Building Models

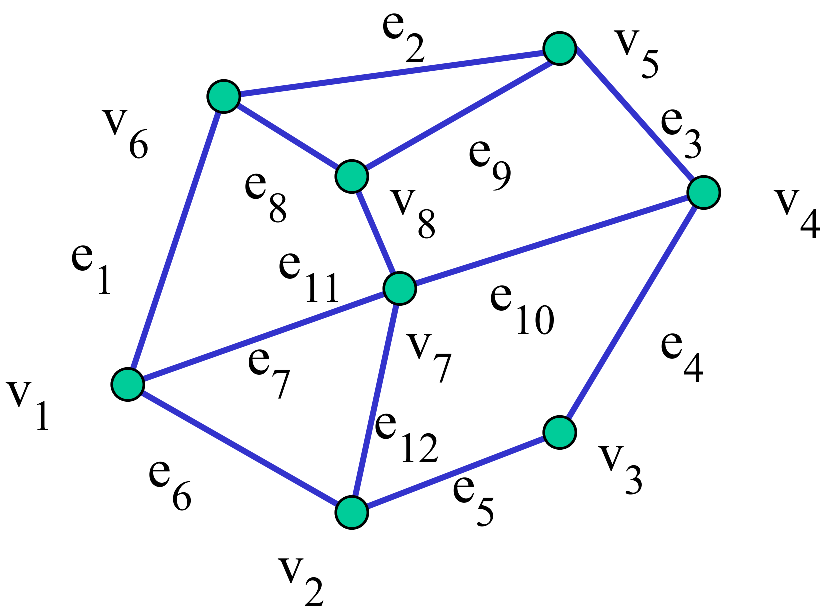
Sorin Babii
sorin.babii@cs.upt.ro

Objectives

- Introduce simple data structures for building polygonal models
  - Vertex lists
  - Edge lists

Representing a Mesh

- Consider a mesh



- There are 8 nodes and 12 edges
  - 5 interior polygons
  - 6 interior (shared) edges
- Each vertex has a location $v_i = (x_i\ y_i\ z_i)$

Simple Representation

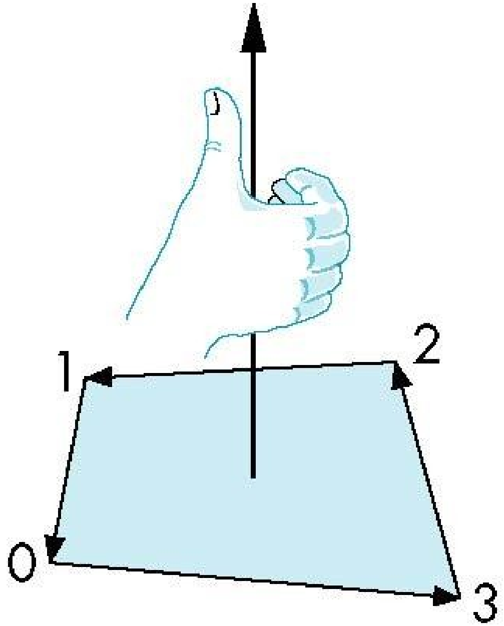
- Define each polygon by the geometric locations of its vertices
- Leads to WebGL code such as

```
vertex.push(vec3(x1, y1, z1));
vertex.push(vec3(x6, y6, z6));
vertex.push(vec3(x7, y7, z7));
```

- Inefficient and unstructured
    - Consider moving a vertex to a new location
    - Must search for all occurrences

Inward and Outward Facing Polygons

- The order $\{v_1, v_2, v_7\}$ and $\{v_7, v_2, v_1\}$ are equivalent in that the same polygon will be rendered by OpenGL but the order $\{v_1, v_2, v_7\}$ is different
- The first two describe *outwardly facing* polygons
- Use the *right-hand rule* = counter-clockwise encirclement of outward-pointing normal
- OpenGL can treat inward and outward facing polygons differently

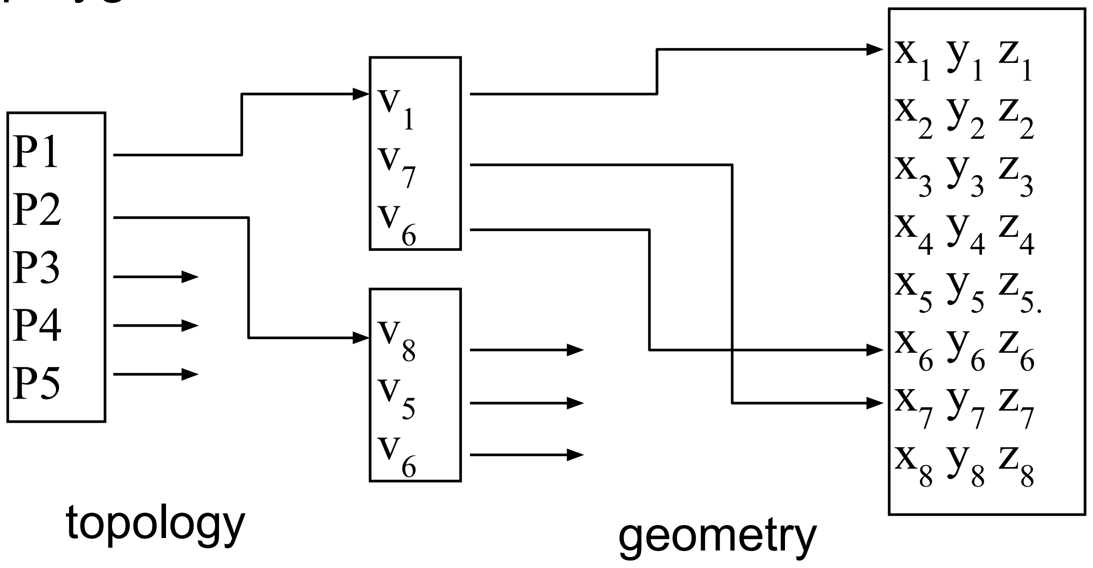


Geometry vs Topology

- Generally it is a good idea to look for data structures that separate the geometry from the topology
  - Geometry: locations of the vertices
  - Topology: organization of the vertices and edges
  - Example: a polygon is an ordered list of vertices with an edge connecting successive pairs of vertices and the last to the first
  - Topology holds even if geometry changes

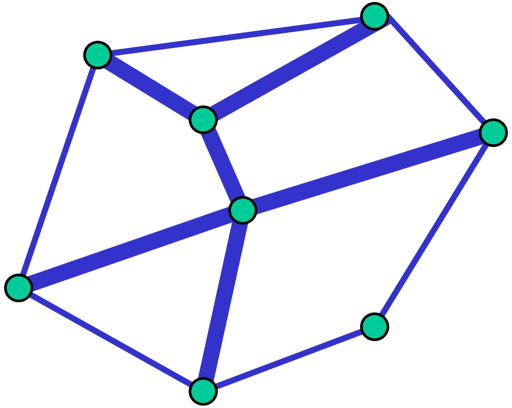
Vertex Lists

- Put the geometry in an array
- Use pointers from the vertices into this array
- Introduce a polygon list



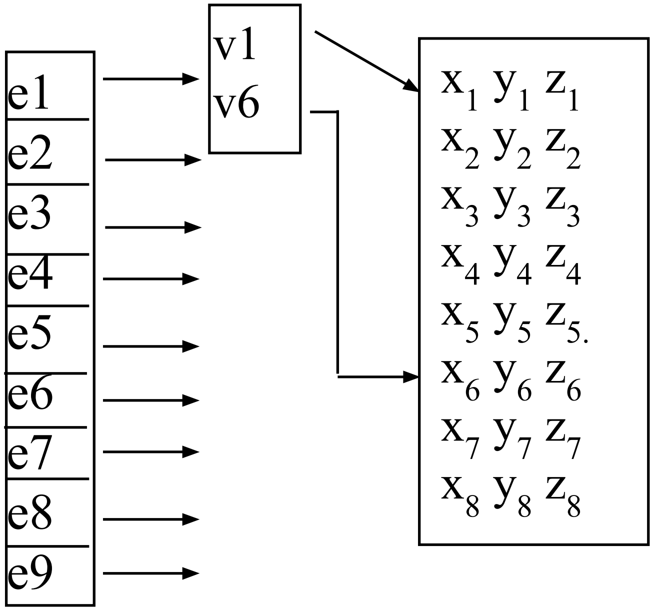
Shared Edges

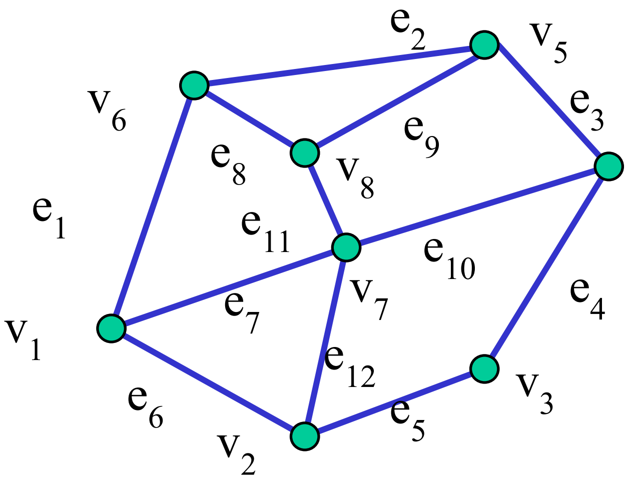
- Vertex lists will draw filled polygons correctly but if we draw the polygon by its edges, shared edges are drawn twice



- Can store mesh by *edge list*

Edge List

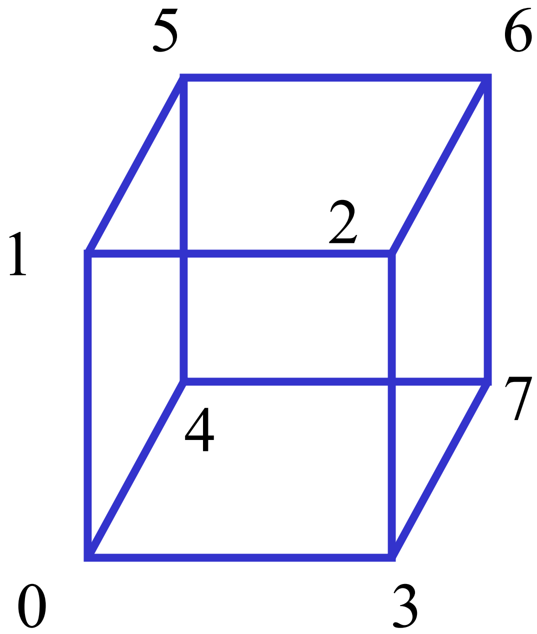




Note polygons are not represented

Draw cube from faces

```
var colorCube( )
{
    quad(0,3,2,1);
    quad(2,3,7,6);
    quad(0,4,7,3);
    quad(1,2,6,5);
    quad(4,5,6,7);
    quad(0,1,5,4);
}
```



The Rotating Square

Objectives

- Put everything together to display rotating cube
- Two methods of display
  - by arrays
  - by elements

Video:

webgl/Code/w05/cube.html

Modeling a Cube

Define global array for vertices

```
var vertices = [
        vec3( -0.5, -0.5,  0.5 ),
        vec3( -0.5,  0.5,  0.5 ),
        vec3(  0.5,  0.5,  0.5 ),
        vec3(  0.5, -0.5,  0.5 ),
        vec3( -0.5, -0.5, -0.5 ),
        vec3( -0.5,  0.5, -0.5 ),
        vec3(  0.5,  0.5, -0.5 ),
        vec3(  0.5, -0.5, -0.5 )
    ];
```

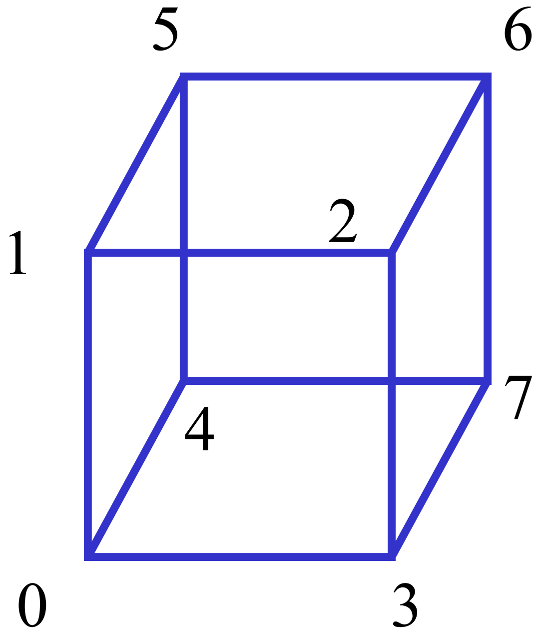
Colors

Define global array for colors

```
var vertexColors = [
        [ 0.0, 0.0, 0.0, 1.0 ],  // black
        [ 1.0, 0.0, 0.0, 1.0 ],  // red
        [ 1.0, 1.0, 0.0, 1.0 ],  // yellow
        [ 0.0, 1.0, 0.0, 1.0 ],  // green
        [ 0.0, 0.0, 1.0, 1.0 ],  // blue
        [ 1.0, 0.0, 1.0, 1.0 ],  // magenta
        [ 0.0, 1.0, 1.0, 1.0 ],  // cyan
        [ 1.0, 1.0, 1.0, 1.0 ]   // white
    ];
```

Draw cube from faces

```
function colorCube( )
{
    quad(0,3,2,1);
    quad(2,3,7,6);
    quad(0,4,7,3);
    quad(1,2,6,5);
    quad(4,5,6,7);
    quad(0,1,5,4);
}
```



Note that vertices are ordered so that we obtain correct outward facing normals
Each quad generates two triangles

Initialization

```
var canvas, gl;
var numVertices  = 36;
var points = [];
var colors = [];

window.onload = function init(){
   canvas = document.getElementById( "gl-canvas" );
   gl = WebGLUtils.setupWebGL( canvas );

   colorCube();

   gl.viewport( 0, 0, canvas.width, canvas.height );
   gl.clearColor( 1.0, 1.0, 1.0, 1.0 );
   gl.enable(gl.DEPTH_TEST);

// rest of initialization and html file
// same as previous examples
```

The `quad` Function

Put position and color data for two triangles from a list of indices into the array **`vertices`**

```
var quad(a, b, c, d)
{
   var indices = [ a, b, c, a, c, d ];
   for ( var i = 0; i < indices.length; ++i ) {
      points.push( vertices[indices[i]]);
      colors.push( vertexColors[indices[i]] );
// for solid colored faces use
// colors.push(vertexColors[a]);

 }
}
```

Render Function

```
function render(){
    gl.clear( gl.COLOR_BUFFER_BIT |gl.DEPTH_BUFFER_BIT);
    gl.drawArrays( gl.TRIANGLES, 0, numVertices );
    requestAnimFrame( render );
}
```

Mapping indices to faces

```
var indices = [
1,0,3,
3,2,1,
2,3,7,
7,6,2,
3,0,4,
4,7,3,
6,5,1,
1,2,6,
4,5,6,
6,7,4,
5,4,0,
0,1,5
];
```

Rendering by Elements

- Send indices to GPU

```
var iBuffer = gl.createBuffer();
gl.bindBuffer(gl.ELEMENT_ARRAY_BUFFER, iBuffer);
gl.bufferData(gl.ELEMENT_ARRAY_BUFFER,
       new Uint8Array(indices), gl.STATIC_DRAW);
```

- Render by elements

```
gl.drawElements( gl.TRIANGLES, numVertices,
    gl.UNSIGNED_BYTE, 0 );
```

- Even more efficient if we use triangle strips or triangle fans

Adding Buttons for Rotation

```
var xAxis = 0;
var yAxis = 1;
var zAxis = 2;
var axis = 0;
var theta = [ 0, 0, 0 ];
var thetaLoc;

document.getElementById( "xButton" ).onclick =
function () {          axis = xAxis;     };
document.getElementById( "yButton" ).onclick =
function () {          axis = yAxis;     };
document.getElementById( "zButton" ).onclick =
function () {          axis = zAxis;     };
```

Render Function

```
function render(){
    gl.clear( gl.COLOR_BUFFER_BIT |gl.DEPTH_BUFFER_BIT);
    theta[axis] += 2.0;
    gl.uniform3fv(thetaLoc, theta);
    gl.drawArrays( gl.TRIANGLES, 0, numVertices );
    requestAnimFrame( render );
}
```

Classical Viewing

Objectives

- Introduce the classical views
- Compare and contrast image formation by computer with how images have been formed by architects, artists, and engineers
- Learn the benefits and drawbacks of each type of view

Classical Viewing

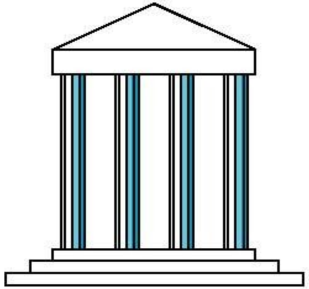
- Viewing requires three basic elements
  - One or more objects
  - A viewer with a projection surface
  - Projectors that go from the object(s) to the projection surface
- Classical views are based on the relationship among these elements
  - The viewer picks up the object and orients it how she would like to see it
- Each object is assumed to constructed from flat *principal faces*
  - Buildings, polyhedra, manufactured objects

Planar Geometric Projections

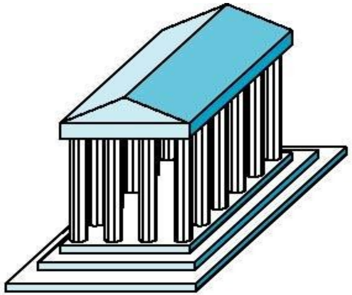
- Standard projections project onto a plane
- Projectors are lines that either
    - converge at a center of projection
    - are parallel
- Such projections preserve lines

  but not necessarily angles
- Nonplanar projections are needed for applications such as map construction

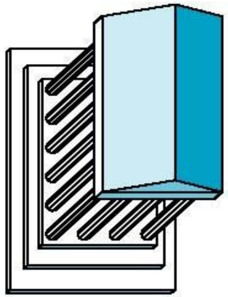
Classical Projections



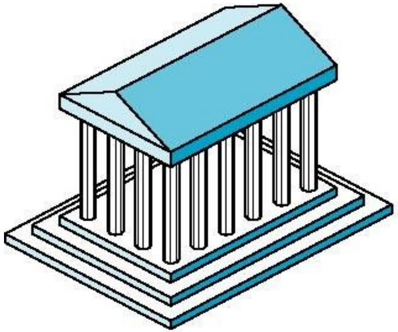
Front elevation



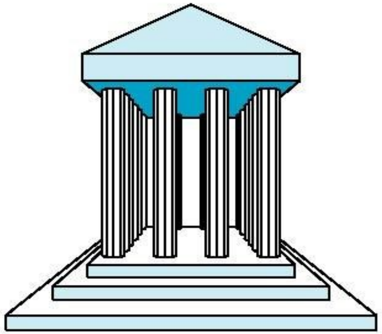
Elevation oblique



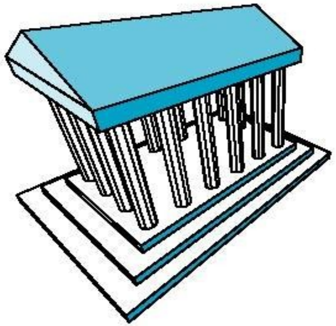
Plan oblique



Isometric



One-point perspective

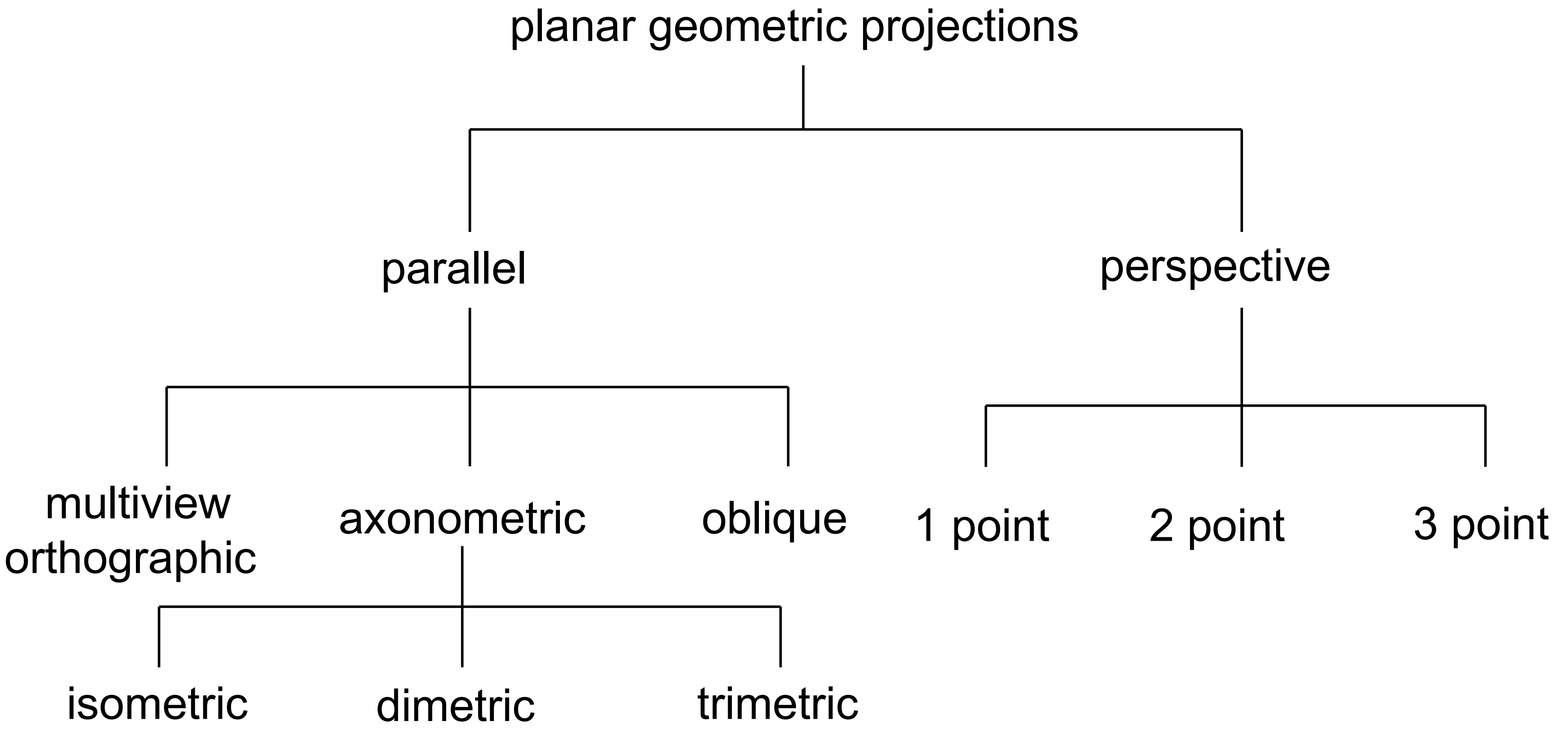


Three-point perspective

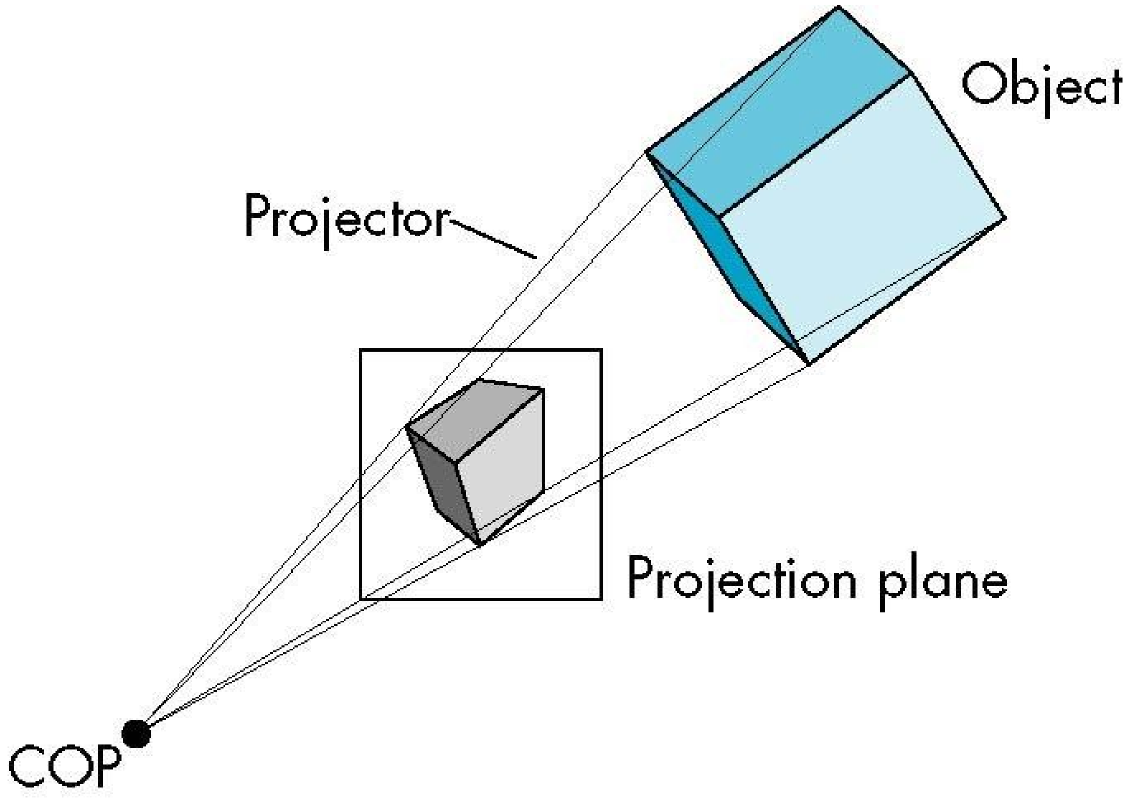
Perspective vs Parallel

- Computer graphics treats all projections the same and implements them with a single pipeline
- Classical viewing developed different techniques for drawing each type of projection
- Fundamental distinction is between parallel and perspective viewing even though mathematically parallel viewing is the limit of perspective viewing

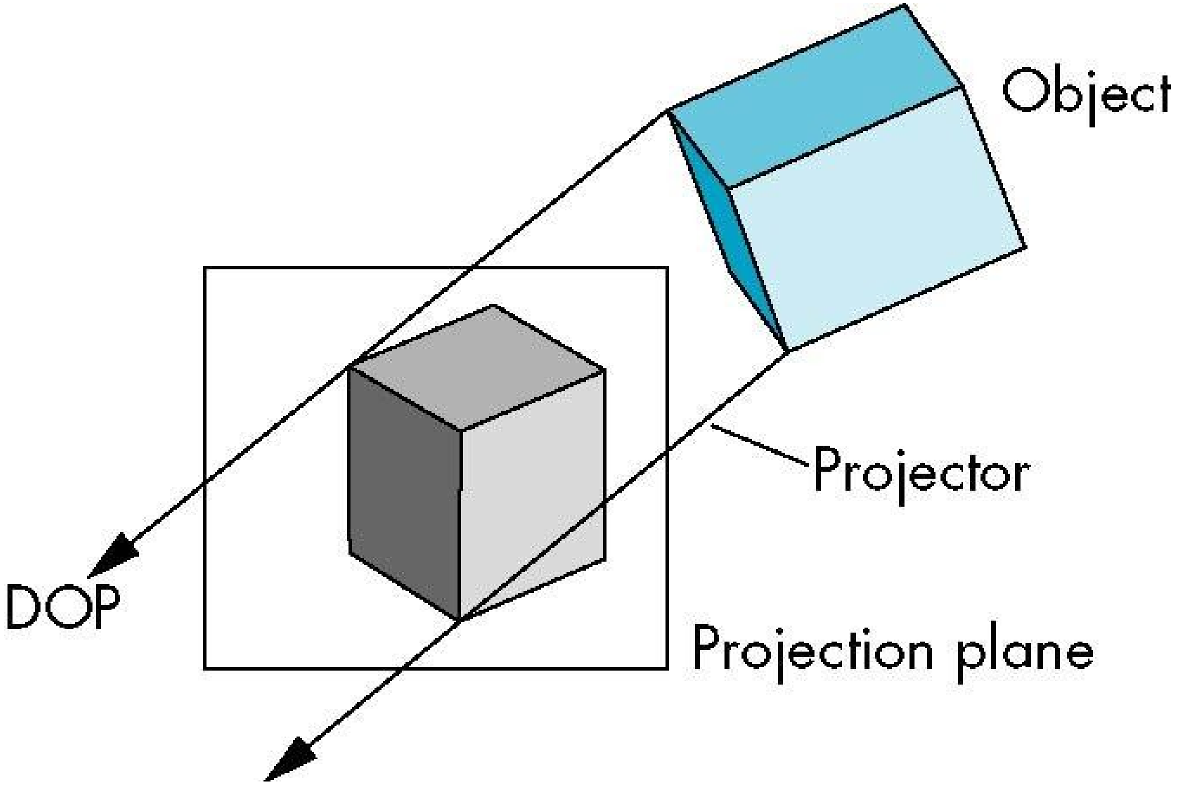
Taxonomy of Planar Geometric Projections



Perspective Projection

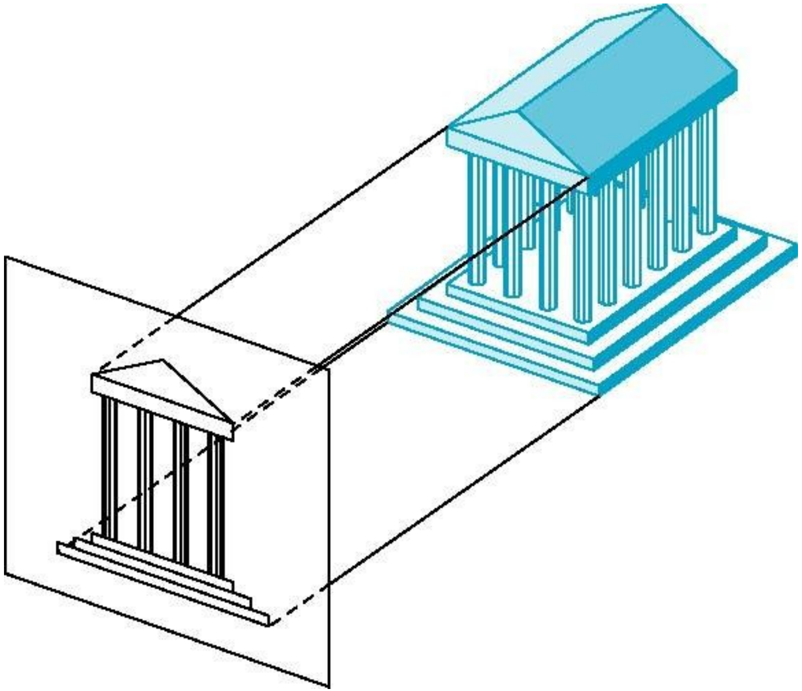


Parallel Projection



Orthographic Projection

Projectors are orthogonal to projection surface



Multiview Orthographic Projection

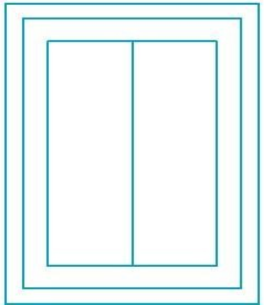
- Projection plane parallel to principal face
- Usually form front, top, side views

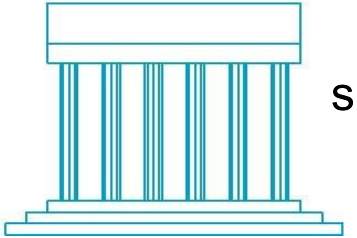
isometric (not multiview orthographic view)

front

in CAD and architecture, we often display three multiviews plus isometric

top





side

Advantages and Disadvantages

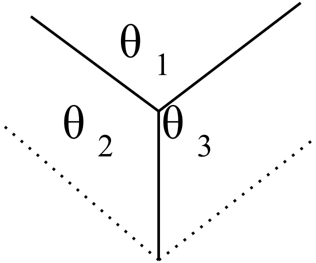
- Preserves both distances and angles
  - Shapes preserved
  - Can be used for measurements
    - Building plans
    - Manuals
- Cannot see what object really looks like because many surfaces hidden from view
  - Often we add the isometric

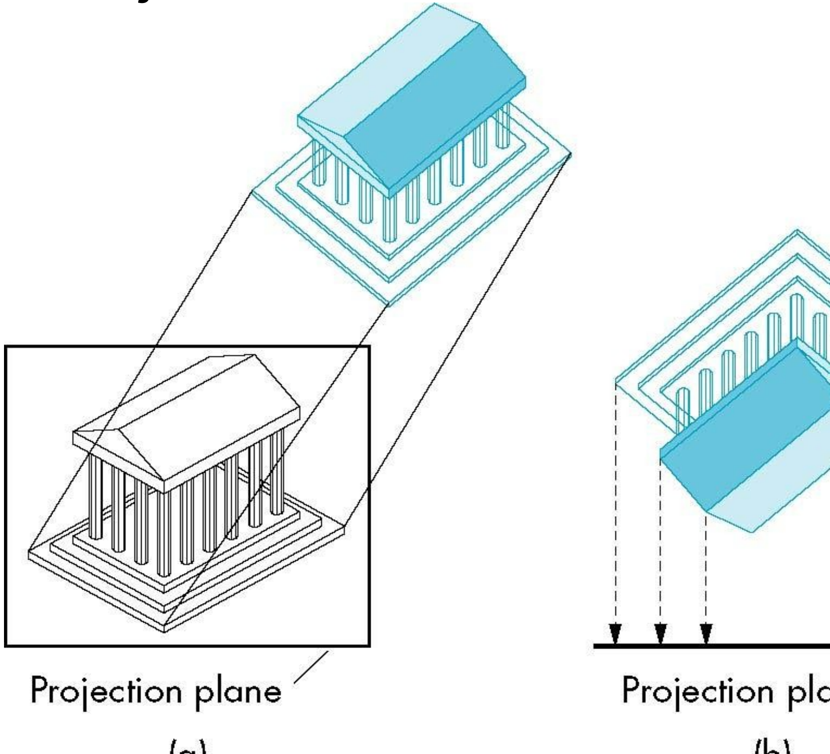
Axonometric Projections

Allow projection plane to move relative to object

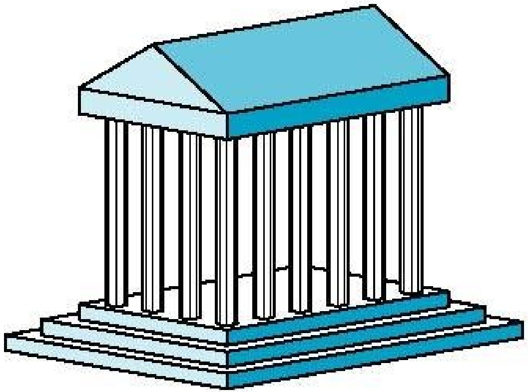
classify by how many angles of a corner of a projected cube are the same

none: trimetric
two: dimetric
three: isometric

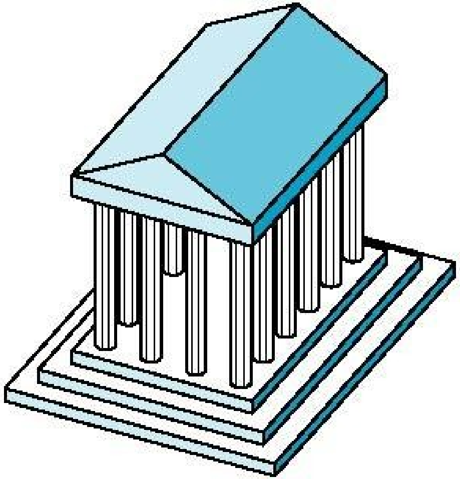




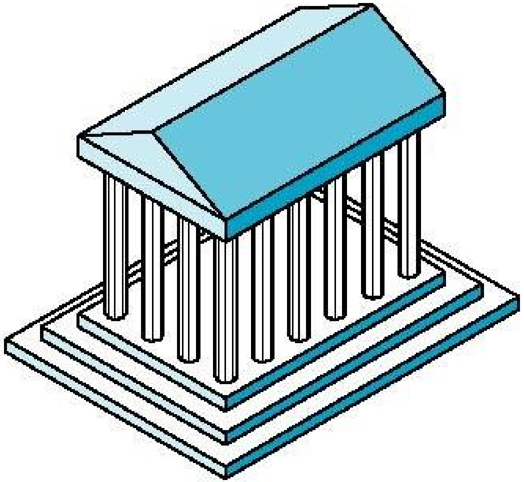
Types of Axonometric Projections



Dimetric



Trimetric



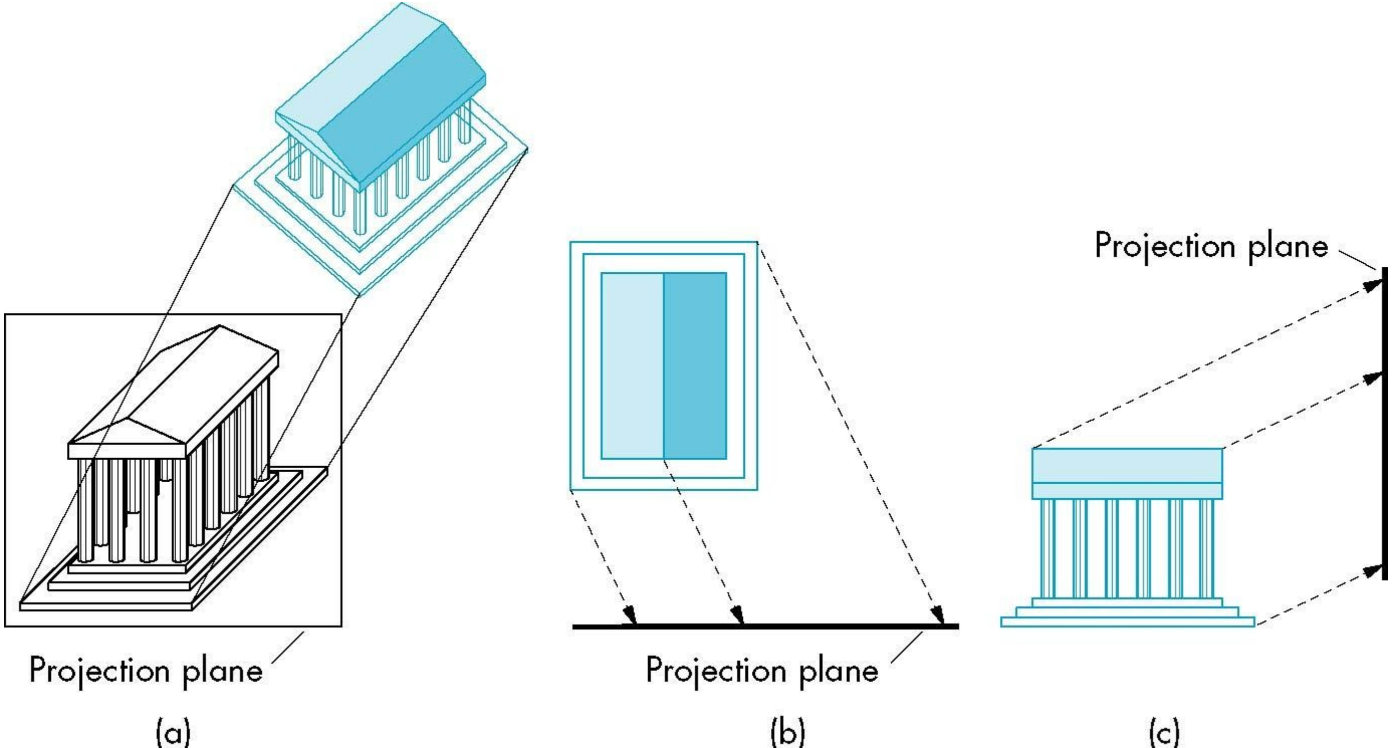
Isometric

Advantages and Disadvantages

- Lines are scaled but can find scaling factors
- Lines preserved but angles are not
    - Projection of a circle in a plane not parallel to the projection plane is an ellipse
- Can see three principal faces of a box-like object
- Some optical illusions possible
    - Parallel lines appear to diverge
- Does not look real because far objects are scaled the same as near objects
- Used in CAD applications

Oblique Projection

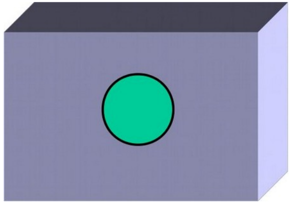
Arbitrary relationship between projectors and projection plane



Advantages and Disadvantages

- Can pick the angles to emphasize a particular face

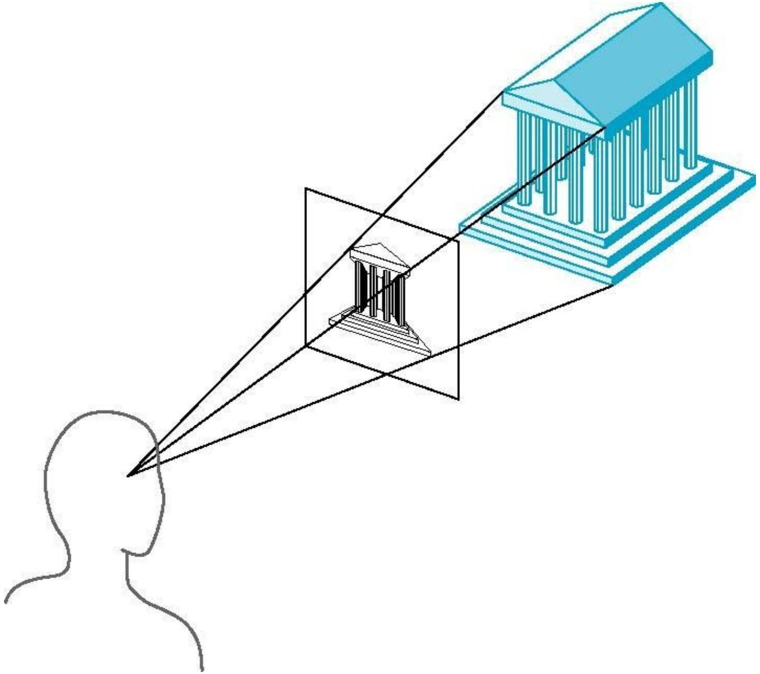
  Architecture: plan oblique, elevation oblique
- Angles in faces parallel to projection plane are preserved while we can still see “around” side



- In physical world, cannot create with simple camera; possible with Bellows camera or special lens (architectural)

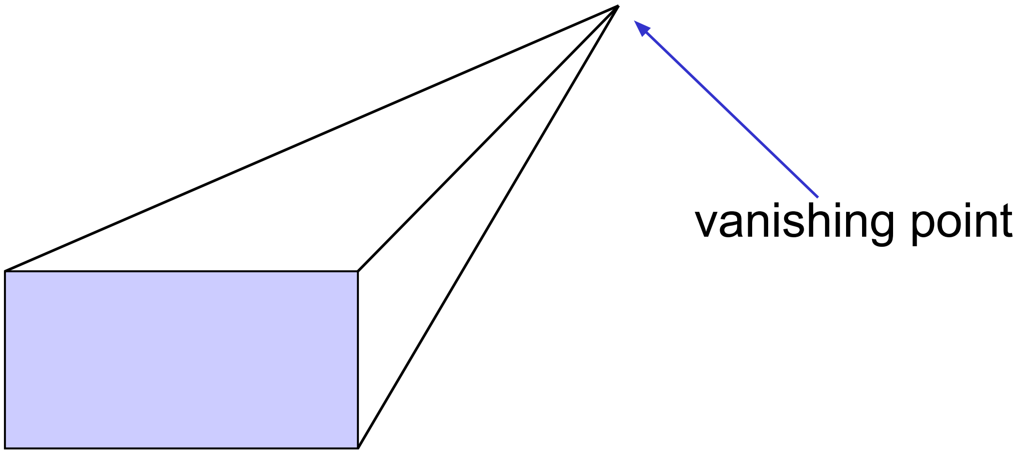
Perspective Projection

Projectors converge at center of projection



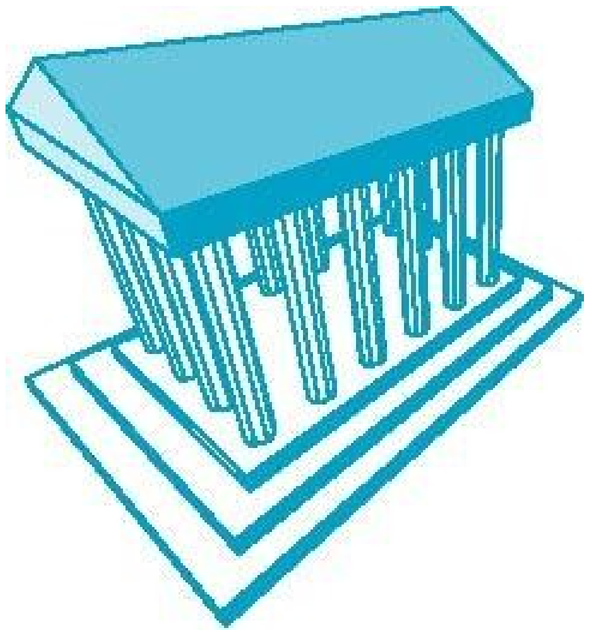
Vanishing Points

- Parallel lines (not parallel to the projection plan) on the object converge at a single point in the projection (the *vanishing point*)
- Drawing simple perspectives by hand uses these vanishing point(s)



Three-Point Perspective

- No principal face parallel to projection plane
- Three vanishing points for cube



Two-Point Perspective

- On principal direction parallel to projection plane
- Two vanishing points for cube

One-Point Perspective

- One principal face parallel to projection plane
- One vanishing point for cube

Advantages and Disadvantages

- Objects further from viewer are projected smaller than the same sized objects closer to the viewer (*diminution*)
  - Looks realistic
- Equal distances along a line are not projected into equal distances (*nonuniform foreshortening*)
- Angles preserved only in planes parallel to the projection plane
- More difficult to construct by hand than parallel projections (but not more difficult by computer)

Computer Viewing: Positioning the Camera

Objectives

- Introduce the mathematics of projection
- Introduce WebGL viewing functions in MV.js
- Look at alternate viewing APIs

From the Beginning

- In the beginning:
  - fixed function pipeline
  - Model-View and Projection Transformation
  - Predefined frames: model, object, camera, clip, ndc, window
- After deprecation
  - pipeline with programmable shaders
  - no transformations
  - clip, ndc window frames
- MV.js reintroduces original capabilities

Computer Viewing

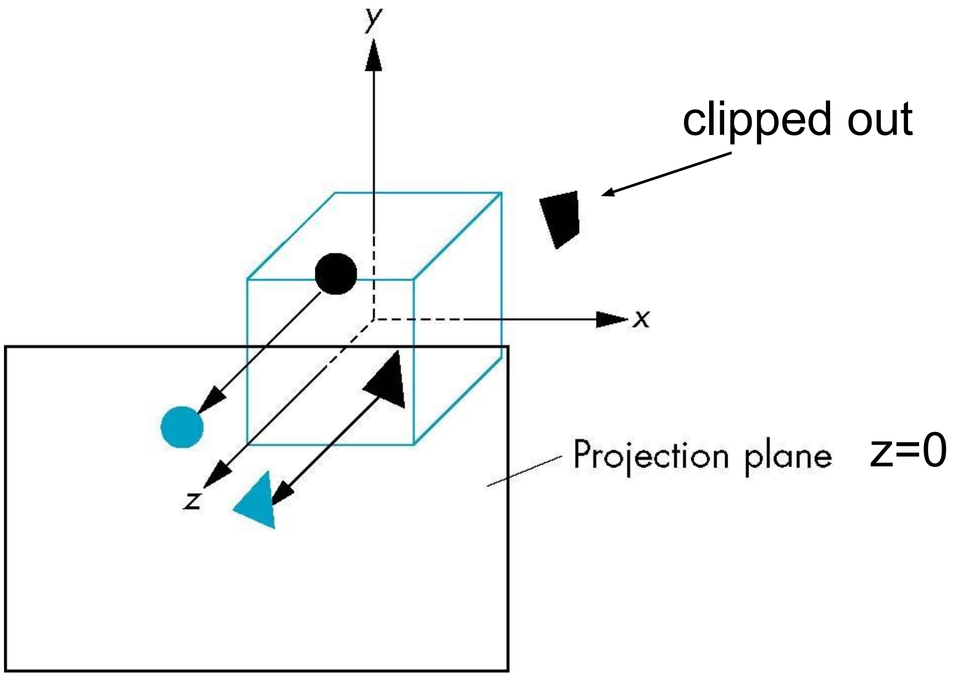
- There are three aspects of the viewing process, all of which are implemented in the pipeline,
  - Positioning the camera
    - Setting the model-view matrix
  - Selecting a lens
    - Setting the projection matrix
  - Clipping
    - Setting the view volume

The WebGL Camera

- In WebGL, initially the object and camera frames are the same
  - Default model-view matrix is an identity
- The camera is located at origin and points in the negative z direction
- WebGL also specifies a *default view volume* that is a cube with sides of length 2 centered at the origin
  - Default projection matrix is an identity

Default Projection

Default projection is orthogonal



Moving the Camera Frame

- If we want to visualize objects with both positive and negative z values we can either

  Move the camera in the positive z direction
    - Translate the camera frame

  Move the objects in the negative z direction
    - Translate the world frame
- Both of these views are equivalent and are determined by the model-view matrix

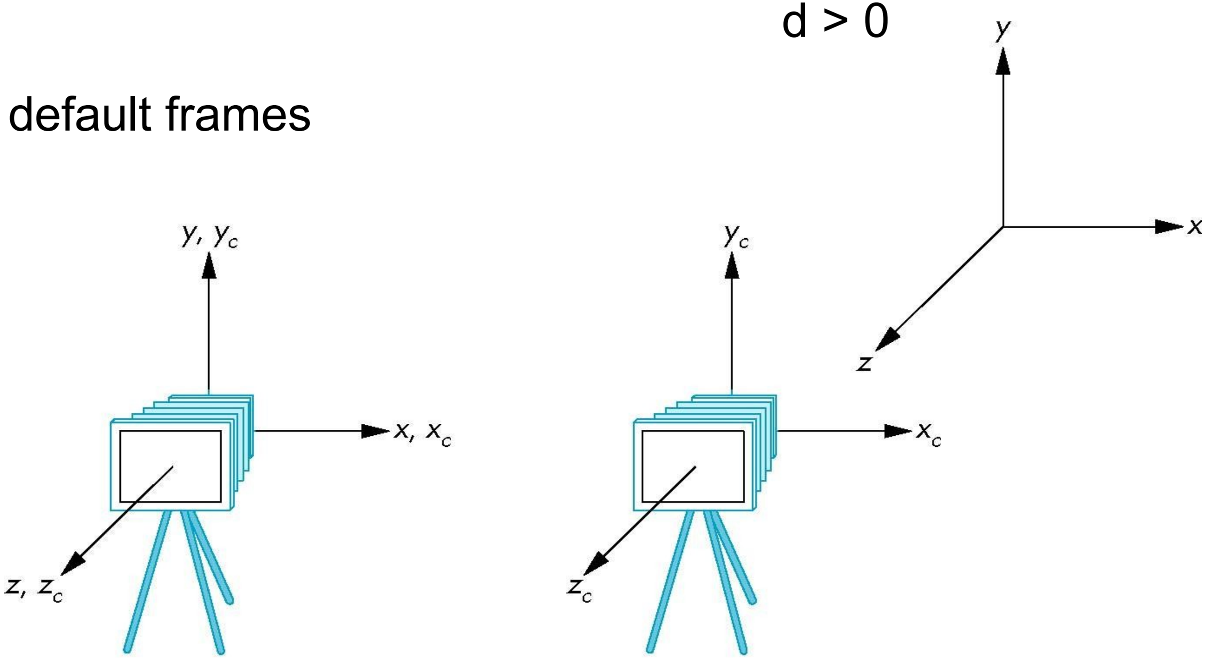
  Want a translation (**`translate(0.0,0.0,-d);`**)

  `d > 0`

Moving Camera back from Origin

frames after translation by –d
d > 0

default frames

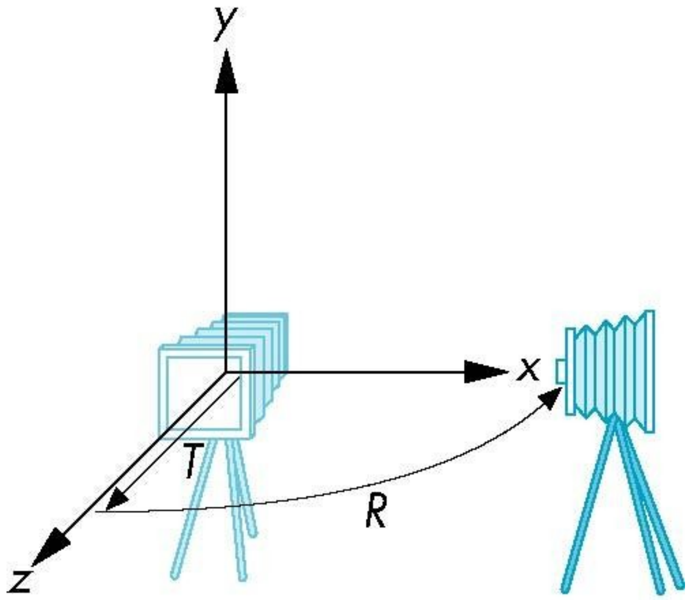


(a)

(b)

Moving the Camera

- We can move the camera to any desired position by a sequence of rotations and translations
- Example: side view
  - Rotate the camera
  - Move it away from origin
  - Model-view matrix C = TR



WebGL code

Remember that last transformation specified is first to be applied

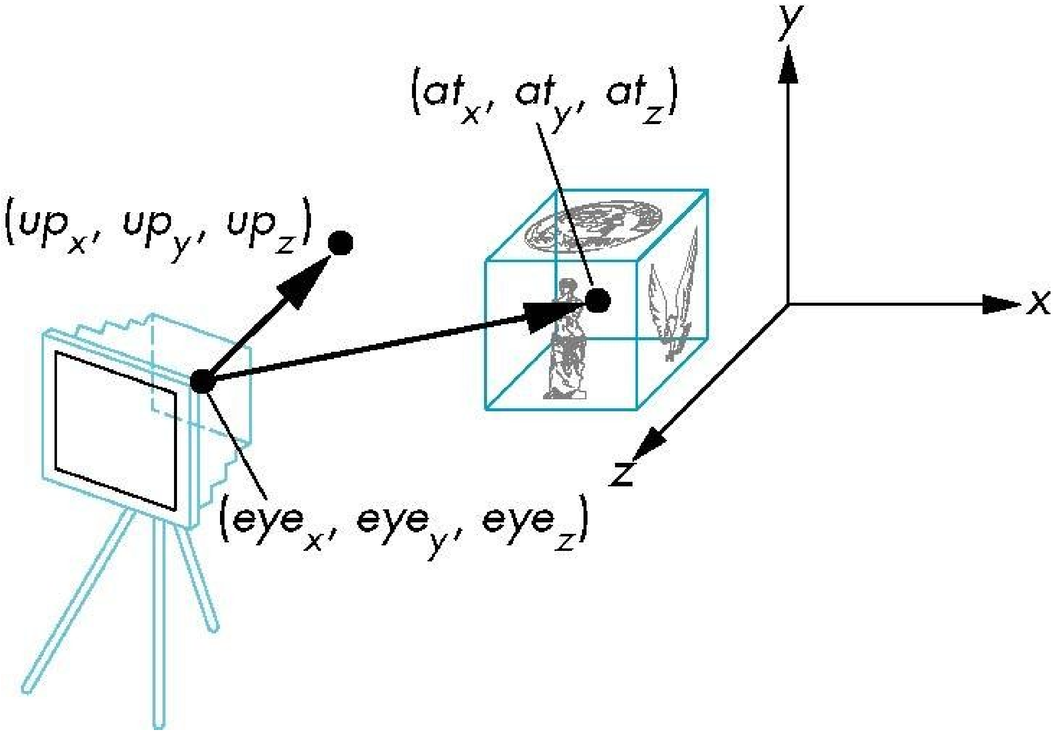
```
// Using MV.js

var t = translate (0.0, 0.0, -d);
var ry = rotateY(90.0);
var m = mult(t, ry);
```

or

```
var m = mult(translate (0.0, 0.0, -d),
         rotateY(90.0););
```

lookAt

```
LookAt(eye, at, up)
```



The lookAt Function

- The GLU library contained the function gluLookAt to form the required modelview matrix through a simple interface
- Note the need for setting an up direction
- Replaced by lookAt() in MV.js

  Can concatenate with modeling transformations
- Example: isometric view of cube aligned with axes

```
var eye = vec3(1.0, 1.0, 1.0);
var at = vec3(0.0, 0.0, 0.0);
var up = vec3(0.0, 1.0, 0.0);

var mv = LookAt(eye, at, up);
```

Other Viewing APIs

- The LookAt function is only one possible API for positioning the camera
- Others include
    - View reference point, view plane normal, view up (PHIGS, GKS-3D)
    - Yaw, pitch, roll
    - Elevation, azimuth, twist
    - Direction angles

Computer Viewing: Projection

Objectives

- Introduce the mathematics of projection
- Add WebGL projection functions in MV.js

Projections and Normalization

- The default projection in the eye (camera) frame is orthogonal
- For points within the default view volume

$$x_p = x$$
$$y_p = y$$
$$z_p = 0$$

- Most graphics systems use *view normalization*
  - All other views are converted to the default view by transformations that determine the projection matrix
  - Allows use of the same pipeline for all views

Homogeneous Coordinate Representation

default orthographic projection

$$x_p = x$$
$$y_p = y$$
$$z_p = 0$$
$$w_p = 1$$

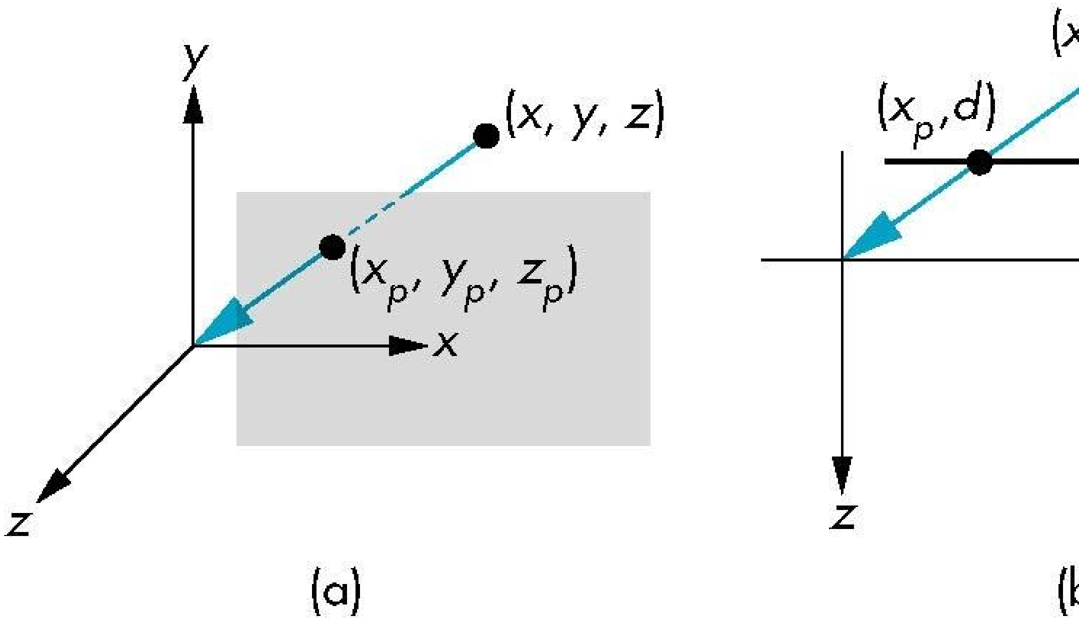
$$\mathbf{p}_p = \mathbf{Mp}$$

$$\mathbf{M} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

In practice, we can let $\mathbf{M} = \mathbf{I}$ and set the *z* term to zero later

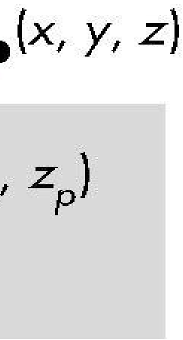
Simple Perspective

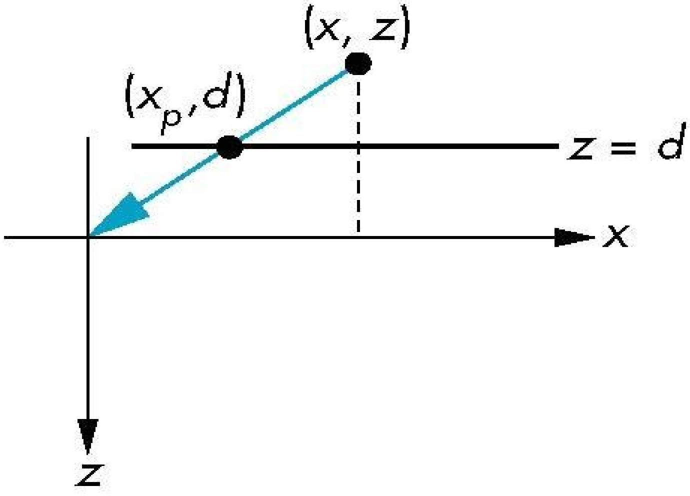
- Center of projection at the origin
- Projection plane $z = d, d < 0$



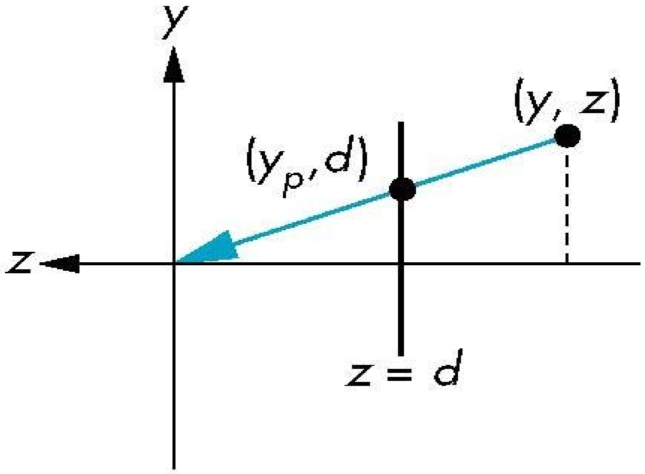
Perspective Equations

Consider top and side views





(b)



(c)

$$x_p = \frac{x}{z/d} \qquad y_p = \frac{y}{z/d} \qquad z_p = d$$

Homogeneous Coordinate Form

consider $\mathbf{p} = \mathbf{M}\mathbf{q}$ where $\mathbf{M} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 1/d & 0 \end{bmatrix}$

$$\mathbf{q} = \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \quad \Rightarrow \quad \mathbf{p} = \begin{bmatrix} x \\ y \\ z \\ z/d \end{bmatrix}$$

Perspective Division

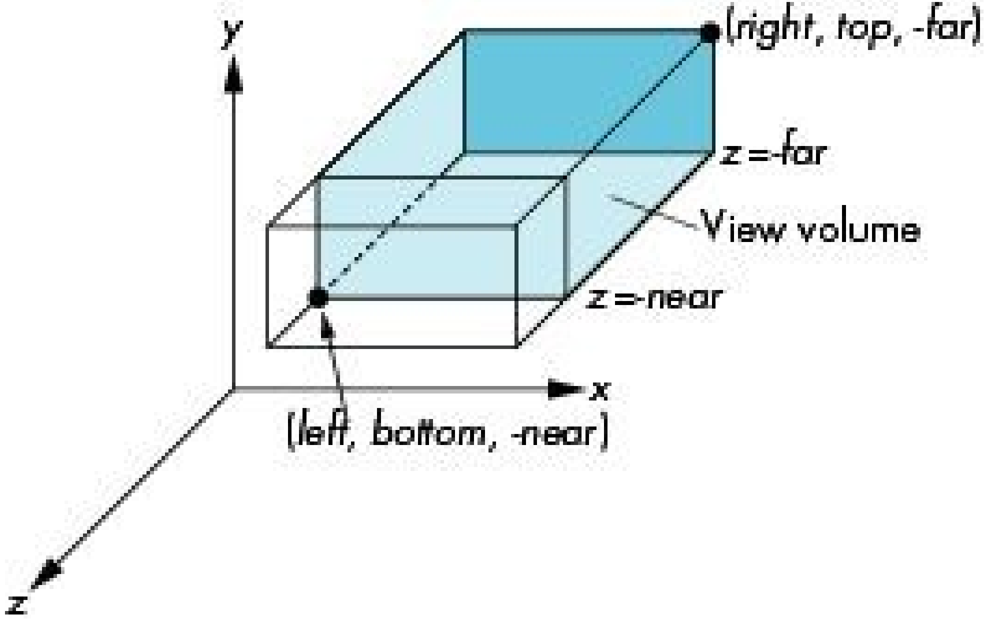
- However $w \neq 1$, so we must divide by w to return from homogeneous coordinates
- This *perspective division* yields

$$x_p = \frac{x}{z/d} \qquad y_p = \frac{y}{z/d} \qquad z_p = d$$

  the desired perspective equations
- We will consider the corresponding clipping volume with **`mat.h`** functions that are equivalent to deprecated OpenGL functions

WebGL Orthogonal Viewing

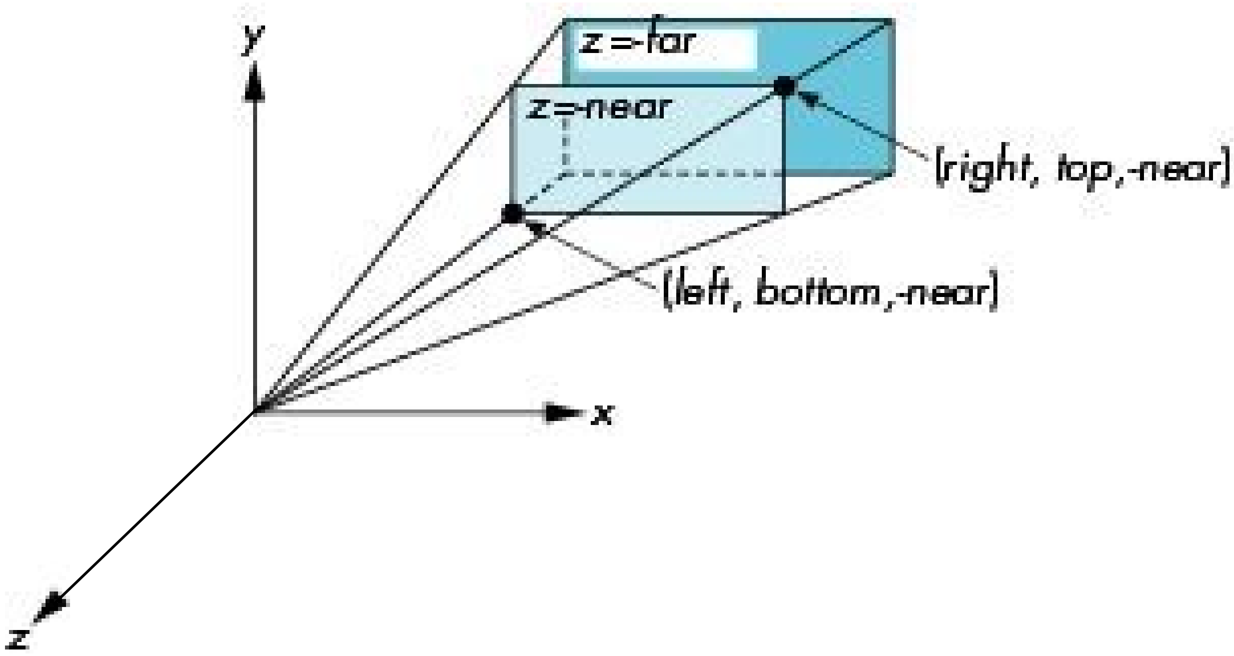
`ortho(left,right,bottom,top,near,far)`



`near` and **`far`** measured <u>from</u> camera

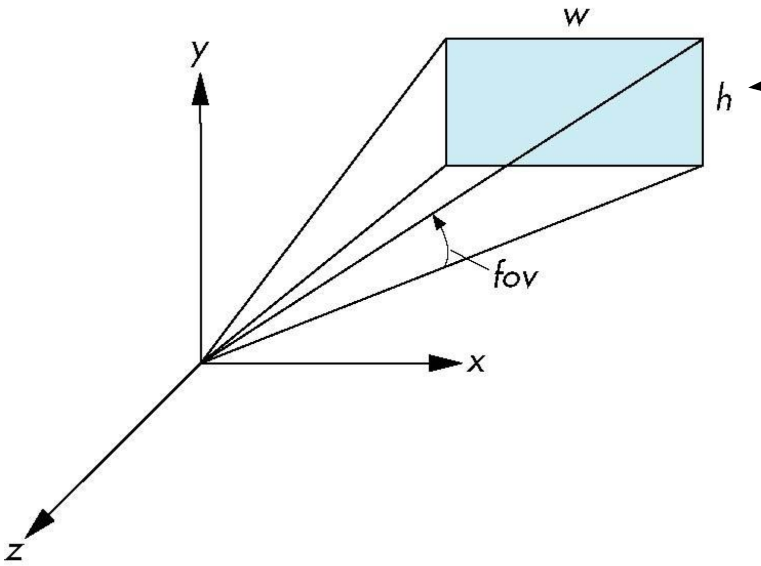
WebGL Perspective

`frustum(left,right,bottom,top,near,far)`



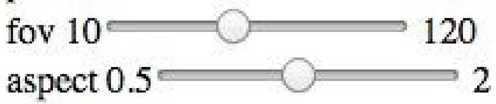
Using Field of View

- With **`frustum`** it is often difficult to get the desired view
- **`perspective(fovy, aspect, near, far)`** often provides a better interface



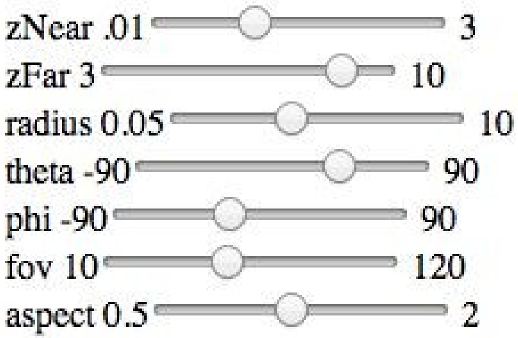
front plane

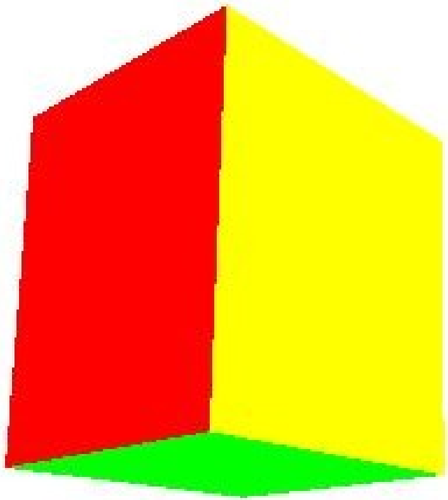
`aspect = w/h`



Computing Matrices

- Compute in JS file, send to vertex shader with **`gl.uniformMatrix4fv`**
- Dynamic: update in **`render()`** or shader





Video

webgl/Code/w06/perspective2.html

perspective2.js

```
var render = function(){
    gl.clear( gl.COLOR_BUFFER_BIT | gl.DEPTH_BUFFER_BIT);
     eye = vec3(radius*Math.sin(theta)*Math.cos(phi),
         radius*Math.sin(theta)*Math.sin(phi),
         radius*Math.cos(theta));
    modelViewMatrix = lookAt(eye, at , up);
    projectionMatrix = perspective(fovy, aspect, near, far);
    gl.uniformMatrix4fv( modelViewMatrixLoc, false,
          flatten(modelViewMatrix) );
    gl.uniformMatrix4fv( projectionMatrixLoc, false,
         flatten(projectionMatrix) );
    gl.drawArrays( gl.TRIANGLES, 0, NumVertices );
    requestAnimFrame(render);
}
```

vertex shader

```
attribute  vec4 vPosition;
attribute  vec4 vColor;
varying vec4 fColor;
uniform mat4 modelViewMatrix;
uniform mat4 projectionMatrix;

void main() {
    gl_Position = projectionMatrix*modelViewMatrix*vPosition;
    fColor = vColor;
}
```