University of
British Columbia

Chapter 3

Rendering Pipeline

OpenGL/Glut

3D Graphics

- Modeling
  - representing object properties
    - geometry: polygons, smooth surfaces etc.
    - materials: reflection models etc.
- Rendering
  - generation of images from models
    - interactive rendering
    - ray-tracing
- Animation
  - making geometric models move and deform

University of
British Columbia

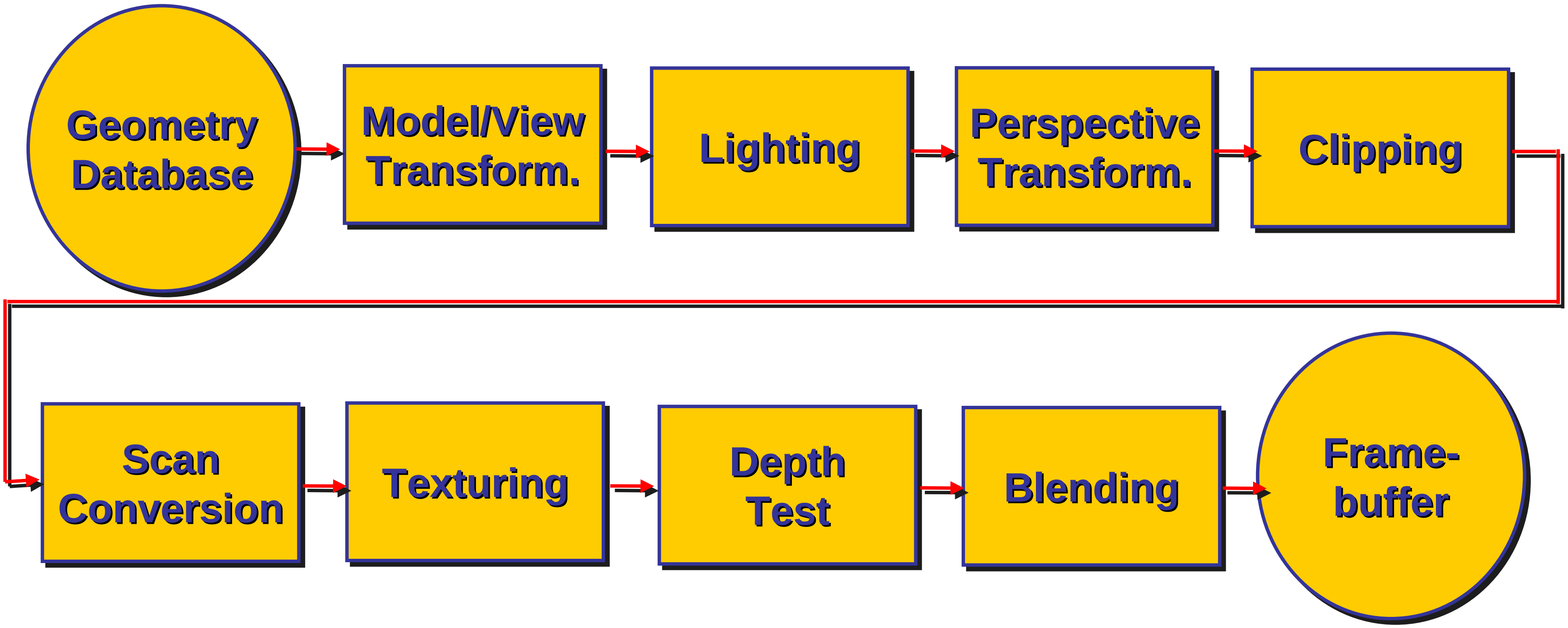
Rendering

- Goal
  - transform computer models into images
  - photo-realistic or not
- Interactive rendering
  - fast, but limited quality
  - roughly follows a fixed patterns of operations
    - rendering pipeline
- Offline rendering
  - ray-tracing
  - global illumination

Rendering

- Tasks (in no particular order):
  - project all 3D geometry onto the image plane
    - geometric transformations
  - determine which primitives or parts of primitives are visible
    - hidden surface removal
  - determine which pixels a geometric primitive covers
    - scan conversion
  - compute the color of every visible surface point
    - lighting, shading, texture mapping

The Rendering Pipeline



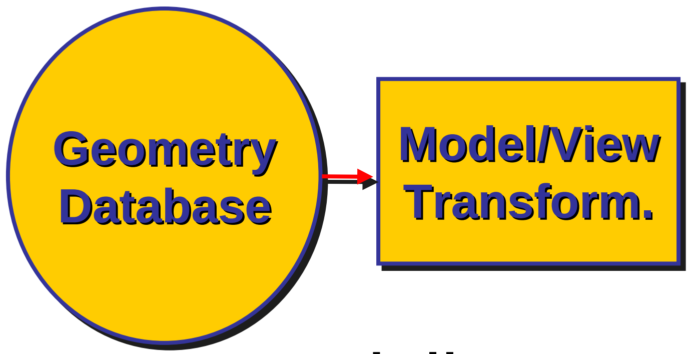
Geometry Database

Geometry Database

- Geometry database:
  - Application-specific data structure for holding geometric information
  - Depends on specific needs of application
    - Independent triangles, connectivity information etc.

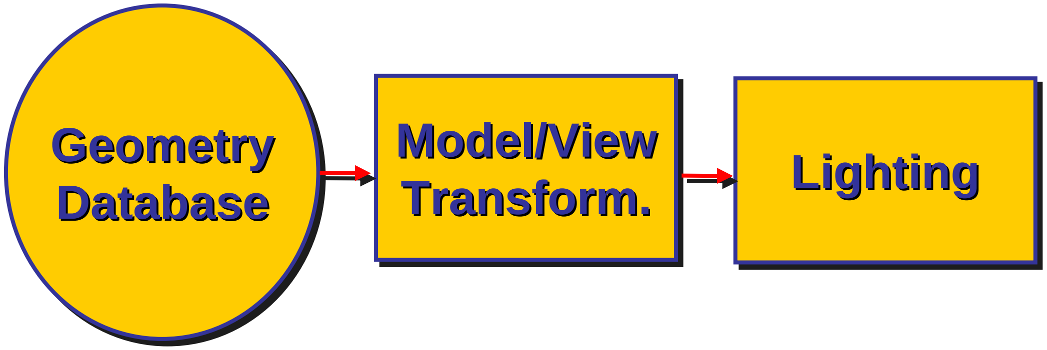
University of British Columbia

Model/View Transformation



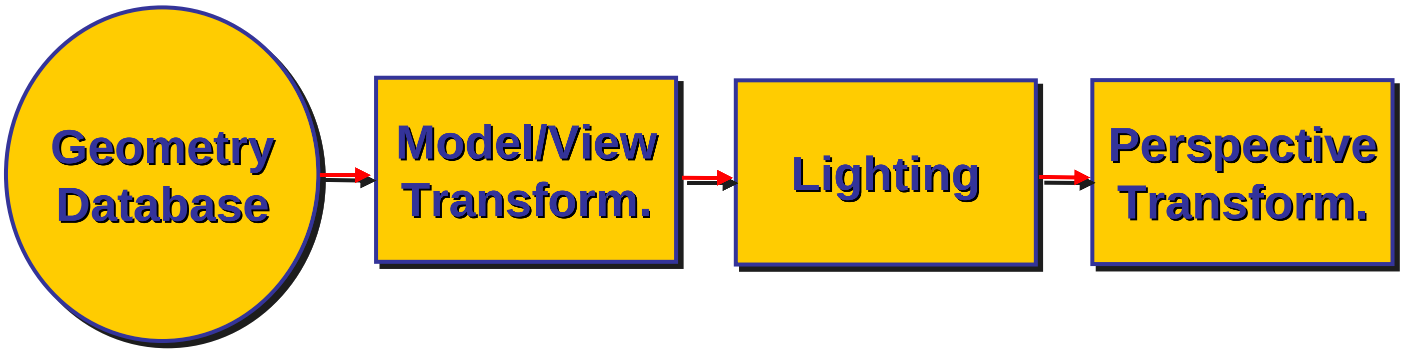
- Modeling transformation:
  - Map all geometric objects from a local coordinate system into a world coordinate system
- Viewing transformation:
  - Map all geometry from world coordinates into camera coordinates

Lighting



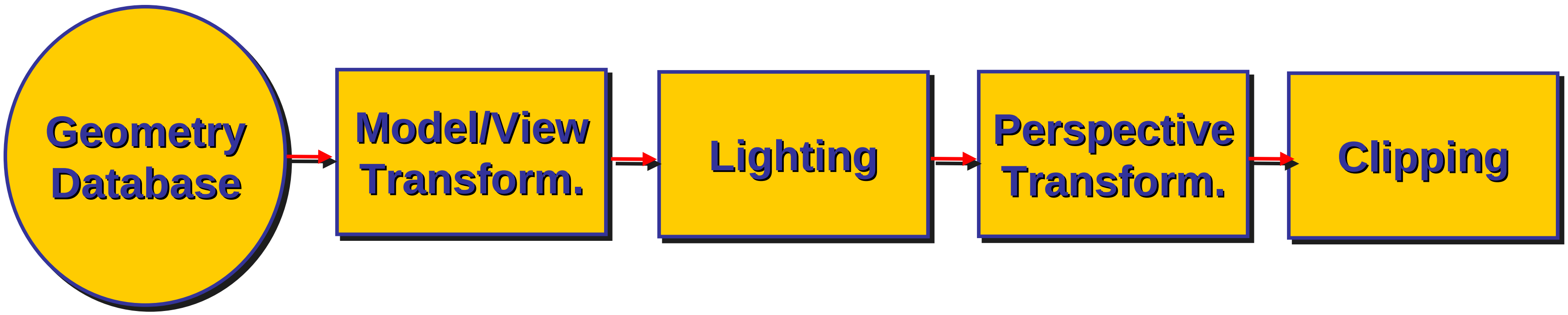
- Lighting:
  - Compute the brightness of every point based on its material properties (e.g. Lambertian diffuse) and the light position(s)
  - Computation is performed *per-vertex*

Perspective Transformation



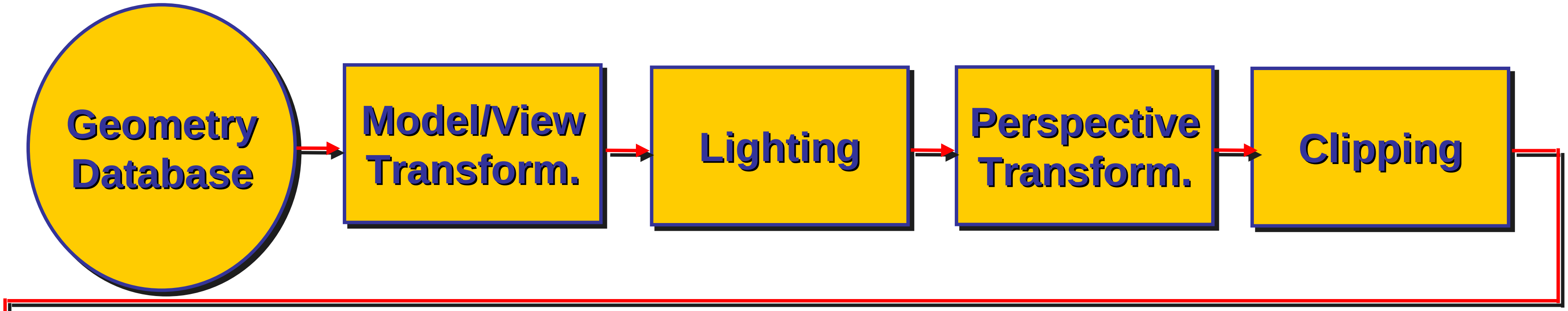
- Perspective transformation
  - Projecting the geometry onto the image plane
  - Projective transformations and model/view transformations can all be expressed with 4x4 matrix operations

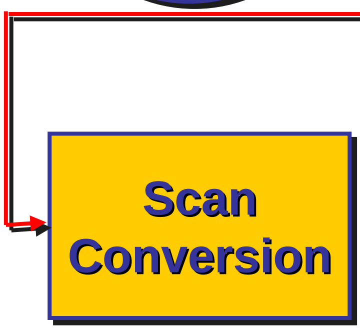
Clipping



- Clipping
  - Removal of parts of the geometry that fall outside the visible screen or window region
  - May require *re-tessellation* of geometry

Scan Conversion

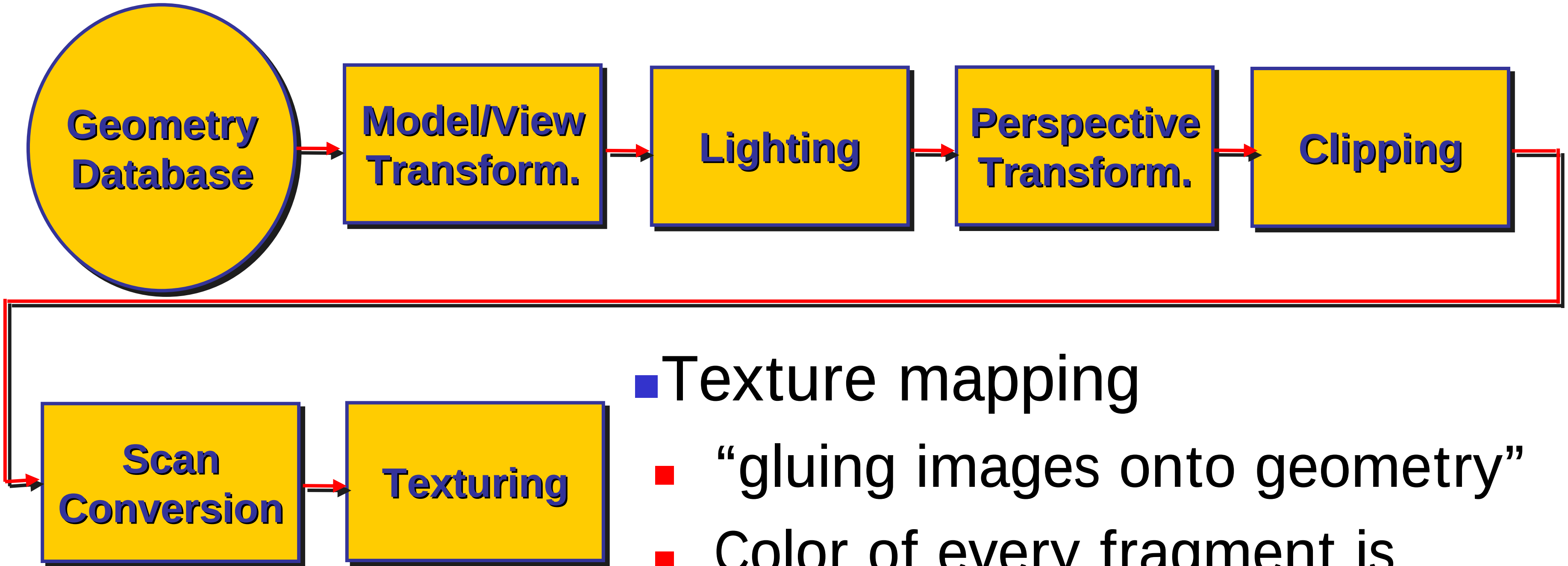




- Scan conversion
  - Turn 2D drawing primitives (lines, polygons etc.) into individual pixels (*discretizing/sampling*)
  - Interpolate color across primitive
  - Generate discrete *fragments*

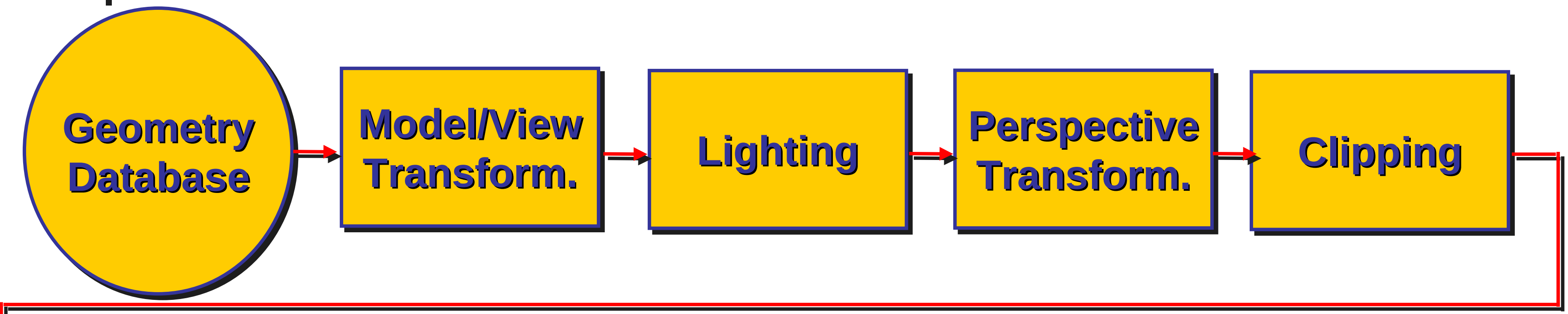
University of British Columbia

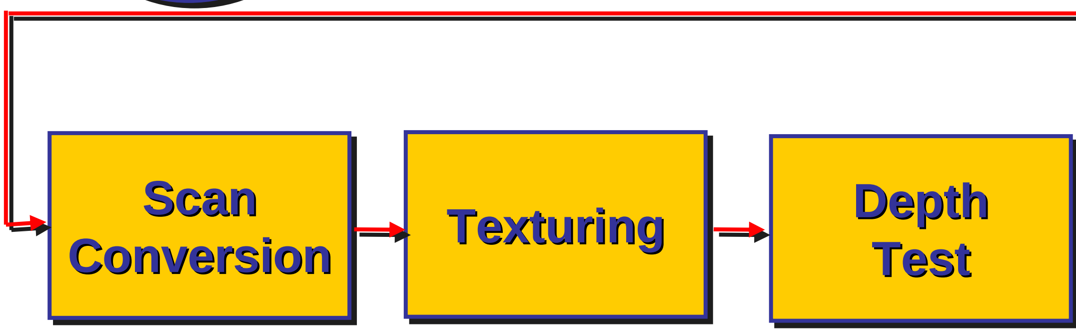
Texture Mapping



- Texture mapping
  - “gluing images onto geometry”
  - Color of every fragment is altered by looking up a new color value from an image

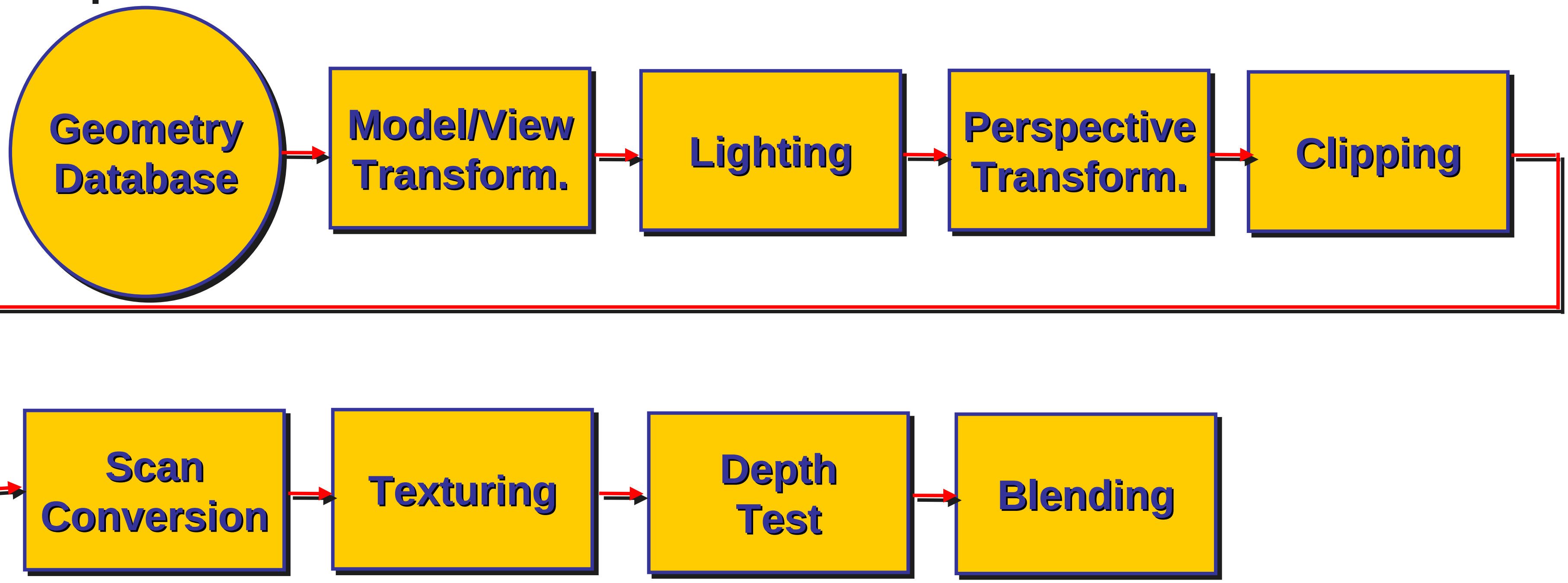
Depth Test





- Depth test:
  - Remove parts of geometry hidden behind other geometry
- Perform on every individual fragment
  - other approaches (later)

Blending

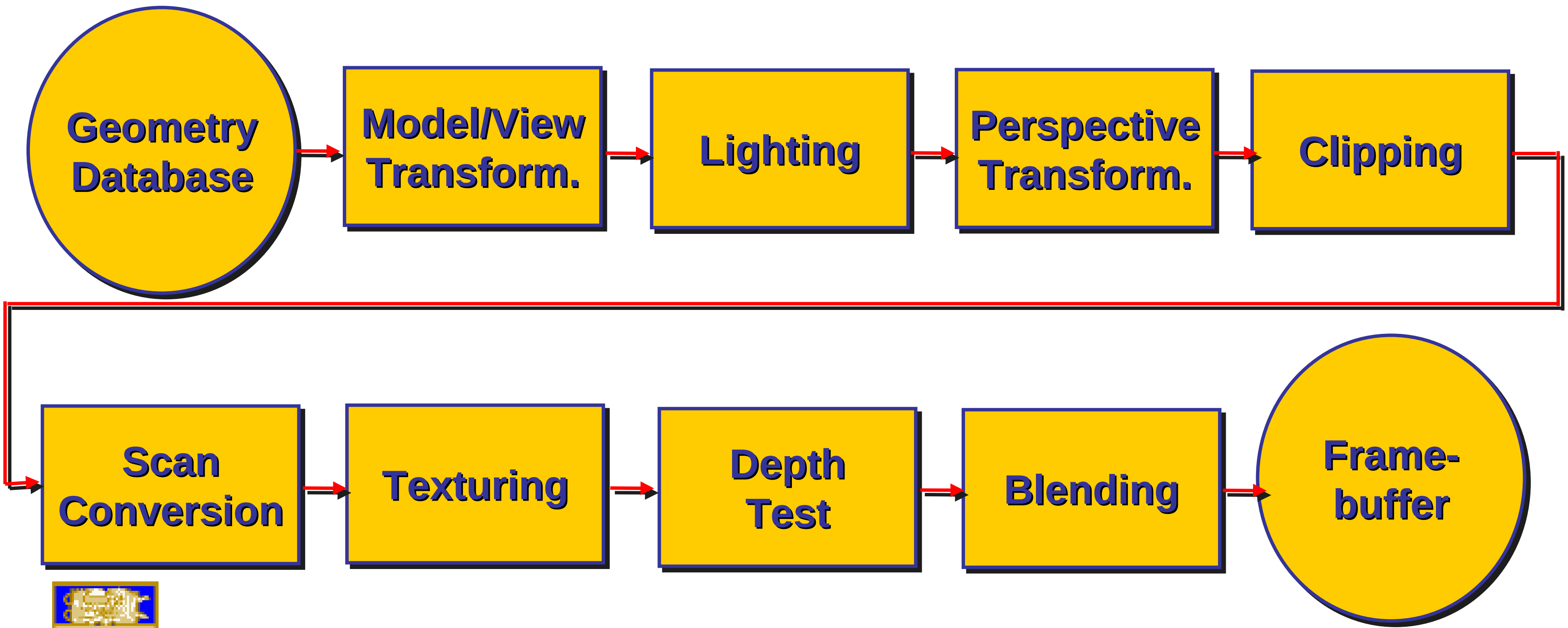


University of
British Columbia

Blending

- Blending:
  - Final image: write fragments to pixels
  - Draw from farthest to nearest
  - No blending – replace previous color
  - Blending: combine new & old values with some arithmetic operations
  - *Framebuffer :* video memory on graphics board that holds resulting image & used to display it

The Rendering Pipeline



University of
British Columbia

University of
British Columbia

OpenGL/GLUT

OpenGL

- started in 1989 by Kurt Akeley
  - based on IRIS_GL by SGI
- API to graphics hardware
- designed to exploit hardware optimized for display and manipulation of 3D graphics
- implemented on many different platforms
- low level, powerful flexible
- pipeline processing
  - set state as needed

Graphics State

- set state once, remains until overwritten
  - glColor3f(1.0, 1.0, 0.0) → set color to yellow
  - glSetClearColor(0.0, 0.0, 0.2) → dark blue bg
  - glEnable(LIGHT0) → turn on light
  - glEnable(GL_DEPTH_TEST) → hidden surf.

Geometry Pipeline

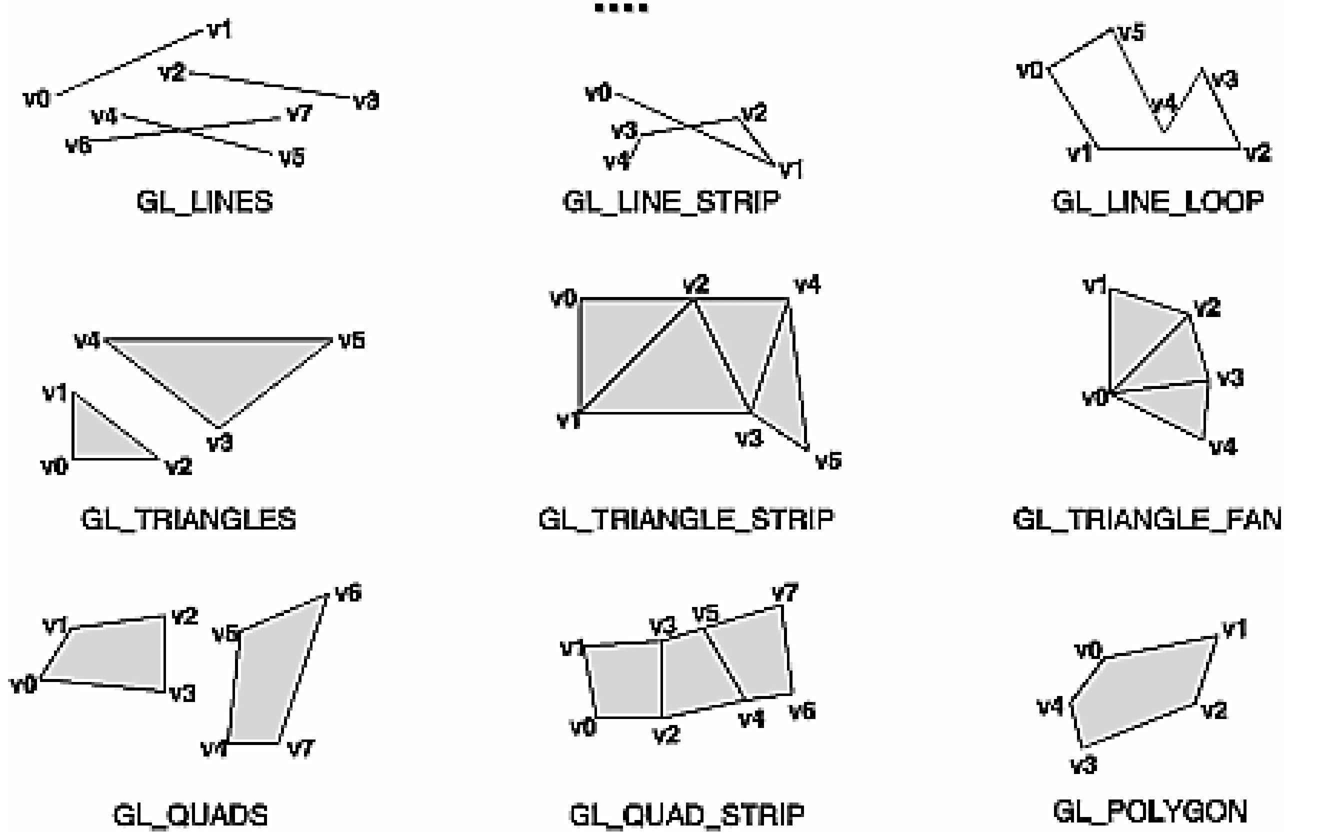
- how to interpret geometry
  - glBegin(<*mode of geometric primitives*>)
  - *mode* = GL_TRIANGLE, GL_POLYGON, etc.

- feed vertices
  - glVertex3f(-1.0, 0.0, -1.0)
  - glVertex3f(1.0, 0.0, -1.0)
  - glVertex3f(0.0, 1.0, -1.0)

- done
  - glEnd()

Open GL: Primitives

glPointSize(float size);
glLineWidth(float width);
glColor3f(float r, float g, float b);
....



University of British Columbia

OpenGL Example

- TRIANGLE…

```
glColor3f(0,1,0);
glBegin( GL_TRIANGLES );
  glVertex3f( 0.0f, 0.5f, 0.0f );
  glVertex3f( -0.5f, -0.5f, 0.0f );
  glVertex3f( 0.5f, -0.5f, 0.0f );
glEnd();
```

GLUT: OpenGL Utility Toolkit

- The basics...

```
int main(int argc, char **argv)
{
      glutInit( &argc, argv );
      glutInitDisplayMode( GLUT_RGB |
                           GLUT_DOUBLE | GLUT_DEPTH);
      glutInitWindowSize( 640, 480 );
      glutCreateWindow( "openGLDemo" );
      glutDisplayFunc( DrawWorld );
      glutIdleFunc(Idle);
      glClearColor( 1,1,1 );
      glutMainLoop();

      return 0;       // never reached
}
```

Event-Driven Programming

- main loop not under your control
  - vs. procedural
- control flow through event callbacks
  - redraw the window now
  - key was pressed
  - mouse moved
- callback functions called from main loop when events occur
  - mouse/keyboard state setting vs. redrawing

OpenGL/GLUT Example

```
void DrawWorld() {
        glMatrixMode( GL_PROJECTION );
        glLoadIdentity();
        glMatrixMode( GL_MODELVIEW );
        glLoadIdentity();
        glClear( GL_COLOR_BUFFER_BIT );
        angle += 0.05;
        glRotatef(angle,0,0,1);
        ...  // draw triangle
        glutSwapBuffers();
}
```

GLUT Example

```
void Idle() {
        angle += 0.05;
        glutPostRedisplay();
}
```

GLUT Input Events

```
  // you supply these kind of functions
void reshape(int w, int h);
void keyboard(unsigned char key, int x, int y);
void mouse(int but, int state, int x, int y);

  // register them with glut
glutReshapeFunc(reshape);
glutKeyboardFunc(keyboard);
glutMouseFunc(mouse);
```

University of
British Columbia

GLUT and GLU primitives

```
gluSphere(...)
gluCylinder(...)

glutSolidSphere(...)
glutWireSphere(...)

glutSolidCube(...)
glutWireCube(...)

glutSolidTorus(...)
glutWireTorus(...)

glutSolidTeapot(...)
glotWireTeapot(...)
```

Depth buffer

- for visibility
  - stores a z-value for every pixel
  - smaller z means "closer"

```
  // allocate depth buffer
glutInitDisplayMode( GLUT_RGB | GLUT_DOUBLE | GLUT_DEPTH);

  // enabling the depth test
glEnable( GL_DEPTH_TEST );

  // clearing the depth buffer for each frame
glClear( GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
```

GLUT menus

```
glutCreateMenu(...)
glutSetMenu(...)
glutGetMenu(...)
glutDestroyMenu(...)
glutAddMenuEntry(...)
glutAddSubMenu(...)
glutAttachMenu(...)

  // Example usage
glutCreateMenu(demo_menu);
glutAddMenuEntry("quit", 1);
glutAddMenuEntry("Increase Square Size", 2);
glutAttachMenu(GLUT_RIGHT_BUTTON);
```

Assignment 0

- Programming:
  - Experience OpenGL & GLUT
  - See “real” models – meshes in OBJ format
- Theory:
  - Basic math review
- Description:

http://www.ugrad.cs.ubc.ca/~cs314/Vsep2004/a0/a0.pdf

- Deadline: Sep 23
- Basis for future assignments