Graphics Pipeline and OpenGL

10 February 2009
CMPT370
Dr. Sean Ho
Trinity Western University

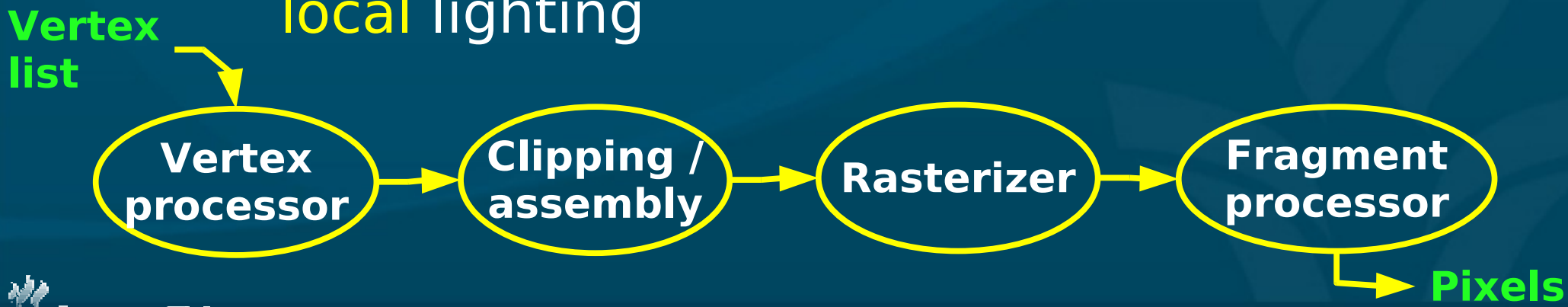
TRINITY WESTERN UNIVERSITY

Review last time

- Light and colour models
- Geometric representation: trimesh
- Off-line rendering: raytracing, radiosity
- Real-time interactive graphics pipeline:
  - Vertex processing
  - Clipping and culling
  - Rasterizing
  - Fragment processing
- Graphics API overview (OpenGL)

Real-time graphics pipeline

- This is what your graphics card hardware does
- Input: scene objects, lighting, camera
  - Most of the data is the vertex list
- Output: pixels stored in the framebuffer
  - Raster graphics
- Usually processes objects one at a time:
  - local lighting

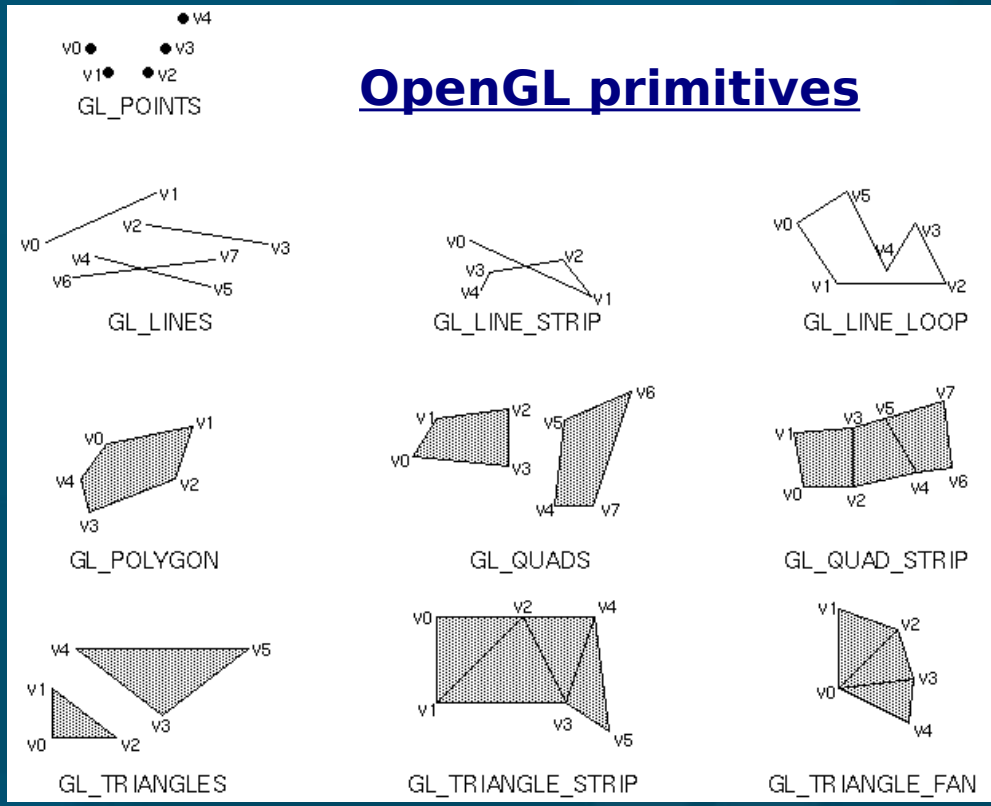


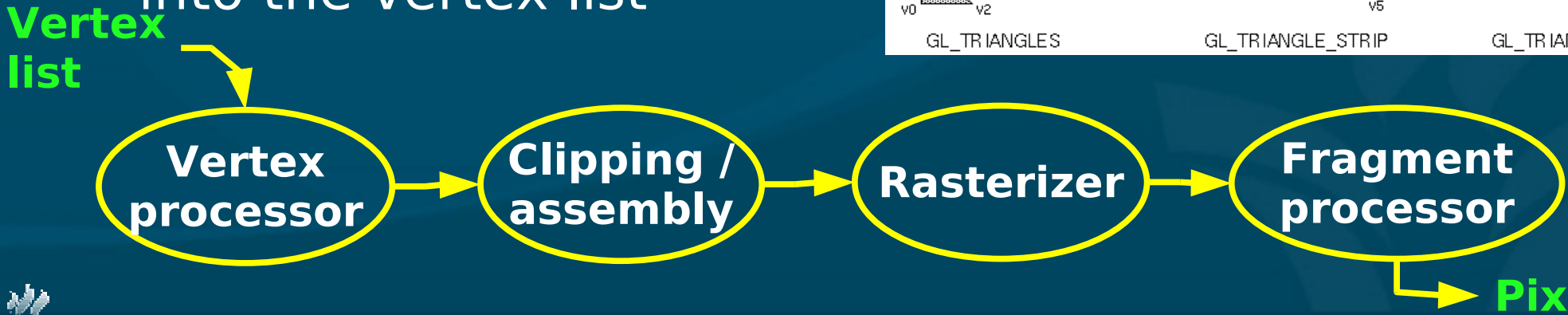
Kinds of coordinate transforms

- The transformations done on vertices include:
  - Translation: shift in (x,y,z)
  - Rotation: e.g., 3 Euler angles
  - Scaling: uniform or along 3 axes
  - (Perspective, affine)
- 3D points are projected onto 2D image plane:
  - Perspective projection:
    - Projection lines meet at center of projection
  - Parallel projection:
    - Projection lines are all parallel

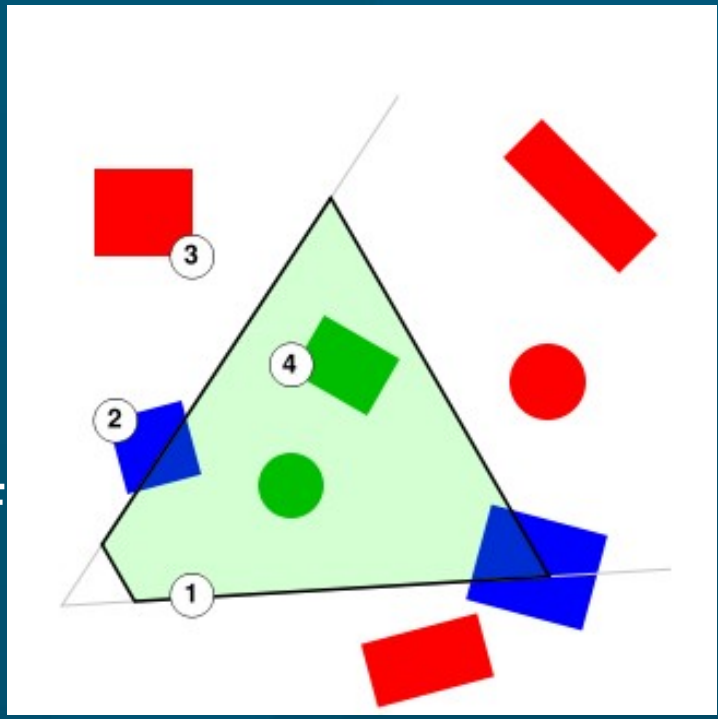
Primitive assembly

- The vertex processor also assembles vertices into primitives:
  - Lines/curves
  - Triangles/polygons/ surfaces
- Uses the face list to index into the vertex list

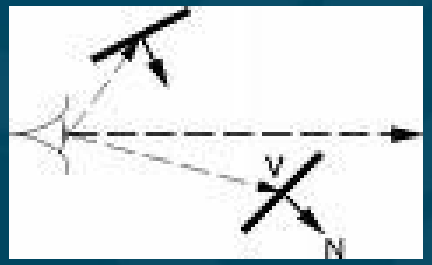




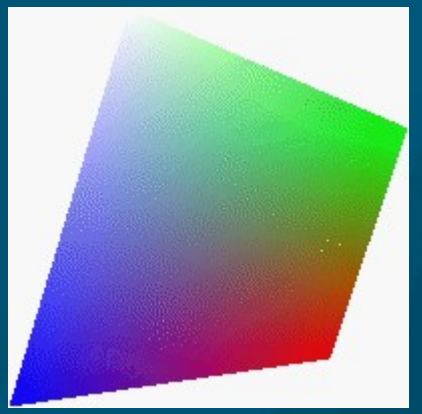
Clipping and culling



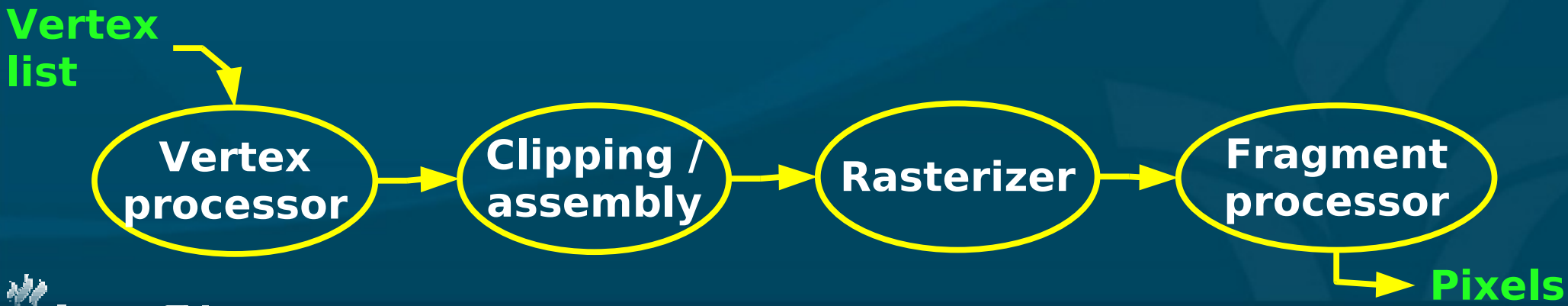
- Don't render what we can't see
- Clipping
  - Remove primitives outside of the camera's view frustrum
- Backface culling
  - Remove triangles facing away from camera
  - Usually cuts down # of triangles by about 50%!
- Other optimizations also possible



Rasterization

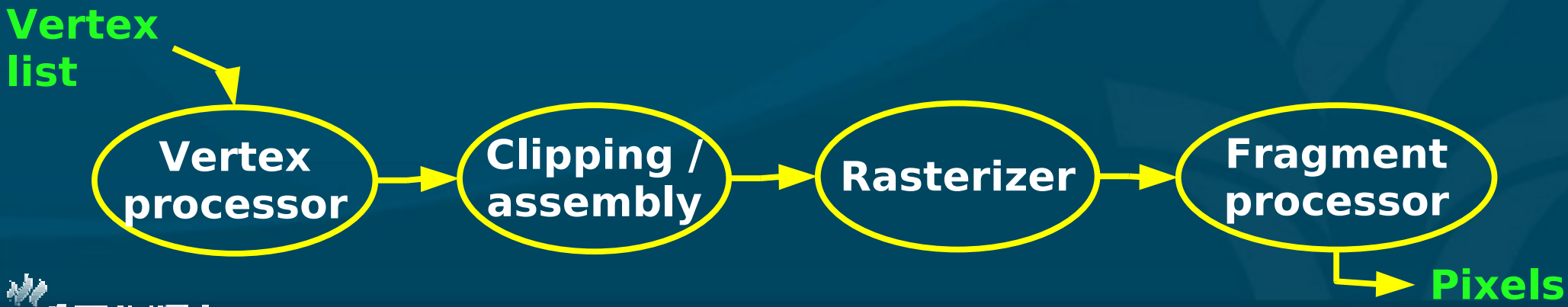


- Convert a primitive into a fragment:
  - Set of pixels just for that primitive
  - Each pixel has both RGB colour and depth
  - Interpolate vertex colours over the fragment
  - Might not correspond to pixels on screen: e.g., occluded pixels



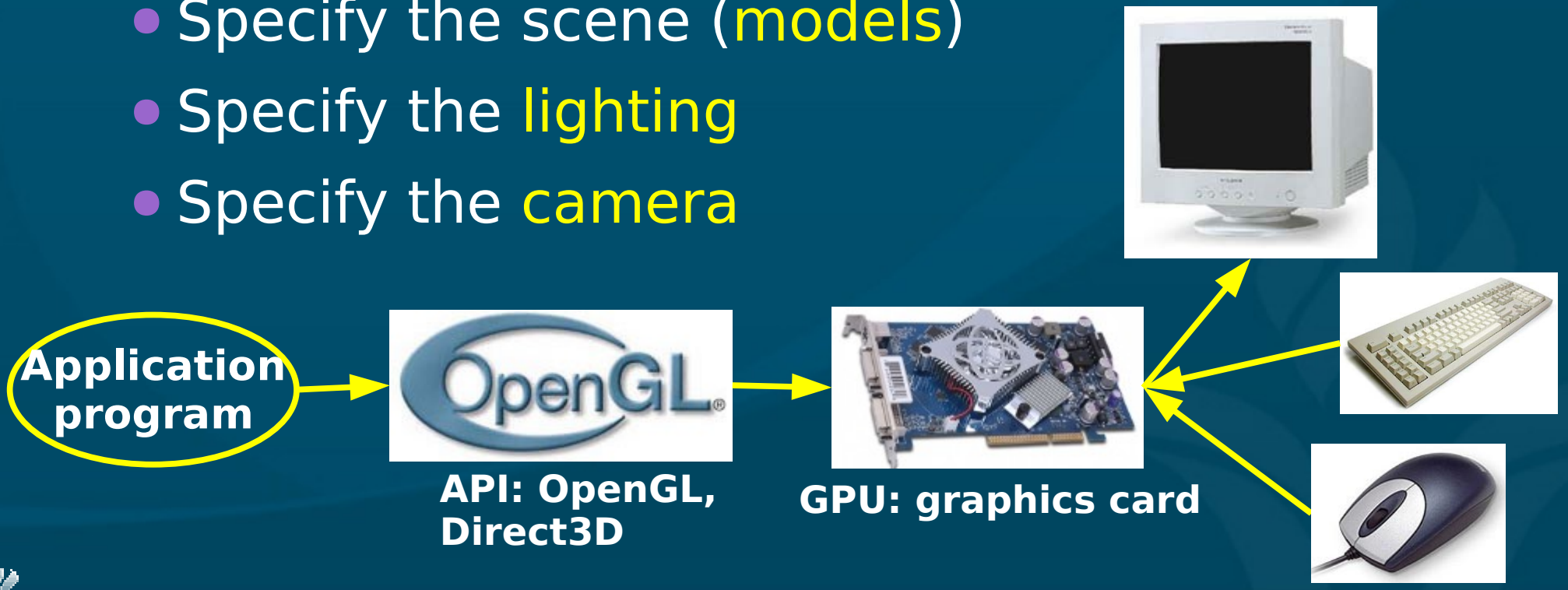
Fragment processing

- Assemble the fragments into final framebuffer
- Hidden-surface removal:
  - Some fragments may occlude parts of others
    - Z-buffer sorts pixels by distance
    - Handle transparency



Programmer's interface

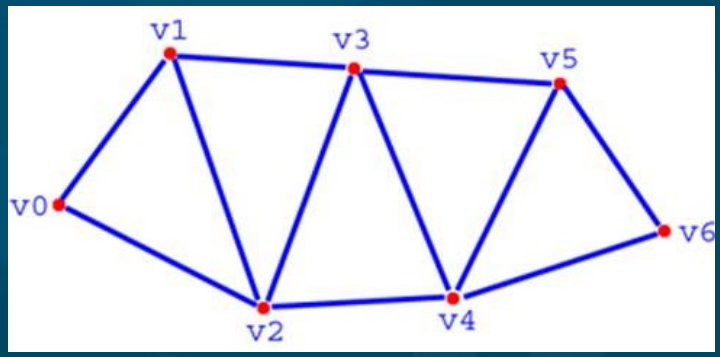
- A graphics API allows a program to interact with the graphics pipeline
- Library subroutines (see CubeView.cxx)
  - Specify the scene (models)
  - Specify the lighting
  - Specify the camera



Graphics API: Model

- Geometry: vertices (0D)
  - Line segments, curves (1D)
  - Polygons (2D), parametric surfaces
- Material properties: colour, specularity, etc.
- Example:

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



GL_TRIANGLE_STRIP

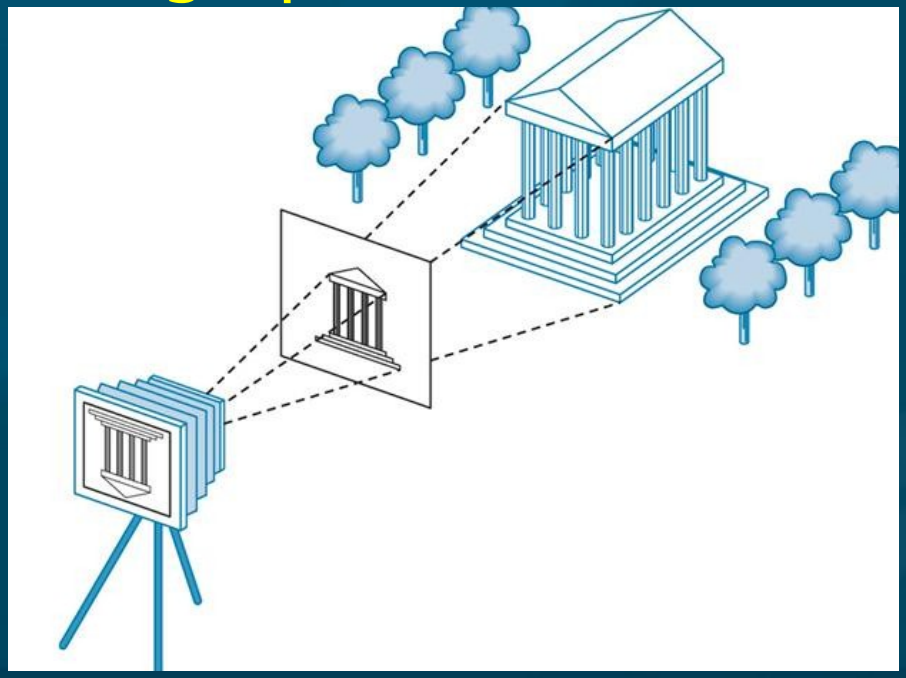
Graphics API: Lighting

- Type of light:
  - Ambient (uniform, everywhere)
  - Directional (e.g., sunlight)
  - Spotlight (cone with falloff)
  - Point vs. area light
- Material properties:
  - Ambient colour
  - Diffuse colour
  - Specular colour
  - Emissive colour



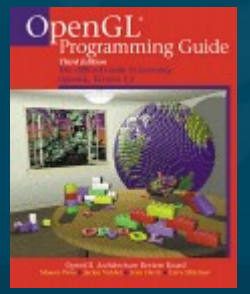

Graphics API: Camera

- 6DOF camera model:
  - Position of center of projection (3DOF)
  - Orientation (3DOF)
- Also: location and size of image plane
- Could also consider modelling lens distortion



History of OpenGL

- Silicon Graphics (SGI) was one of the first to implement graphics pipeline in hardware (1982)
  - In-house library: GL
- OpenGL (1992): platform-independent API
  - Architectural Review Board / Working Group
    - SGI, IBM, HP, MS, Nvidia, 3DLabs
  - Stable, widely-accepted standard (now 2.1)
    - New changes just for new hardware capabilities
  - Lots of documentation and sample code
    - "Red book" and "Blue book"



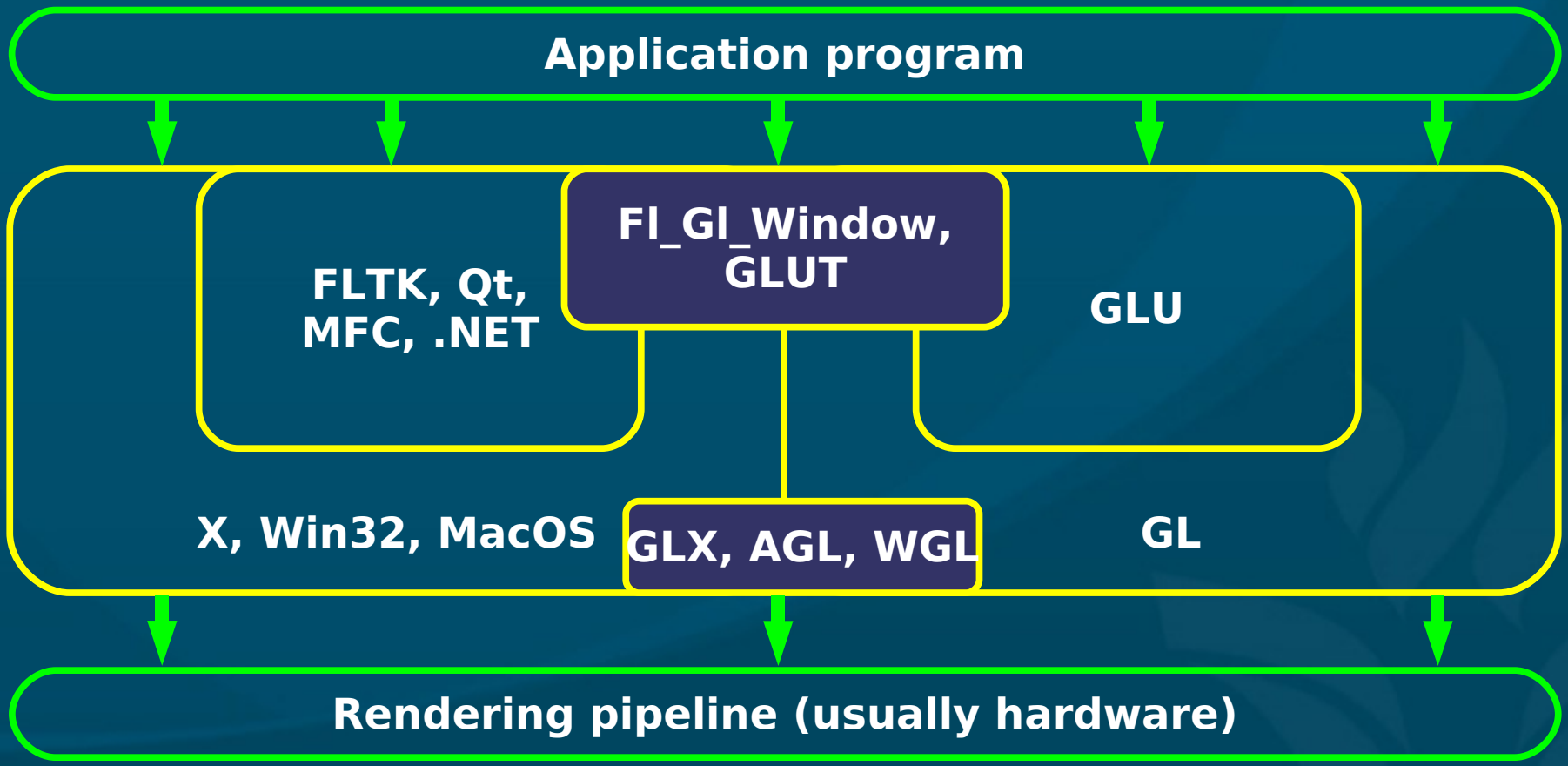
OpenGL libraries

- OpenGL core library
  - On Windows: opengl32.dll
  - On Linux/Unix: libGL.a, libGL.so
- OpenGL utility library: GLU
  - Higher-level drawing routines that use OpenGL core primitives
- OpenGL utility toolkit: GLUT
  - Basic GUI toolkit, very small footprint
  - FLTK is much more powerful
  - Also freeglut, OpenGLUT, GLUI

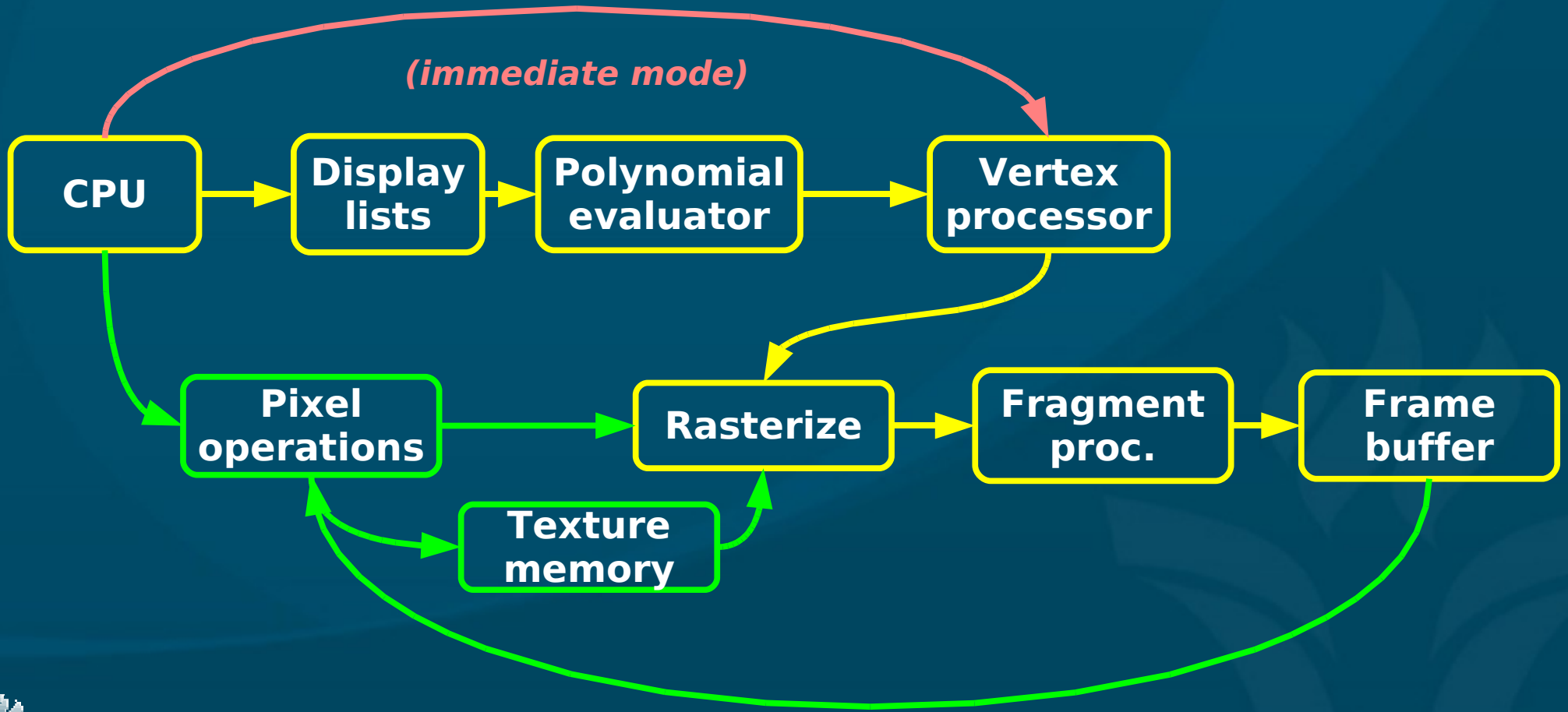
Interface with window system

- OpenGL links with the native window system
  - Windows: WGL, GDI
  - MacOS: AGL (for Carbon), NSOpenGL (Cocoa)
  - Unix: GLX
- This makes it possible to run an OpenGL program over the network:
  - Run Xwin32 on local PC (has GLX)
  - ssh -x carmel
  - run program on carmel, primitives get sent to local PC, uses local hardware acceleration

Software architecture



OpenGL pipeline architecture



OpenGL state machine

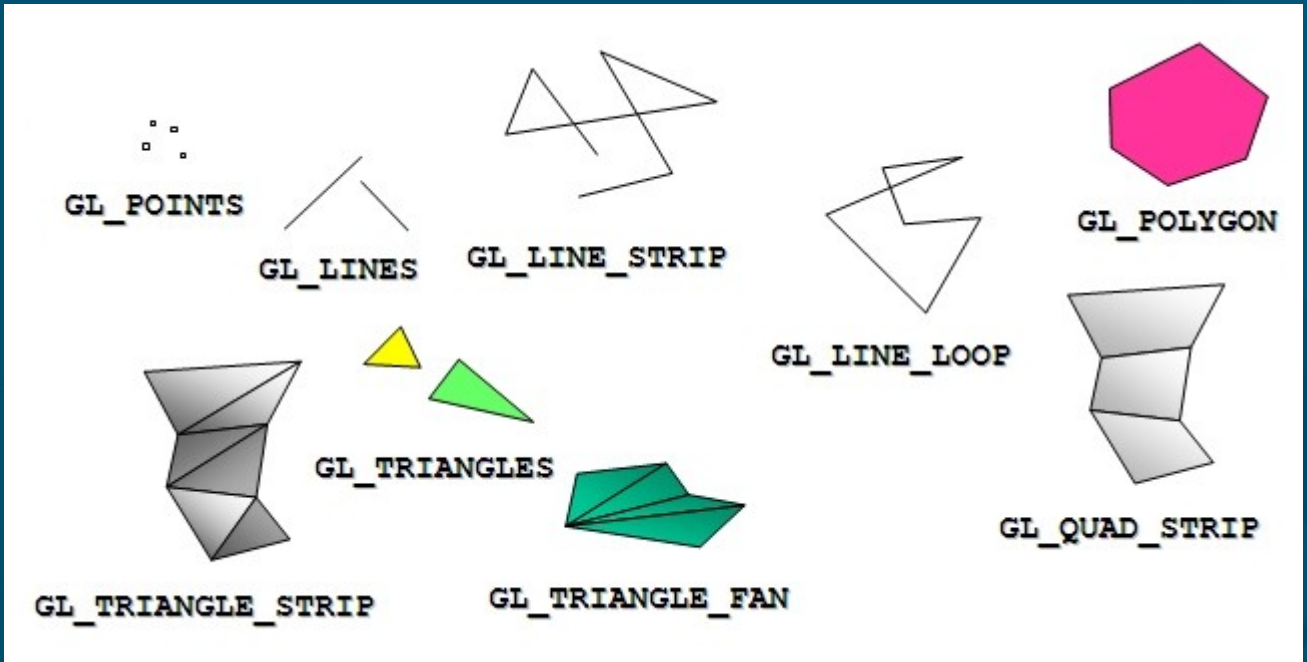
- Two kinds of OpenGL functions
  - Generate primitives
    - Vertex, line, triangle, polygon, etc.
  - Change state
    - Current colour
    - Material properties (shininess, etc.)
    - Transformations: view, model
- Each primitive gets whatever state was current when it was drawn

OpenGL functions

- Most core OpenGL functions look like this:
  - glVertex3f(x, y, z)
    - gl: belongs to core OpenGL library (glu for GLU)
    - Vertex: name of function
    - 3f: argument type: 3 floats
- Not overloaded, for efficiency
  - glVertex3fv(vec)
    - takes a pointer to an array of 3 floats
  - glVertex3i(x, y, z): ints
  - glVertex3d(x, y, z): doubles

OpenGL primitives

- glBegin(GL_*) starts a set of primitives



- Polygons must be simple: edges cannot cross
- Must be convex
- Must be flat: all vertices in the same plane

Drawing in OpenGL (see CubeView)

- Start the set of primitives:
  - glBegin(GL_TRIANGLES);
- Set the colour and other attributes:
  - glColor3f(0.0, 0.0, 1.0);
- Create the vertices:
  - glVertex3f(0.0, 0.1, 0.2);
  - glVertex3f(0.1, 0.0, 0.2);
  - glVertex3f(0.0, 0.0, 0.2);
- End the set of primitives:
  - glEnd();

Projection matrix

- The coordinates of glVertex are in world coords
  - OpenGL converts to camera coords, then to screen coords
- The projection matrix specifies the camera:
  - glMatrixMode(GL_PROJECTION);
- Specify the viewing volume:
  - glLoadIdentity();
  - glOrtho(left, right, bottom, top, near, far)
  - Orthographic (parallel) projection