Rendering Pipeline

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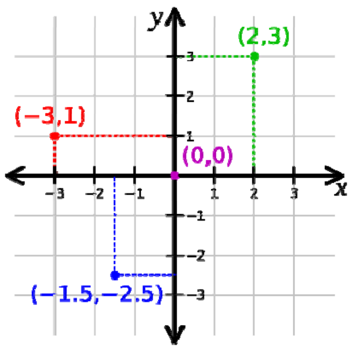
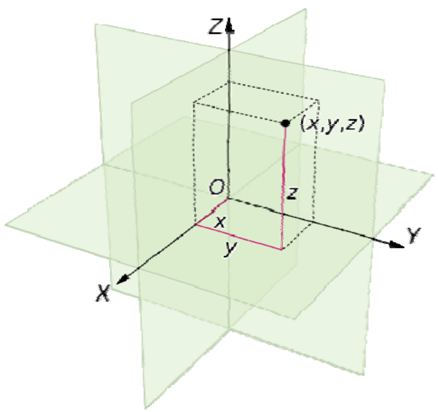
Overview

- 3D Illusion
- 3D Object representations
- Understand the rendering pipeline
  - The process of taking a geometric description of a 3D scene and generating a 2D image from it

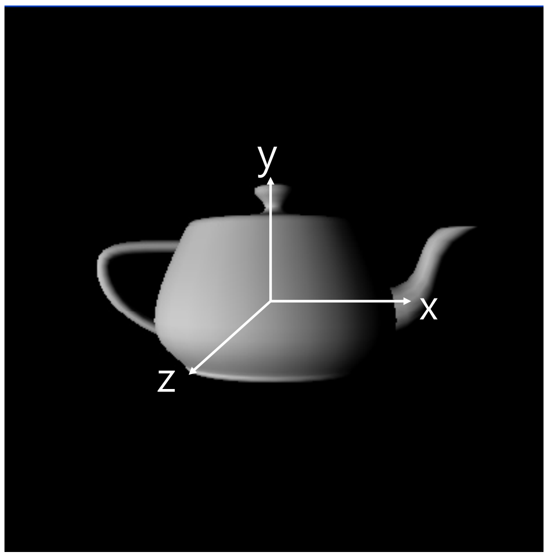
Coordinate Systems

- 2D Cartesian Coordination Systems
- 3D Cartesian Coordination Systems



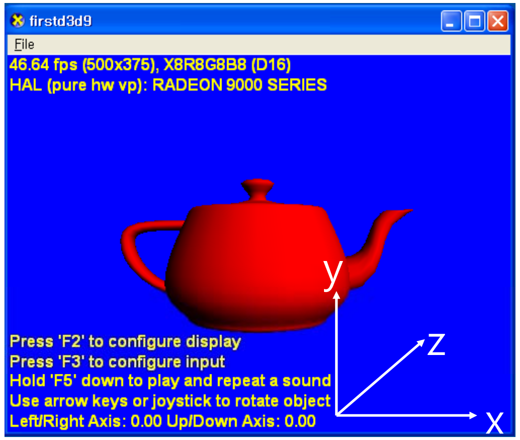


3D Coordinate Systems



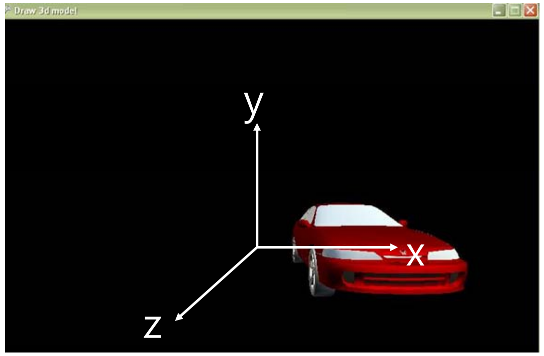
- OpenGL coordinate system is right-handed
- x+ to the right
- y+ up
- z+ coming out of the screen

3D Coordinate Systems



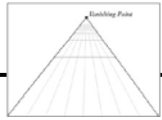
- Direct3D coordinate system is left-handed
- x+ to the right
- y+ up
- z+ forward

3D Coordinate Systems



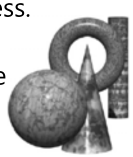
- XNA coordinate system is right-handed
- Same as OpenGL

3D Illusion



- Linear perspective
  - Objects get smaller the further away they are and parallel line converge in distance.
- Size of known objects
  - We expect certain object to be smaller than others.

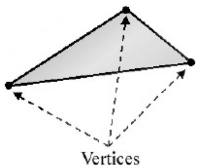
- Detail (texture gradient)
  - Close objects appear in more detail, distant objects less.
- Occlusion (hidden surfaces)
  - An object that blocks another is assumed to be in the foreground.

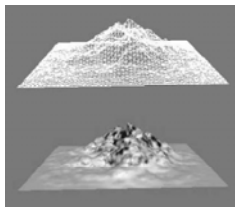


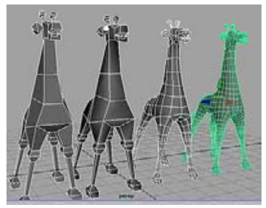
- Lighting and Shadows
  - Closer objects are brighter, distant ones dimmer. Shadow is a form of occlusion.
- Relative motion (motion parallax due to head motion)
  - Objects further away seem to move more slowly than objects in the foreground.

3D Model Representation

- A scene is composed of objects or models
- An object is represented as a triangle mesh approximation
- A triangle is defined by its the three vertices
- Model representation
  - Vertex format
  - Triangle
  - Index

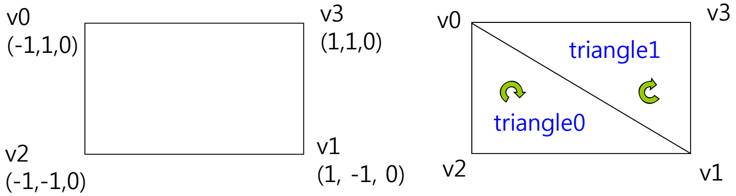






Triangle

- Triangle
  - The basic building blocks of 3D objects
  - For example, to construct a quad we break it into 2 triangles.

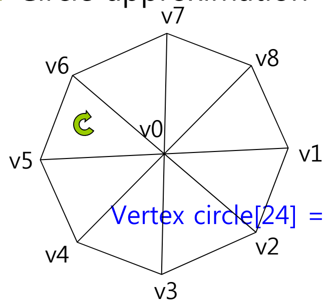



```
Vertex quad[6] = { v0, v1, v2,        // triangle 0
                   v0, v3, v1 };      // triangle 1
```

  - XNA vertex winding order is CW (same as Direct3D; opposite to OpenGL)

Triangle

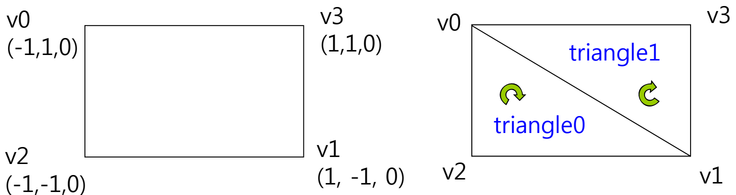
- Circle approximation




```
Vertex circle[24] = { v0, v1, v2,     // triangle 0
                      v0, v2, v3,     // triangle 1
                      v0, v3, v4,     // triangle 2
                      v0, v4, v5,     // triangle 3
                      v0, v5, v6,     // triangle 4
                      v0, v6, v7,     // triangle 5
                      v0, v7, v8,     // triangle 6
                      v0, v8, v1};    // triangle 7
```

Index

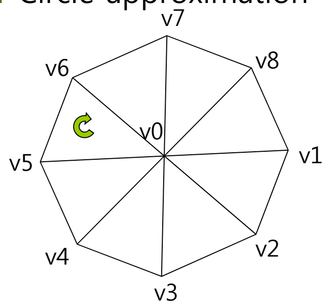
- Index list
  - Triangles that form a 3D object share many of the same vertices
  - 2 reasons why we do not want to duplicate vertices: increased memory & graphics processing
  - Hence, we build *vertex list* and *index list*




```
Vertex vertexList[4] = { v0, v1, v2, v3};     // vertex list
WORD indexList[6] = {0, 1, 2,                 // index list
                     0, 3, 1 };
```

Index

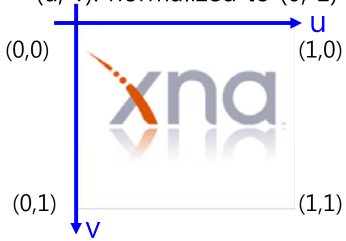
- Circle approximation



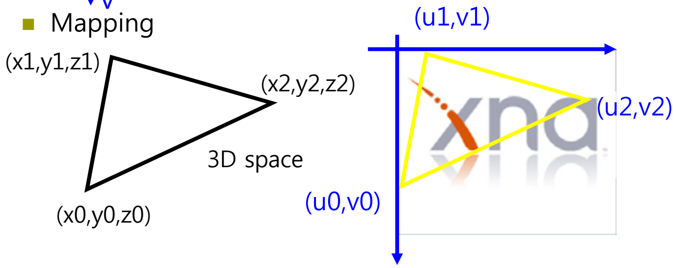

```
Vertex vertexList[9] = {v0, v1, v2, v3, v4, v5, v6, v7, v8};
WORD IndexList[24] = { 0, 1, 2, // triangle 0
                       0, 2, 3, // triangle 1
                       ...
                       0, 7, 8, // triangle 6
                       0, 8, 1}; // triangle 7
```

Texture Coordinates

- Texture Coordinates
  - (u, v): normalized to (0, 1)



  - Mapping



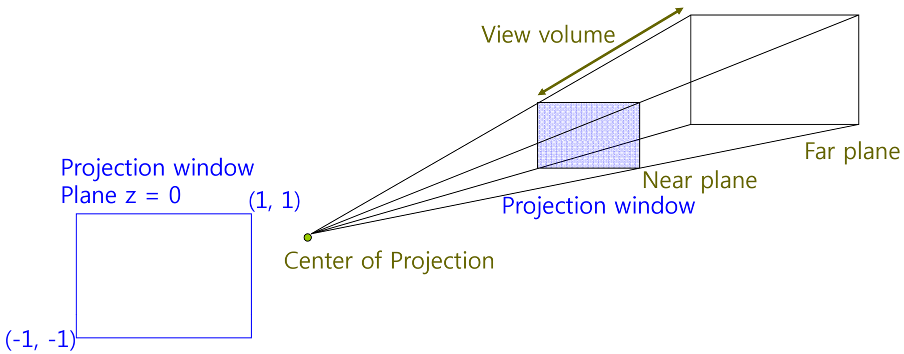
VertexPositionNormalTexture

- Vertex structure include texture coordinates

```
public struct VertexPositionNormalTexture {
public Vector3 Normal;
public Vector3 Position;
public Vector2 TextureCoordinate;
public static readonly VertexElement[] VertexElements;
public VertexPositionNormalTexture(Vector3 position, Vector3 normal,
Vector2 textureCoordinate);
public static bool operator !=(VertexPositionNormalTexture left,
VertexPositionNormalTexture right);
public static bool operator ==(VertexPositionNormalTexture left,
VertexPositionNormalTexture right);
public static int SizeInBytes { get; }
public override bool Equals(object obj);
public override int GetHashCode();
public override string ToString();
}
```

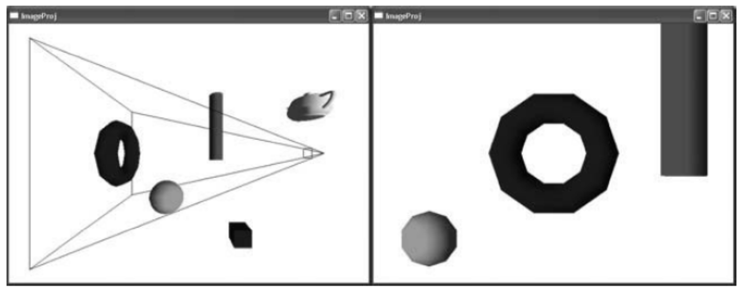
Virtual Camera

- Virtual Camera
  - Camera specifies what part of the world the viewer can see and thus what part of the world we need to generate a 2D image.
  - Projection window is defined as plane z=0, in XNA.



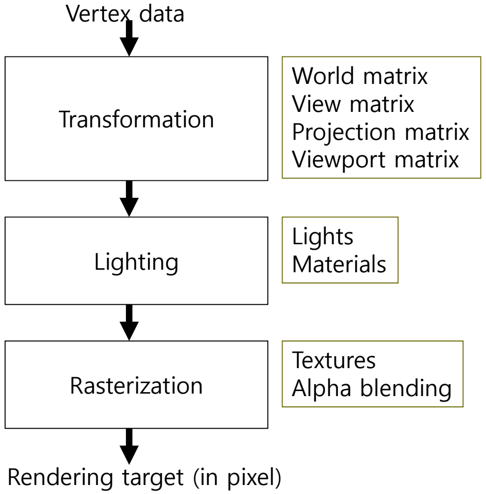
Rendering Pipeline

- Rendering pipeline refers to the entire sequence of steps necessary to generate a 2D image that can be displayed on a monitor screen based on what the virtual camera sees.



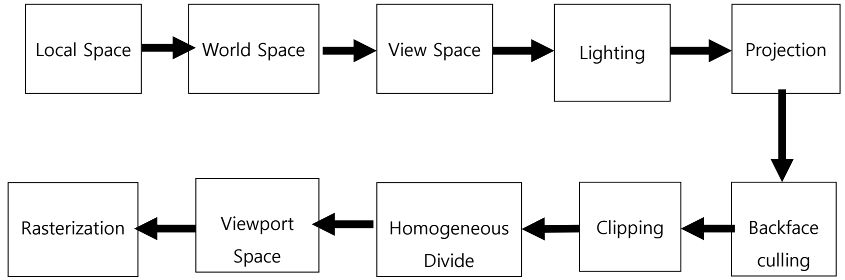
Rendering Pipeline

- 3D scene => 2D image



Rendering Pipeline

- Geometry stage rendering pipeline



Local Space & World Space

- Local space (i.e., Modeling space)
  - The 3D object is constructed in a local coordinate system, where the object is the center of the coordinate system
- World space
  - Once the 3D model is built in local space, it is placed in a scene in world space, by executing a change of coordinates transformation (called *world transform*).

$$W = \begin{pmatrix} r_x & r_y & r_z & 0 \\ u_x & u_y & u_z & 0 \\ f_x & f_y & f_z & 0 \\ p_x & p_y & p_z & 1 \end{pmatrix}$$

$\vec{p}$ *is the origin*

$\vec{r}, \vec{u}, \vec{f}$ *of LCS*

Modeling Transformation

- Local space => World space

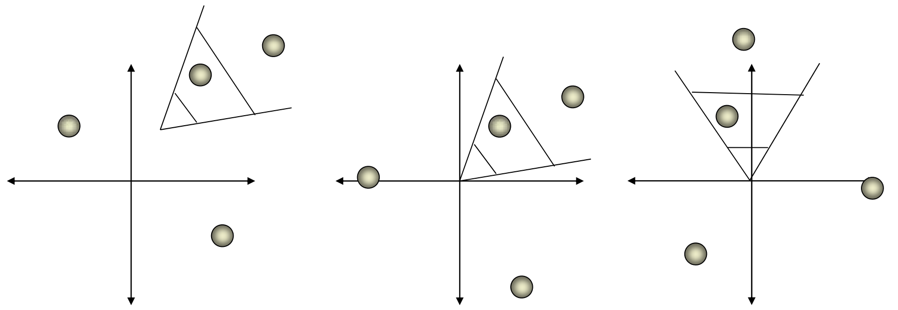
```
// place a rectangle in (3, 0, -10)
world = Matrix.CreateTranslation(new Vector3(3.0f, 0, -10.0f));
DrawRectangle(ref world);

// set transform for rectangle
world = Matrix.CreateScale(0.75f) *
    Matrix.CreateRotationX(MathHelper.ToRadians(15.0f)) *
    Matrix.CreateRotationY(MathHelper.ToRadians(15.0f)) *
    Matrix.CreateTranslation(new Vector3(-3.0f, -1.0f, -5.0f));
DrawRectangle(ref world);
```

View Space

- Geometry object and camera is specified in world space, and then transformed to view space for projection.
- View space transformation
  - Translate the camera to the origin of world space, and then rotate it to align into +z-axis.
- World space => view space
  - void Matrix.CreateLookAt (

```
    ref Vector3 cameraPosition,   // camera position
    ref Vector3 cameraTarget,     // camera look-at position
    ref Vector3 cameraUpVector,   // world up (0, 1, 0)
    out Matrix result             // ViewMatrix
);
```

View Space



Objects and the camera in World Space

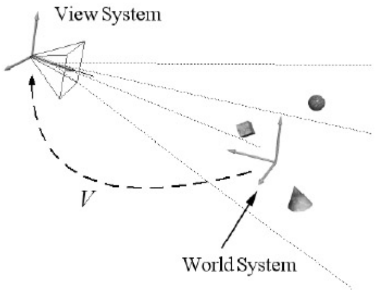
Translate the camera to the origin of World Space

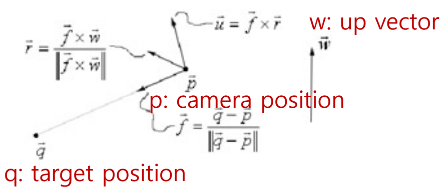
Rotate the camera to align into +Z-axis. Objects are also transformed.

View Space

$$V = (RT)^{-1} = T^{-1}R^{-1}$$

$$= \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -p_x & -p_y & -p_z & 1 \end{pmatrix} \begin{pmatrix} r_x & u_x & f_x & 0 \\ r_y & u_y & f_y & 0 \\ r_z & u_z & f_z & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} = \begin{pmatrix} r_x & u_x & f_x & 0 \\ r_y & u_y & f_y & 0 \\ r_z & u_z & f_z & 0 \\ -\vec{p}\bullet\vec{r} & -\vec{p}\bullet\vec{u} & -\vec{p}\bullet\vec{f} & 1 \end{pmatrix}$$





Viewing Transformation

- World space => View space

```
// the camera is located in (0, 0, 3), looking down the origin (0, 0, 0)
// set camera
private Vector3 cameraPosition = new Vector3(0.0f, 0.0f, 3.0f);
private Vector3 cameraTarget = Vector3.Zero;
private Vector3 cameraUpVector = Vector3.Up;
// set view matrix
private Matrix view;
Matrix.CreateLookAt(ref cameraPosition, ref cameraTarget, ref cameraUpVector, out view);

private BasicEffect effect;
effect.View = view;
```

Lighting

- Lighting
  - Lights are specified directly in World Space relative to the overall scene.
  - We can always transform lights into local space or view space.

Projection

- Projection
  - All the vertices of the 3D scene are in View Space and lighting has been completed, a projection transformation is applied.
  - Perspective projection vs. Orthogonal projection
- Projection matrix

```
void Matrix.CreatePerspectiveFieldOfView(
    float fieldOfView,// field of view in y-axis (in radian)
    float aspectRatio,// aspect  ratio (= screen width/screen height)
    float nearPlaneDistance,  // z-value of near plane
    float farPlaneDistance,   // z-value of far plane
    out Matrix result         // ProjectionMatrix
)
```

Aspect ratio는 projection window(정사각형)을 screen window space(직사각형)으로 만드는 과정에서 왜곡을 보정하는 역할

Perspective Projection

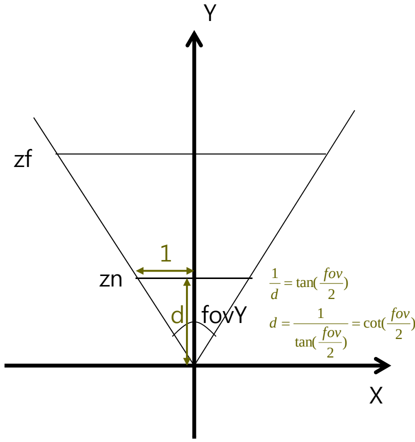
- Projection plane in front of the center of projection

$$\begin{bmatrix} xScale & 0 & 0 & 0 \\ 0 & yScale & 0 & 0 \\ 0 & 0 & \dfrac{zf}{zf-zn} & 1 \\ 0 & 0 & \dfrac{-zn*zf}{zf-zn} & 0 \end{bmatrix}$$

$$where\ \ yScale = \cot(fovY/2)$$

$$xScale = yScale / Aspect$$

$$Aspect = weight / height$$

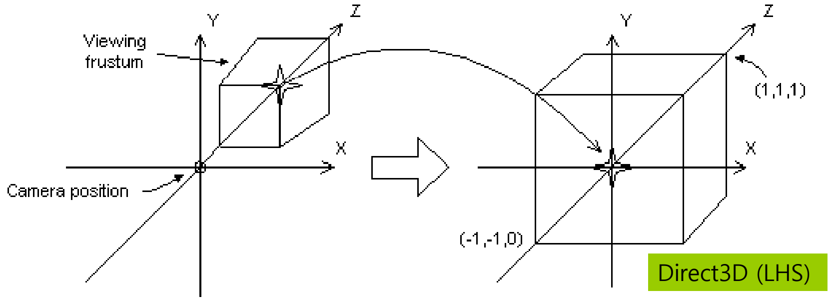


$$\frac{1}{d} = \tan(\frac{fov}{2})$$

$$d = \frac{1}{\tan(\frac{fov}{2})} = \cot(\frac{fov}{2})$$

Perspective Projection

- XNA/Direct3D view volume normalization
  - (-x, -y, zn) → (-1, -1, 0)
  - (x, y, zf) → (1, 1, 1)



Projection Transformation

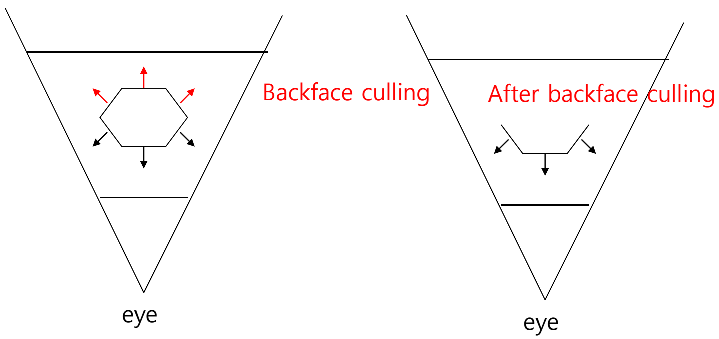
- Projection Transformation

```
// 45 degree FOV, near plane at 0.0001, far plane at 1000.0 frustum
// projection matrix.
// set camera
private Matrix projection;
float aspectRatio = (float)graphics.GraphicsDevice.Viewport.Width/
   (float)graphics.GraphicsDevice.Viewport.Height;
Matrix.CreatePerspectiveFieldOfView(
   Math.Helper.PiOver4, aspectRatio, 1.0f, 100.0f, out projection);

private BasicEffect effect;
effect.Projection = projection;
```

Backface culling

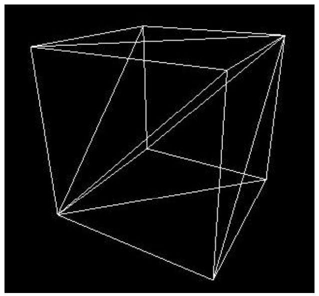
- Backface culling
  - A polygon has the front face and the back face.
  - Backface culling can quickly discard about half of the scene's dataset from further processing – an excellent speed up.
- Determine which polygons are front facing or back facing
  - By default, triangles with clockwise winding order are front facing
  - Visibility test: planeNormal • viewVector > 0
- Set culling
  - graphics.GraphicsDevice.RenderState.CullMode = Cullmode.None;
  - Value
    - NONE: disable backface culling
    - CW: triangles with a clockwise winding are culled
    - CCW: triangles with a counterclockwise winding are culled (default)

Backface culling

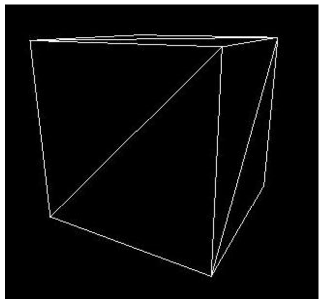


Backface culling

No Culling (All faces are seen)

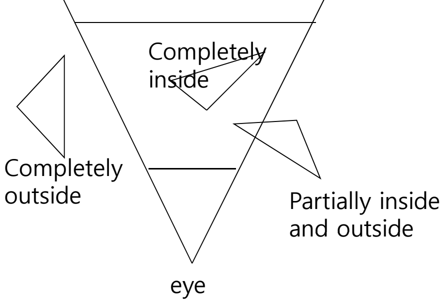


Backface Culling



Clipping

- Clipping
  - Clipping culls the geometry that is outside the viewing volume
  - 3 possible locations of triangle in the frustum:
    - Completely inside: it is kept
    - Completely outside: it is culled
    - Partially inside: then, the triangle is split into two parts. The part inside the frustum is kept, while the part outside is culled.
  - D3DRS_CLIPPING
    - Enable clipping or not



Viewport Transformation

- Viewport Transformation
  - Projection window => viewport (on screen)

```
Viewport()
    AspectRatio;        // aspect radio
    Bounds;             // size of this resource
    MinDepth, MaxDepth;     // range of min, max depth values
    TitleSafeArea;      // title safe area of the current viewport
    Width, Height;      // width, height dimension of the viewport
    X, Y;               // pixel coords of the upper-left corner
```

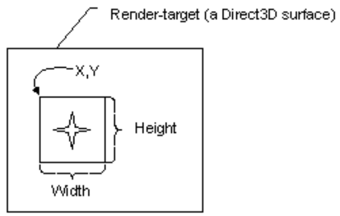
- Viewport matrix

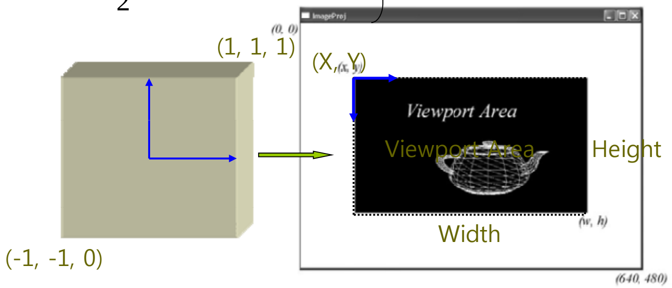
```
Viewport vp(0, 0, 640, 480);
graphics.GraphicsDevice.Viewport = vp;
```

Viewport

- Viewport Matrix

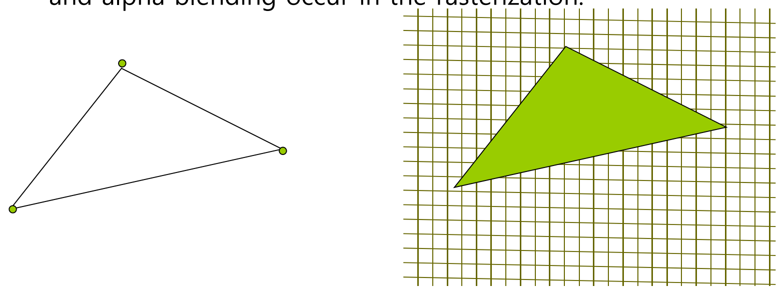
$$\begin{pmatrix} \frac{Width}{2} & 0 & 0 & 0 \\ 0 & -\frac{Height}{2} & 0 & 0 \\ 0 & 0 & MaxZ-MinZ & 0 \\ X+\frac{Width}{2} & Y+\frac{Height}{2} & MinZ & 1 \end{pmatrix}$$





Rasterization

- Rasterization
  - After the vertices are transformed to the back buffer, we have a list of 2D triangles in image space to be processed one by one.
  - Rasterization is responsible for computing the colors of the individual pixels that make up the interiors and boundaries of these triangles.
  - Pixel operations like texturing, pixel shaders, depth buffering, and alpha blending occur in the rasterization.



BasicEffect

- Using the basic effect class requires a set of world, view, and projection matrices, a vertex buffer, a vertex declaration, and an instance of the **BasicEffect** class.
- Initialize BasicEffect with transformation and light values

```
private BasicEffect effect;
// Initialize Effect
effect = new BasicEffect(graphics.GraphicsDevice, null);
// Draw
effect.World = world;
effect.Projection = projection;
effect.View = view;
effect.EnableDefaultLighting();
effect.TextureEnabled = true;
effect.Texture = texture;
```

BasicEffect

```
effect.Begin();
foreach (EffectPass pass in effect.CurrentTechnique.Passes)
{
    pass.Begin();
    graphics.GraphicsDevice.DrawUserIndexedPrimitives(
            PrimitiveType.TriangleList, vertices, 0, vertices.Length,
            indices, 0, indices.Length / 3);
    pass.End();
}
effect.End();
```

XNA Game Components

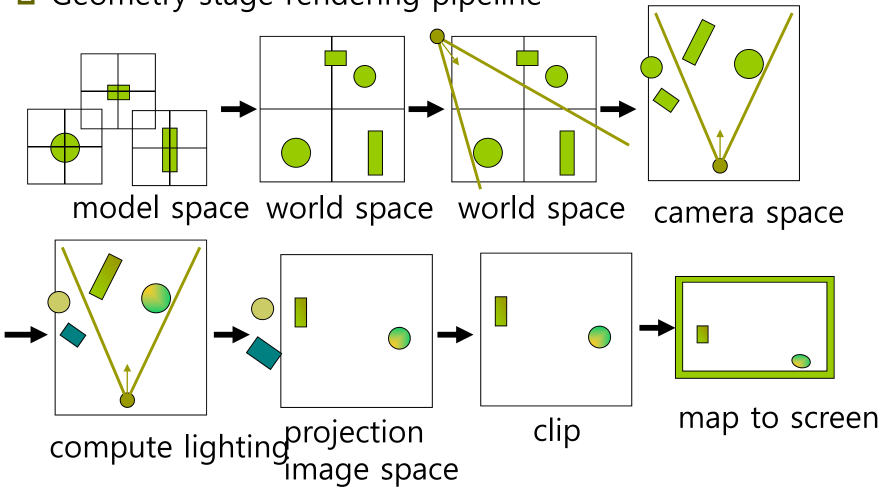
- XNA game component allows us to separate pieces of logic into their own file that will be called automatically by the XNA Framework.
- You derive the new component from GameComponent class, or, if the component loads and draws graphics content, from DrawableGameComponent class
- Method
  - Constructor
  - Initialize() – called by the Framework when the component starts
  - Update() – called by the Framework when the component needs to be updated
  - Draw() – called by the Framework when the component needs to be drawn (for only DrawableGameComponent)

XNA Game Components

```
class FPS : Microsoft.Xna.Framework.DrawableGameComponent
{
FPS(....) {...}
Initialize() {... }
Update(GameTime gt) { ... }
Draw(GameTime gt) { ... } // only for DrawableGameComponent
}

// Add XNA Game Components
fps = new FPS ();
Components.Add(fps);
```

Rendering Pipeline

- Geometry stage rendering pipeline



Reference

- Direct3D Transformation Pipeline - http://msdn2.microsoft.com/en-us/library/bb206260.aspx
- XNA BasicEffect class

  http://msdn.microsoft.com/en-us/library/bb203926.aspx
- XNA GameComponent class

  http://msdn.microsoft.com/en-us/library/microsoft.xna.framework.gamecomponent_members.aspx
- XNA DrawableGameComponent class

  http://msdn.microsoft.com/en-us/library/microsoft.xna.framework.drawablegamecomponent_members.aspx