

## Hierarchical Modeling

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## Reading

Required:

- ♦ Angel, sections 10.1 – 10.6, 10.8

Optional:

- ♦ *OpenGL Programming Guide*, chapter 3

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## Symbols and instances

Most graphics APIs support a few geometric primitives:

- ♦ spheres
- ♦ cubes
- ♦ cylinders

`gluSphere()`

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



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

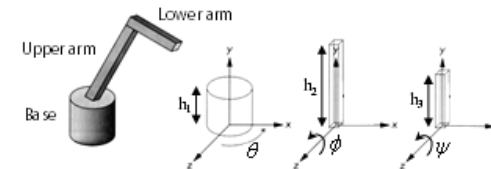
$$M = TRS$$

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## 3D Example: A robot arm

Consider this robot arm with 3 degrees of freedom:

- ♦ Base rotates about its vertical axis by  $\theta$
- ♦ Upper arm rotates in its  $xy$ -plane by  $\phi$
- ♦ Lower arm rotates in its  $xy$ -plane by  $\psi$



(Note that the angles are set to zero in the figure; i.e., the parts are shown in their "default" positions.)

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

$$R_z(\theta)$$

Q: What matrix for the upper arm?

$$T(0, h_1, 0)$$

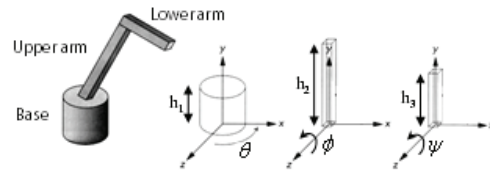
Q: What matrix for the lower arm?

$$\underbrace{R_y(\theta)}_{\text{base}} \underbrace{T(0, h_1, 0)}_{\text{upper arm}} \underbrace{R_z(\phi) T(0, h_2, 0) R_z(\psi)}_{\text{lower arm}}$$

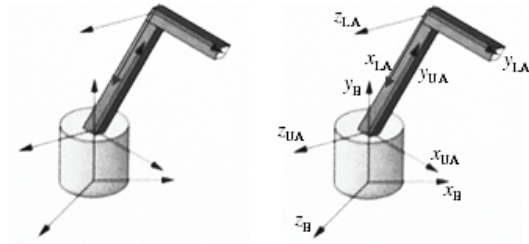
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## 3D Example: A robot arm

An alternative interpretation is that we are taking the original coordinate frames...



... and translating and rotating them into place:



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

Do the matrix computations seem wasteful?

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## 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);
    upper_arm();
    M_model *= T(0,h2,0)*R_z(psi);
    lower_arm();
}
```

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## Robot arm implementation, OpenGL

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

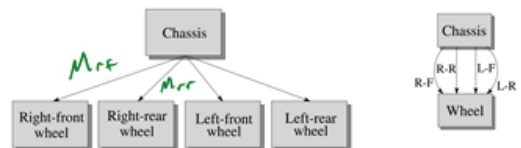
```
main()
{
    . . .
    glMatrixMode( GL_MODELVIEW );
    glLoadIdentity();
    robot_arm();
    . . .
}

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();
}
```

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## Hierarchical modeling

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



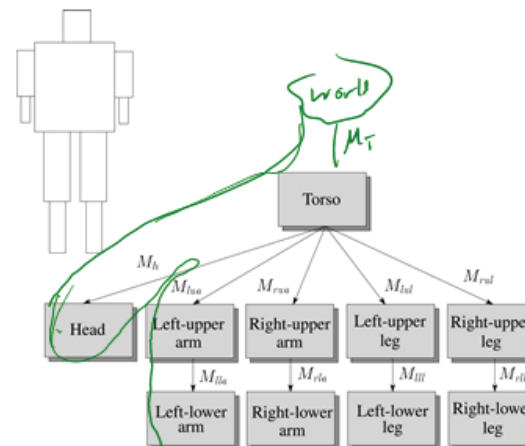
- ◆ edges contain geometric transformations
- ◆ nodes contain geometry (and possibly drawing attributes)

How might we draw the tree for the robot arm?



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## A complex example: human figure



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

depth first search w/ stack

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## Human figure implementation, Open GL

```

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

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## 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.

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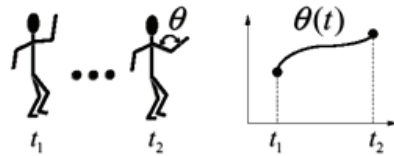
## Key-frame animation

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



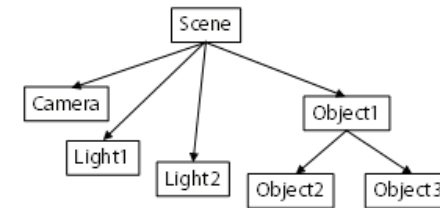
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## Scene graphs

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**.



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## Summary

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

- ◆ All the **bold faced terms**.
- ◆ How primitives can be instantiated 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.

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