University of British Columbia
CPSC 314 Computer Graphics
Jan-Apr 2007

Tamara Munzner

OpenGL/GLUT Intro

Week 1, Fri Jan 12

http://www.ugrad.cs.ubc.ca/~cs314/Vjan2007

News

- Labs start next week
- Reminder: my office hours Wed/Fri 11-12
  - in your 011 lab, not my X661 office
- Leftover handouts will be in 011 lab

Today's Readings

- today
  - RB Chap Introduction to OpenGL
  - RB Chap State Management and Drawing Geometric Objects
  - RB App Basics of GLUT (Aux in v 1.1)

Readings for Next Four Lectures

- FCG Chap 6 Transformation Matrices
  - *except* 6.1.6, 6.3.1
- FCG Sect 13.3 Scene Graphs
- RB Chap Viewing
  - Viewing and Modeling Transforms *until* Viewing Transformations
  - Examples of Composing Several Transformations *through* Building an Articulated Robot Arm
- RB Appendix Homogeneous Coordinates and Transformation Matrices
  - *until* Perspective Projection
- RB Chap Display Lists

Correction: Vector-Vector Multiplication

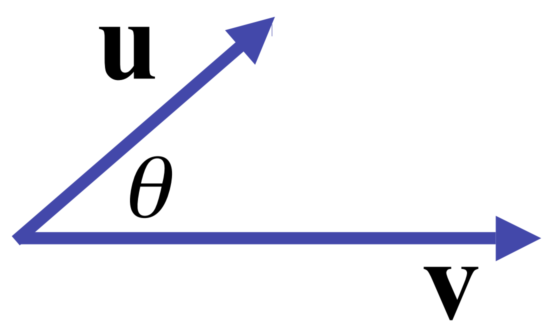
- multiply: vector * vector = scalar
- dot product, aka inner product

$$\mathbf{u} \bullet \mathbf{v}$$

$$\begin{bmatrix} u_1 \\ u_2 \\ u_3 \end{bmatrix} \bullet \begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} = (u_1 * v_1) + (u_2 * v_2) + (u_3 * v_3)$$

$$\mathbf{u} \bullet \mathbf{v} = \|\mathbf{u}\| \|\mathbf{v}\| \cos\theta$$

- geometric interpretation
  - lengths, angles
  - can find angle between two vectors

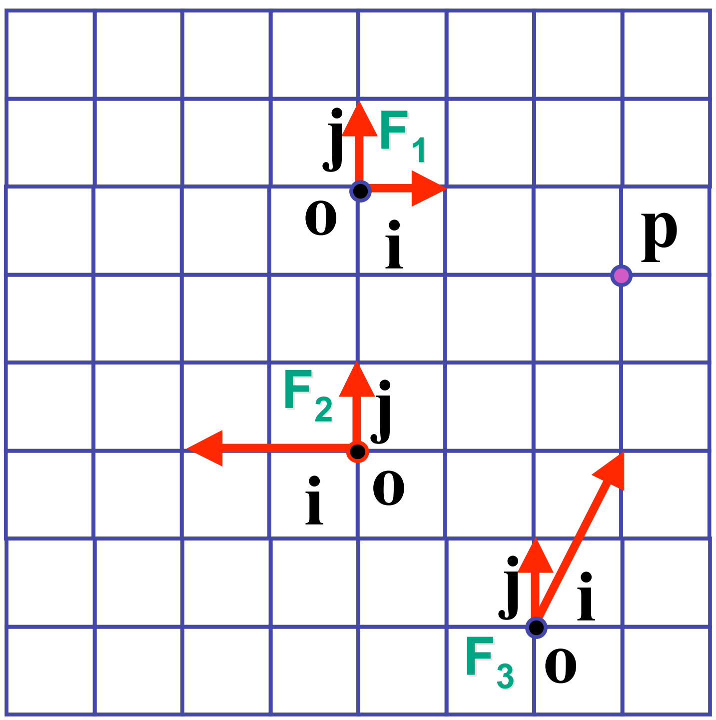


Correction: Dot Product Example

$$\begin{bmatrix} u_1 \\ u_2 \\ u_3 \end{bmatrix} \bullet \begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} = (u_1 * v_1) + \boxed{(u_2} * v_2) + (u_3 * v_3)$$

$$\begin{bmatrix} 6 \\ 1 \\ 2 \end{bmatrix} \bullet \begin{bmatrix} 1 \\ 7 \\ 3 \end{bmatrix} = (6 * 1) + (1 * 7) + (2 * 3) = 6 + 7 + 6 = 19$$

Review: Working with Frames



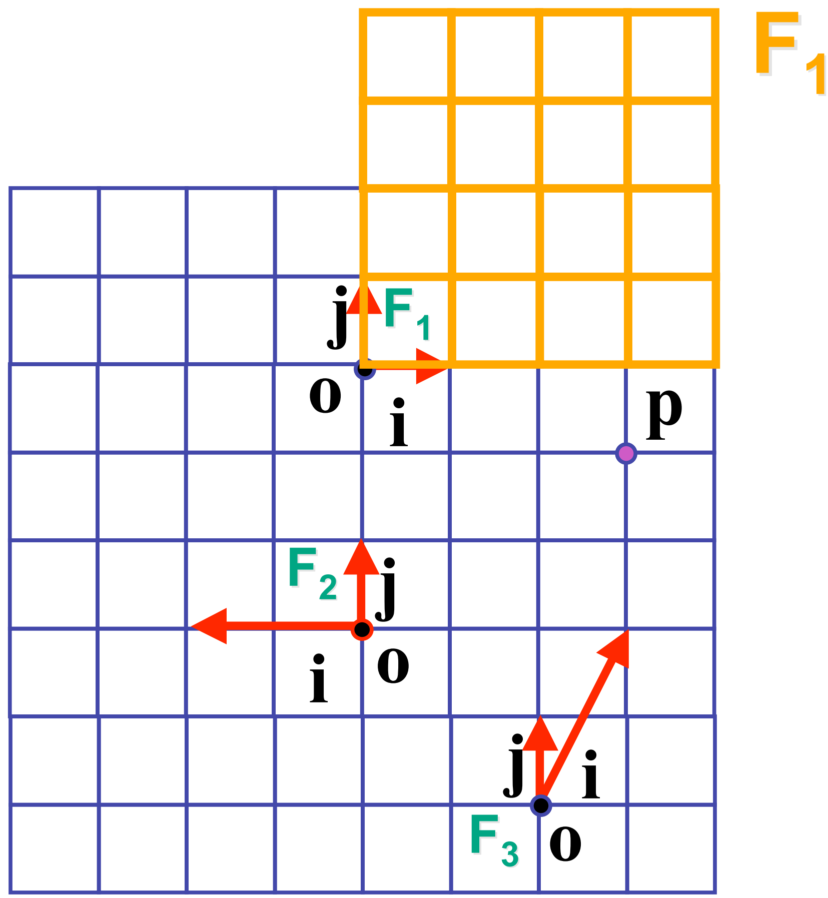
$$\mathbf{p} = \mathbf{o} + x\mathbf{i} + y\mathbf{j}$$

F_1 p = (3,-1)

F_2 p = (-1.5,2)

F_3 p = (1,2)

More: Working with Frames



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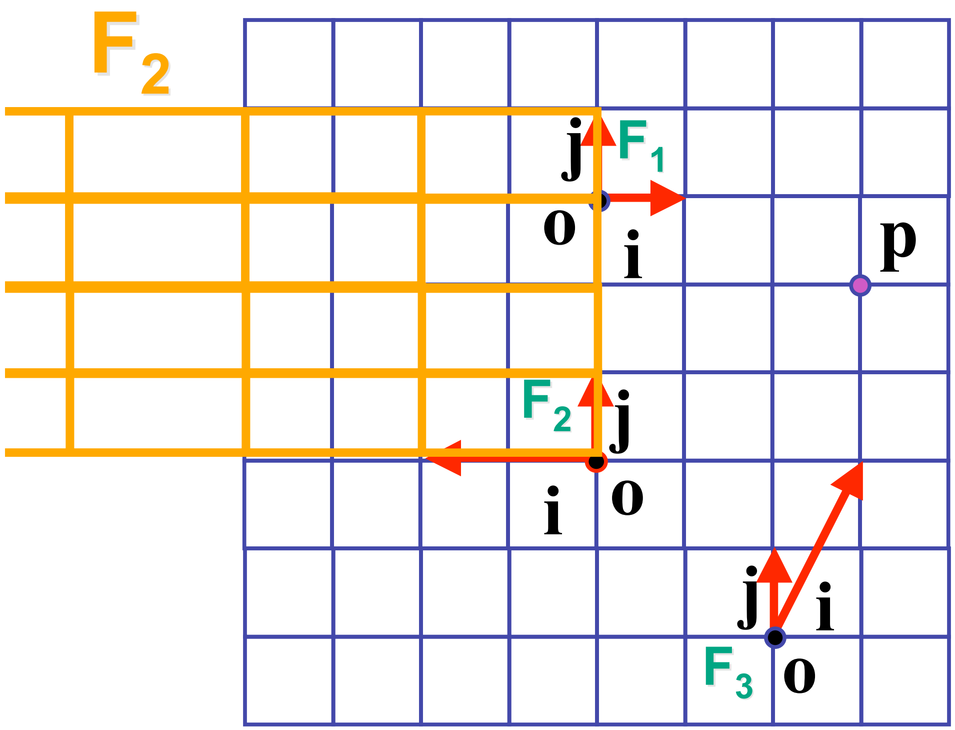

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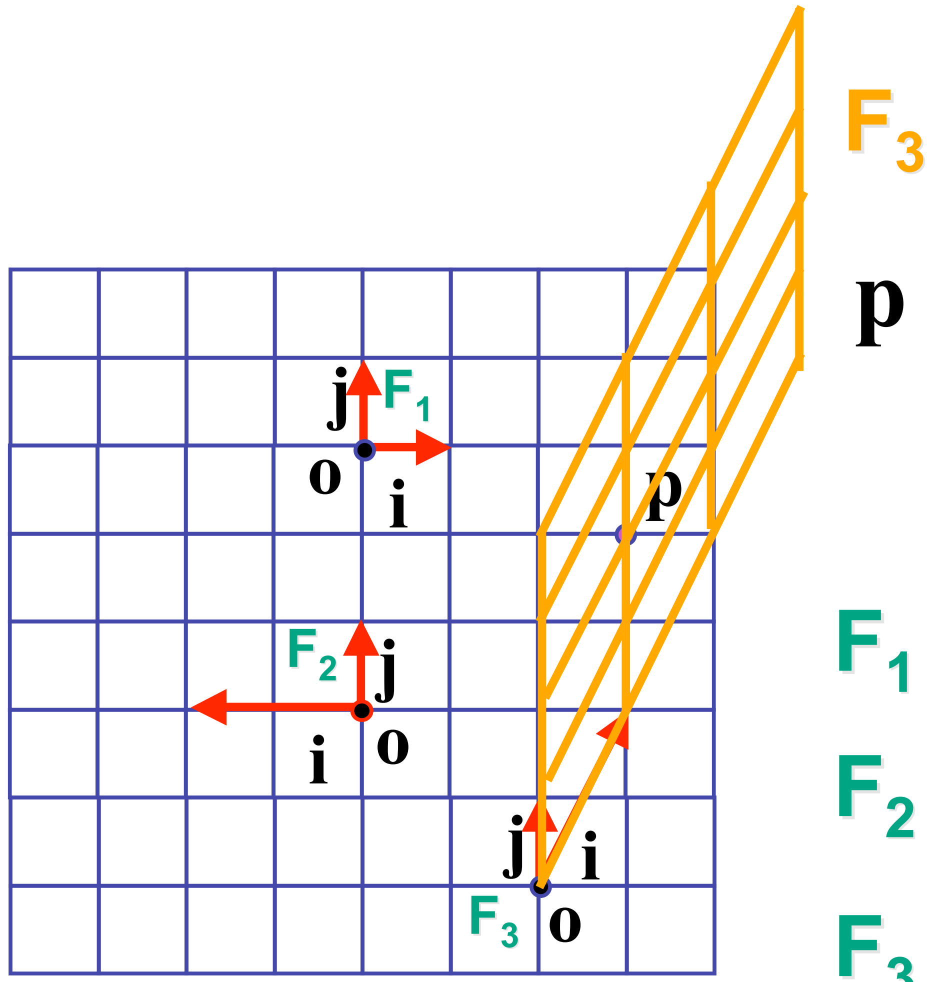
More: Working with Frames



$$\mathbf{p} = \mathbf{o} + x\mathbf{i} + y\mathbf{j}$$

F_1 p = (3,-1)

F_2 p = (-1.5,2)

F_3 p = (1,2)

Rendering

- goal
  - transform computer models into images
  - may or may not be photo-realistic
- interactive rendering
  - fast, but limited quality
  - roughly follows a fixed patterns of operations
    - rendering pipeline
- offline rendering
  - ray tracing
  - global illumination

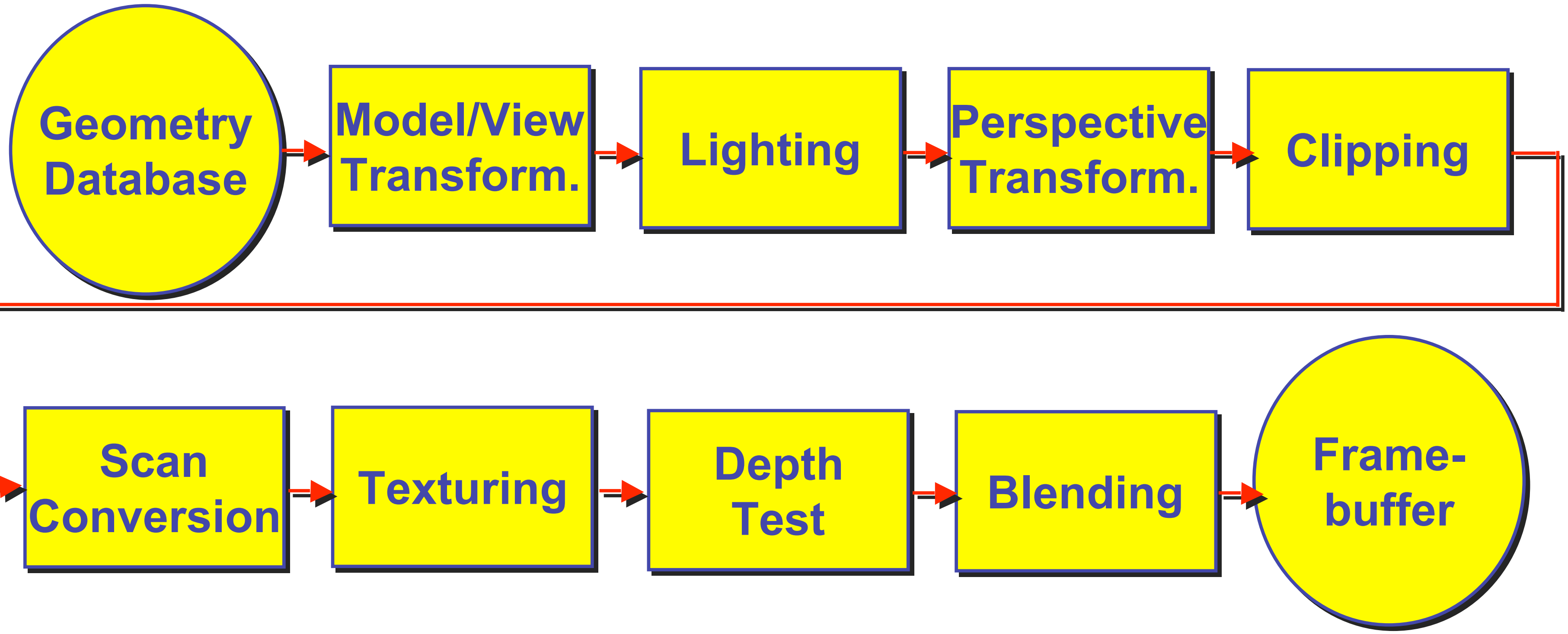
Rendering

- tasks that need to be performed
  (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

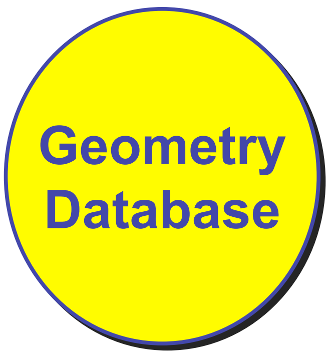
Rendering Pipeline

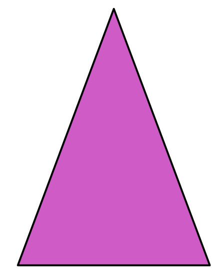
- what is the pipeline?
  - abstract model for sequence of operations to transform geometric model into digital image
  - abstraction of the way graphics hardware works
  - underlying model for application programming interfaces (APIs) that allow programming of graphics hardware
    - OpenGL
    - Direct 3D
- actual implementation details of rendering pipeline will vary

Rendering Pipeline



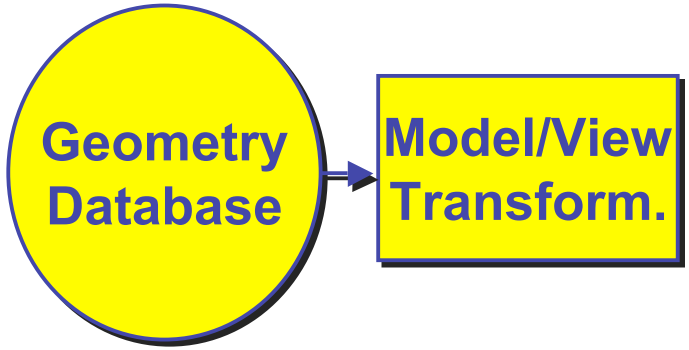
Geometry Database

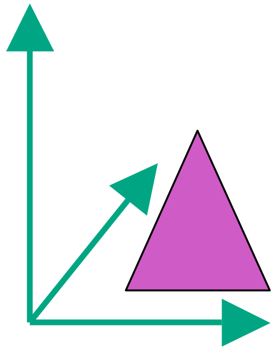




- geometry database
  - application-specific data structure for holding geometric information
  - depends on specific needs of application
    - triangle soup, points, mesh with connectivity information, curved surface

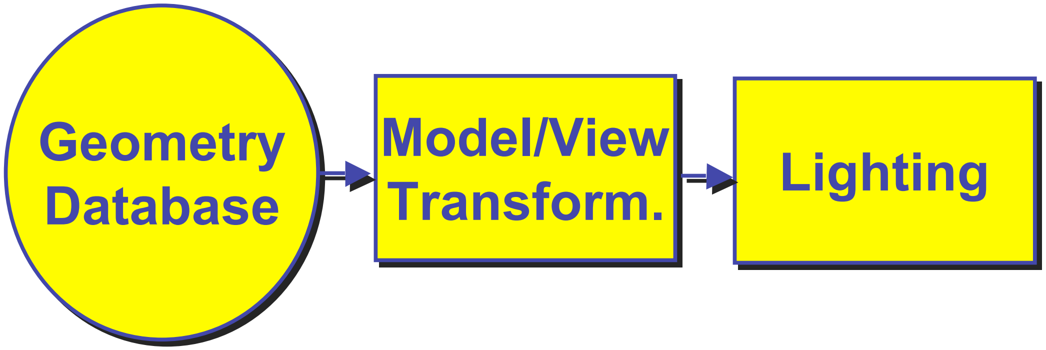
Model/View Transformation

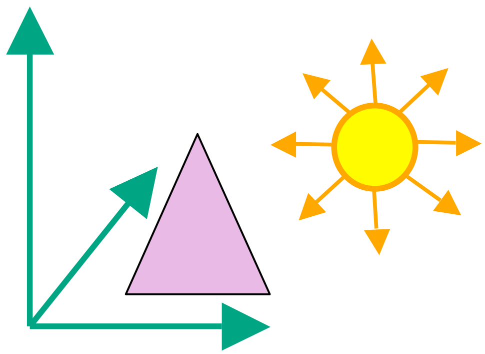




- modeling transformation
  - map all geometric objects from local coordinate system into world coordinates
- viewing transformation
  - map all geometry from world coordinates into camera coordinates

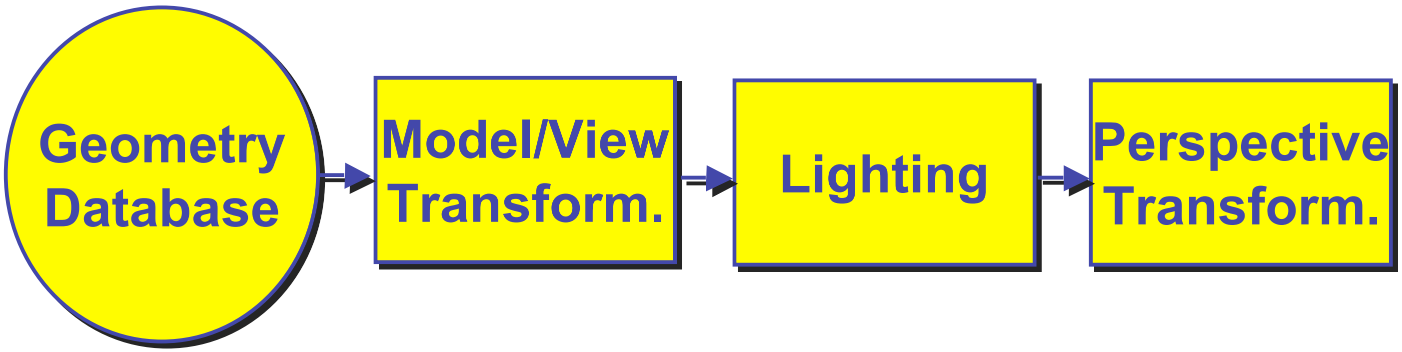
Lighting

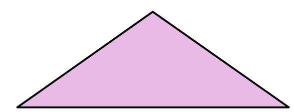




- lighting
  - compute brightness based on property of material and light position(s)
  - computation is performed *per-vertex*

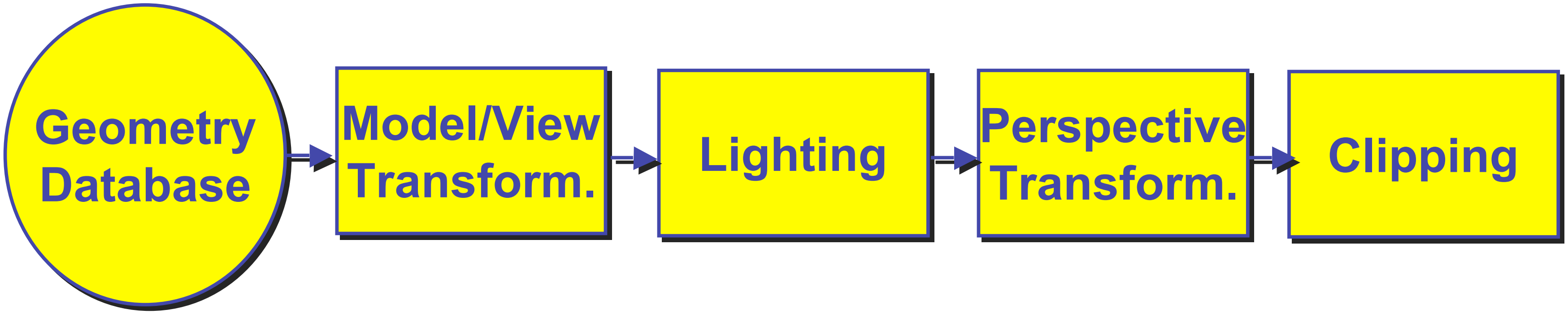
Perspective Transformation

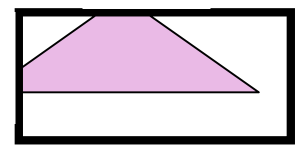




- perspective transformation
  - projecting the geometry onto the image plane
  - projective transformations and model/view transformations can all be expressed with 4x4 matrix operations

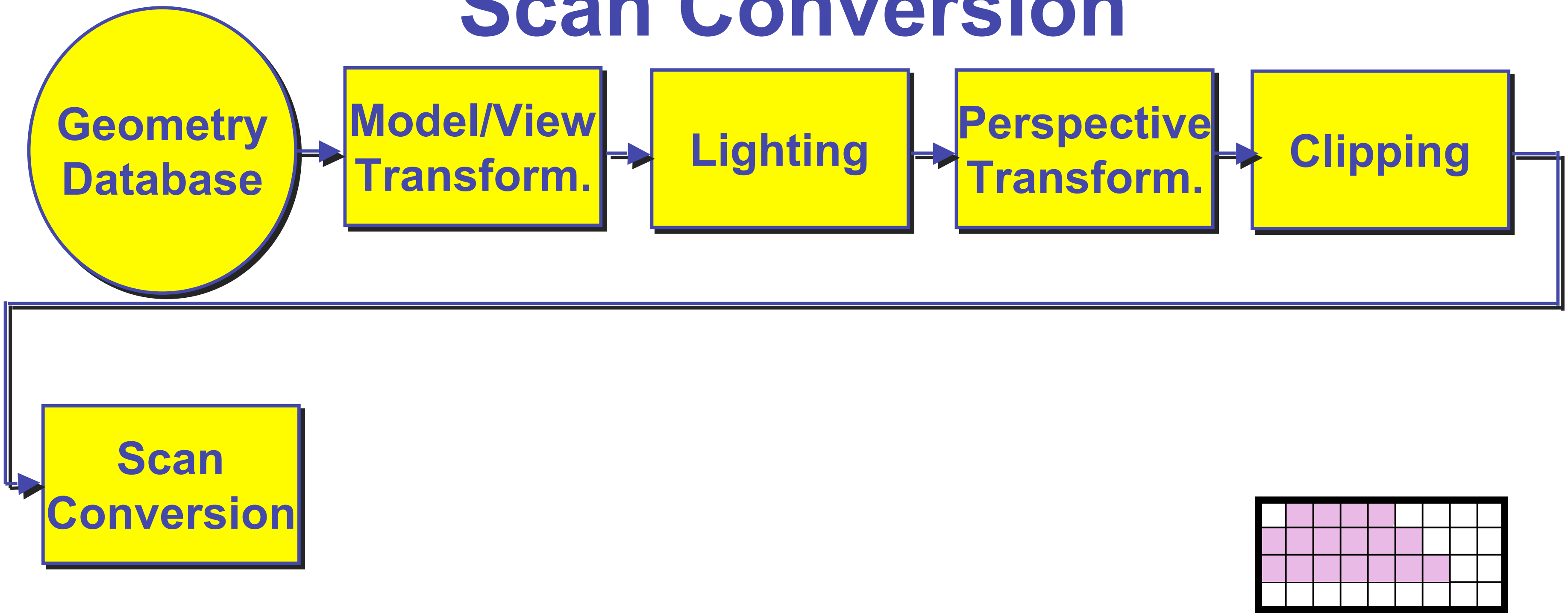
Clipping





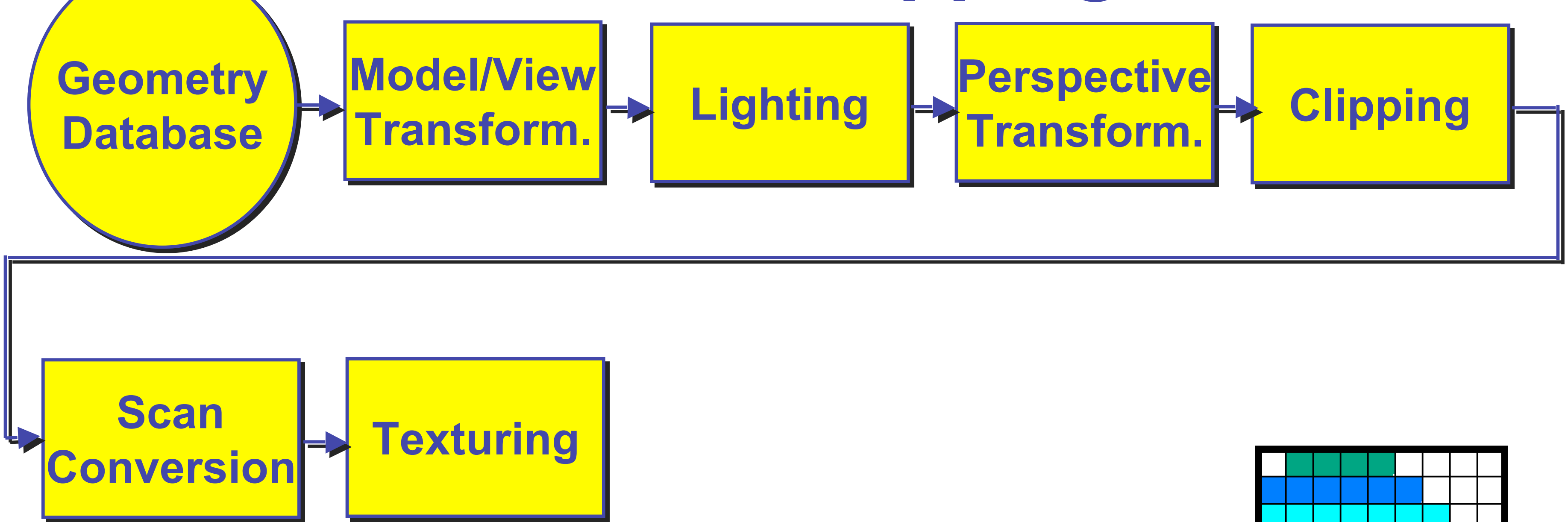
- clipping
  - removal of parts of the geometry that fall outside the visible screen or window region
  - may require *re-tessellation* of geometry

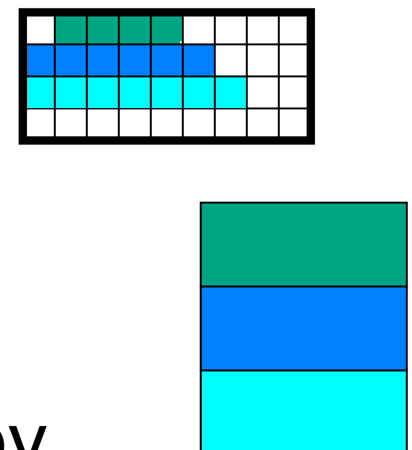
Scan Conversion



- scan conversion
  - turn 2D drawing primitives (lines, polygons etc.) into individual pixels (discretizing/sampling)
  - interpolate color across primitive
  - generate discrete fragments

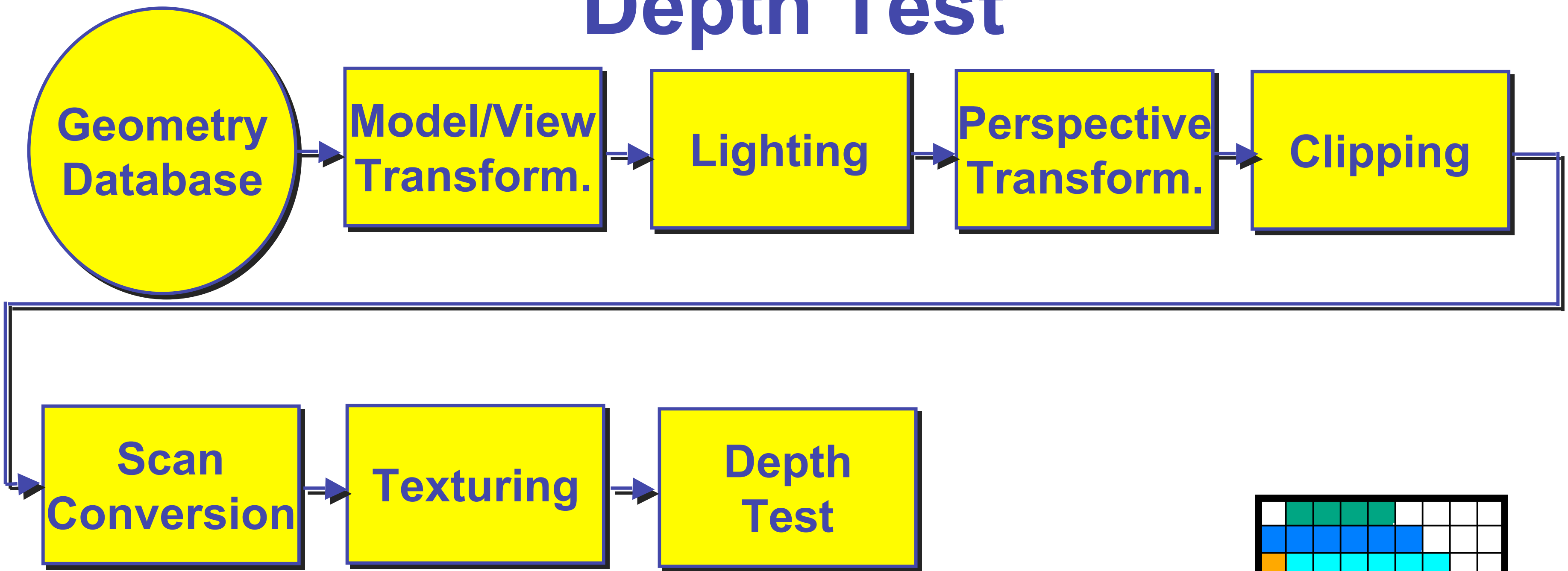
Texture Mapping

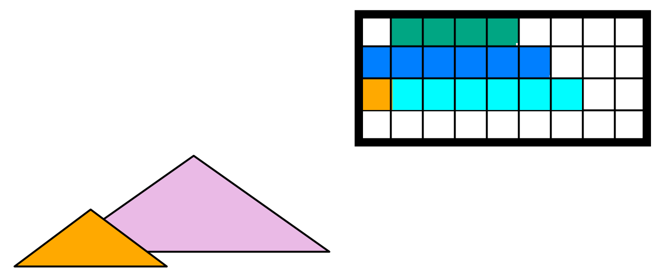




- texture mapping
  - “gluing images onto geometry”
  - color of every fragment is altered by looking up a new color value from an image

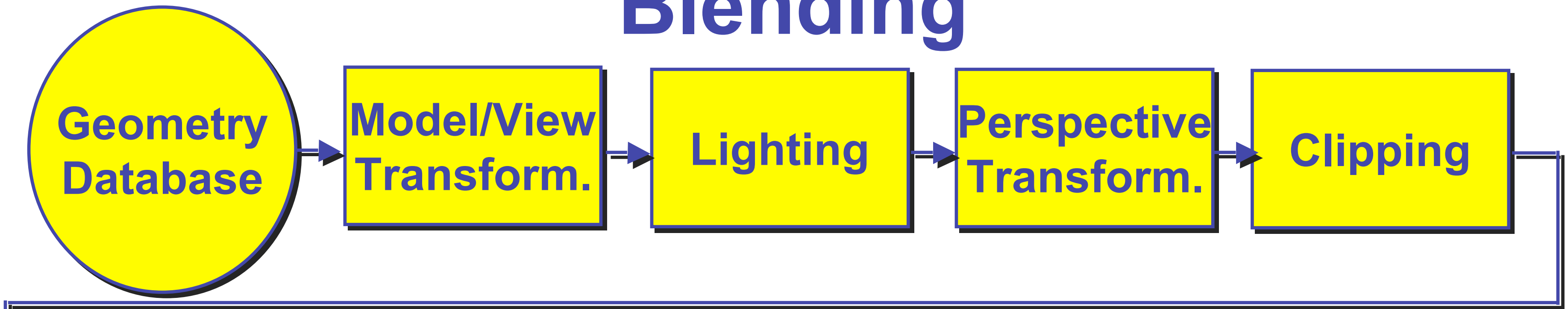
Depth Test

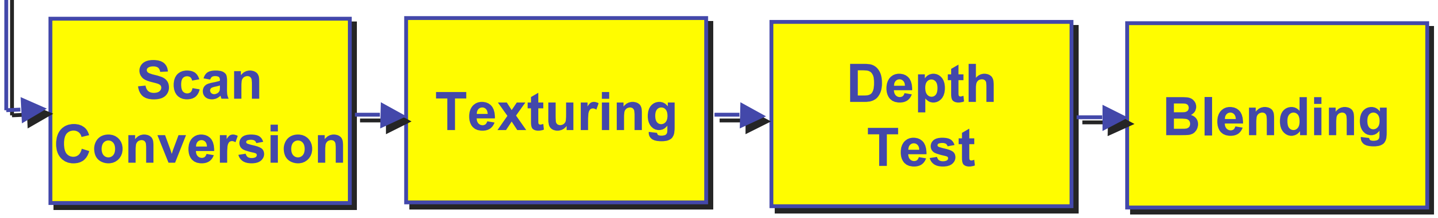


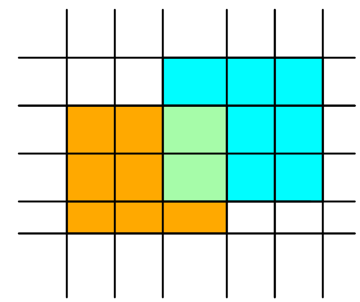


- depth test
  - remove parts of geometry hidden behind other geometric objects
  - perform on every individual fragment
    - other approaches (later)

Blending

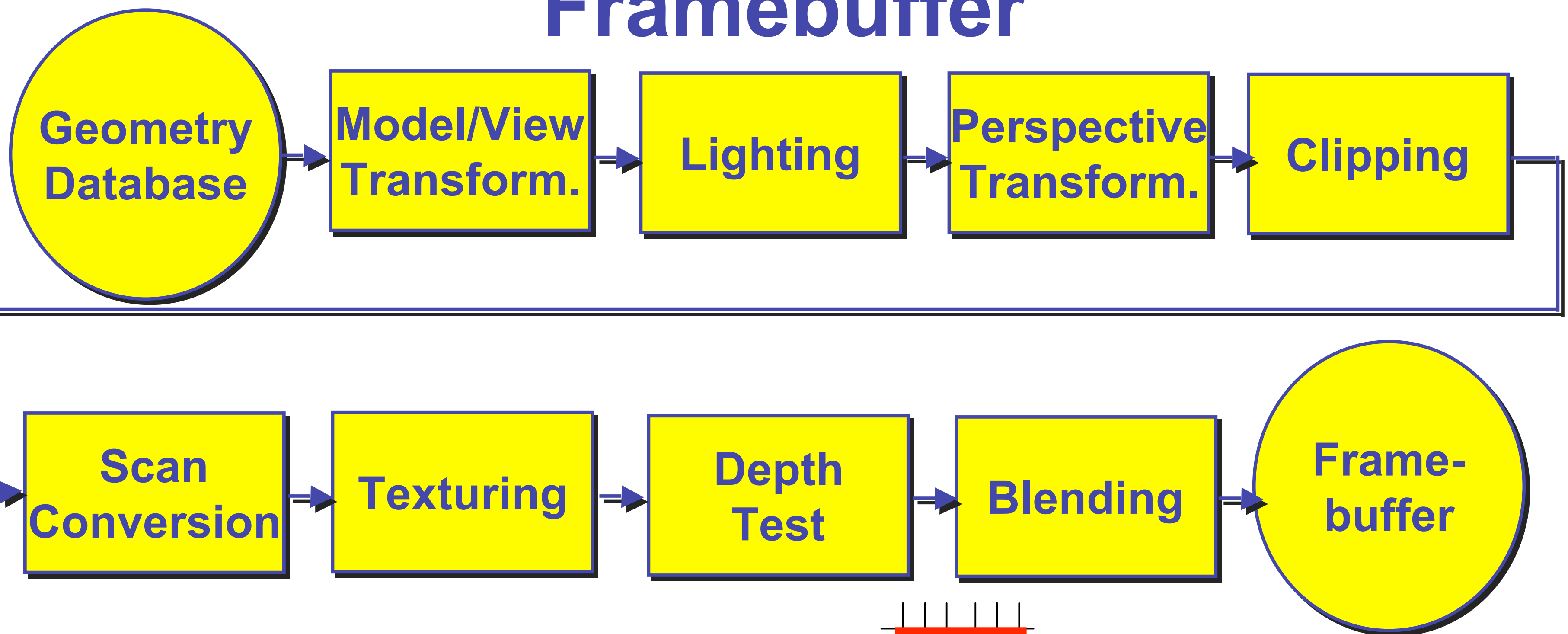


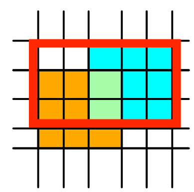




- blending
  - final image: write fragments to pixels
  - draw from farthest to nearest
  - no blending – replace previous color
  - blending: combine new & old values with arithmetic operations

Framebuffer





- framebuffer
  - video memory on graphics board that holds image
  - double-buffering: two separate buffers
    - draw into one while displaying other, then swap to avoid flicker

255 255 255	255 255 255	0 255 255	0 255 255	0 255 255
255 155 0	255 155 0	155 255 155	0 255 255	0 255 255
255 155 0	255 155 0	155 255 155	0 255 255	0 255 255

Pipeline Advantages

- modularity: logical separation of different components
- easy to parallelize
  - earlier stages can already work on new data while later stages still work with previous data
  - similar to pipelining in modern CPUs
  - but much more aggressive parallelization possible (special purpose hardware!)
  - important for hardware implementations
- only local knowledge of the scene is necessary

Pipeline Disadvantages

- limited flexibility
- some algorithms would require different ordering of pipeline stages
  - hard to achieve while still preserving compatibility
- only local knowledge of scene is available
  - shadows, global illumination difficult

OpenGL (briefly)

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 the 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.

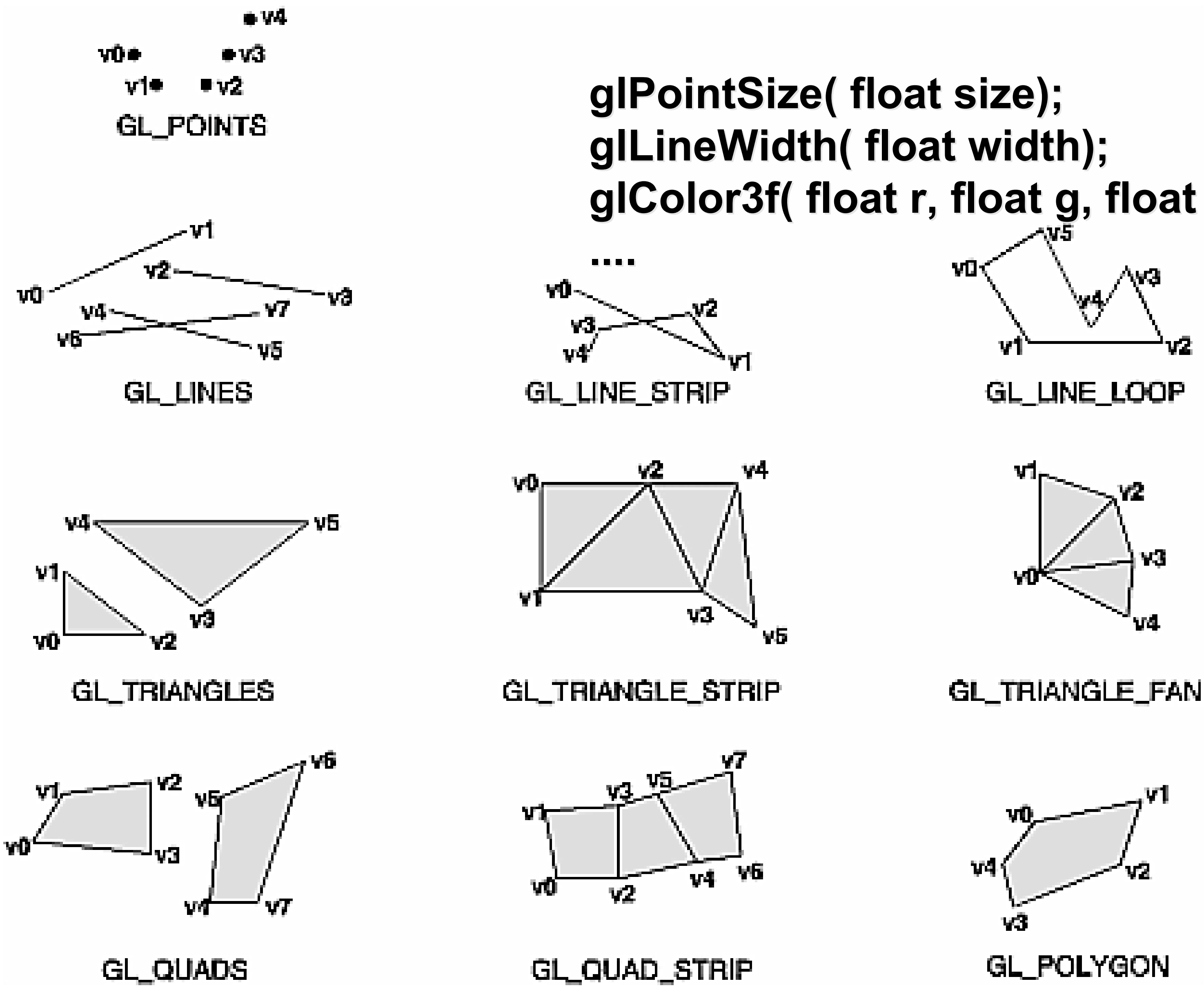
Geometry Pipeline

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

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

- tell it you're done
  - glEnd()

Open GL: Geometric Primitives



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

Code Sample

```
void display()
{
  glClearColor(0.0, 0.0, 0.0, 0.0);
  glClear(GL_COLOR_BUFFER_BIT);
  glColor3f(0.0, 1.0, 0.0);
  glBegin(GL_POLYGON);
    glVertex3f(0.25, 0.25, -0.5);
    glVertex3f(0.75, 0.25, -0.5);
    glVertex3f(0.75, 0.75, -0.5);
    glVertex3f(0.25, 0.75, -0.5);
  glEnd();
  glFlush();
}
```

- more OpenGL as course continues

GLUT

GLUT: OpenGL Utility Toolkit

- developed by Mark Kilgard (also from SGI)
- simple, portable window manager
  - opening windows
    - handling graphics contexts
  - handling input with callbacks
    - keyboard, mouse, window reshape events
  - timing
    - idle processing, idle events
- designed for small-medium size applications
- distributed as binaries
  - free, but not open source

GLUT Draw World

```
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. batch mode where you control the flow
- 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

GLUT Callback Functions

```
  // 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);
void idle();
void display();


  // register them with glut

glutReshapeFunc(reshape);
glutKeyboardFunc(keyboard);
glutMouseFunc(mouse);
glutIdleFunc(idle);
glutDisplayFunc(display);
```

```
void glutDisplayFunc (void (*func)(void));
void glutKeyboardFunc (void (*func)(unsigned char key, int x, int y));
void glutIdleFunc (void (*func)());
void glutReshapeFunc (void (*func)(int width, int height));
```

Display Function

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

- directly update value of angle variable
  - so, why doesn't it spin?
  - only called in response to window/input event!

Idle Function

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

- called from main loop when no user input
- should return control to main loop quickly
  - update value of angle variable here
  - then request redraw event from GLUT
    - draw function will be called next time through
- continues to rotate even when no user action

Keyboard/Mouse Callbacks

- do minimal work
- request redraw for display
- example: keypress triggering animation
  - do not create loop in input callback!
    - what if user hits another key during animation?
  - shared/global variables to keep track of state
  - display function acts on current variable value

Labs

Week 2 Lab

- labs start Tuesday
- project 0
  - http://www.ugrad.cs.ubc.ca/~cs314/Vjan2007/a0

  - make sure you can compile OpenGL/GLUT
    - very useful to test home computing environment
  - template: spin around obj files
  - todo: change rotation axis
  - do **`handin`** to test configuration, but not graded

Remote Graphics

- OpenGL does not work well remotely
  - very slow
- only one user can use graphics at a time
  - current X server doesn't give priority to console, just does first come first served
  - problem: FCFS policy = confusion/chaos
- solution: console user gets priority
  - only use graphics remotely if nobody else logged on
    - with 'who' command, ":0" is console person
  - stop using graphics if asked by console user via email
  - or console user can reboot machine out from under you