CS312

OpenGL

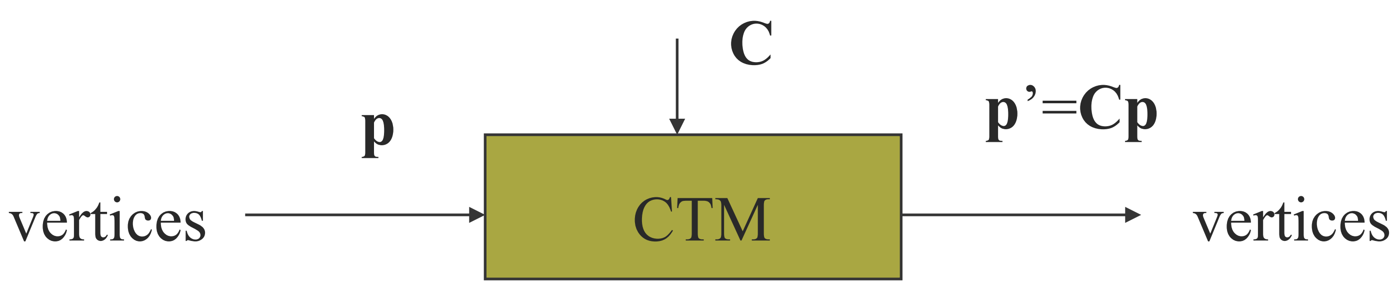
Modeling Transformations

OpenGL Matrices

- In OpenGL matrices are part of the state
- Three types
  - Model-View (**`GL_MODELVIEW`**)
  - Projection (**`GL_PROJECTION`**)
  - Texture (**`GL_TEXTURE`**) (ignore for now)
- Single set of functions for manipulation
- Select which to manipulated by
  - **`glMatrixMode(GL_MODELVIEW);`**
  - **`glMatrixMode(GL_PROJECTION);`**

Current Transformation Matrix (CTM)

- Conceptually there is a 4 x 4 homogeneous coordinate matrix, the *current transformation matrix* (CTM) that is applied to all vertices that pass down the pipeline
- The CTM is defined in the user program and loaded into a transformation unit



CTM operations

- The CTM can be altered either by loading a new CTM or by postmutiplication

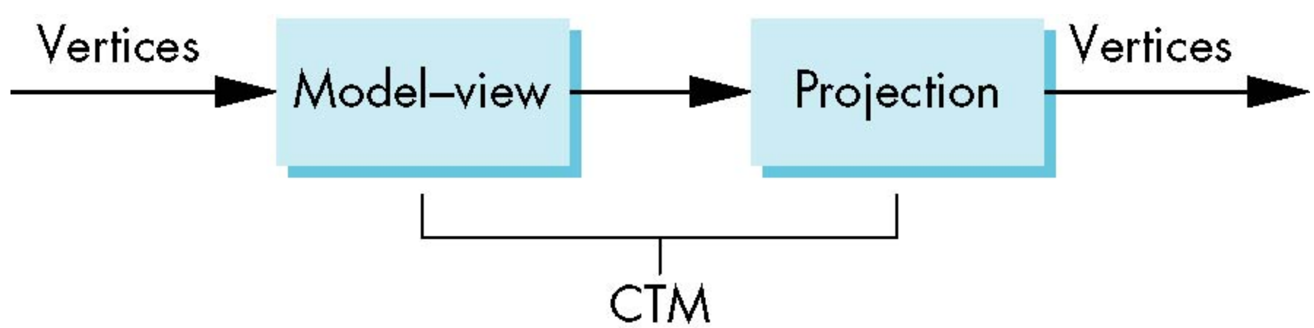
  Load an identity matrix: $\mathbf{C} \leftarrow \mathbf{I}$
  Load an arbitrary matrix: $\mathbf{C} \leftarrow \mathbf{M}$

  Load a translation matrix: $\mathbf{C} \leftarrow \mathbf{T}$
  Load a rotation matrix: $\mathbf{C} \leftarrow \mathbf{R}$
  Load a scaling matrix: $\mathbf{C} \leftarrow \mathbf{S}$

  Postmultiply by an arbitrary matrix: $\mathbf{C} \leftarrow \mathbf{CM}$
  Postmultiply by a translation matrix: $\mathbf{C} \leftarrow \mathbf{CT}$
  Postmultiply by a rotation matrix: $\mathbf{C} \leftarrow \mathbf{C}\ \mathbf{R}$
  Postmultiply by a scaling matrix: $\mathbf{C} \leftarrow \mathbf{C}\ \mathbf{S}$

CTM in OpenGL

- OpenGL has a model-view and a projection matrix in the pipeline which are concatenated together to form the CTM
- Can manipulate each by first setting the correct matrix mode



Matrix Operations

- Specify current matrix stack

  `glMatrixMode(GL_MODELVIEW)` or

  `glMatrixMode(GL_PROJECTION)`
- Matrix operations
  - **`glLoadIdentity()`**
  - **`glPushMatrix()`**
  - **`glPopMatrix()`**
  - **`glLoadMatrix()`**
  - **`glMultMatrix()`**

Modeling Transformations

- Translation
  - **`glTranslate{fd}(x,y,z)`**
- Rotation around arbitrary axis
  - **`glRotate{fd}(angle, x,y,z)`**
- Scaling
  - **`glScale{fd}(x,y,z)`**
- Multiplies onto the current matrix (use **`GL_MODELVIEW`**)

Order of Transformations

- OpenGL post-multiplies matrices
- Operations occur in reverse order

```
glLoadIdentity();
glMultMatrix(M);
glMultMatrix(N);        →   CIMNO(v)
glMultMatrix(O);
glBegin(GL_POINTS);
glVertex3fv(v);
glEnd();
```

Post-multiplication: Rotation about a Fixed Point

- Start with identity matrix: $\mathbf{C} \leftarrow \mathbf{I}$
- Move fixed point to origin: $\mathbf{C} \leftarrow \mathbf{CT}$
- Rotate: $\mathbf{C} \leftarrow \mathbf{CR}$
- Move fixed point back: $\mathbf{C} \leftarrow \mathbf{CT}^{-1}$
- Result: $\mathbf{C} = \mathbf{TR}\,\mathbf{T}^{-1}$ which is backwards.
- This result is a consequence of doing postmultiplications.

Reversing the Order

- We want $\mathbf{C} = \mathbf{T}^{-1}\,\mathbf{R}\,\mathbf{T}$
  - $\mathbf{C} \leftarrow \mathbf{I}$
  - $\mathbf{C} \leftarrow \mathbf{C}\mathbf{T}^{-1}$
  - $\mathbf{C} \leftarrow \mathbf{C}\mathbf{R}$
  - $\mathbf{C} \leftarrow \mathbf{C}\mathbf{T}$
  - Each operation corresponds to one function call in the program.
- Note that the last operation specified is the first executed in the program

Example

- Rotation about z axis by 30 degrees with a fixed point of (1.0, 2.0, 3.0)

```
glMatrixMode(GL_MODELVIEW);
glLoadIdentity();
glTranslatef(1.0, 2.0, 3.0);
glRotatef(30.0, 0.0, 0.0, 1.0);
glTranslatef(-1.0, -2.0, -3.0);
```

- Remember that last matrix specified in the program is the first applied

Arbitrary Matrices

- Can load and multiply by matrices defined in the application program

```
glLoadMatrixf(m)
glMultMatrixf(m)
```

- The matrix **`m`** is a one dimension array of 16 elements which are the components of the desired 4 x 4 matrix stored by <u>columns</u>
- In **`glMultMatrixf`**, **`m`** multiplies the existing matrix on the right

Matrix Stacks

- In many situations we want to save transformation matrices for use later
  - Traversing hierarchical data structures
  - Avoiding state changes when executing display lists (introduced later)
- OpenGL maintains stacks for each type of matrix
  - Access present type (as set by **`glMatrixMode`**) by **`glPushMatrix()`**
    `glPopMatrix()`

Matrix Stack

- Code often looks like this:

```
glPushMatrix();
glTranslatef(…);
glRotatef(…);
/* draw object */
glPopMatrix();
```

Reading Back Matrices

- Can also access matrices (and other parts of the state) by *query* functions

```
glGetIntegerv
glGetFloatv
glGetBooleanv
glGetDoublev
glIsEnabled
```

- For matrices, we use as

```
double m[16];
glGetFloatv(GL_MODELVIEW, m);
```

Smooth Rotation

- From a practical standpoint, we are often want to use transformations to move and reorient an object smoothly
  - Problem: find a sequence of model-view matrices $\mathbf{M}_0, \mathbf{M}_1, \ldots, \mathbf{M}_n$ so that when they are applied successively to one or more objects we see a smooth transition
- For orientating an object, we can use the fact that every rotation corresponds to part of a great circle on a sphere
  - Find the axis of rotation and angle

Incremental Rotation

- Consider the two approaches
  - For a sequence of rotation matrices $\mathbf{R}_0, \mathbf{R}_1, \ldots\ldots, \mathbf{R}_n$, find the Euler angles for each and use $\mathbf{R}_i = \mathbf{R}_{iz}\,\mathbf{R}_{iy}\,\mathbf{R}_{ix}$
    - Not very efficient
  - Use the final positions to determine the axis and angle of rotation, then increment only the angle

Animate with the Idle Callback

```
void draw() {
   glPushMatrix();
   glRotatef(angle, 0,0,1);
   // draw
   glPopMatrix();
   glutSwapBuffers();
}
void animate() {
   angle += 2.0;
   glutPostRedisplay();
}
glutIdleFunc(animate);
```

Double buffering

- Two color buffers so that when one is displayed, the other is being redrawn.
- When drawing is complete, buffers are swapped.
- The viewer never sees an incompletely drawn buffer.
- Eliminates flickering.

Animation using Double Buffering

- Requests a double buffered color buffer
- Clear color buffer

`glClear(GL_COLOR_BUFFER_BIT)`

- Render scene
- Request swapping of front and back buffers

Double buffering in GL

- `glInitDisplayMode(GLUT_DOUBLE);`
-
```
void display() {
  glClear(GL_COLOR_BUFFER_BIT);
  ...
  glutSwapBuffers();
}
```
- `glutSwapBuffers()` flushes automatically