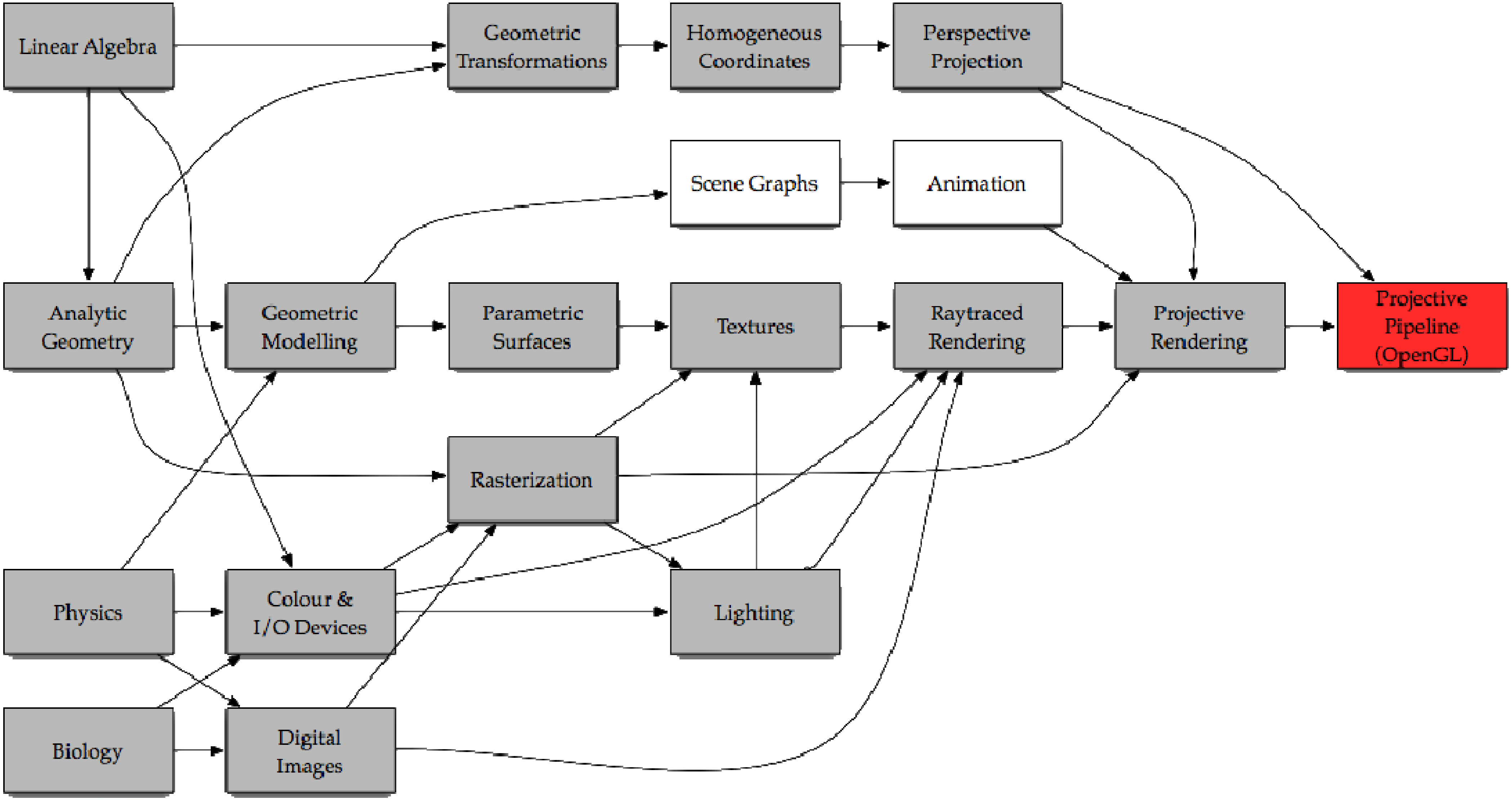
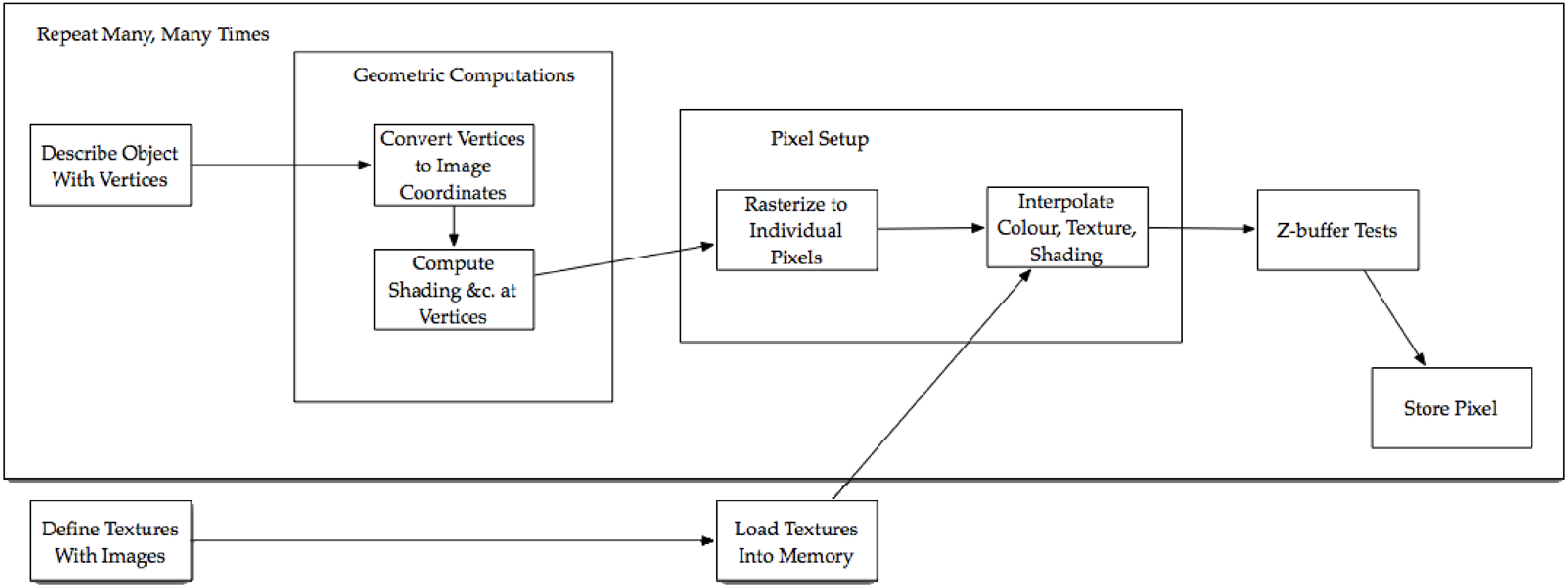
Early (1 -2) Open GL & Projective Hardware

Where we Are

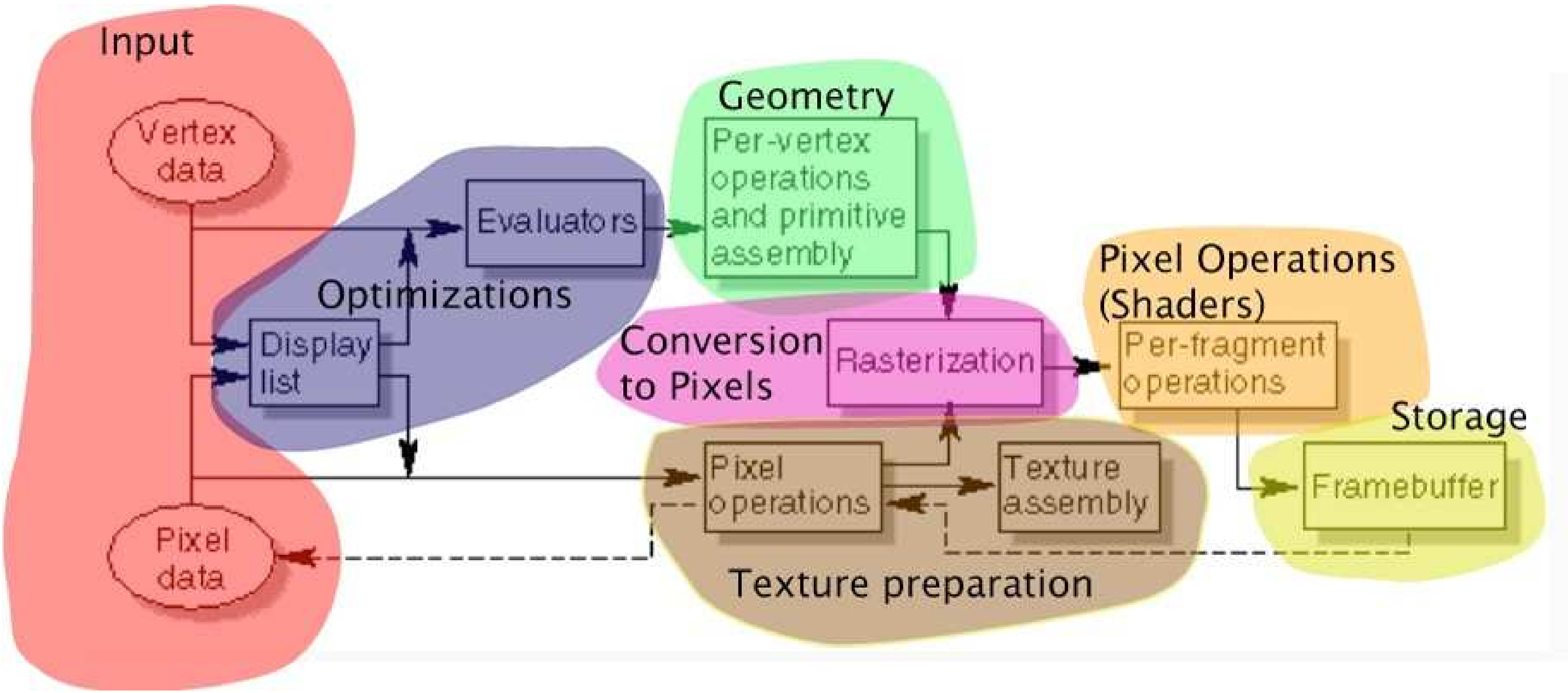


Linear Algebra
Geometric Transformations
Homogeneous Coordinates
Perspective Projection
Scene Graphs
Animation
Analytic Geometry
Geometric Modelling
Parametric Surfaces
Textures
Raytraced Rendering
Projective Rendering
Projective Pipeline (OpenGL)
Rasterization
Physics
Colour & I/O Devices
Lighting
Biology
Digital Images

Projective Pipeline



OpenGL 2 Pipeline



- From the OpenGL Red Book

Origin of OpenGL

- IrisGL on Silicon Graphics Irix OS
- SGI opened it up for other OS'es
- Now the *de facto* standard in graphics
  - projectively rendered triangles
  - hardware-accelerated (pipelines)
  - texture-oriented

Input

- We will:
  - create & model surfaces using triangles
  - feed the triangles into the pipeline
    - with surface properties
      - colour, texture, material, &c.

Optimization

- We will talk about:
  - display lists
  - evaluators
  - splines
- LATER!
- For now, ignore them

Vertex Operations

- Per-vertex operations are mostly geometric:
  - transformations are applied here
    - rotation, projection, &c.
  - texture coordinates are calculated
  - lighting is computed

Primitive Assembly

- This includes:
  - *clipping* objects at boundaries
  - *culling* objects that are invisible
  - *perspective division* for foreshortening

Texture Preparation

- Loading textures into memory (or VRAM)
  - from main memory
  - from disk
  - from framebuffer
  - and modifying them if needed

Rasterization

- Converts triangles, &c. to *pixels*
  - also known as *scan conversion*
- Generates multiple pixels per triangles
  - this allows parallelization
- Assigns colour, depth, &c. to each pixel
- OpenGL calls pixels *fragments* here

Pixel Operations

- For each pixel, video card computes:
  - texture effects
  - fog, scissor, alpha, stencil, & z-buffer
  - blending, dithering, masking, logic
  - programmable shaders go here!

An Example

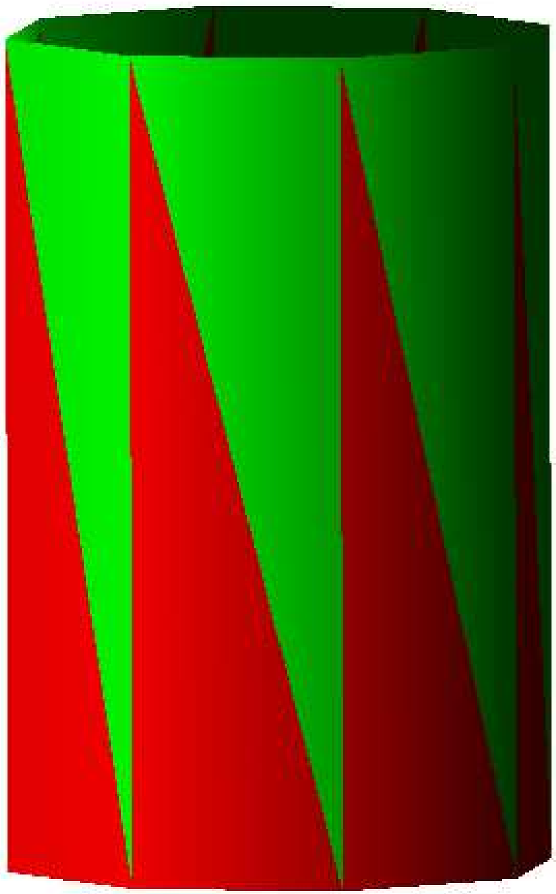
```
For (float i = 0.0; i < nSegments; i += 1.0)
  { /* a loop around circumference of a tube */
  float angle = PI * i * 2.0 / nSegments ;
  float nextAngle = PI * (i + 1.0) * 2.0 / nSegments;

  /* compute sin & cosine */
  float x1 = sin(angle), y1 = cos(angle);
  float x2 = sin(angle), y2 = cos(angle);

  /* draw top (green) triangle */
  glNormal3f(x1, y1, 0.0); glVertex3f(x1, y1, 0.0);
  glNormal3f(x2, y2, 0.0); glVertex3f(x2, y2, 1.0);
  glNormal3f(x1, y1, 0.0); glVertex3f(x1, y1, 1.0);

  /* draw bottom (red) triangle */
  glNormal3f(x1, y1, 0.0); glVertex3f(x1, y1, 0.0);
  glNormal3f(x2, y2, 0.0); glVertex3f(x2, y2, 0.0);
  glNormal3f(x2, y2, 0.0); glVertex3f(x2, y2, 1.0);

  } /* a loop around circumference of a tube */
```



OpenGL Conventions

- All functions start with gl: e.g. glEnd()
- Constants start with GL_: e.g. GL_LINES
- Suffix describes parameters, e.g. in glVertex3fv(...), suffix 3fv gives:
  - dimension: 1, 2, 3, or 4:
  - data type: (b)yte, (i)nt, (f)loat, (d)ouble
  - whether data is an array: (v)ector

OpenGL State

- Once a property is set, it hangs around
  - e.g. transformation matrices
  - also colour, texture, &c., &c.
- This is technically referred to as *state*
  - often a source of problems

Input (Vertices)

- OpenGL describes objects with vertices:
  - use glBegin() to start
  - use glEnd() to stop
- OpenGL does **<u>NOT</u>** balance pairs
  - so be careful

glBegin()

- glBegin(GLenum mode);
- mode can be:
  - GL_POINTS
  - GL_LINES
  - GL_TRIANGLES
  - among others

glBegin() & glEnd()

- Vertices between these are grouped:
  - if GL_POINTS, each vertex is a point
  - if GL_LINES, each pair is a line
  - if GL_TRIANGLES, each trio is a triangle
- Extra vertices are discarded

Restrictions

- Only the following can be used between glBegin() and glEnd():
  - glVertex(), glNormal()
  - glColor(), glMaterial()
  - glTexCoord()
  - & some others (not relevant yet)

Vertex Properties

- Vertices can be assigned:
  - Normal Vectors - glNormal()
  - Colours - glColor() (if lighting off)
  - Materials - glMaterial() (if lighting on)
  - Textures - glTexCoord()
  - Position - glVertex() (always comes *last)*

or Surface Properties

- These are actually *surface* properties
  - *normal* is perpendicular to surface
    - ***NOT*** to the triangle!
  - OpenGL will interpolate properties
    - pick values between those of vertices
    - computed during rasterization

OpenGL Lighting

- Turn on / off lighting
  - glEnable(GL_LIGHTING)
  - glDisable(GL_LIGHTING)
- Turn on a specific light
  - glEnable(GL_LIGHT0)
  - glDisable(GL_LIGHT0)

Light Parameters

- Lights have:
  - position, colour, and other properties
- Specify with glLightf()
  - `glLightf(GL_LIGHT0,GL_AMBIENT,redColour)`
  - assigns a red ambient colour to #0

Light Parameters

- colour: GL_AMBIENT, GL_DIFFUSE, GL_SPECULAR
- position: GL_POSITION
- spotlights: GL_SPOT_DIRECTION, GL_SPOT_EXPONENT, &c.

Shading Model

- Can use flat or smooth (Gouraud)
  - glShadeModel(GL_FLAT)
  - glShadeModel(GL_SMOOTH)
  - can’t use Phong shading

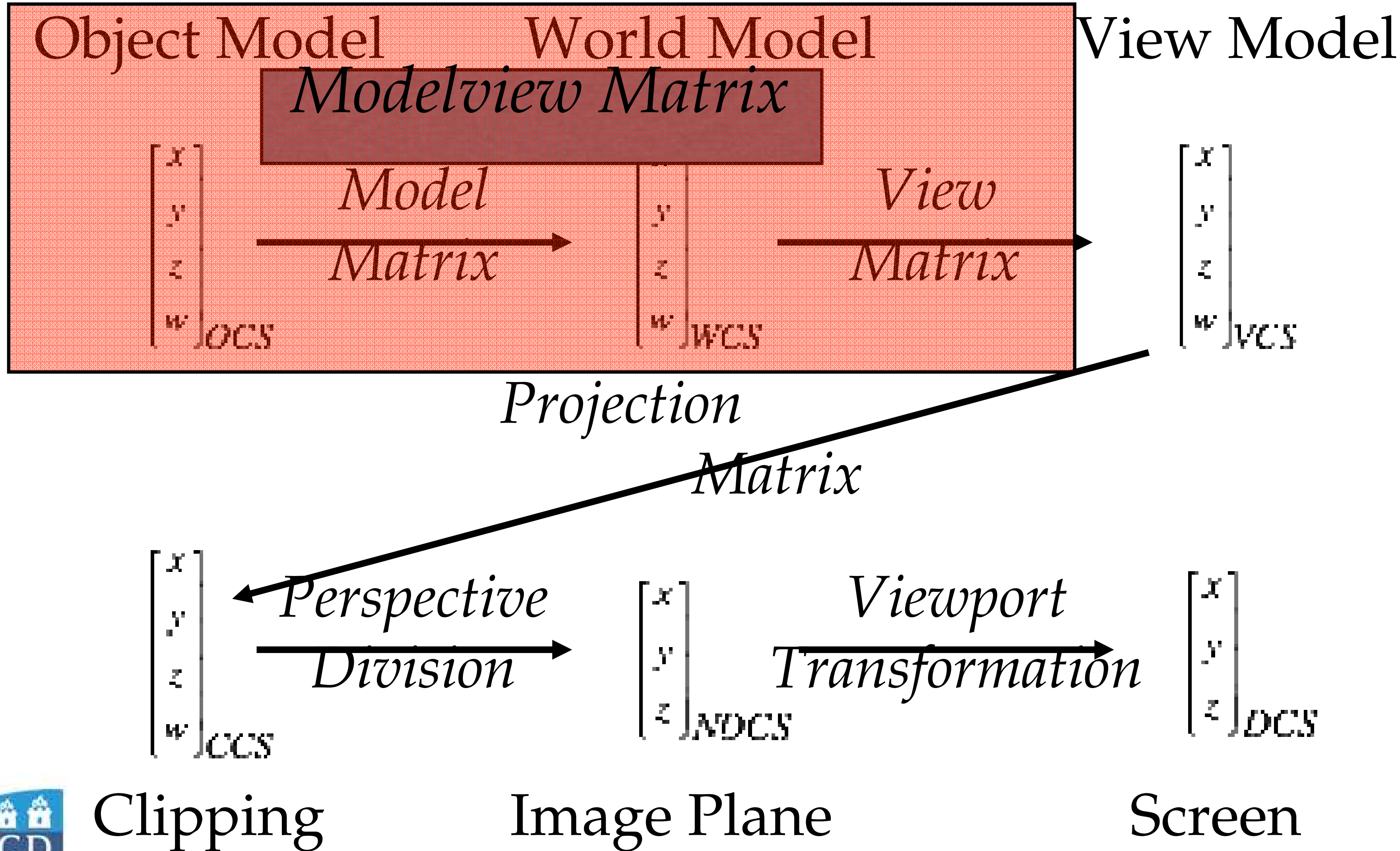
Lighting Model

- glLightModel(GL_LIGHT_MODEL_TWO_SIDE,1)
- switches on two-sided lighting

Transformations

- OpenGL uses two principal matrices
  - a *modelview* matrix
  - a *projection* matrix
- To specify which one is being changed:
  - glMatrixMode(GL_MODELVIEW);
  - glMatrixMode(GL_PROJECTION);

Matrices



Object Model
World Model
View Model
Modelview Matrix
Model Matrix
View Matrix
$[x, y, z, w]_{OCS}$
$[x, y, z, w]_{WCS}$
$[x, y, z, w]_{VCS}$
Projection Matrix
$[x, y, z, w]_{CCS}$
Perspective Division
$[x, y, z]_{NDCS}$
Viewport Transformation
$[x, y, z]_{DCS}$
Clipping
Image Plane
Screen

Modelview Matrix

- Combines *model* (M) and *view* (V) matrices
  - view transformation happens last
  - so always specify it first
  - but view matrix changes less anyway
  - if needed, make V changes in proj. mat.

Matrix Manipulation

- glLoadIdentity(): sets matrix back to I
  - good idea always to start with this
- glLoadMatrix(): sets a specific matrix
  - stored in *column-major* order
- glMultMatrix(): *multiply* current matrix
  - applies additional transformation

Column-Major Order

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 2 & 1 & 0 & 0 \\ 3 & 2 & 1 & 0 \\ 4 & 3 & 2 & 1 \end{bmatrix}$$

- OpenGL stores this matrix as:
  - glInt *M = {1, 2, 3, 4, 0, 1, 2, 3, 0, 0, 1, 2, 0, 0, 0, 1};

Transformations

- glTranslate() is easy
- so is glScale()
- glRotate(angle, x, y, z) rotates by angle
    - CCW around vector (x, y, z)
    - looking in from (x, y, z) to origin
- there is no glShear()

View Coordinates

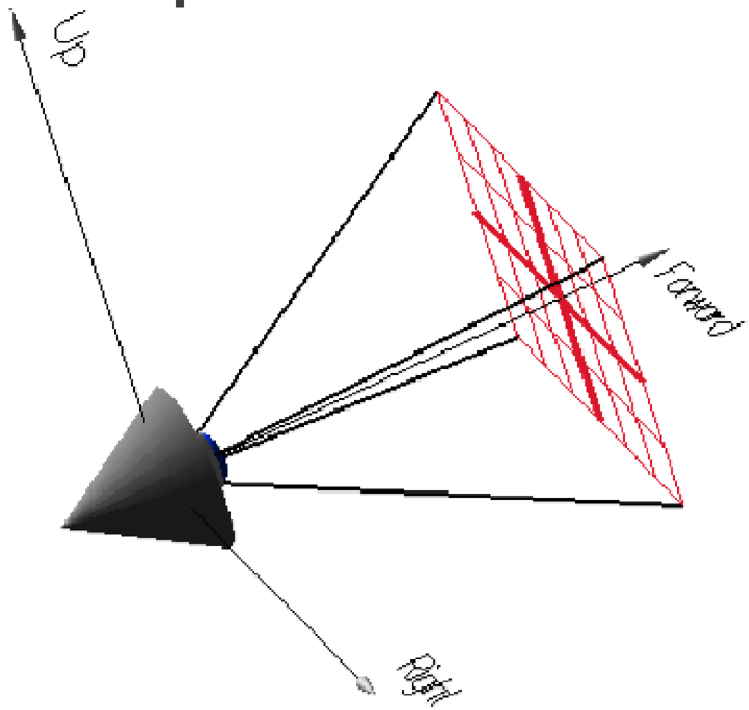
- We can specify the view point with

$$\text{gluLookAt}\left(e_x, e_y, e_z, c_x, c_y, c_z, u_x, u_y, u_z\right);$$

which puts the eye at $\left(e_x, e_y, e_z\right)$,

facing toward $\left(c_x, c_y, c_z\right)$,

with *up* vector $\left(u_x, u_y, u_z\right)$



Projection Matrix

- Switch with glMatrixMode(GL_PROJECTION);
- Then define projection with:
  - glFrustum(*left*, *right*, *bottom*, *top*, *zNear*, *zFar*);
  - gluPerspective(*fovy*, *aspect*, *zNear*, *zFar*);
  - glOrtho(*left*, *right*, *bottom*, *top*, *zNear*, *zFar*);
- All set matrix for eye at origin looking at (0,0, -1)
  - often convenient to apply transforms first

glFrustum()

- near plane of frustum is given by:
  - (*left, bottom, -zNear*)
  - (*right, top, -zNear*)
- far plane is at distance *zFar*
  - with left, right, &c. scaled appropriately
- Anything outside frustum will be *clipped*

gluPerspective()

- *fovy* is the field of view in y-direction
    - in degrees
- *aspect* is the aspect ratio:
    - ratio between x- and y- fields of view
- *zNear* and *zFar* are same as glFrustum()

Viewport

- Specifies mapping from *NDCS* to *DCS*
  - *NDCS* usually ends up in range -1 .. 1
  - *DCS* is in terms of pixel location
    - use glViewport(*0, 0, width, height*)
      - *width* is pixel width of window
      - *height* is pixel height of window