Hierarchical Modeling

Reading

Required:

- Angel, sections 9.1 – 9.6, 9.8

Optional:

- *OpenGL Programming Guide*, the Red Book, chapter 3

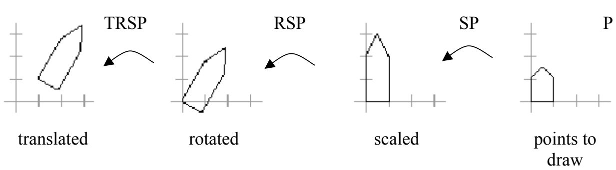
Symbols and instances

Most graphics APIs support a few geometric **primitives**:

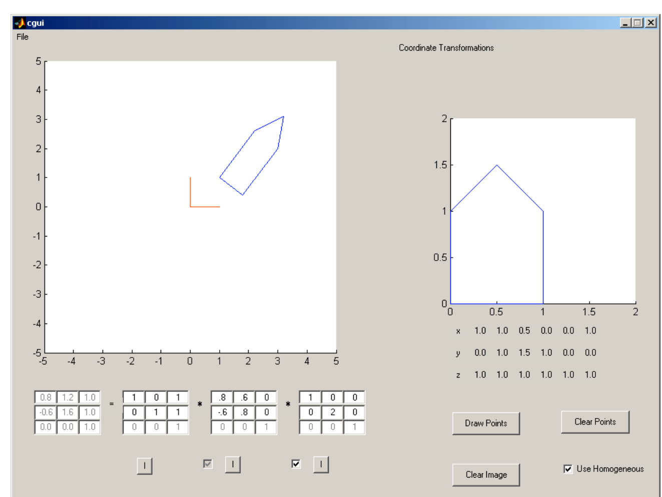
- spheres, cubes, cylinders
- these procedures define points for you, but they're still just points **P**

These symbols are **instanced** using an **instance transformation.**

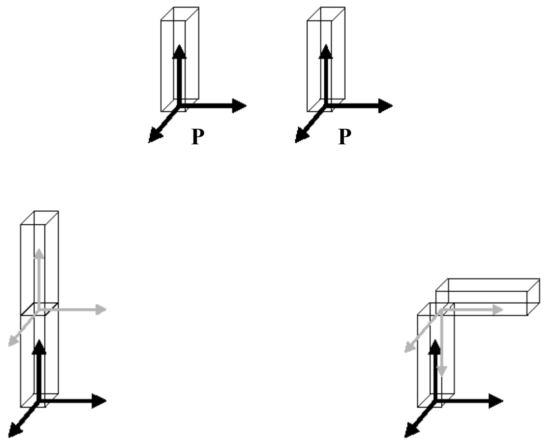
- the points are originally defined in a local coordinate system (eg, unit cube)



Q: What is the matrix for the instance transformation above?



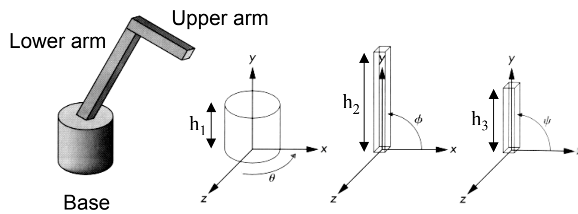
Connecting primitives



3D Example: A robot arm

Consider this robot arm with 3 degrees of freedom:

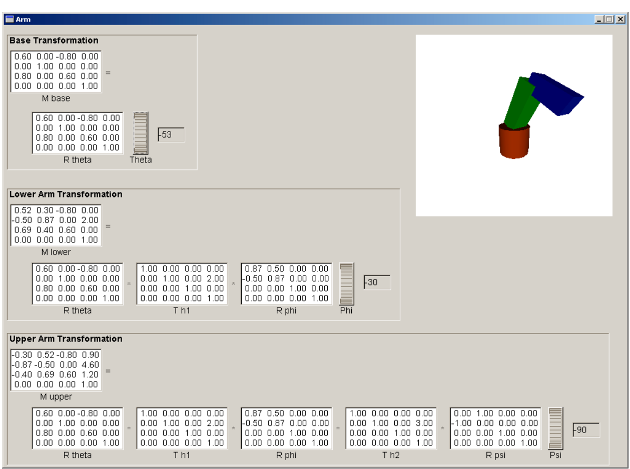
- Base rotates about its vertical axis by θ
- Lower arm rotates in its *xy*-plane by ϕ
- Upper arm rotates in its *xy*-plane by ψ



Q: What matrix do we use to transform the base?

Q: What matrix for the upper arm?

Q: What matrix for the lower arm?



Robot arm implementation

The robot arm can be displayed by keeping a global matrix and computing it at each step:

```
Matrix M_model;

main()
{
    . . .
    robot_arm();
    . . .
}

robot_arm()
{
    M_model = R_y(theta);
    base();
    M_model = R_y(theta)*T(0,h1,0)*R_z(phi);
    lower_arm();
    M_model = R_y(theta)*T(0,h1,0)*R_z(phi)
                          *T(0,h2,0)*R_z(psi);
    upper_arm();
}
```

Do the matrix computations seem a tad wasteful?

Robot arm implementation, better

Instead of recalculating the global matrix each time, we can just update it *in place* by concatenating matrices on the right:

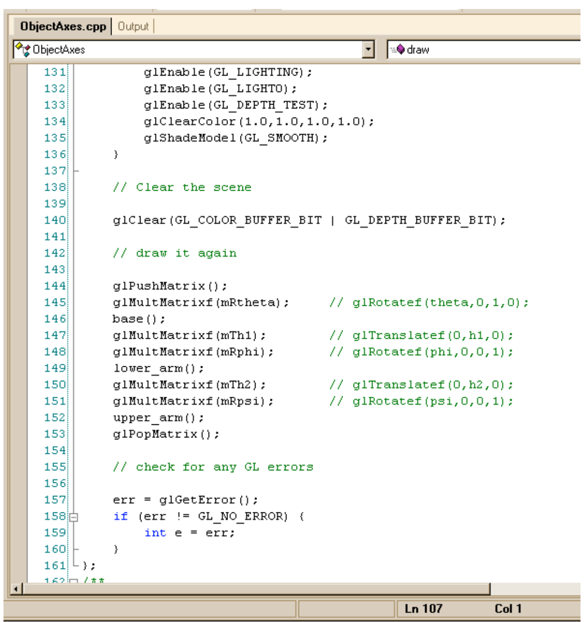
```
Matrix M_model;

main()
{
    . . .
    M_model = Identity();
    robot_arm();
    . . .
}

robot_arm()
{
    M_model *= R_y(theta);
    base();
    M_model *= T(0,h1,0)*R_z(phi);
    lower_arm();
    M_model *= T(0,h2,0)*R_z(psi);
    upper_arm();
}
```


Robot arm implementation, OpenGL

OpenGL maintains a global state matrix called the **model-view matrix**, which is updated by concatenating matrices on the ***right***.

```
main()
{
    . . .
    glMatrixMode( GL_MODELVIEW );
    glLoadIdentity();
    robot_arm();
    . . .
}

robot_arm()
{
    glRotatef( theta, 0.0, 1.0, 0.0 );
    base();
    glTranslatef( 0.0, h1, 0.0 );
    glRotatef( phi, 0.0, 0.0, 1.0 );
    lower_arm();
    glTranslatef( 0.0, h2, 0.0 );
    glRotatef( psi, 0.0, 0.0, 1.0 );
    upper_arm();
}
```

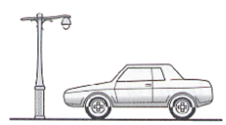

ObjectAxes.cpp

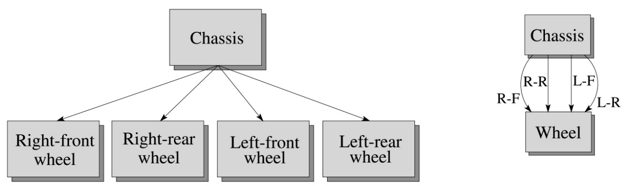


```
ObjectAxes.cpp | Output
ObjectAxes                         draw
        glEnable(GL_LIGHTING);
        glEnable(GL_LIGHT0);
        glEnable(GL_DEPTH_TEST);
        glClearColor(1.0,1.0,1.0,1.0);
        glShadeModel(GL_SMOOTH);
    }

    // Clear the scene

    glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);

    // draw it again

    glPushMatrix();
    glMultMatrixf(mRtheta);      // glRotatef(theta,0,1,0);
    base();
    glMultMatrixf(mTh1);         // glTranslatef(0,h1,0);
    glMultMatrixf(mRphi);        // glRotatef(phi,0,0,1);
    lower_arm();
    glMultMatrixf(mTh2);         // glTranslatef(0,h2,0);
    glMultMatrixf(mRpsi);        // glRotatef(psi,0,0,1);
    upper_arm();
    glPopMatrix();

    // check for any GL errors

    err = glGetError();
    if (err != GL_NO_ERROR) {
        int e = err;
    }
};
/**
Ln 107      Col 1
```


Hierarchical modeling

Hierarchical models can be composed of instances using trees or DAGs:

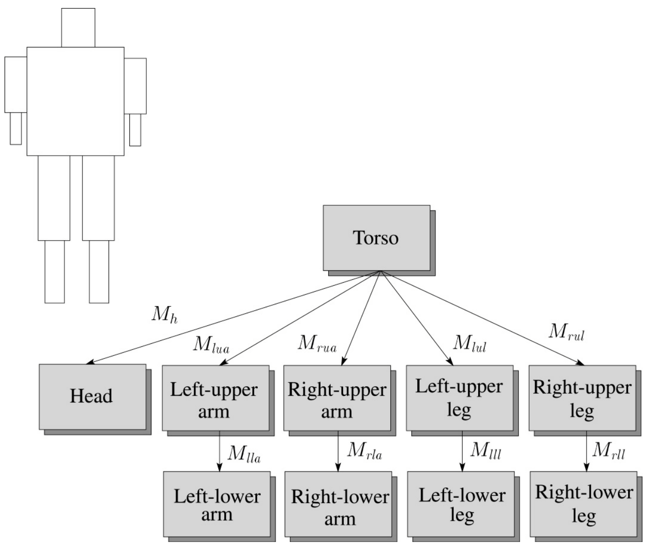




- edges contain geometric transformations
- nodes contain geometry (and possibly drawing attributes)

How might we draw the tree for the robot arm?

A complex example: human figure



Q: What's the most sensible way to traverse this tree?

Human figure implementation, OpenGL

```
figure()
{
    torso();
    glPushMatrix();
        glTranslate( ... );
        glRotate( ... );
        head();
    glPopMatrix();
    glPushMatrix();
        glTranslate( ... );
        glRotate( ... );
        left_upper_arm();
        glPushMatrix();
            glTranslate( ... );
            glRotate( ... );
            left_lower_arm();
        glPopMatrix();
     glPopMatrix();
     . . .
}
```


Order of transformations

Let's revisit the very first simple example in this lecture.

To draw the transformed house, we would write OpenGL code like:

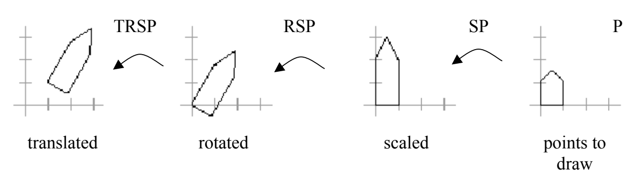
```
glMatrixMode( GL_MODELVIEW );
glLoadIdentity();
glTranslatef( ... );
glRotatef( ... );
glScalef( ... );
house();
```

Note that we are building the composite transformation matrix by starting from the left and postmultiplying each additional matrix

Global, fixed coordinate system

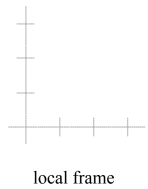
One way to think of transformations is as movement of points in a *global, fixed coordinate system*

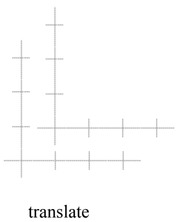
- Build the transformation matrix sequentially from left to right: T, then R, then S
- Then apply the transformation matrix to the object points: multiply all the points in P by the composite matrix TRS
  - this transformation takes the points from original to final positions

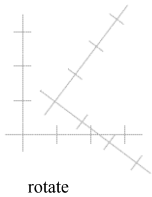


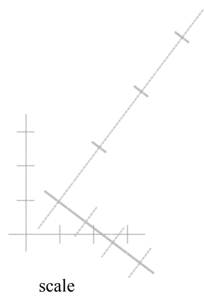
Local, changing coordinate system

Another way to think of transformations is as affecting a *local coordinate system* that the primitive is eventually drawn in.



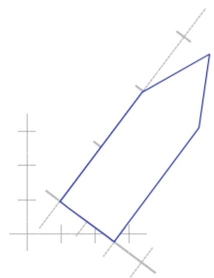






This is EXACTLY the same transformation as on the previous page, it's just how you look at it.

Draw!



Animation

The above examples are called **articulated models**:

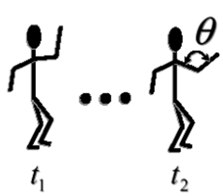
- rigid parts
- connected by joints

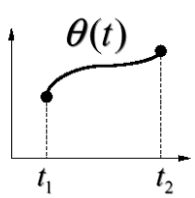
They can be animated by specifying the joint angles (or other display parameters) as functions of time.

Key-frame animation

The most common method for character animation in production is **key-frame animation.**

- Each joint specified at various **key frames** (not necessarily the same as other joints)
- System does interpolation or **in-betweening**





Doing this well requires:

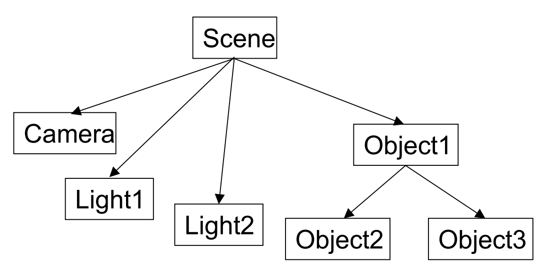
- A way of smoothly interpolating key frames: **splines**
- A good interactive system
- A lot of skill on the part of the animator

Scene graphs

The idea of hierarchical modeling can be extended to an entire scene, encompassing:

- many different objects
- lights
- camera position

This is called a **scene tree** or **scene graph.**



Summary

Here’s what you should take home from this lecture:

- All the **boldfaced terms**.
- How primitives can be instanced and composed to create hierarchical models using geometric transforms.
- How the notion of a model tree or DAG can be extended to entire scenes.
- How OpenGL transformations can be used in hierarchical modeling.
- How keyframe animation works.