinAngle = sin(rotationAngleInRadians);
158             double rotationMatrix[4][4];
159
160             switch(axis){
161                 case xAxis:{
162                     double temp[4][4] = {   {1, 0, 0, 0},
163                                             {0, cosAngle, -sinAngle, 0},
164                                             {0, sinAngle, cosAngle, 0},
165                                             {0, 0, 0, 1}};
166
167                     memcpy(rotationMatrix, temp, sizeof(temp));
168                     break;
169                 }
170
171                 case yAxis:{
172                     double temp[4][4] = {   {cosAngle, 0, sinAngle, 0},
173                                             {0, 1, 0, 0},
174                                             {-sinAngle, 0, cosAngle, 0},
175                                             {0, 0, 0, 1}};
176
177                     memcpy(rotationMatrix, temp, sizeof(temp));
178                     break;
179                 }
180
181                 case zAxis:{
182                     double temp[4][4] = {   {cosAngle, -sinAngle, 0, 0},
183                                             {sinAngle, cosAngle, 0, 0},
184                                             {0, 0, 1, 0},
185                                             {0, 0, 0, 1}};
186
187                     memcpy(rotationMatrix, temp, sizeof(temp));
188                     break;
189                 }
190             }
191
```

```
192             Object3D transformedObject(numFaces);
193 
194             for(int i = 0; i < numFaces; i++){
195                 Face fDash = faces[i].transform(rotationMatrix);
196                 transformedObject.setIthFace(i, fDash);
197             }
198 
199             return transformedObject;
200         }
201 
202         Object3D shearObject3D(int axis, double shx = 0, double shy = 0,
    double shz = 0){
203             //To shear the 3D object wrt. an axis and the given shear
    parameters
204 
205             double shearingMatrix[4][4];
206 
207             switch(axis){
208                 case xAxis:{
209                     double temp[4][4] = {   {1, 0, 0, 0},
210                                             {shy, 1, 0, 0},
211                                             {shz, 0, 1, 0},
212                                             {0, 0, 0, 1}};
213 
214                     memcpy(shearingMatrix, temp, sizeof(temp));
215                     break;
216                 }
217 
218                 case yAxis:{
219                     double temp[4][4] = {   {1, shx, 0, 0},
220                                             {0, 1, 0, 0},
221                                             {0, shz, 1, 0},
222                                             {0, 0, 0, 1}};
223 
224                     memcpy(shearingMatrix, temp, sizeof(temp));
225                     break;
226                 }
227 
228                 case zAxis:{
229                     double temp[4][4] = {   {1, 0, shx, 0},
230                                             {0, 1, shy, 0},
231                                             {0, 0, 1, 0},
232                                             {0, 0, 0, 1}};
233 
234                     memcpy(shearingMatrix, temp, sizeof(temp));
235                     break;
236                 }
237             }
238 
239             Object3D transformedObject(numFaces);
240 
```

```
241             for(int i = 0; i < numFaces; i++){
242                 Face fDash = faces[i].transform(shearingMatrix);
243                 transformedObject.setIthFace(i, fDash);
244             }
245 
246             return transformedObject;
247         }
248 
249         Object3D reflectObject3D(int plane){
250             //To reflect the 3D Object about a given plane
251 
252             double reflectionMatrix[4][4];
253 
254             switch(plane){
255                 case xyPlane:{
256                     double temp[4][4] = {   {1, 0, 0, 0},
257                                             {0, 1, 0, 0},
258                                             {0, 0, -1, 0},
259                                             {0, 0, 0, 1}};
260 
261                     memcpy(reflectionMatrix, temp, sizeof(temp));
262                     break;
263                 }
264 
265                 case yzPlane:{
266                     double temp[4][4] = {   {-1, 0, 0, 0},
267                                             {0, 1, 0, 0},
268                                             {0, 0, 1, 0},
269                                             {0, 0, 0, 1}};
270 
271                     memcpy(reflectionMatrix, temp, sizeof(temp));
272                     break;
273                 }
274 
275                 case zxPlane:{
276                     double temp[4][4] = {   {1, 0, 0, 0},
277                                             {0, -1, 0, 0},
278                                             {0, 0, 1, 0},
279                                             {0, 0, 0, 1}};
280 
281                     memcpy(reflectionMatrix, temp, sizeof(temp));
282                     break;
283                 }
284             }
285 
286             Object3D transformedObject(numFaces);
287 
288             for(int i = 0; i < numFaces; i++){
289                 Face fDash = faces[i].transform(reflectionMatrix);
290                 transformedObject.setIthFace(i, fDash);
291             }
```

```
292
293             return transformedObject;
294         }
295 };
296
297 void dummyFunction();
298 void mainLoop(int val);
299 void initializeDisplay();
300 void initializeBaseCube();
301 void plotBase3DObject();
302 void plotTransformation();
303
304 Object3D cube;
305
306 int main(int argc, char **argv){
307     glutInit(&argc, argv);
308     glutInitDisplayMode(GLUT_SINGLE|GLUT_RGB|GLUT_DEPTH);
309     glutInitWindowSize(WINDOW_WIDTH, WINDOW_HEIGHT);
310     glutCreateWindow("3D Transformations - Examples");
311
312     initializeBaseCube();
313     initializeDisplay();
314
315     glutDisplayFunc(dummyFunction);
316     glutTimerFunc(1000/FPS, mainLoop, 0);
317     glutMainLoop();
318
319     return 1;
320 }
321
322 void mainLoop(int val){
323     //Render the display using the timer function
324     plotTransformation();
325 }
326
327 void dummyFunction(){
328     //Placeholder function
329 }
330
331 void initializeDisplay(){
332     glClearColor(1, 1, 1, 1);
333     glOrtho(-800, 800, -800, 800, -800, 800);   //Orthographic projection
334     glEnable(GL_DEPTH_TEST);    //Enable depth
335
336     glClear(GL_COLOR_BUFFER_BIT|GL_DEPTH_BUFFER_BIT);
337
338     //Rotate the entire display so that different sides of the 3D object
    can be seen
339     glRotatef(50, 1, 0, 0);
340     glRotatef(50, 0, 1, 0);
341     glRotatef(50, 0, 0, 1);
```

```
342
343     glEnable(GL_BLEND);     //enable blending (translucent colors)
344     glDepthMask(GL_FALSE);
345     glBlendFunc(GL_SRC_ALPHA, GL_ONE_MINUS_SRC_ALPHA);  //set the blend
        function for translucency
346 }
347
348 void initializeBaseCube(){
349     //Set the coordinates for the base cube
350
351     cube = Object3D(6);
352
353     Face front, back, left, right, bottom, top;
354
355     front = Face(1, 0, 0, 0.75);   //Red
356     front.setIthVertex(0, -100, 100, 100);
357     front.setIthVertex(1, 100, 100, 100);
358     front.setIthVertex(2, 100, -100, 100);
359     front.setIthVertex(3, -100, -100, 100);
360
361     back = Face(0, 1, 0, 0.75);    //Green
362     back.setIthVertex(0, -100, 100, -100);
363     back.setIthVertex(1, 100, 100, -100);
364     back.setIthVertex(2, 100, -100, -100);
365     back.setIthVertex(3, -100, -100, -100);
366
367     left = Face(0, 0, 1, 0.75);    //Blue
368     left.setIthVertex(0, -100, 100, -100);
369     left.setIthVertex(1, -100, 100, 100);
370     left.setIthVertex(2, -100, -100, 100);
371     left.setIthVertex(3, -100, -100, -100);
372
373     right = Face(1, 1, 0, 0.75);   //Yellow
374     right.setIthVertex(0, 100, 100, -100);
375     right.setIthVertex(1, 100, 100, 100);
376     right.setIthVertex(2, 100, -100, 100);
377     right.setIthVertex(3, 100, -100, -100);
378
379     bottom = Face(0, 1, 1, 0.75);  //Cyan
380     bottom.setIthVertex(0, -100, -100, -100);
381     bottom.setIthVertex(1, 100, -100, -100);
382     bottom.setIthVertex(2, 100, -100, 100);
383     bottom.setIthVertex(3, -100, -100, 100);
384
385     top = Face(1, 0, 1, 0.75);     //Magenta
386     top.setIthVertex(0, -100, 100, -100);
387     top.setIthVertex(1, 100, 100, -100);
388     top.setIthVertex(2, 100, 100, 100);
389     top.setIthVertex(3, -100, 100, 100);
390
391     cube.setIthFace(0, front);
```

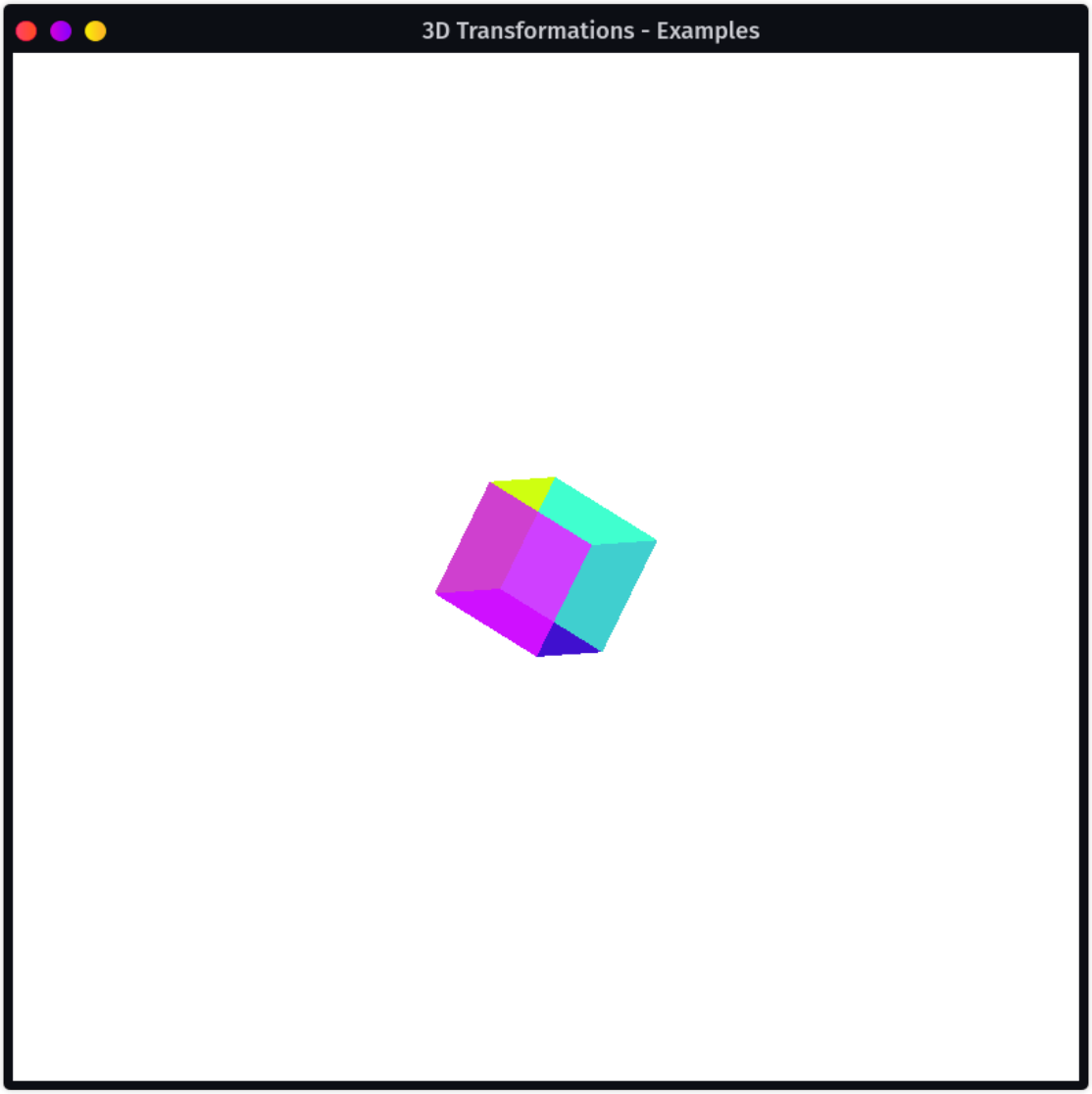
```
392     cube.setIthFace(1, back);
393     cube.setIthFace(2, left);
394     cube.setIthFace(3, right);
395     cube.setIthFace(4, bottom);
396     cube.setIthFace(5, top);
397 }
398 
399 void plotBase3DObject(){
400     //Plot the base 3D object without any transformations
401 
402     glClear(GL_COLOR_BUFFER_BIT|GL_DEPTH_BUFFER_BIT);   //Clear window
403     cube.drawObject3D();
404     glFlush();
405 }
406 
407 void plotTransformation(){
408     //Plot the transformation
409 
410     plotBase3DObject();
411     glFlush();
412 
413     int transform = 0;
414     Object3D cubeDash;
415 
416     while(true){
417         //Await user input
418 
419         cout << "\nChoose Transformation: " << endl;
420         cout << "\t1 for Translation" << endl;
421         cout << "\t2 for Rotation" << endl;
422         cout << "\t3 for Scaling" << endl;
423         cout << "\t4 for Reflection" << endl;
424         cout << "\t5 for Shearing" << endl;
425         cout << "\t0 to Exit" << endl;
426         cout << "\tYour Option -> ";
427         cin >> transform;
428 
429         switch(transform){
430             case 0:{
431                 exit(0);
432             }
433 
434             case 1:{
435                 float tx, ty, tz;
436                 cout << endl << "-----TRANSLATION-----" << endl;
437                 cout << "\nEnter Translation Vector Coordinates: " << endl
    ;
438                 cout << "\nEnter X: "; cin >> tx;
439                 cout << "\nEnter Y: "; cin >> ty;
440                 cout << "\nEnter Z: "; cin >> tz;
441 
```

```
442                 cubeDash = cube.translateObject3D(tx, ty, tz);
443                 cout << endl << "------TRANSLATION DONE-----" << endl;
444 
445                 break;
446             }
447 
448             case 2:{
449                 double angle; int axis;
450                 cout << endl << "-----ROTATION-----" << endl;
451                 cout << "\nEnter Rotation Axis: " << endl;
452                 cout << "\t0 for X-Axis" << endl;
453                 cout << "\t1 for Y-Axis" << endl;
454                 cout << "\t2 for Z-Axis" << endl;
455                 cout << "\tYour Option -> ";
456                 cin >> axis;
457 
458                 cout << "\nEnter Rotation Angle: "; cin >> angle;
459 
460                 cubeDash = cube.rotateObject3D(axis, angle);
461                 cout << endl << "-----ROTATION DONE-----" << endl;
462                 break;
463             }
464 
465             case 3:{
466                 float sx, sy, sz;
467 
468                 cout << endl << "-----SCALING-----" << endl;
469                 cout << "\nEnter Scale Factors: " << endl;
470                 cout << "\nEnter X Factor: "; cin >> sx;
471                 cout << "\nEnter Y Factor: "; cin >> sy;
472                 cout << "\nEnter Z Factor: "; cin >> sz;
473 
474                 cubeDash = cube.scaleObject3D(sx, sy, sz);
475                 cout << endl << "------SCALING DONE-----" << endl;
476 
477                 break;
478             }
479 
480             case 4:{
481                 int plane;
482                 cout << endl << "-----REFLECTION-----" << endl;
483                 cout << "\nEnter Reflection Plane: " << endl;
484                 cout << "\t0 for XY-Plane" << endl;
485                 cout << "\t1 for YZ-Plane" << endl;
486                 cout << "\t2 for ZX-Plane" << endl;
487                 cout << "\tYour Option -> ";
488                 cin >> plane;
489 
490                 cubeDash = cube.reflectObject3D(plane);
491                 cout << endl << "-----REFLECTION DONE-----" << endl;
492                 break;
```

```
493             }
494
495             case 5:{
496                 double shx = 0, shy = 0, shz = 0; int axis;
497
498                 cout << endl << "-----SHEARING-----" << endl;
499                 cout << "\nEnter Shear Axis: " << endl;
500                 cout << "\t0 for X-Axis" << endl;
501                 cout << "\t1 for Y-Axis" << endl;
502                 cout << "\t2 for Z-Axis" << endl;
503                 cout << "\tYour Option -> ";
504                 cin >> axis;
505
506                 cout << "\nEnter Shear Factors: " << endl;
507
508                 switch(axis){
509                     case xAxis:{
510                         cout << "\n Enter Y Factor: "; cin >> shy;
511                         cout << "\n Enter Z Factor: "; cin >> shz;
512                         break;
513                     }
514
515                     case yAxis:{
516                         cout << "\n Enter X Factor: "; cin >> shx;
517                         cout << "\n Enter Z Factor: "; cin >> shz;
518                         break;
519                     }
520
521                     case zAxis:{
522                         cout << "\n Enter X Factor: "; cin >> shx;
523                         cout << "\n Enter Y Factor: "; cin >> shy;
524                         break;
525                     }
526                 }
527
528                 cubeDash = cube.shearObject3D(axis, shx, shy, shz);
529                 cout << endl << "-----SHEARING DONE-----" << endl;
530                 break;
531             }
532         }
533
534         plotBase3DObject();
535         cubeDash.drawObject3D();
536         glFlush();
537     }
538 }
```

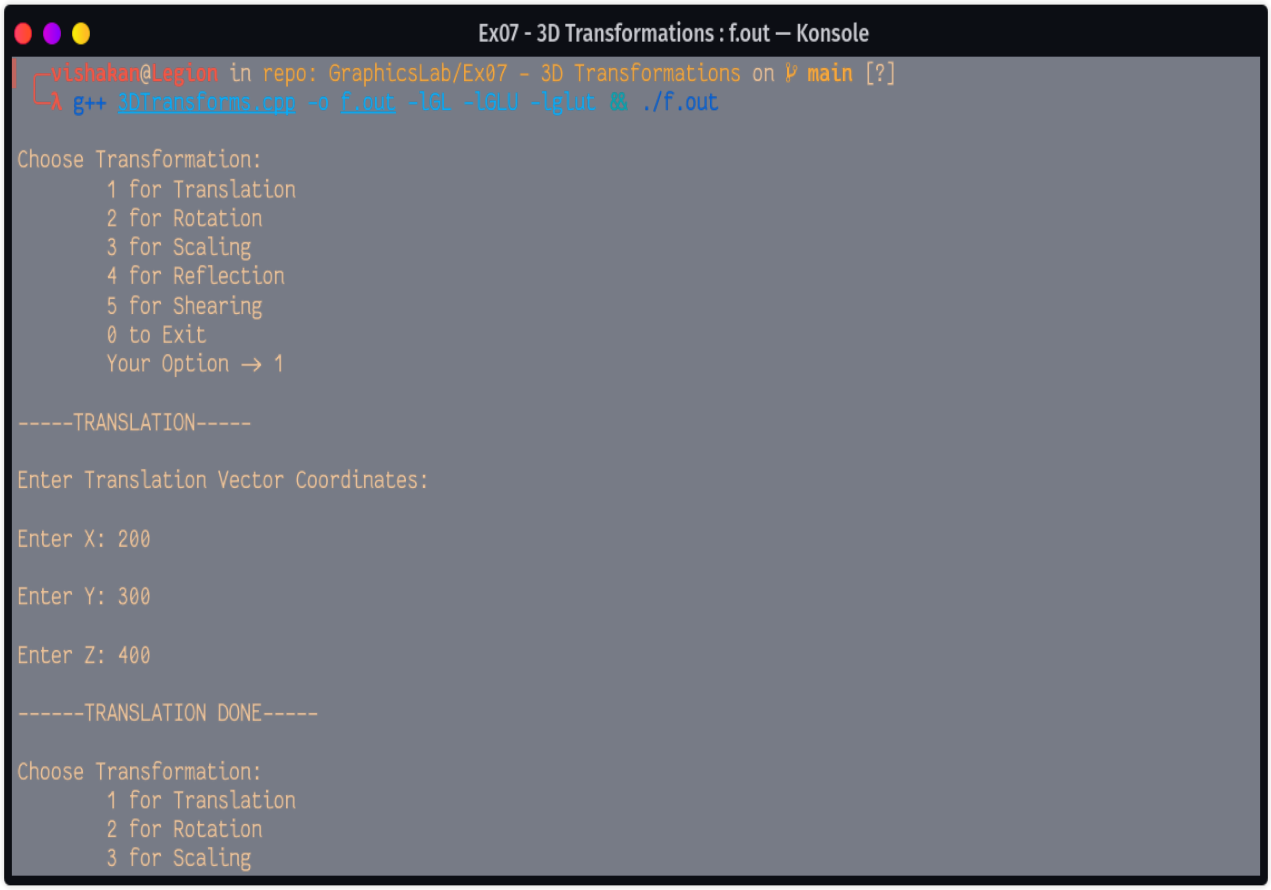
Output: Base 3D Object

Figure 1: Base 3D Object.



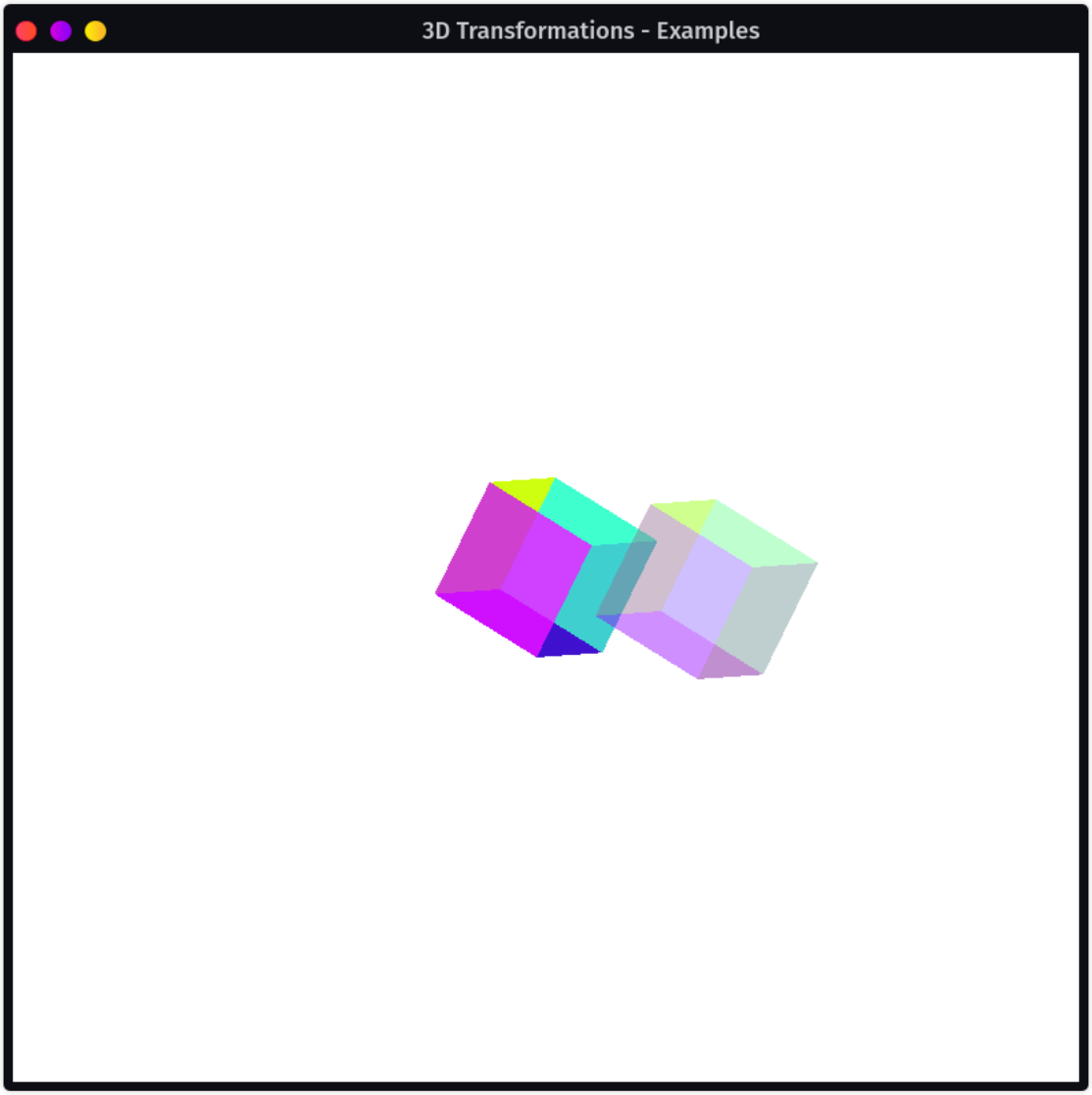
Output: Console - Translation, (200, 300, 400)

Figure 2: Output: Console - Translation, (200, 300, 400).



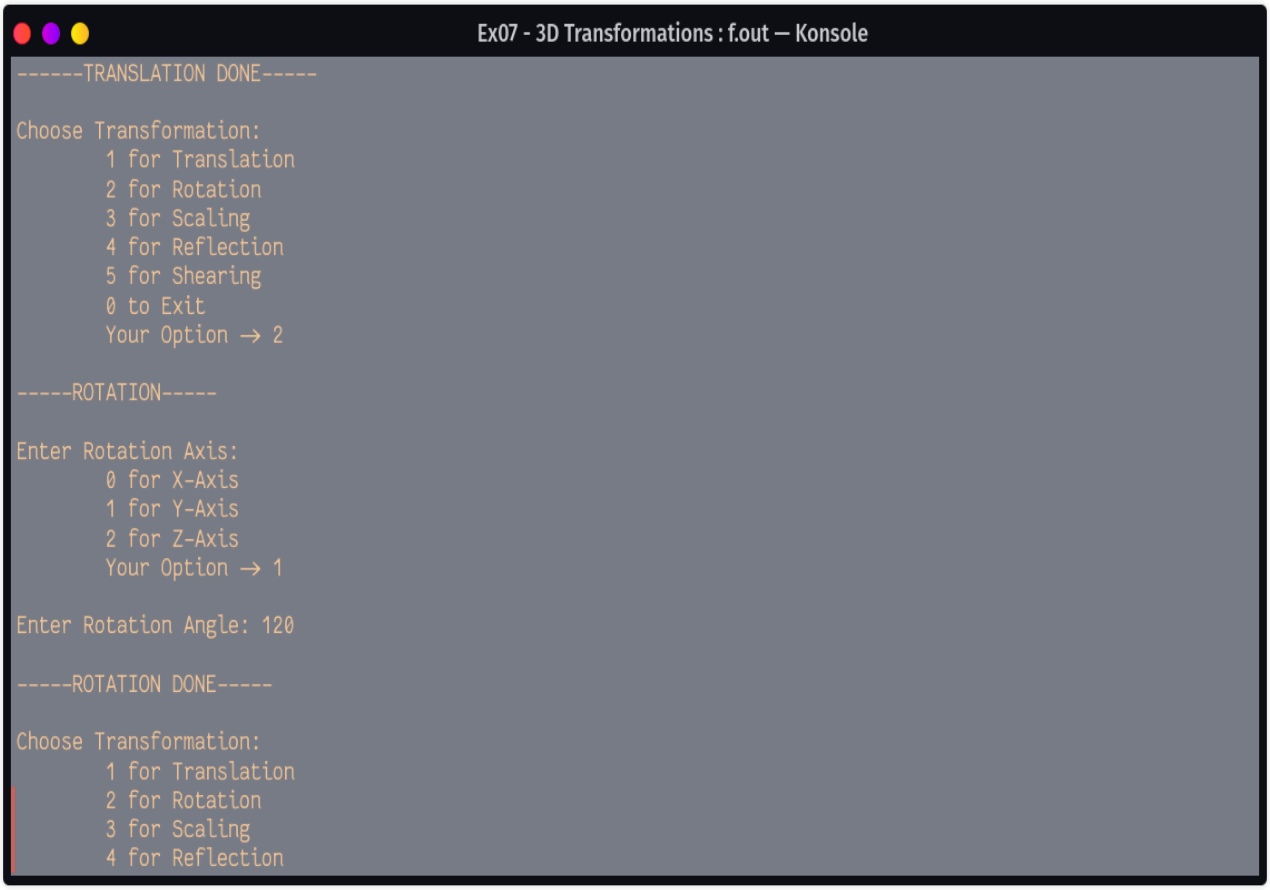
Output: Translated 3D Object, (200, 300, 400)

Figure 3: Translated 3D Object, (200, 300, 400).



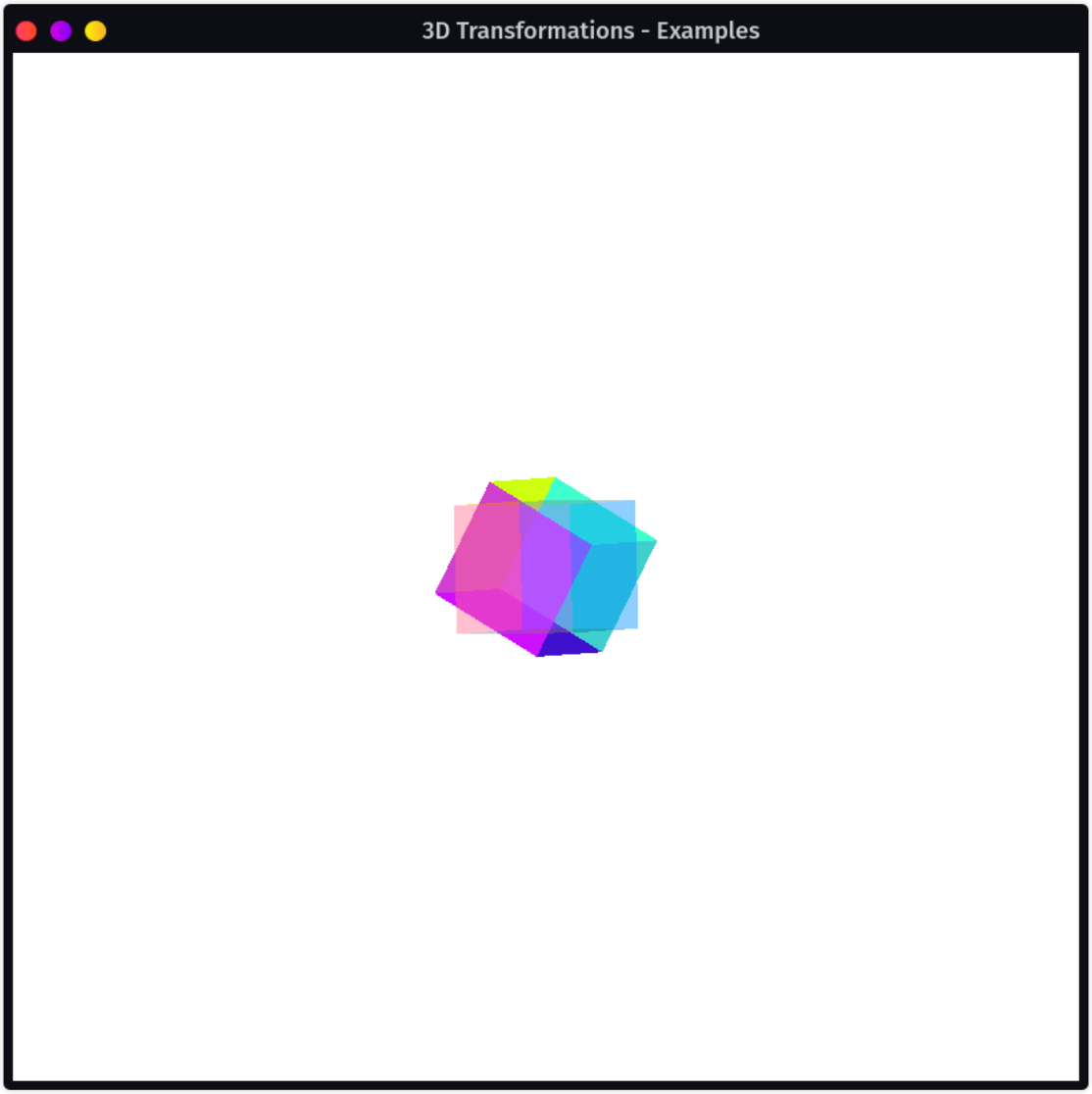
Output: Console - Rotation, Y-Axis, 120°

Figure 4: Output: Console - Rotation, Y-Axis, 120°.



Output: Rotated 3D Object, Y-Axis, 120°

Figure 5: Rotated 3D Object, Y-Axis, 120°.

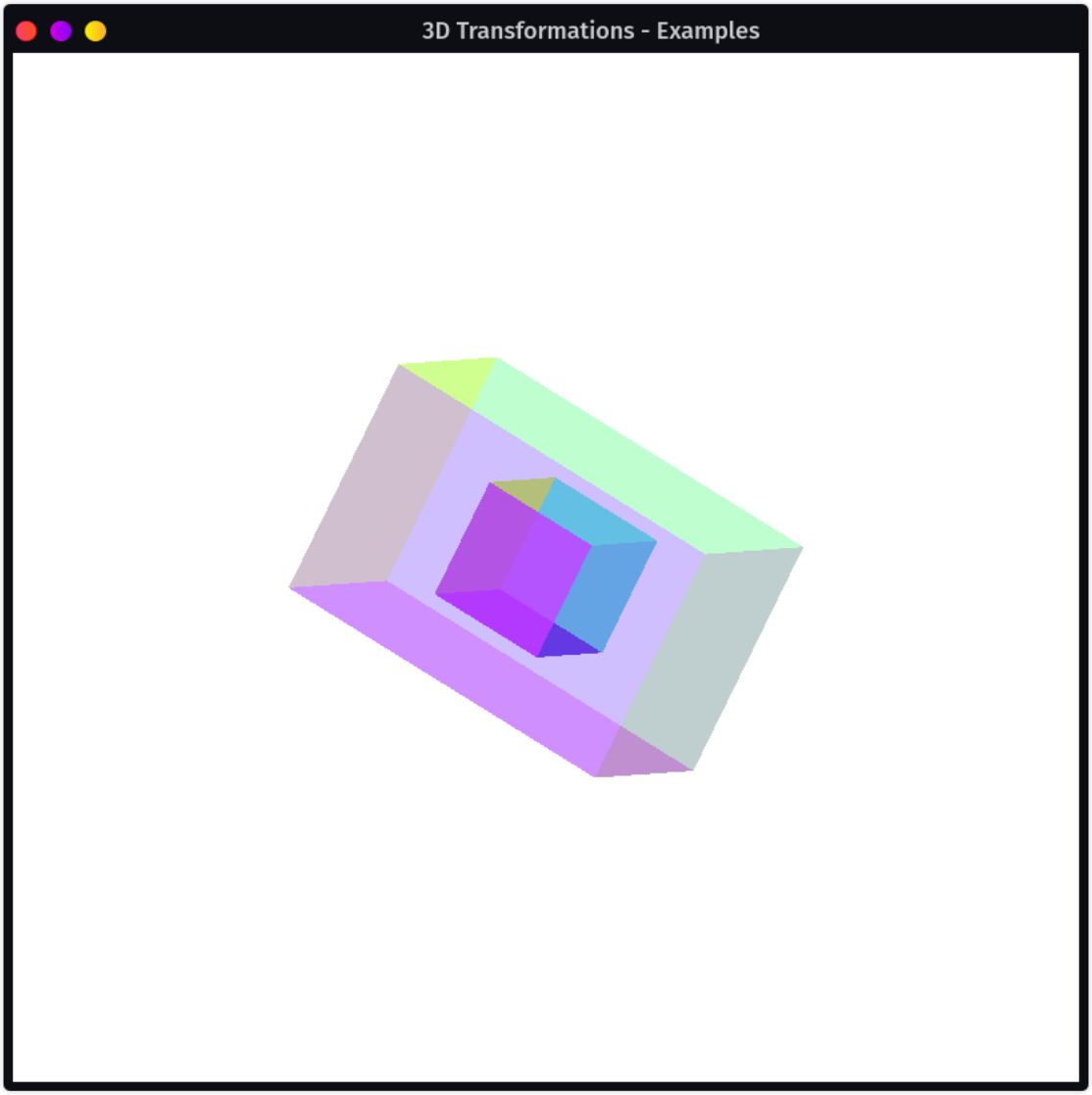


Output: Console - Scaling, (2, 1.5, 3)

Figure 6: Output: Console - Scaling, (2, 1.5, 3).

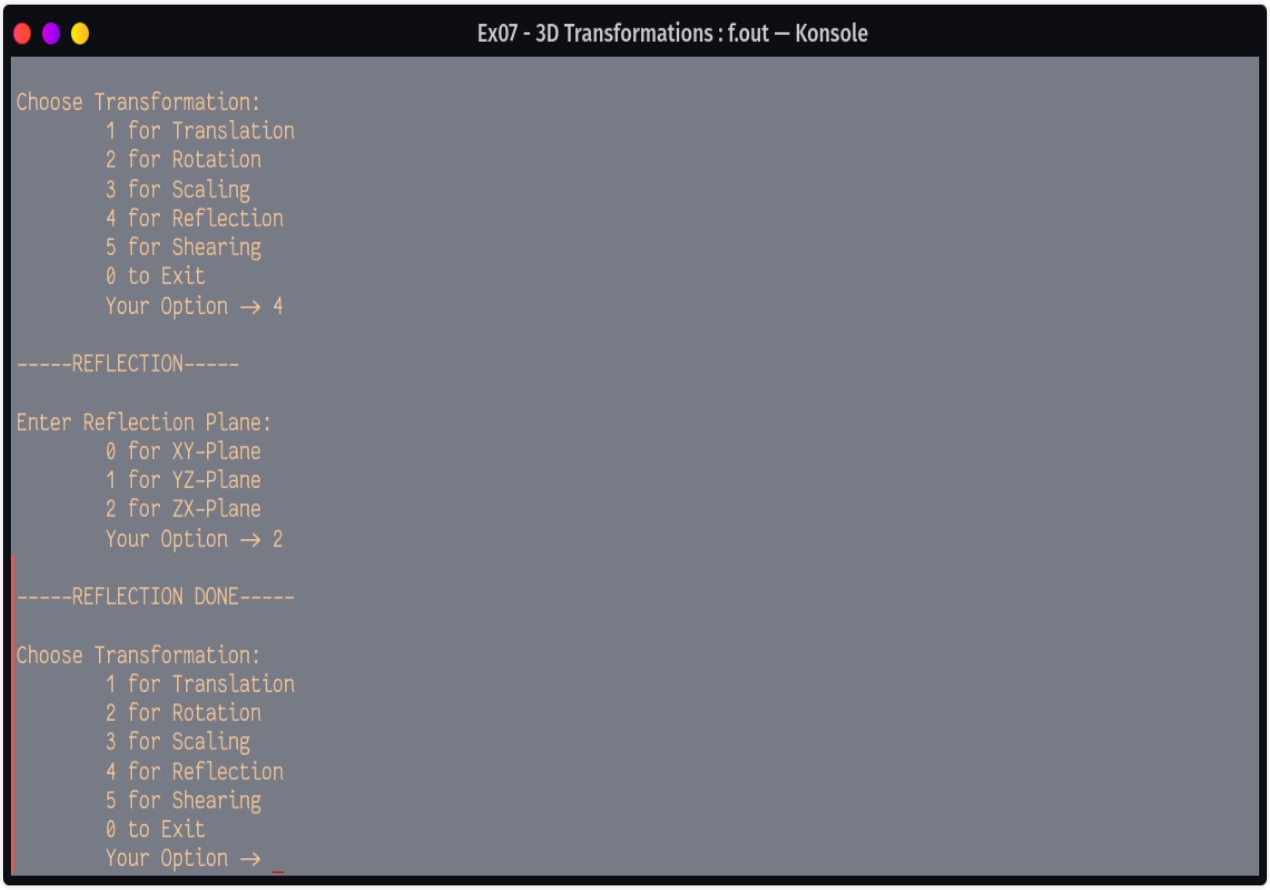
Output: Scaled 3D Object, (2, 1.5, 3)

Figure 7: Scaled 3D Object, (2, 1.5, 3).



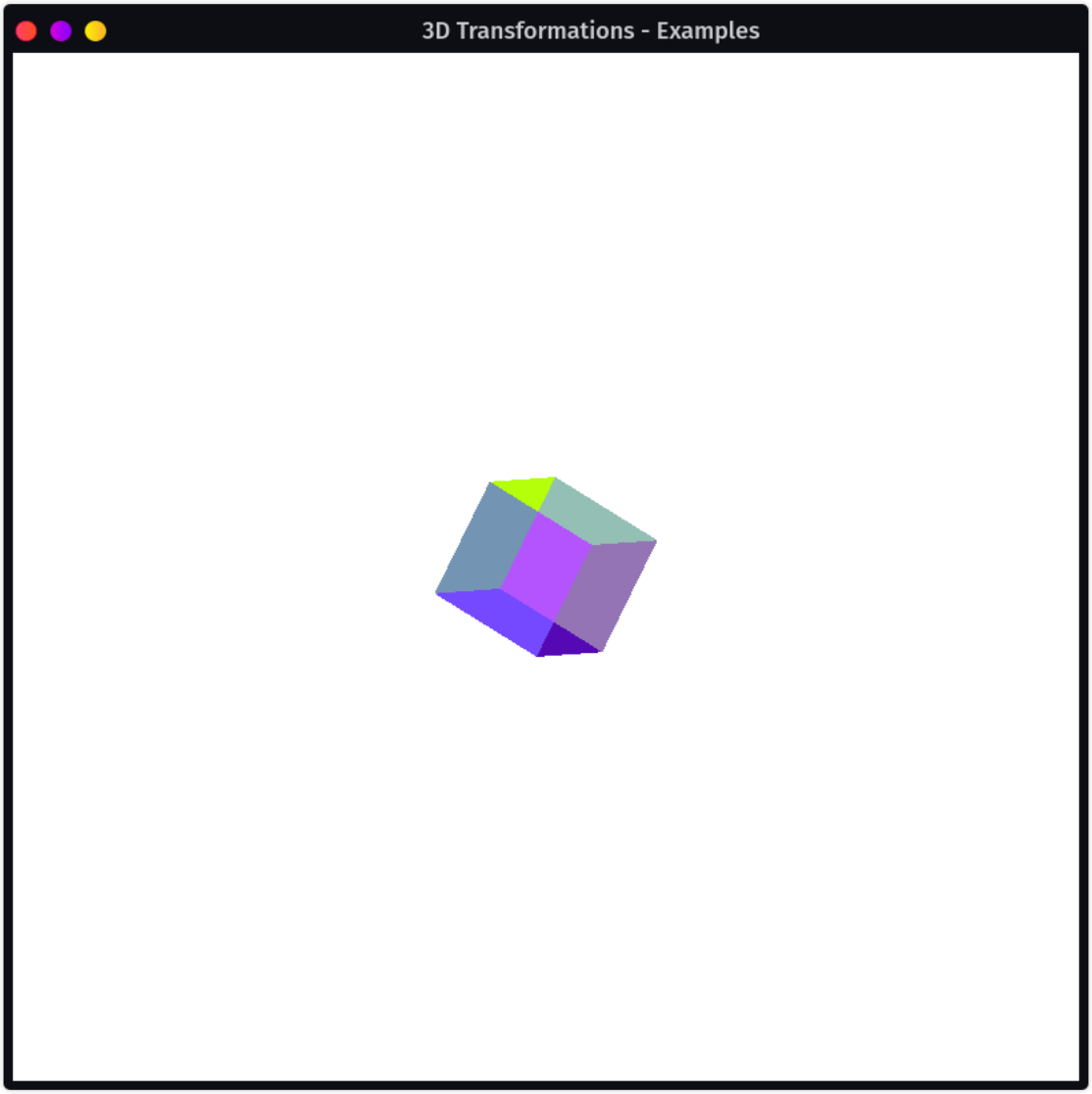
Output: Console - Reflection, ZX Plane

Figure 8: Output: Console - Reflection, ZX Plane.



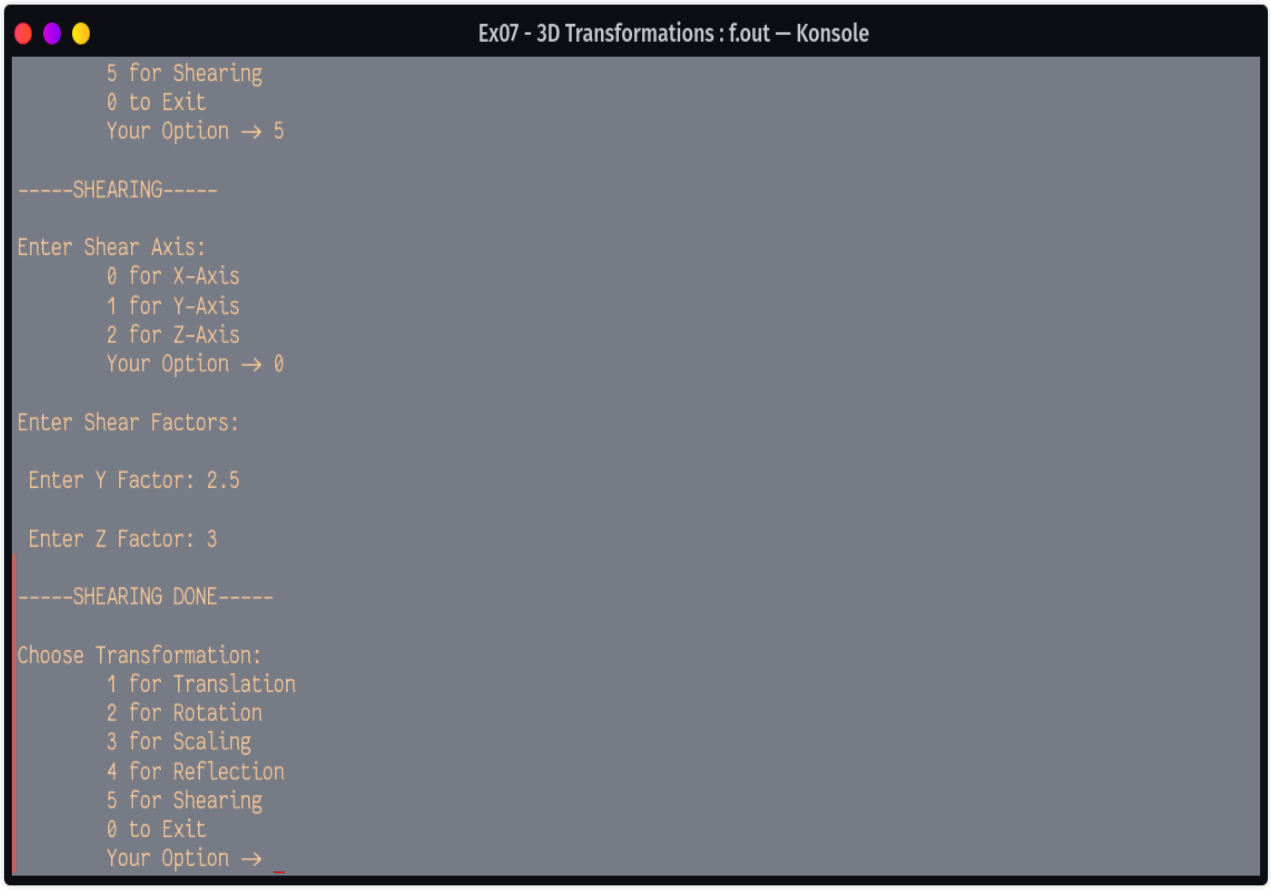
Output: Reflected 3D Object, ZX Plane

Figure 9: Reflected 3D Object, ZX Plane.



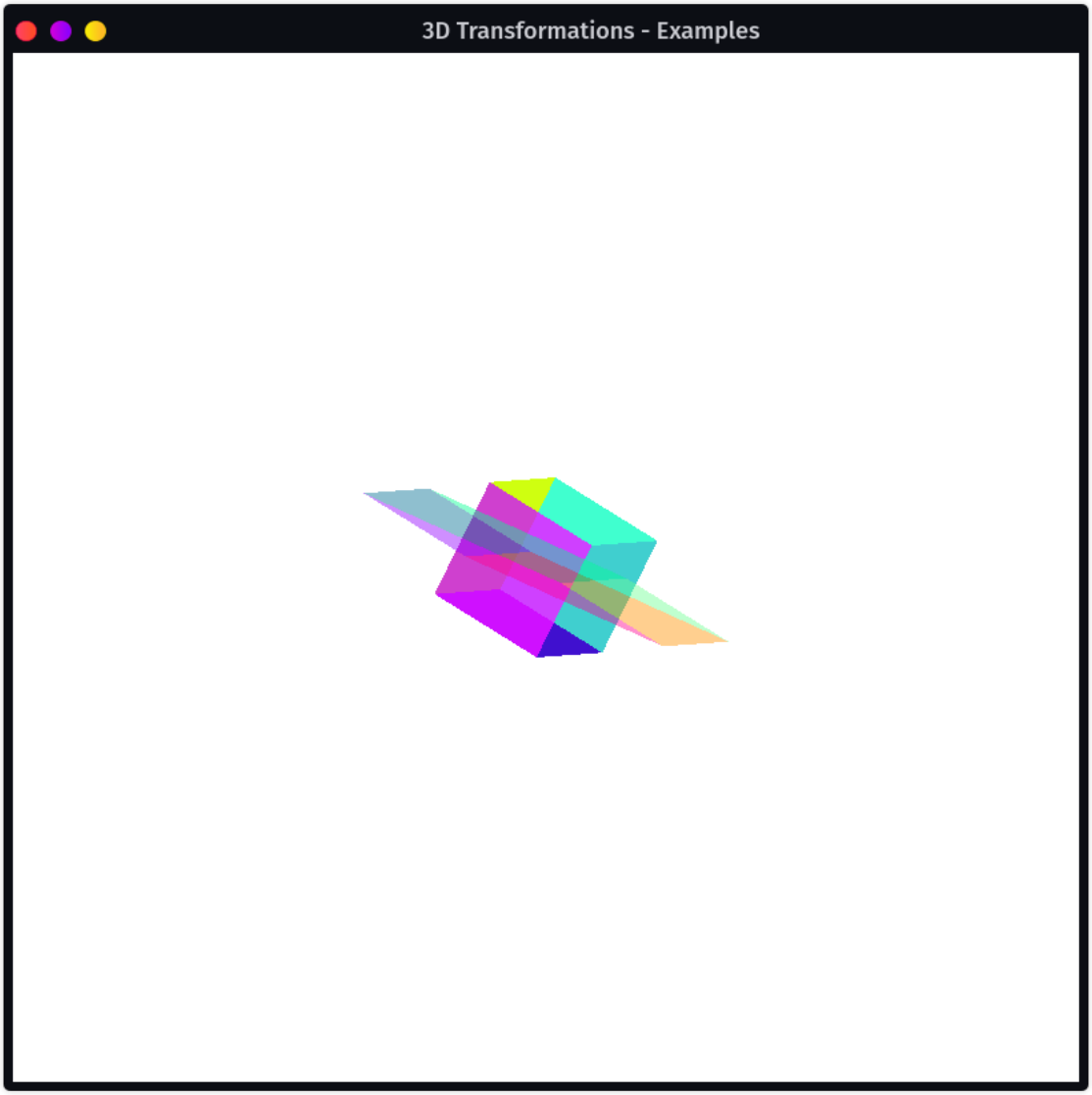
Output: Console - Shearing, X Axis, (2.5, 3)

Figure 10: Output: Console - Shearing, X Axis, (2.5, 3).



Output: Sheared 3D Object, X Axis, (2.5, 3)

Figure 11: Sheared 3D Object, X Axis, (2.5, 3).



Learning Outcome:

- I learnt how to represent a **3D Object** in terms of its **2D Faces** as planar polygons.
- I learnt how to perform **Translation, Rotation, Scaling, Reflection and Shearing** upon a given 3D Object with the use of 3D transformation matrices.
- I learnt about the different transformation matrices and how to calculate them.
- I learnt how to set **depth flags** to enable the **Z-Axis** projections.
- I came to know about inbuilt functions that perform the same transformations like **glRotate3f()** in OpenGL.
- I learnt how to do **orthographic projection** in 3D with OpenGL, using **glOrtho()**.
- I learnt to use parametrized and default constructors in C++ and to call them from other constructors.