HARDWARE ACCELERATED RAY-TRACING

JAGI NATARAJAN & ERIC SLYMAN

MOTIVATION

Physically Realistic

Intuitive

Slow

HISTORICAL CONTEXT

1968 (Appel)

Some Techniques for Shading Machine Renderings of Solids

- Trace the path of a light ray through each pixel on a 2D viewing surface out into a 3D model of the scene
- The first implementation of ray casting, although the term was not used

1980 (Whitted)

An Improved Illumination Model For Shaded Display

- Capturing shadows, reflection, and refraction

1982 (Roth)

Ray Casting For Modeling Solids

- Restricted ray-tracing that can be done real time
- First to use the term ray casting

1984 (Cook et. al.)

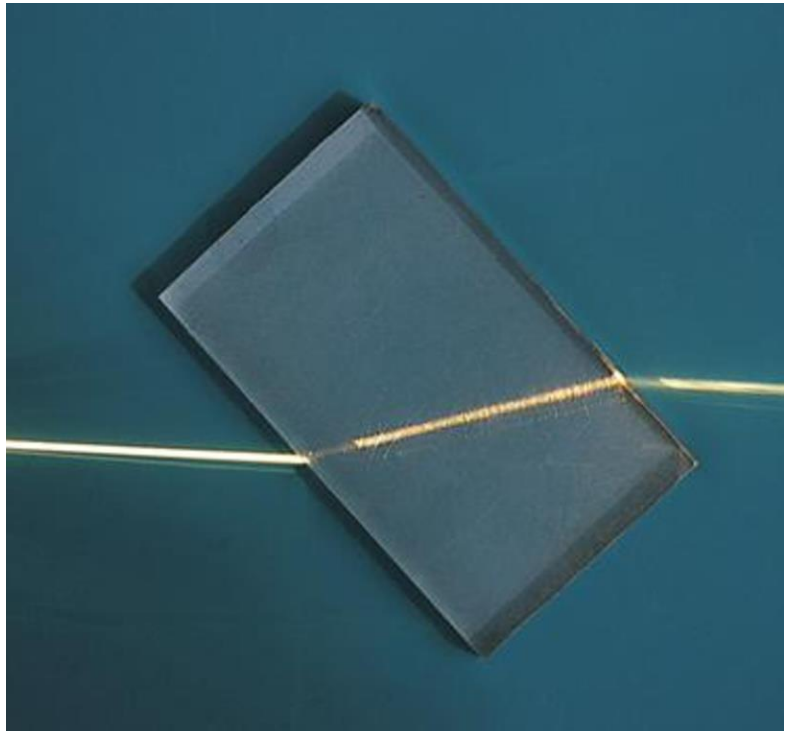
Distributed Ray Tracing

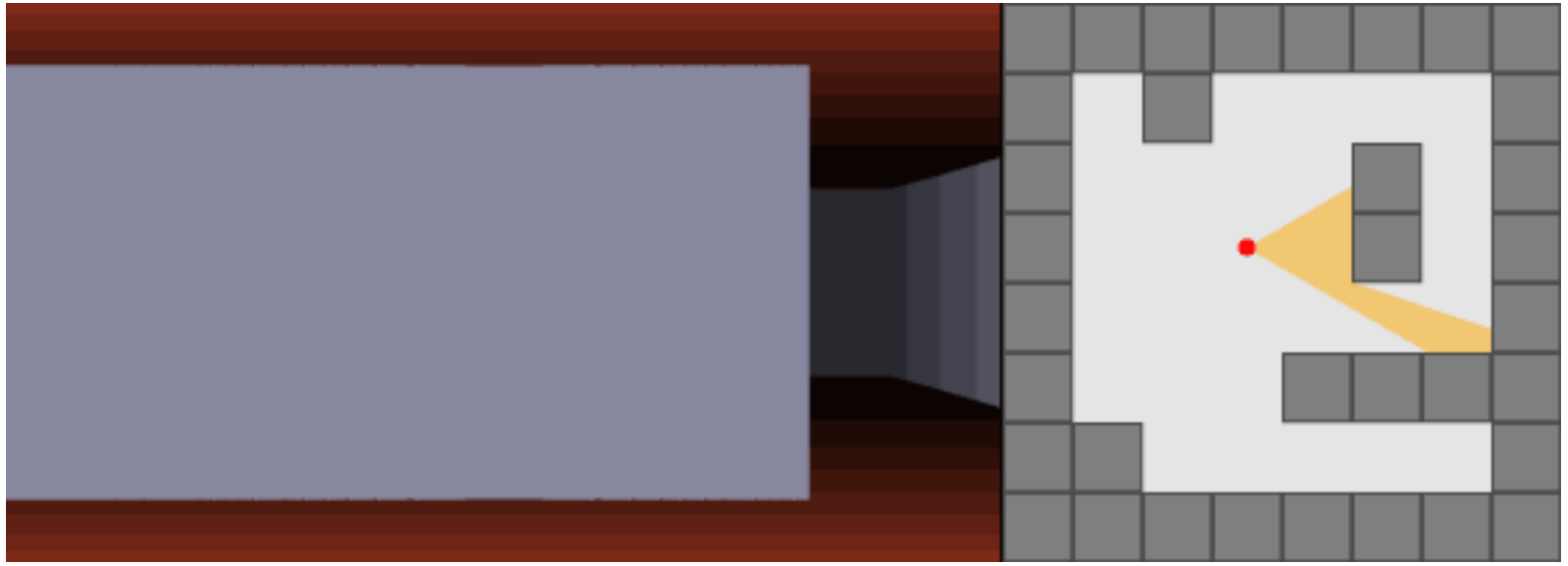
- Motion blur, depth of field, penumbras, translucency, and fuzzy reflections

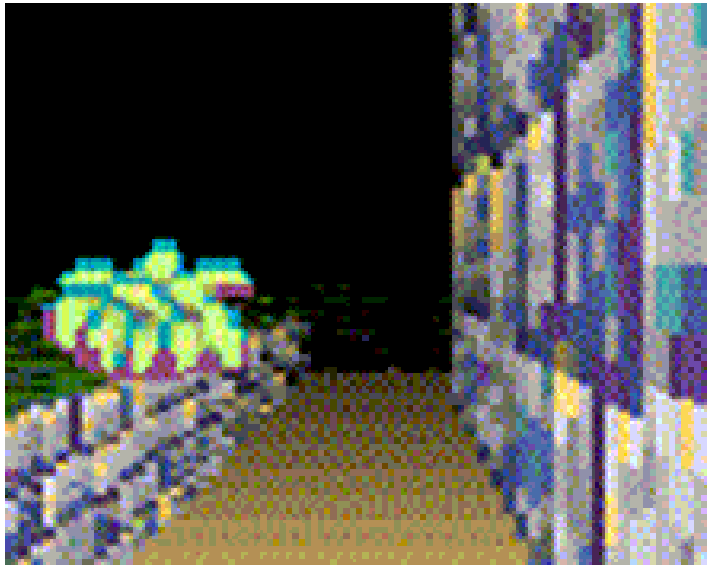
1992 (id Software)

Real-Time Ray Casting in Wolfenstein 3D

HISTORICAL CONTEXT - RAY CASTING







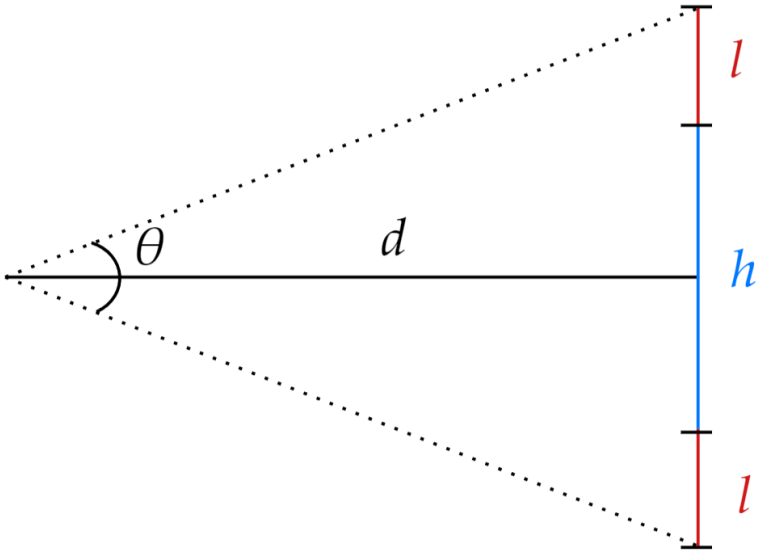
WOLFENSTEIN 3D

RAY CASTING & 2D PROJECTION

- Cast rays in two dimensions instead of three
- Each column of pixels corresponds to a single ray
- Rendered column depends on distance to ray intersect

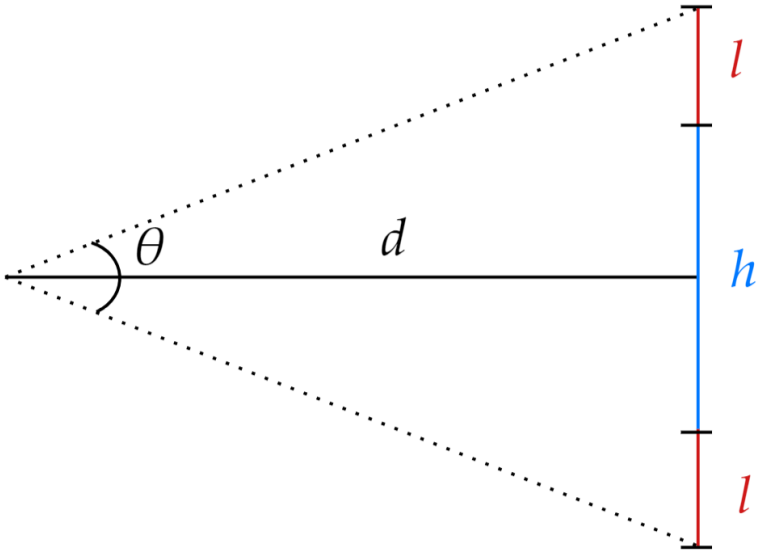
RAY CASTING & 2D PROJECTION

- Determine the value of l in terms of $\theta,\ d,\ h$



RAY CASTING & 2D PROJECTION

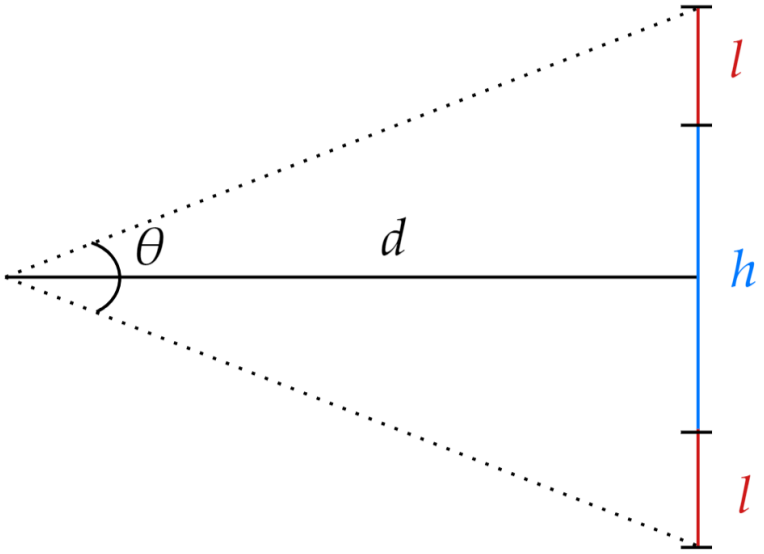
- Determine the value of l in terms of $\theta,\ d,\ h$
- Find R, the ratio of l to the total height of the column (Hint: Total column height is $2l + h$)



RAY CASTING & 2D PROJECTION

- Determine the value of l in terms of $\theta,\ d,\ h$
- Find R, the ratio of l to the total height of the column (Hint: Total column height is $2l + h$)
- Use this relationship along with the viewport height V_h to draw a single column

```
draw_col(x, θ, h, d, V_h):
    R ← __
    for i ← __ to __ do:
        canvas[x, i] = ground_color;
    for i ← __ to __ do:
        canvas[x, i] = wall_color;
    for i ← __ to __ do:
        canvas[x, i] = sky_color;
```



RAY CASTING & 2D PROJECTION

https://www.desmos.com/calculator/tsbagqmiiy

RAY CASTING & 2D PROJECTION

- Determine the value of l in terms of $\theta,\ d,\ h$
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```
draw_col(x, θ, h, d, V_h):
    R ← 1/2 − h / (4d tan(θ/2))
    for i ← 1 to R*V_h do:
        canvas[x, i] = ground_color;
    for i ← R*V_h to (1-R)*V_h do:
        canvas[x, i] = wall_color;
    for i ← (1-R)*V_h to V_h do:
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```

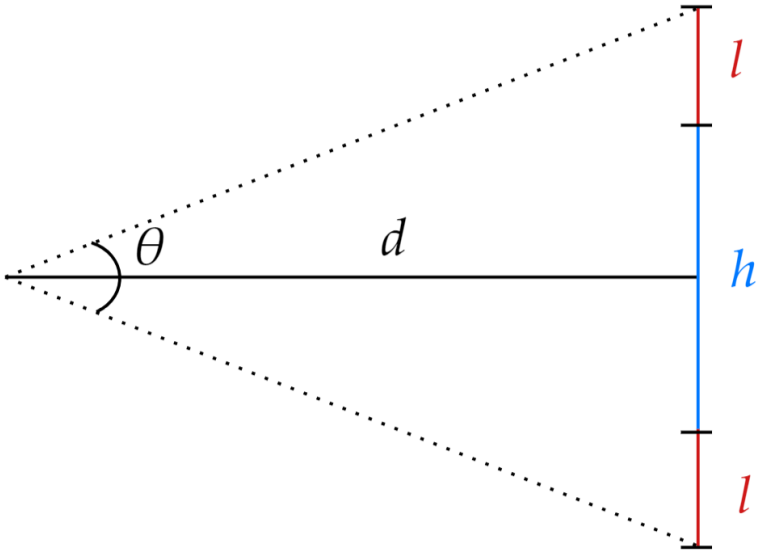

HISTORICAL CONTEXT

1999

Nvidia releases the GeForce 256 "The Worlds First GPU"

2005 – 2019 Iterative Improvements

GDC 2019

Nvidia offers hardware-accelerated ray tracing on RTX series Turing architecture GPUs

- RT Core (BVH Traversal, BVH Node Decompression, ray-AABB intersection, and ray-triangle intersection)

Introduction To Realtime Ray Tracing

SIGGRAPH 2005

Nvidia Announces OptiX, a API for real-time ray tracing on Nvidia GPUs.

- Used in AfterEffects, Bunkspeed shot, Autodesk Maya, 3ds max, etc.

SIGGRAPH 2019

AMD to offer hardware-accelerated ray tracing on second generation Navi architecture GPUs

2020

INTRODUCTION TO REAL-TIME RAY RACING (SIGGRAPH 2005)

“ It turns out that many researchers have repeatedly stated very early that ray tracing would eventually become faster than rasterization because of its logarithmic complexity in terms of scene size. However, these claims have not been fulfilled for more than twenty years, and **research on ray tracing essentially stopped in the late 1980s [to] early 1990s.** There had been no research that has explored WHY ray tracing has been so dramatically slower than rasterization despite other expectations ”

– Slusallek et. al.

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2020

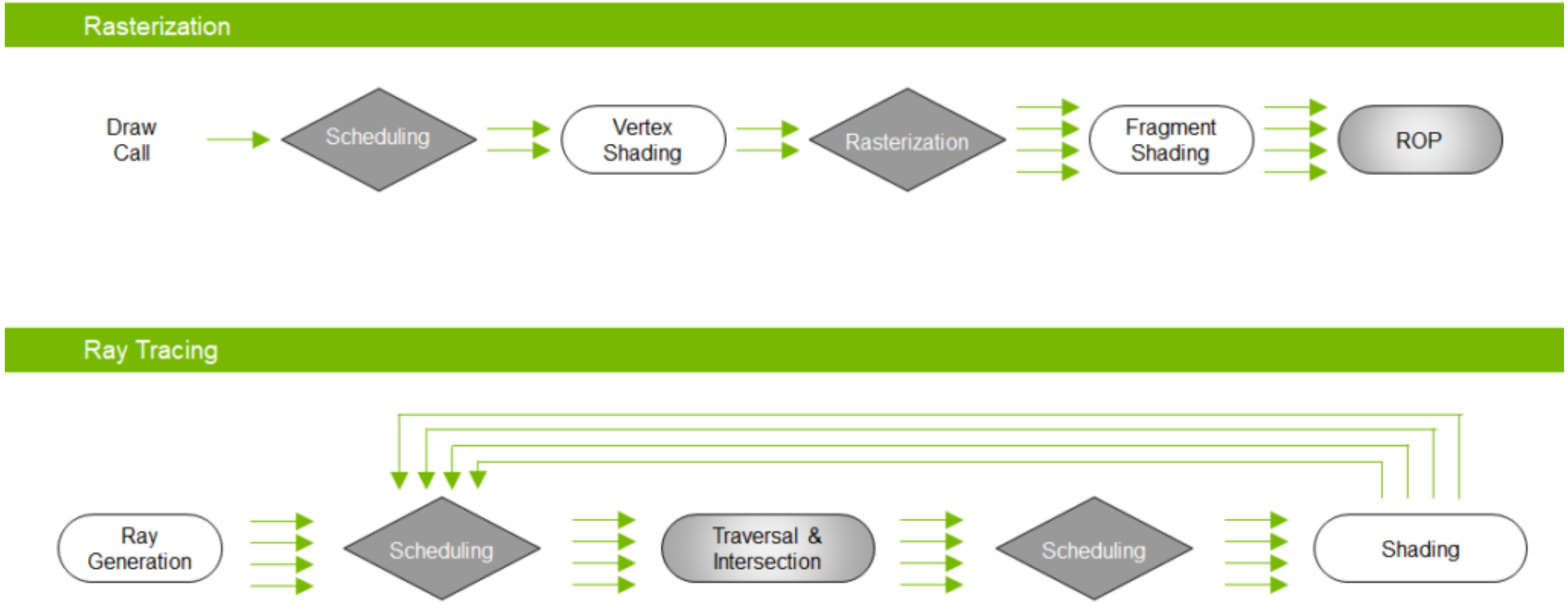
WHY DO WE CARE NOW?

Real Time

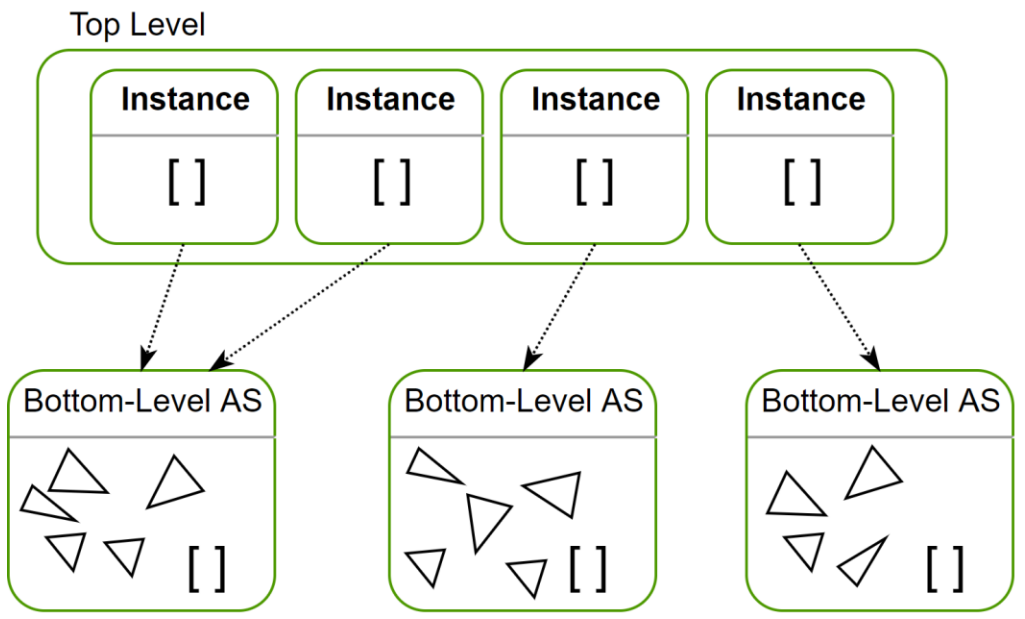
Interactive

Available To Consumers

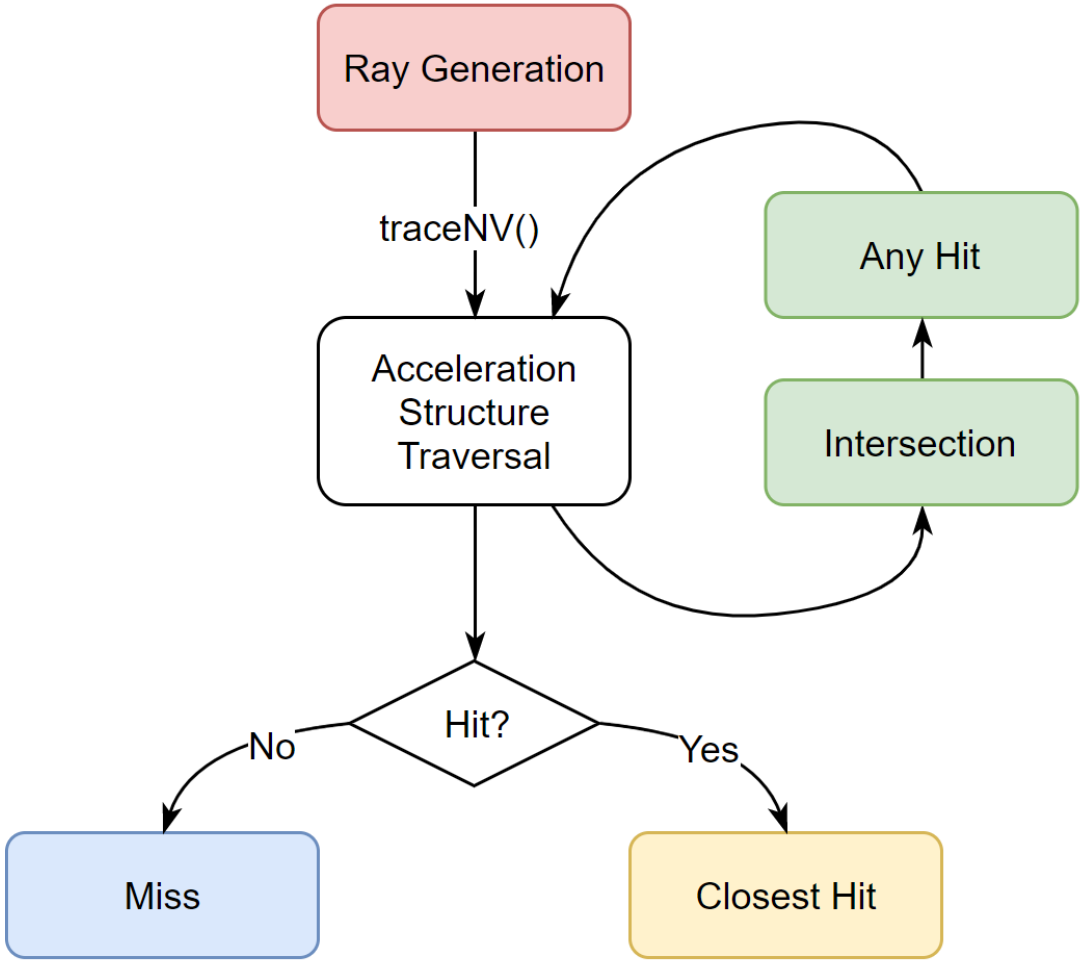
PIPELINE OVERVIEW



ACCELERATION STRUCTURES

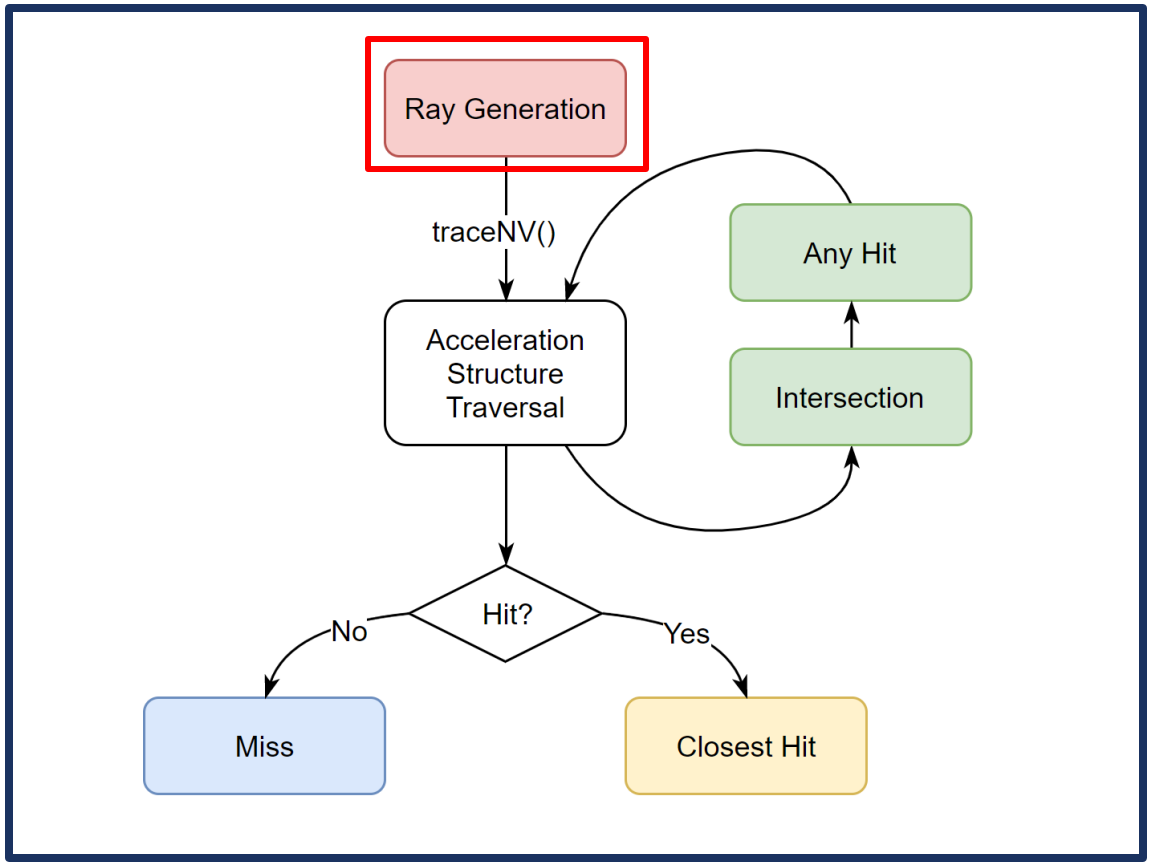


- Opaque, hardware-specific structures for fast intersections
- Two levels: top-level, bottom-level (TLAS, BLAS)
- Simple 2-layer scene graph
- GPU typically converts to a BVH under the hood
  - Custom geometry (perfect spheres, etc.) must specify AABB container as part of BLAS



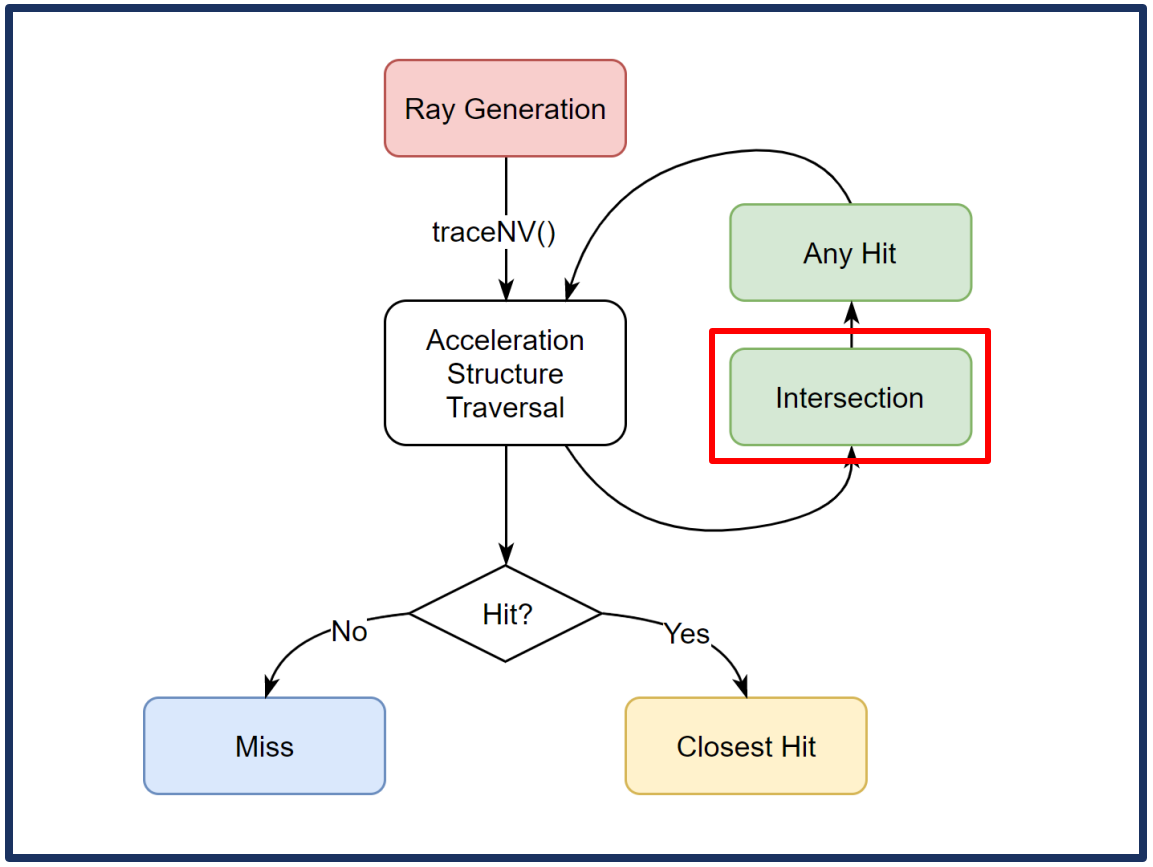
RAYTRACING SHADER PROGRAMS

RAY GENERATION SHADER



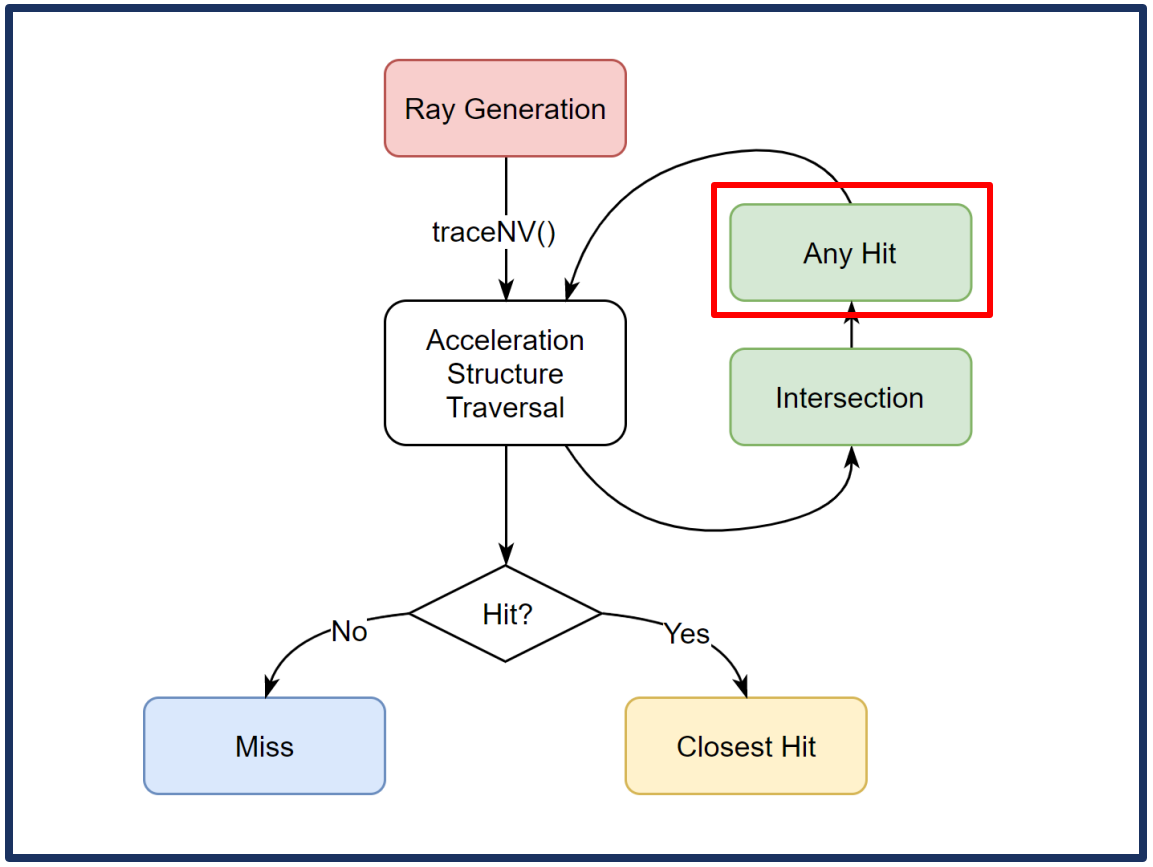
- For each pixel in the target image buffer
  - Compute ray from pixel coordinate and camera
  - Call raytrace function
  - Store resulting "payload" (pixel color) in image buffer
- Supersampling, jitter can be implemented here
  - Send multiple rays per pixel, attenuate ray directions, etc.

INTERSECTION SHADER



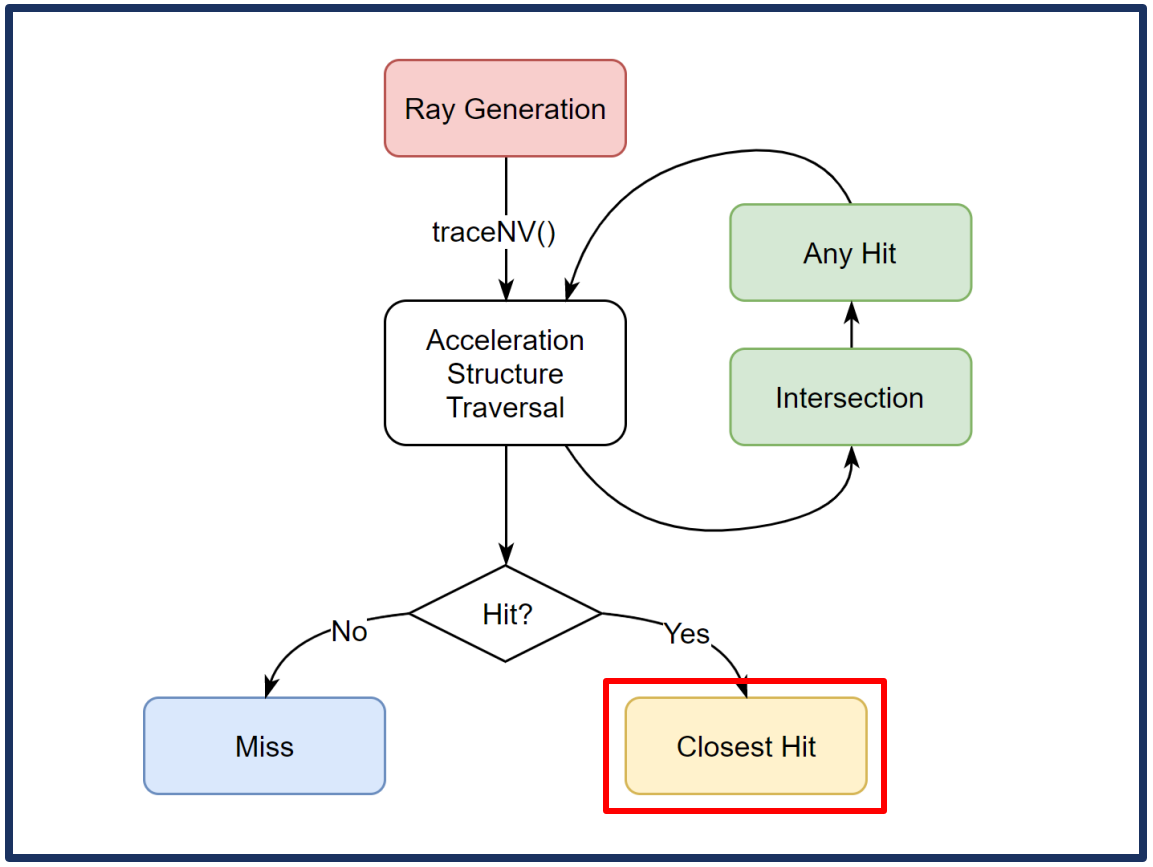
- Optional shader that allows for custom geometry intersections, e.g. perfect spheres
- Given ray and object AABB container, determine if ray collides with object
- Yield *t* value and optional parameters (barycentric coordinates, etc.)
- Built-in triangle intersection shader is default in DX12 and Vulkan

ANY HIT SHADER



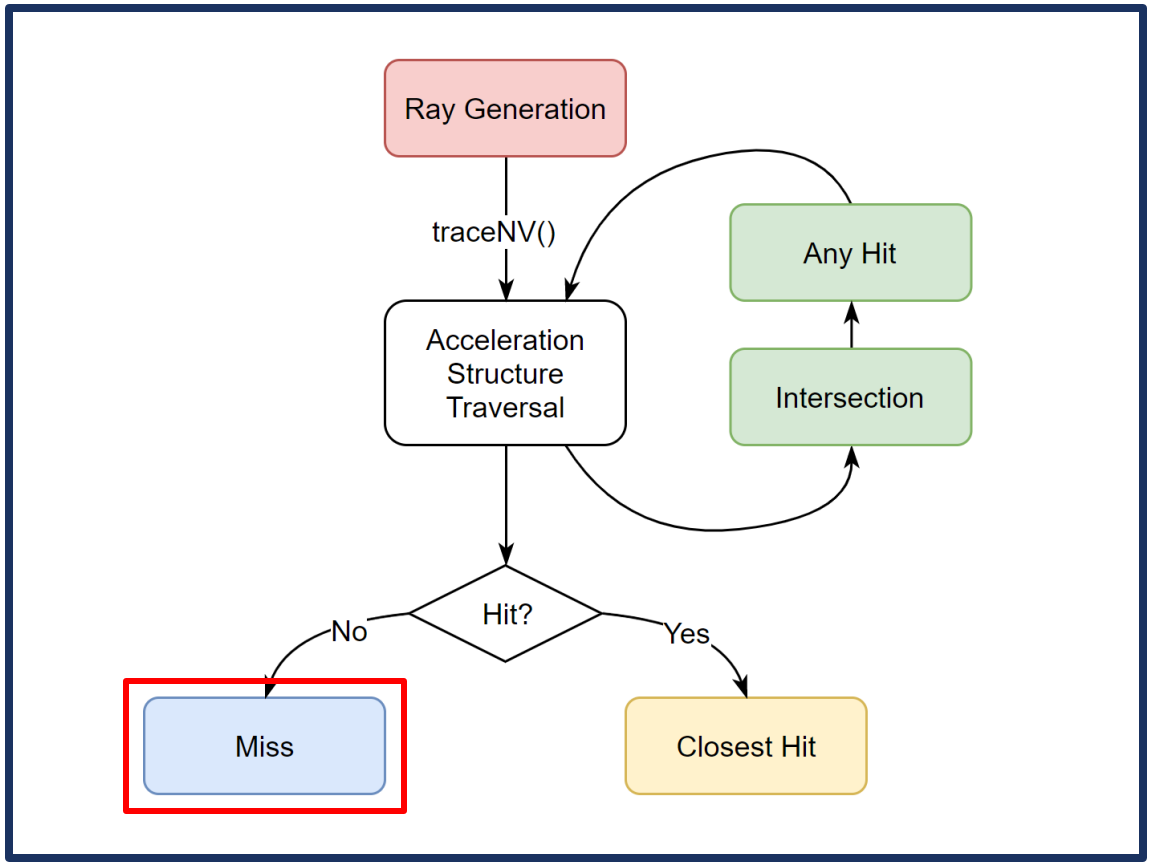
- Optional shader which is executed for all hits
- Useful for specific ray-tracing techniques
  - Shadows – Fire rays with a boolean ray payload, short-circuit as soon as any hit occurs

CLOSEST HIT SHADER



- Called after intersecting all geometry, on hit with smallest *t* value
- Determine color, lighting calculations
- May recursively spawn new rays
  - Reflection, refraction, etc.
- Shader can be defined per-scene, or per-object

MISS SHADER



- Called if ray intersects with no objects
- Determine background color
- Environment mapping

CURRENT PLATFORMS

- Two vendors provide raytracing APIs with Nvidia RTX hardware support
  - Microsoft's DirectX12 – DXR API
  - Khronos' Vulkan – VK_NV_ray_tracing API extension
- Both APIs also support pre-RTX graphics cards (GTX 10xx and above)
  - Less than half the performance of equivalent RTX GPUs
- Raytracing can be hacked together in OpenGL using a fragment shader
  - Takes no advantage of hardware support, acceleration structures
  - Scene must be of limited size, represented as shader uniforms

QUESTIONS?

SOURCES

- Appel, Arthur. "Some techniques for shading machine renderings of solids." *Proceedings of the April 30–May 2, 1968, spring joint computer conference*. 1968.
- Whitted, Turner. "An improved illumination model for shaded display." *Proceedings of the 6th annual conference on Computer graphics and interactive techniques*. 1979.
- Cook, Robert L., Thomas Porter, and Loren Carpenter. "Distributed ray tracing." *Proceedings of the 11th annual conference on Computer graphics and interactive techniques*. 1984.
- Slusallek, Philipp, et al. "Introduction to real-time ray tracing." *ACM SIGGRAPH 2005 Courses*. 2005. 1-es.