VGP351 – Week 4

- Agenda:
  - Hidden surface removal / occlusion
    - Backface culling
    - Painters algorithm
    - Z-buffer
    - Frustum culling

Hidden Surface Removal

- Why?

Hidden Surface Removal

- Why?
  - Correctness: if object A is behind object B, object A should not obscure object B
  - Performance: don't spend time drawing things that cannot be seen
    - Obscured objects
    - Polygons on the “backside” of objects
    - Objects outside the camera's view

Backface Culling

- The faces on the back side of this cube can't be seen because they face *away* from the viewer
  - There are two common ways to determine that polygon faces away from viewer

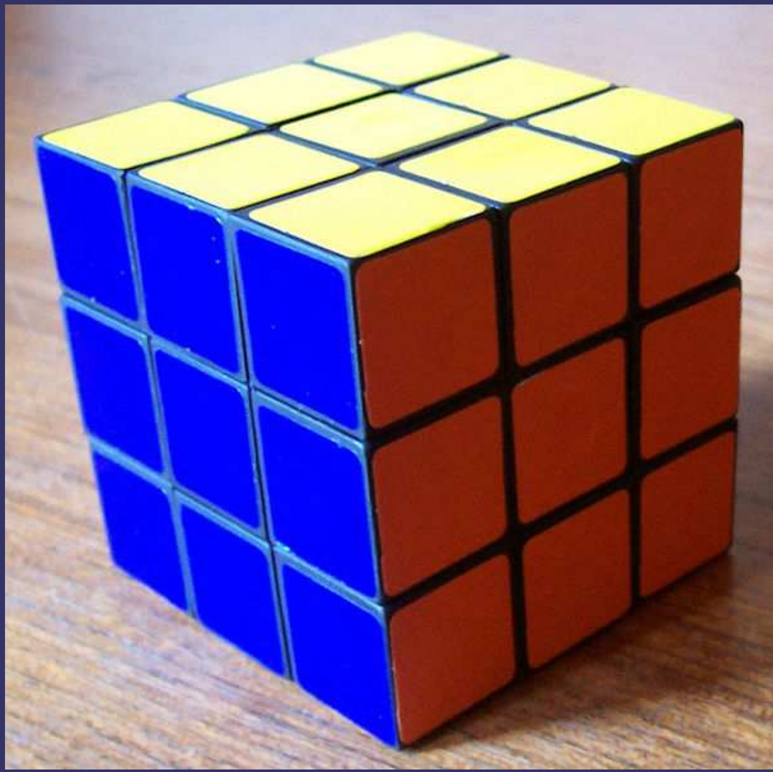

Image from http://en.wikipedia.org/wiki/File:Cubo_rubik_2.jpg

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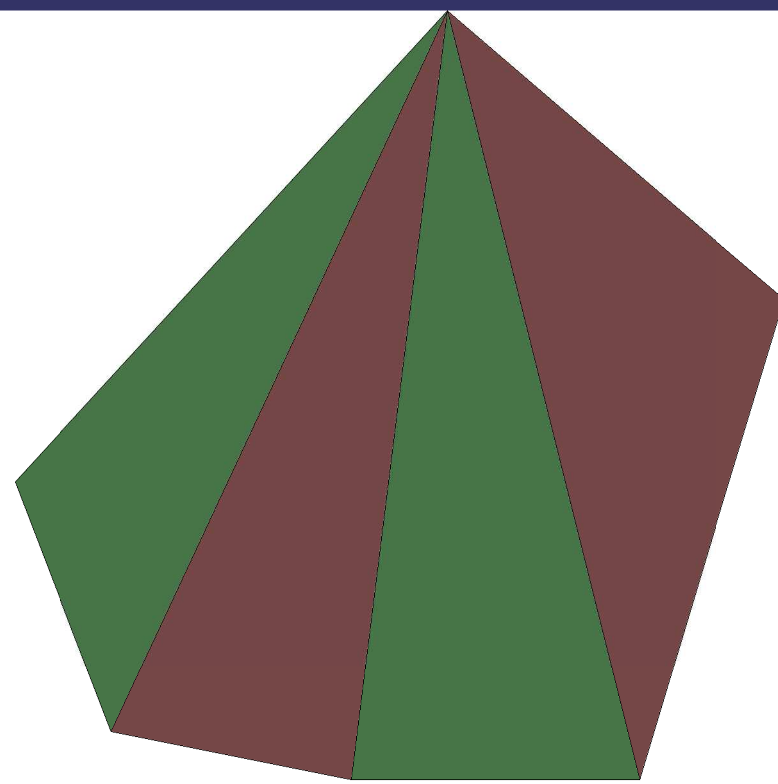
Backface Culling

- Compare the direction of the surface normal with the viewing direction
  - If $\mathbf{n} \cdot \mathbf{v} > 0$, the surface faces away from the camera
- Several problems with this method:
  - Requires that you have *surface* normals
  - Must be implemented differently for different types of viewing projections

Backface Culling

- After projection to 2D, it is possible to determine if vertices are ordered clockwise or counter-clockwise



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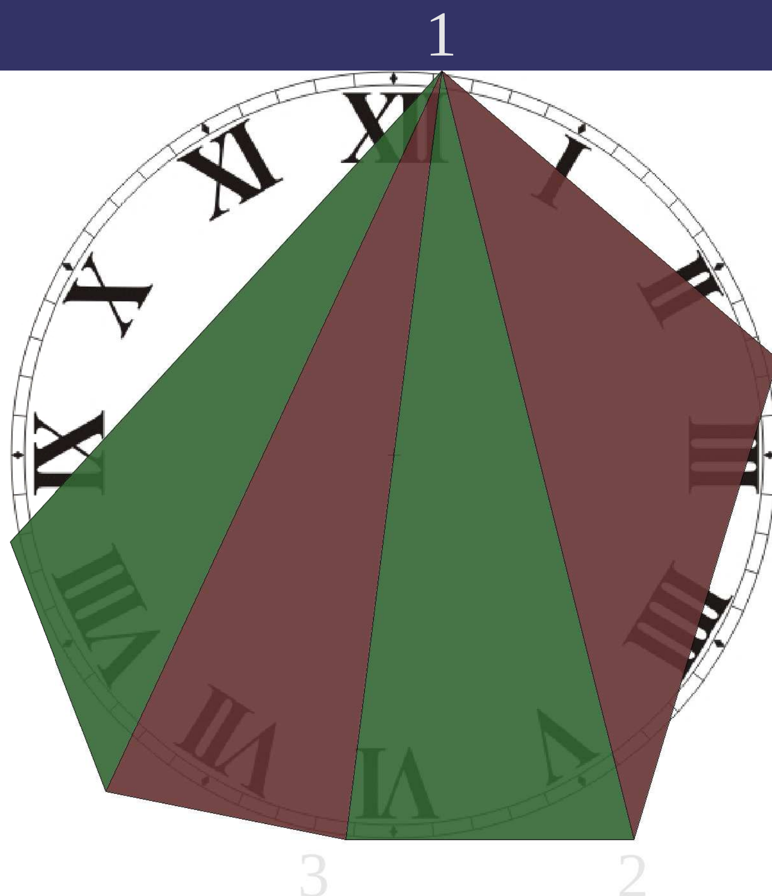

Backface Culling

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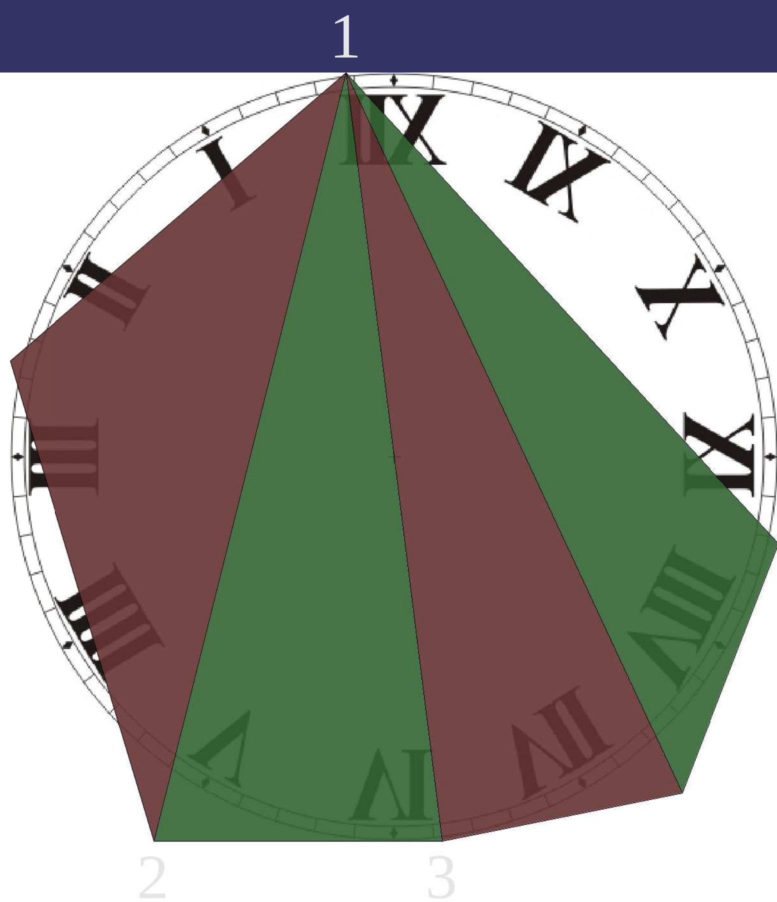
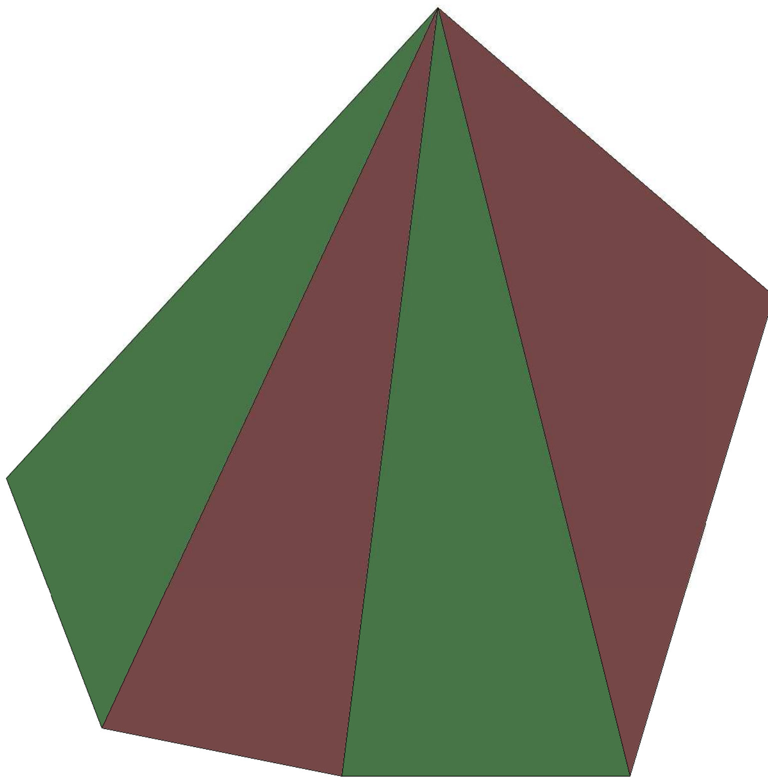


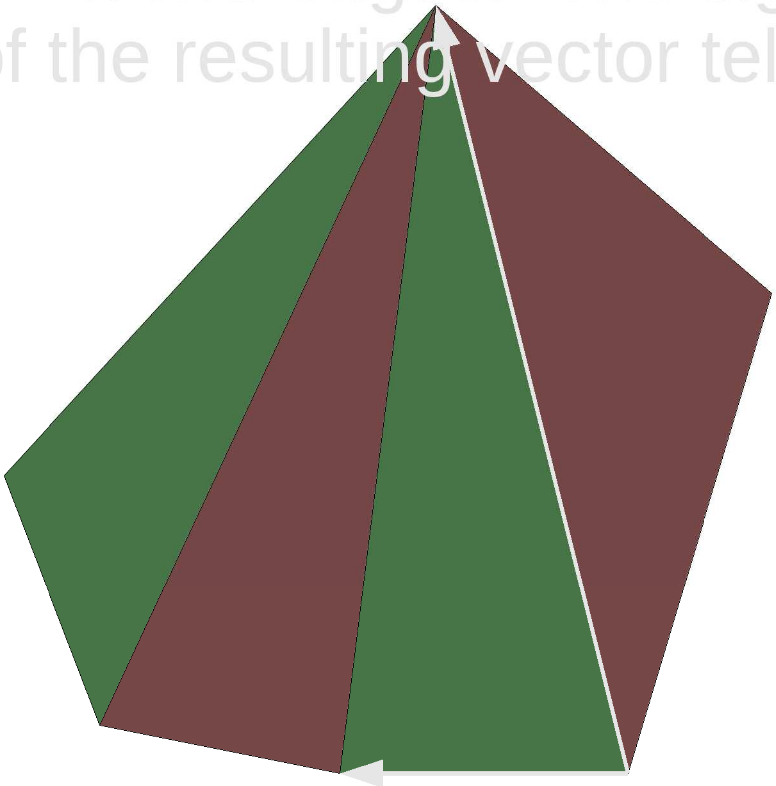
Backface Culling

- After projection to 2D, it is possible to determine if vertices are ordered clockwise or counter-clockwise
  - How?



Backface Culling

- After projection to 2D, it is possible to determine if vertices are ordered clockwise or counter-clockwise
  - Cross-product of two edges! The sign of the Z-component of the resulting vector tells you the facing



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Backface Culling

- Backface culling is enabled with:

```
glEnable(GL_CULL_FACE);
```

- Frontface orientation is selected with:

```
glFrontFace(GL_CW);
```

  – Clockwise ordered polygons are considered front-facing

```
glFrontFace(GL_CCW);
```

  – Counter-clockwise ordered polygons are considered front-facing
  – This is the default setting

Depth Ordering

- Just drawing objects in arbitrary order gives incorrect results

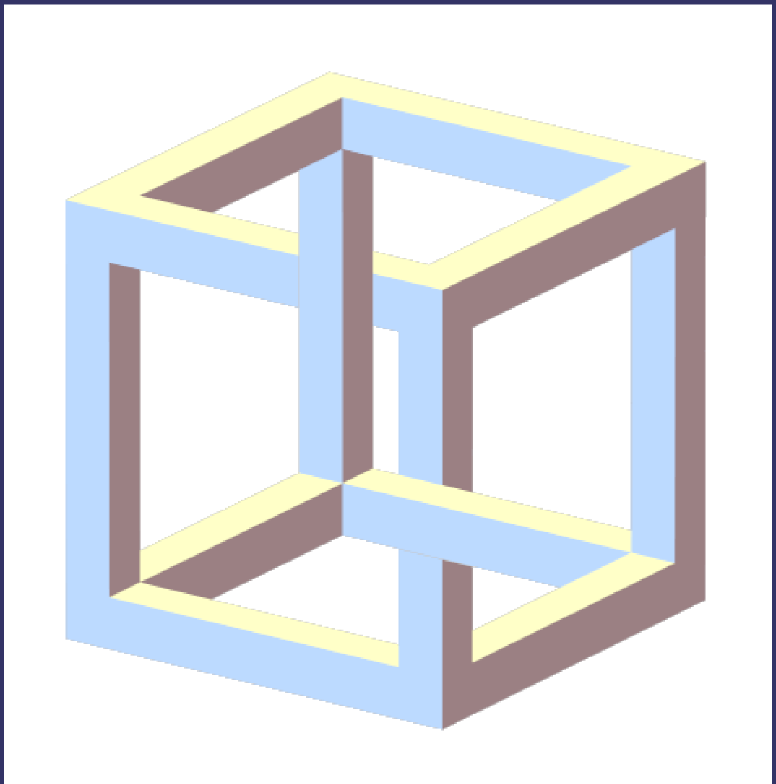


Image from http://www.planetperplex.com/en/item253

Depth Ordering

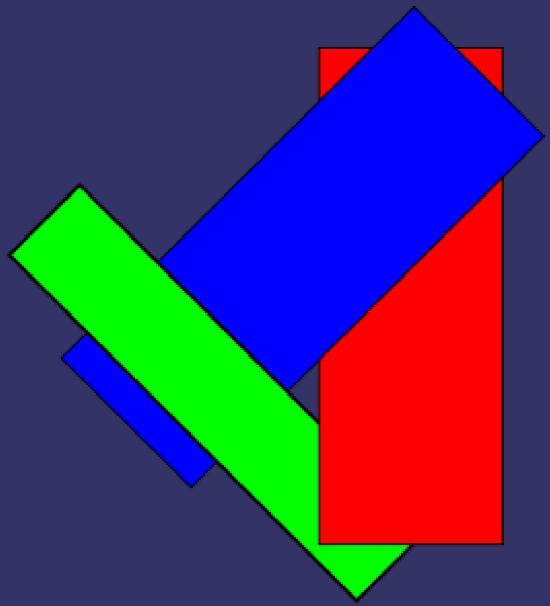
- Just drawing objects in arbitrary order gives incorrect results
- Several geometric solutions exist
  - Painter's algorithm
  - BSP tree
  - Warnock's algorithm
    - We won't actually talk about this algorithm
  - Ray tracing
    - More on this *much* later...

Painter's Algorithm

- Algorithm traditionally used for real-time 3D *before* hardware accelerators:

  The name "painter's algorithm" refers to the technique employed by many painters of painting distant parts of a scene before parts which are nearer....The [algorithm] sorts all the polygons in a scene by their depth and then paints them in this order, furthest to closest.[1]

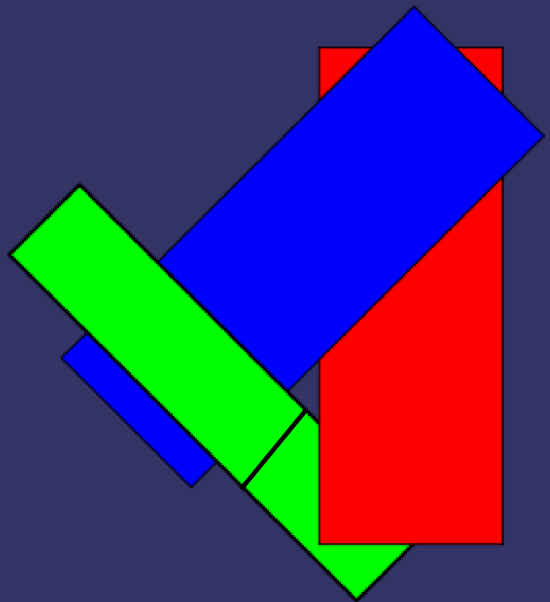
- Many problems:
  - Sorting step is slow
    - $n \log n$ on # of polygons per frame
  - Mutually overlapping polygons fail



1 http://en.wikipedia.org/wiki/Painter%27s_algorithm

BSP Tree

- Binary tree where each node splits space
  - Each node contains an n-dimensional split-plane
  - One child is in the positive-space of the plane and the other is in the negative-space
  - If a polygon is added to a node crosses the split-plane, partition the polygon at the plane



- Tree can be traversed *in order* in linear time
  - Part of the method used in Quake and Quake II for hidden surface removal

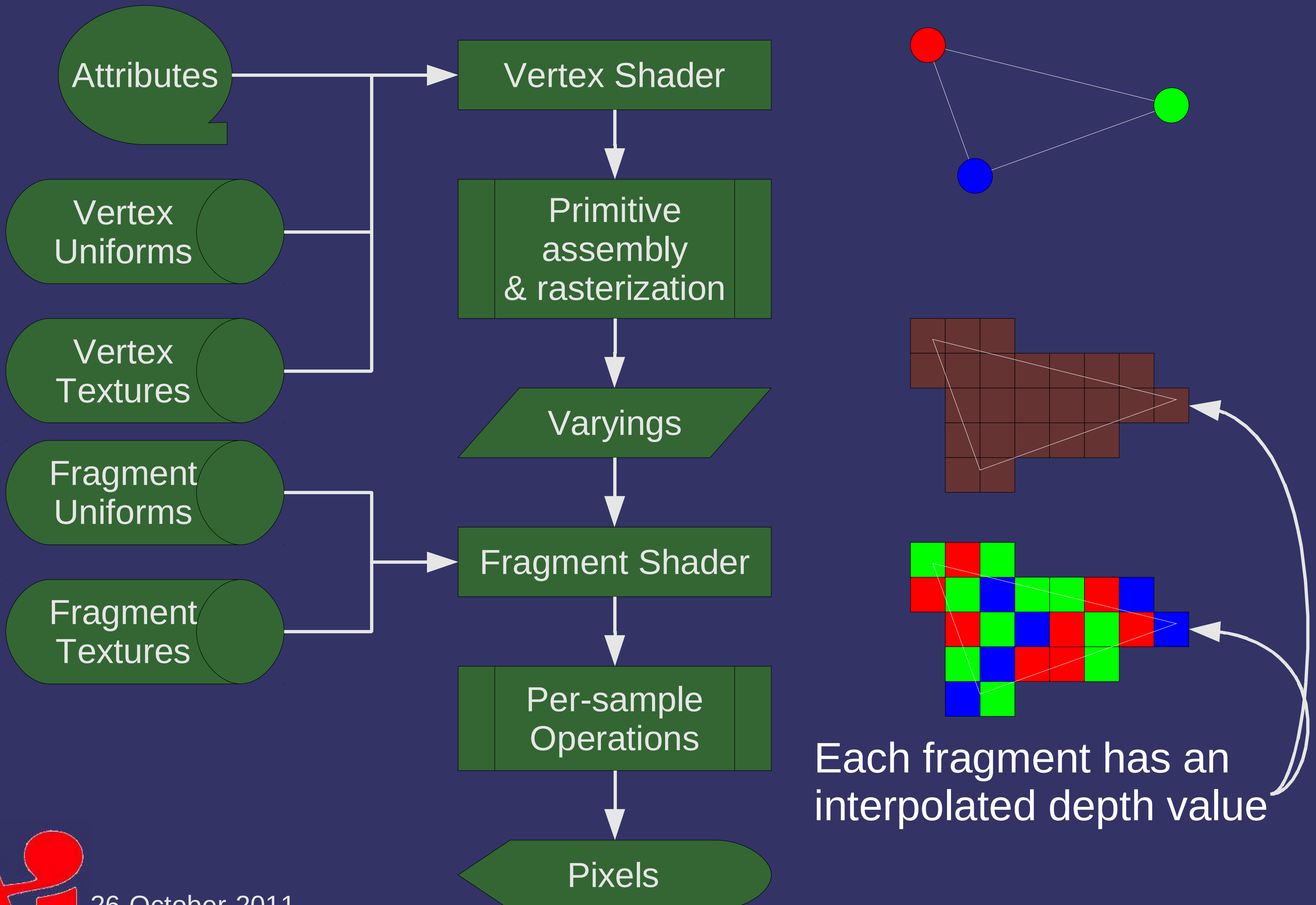
BSP Tree

- There are still several drawbacks:
  - Splitting polygons can create lots of extra data
  - Splitting polygons can create cracks due to numeric round-off
  - Creating good trees is *very* expensive!
    - Largely useless for scenes with lots of dynamic objects
    - This is why you can't destroy walls in most 3D games. :)

Depth Ordering

- Geometric solutions to the visibility problem have largely proven ineffective
  - The usual solution is an image-space solution: the depth buffer

Pipeline Data Flow



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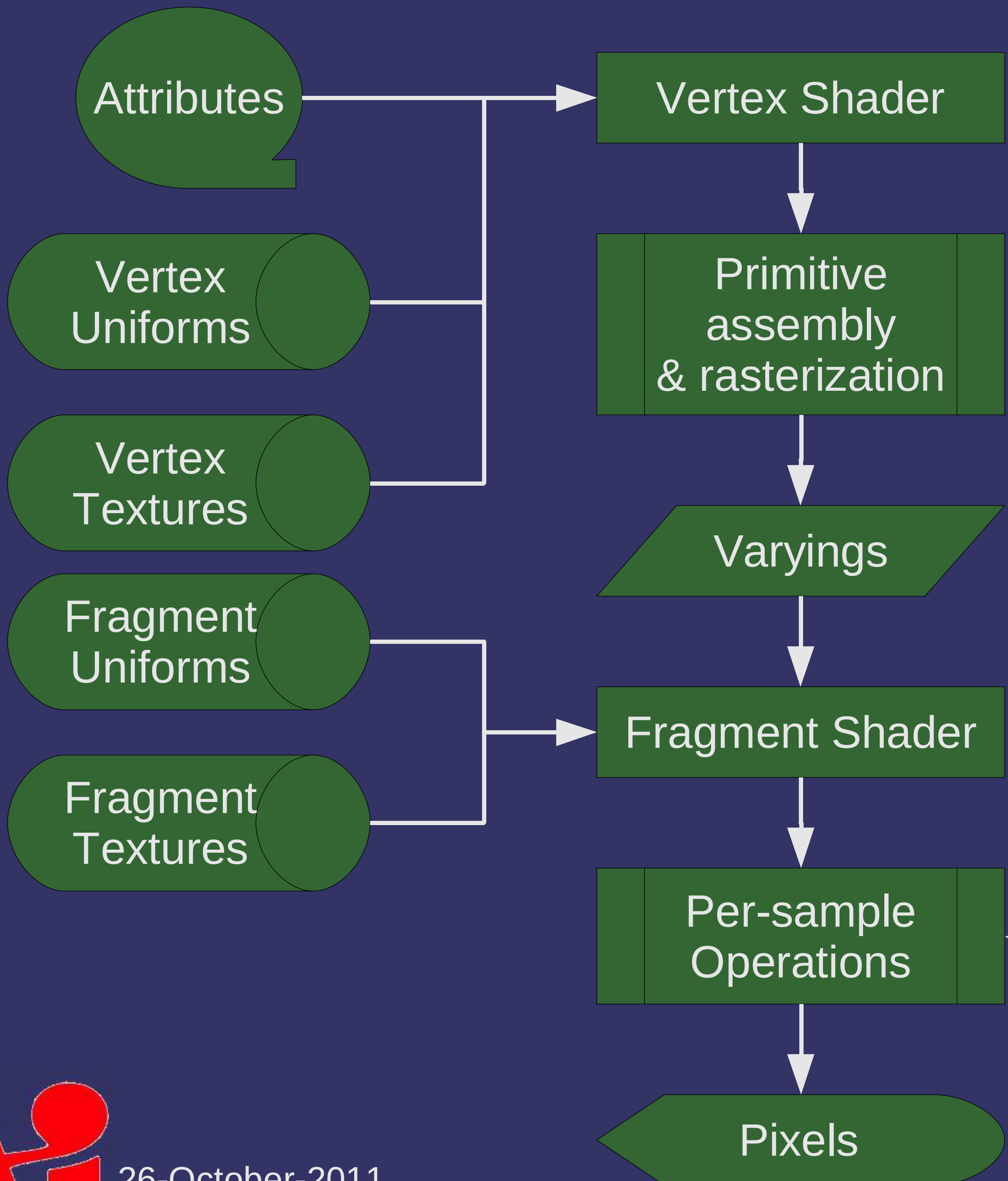
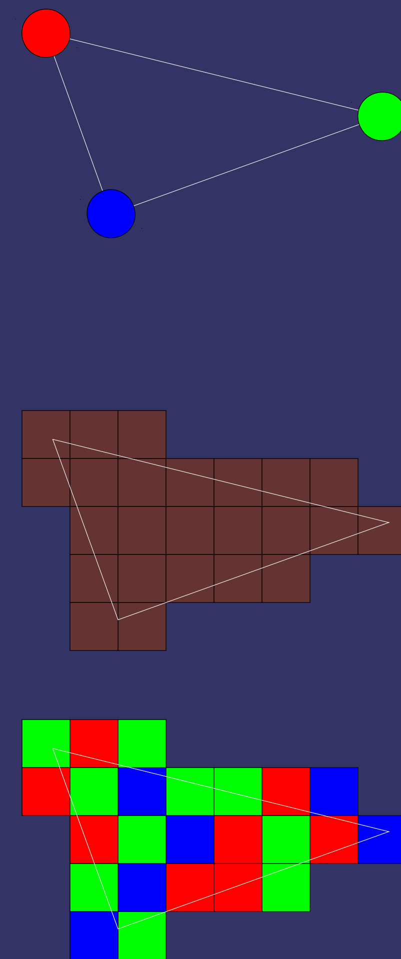
Pipeline Data Flow





Fragment depth can be compared with previously seen depth values

Depth Buffer

- Depth buffering isn't perfect
  - Differences in interpolation values can lead to errors...

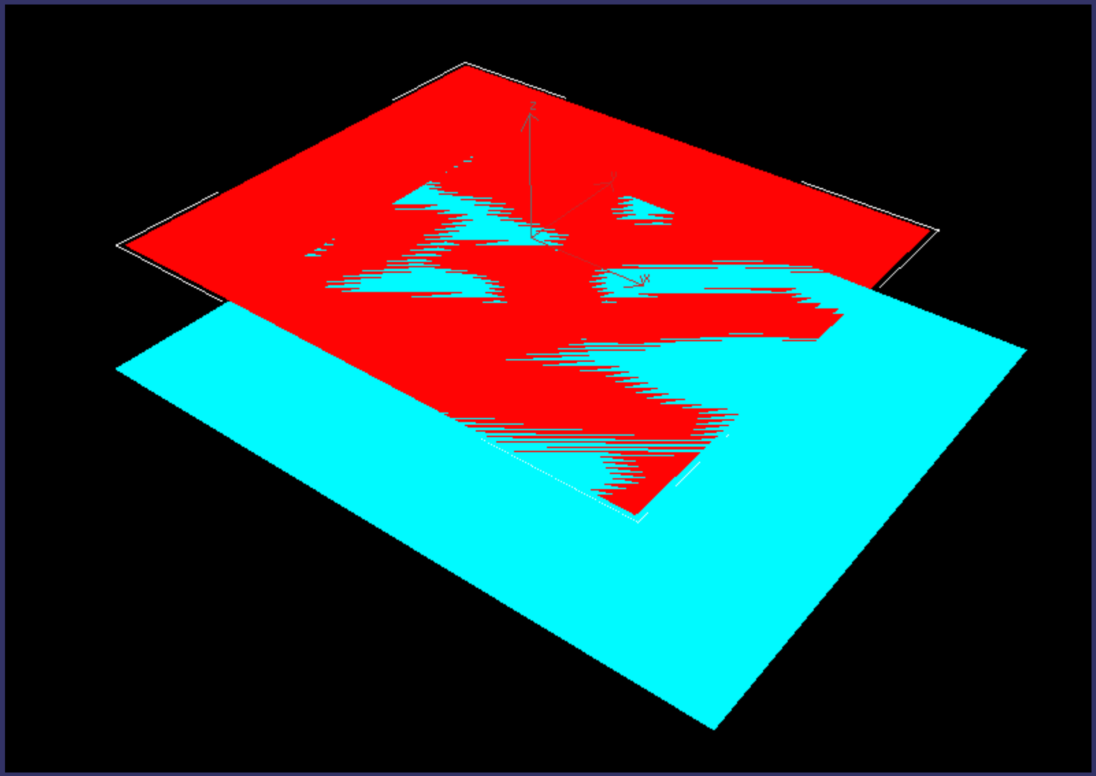


Image from http://en.wikipedia.org/wiki/File:Z-fighting.png

Depth Buffer in OpenGL

- Depth test compares the depth value of each fragment of a polygon with the depth value stored at each pixel
  - If the test passes, the fragment is drawn
  - If the test fails, the fragment is discarded
- To use a depth buffer, we have to allocate one:

```
SDL_GL_SetAttribute(SDL_GL_DEPTH_SIZE, 24);
```

Common maximum depth buffer size

Depth Buffer in OpenGL

- Depth test has an enable:

```
glEnable(GL_DEPTH_TEST);
```

- Must also set the comparison mode:

```
glDepthFunc(GLenum mode);
```

  - `mode` is one of `GL_LESS`, `GL_LEQUAL`, `GL_GREATER`, `GL_GEQUAL`, `GL_EQUAL`, `GL_NOTEQUAL`, `GL_NEVER`, `GL_ALWAYS`

Depth Buffer in OpenGL

- Clear the depth buffer just like the color buffer:

```
glClear(GL_COLOR_BUFFER_BIT |
        GL_DEPTH_BUFFER_BIT);
```

- Set the clear value:

```
void glClearDepth(GLclampd depth);
```

Special type! Means that a floating-point value from 0.0 to 1.0 is required.

Perspective Projection

$$\mathbf{M}_p = \begin{bmatrix} \frac{f}{aspect} & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & -\frac{far+near}{far-near} & -\frac{2\times far\times near}{far-near} \\ 0 & 0 & -1 & 0 \end{bmatrix}$$

This row remaps Z values on the range [-*near*, -*far*] to [-1, 1].

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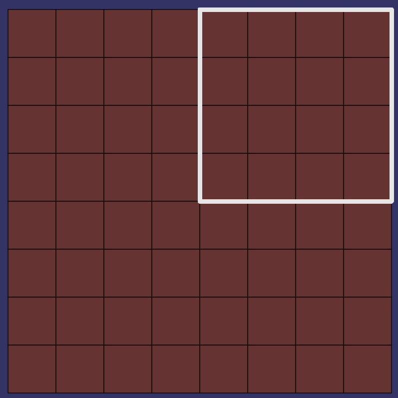
Depth Buffer Acceleration

- Per-pixel depth comparison in complex environments is *very* expensive
- Many common optimizations exist:
  - Test depth before the fragment shader (aka “early Z”)
    - Saves cost of fragment shader on occluded fragments
    - Cannot be used if the fragment shader alters the depth value
  - Hierarchical depth buffer (aka “HiZ”)
  - Depth buffer compression
  - Fast Z clear

Hierarchical Depth Buffer

- Depth buffer is stored by tiles
  - Store the minimum (or maximum) value of each tile



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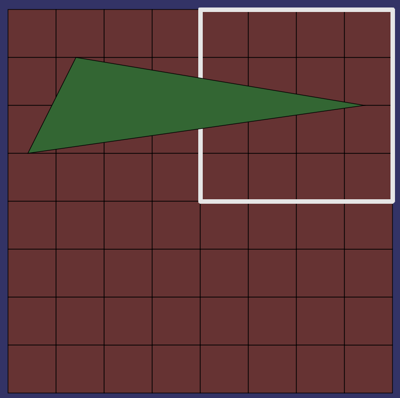
Hierarchical Depth Buffer

- Depth buffer is stored by tiles
  - Store the minimum (or maximum) value of each tile
- Compare an entire polygon against the tiles that it overlaps
  - Allows rejection of entire polygons or large portions of a polygon very quickly



Depth Buffer Compression

- Several observations:
  - Most of the depth buffer will contain the clear value
  - Most values in a block will be close to the HiZ value
  - Most values in a block will be close to each other
- Individual blocks can be stored more compactly
  - Most methods store one full precision value and lower precision per-pixel deltas from that value

Fast Z Clear

- Writing the same value to all locations in the depth buffer takes a lot of bandwidth
  - Store a single “this block is clear” bit per $n \times n$ block
  - Set that single bit per block when `glClear` is called
  - When rendering, if the bit is set, use the clear value for the whole block
- Why does this work?
  - The block size matches the cache line size
  - Data is written back one cache line at a time, so writing the cleared block back adds no extra cost

View-volume Culling

- Determine that an object is entirely outside the viewing volume
  - Usually an approximation called a *bounding volume* is used to represent the object
  - This early culling allows us to avoid even sending the object to the graphics library

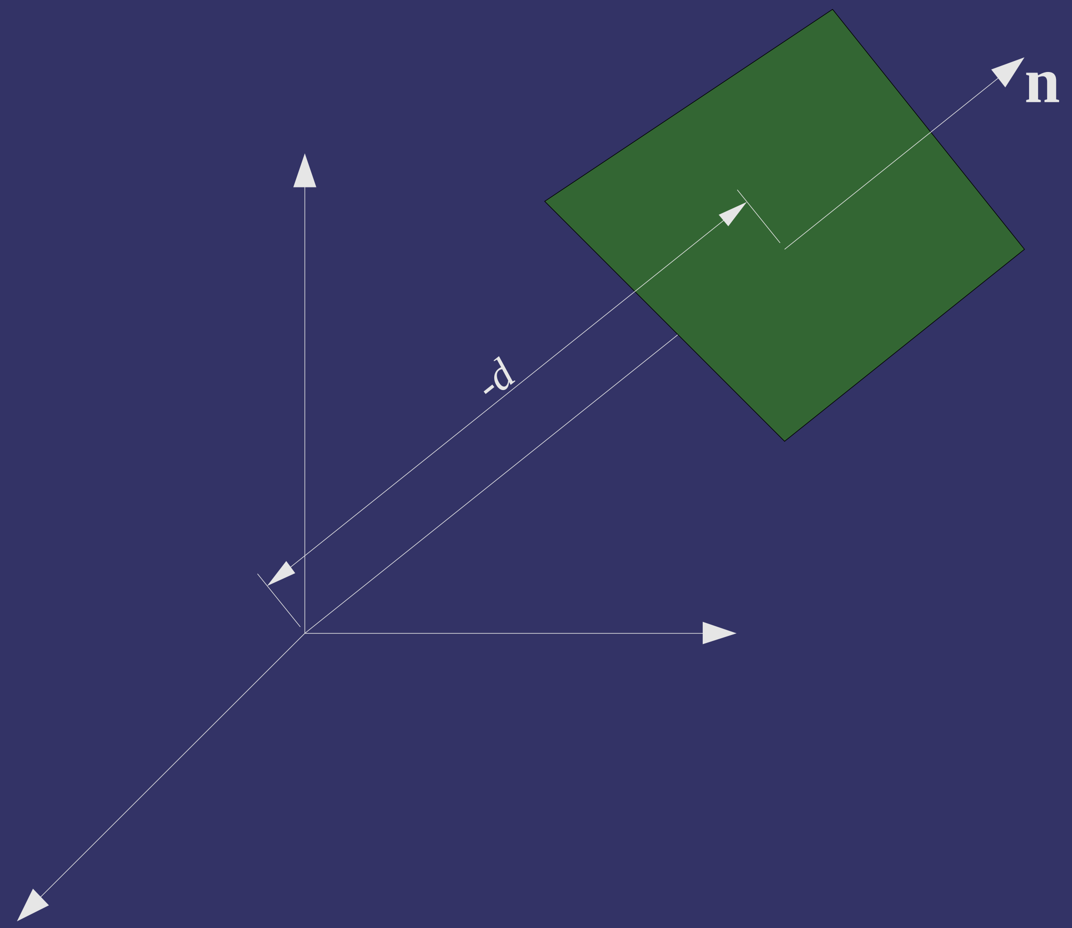
Plane Equation

- Arbitrary planes in a space are represented by a *plane equation* with the following form:

$$(\mathbf{n}_p \cdot \mathbf{p}) + d_P = 0$$

  - $\mathbf{n}_p$ is the normal of the plane
  - $-d_p$ is the distance from the origin to the plane in the direction of the normal

Plane Equation



Plane Equation

- If we know three non-colinear points on the plane, the plane equation is easy to calculate
  - Calculate the normal from the cross-product of two edge vectors:

$$\hat{\mathbf{v}}_0 = \mathbf{v}_0 - \mathbf{v}_1$$

$$\hat{\mathbf{v}}_1 = \mathbf{v}_2 - \mathbf{v}_1$$

$$\mathbf{n}_p = \frac{\hat{\mathbf{v}}_0 \times \hat{\mathbf{v}}_1}{\left|\hat{\mathbf{v}}_0 \times \hat{\mathbf{v}}_1\right|}$$

  - Calculate d using the dot product:

$$-d = \mathbf{n}_p \cdot \mathbf{v}$$

  - $\mathbf{v}$ is *any* point on the plane

Plane Equation

- Using the equation of a plane, we can determine which "side" of the plane a point is on

$$(\mathbf{n}_p \cdot \mathbf{p}) + d = k$$

  - $\mathbf{p}$ is a point to be tested
  - If $k = 0$, then $\mathbf{p}$ is on the plane
  - If $k < 0$, then $\mathbf{p}$ is "inside" the plane
    - Technically, it is in the negative half-space
  - If $k > 0$, then $\mathbf{p}$ is "outside" the plane
    - Technically, it is in the positive half-space

View-volume Culling

- Observation: a view-volume is made from 6 planes
  - If a point is in the positive half-space of *any* of the 6 planes, it is outside the view volume
- If we have a bounding sphere for each object in the scene, we can use the point-in-volume test
  - For each object, “grow” the frustum by the radius of the sphere
  - Test the center of the sphere against the new planes

$$(\mathbf{n}_p \cdot \mathbf{c}) + (d - r) = k$$

Further Reading

Ulf Assarsson and Tomas Möller, "Optimized View Frustum Culling Algorithms for Bounding Boxes," *journal of graphics tools*, 5(1), pp 9-22, 2000. http://www.cse.chalmers.se/~uffe/vfc_bbox.pdf

http://www.realtimerendering.com/intersections.html

Next week...

- Quiz #2
- Lighting!
  - Lighting models
  - Shading methods
  - Types of lights

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