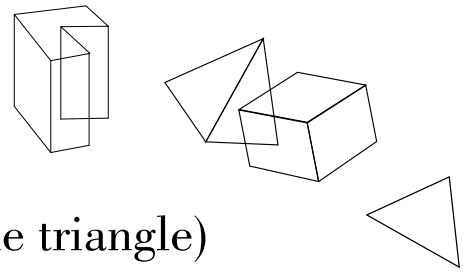
Vectors in Action:
Backface Culling

- Your first look at applying vectors and their operations in computer graphics is also a first look at an algorithm that can be done transparently for you by the graphics subsystem: hidden surface removal (HSR)
- Full-blown HSR will be tackled later, but there is one aspect that we can look at now: backface culling
- The principle behind backface culling is that, if a polygon on a 3D model is facing "away" from you, then you probably will not see it

Culling Exceptions

- It might already be apparent to you that, based on this principle, backface culling is not the full solution to HSR—exceptions are easy to identify:
  - Non-convex polyhedrons
  - Multiple objects
  - "Flat" objects (e.g., a single triangle)

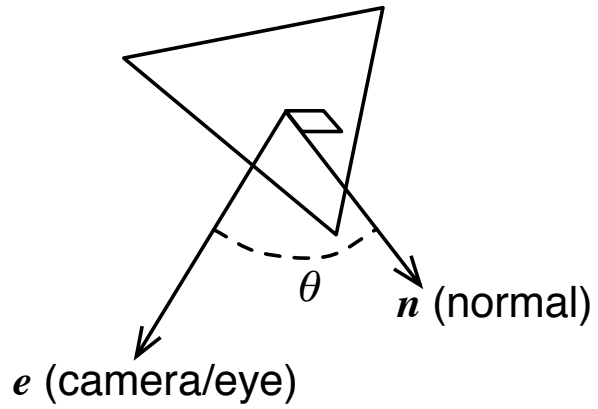


- However, it may "cull" a good number of polygons from the picture, thus serving as a kind of optimization

So, Those Vectors…

Determining whether a polygon faces front is easier than it may seem, thanks to some vector math: a polygon faces front if the angle between its normal and the vector toward the camera/eye/viewer is between –90 and 90 degrees, or

$$cos\ \theta \geq 0$$



- Hmmm…we've seen cosines related to vectors before… oh yes, this:

$$\cos\theta = \frac{u \cdot v}{|u||v|}$$

- Now, assuming WLOG that the camera/eye/viewer and normal vectors in the diagram above are unit vectors, this gives us:

$$e \cdot n \geq 0$$

- But, in a right-handed coordinate system, e is simply $<0, 0, 1>$, meaning $e \cdot n =$ the z component of n
- Thus, backface culling is a matter of checking whether the z component of n is greater than zero!

Yay! Oh, wait...

- So, this is great—just look at the normal vector and we're done!

  But…we don't have the normal vector…

- Fortunately, we can compute it—vectors to the rescue one more time:

$$u \times v = \langle y_u z_v - z_u y_v, z_u x_v - x_u z_v, x_u y_v - y_u x_v \rangle$$

- Recall that this cross product computes the normal vector to the plane defined by its two operand vectors—this is exactly what we need!

But I Have Vertices!

- Digging one step deeper, you probably noticed that we don't have vectors—we have vertices
- Again, no problem: vectors can be derived from the vertices by subtracting them from each other
- Given the vertices of a polygon, what vectors do we use to calculate the normal vector?
- Well…let's just pick two that we have for sure: the vector from the first to the second vertex, then the one from the second to the third

And Finally…

- So we have our vectors, but you might have realized that there is one last detail: for a given plane defined by these two vectors, there are two possible normals—one for each side of the plane!
- As it turns out, the direction of the vertices influences the vectors that we get, and thus which normal gets computed when multiplying our two selected vectors
- So we must not only standardize on our vectors, but the order in which we list our vertices

- A little study reveals that the normal vector will have $z > 0$ when the vertices are listed counterclockwise as viewed from the polygon's "front"
- Thus, we finally meet the level of our vertex data and code with this rule:

> In order to use backface culling, we standardize on listing our polygons' vertices so that they "wind" counterclockwise when viewed from their front

- Once we have this, we can then just "turn it on:"

```
gl.enable(gl.CULL_FACE);
```

…thus gaining this bit of optimization!