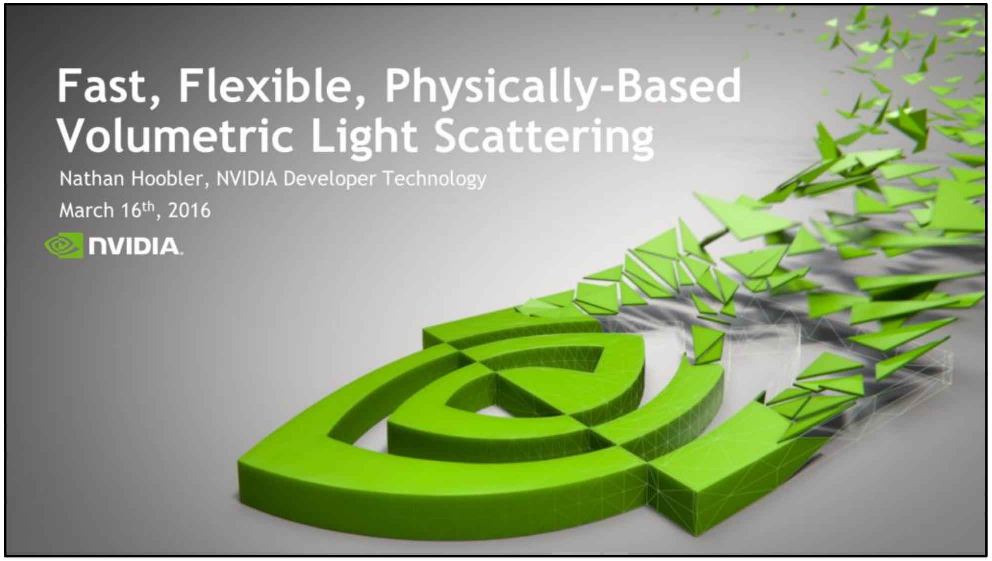
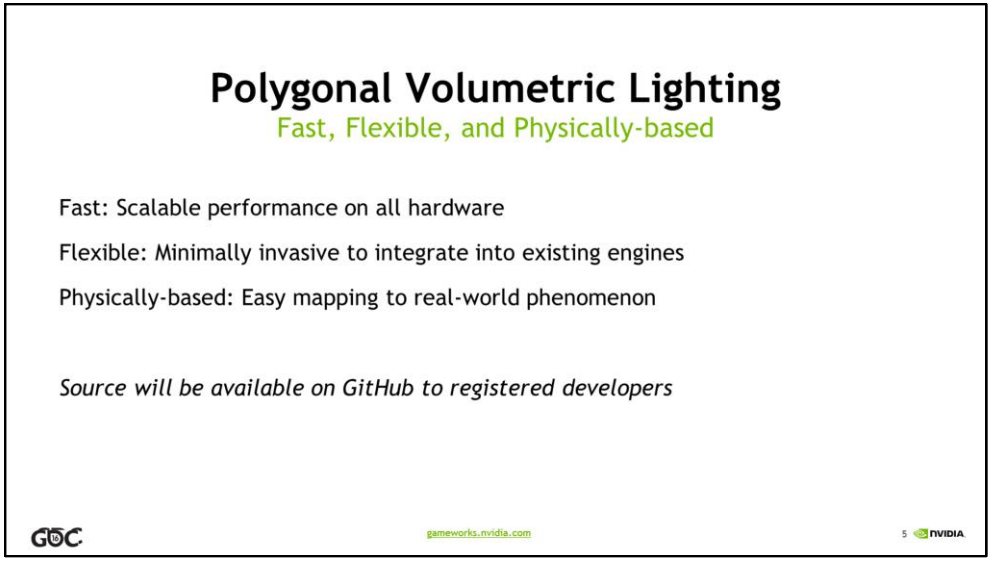

Fast, Flexible, Physically-Based Volumetric Light Scattering
Nathan Hoobler, NVIDIA Developer Technology
March 16th, 2016
NVIDIA



Fast:

- Tunable quality knobs to provide best performance for a variety of platforms
- Scales well with large numbers of emitters

Flexible:

- Requires minimal modification of existing pipeline
- Works anywhere you can provide a shadow map and a scene depth
- Flexible lighting model to accommodate specific pipeline quirks (complex falloff functions, etc.)

Physically-based:

- Lighting model derived from physical integrals, making it suitable for integration into physically-based renderers
- Media properties derived from real-world models, making it straightforward to get a ‘realistic’ starting point
- … but still flexible enough to give artists a simple interface for tweaking

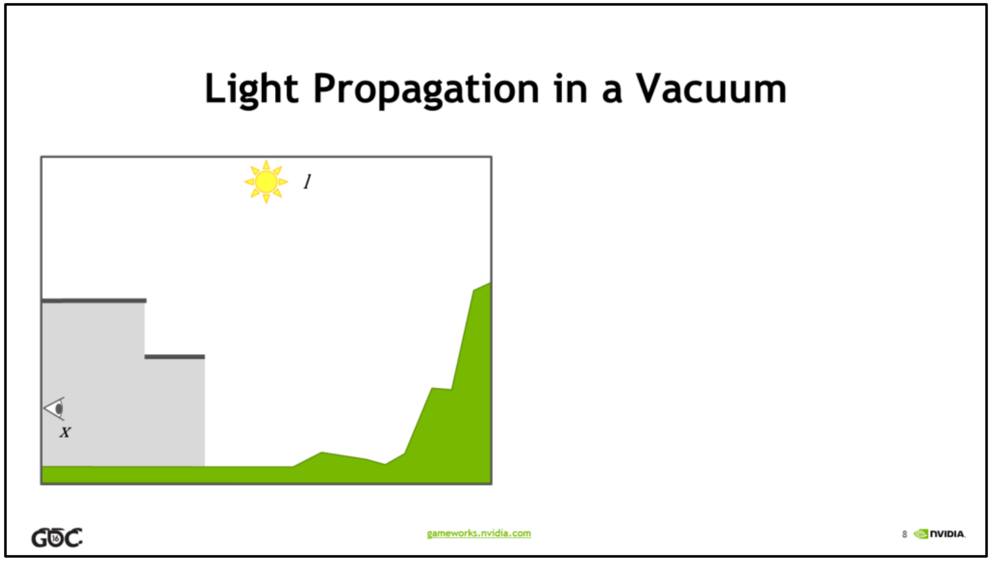
AGENDA

Background & Motivation

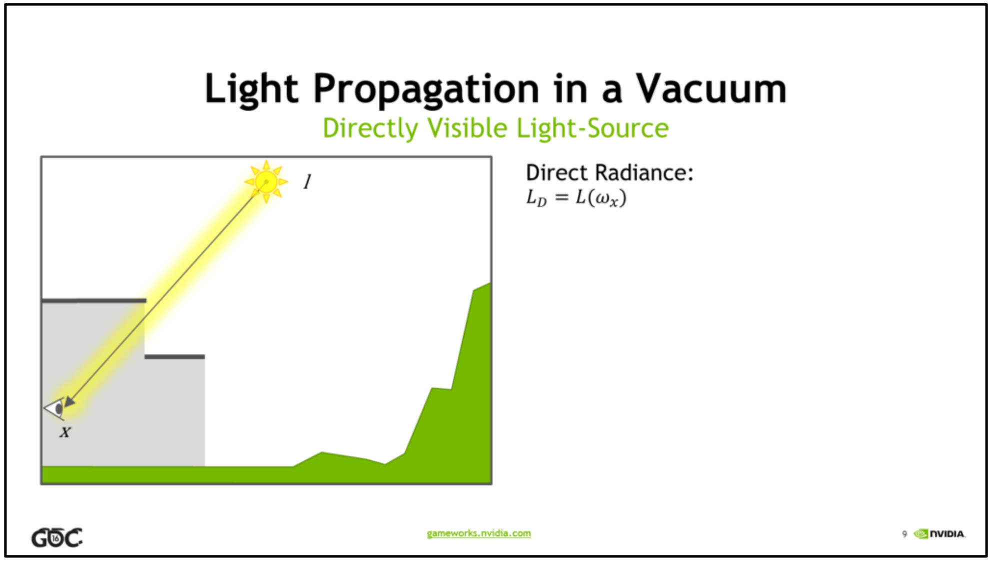
Algorithm Overview

Integration into *Fallout 4*

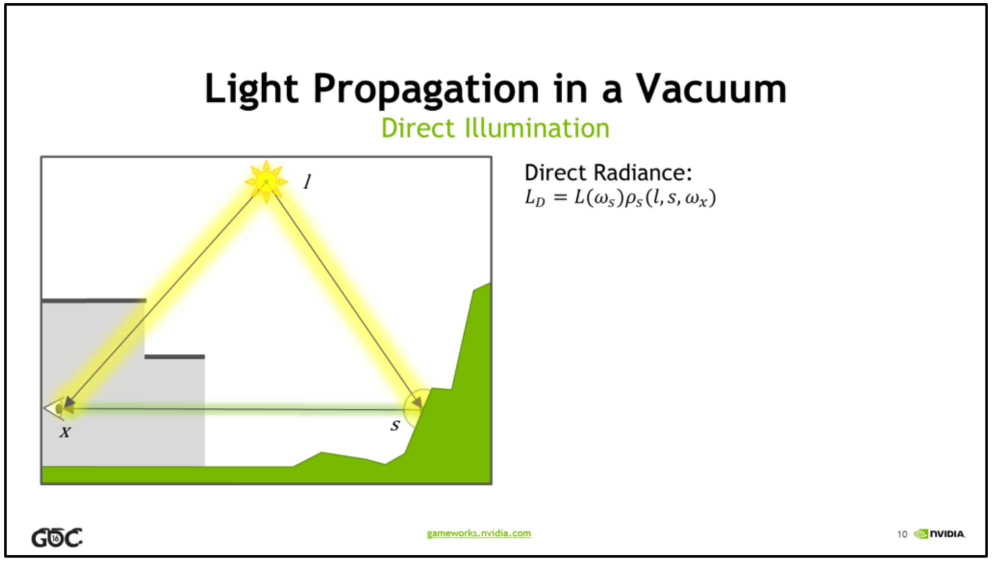
Background & Motivation



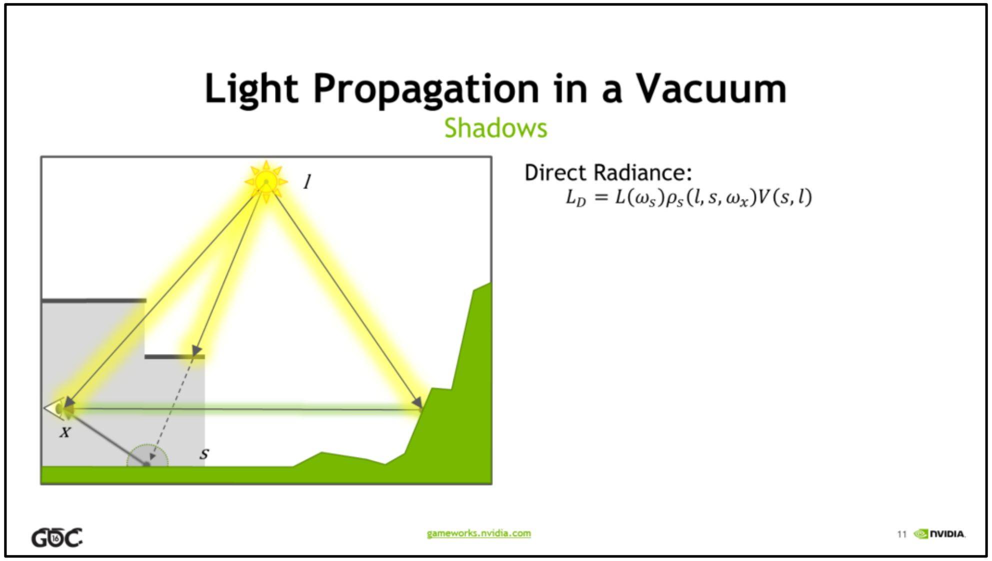
Basic scene – Light, World, and Viewer looking at lit and shadowed areas



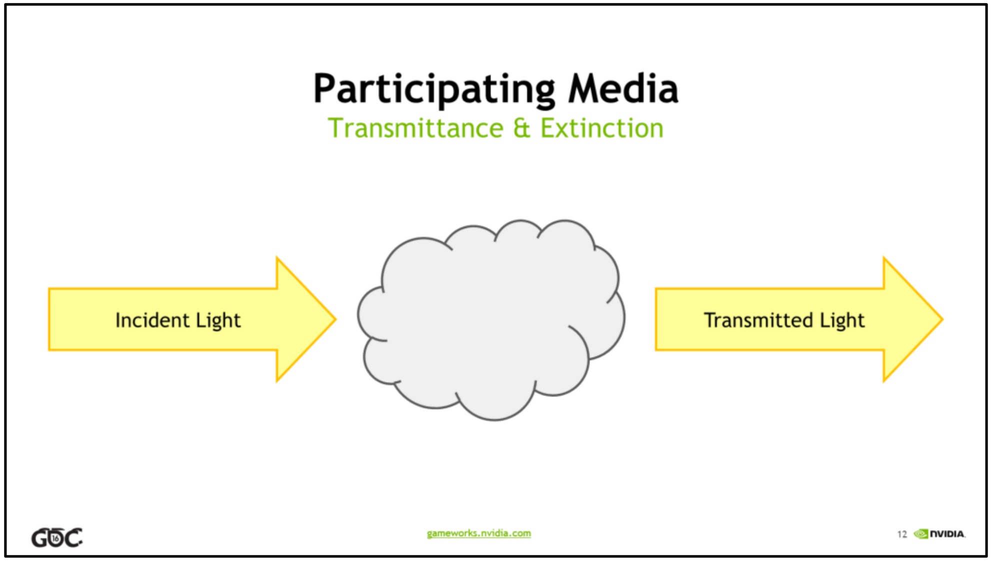
Light directly visible by the viewer



Light that is reflected by the scene towards the viewer

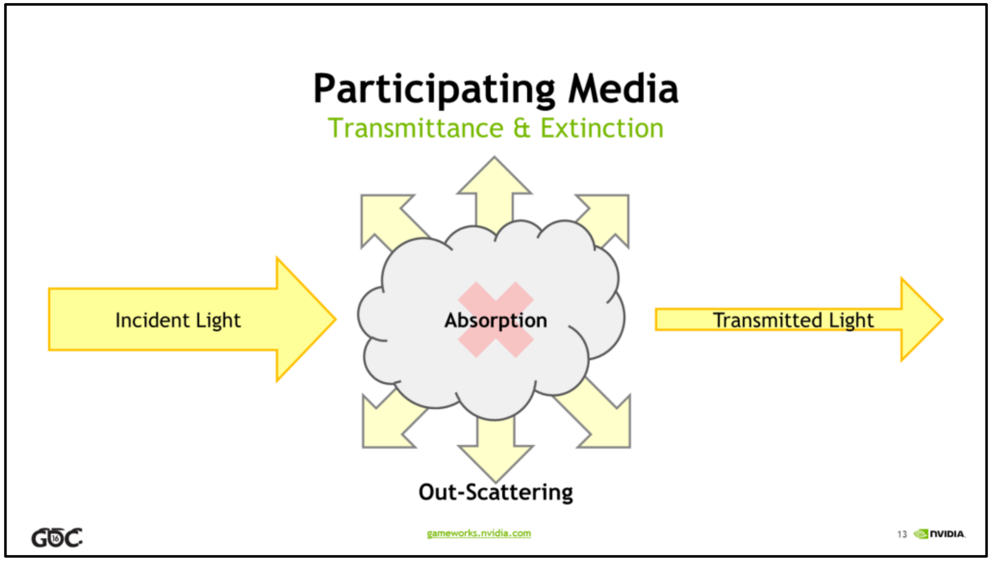


Points in the scene where the light is not directly visible



This is all in a vacuum – the air affects the light too

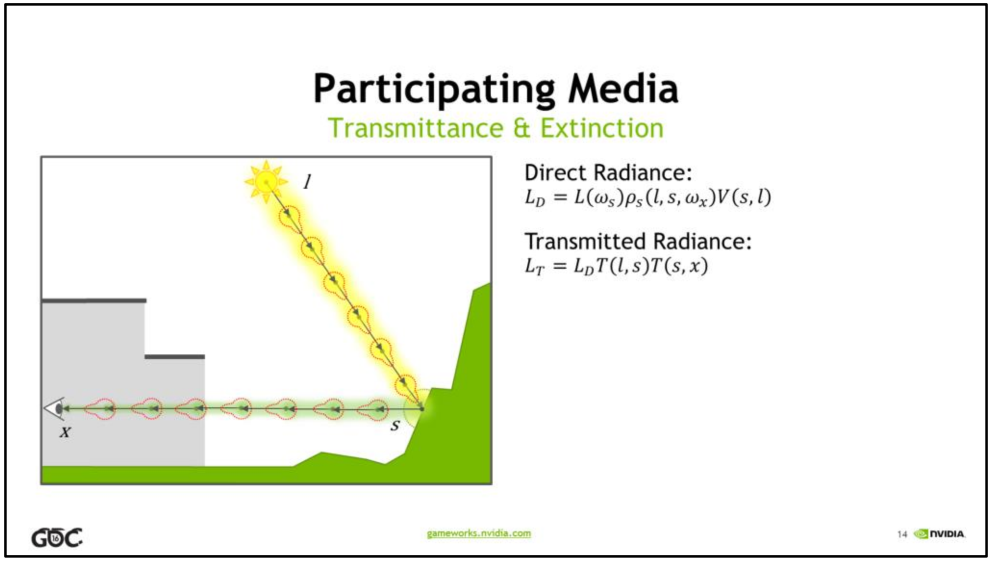
Not just theoretical: scattering is an important visual cue for distance, grounds environment, adds ‘weight’ to shadows.



Light is attenuated in two ways

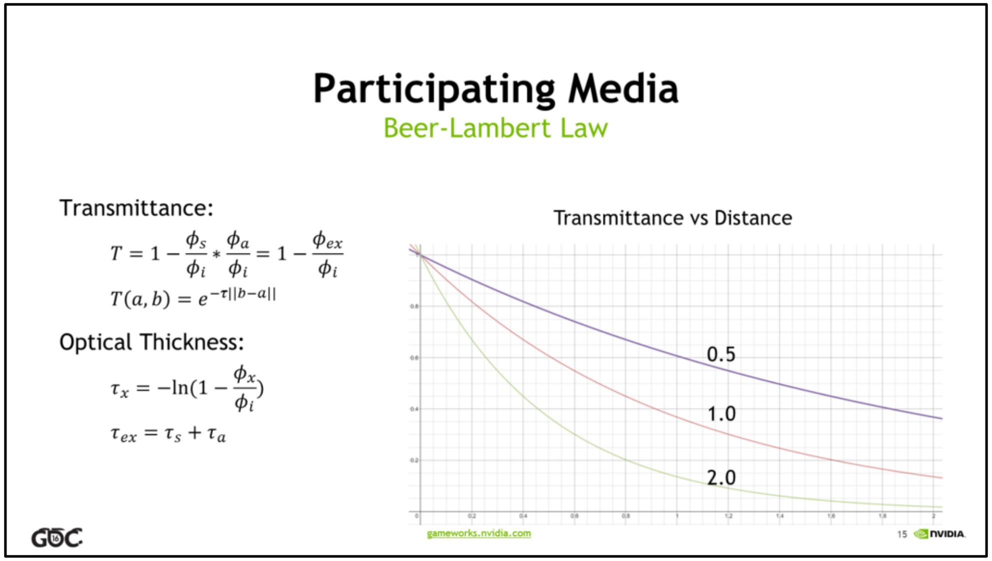
- Absorption
- Scattering

Together, the net effect is called “extinction”



We want to know how much light traveling along a path makes it to the end point (Transmittance)

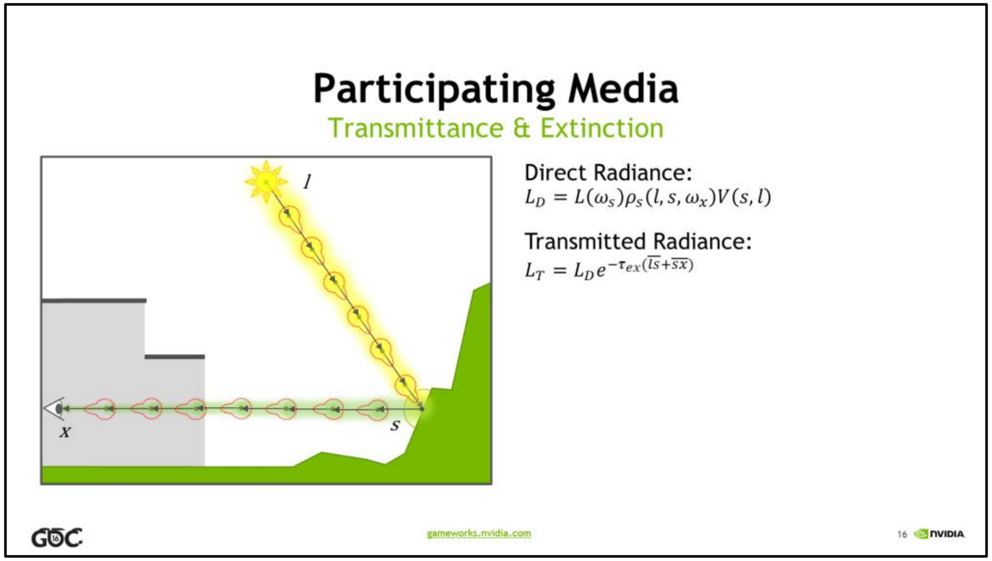
We care about the transmittance from L to S, then from S to X.



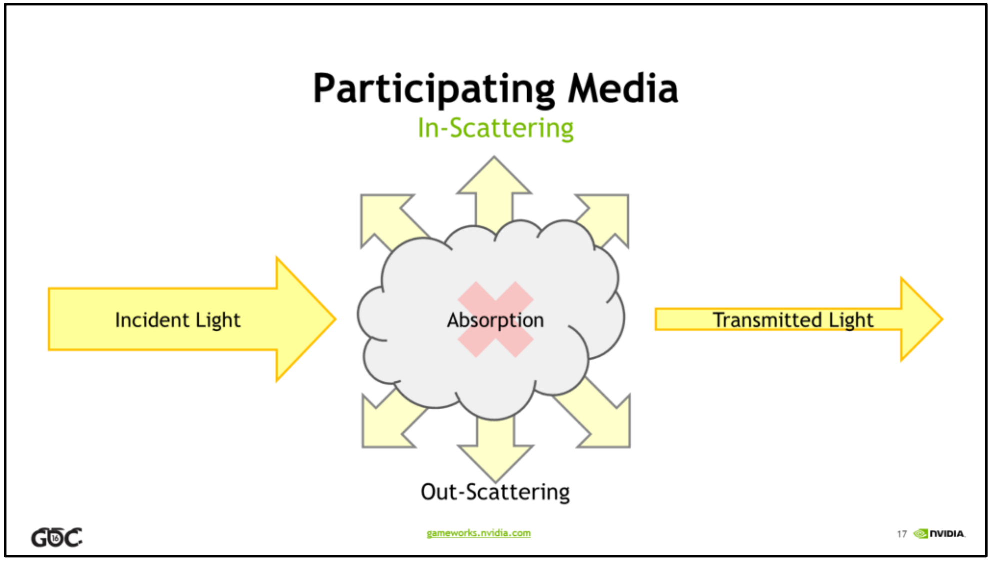
Tramsmittance: Ratio of power that passes out along a given ray to the power coming in along that ray over a given distance

Beer-Lambert Law: Solution to the differential equation gives us an exponential relative to the distance and thickness

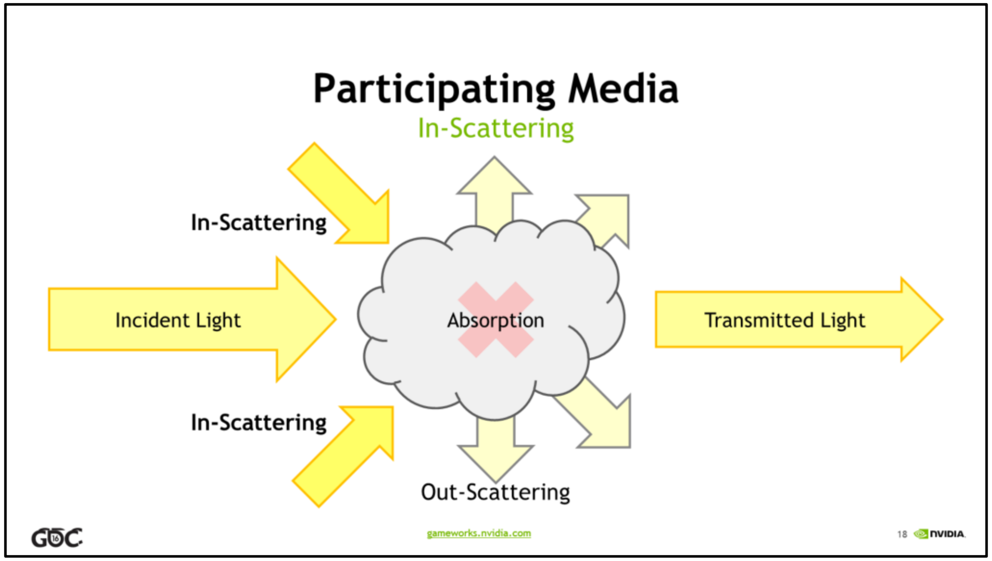
Optical Thickness: Scale factor that tells how quickly the attenuation happens.



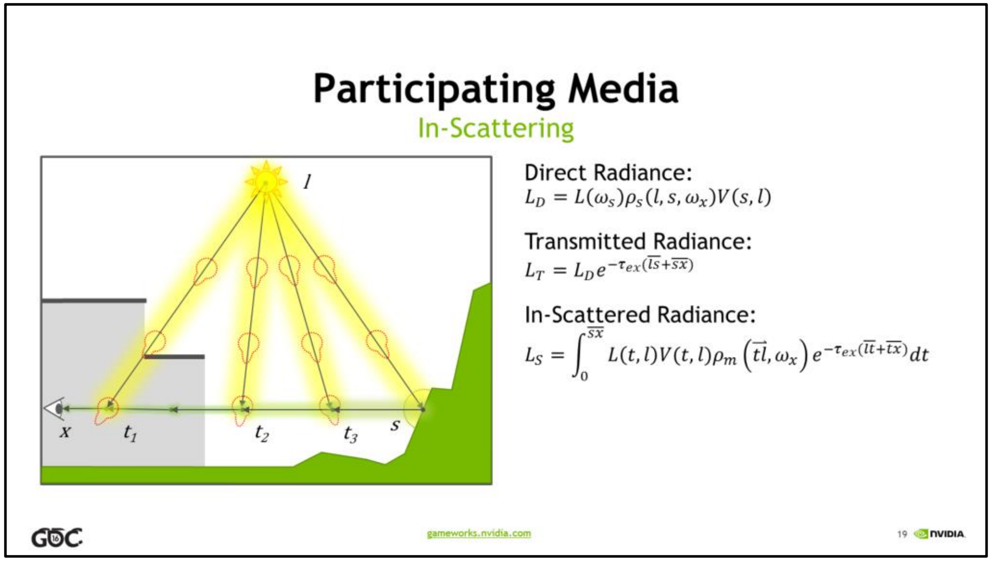
Using the Beer-Lambert law and a given optical thickness and distance, the transmittance becomes an exponential term.



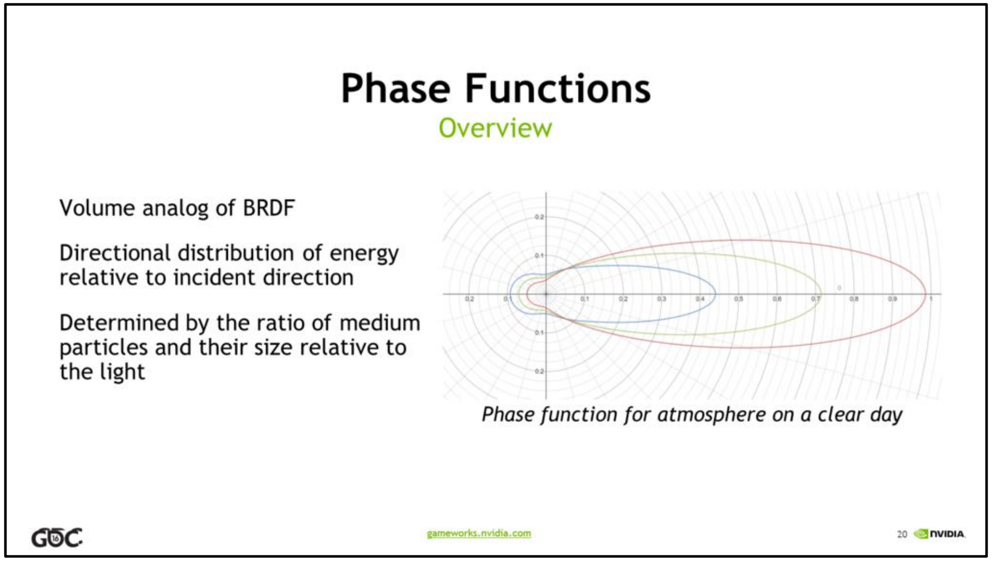
When light is scattered, it exits in a different direction from where it came in.



This means we don’t only care about light traveling along the ray from the scene to the eye, but also thre sum of all the light crossing that path and gets scattered towards the eye as well.

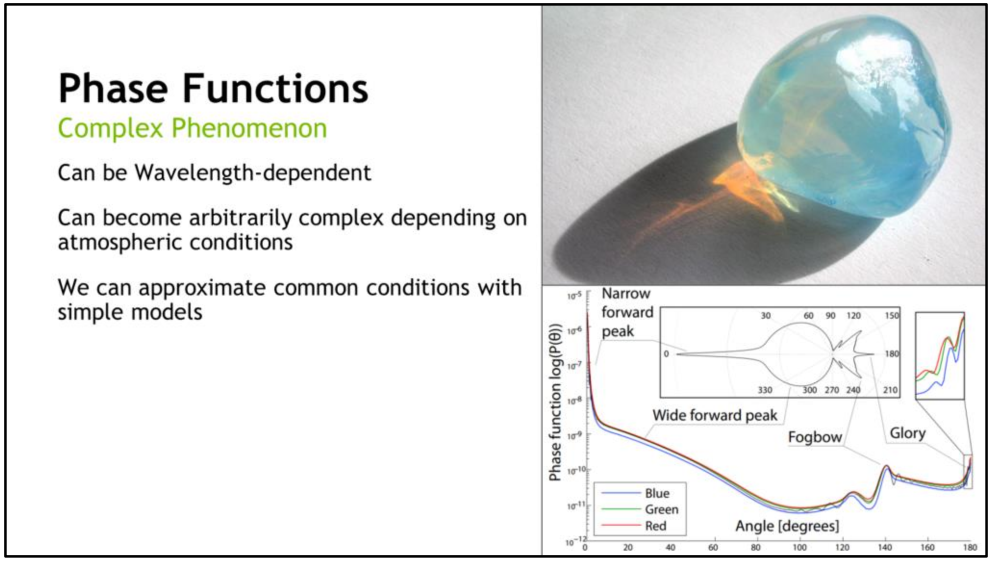


The in-scattered light is the result of an integral over the view vector that accounts for the amount of light reaching that point, the angle between the viewer and the light direction, and the scattering distribution.



The Phase Function is a distribution of how light is scattered relative to the incoming direction.

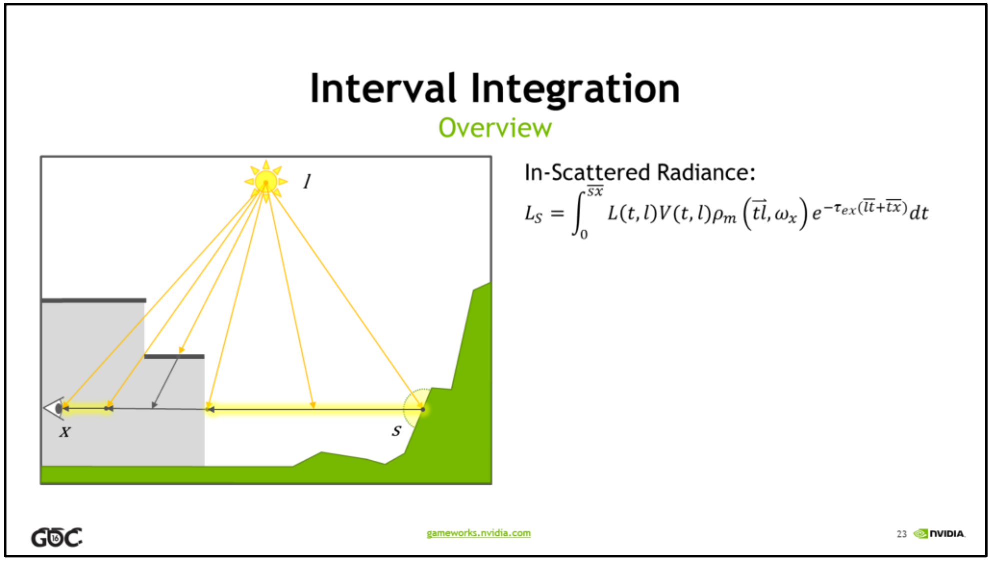
Determined by the individual particles in the medium and their proportions relative to one another and the light itself.



In the real world this can be incredibly complex due to things like irregular particle shapes (like ice crystals) or wavelength level effects.

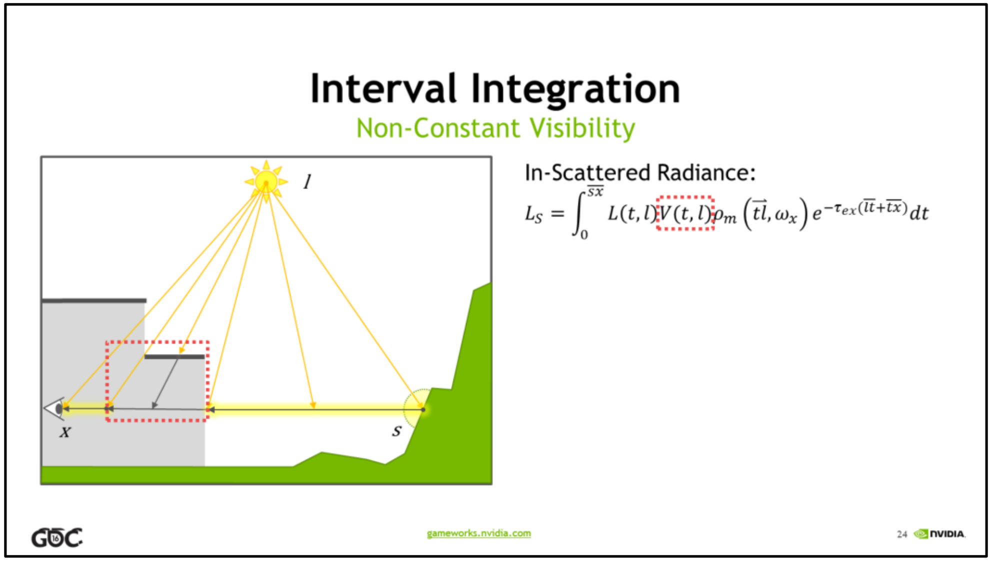
For thin atmosphere (not clouds) and small distances (scenes, not whole atmospheres) we can approximate all this with simpler functions.

Algorithm Overview



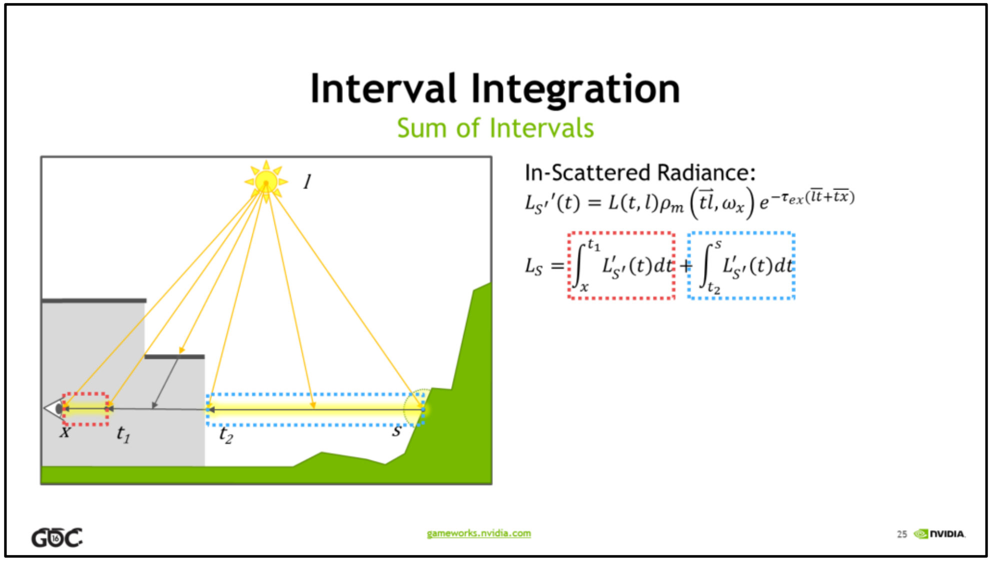
In theory we just need to solve the in-scattering integral along each view vector.

- Analytical solutions
- Ray-Marching = numerical integration

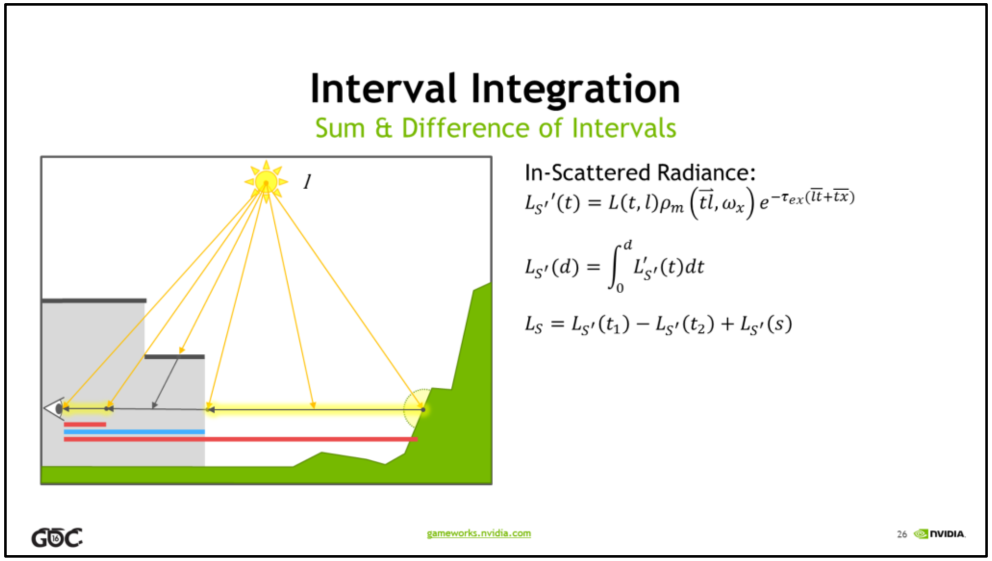


This gets complicated by the visibility term, which can be arbitrary. Some sections of the path may not be lit.

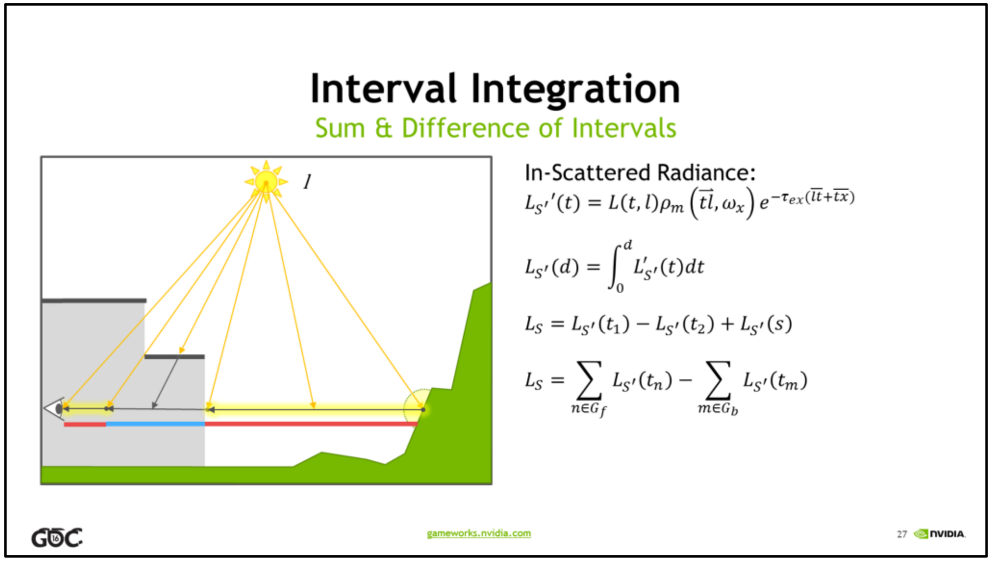
Ray marching has trouble because you need a lot of steps to capture occlusion features.



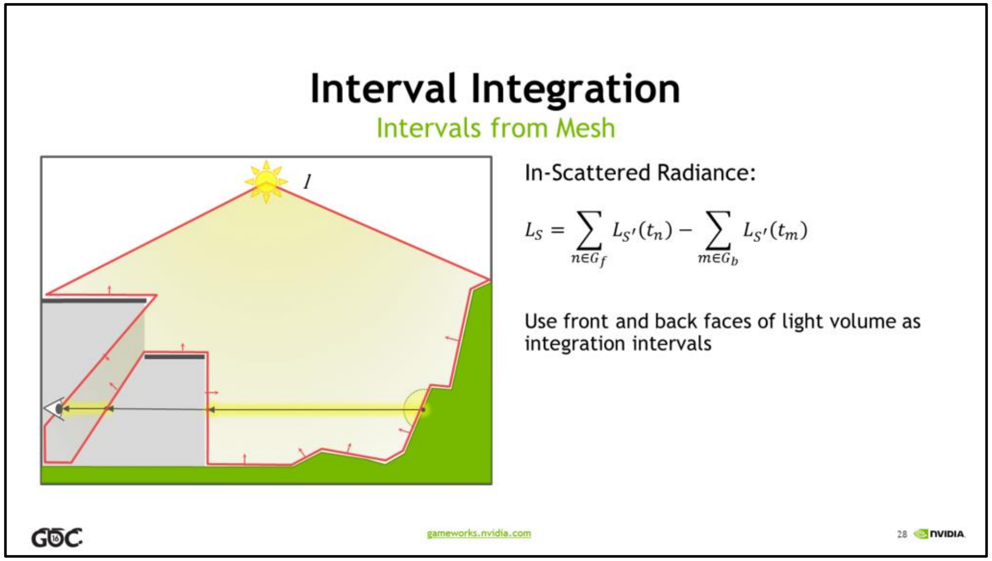
However, we observe that visibility is binary, so we can express the integral as the sum of integrals over the lit intervals and eliminate the visibility term.



We also see that the intervals can be expressed as the sum and differences a set of integrals starting at the eye.



We want some way to automatically figure out where these intervals are, rather than trying to sample the lighting function repeatedly and hoping we get it right as with ray marching.



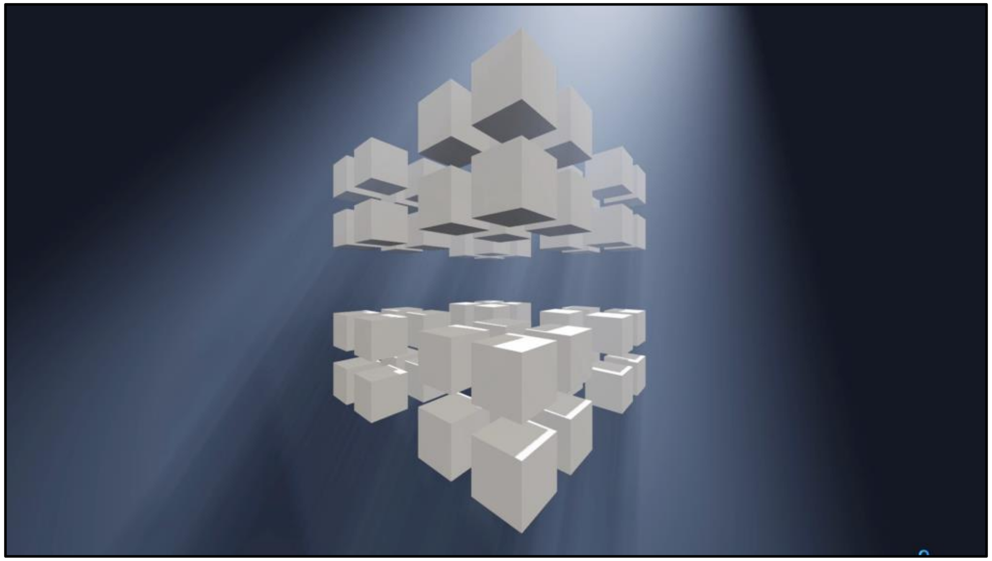
We invert the process, by using the depth data stored in a light's shadow map to create a mesh that fills the lit volume. The intervals we add correspond to front faces, and the intervals we want to subtract correspond to back faces.

Here’s a lit scene with no volumetric lighting.

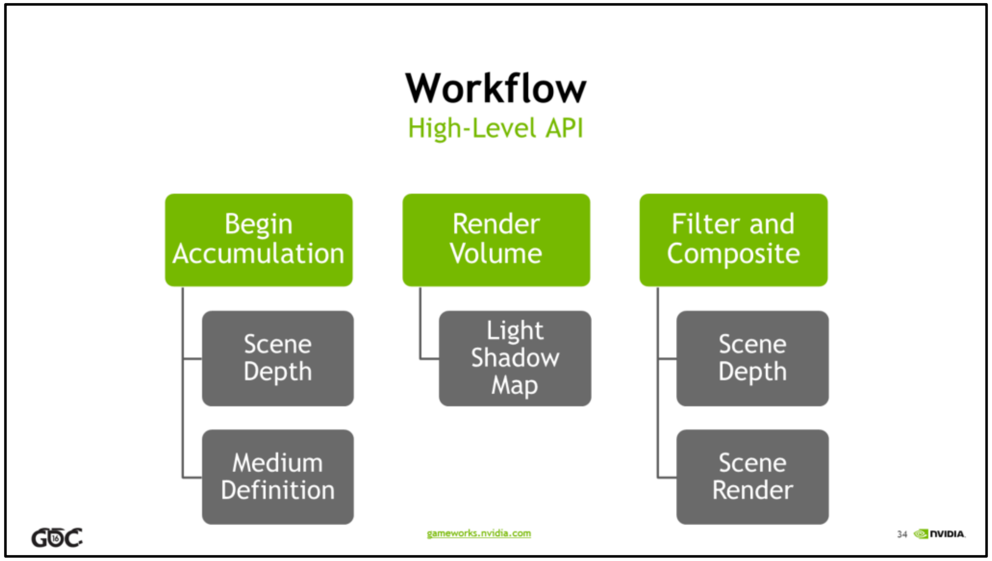
Here is the extruded volume laid over the image. We create a mesh that fills the light’s frustum in clip space, tessellating the far plane and using the shadow map to displace the tessellated vertices causing it to match the scene geometry.

Here’s the computed inscattering. In the pixel shader we compute the integral to the fragment depth, and then use blending to add or subtract the integral to an accumulation buffer.

The combined result

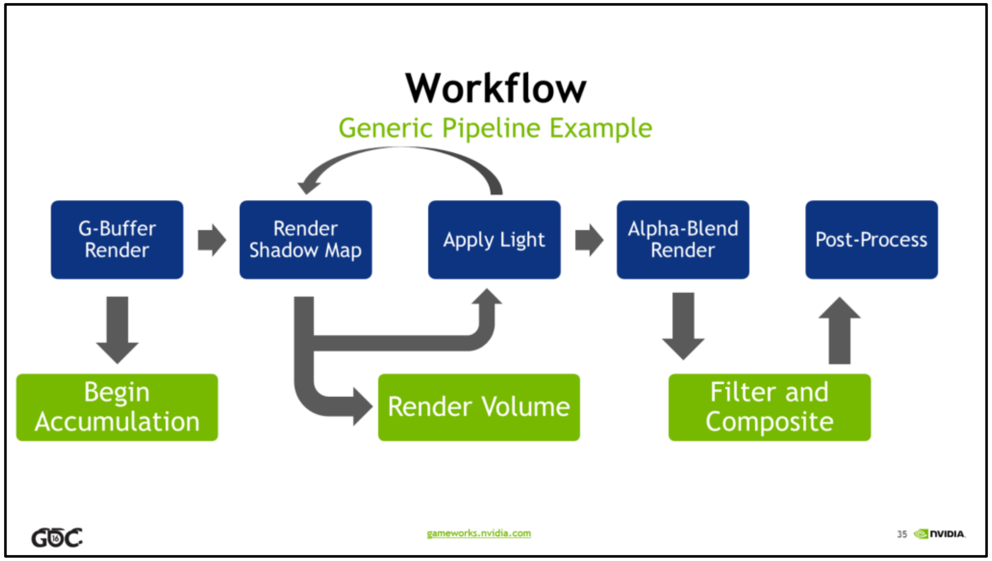


Animation showing the process in action



Three main hooks to the API.

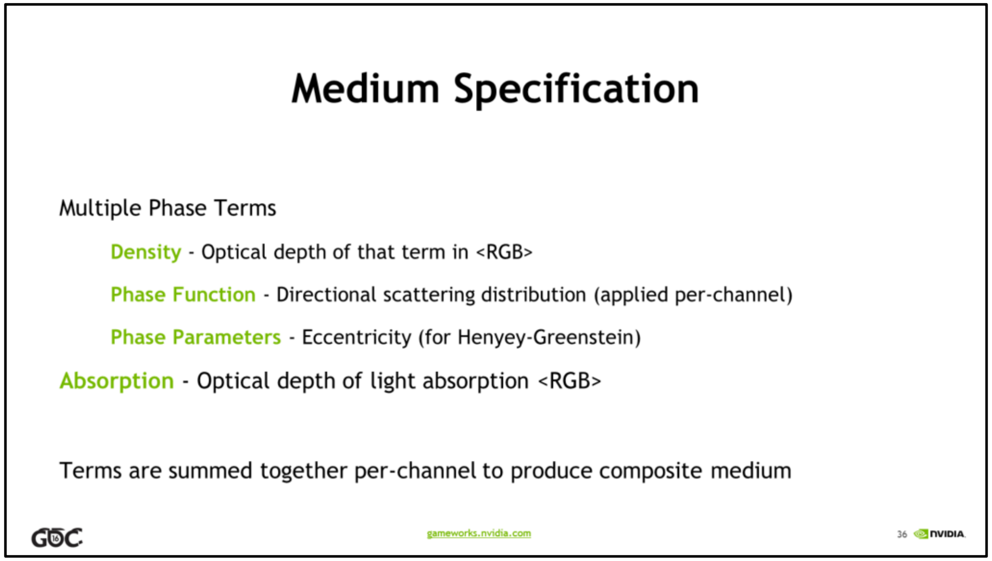
The library needs a scene depth buffer and media description, then shadow map information and light descriptions for each light we want to accumulate.



Assumes deferred renderer

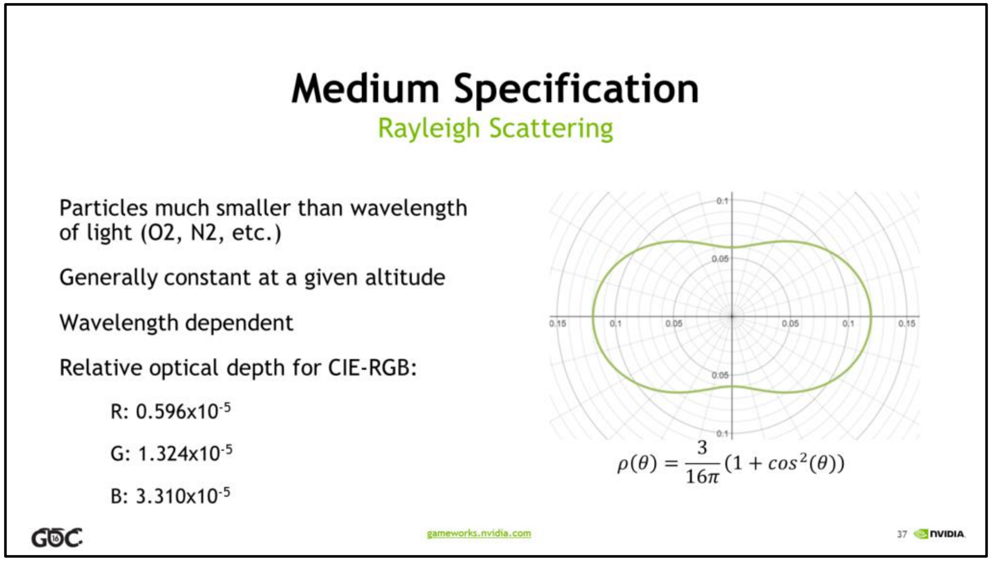
Only issue with forward renderer is that a depth pre-pass is needed

We want to accumulate after alpha-blended objects are rendered

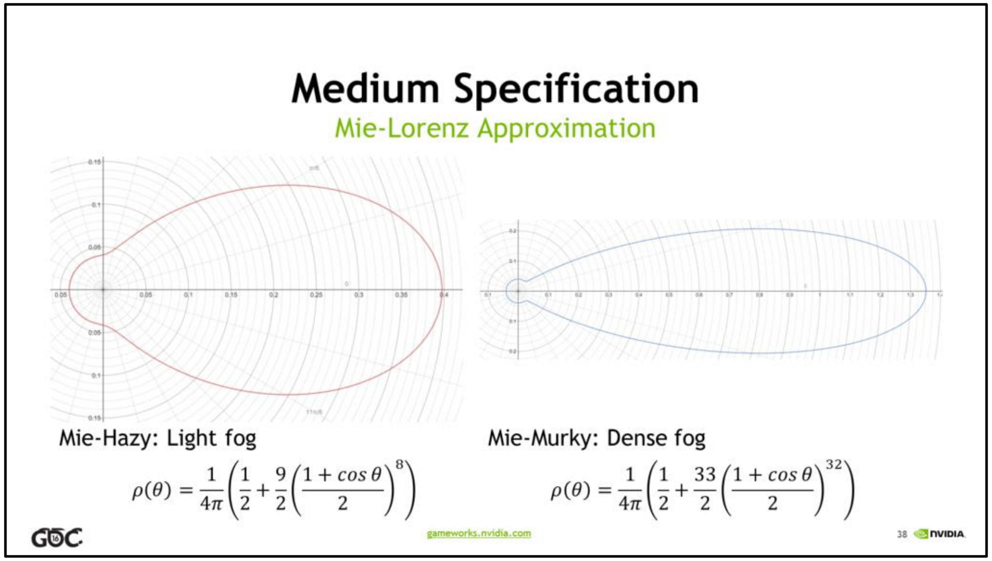


A medium is described by an absorption coefficient and a set of phase terms

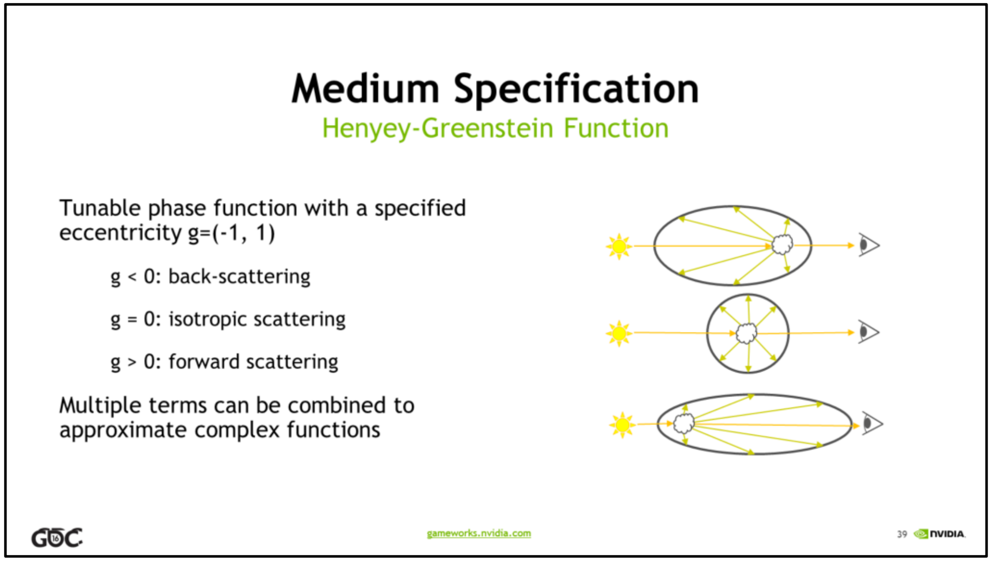
We support different phase terms to express different media, then add them together for a composite volume



Rayleigh scattering describes pure “clean” air (particles much smaller than light wavelengths)

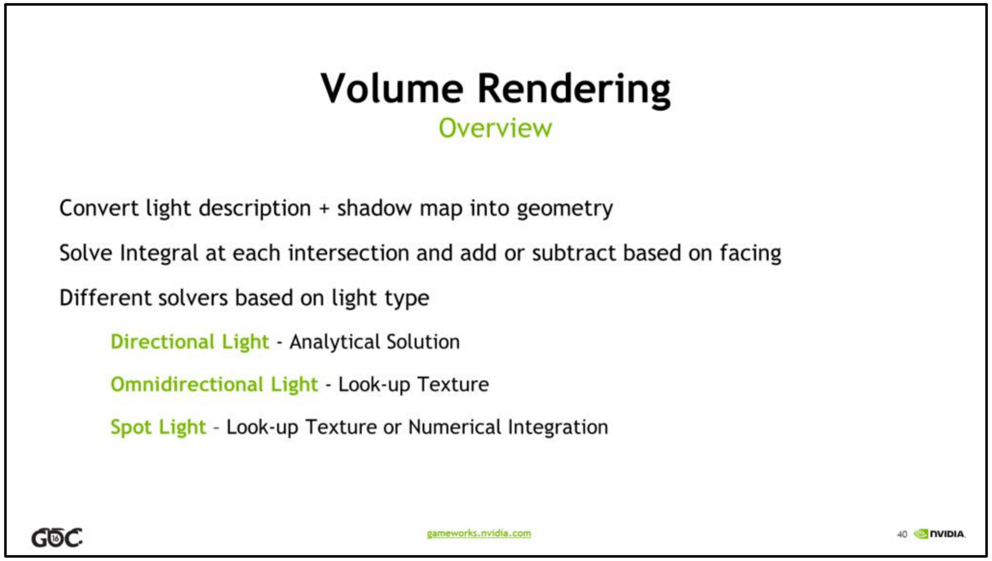


Mie scattering covers larger particles which have a large forward scattering component.

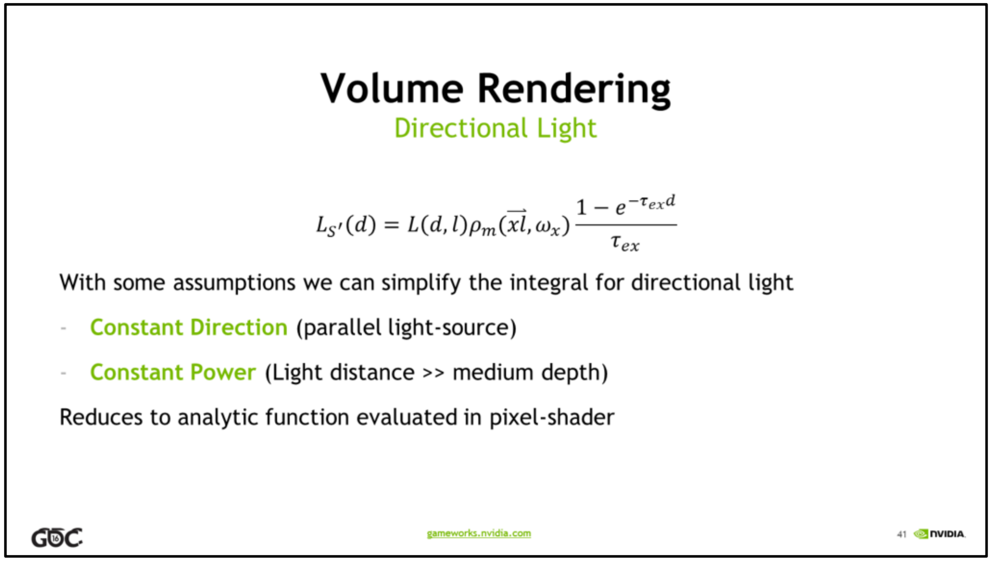


Henyey-Greenstein scattering is useful for modeling arbitrary phase functions.

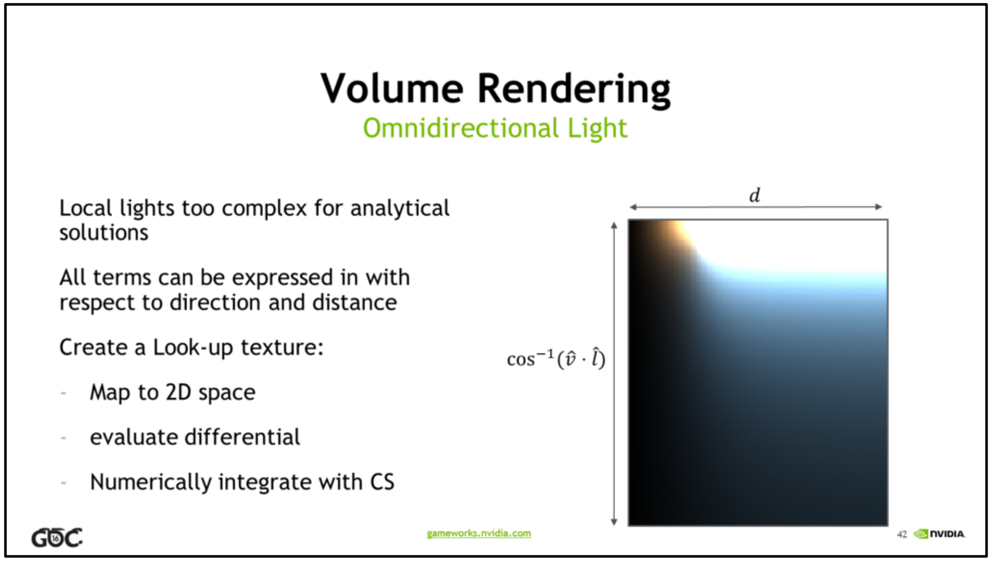
Sum multiple terms with different G values.



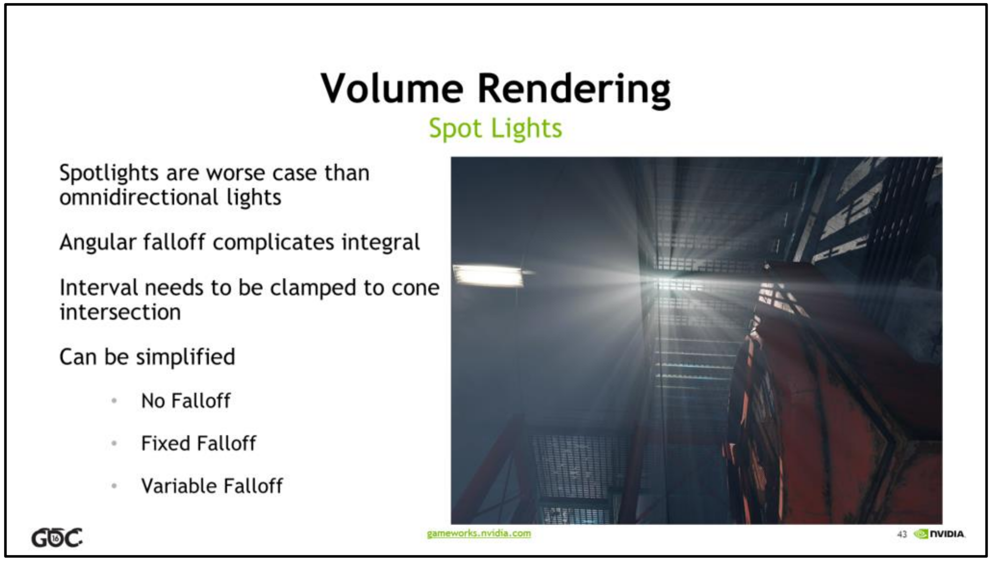
When lights are rendered we generate a mesh based on the Light/Shadow map description, then render it with a pixel shader that evaluates the integral based on the type of light.



Directional lights can be simplified to an analytic solution if we make some assumptions

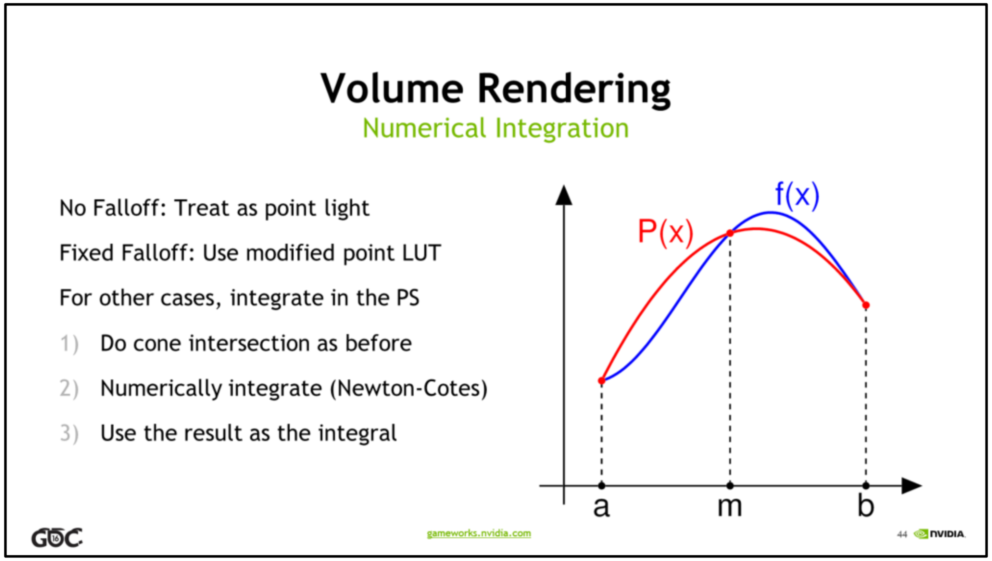


Omnidirectional lights are solved using a look-up texture we generate that contains a numerically integrated solution.



Spotlights are just omni-lights with an angle restriction, but that makes the integral much harder

Broken into subclasses and solved separately

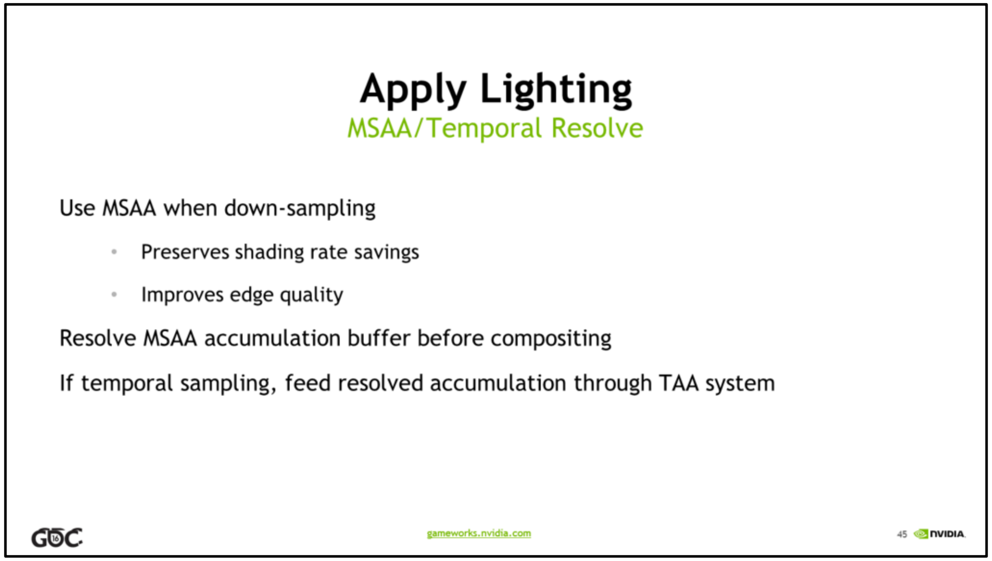


No Falloff is very fast, just use the same look-up technique as omni lights and clamp interval to cone intersection

Fixed falloff uses a special case of the integral where the spotlight power N=1 that lets us reduce the integral to the sum of three 2D lookups

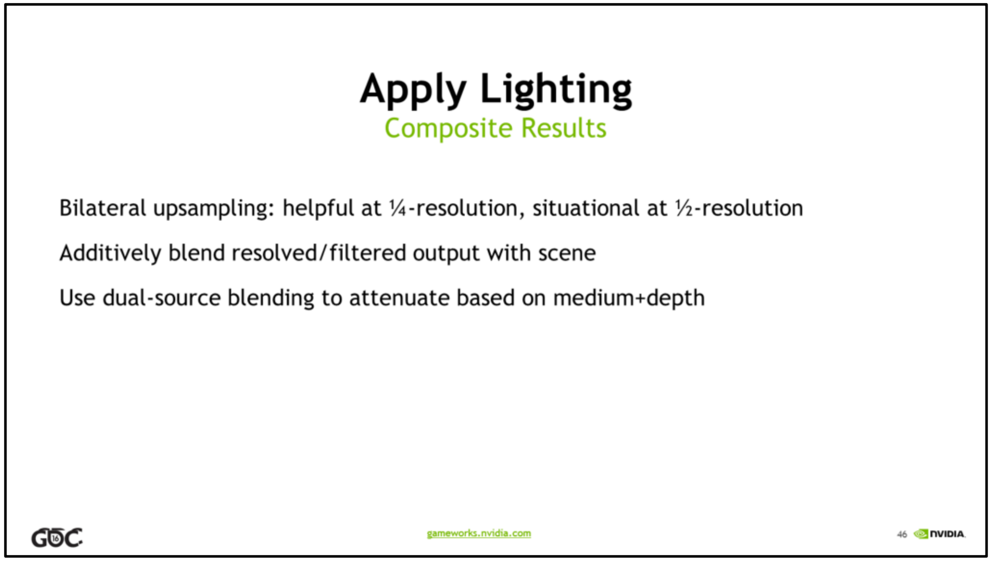
Spotlights with arbitrary falloff power can be solved using numerical integration over the interval

We use Newton-Coates, which approximates the function as the sum of polynomial intervals. More expensive, but still fairly fast.



All the results are summed into an accumulation texture.

We might use MSAA or temporal AA to improve the rendering quality, so we have to resolve the accumulation buffer before final compositing.



For the actual compositing, we simply upsample the resolved accumultated inscatter and additively blend it with the scene output.

We have bilateral filtering in place for the upsampling, but it anecdotally it seems like the slight blur of bilinear is preferable to the hard edge of a bilateral for half-resolution. At quarter-resolution the blur gets wider, so bilateral becomes preferable.

The composite pass also supports attenuating the transmitted light from the scene, but this is optional as the application may already have a fogging component baked into the framebuffer.

Integration into *Fallout 4*

Fallout 4 Integration

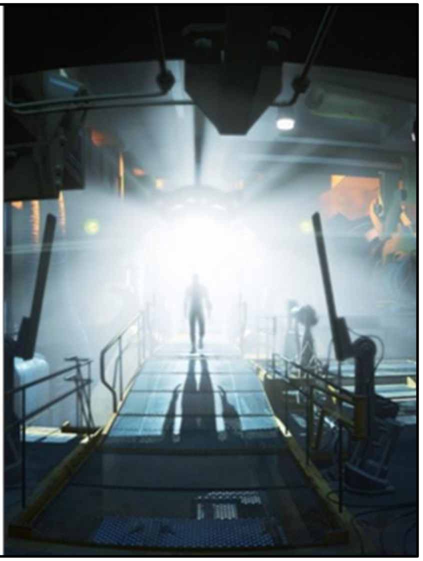
Feb: Development/Integration Begins

March: Artists authoring environments

April-June: Console Ports

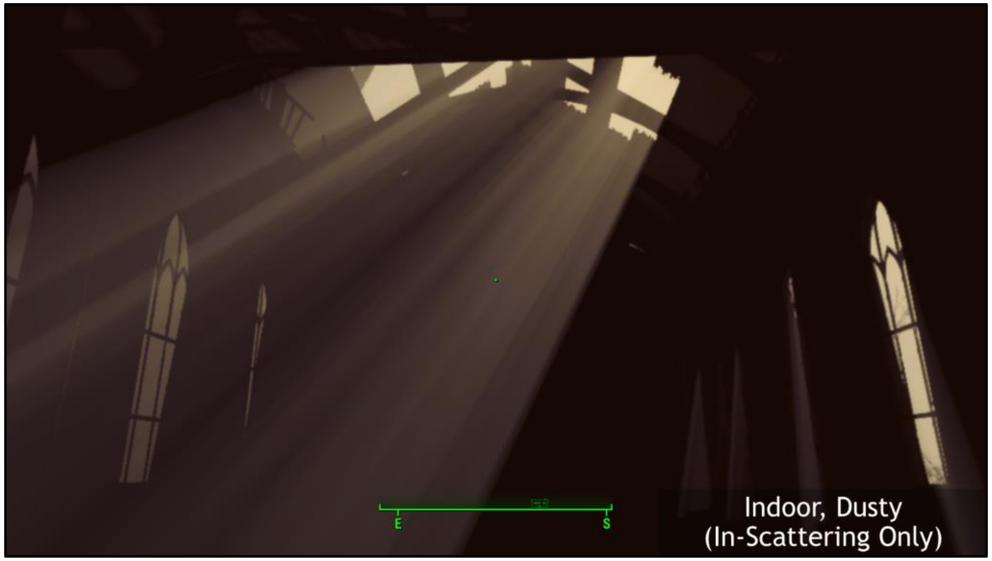
July-August: Optimization (PC+Console)

Dedicated NVIDIA QA resources



Indoor scene with dusty atmosphere, light shafts coming through a hole in the roof

This is the kind of effect that would be hand-made by artists, but is generated automatically



Inscattering-only view

Note we capture the fine details around the opening in a way that would be hard for ray marchers, and the edges of the volume are crisp and clean.

Outdoors, clear sky, mid-day. No inscattering.

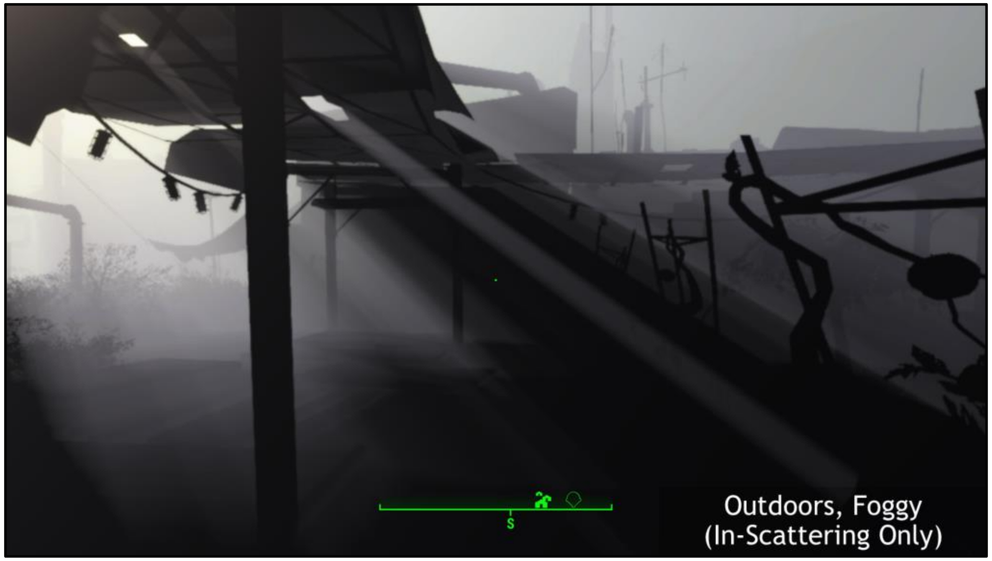
Inscattering view. Off-screen occluders cast shadows into the view.

Note the chromatic effects from rayleigh scattering tinting the aerial perspective

Combined result.

See how the structure shadows reduce the atmospheric perspective, giving them a sense of “mass”

Same location, different view. Morning, misty environment. No Inscattering.



Inscatter-only.

Small features are captured well by the mesh and there are crisp, sharp edges at discontinuities.

Combined results.

Outdoors, dusty street-scape. No Inscatter.

Inscatter only.

A wide phase function from the dust gives a large ‘bleed over’ around the light source. Realistic bloom!

Detailed enough to capture the thin elements of the fire escape on the far side.

Combined results.

We used this scene with various settings to generate perf numbers.

Gpu Performance

Concord, High Quality @ 1080p

	BEGIN	RENDER VOLUME	FILTER & COMPOSITE	TOTAL
GTX 980 Ti	0.037 ms	0.908 ms	0.264 ms	**1.209 ms**
GTX 970	0.049 ms	1.364 ms	0.389 ms	**1.802 ms**
Radeon Fury X	0.038 ms	2.581 ms	0.305 ms	**2.924 ms**

gameworks.nvidia.com

High Quality: Half-Resolution

Begin pass is cheap (generate media LUT and downsample depth).

Render Volume generally scales relative to the total pixel coverage of the volume rather than number of volumes. Multiple small lights on the screen shouldn’t cost much.

Gpu Performance

Concord, Medium Quality @ 1080p

	BEGIN	RENDER VOLUME	FILTER & COMPOSITE	TOTAL
GTX 980 Ti	0.035 ms	0.415 ms	0.394 ms	**0.844 ms**
GTX 970	0.049 ms	0.610 ms	0.565 ms	**1.224 ms**
Radeon Fury X	0.041 ms	1.074 ms	0.636 ms	**1.751 ms**

GDC gameworks.nvidia.com 61

Medium Quality: Quarter-resolution, 4x MSAA, Bilateral Upsampling

The reduced shading rate dramatically helps the volume render pass, but MSAA allows us to keep surprisingly good quality around light edges. Filtering&Composite gets more expensive due to the additional processing to maintain quality.

INTEGRATION TIPS

- Maximize Dynamic Range
- Make sure shadow maps are consistent
- Temporal filter low-res effects separately
- Be aware of worst-case scenes

Implementation Issues

Reduced Dynamic Range Limits Contrast

Problem: Hard to get intense effects without washing out scene

Intensity proportional to light source power

Real-world effects involve 10,000:1 contrast between source and scene!

Baked-in ambient normalizes intensity between bright and dark areas

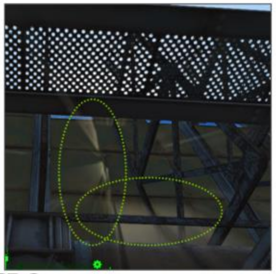
Simply increasing medium density causes wash-out

Solution: Need HDR with real adaptation between dark and bright

Implementation Issues

Shadow Map/Scene Inconsistencies

Problem: Shadow Map inconsistencies become much more noticeable



Implementation Issues

Shadow Map/Scene Inconsistencies

Problem: Shadow Map inconsistencies become much more noticeable

"Bug" in art, but not noticeable because surface and shadows not usually visible

May only render front-faces to shadow map, but there may not have consistent geometry/alpha masks on both sides

May not render "distant" occluders to the shadow map

May use a separate, high-detail map for certain occluders

Solution: be consistent with your shadow map contents!

Implementation Issues

Temporal Jittering Causes Flicker

Problem: Temporal AA jitter causes flickering

Temporal AA jitters to increase effective resolution, then filters to smooth

Library runs at ½ - ¼ resolution to improve performance

A 1 px flicker at full-res could become 4x4 px in the down-sampled buffer!

Full-res temporal filter not designed to smooth artifacts that large

Solution: Added separate TAA resolve to down-sampled buffers

Implementation Issues

Perf Drop with High Frequency Occluders

Problem: Poor perf in specific views

Cost proportional to total pixel coverage

Dense occluders are no problem but create overhead at low angles

Ex: Sunset through the woods

Solution: Adjust tessellation factor based on view angle

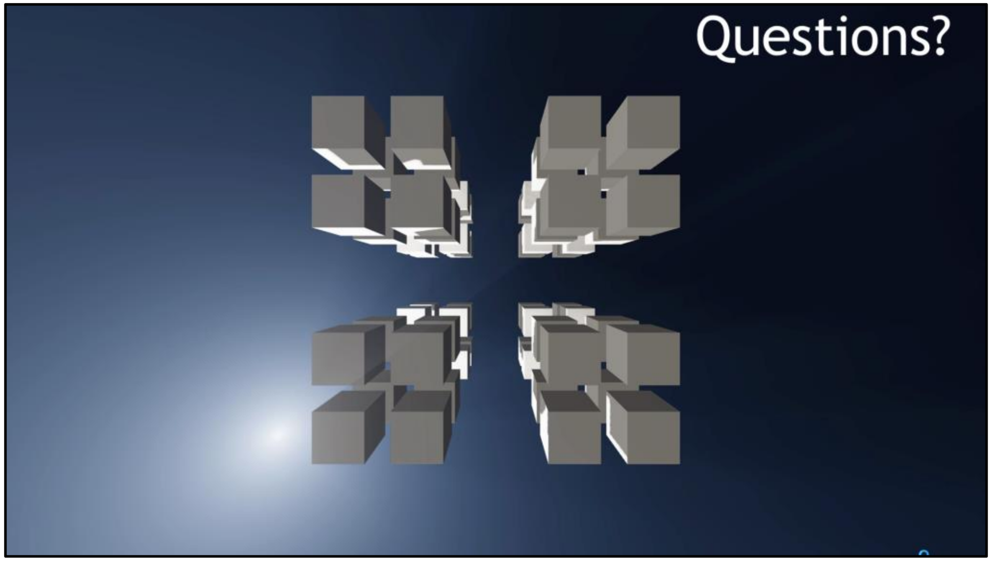
Solution: Pre-filter shadow map

SUMMARY

Gameworks Volumetric Lighting is…

- Fast enough for entire spec range
- Flexible enough for almost any engine
- Compatible with physically-based engines
- Currently available in DirectX 11 (with ports being added according to demand)

http://developer.nvidia.com



Look-up is small, but flexible

Function is smooth, so it approximates well

RELATED READING

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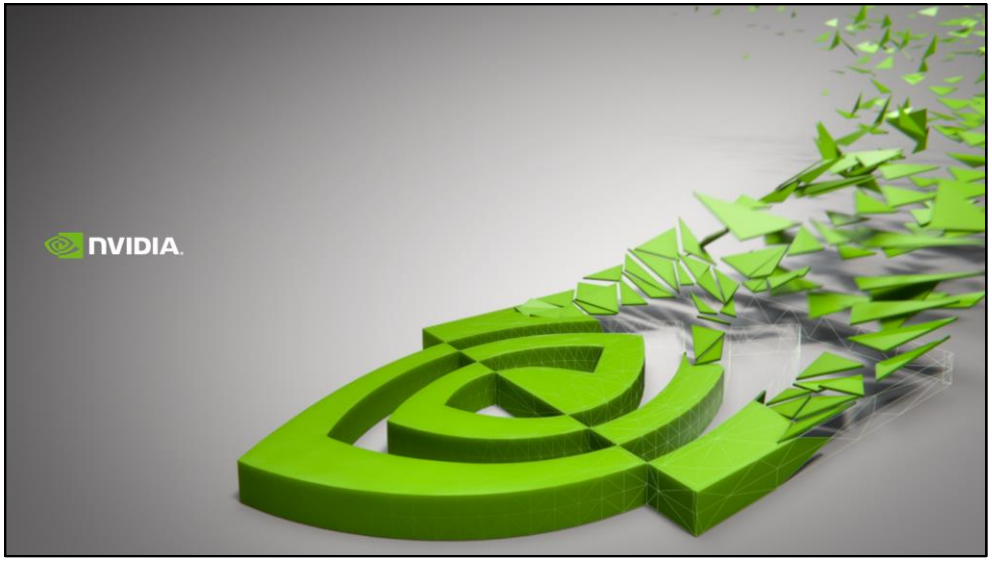
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