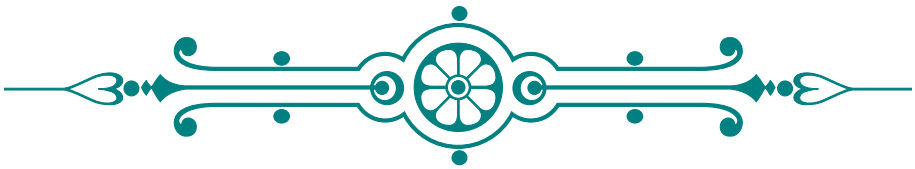

컴퓨터 그래픽스 입문

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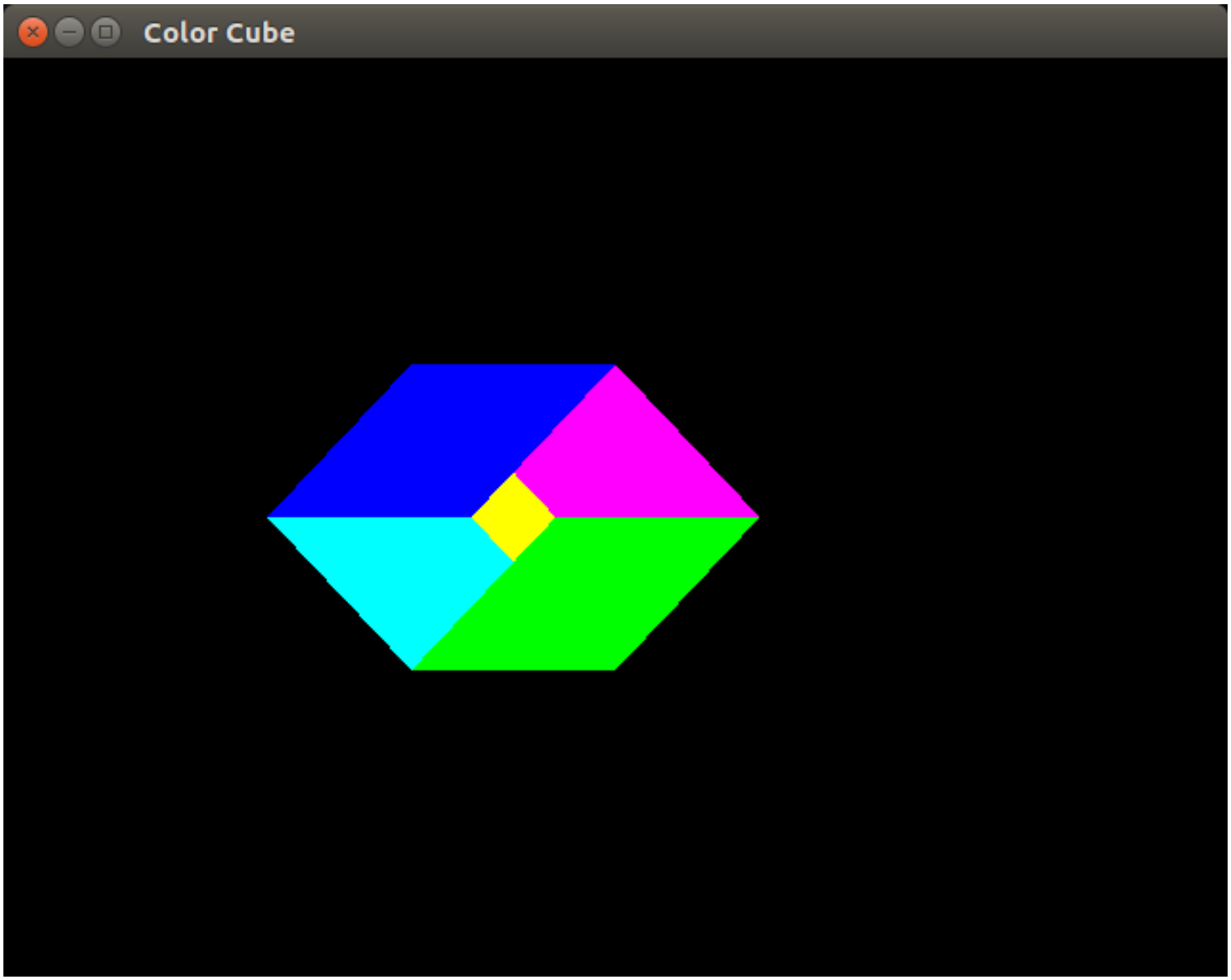
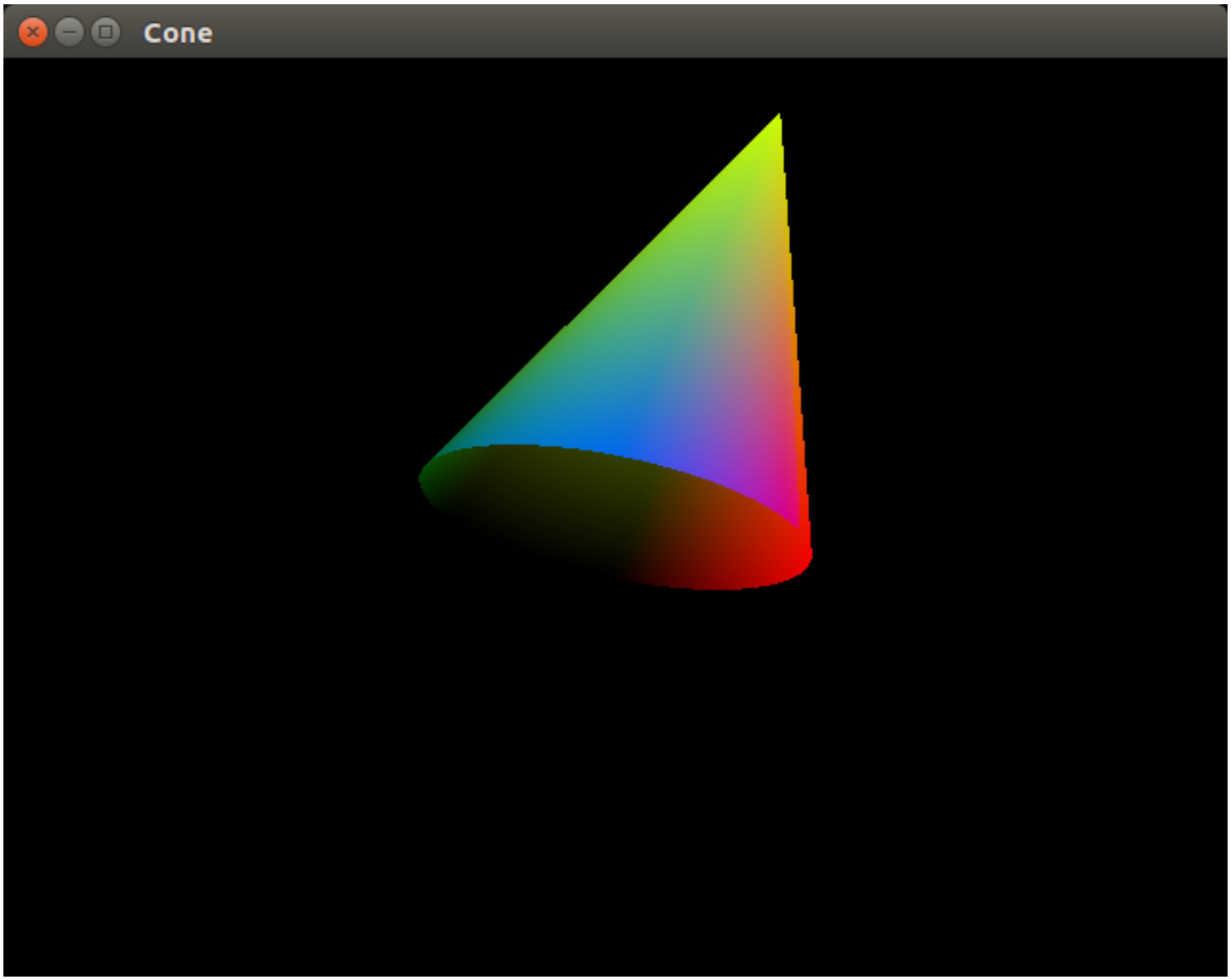
제 1 절 Draw a cube




```
#include"glutil.h"
using namespace std;
extern Matrix<float> grotate;
extern Matrix<float> translate;

int main()
{
    grotate.glrotateY(M_PI/4);
    translate.gltranslate(0,0,sqrt(2));
    if(!glfwInit()) return -1;
    GLFWwindow* window = glfwCreateWindow(640, 480, "Color Cube", NULL, NULL);
    if(!glinit(window)) return -1;
    glortho(3);

    auto pl = polygon(4);
    vector<Matrix<float>> pl2;
    pl2.insert(pl2.end(), begin(pl), end(pl));
```

```
    pl = translate * pl; //z+1
    pl2.insert(pl2.end(), begin(pl), end(pl)); //append elevated 4 vertex
    for(auto& a : pl2) a = grotate * a; // rotate a little to have a good view
    valarray<float> color(72); //{}does not make 72 size — initialize_list construct
    color[slice(0,12,3)] = 1;
    color[slice(26,12,3)] = 1;
    color[slice(13,4,3)] = 1;
    color[slice(49,8,3)] = 1;

    int idx[24] = {0,1,2,3, 4,5,6,7, 0,1,5,4, 1,2,6,5, 2,3,7,6, 0,3,7,4};
    vector<Matrix<float>> v;
    for(auto& a : idx) v.push_back(pl2[a]);

    auto fc = gl_transfer_data(color);
    auto fv = gl_transfer_data(v);

    while (!glfwWindowShouldClose(window)) {
        glClear(GL_COLOR_BUFFER_BIT);
        glBindBuffer(GL_ARRAY_BUFFER, fc);
        glEnableClientState(GL_COLOR_ARRAY);
        glColorPointer(3, GL_FLOAT, 0, nullptr);

        glBindBuffer(GL_ARRAY_BUFFER, fv);
        glEnableClientState(GL_VERTEX_ARRAY);
        glVertexPointer(3, GL_FLOAT, 0, nullptr); //3 float is 1 vertex stride 0,

        glDrawArrays(GL_QUADS, 0, 24);//mode, first , count

        glDisableClientState(GL_COLOR_ARRAY);
        glDisableClientState(GL_VERTEX_ARRAY);

        glfwSwapBuffers(window);
        glfwPollEvents();
    }
    glfwTerminate();
}
```

제 2 절 Draw a cone




```
#include" glutil .h"
using namespace std;
extern Matrix<float> grotate;
extern Matrix<float> translate ;

int main()
{
    if (! glfwInit () ) return -1;
    GLFWwindow* window = glfwCreateWindow(640, 480, "Cone", NULL, NULL);
    if (! glinit (window)) return -1;
    glortho (3) ;

    auto pl = polygon(100); // return 100 circle vertexes
    vector<Matrix<float>> pl2;
    pl2 .push_back ({0,0,3}) ; // top point of cone
    pl2 . insert (pl2 .end() , begin(pl) , end(pl)) ;
    pl2 .push_back(pl [0]) ;
```

```
    grotate . glrotateX (5* M_PI/4 + 0.1) ;
    for(auto& a : pl2) a = grotate * a; // rotate a little to have a good view
    grotate .E() ;
    while (!glfwWindowShouldClose(window)) {
        glClear (GL_COLOR_BUFFER_BIT);

        glBegin(GL_TRIANGLE_FAN);
        for(auto& a : pl2) {
            glColor3fv (a.data () ) ;
            a = grotate * a;
            glVertex3fv (a.data () ) ;
        }
        glEnd() ;
        glfwSwapBuffers(window);

        glfwPollEvents () ;

    }
    glfwTerminate() ;

}
```

Listing 1: glutil.h

```
#pragma once
#include<GL/glew.h>
#include<GLFW/glfw3.h>
#include<vector>
#include<valarray>
#include<type_traits>
#include"matrix.h"

void glortho(float r);
void glcolor (unsigned char r, unsigned char g, unsigned char b, unsigned char a);
bool glinit (GLFWwindow* window);
std :: valarray<Matrix<float>> polygon(int points_count=100, float r=1);

template <typename T>
unsigned int gl_transfer_data (T* begin, T* end, GLenum mode = GL_ARRAY_BUFFER)
{
    int sz = end - begin;
    unsigned int vbo;
    glGenBuffers (1, &vbo);
```

```
    glBindBuffer(mode, vbo);

    T ar[sz];
    memcpy(ar, begin, sizeof(ar));
    glBufferData(mode, sizeof(ar), ar, GL_STATIC_DRAW);
    return vbo;
}

static void mcopy(float* p, const Matrix<float>& m) {
    memcpy(p, m.data(), 3 * sizeof(float));
}
static void mcopy(float* p, float m) {
    *p = m;
}
template <typename T>
unsigned int gl_transfer_data (const T& v, GLenum mode = GL_ARRAY_BUFFER)
{ //v should offer operator []
    int dim = 1;
    int sz = v.size();
    unsigned int vbo;
    glGenBuffers(1, &vbo);
    glBindBuffer(mode, vbo);

    if(std::is_class<typename T::value_type>::value) dim = 3; // if Matrix
    float ar[sz * dim];
    for(int i=0; i<sz; i++) mcopy(ar+i*dim, v[i]);
    glBufferData(mode, sizeof(ar), ar, GL_STATIC_DRAW);
    return vbo;
}
```

Listing 2: callbacks.cc : glutil implementation

```
#include<GL/glew.h>
#include<GLFW/glfw3.h>
#include<iostream>
#include<vector>
#include<valarray>
#include"matrix.h"
using namespace std;
Matrix<float> translate {4,4};
Matrix<float> grotate{4,4};
static Matrix<float> m{4,4};
bool record = false;
```

```
float camera_x=1, camera_y=1;
void key_callback(GLFWwindow* window, int key, int scancode, int action, int mods) {
    if(key == GLFW_KEY_LEFT && action == GLFW_PRESS) translate[4][1]-=0.01;
    if(key == GLFW_KEY_DOWN && action == GLFW_PRESS) translate[4][2]-=0.01;
    if(key == GLFW_KEY_RIGHT && action == GLFW_PRESS) translate[4][1]+=0.01;
    if(key == GLFW_KEY_UP && action == GLFW_PRESS) translate[4][2]+=0.01;

    if(key == GLFW_KEY_W && action == GLFW_PRESS) grotate *= m.glrotateX(0.01);
    if(key == GLFW_KEY_A && action == GLFW_PRESS) grotate *= m.glrotateY(-0.01);
    if(key == GLFW_KEY_S && action == GLFW_PRESS) grotate *= m.glrotateX(-0.01);
    if(key == GLFW_KEY_D && action == GLFW_PRESS) grotate *= m.glrotateY(0.01);
    if(key == GLFW_KEY_SPACE && action == GLFW_PRESS) grotate.E();
    if(key == GLFW_KEY_J && action == GLFW_PRESS) camera_x-=0.1;
    if(key == GLFW_KEY_K && action == GLFW_PRESS) camera_y-=0.1;
    if(key == GLFW_KEY_L && action == GLFW_PRESS) camera_x+=0.1;
    if(key == GLFW_KEY_I && action == GLFW_PRESS) camera_y+=0.1;
}

void mouse_button_callback(GLFWwindow* window, int button, int action, int mods)
{
    double x, y;
    if(button == GLFW_MOUSE_BUTTON_LEFT && action == GLFW_PRESS) {//GLFW_RELEASE
        glfwGetCursorPos(window, &x, &y);
        cout << '(' << x / 4 << ',' << y / 4 << ')' << flush;
    }
}

void cursor_pos_callback(GLFWwindow* window, double xpos, double ypos) {
    if(record) cout << xpos << ' ' << ypos << ' ' << flush;
}

void glortho(float r) {
    glOrtho(-r,r,-r,r,-r,r);
}
void glcolor(unsigned char r, unsigned char g, unsigned char b, unsigned char a) {
    glColor4f(float(r)/256, float(g)/256, float(b)/256, float(a)/256);
}
bool glinit(GLFWwindow* window) {
    if(!window) {
        glfwTerminate();
        return false;
    }
```

```
    // callbacks here
    glfwSetKeyCallback(window, key_callback);
    glfwSetMouseButtonCallback(window, mouse_button_callback);
    glfwSetCursorPosCallback(window, cursor_pos_callback);
    /* Make the window's context current */
    glfwMakeContextCurrent(window);
    glClearColor (0, 0, 0, 0); // white background

    glewExperimental = true; // Needed for core profile
    if (glewInit () != GLEW_OK) {
        fprintf (stderr, "Failed to initialize GLEW\n");
        glfwTerminate();
        return false;
    }
    return true;
}

std :: valarray<Matrix<float>> polygon(int points_count, float r)
{
    Matrix<float> p{r, 0, 0}; // when arg is 3 or 4, it makes 4x1 matrix r ,0,0,1
    Matrix<float> rz{4, 4}; // this makes 4x4 matrix
    std :: valarray<Matrix<float>> pts{Matrix<float>{0,0,0}, points_count};
    rz.glrotateZ(2 * M_PI / points_count);
    for(int i=0; i<points_count; i++) {
        pts[i] = p;
        p = rz * p;
    }
    return pts;
}
```

Listing 3: Matrix class

```
#pragma once
#include<cstring>
#include<sstream>
#include<cmath>
#include<cassert>
#include<iostream>
#include<iomanip>
#include"combi.h"

template <typename T> class Matrix
{
```

```
public:
    Matrix(unsigned short w, unsigned short h) {
        width = w; height = h;
        arr = new T[h * w];
        for(int i=0; i<w * h; i++) arr[i] = 0;
    }

    Matrix(T x, T y, T z, T w = 1) : Matrix{1,4} {
        arr[0] = x; arr[1] = y; arr[2] = z; arr[3] = w;
    }

    Matrix(std::initializer_list<std::initializer_list<T>> li)
        : Matrix<T>{static_cast<unsigned short>(li.begin()->size()),
                    static_cast<unsigned short>(li.size())} {
        int x = 1, y = 1;
        for(auto& a : li) {
            for(auto& b : a) (*this)[x++][y] = b;
            y++; x = 1;
        }
    }

    Matrix(const Matrix<T>& r) : Matrix(r.width, r.height) {
        for(int i=0; i<width * height; i++) arr[i] = r.arr[i];
    }

    Matrix(Matrix<T>&& r) {
        arr = r.arr; r.arr = nullptr;
        width = r.width; height = r.height;
    }

    virtual ~Matrix() {if(arr) delete [] arr;}

    /// getters
    T* data() const {return arr;}
    unsigned short get_width() const{return width;}
    unsigned short get_height() const{return height;}

    /// operator overloading
    T* operator[](int x) {// start from 11 21 31
        assert(x > 0);
        return arr + (x -1) * height - 1;
    }
```

```
T* operator[](int x)const { // start from 11 21 31
    assert(x > 0);
    return arr + (x -1) * height - 1;
}

Matrix<T> operator+(const Matrix<T>& r) const {
    if(width != r.width || height != r.height) throw "Matrix size not match";
    Matrix<T> m(width, height);
    for(int i=0; i<width*height; i++) m.arr[i] = arr[i] + r.arr[i];
    return m;
}

Matrix<T> operator-(const Matrix<T>& r) const {
    if(width != r.width || height != r.height) throw "Matrix size not match";
    Matrix<T> m(width, height);
    for(int i=0; i<width*height; i++) m.arr[i] = arr[i] - r.arr[i];
    return m;
}

Matrix<T> operator*(const Matrix<T>& r) const {
    if(width != r.height) throw "Matrix size not match";
    Matrix<T> m(r.width, height);
    for(int x = 1; x <= r.width; x++) for(int y = 1; y <= height; y++)
        m[x][y] = inner_product(y, r.column(x));
    return m;
}

Matrix<T>& operator=(const Matrix<T>& r) {
    if(width != r.width || height != r.height) throw "Matrix size not match";
    for(int i=0; i<width*height; i++) arr[i] = r.arr[i];
    return *this;
}

Matrix<T>& operator*=(const Matrix<T>& r) {
    *this = *this * r;
    return *this;
}

Matrix<T> operator*(const T& r) const {return r * *this;}

bool operator==(const Matrix<T>& r) const {
    if(width != r.width || height != r.height) return false;
```

```
    for(int i=0; i<width*height; i++) if(arr[i] != r.arr[i]) return false;
    return true;
}

friend Matrix<T> operator*(const T l, const Matrix<T>& r) {
    Matrix<T> m(r.width, r.height);
    for(int y=0; y<r.height; y++) for(int x=0; x<r.width; x++)
        m.arr[y*r.width+x] = l * r.arr[y*r.width+x];
    return m;
}

Matrix<T> inverse() const{
    auto a = LU_decompose();
    auto P = a[0], L = a[1], U = a[2];
    Matrix<T> I{width, height};
    for(int i=1; i<=height; i++) {
        Matrix B{1, height}; // divide E into column pieces
        B[1][i] = 1;
        auto Ux = LxB(L, P * B); //Ax = B <==> PAx = PB <==> LUx = PB
        auto x = UxB(U, Ux);
        for(int j=1; j<=height; j++) I[i][j] = x[1][j];
    }
    return I;
}

Matrix<T> transpose() const{
    Matrix<T> m{height, width};
    for(int x=1; x<=width; x++) for(int y=1; y<=height; y++)
        m[y][x] = (*this)[x][y];
    return m;
}

Matrix<T> E() {
    if(width != height) throw "must be square matrix!";
    for(int x = 1; x <= width; x++) for(int y = 1; y <= height; y++) {
        if(x == y) (*this)[x][y] = 1;
        else (*this)[x][y] = 0;
    }
    return *this;
}
Matrix<T> gltranslate(T x, T y, T z) {
    if(width != 4 || height != 4) throw "should be 4x4";
```

```
        E();
        (*this)[4][1] = x;
        (*this)[4][2] = y;
        (*this)[4][3] = z;
        return *this;
    }
    Matrix<T> glrotateZ(T th) {
        if(width != 4 || height != 4) throw "should be 4x4";
        E();
        (*this)[1][1] = cos(th);
        (*this)[2][1] = -sin(th);
        (*this)[1][2] = sin(th);
        (*this)[2][2] = cos(th);
        return *this;
    }
    Matrix<T> glrotateX(T th) {
        if(width != 4 || height != 4) throw "should be 4x4";
        E();
        (*this)[2][2] = cos(th);
        (*this)[3][2] = -sin(th);
        (*this)[2][3] = sin(th);
        (*this)[3][3] = cos(th);
        return *this;
    }
    Matrix<T> glrotateY(T th) {
        if(width != 4 || height != 4) throw "should be 4x4";
        E();
        (*this)[1][1] = cos(th);
        (*this)[3][1] = -sin(th);
        (*this)[1][3] = sin(th);
        (*this)[3][3] = cos(th);
        return *this;
    }
    Matrix<T> glscale(T x, T y, T z) {
        if(width != 4 || height != 4) throw "should be 4x4";
        E();
        (*this)[1][1] = x;
        (*this)[2][2] = y;
        (*this)[3][3] = z;
        return *this;
    }
```

```
    Matrix<T> One() const {
        for(int i=0; i<width*height; i++)  arr[i] = 1;
    }
    Matrix<T> surround(T wall = 0) const {
        Matrix<T> m{width + 2, height + 2};
        for(int i=0; i<m.width*m.height; i++) m.arr[i] = wall;
        for(int x=1; x<=width; x++) for(int y=1; y<=height; y++)
            m[x+1][y+1] = (*this)[x][y];
        return m;
    }

protected:
    T* arr;
    unsigned short width, height;

private:
    T* column(int x) const{
        return arr + (x - 1) * height;
    }

    T inner_product(int row, T* col) const{
        T sum = 0;
        for(int i=0; i<width; i++) sum += (*this)[i+1][row] * *(col+i);
        return sum;
    }
    static Matrix<T> LU_decompose(Matrix<T> m) {
        int w = m.width;
        int h = m.height;
        if (!m[1][1]) return Matrix<T>{w,h};
        if (m.width == 1) return m;
        for(int y=2; y<=h; y++) m[1][y] /= m[1][1]; // c /= a11
        for(int x=2; x<=w; x++) for(int y=2; y<=h; y++)
            m[x][y] -= m[x][1] * m[1][y]; // A' -= ch
        Matrix<T> mm{w-1, w-1};
        for(int x=1; x<w; x++) for(int y=1; y<w; y++) mm[x][y] = m[x+1][y+1];
        mm = LU_decompose(mm);// A' part recursive
        if (!mm[1][1]) return Matrix<T>{w,h};//if a11 == 0 -> change P, redo
        for(int x=1; x<w; x++) for(int y=1; y<w; y++) m[x+1][y+1] = mm[x][y];
        return m;
    }

    auto LU_decompose() const{
```

```
    if(width != height) throw "should be square";
    nPr npr{width, width};
    while(npr.next()) {
        Matrix<T> P{width, width};// 조합으로 순열 매트릭스 생성 .
        for(int j=1,i=0; j<=height; j++) P[npr[i++]][j] = 1;
        auto m = P * (*this);
        m = LU_decompose(m);
        if(!m[1][1]) continue;
        else {
            Matrix<T> L{width, height};
            Matrix<T> U{width, height};
            for(int x=1; x<=width; x++)
                for(int y=1; y<=width; y++)
                    if(x<y) L[x][y] = m[x][y];
                    else U[x][y] = m[x][y];
            for(int x=1; x<=width; x++) L[x][x] = 1;
            return std :: array<Matrix<T>, 3>{P, L, U};
        }
    }
    throw "no inverse";
}
static Matrix<T> LxB(Matrix<T> L, Matrix<T> B)
{///get x from Lx = B
    int h = L.get_height();
    if(L.get_width() != h || B.get_width() != 1 || B.get_height() != h)
        throw "type mismatch";
    Matrix<T> x{1, h};
    for(int i=1; i<=h; i++) {
        T sum = 0;
        for(int j=1; j<i; j++) sum += L[j][i] * x[1][j];
        x[1][i] = B[1][i] - sum;
    }
    return x;
}

static Matrix<T> UxB(Matrix<T> U, Matrix<T> B)
{///get x from Ux = B
    int h = U.get_height();
    if(U.get_width() != h || B.get_width() != 1 || B.get_height() != h)
        throw "type mismatch";
    Matrix<T> x{1, h};
    for(int i=h; i>0; i--) {
```

```
            T sum = 0;
            for(int j=h; j>i; j--) sum += x[1][j] * U[j][i];
            x[1][i] = (B[1][i] - sum) / U[i][i];
        }
        return x;
    }
};

template <typename T> std::ostream& operator<<(std::ostream& o, const Matrix<T>& r){
    int w = r.get_width(), h = r.get_height();
    int gap[w+1] {0,};
    for(int y=1; y<=h; y++) for(int x=1; x<=w; x++) {
        std::stringstream ss;
        ss << r[x][y];
        int sz = ss.str().length();
        if(gap[x] < sz) gap[x] = sz;
    }

    o << "\u23a1" << ' ';
    for(int x=1; x<=w; x++) o << std::setw(gap[x]) << r[x][1] << ' ';
    o << "\u23a4" << std::endl;
    for(int y=2; y<h; y++) {
        o << "\u23a2" << ' ';
        for(int x=1; x<=w; x++) o << std::setw(gap[x]) << r[x][y] << ' ';
        o << "\u23a5" << std::endl;
    }
    o << "\u23a3" << ' ';
    for(int x=1; x<=w; x++) o << std::setw(gap[x]) << r[x][h] << ' ';
    o << "\u23a6" << std::endl;

    return o;
}

template<typename T> class MatrixStream : public Matrix<T>
{
public:
    MatrixStream(const Matrix<T>& m) : Matrix<T>{m} {
        int w = this->width, h = this->height;
        gap = new int[w];
        memset((void*)gap, 0, sizeof(int) * w);
        linebyline = new std::string[h];
        for(int y=1; y<=h; y++) for(int x=1; x<=w; x++) {
```

```
            std :: stringstream  ss;
            ss  << (*this)[x][y];
            int  sz  =  ss. str () . length () ;
            if (gap[x-1] < sz)  gap[x-1] = sz; // get  maximum length
        } // print  with  setw

        std :: stringstream  ss;
        ss  << (h-1 ? "\u23a1 " :  "[  ") ; // matrix  bracket  first  line
        for(int  x=1;  x<=w; x++) ss  << std::setw(gap[x-1]) << (*this)[x][1]  << ' ';
        ss  << (h-1 ? "\u23a4" :  "]") ;
        linebyline [0]  =  ss. str () ;
        ss. str ("") ;
        ss. clear () ;

        for(int  y=2;  y<h; y++) { // middle  lines
            ss  << "\u23a2" << ' ';
            for(int  x=1;  x<=w; x++) ss  << std::setw(gap[x-1]) << (*this)[x][y]  << ' ';
            ss  << "\u23a5";
            linebyline [y-1] = ss. str () ;
            ss. str ("") ;
            ss. clear () ;
        }

        if (h > 1) { // last  line
            ss  << "\u23a3" << ' ';
            for(int  x=1;  x<=w; x++) ss  << std::setw(gap[x-1]) << (*this)[x][h]  << ' ';
            ss  << "\u23a6";
            linebyline [h-1] = ss. str () ;
        }
    }

    ~MatrixStream() {
        if (gap) delete[] gap;
        if ( linebyline ) delete[]  linebyline ;
    }

    std :: string  space () { // make space  string  wide  exactly  the  same width  of  matrix
        std :: string  s; // to  occupy  the  blank  space
        int  sum = 0;
        for(int  i=0;  i<this->width; i++) sum += gap[i];
        for(int  i=0;  i  < sum + this->width + 3; i++)  s  += '  ';
        return s;
```

```
    }

    template<typename T2>
    friend std :: ostream& operator<<(std::ostream& o, MatrixStream<T2>& r);

protected:
    int* gap = nullptr ; ///<contain biggest output width per every x -> setw()
    std :: string* linebyline = nullptr ; ///<output line by line
    int pos = 0; ///< indicate what line to print
};

template<typename T>
std :: ostream& operator<<(std::ostream& o, MatrixStream<T>& r) {
    if(r.pos == r.height) r.pos = 0;
    o << r.linebyline[r.pos++];
    return o;
}
```