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# Vulkan Ray Tracing – 5 New Shader Types!

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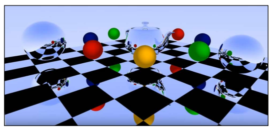



## Analog Ray Tracing Example ☺

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## Digital Ray Tracing Examples

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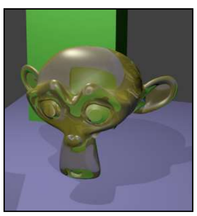
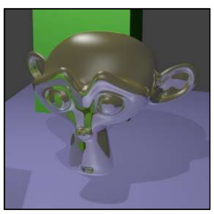
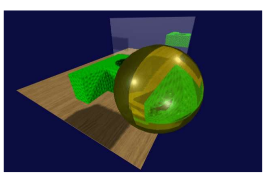




Blender



IronCad



## In a Raytracing, each ray typically hits a lot of Things

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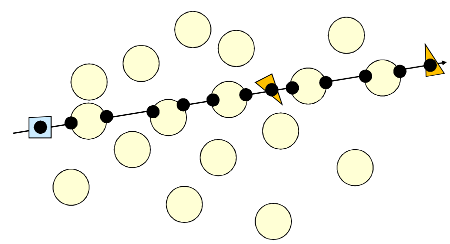



## Parametrizing a Ray

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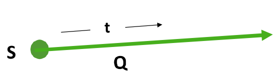
**Given:**
**S** is the (x,y,z) starting point
**Q** is the (x,y,z) direction of travel

Then, the (x,y,z) position of a point ***p*** at some position along its direction of travel is:




$$p = S + tQ$$

$$t \geq 0.$$



## Example: The Ray Intersection Process for a Sphere

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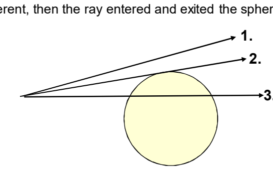
Sphere equation: $(x-x_c)^2 + (y-y_c)^2 + (z-z_c)^2 = R^2$
Ray equation: $(x,y,z) = (x_0,y_0,z_0) + t*(dx,dy,dz)$

Plugging (x,y,z) from the second equation into the first equation and multiplying-through and simplifying gives:

$$At^2 + Bt + C = 0 \Rightarrow t_1, t_2 = \frac{-B \pm \sqrt{B^2-4AC}}{2A}$$

Solve for $t_1$, $t_2$ and analyze the solution like this:

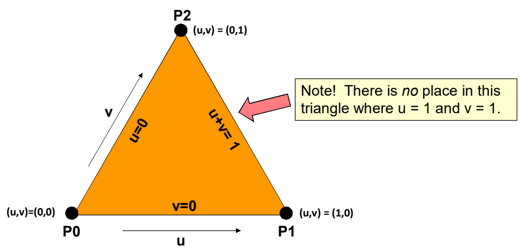
1. If both $t_1$ and $t_2$ are complex (i.e., have an imaginary component), then the ray missed the sphere completely.
2. If both $t_1$ and $t_2$ are real and identical, then the ray brushed the sphere at a tangent point.
3. If both $t_1$ and $t_2$ are real and different, then the ray entered and exited the sphere.



## Parameterizing a Triangle



It's often useful to be able to parameterize a triangle into (u,v), like this:



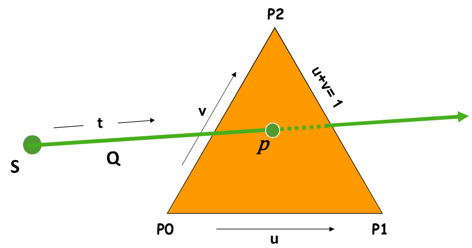

**p = P0 + u*(P1-P0) + v*(P2-P0)**



## The Setup



We want to find out where the ray intersects the triangle.
That is, where is the point $p$ that is common to both the ray and the triangle?




Such that:

$$t \geq 0.$$
$$0. \leq u \leq 1.$$
$$0. \leq v \leq 1.\text{-}u$$

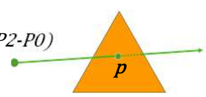


## Equation Setup



Triangle: $p = P0 + u*(P1\text{-}P0) + v*(P2\text{-}P0)$

Ray: $p = S + tQ$




Re-arranging:

$$P0 + u*(P1\text{-}P0) + v*(P2\text{-}P0) = S + tQ$$

Re-arranging some more:

$$-tQ + u*(P1\text{-}P0) + v*(P2\text{-}P0) = S - P0$$

Then collecting terms, we get:

$$At + Bu + Cv = D$$

where:

$$A = -Q$$
$$B = P1\text{-}P0$$
$$C = P2\text{-}P0$$
$$D = S - P0$$



## Three Equations, Three Unknowns



Remembering that this equation is really 3 equations in (x,y,z):

$$At + Bu + Cv = D$$

we have 3 equations with 3 unknowns, which can be cast into a matrix form

$$\begin{bmatrix} A_x & B_x & C_x \\ A_y & B_y & C_y \\ A_z & B_z & C_z \end{bmatrix} \begin{Bmatrix} t \\ u \\ v \end{Bmatrix} = \begin{Bmatrix} D_x \\ D_y \\ D_z \end{Bmatrix}$$

Our goal is to solve this for t*, u*, and v*



## Solve for (t*,u*,v*) using Cramer's Rule



$$\begin{bmatrix} A_x & B_x & C_x \\ A_z & B_y & C_y \\ A_z & B_z & C_z \end{bmatrix} \begin{Bmatrix} t \\ u \\ v \end{Bmatrix} = \begin{Bmatrix} D_x \\ D_y \\ D_z \end{Bmatrix}$$

$$D_0 = det \begin{vmatrix} A_x & B_x & C_x \\ A_y & B_y & C_y \\ A_z & B_z & C_z \end{vmatrix}$$

$$D_t = det \begin{vmatrix} D_x & B_x & C_x \\ D_y & B_y & C_y \\ D_z & B_z & C_z \end{vmatrix} \qquad \boldsymbol{t^* = \frac{D_t}{D_0}}$$

$$D_u = det \begin{vmatrix} A_x & D_x & C_x \\ A_y & D_y & C_y \\ A_z & D_z & C_z \end{vmatrix} \qquad \boldsymbol{u^* = \frac{D_u}{D_0}}$$

$$D_v = det \begin{vmatrix} A_x & B_x & D_x \\ A_y & B_y & D_y \\ A_z & B_z & D_z \end{vmatrix} \qquad \boldsymbol{v^* = \frac{D_v}{D_0}}$$



## The Steps



1. Compute $D_0$
2. If $D_0 \approx 0.$, then the ray is *parallel* to the plane of the triangle STOP
3. Compute $D_t$
4. Compute t*
5. If t* < 0., the ray goes away from the triangle STOP
6. Compute $D_u$
7. Compute u*
8. If u* < 0. or u* > 1., then the ray hits outside the triangle STOP
9. Compute $D_v$
10. Compute v*
11. If v* < 0. or v* > 1.-u*, then the ray hits outside the triangle STOP
12. The intersection is at the point ***p = S + Qt****

This is known as the **Möller-Trumbore Triangle Intersection Algorithm**

### The Rasterization Shader Pipeline That You Are used to Doesn't Apply to Vulkan Ray Tracing

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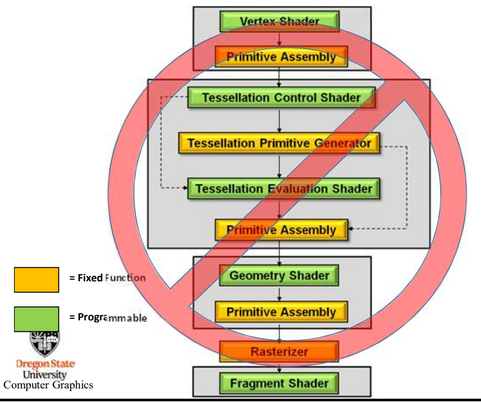


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### The Vulkan Ray Tracing Pipeline Involves Five New Shader Types

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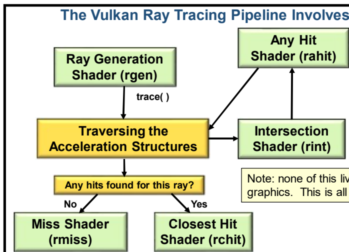


Unlike the rasterization pipeline, there is no constant flow from one shader to the next. Rather, particular shaders are called to respond to particular ***events***.

Note: none of this lives in the hardware meant for rasterization graphics. This is all built on top of the GPU *compute* functionality.

- A **Ray Generation Shader** runs on a 2D grid of threads. It begins the entire ray-tracing operation.
- An **Intersection Shader** implements ray-primitive intersections.
- An **Any Hit Shader** is called when the Intersection Shader finds a hit. It decides if that intersection should be accepted or ignored.
- The **Closest Hit Shader** is called with the information about the hit that happened closest to the viewer. Typically, lighting is done here, or firing off new rays to handle shadows, reflections, and refractions.
- A **Miss Shader** is called when no intersections are found for a given ray. Typically, it just sets its pixel color to the background color.

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### Acceleration Structures

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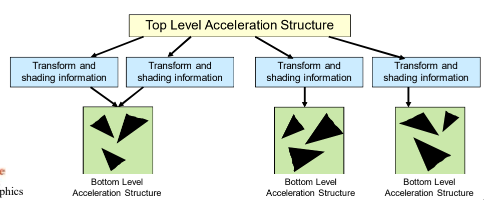
- A Bottom-level Acceleration Structure (BLAS) reads the vertex data from vertex and index VkBuffers to determine bounding boxes.
- You can also supply your own bounding box information to a BLAS.
- A Top-level Acceleration Structure (TLAS) holds transformations and pointers to multiple BLASes.
- The BLAS is essentially used as a Model Coordinate bounding box, while the TLAS is used as a World Coordinate bounding box.

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### Check This Out!

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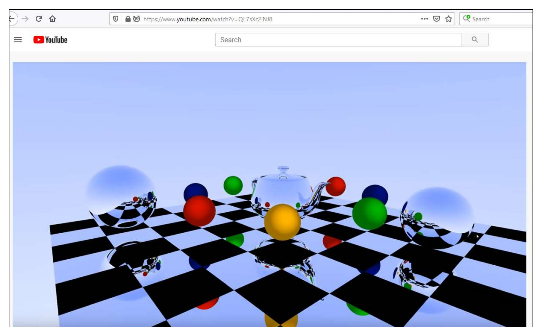

https://www.youtube.com/watch?v=QL7sXc2iNJ8

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