Transformation Hierarchies

Wolfgang Heidrich

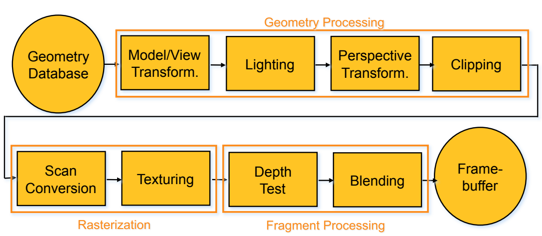
Course News

Assignment 1
- Due January 31

Homework 2
- Exercise problems for perspective
- Discussed in labs next week

Reading
- Chapter 7 (new book) or 6 (old book)

The Rendering Pipeline



Rendering Geometry in OpenGL

Example:

```
glBegin( GL_TRIANGLES );
  glColor3f( 1.0, 0.0, 0.0 );
  glVertex3f( 1.0, 0.0, 0.0 );
  glColor3f( 0.0, 0.0, 1.0 );
  glVertex3f( 0.0, 1.0, 0.0 );
  glVertex3f( 0.0, 0.0, 0.0 );
glEnd();
```

Recap: Rendering Geometry in OpenGL

Additional attributes
- glColor3f: RGB color value (0…1 per component)
- glNormal3f: normal vector
- glTexCoord2f: texture coordinate (explained later)

OpenGL is state machine:
- Every vertex gets color, normal etc. that corresponds to last specified value

Recap: Interpreting Composite OpenGL Transformations

Example for earlier lectures:
- Rotation around arbitrary center
- In OpenGL:

```
// initialization of matrix
glMatrixMode( GL_MODELVIEW );
glLoadIdentity();

glTranslatef( 4, 3 );
glRotatef( 30, 0.0, 0.0, 1.0 );
glTranslatef( -4, -3 );

glBegin( GL_TRIANGLES );
// specify object geometry…
```

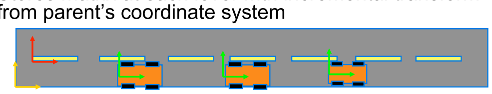
Top-to-bottom: transf. of coordinate frame

Bottom-to-top: transf. of object

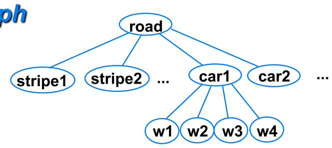
Transformation Hierarchies

Scene may have a hierarchy of coordinate systems

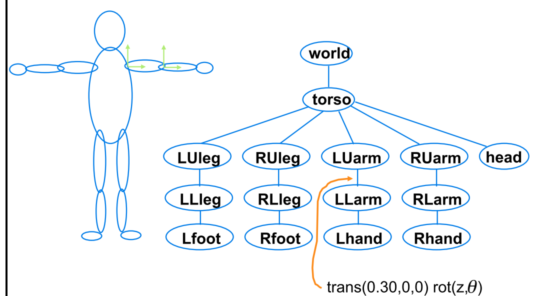
- Stores matrix at each level with incremental transform from parent's coordinate system



Scene graph

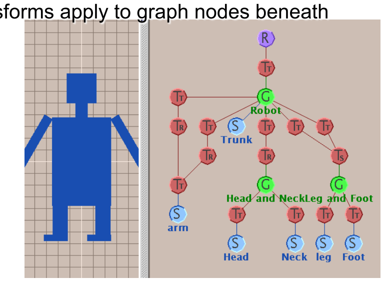


Transformation Hierarchy Example 1



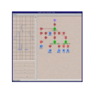
Transformation Hierarchies

- Hierarchies don't fall apart when changed
- transforms apply to graph nodes beneath



Brown Applets

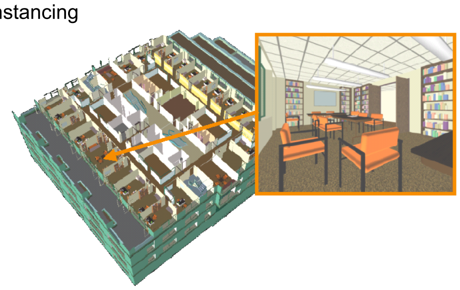
```
http://www.cs.brown.edu/exploratories/
freeSoftware/catalogs/scenegraphs.html
```



- Have a look later

Transformation Hierarchy Example 2

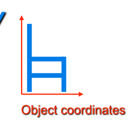
- Draw same 3D data with different transformations: instancing

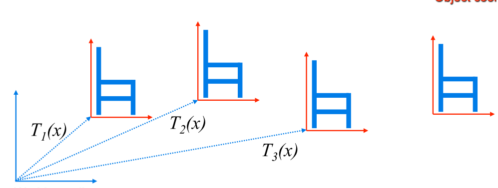


Matrix Stacks

Challenge of avoiding unnecessary computation

- Using inverse to return to origin
- Computing incremental T_1 -> T_2



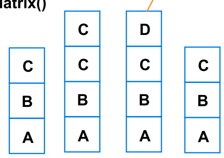


Matrix Stacks

glPushMatrix()

glPopMatrix()

D = C scale(2,2,2) trans(1,0,0)




```
DrawSquare()
glPushMatrix()
glScale3f(2,2,2)
glTranslate3f(1,0,0)
DrawSquare()
glPopMatrix()
```


Modularization

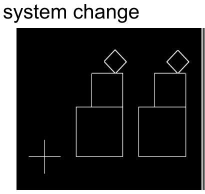
Drawing a scaled square

- Push/pop ensures no coord system change

```
void drawBlock(float k) {
  glPushMatrix();

  glScalef(k,k,k);
  glBegin(GL_LINE_LOOP);
  glVertex3f(0,0,0);
  glVertex3f(1,0,0);
  glVertex3f(1,1,0);
  glVertex3f(0,1,0);
  glEnd();

  glPopMatrix();
}
```



Matrix Stacks

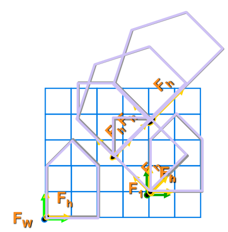
Advantages

- No need to compute inverse matrices all the time
- Modularize changes to pipeline state
- Avoids incremental changes to coordinate systems
  - *Accumulation of numerical errors*

Practical issues

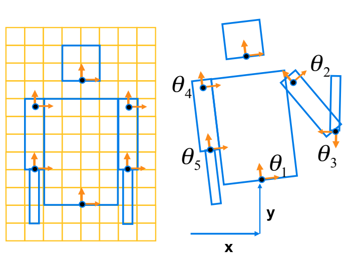
- In graphics hardware, depth of matrix stacks is limited
  - *(typically 16 for model/view and about 4 for projective matrix)*

Transformation Hierarchy Example 3




```
glLoadIdentity();
glTranslatef(4,1,0);
glPushMatrix();
glRotatef(45,0,0,1);
glTranslatef(0,2,0);
glScalef(2,1,1);
glTranslate(1,0,0);
glPopMatrix();
```


Transformation Hierarchy Example 4




```
glTranslate3f(x,y,0);
glRotatef(θ1,0,0,1);
DrawBody();
glPushMatrix();
  glTranslate3f(0,7,0);
  DrawHead();
glPopMatrix();
glPushMatrix();
  glTranslate(2.5,5.5,0);
  glRotatef(θ2,0,0,1);
  DrawUArm();
  glTranslate(0,-3.5,0);
  glRotatef(θ3,0,0,1);
  DrawLArm();
glPopMatrix();
... (draw other arm)
```


Hierarchical Modeling

Advantages

- Define object once, instantiate multiple copies
- Transformation parameters often good control knobs
- Maintain structural constraints if well-designed

Limitations

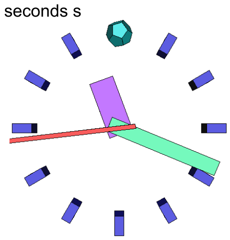
- Expressivity: not always the best controls
- Can't do closed kinematic chains
  - *Keep hand on hip*

Single Parameter: simple

Parameters as functions of other params

- Clock: control all hands with seconds s

m = s/60, h=m/60,
theta_s = (2 pi s) / 60,
theta_m = (2 pi m) / 60,
theta_h = (2 pi h) / 60



Single Parameter: complex

Mechanisms not easily expressible with affine transforms

http://www.flying-pig.co.uk

Representing Complex Geometry

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Display Lists

Concept:

- If multiple copies of an object are required, it can be compiled into a display list:

```
glNewList( listId, GL_COMPILE );
  glBegin( …);
  … // geometry goes here
glEndList();
// render two copies of geometry offset by 1 in z-direction:
glCallList( listId );
glTranslatef( 0.0, 0.0, 1.0 );
glCallList( listId) ;
```


Display Lists

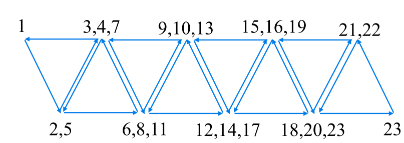
Advantages:

- More efficient than individual function calls for every vertex/attribute
- Can be cached on the graphics board (bandwidth!)
- Display lists exist across multiple frames
  - *Represent static objects in an interactive application*

Shared Vertices

Triangle Meshes

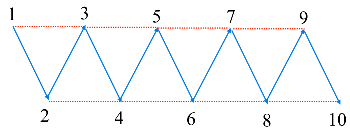
- Multiple triangles share vertices
- If individual triangles are sent to graphics board, every vertex is sent and transformed multiple times!
  - *Computational expense*
  - *Bandwidth*



Triangle Strips

Idea:

- Encode neighboring triangles that share vertices
- Use an encoding that requires only a constant-sized part of the whole geometry to determine a single triangle
- N triangles need n+2 vertices



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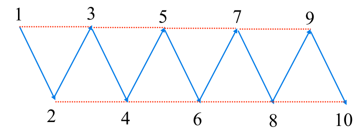
Triangle Strips

Orientation:

- Strip starts with a counter-clockwise triangle
- Then alternates between clockwise and counter-clockwise



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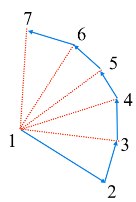
Triangle Fans

Similar concept:

- All triangles share on center vertex
- All other vertices are specified in CCW order



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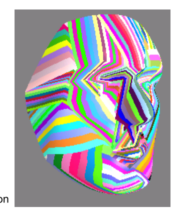
Triangle Strips and Fans

Transformations:

- n+2 for n triangles
- Only requires 3 vertices to be stored according to simple access scheme
- Ideal for pipeline (local knowledge)

Generation

- E.g. from directed edge data structure
- Optimize for longest strips/fans



Strippification by Dana Sharon

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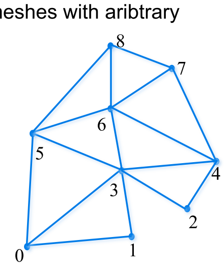
Vertex Arrays

Concept:

- Store array of vertex data for meshes with aribtrary connectivity (topology)

```
GLfloat *points[3*nvertices];
GLfloat *colors[3*nvertices];
Glint *tris[numtris]=
  {0,1,3,  3,2,4, …};
glVertexPointer( …, points );
glColorPointer( …,colors );
glDrawElements(
  GL_TRIANGLES,…,tris );
```



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Vertex Arrays

Benefits:

- Ideally, vertex array fits into memory on GPU
- Then all vertices are transformed exactly once

In practice:

- Graphics memory may not be sufficient to hold model
- Then either:
  - *Cache only parts of the vertex array on board (may lead to cache trashing!)*
  - *Transform everything in software and just send results for individual triangles (bandwidth problem: multiple transfers of same vertex!)*

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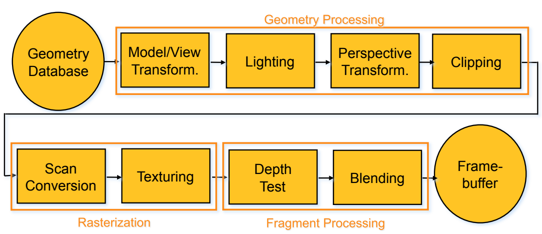
The Rendering Pipeline



Coming Up:

This Week:

- Perspective projection