Introduction to DirectX Raytracing:

Overview of Ray Tracing

Peter Shirley, NVIDIA

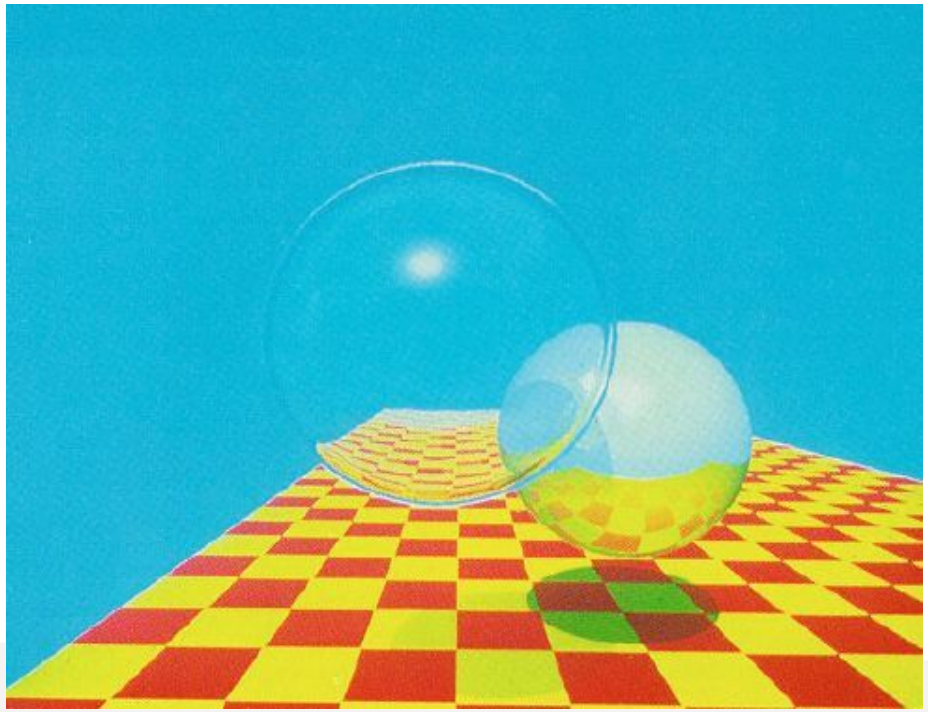
More information: http://intro-to-dxr.cwyman.org

Turner Whitted 1980

included a bounding volume hierarchy

reflection and refraction

adaptive antialiasing



Graphics and Image Processing — J.D. Foley Editor

An Improved Illumination Model for Shaded Display

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To accurately render a two-dimensional image of a three-dimensional scene, global illumination information that affects the intensity of each pixel of the image must be known at the time the intensity is calculated. In a simplified form, this information is stored in a tree of "rays" extending from the viewer to the first surface encountered and from there to other surfaces and to the light sources. A visible surface algorithm creates this tree for each pixel of the display and passes it to the shader. The shader then traverses the tree to determine the intensity of the light received by the viewer. Consideration of all of these factors allows the shader to accurately simulate true reflection, shadows, and refraction, as well as the effects simulated by conventional shaders. Anti-aliasing is included as an integral part of the visibility calculations. Surfaces displayed include curved as well as polygonal surfaces.

The role of the illumination model is to determine how much light is reflected to the viewer from a visible point on a surface as a function of light source direction and strength, viewer position, surface orientation, and surface properties. The shading calculations can be performed on three scales: microscopic, local, and global. Although the exact nature of reflection from surfaces is best explained in terms of microscopic interactions between light rays and the surface [3], most shaders produce excellent results using aggregate local surface data. Unfortunately, these models are usually limited in scope, i.e., they look only at light source and surface orientations, while ignoring the overall setting in which the surface is placed. The reason that shaders tend to operate on local data is that traditional visible surface algorithms cannot provide the necessary global data.

A shading model is presented here that uses global information to calculate intensities. Then, to support this shader, extensions to a ray tracing visible surface algorithm are presented.

1. Conventional Models

The simplest visible surface algorithms use shaders based on Lambert's cosine law. The intensity of the reflected light is proportional to the dot product of the surface normal and the light source direction, simulating a perfect diffuser and yielding a reasonable looking approximation to a dull, matte surface. A more sophisticated model is the one devised by Bui-Tuong Phong [8]. Intensity from Phong's model is given by

$$I = I_a + k_d \sum_{j=1}^{j=ls} (\bar{N} \cdot \bar{L}_j) + k_s \sum_{j=1}^{j=ls} (\bar{N} \cdot \bar{L}_j')^n, \qquad (1)$$

where

Ray Tracing flavors

Whitted 1980: shiny

reflection rays off perfect surfaces

shadow rays to point sources

Cook 1984 (distribution ray tracing): fuzzy

reflection rays are randomly perturbed off pure specular direction

soft shadows by sending rays to random points on area light source

Kajiya 1986 (path tracing): diffuse intereflection

Now go fully random for diffuse surfaces

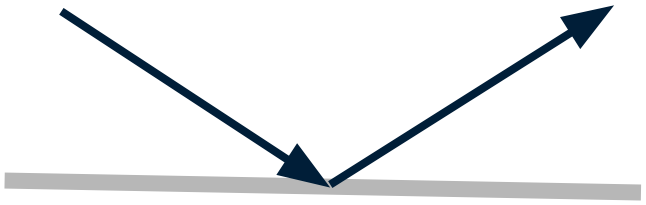
A typical batch 1980s ray tracing program (Whitted style ray tracing)

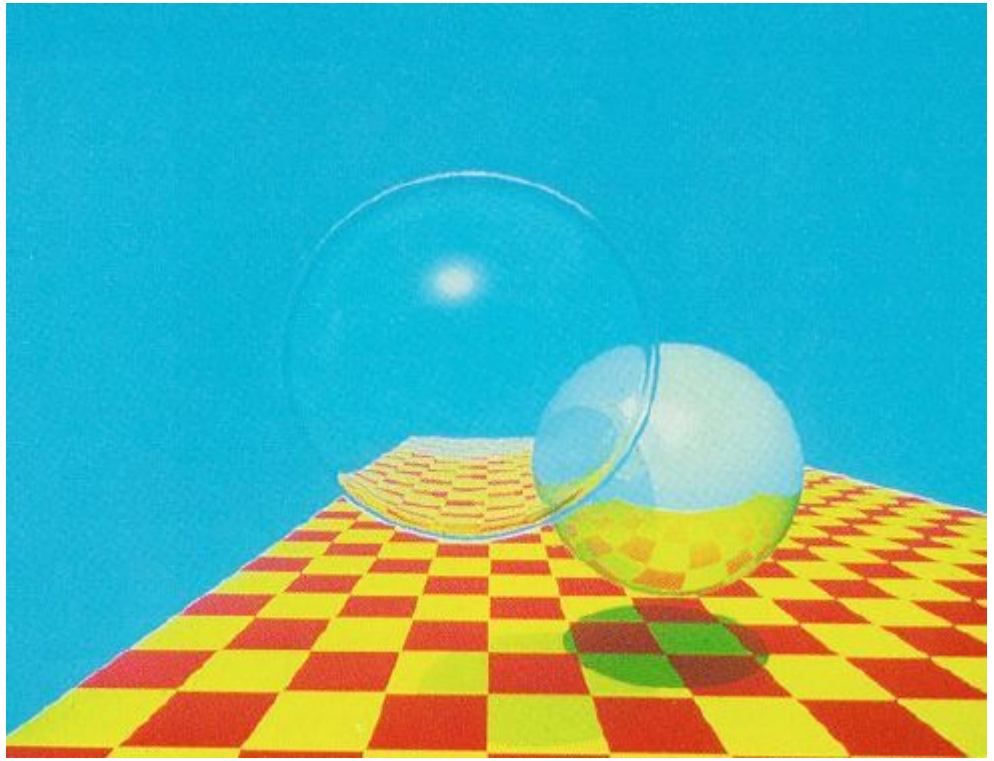
For each pixel

Send a visibility ray (or many for antialiasing)

If a diffuse surface, send a shadow ray to each light source and shade

If a mirror surface, send a reflection ray

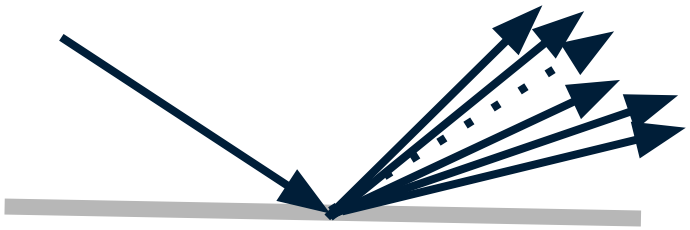


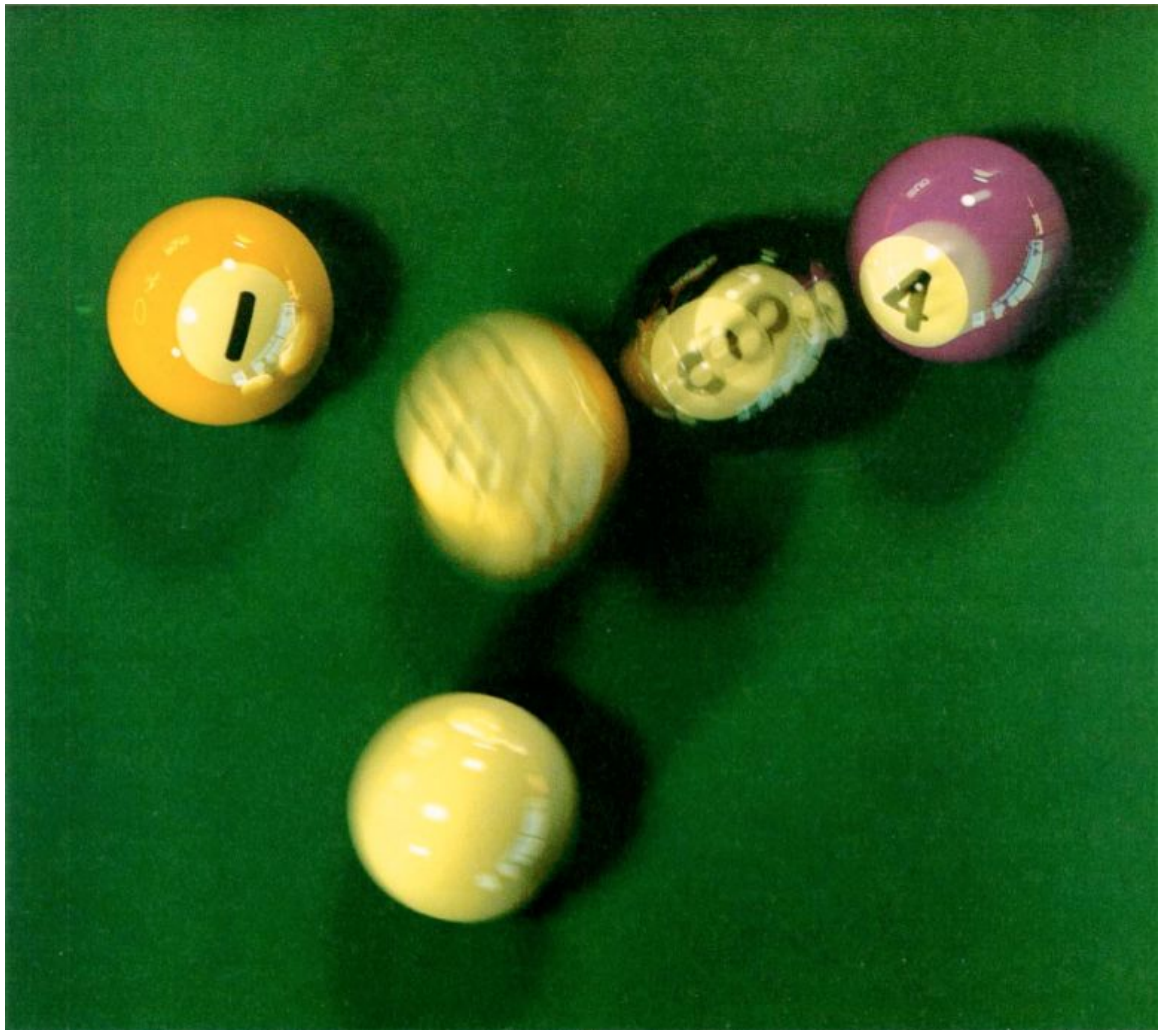


A typical batch 1990s ray tracing program (Cook style ray tracing)

Allow shadow rays to go to a random point on area light

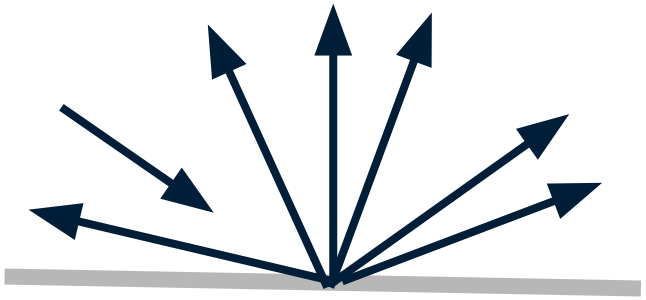
Allow specular rays to be perturbed specularly around the ideal reflection





Kajiya style diffuse interreflection

Note bounce light on bottom of squashed sphere on the upper left



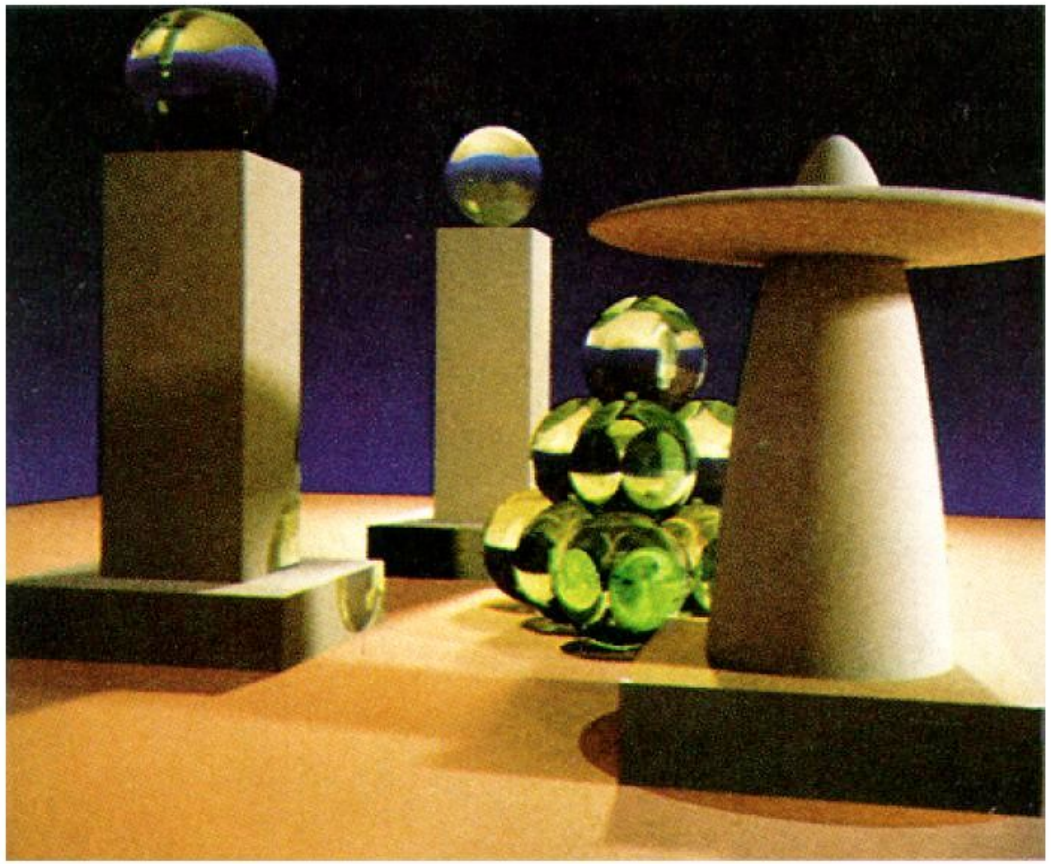


Figure 6. A sample image. All objects are neutral grey. Color on the objects is due to caustics from the green glass balls and color bleeding from the base polygon.

Denoising

Ray Tracing Versus Rasterization for primary visibility

Rasterization: stream triangles to pixel buffer to see that pixels they cover

Ray Tracing: stream pixels to triangle buffer to see what triangles cover them

Rasterization vs Ray Tracing

Key Concept	Rasterization	Ray Tracing
Fundamental question	What pixels does geometry cover?	What is visible along this ray?
Key operation	Test if pixel is inside triangle	Ray-triangle intersection
How streaming works	Stream triangles (each tests pixels)	Stream rays (each tests intersections)
Inefficiencies	Shade many tris per pixel (overdraw)	Test many intersections per ray
Acceleration structure	(Hierarchical) Z-buffering	Bounding volume hierarchies
Drawbacks	Incoherent queries difficult to make	Traverses memory incoherently

What is a Ray?

USUALLY, at least conceptually, it is a 3D origin **point** and a **direction** of propagation, like a laser beam

How do I represent such a thing in code? As a line somehow?

In 2D a line might be **y = mx + b** (implicit equation)

In 3D can we do that? No, there is no implicit equation for a 1D object embedded in 3D

How about geometrically? The intersection of two planes? Is rarely done.

Blending points

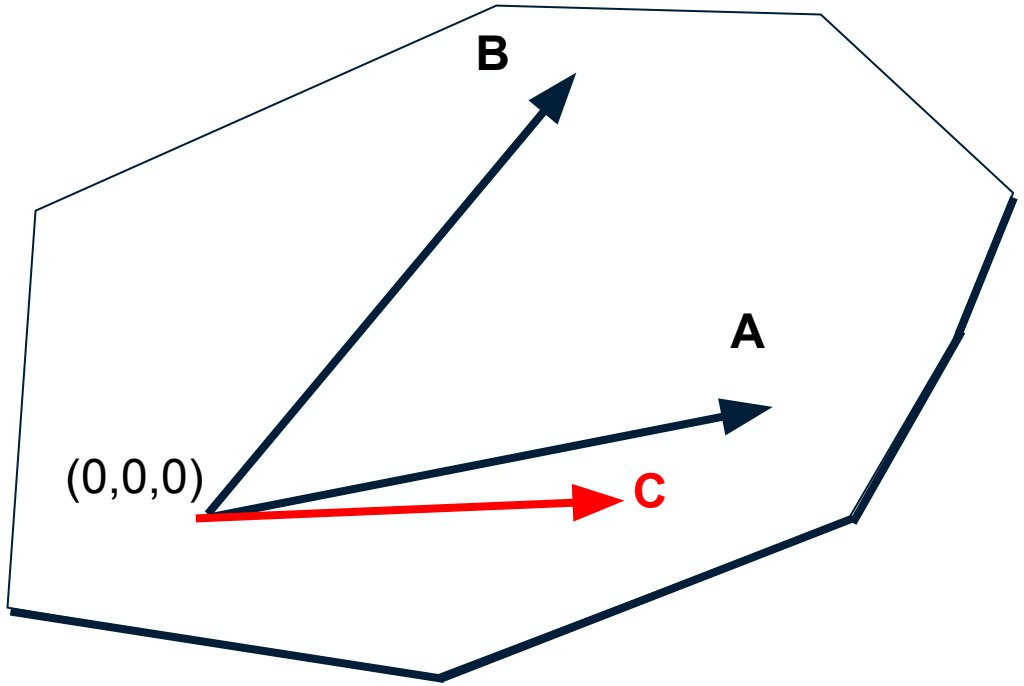
A linear combination of two points **A** and **B**

vec3 **A**

vec3 **B**

vec3 **C** = 0.9f***A** - 0.2f***B**

Arbitrary linear combinations of **A** and **B** like that are a point in the plane through the origin vec3(0,0,0) and **A** and **B**.



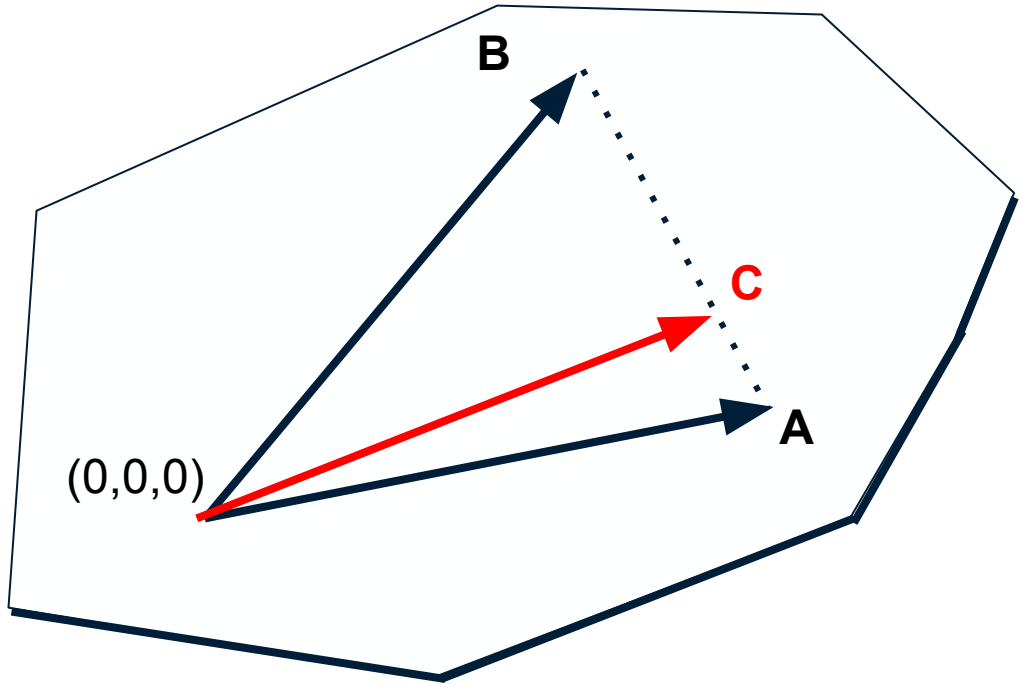
Weighted average of points

vec3 **A**

vec3 **B**

vec3 **C** = (1.0f - 0.37f) * **A** + 0.37f * **B**

C will be on the 3D line through **A** and **B**



A “parametric” 3D line

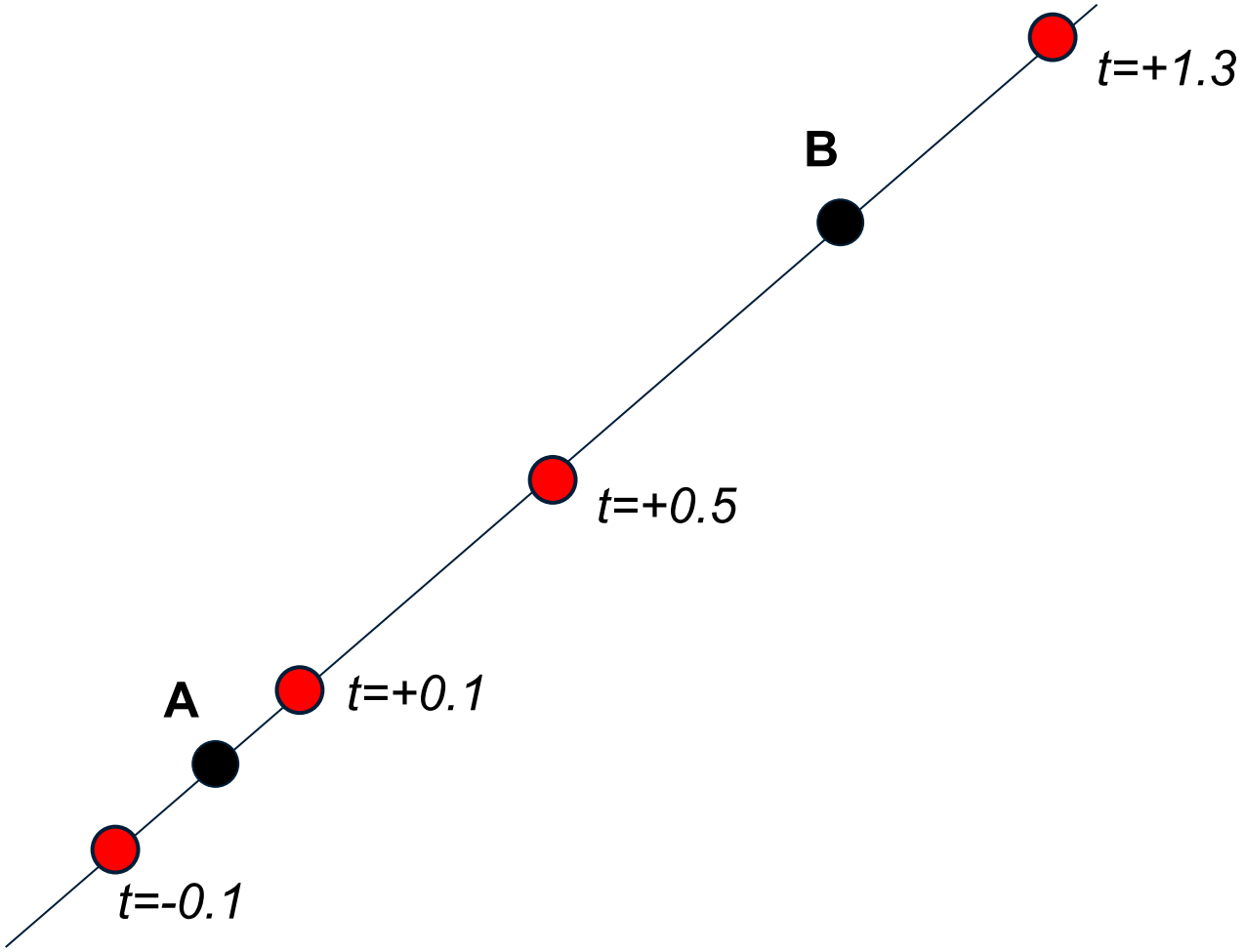
vec3 **A**

vec3 **B**

float t

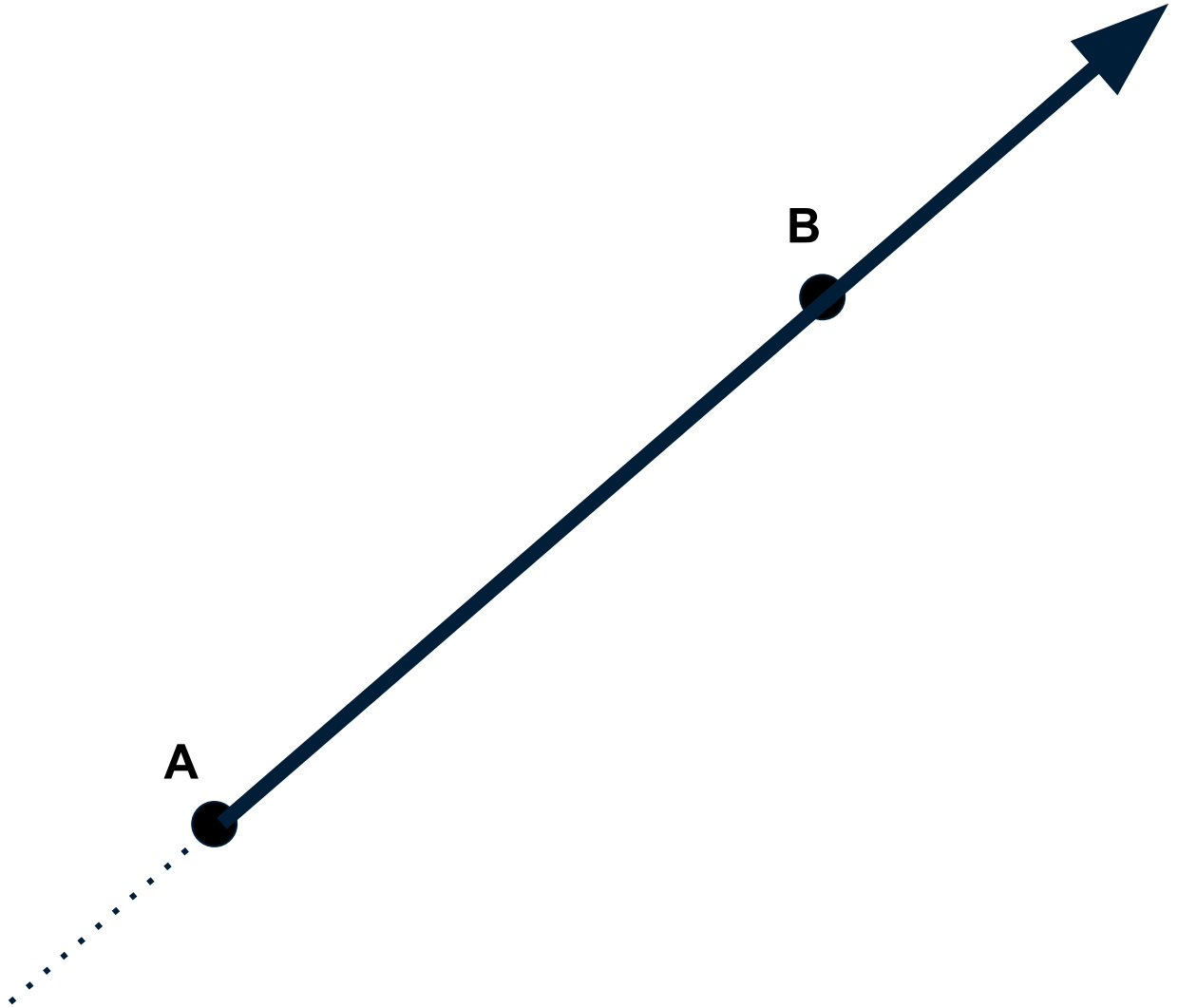
vec3 **C** = (1-t)***A** + t***B**

t is the **parameter** that says where on the line **C** is



A ray as a half line

t >= 0



Variations on half-lines

Ray as half-line through **A** and **B** is all points **P**:

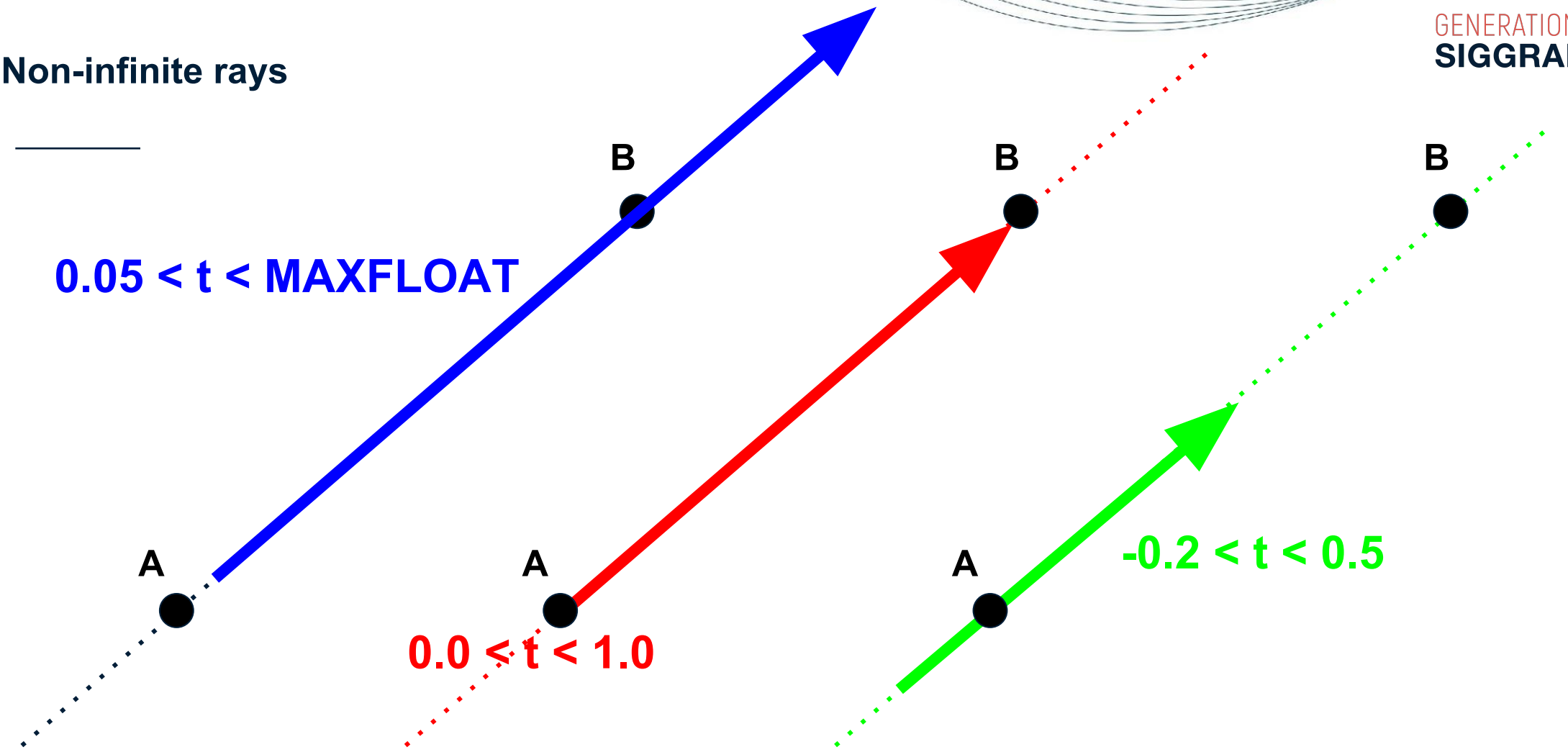
P(t) = (1-t)***A** + t***B**

P(t) = **A** + t*(**B-A)**

P(t) = **A** + t***V**

P(s) = **A** + s*unit_vector(**V**)

Non-infinite rays



What do we do with rays?

Ask various questions:

1. Does a ray hit anything for t > epsilon *(shadow query)*
2. How far away is the nearest thing in the direction of the ray *(proximity query)*
3. What if anything does a ray first hit for t > epsilon *(viewing query)*
4. What if anything does a ray first hit for 13.2 < t < 22.5 *(viewing query)*
5. What are all the things hit by a ray *(useful for things like CSG)*

How to make rays faster

A brute force ray tracer

hit(ray)

Test ray against every triangle

A faster ray tracer (if many rays are sent):

Organize triangles into a tree structure

hit(ray)

Traverse tree and test ray against triangles not culled in traversal

a

The Bounding Volume Hierarchy (BVH)

There are many data structures used to help faster ray tracing but the BVH is the most common used

Building a BVH is typically **O(N log N)** for **N** triangles

Updating a BVH is typically **O(N)** for **N** triangles

Traversing a BVH (i.e., tracing a ray) is typically **O(logN)**

Usual program: build BVH as preprocess, then per frame then loop over

If needed update BVH

Trace rays

Closing remarks

There is no single ray tracing ``algorithm''

There are lots of algorithms that use ray tracing

The ray tracing query has lots of unexplored possibilities in the real time world-- it has never been available before

When programmable shading was made available to practitioners, they did many creative things few would have predicted. There isn't a "right" way to use ray tracing; add it as a arrow in your programming quiver and go create!