OpenGL Programming-2

EE – 7000

Sep, 21,2011

- Last class:

  Opengl basics

  Drawing geometric objects

- This class:

  Viewing

  Color

Viewing

Creating and Viewing a Scene

- How to view the geometric models that you can now draw with OpenGL

- Two key factors:

  Define the position and orientation of geometric objects in 3D space (creating the scene)

  Specify the location and orientation of the viewpoint in the 3D space (viewing the scene)

- Try to visualize the scene in 3D space that lies deep inside your computer

The Camera Analogy

- Position and aim the Camera at the scene

  Viewing transformation: Position the viewing volume in the world

- Arrange the scene to be photograph into the desired composition

  Modeling transformation: Position the models in the world

- Choose a camera lens or adjust the zoom to adjust field of view

  Projection transformation: Determine the shape of the viewing volume

- Determine the size of the developed (final) photograph

  Viewport transformation

A Series of Operations Needed

- Transformations

  Modeling, viewing and projection operations

- Clipping

  Removing objects (or portions of objects) lying outside the window

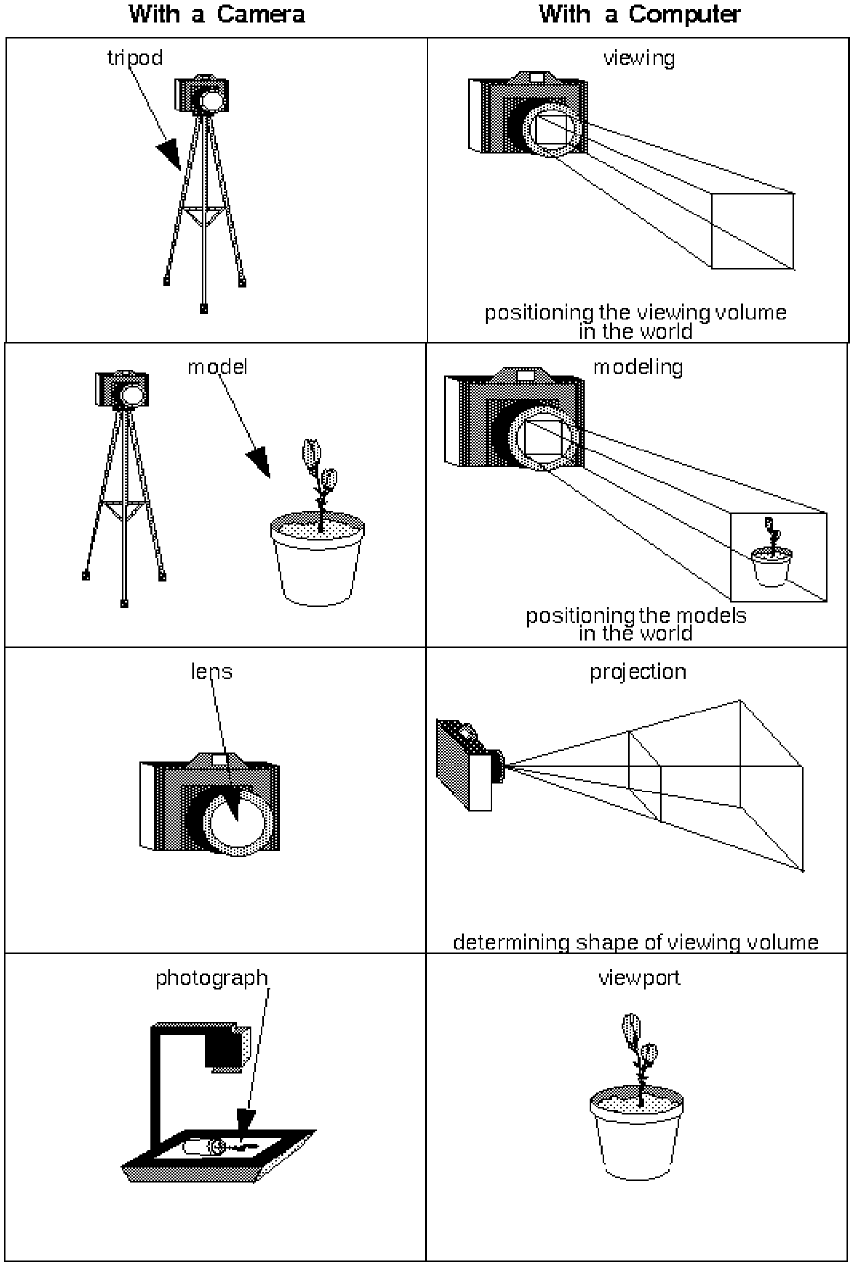
- Viewport Transformation

  Establishing a correspondence between the transformed coordinates (geometric data) and screen pixels

Take real pictures VS "Electronic Pictures"

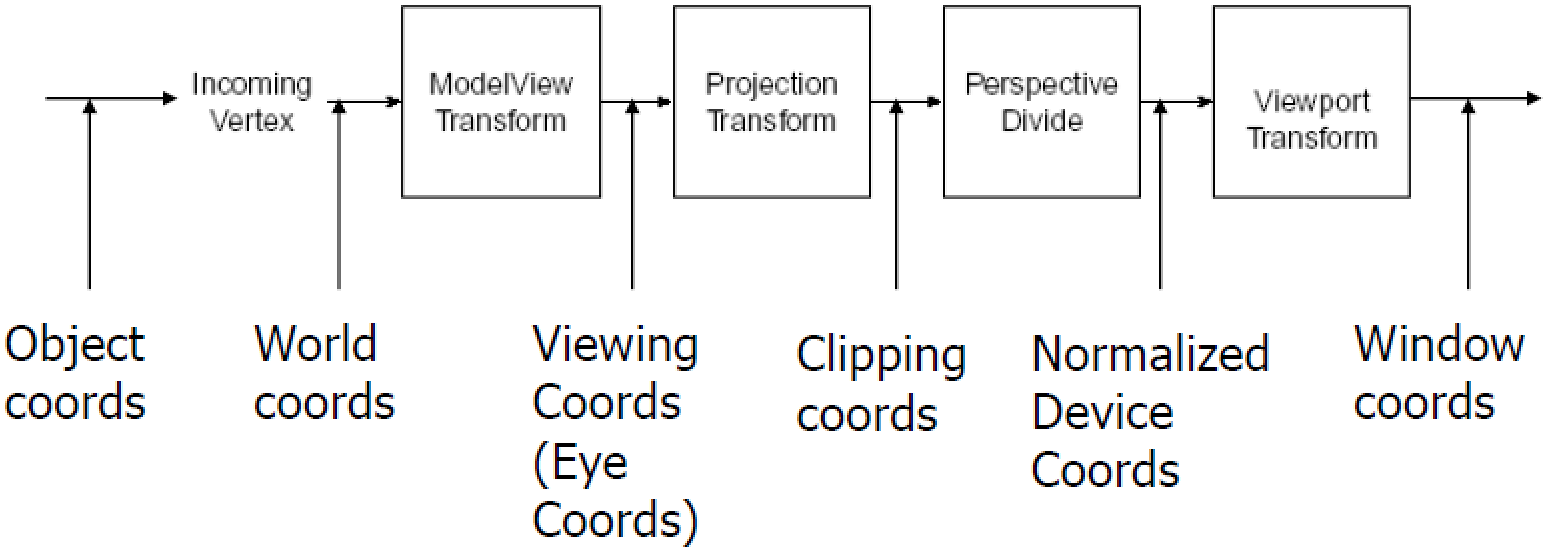
Modeling

- Set up tripod and point at your camera at your scene
- Viewing transformation
- Arrange the scene into a desired composition
- Modeling transformation
- Choose a lens or adjust zoom
- Projection transformation
- Determine how large you want the final photo to be
- Viewport transformation



OpenGL Coordinate System

- OpenGL Pipeline



Check details at:

http://research.cs.queensu.ca/~jstewart/454/notes/pipeline/

Viewing and Modeling Transformation

- Modeling Transformations

  void glTranslatef (float x, float y, float z);

  void glRotatef (float angle, float x, float y, float z);

  void glScalef (float x, float y, float z);

  Your own matrix:

  float m[]={…}

  glMultMatrixf (m)

- Viewing Transformations

  void gluLookAt (Gldouble eyeX, Gldouble eyeY, Gldouble eyeZ, GLdouble centerX, Gldouble centerY, Gldouble centerZ, Gldouble upX, Gldouble upY, Gldouble upZ)

  defines a line of sight (most convenient)

  encapsulates a series of rotation and translation

  Same effect can be achieved by glTranslate*(), glRotate*(), glScale*()…

Mathematics in OpenGL

Transformation matrix

- Transformation is represented by matrix multiplication
- Construct a 4x4 matrix ***M*** which is then multiplied by the coordinates of each vertex ***v*** in the scene to transform them to new coordinates ***v'***

$$\mathbf{v'} = \boldsymbol{M}\mathbf{v}$$

$$\begin{bmatrix} x' \\ y' \\ z' \\ w' \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{bmatrix} \begin{bmatrix} x \\ y \\ y \\ w \end{bmatrix}$$

Homogeneous Coordinates:

$$v = (x, y, z, w)^T$$

Relation between Cartesian and homogeneous coordinates:

$$x_c = x/w, y_c = y/w, z_c = z/w$$

Mathematics in OpenGL

Translation

(x,y,z)->(x+tx, y+ty, z+tz)

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & tx \\ 0 & 1 & 0 & ty \\ 0 & 0 & 1 & tz \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

resulting coordinate — 3d translation matrix — original coordinate

Mathematics in OpenGL

Rotation

Arbitrary rotation matrix is the concatenation of three rotation matices

Note:

Since matrix multiplication is not commutative, the order of rotation can not be exchanged.

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 & 0 \\ \sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

resulting coordinate — 3d rotation matrix in Z — original coordinate

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta & 0 \\ 0 & \sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

resulting coordinate — 3d rotation matrix in X — original coordinate

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 & \sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

resulting coordinate — 3d rotation matrix in Y — original coordinate

Mathematics in OpenGL

Scaling

(x, y, z)->

(sx*x, sy*y, sz*z)

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} sx & 0 & 0 & 0 \\ 0 & sy & 0 & 0 \\ 0 & 0 & sz & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

resulting coordinate — 3d scaling matrix — original coordinate

Order of Matrix Multiplication

- Each transformation command multiplies a new matrix M by the current matrix C

  Last command called in the program is the first one applied to the vertices

```
glLoadIdentity();
glMultMatrixf(N);
glMultMatrixf(M)
glMultMatrix(L)
glBegin(GL_POINTS);
    glVertec3f(v);
glEnd();
```

  The transformed vertex is INMLv

  Transformations occur in the opposite order than they applied

- Transformations are first defined and then objects are drawn

Coordinate Systems

- Grand, fixed coordinate system

  Geometric models are transformed in the fixed coordinate system

  Matrix multiplication occur in the opposite order from how they appear in the code, e.g.,

  ```
  glMultMatrixf(T);
  glMultMatrixf(R);
  ```

  The order is T(Rv)

- Local coordinate system

  The system is tied to the object you are drawing

  All operations occur relative to this moving coordinate system

  Matrix multiplications appear in the natural order, e.g, R(Tv)

  Useful for applications such as robot arms

General Purpose Transformation Commands

- void **glMatrixMode**(GLenum *mode*);

  Specifies which matrix will be modified, using GL_MODELVIEW or GL_PROJECTION for *mode*

- Multiplies the current matrix ***C*** by the specified matrix ***M*** and then sets the result to be the current matrix

  Final matrix will be ***CM***

  Combines previous transformation matrices with the new one

  But you may not want such combinations in many cases

- void **glLoadIdentity**(*void*);

  Sets the current matrix to the 4x4 identity matrix

  Clears the current matrix so that you avoid compound transformation for new matrix

More Commands

- void **glLoadMatrix**(const *TYPE* *m);

  Specifies a matrix that is to be loaded as the current matrix

  Sets the sixteen values of the current matrix

  to those specified by m

$$M = \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{bmatrix}$$

- void **glMultMatrix**(const *TYPE* *m);

  Multiplies the matrix specified M by the current matrix and stores the result as the current matrix

Modeling Transformations

- Positioning and orienting the geometric model

  MTs appear in display function
- Translate, rotate and/or scale the model

  Combine different transformations to get a single matrix

  Order of matrix multiplication is important
- Affine transformation

$$v' = Av + b$$

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & b_1 \\ a_{21} & a_{22} & a_{23} & b_2 \\ a_{31} & a_{32} & a_{33} & b_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

OpenGL Routines for MTs

- void **glTranslate**{fd}(*TYPE x*, *TYPE y*, *TYPE z*);

  Moves (translates) an object by given *x*, *y* and *z* values

- void **glRotate**{fd}(*TYPE angle*, *TYPE x*, *TYPE y*, *TYPE z*);

  Rotates an object in a counterclockwise direction by *angle* (in degrees) about the rotation axis specified by vector (*x*,*y*,*z*)

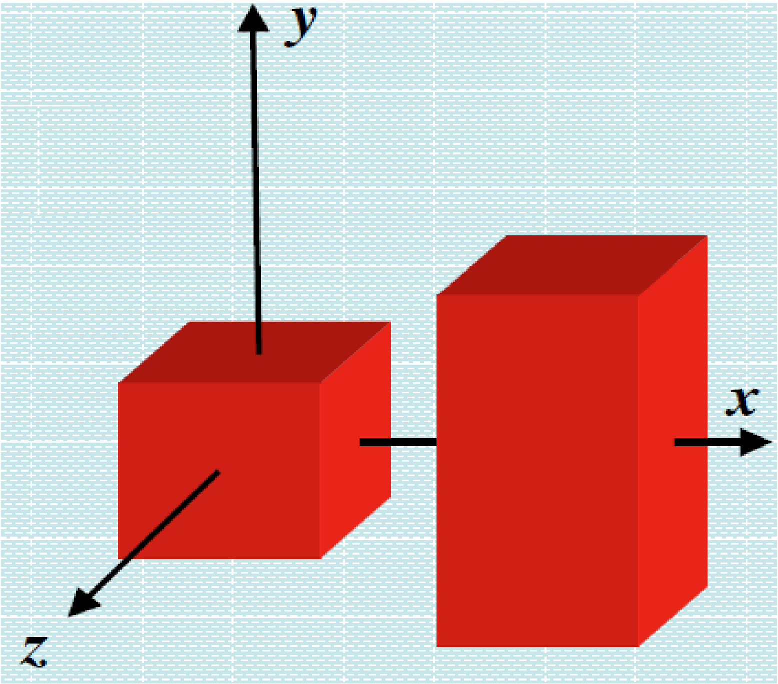
- void **glScale**{fd}(*TYPE x*, *TYPE y*, *TYPE z*);

  Shrinks or stretches or reflects an object by specified factors in x, y and z directions

- Your Own Matrix

Transformed Cube

```
void {display}
{
    glMatrixMode(GL_MODELVIEW);
    glLoadIdentity();
    gluLookAt(0.0,0.0,5.0, 0.0,0.0,0.0,
    0.0,1.0,0.0);
    glutSolidCube(1);
    glTranslatef(3, 0.0, 0.0);
    glScalef(1.0, 2.0, 1.0);
    glutSolidCube(1);
}
```



First cube is centered at (0,0,0)
Second cube is at (3,0,0)
and its y-length is scaled twice

Viewing Transformations

- Specify the position and orientation of viewpoint

- Often called before any modeling transformations so that

the later take effect on the objects first

Defined in *display or reshape* functions

- Default: Viewpoint is situated at the origin, pointing down the negative *z*-axis, and has an up-vector along the positive *y*-axis

- VTs are generally composed of translations and rotations

- Define a custom utility for VTs in specialized applications

Using GLU Routine for VT

- void **gluLookAt**(GLdouble *eyex*, GLdouble *eyey*, GLdouble *eyez*, GLdouble *centerx*, GLdouble *centery*, GLdouble *centerz*, GLdouble *upx*, GLdouble *upy*, GLdouble *upz*);

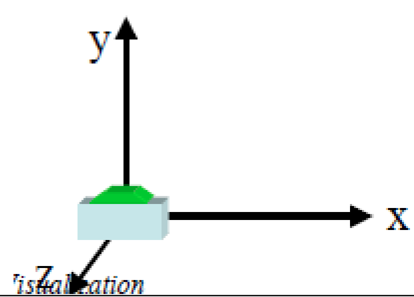
  Defines a viewing matrix and multiplies it by the current matrix

  eyex,eyz,eyz = position of the viewpoint

  centerx,centery,centerz = any point along the desired line of sight

  upx,upy,upz = up direction from the bottom to the top of vewing volume

  gluLookAt(0.0,0.0,5.0, 0.0,0.0,-10.0, 0.0,1.0,0.0);



Using glTranslate and glRotate for VT

- Use modeling transformation commands to emulate viewing transformation

- **glTranslatef**(0.0, 0.0, -5.0)

  Moves the objects in the scene -5 units along the *z*-axis

  This is equivalent to moving the viewpoint +5 units along the *z*-axis

- **glRotatef**(45.0, 0.0, 1.0, 0.0);

  Rotates objects (local coordinates) by 45 degrees about *y*-axis

  To view objects from the side

  This is equivalent to rotating camera in opposite sense

- Total effect is equivalent to

gluLookAt (3.53,0.0,3.53, 0.0,0.0,0.0, 0.0,1.0,0.0);

Modelview Matrix

- Modeling and viewing transformations are complimentary so they are combined to the modelview matrix mode

- To activate the modelview transformation

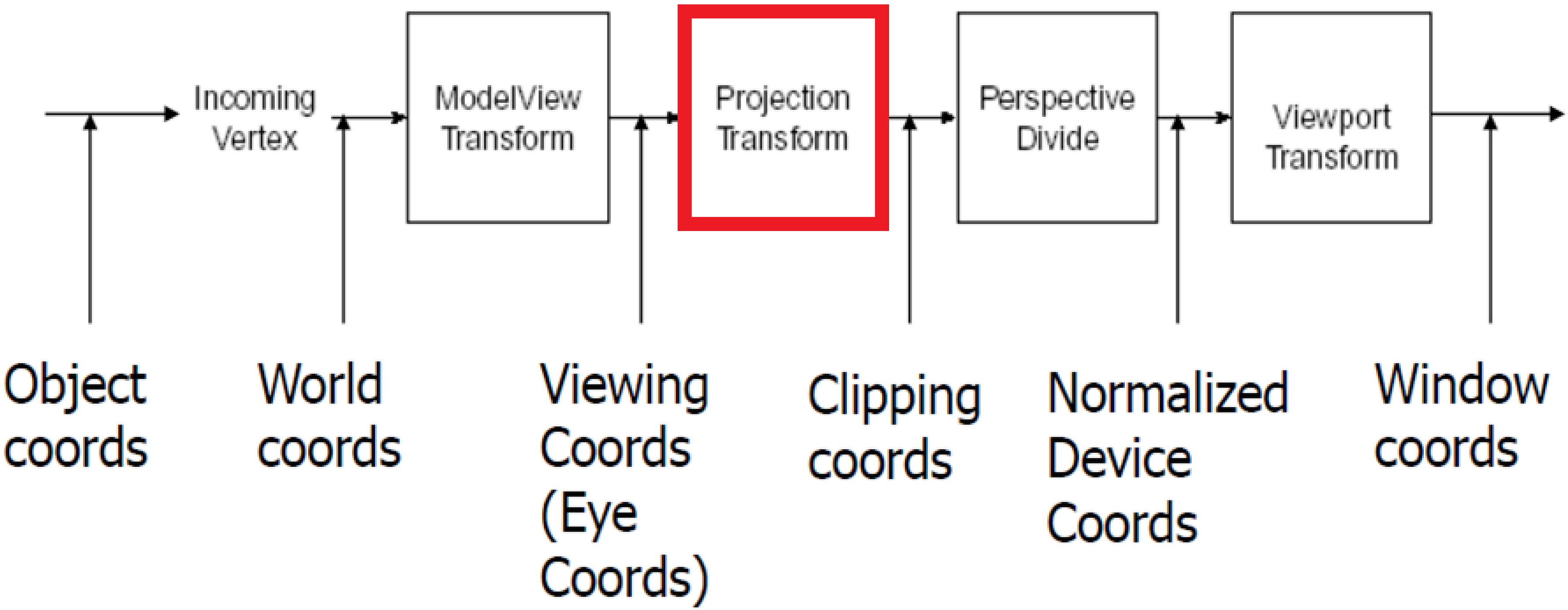
  glMatrixMode(GL_MODELVIEW);
  glLoadIdentity();
  glTranslate();
  glRotate();

- Default *mode* is set at modelview

  Needs to be specified only if the other *mode (projection) is* activated and you want to go back to *modelview mode*

Example 1

- Modeling and Viewing Transformation


Incoming
Vertex
ModelView
Transform
Projection
Transform
Perspective
Divide
Viewport
Transform
Object
coords
World
coords
Viewing
Coords
(Eye
Coords)
Clipping
coords
Normalized
Device
Coords
Window
coords

Projection Transformation

- Call **glMatrixMode**(GL_PROJECTION);

  glLoadIdentity();

  activate the projection matrix

  PT is defined in *reshape* function

- To define the field of view or viewing volume

  how an object is projected on the screen

  which objects or portions of objects are clipped out of the final image

Two Types of Projection

- Perspective projection

  Foreshortening:

  The farther an object is from the camera, the smaller it appears in the final image

  Gives a realism: How our eyes work

  Viewing volume is frustum of a pyramid

- Orthographic projection

  Size of object is independent of distance

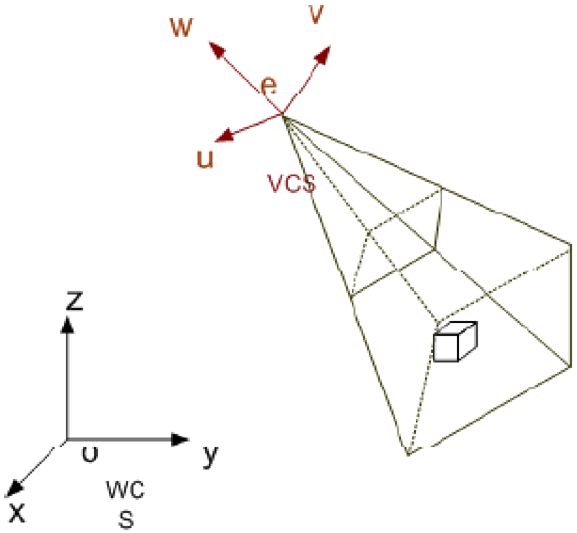
  Viewing volume is a rectangular parallelepiped (a box)

Project Transformations

- Perspective Projection

  Things farther away get smaller

  Parallel lines no longer parallel: vanishing point



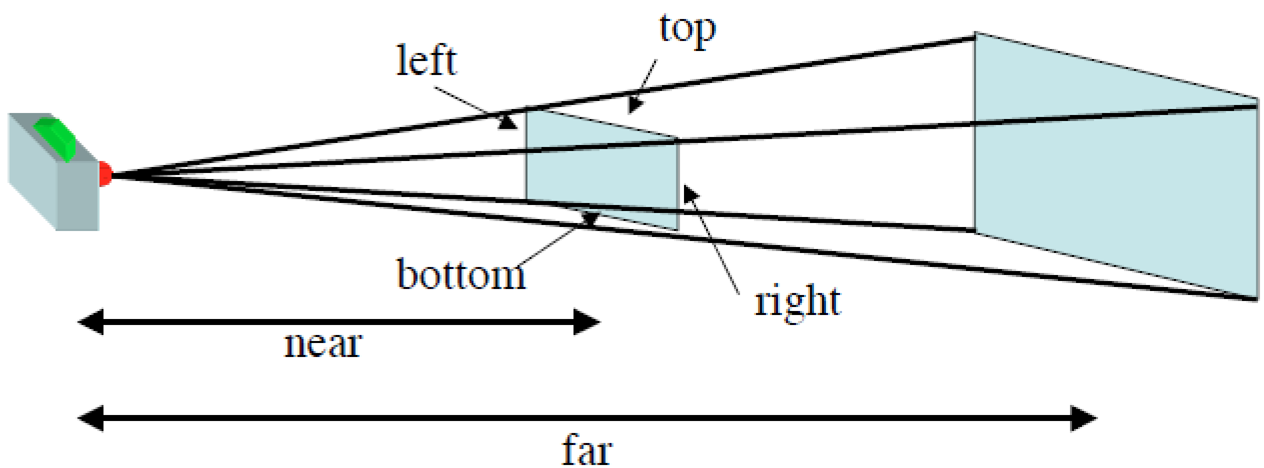
Viewing Coordinate System (VCS)

glFrustum

- void **glFrustum**(GLdouble *left*, GLdouble *right*, Gldouble *bottom*, GLdouble *top*, GLdouble *near*, GLdouble *far*);

  Creates a matrix for perspective-view frustum

  The frustum's viewing volume is defined by the coordinates of the lower-left and upper-right corners of the near clipping plane



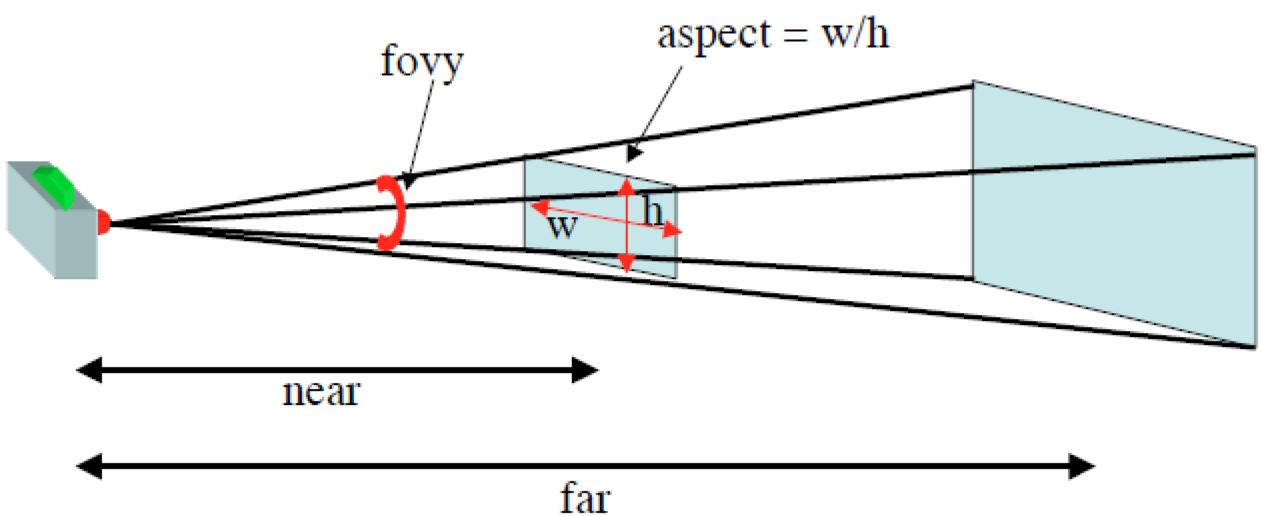
gluPerspective

- void **gluPerspective**(GLdouble *fovy*, GLdouble *aspect*, GLdouble *near*, GLdouble *far*);

  Creates a matrix for a symmetric perspective-view frustum

  Frustum is defined by *fovy* (angle in *yz* plane) and *aspect ratio*

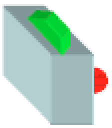
  Near and far clipping planes

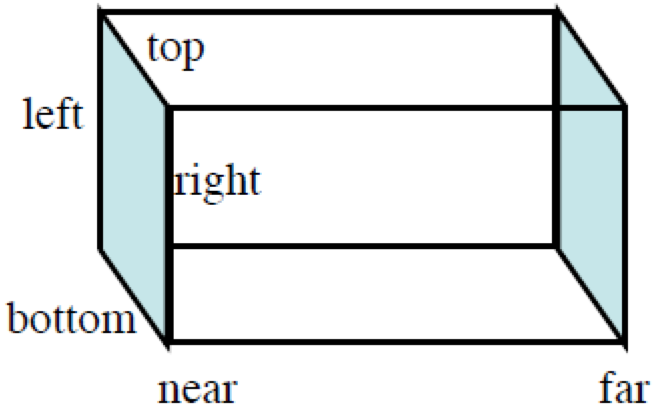


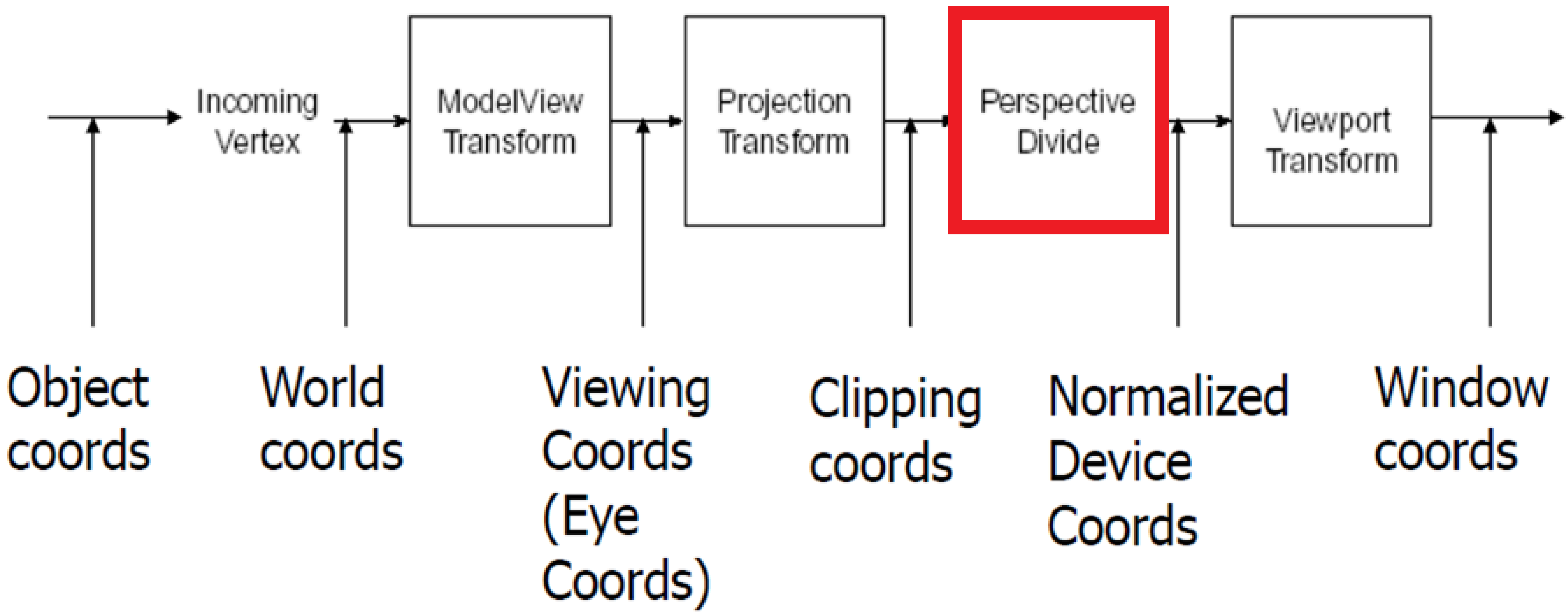
Orthographic Projection

- Void **glOrtho**(GLdouble *left*, GLdouble *right*, GLdouble *bottom*, GLdouble *top*, Gldouble *near*, GLdouble *far*);

    Creates an orthographic parallel viewing volume






Incoming Vertex
ModelView Transform
Projection Transform
Perspective Divide
Viewport Transform
Object coords
World coords
Viewing Coords (Eye Coords)
Clipping coords
Normalized Device Coords
Window coords

Viewing Volume Clipping

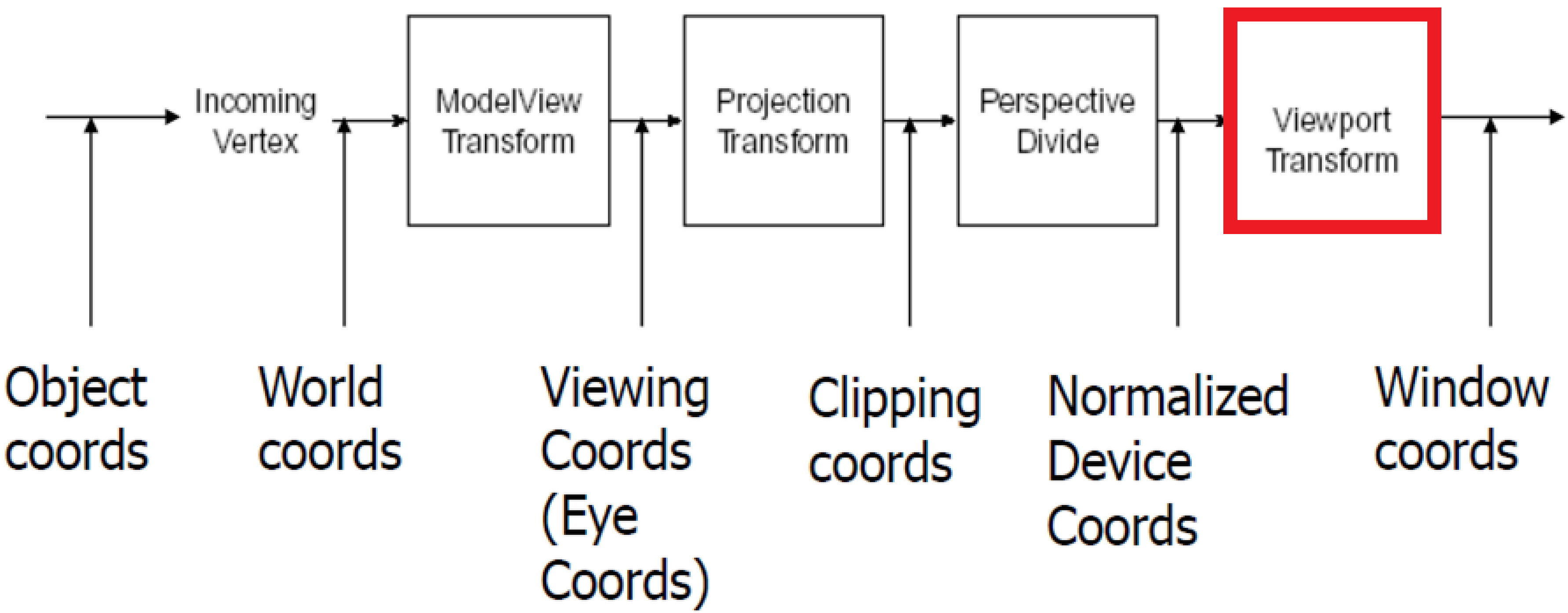
- Clipping
  Frustum defined by six planes (left, right, bottom, top, near, and far
  Clipping is effective after modelview and projection transformations

- Further restricting the viewing volume by specifying additional clipping planes (up to 6)

- **glClipPlane**(GLenum *plane*, const GLdouble **equation*)
  Defines a clipping plane.
  The *equation* argument points to the coefficients of the plane equation $Ac+By+Cz+D=0$
  Only points that satisfy $(A\ B\ C\ D)M\text{-}1(xe\ ye\ ze\ we)T >= 0$ are kept.
  The *plane* argument is GL_CLIP_PLANEi, where is labels the clipping plane
  Needs to be enabled and disabled

Example 2: Clipping

```
void display (void)
{
    GLdouble eqn0[4] = {0.0, 1.0, 0.0, 0.0);
    GLdouble eqn1[4] = {1.0, 0.0, 0.0, 0.0);
    glClearColor (0.0, 0.0, 0.0, 0.0);
    glClear (GL_COLOR_BUFFER_BIT);
    glColor3f (1.0, 0.0, 0.0);
    glClipPlane (GL_CLIP_PLANE0, eqn0);
    glEnable (GL_CLIP_PLANE0);
    glClipPlane (GL_CLIP_PLANE1, eqn1);
    glEnable (GL_CLIP_PLANE1);
    glutWireSphere(1.0, 20, 16);
    glFlush();
}
```



Incoming Vertex
ModelView Transform
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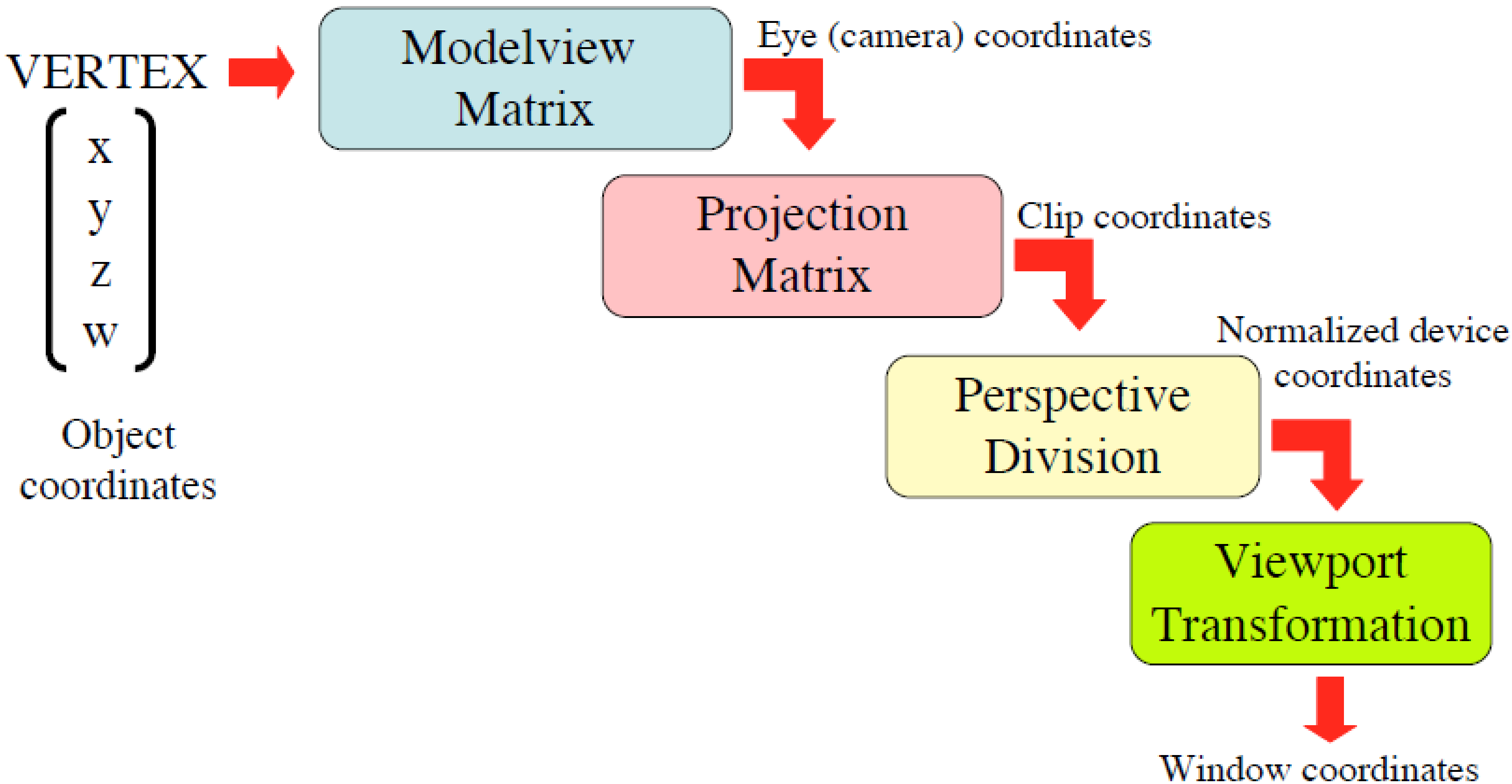
Viewport Transformation

- Viewport is a rectangular region of window where the image is drawn
  - Measured in window coordinates
  - Reflects the position of pixels on the screen relative to lower-left corner of the window
- void **glViewport**(GLint *x*, GLint *y*, GLsizei *width*, GLsizei *height*);
  - Defines a pixel rectangle in the window into which the final image is mapped
  - Aspect ratio of a viewport = aspect ratio of the viewing volume, so that the projected image is undistorted
  - **glViewport** is called in *reshape* function

Vertex Transformation Flow

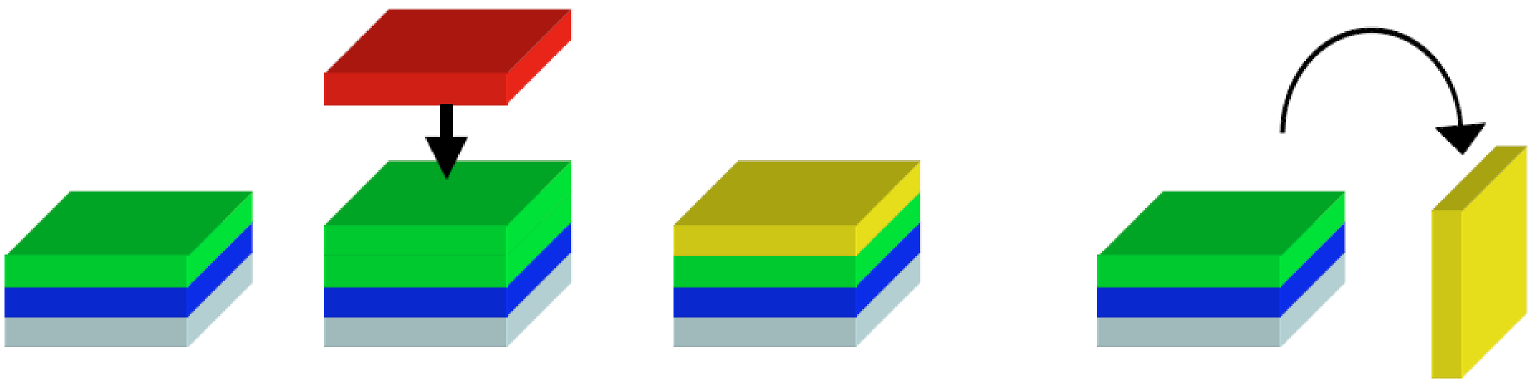


Matrix Stacks

- OpenGL maintains stacks of transformation matrices
  - At the top of the stack is the current matrix
  - Initially the topmost matrix is the identity matrix
  - Provides an mechanism for successive remembering, translating and throwing
  - Get back to a previous coordinate system
- Modelview matrix stack
  - Has 32 matrices or more on the stack
  - Composite transformations
- Projection matrix stack
  - is only two or four levels deep

Pushing and Popping the Matrix Stack

- void **glPushMatrix**(void);
  - Pushes all matrices in the current stack down one level
  - Topmost matrix is copied so its contents are duplicated in both the top and second-from-the-top matrix
  - Remember where you are
- void **glPopMatrix**(void);
  - Eliminates (pops off) the top matrix (destroying the contents of the popped matrix) to expose the second-from-the-top matrix in the stack
  - Go back to where you were



Example 3: Building A Solar System

- How to combine several transformations to achieve a particular result
- Solar system (with a planet and a sun)
  - Setup a viewing and a projection transformation
  - Use **glRotate** to make both grand and local coordinate systems rotate
  - Draw the sun which rotates about the grand axes
  - **glTranslate** to move the local coordinate system to a position where planet will be drawn
  - A second **glRotate** rotates the local coordinate system about the local axes
  - Draw a planet which rotates about its local axes as well as about the grand axes (i.e., orbiting about the sun)

Commands to Draw the Sun and Planet

```
glPushMatrix ();

glRotatef (year, 0.0, 1.0, 0.0);
glutWireSphere (1.0, 20, 16);

glTranslatef (2.0, 0.0, 0.0);
glRotatef (day, 0.0, 1.0, 0.0);

glutWireSphere (0.2, 10, 8);

glPopMatrix ();
```

Color

Color Images

- Goal of OpenGL is to draw color pictures on the computer screen
- Window is a rectangular array of pixels
- How to determine the final color of every pixel

Color Perception

- Our eyes see a mixture of photons of different wavelengths as a color
- Visible spectrum:

  Violet (390 nm) to Red (720 nm)
- Cone cells in the retina are excited by photons

  Three types of cone cells respond best to three different wavelengths

  Red Green Blue

  Other representations: HLS, HSV, CMYK

Computer Color

- Follows RGB analogy

    Each pixel on the screen emits right amounts of the R, G and B light to appropriately stimulate different types of cones in the eye to display a particular color

- Color cube

    Combining the R, G and B light results in different colors

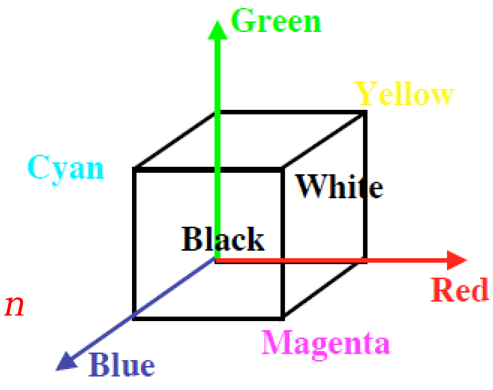
    Red and Blue make megenta

    Red and Green make yellow

- Color buffer

    Memory for the color information for pixels

    Size of buffer is expressed in bits; an *n* bit buffer could 2*n* possible colors for each pixel



Color Display Mode

- RGBA mode

  Red, green, blue and alpha commponets

  The R, G and B values can range from 0.0 (none) to 1.0 (full intensity)

  A 24-bitplane system provides 8 bits each to R, G and B

  The values are clamped to (0.0,1.0)

  Each color component range:

  0/2n = 0.0, 1/2n, 2/2n, ………, 2n/2n =1.0

  thus displaying up to 256x256x256 ~ 16.77 million distinct colors

- Color-Index mode

  Use color map or table

  Stores a single number (index) for each pixel to indicate an entry in a lookup table or color map

Specifying Color

- RGBA mode is preferable over color-index mode

- Each object is drawn using the current color

  Lighting can change the actual color that will ultimately be shown

- void **glColor4**{b s i f d ub us ui}(*TYPE r*, *TYPE g*, *TYPE b*, *TYPE a*);

  void **glColor4**{b s i f d ub us ui}**v**(const, *TYPE* **v*);

  Sets the current red, green, blue, and alpha values

  Default value of alpha value (a) is 1.0

  Several acceptable data types for parameters

  glColor3f(1.0,0.0,0.0) RED

  glColor3f(1.0,1.0,0.0) YELLOW

  glColor3f(1.0,1.0,1.0) WHITE

  glColor3f(0.0,0.0,0.0) BLACK

Shading Model

- void **glShadeModel**(GLenum *mode*)

  Sets the shading model with argument mode taking GL_FLAT or GL_SMOOTH

- Flat shading

  The color of one particular vertex defines the color of entire primitive

- Smooth (Gouraud) shading

  The color at each vertex is treated individually, and the colors for the interior of the polygon are interpolated between the vertex colors

  Neighboring pixels have slightly different color

Examples 5:

6.cpp (color)