Game Technology

Lecture 7 – 28.11.2015
Physically Based Rendering

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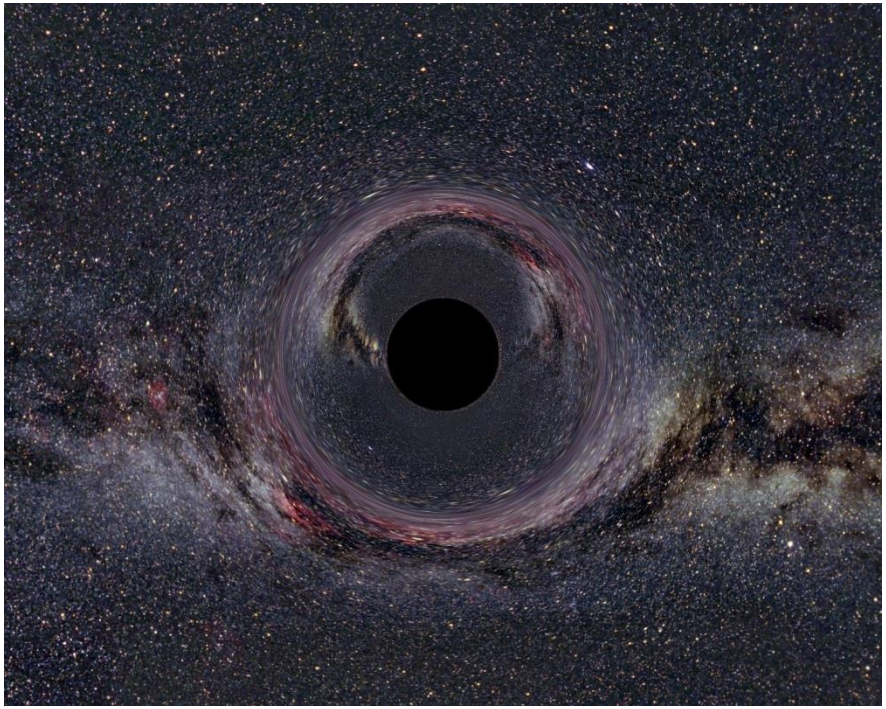

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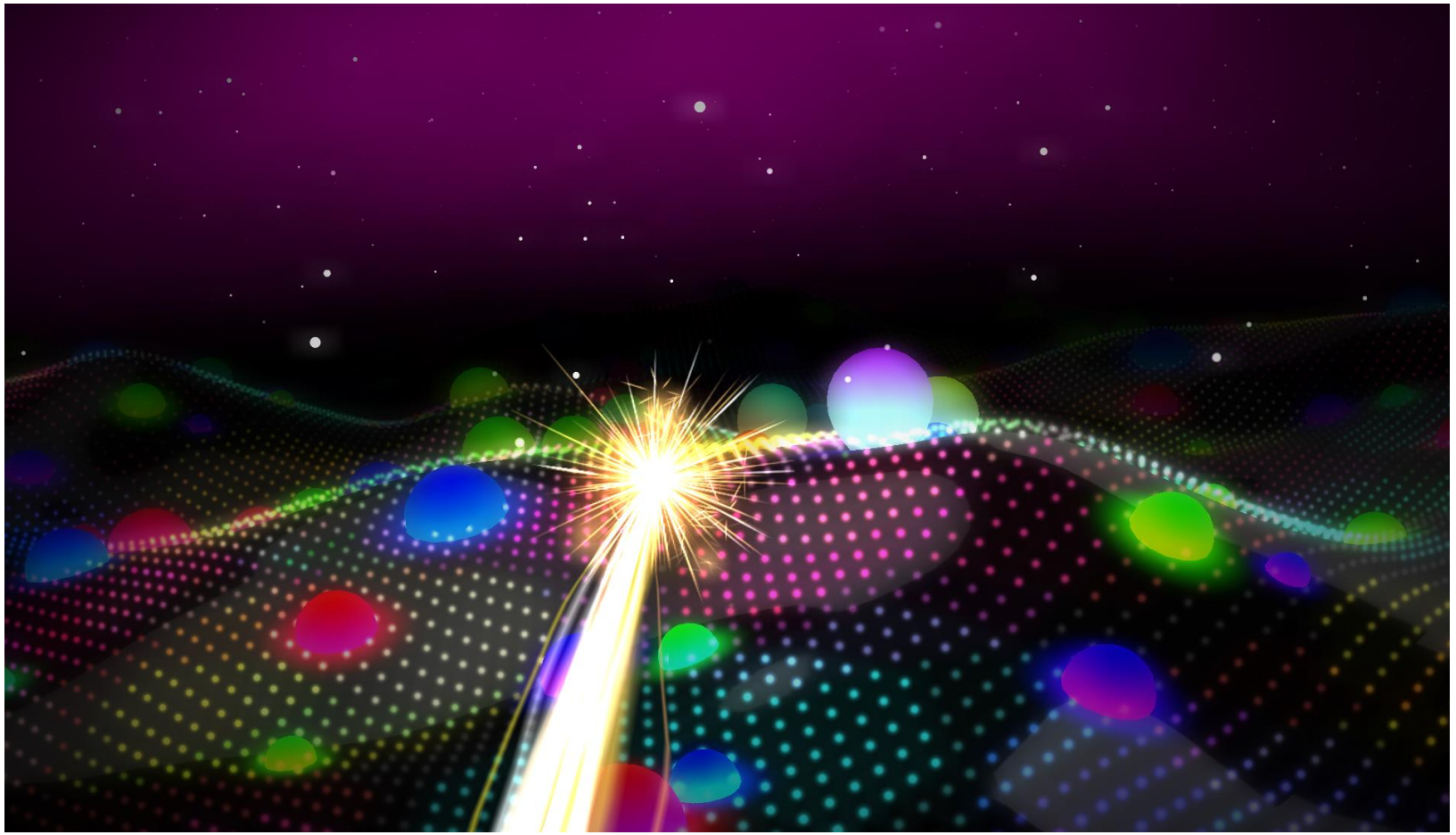
KOM - Multimedia Communications Lab

Light

Light

- Starts from light source
- Bounces around
  - Looses intensity with each collision
- Eventually reaches the camera

Light Sources



http://lights.helloenjoy.com

Point Lights

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Defined by a position and light color/intensity

Directional Light

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Just a direction and light intensity/color

Area Lights

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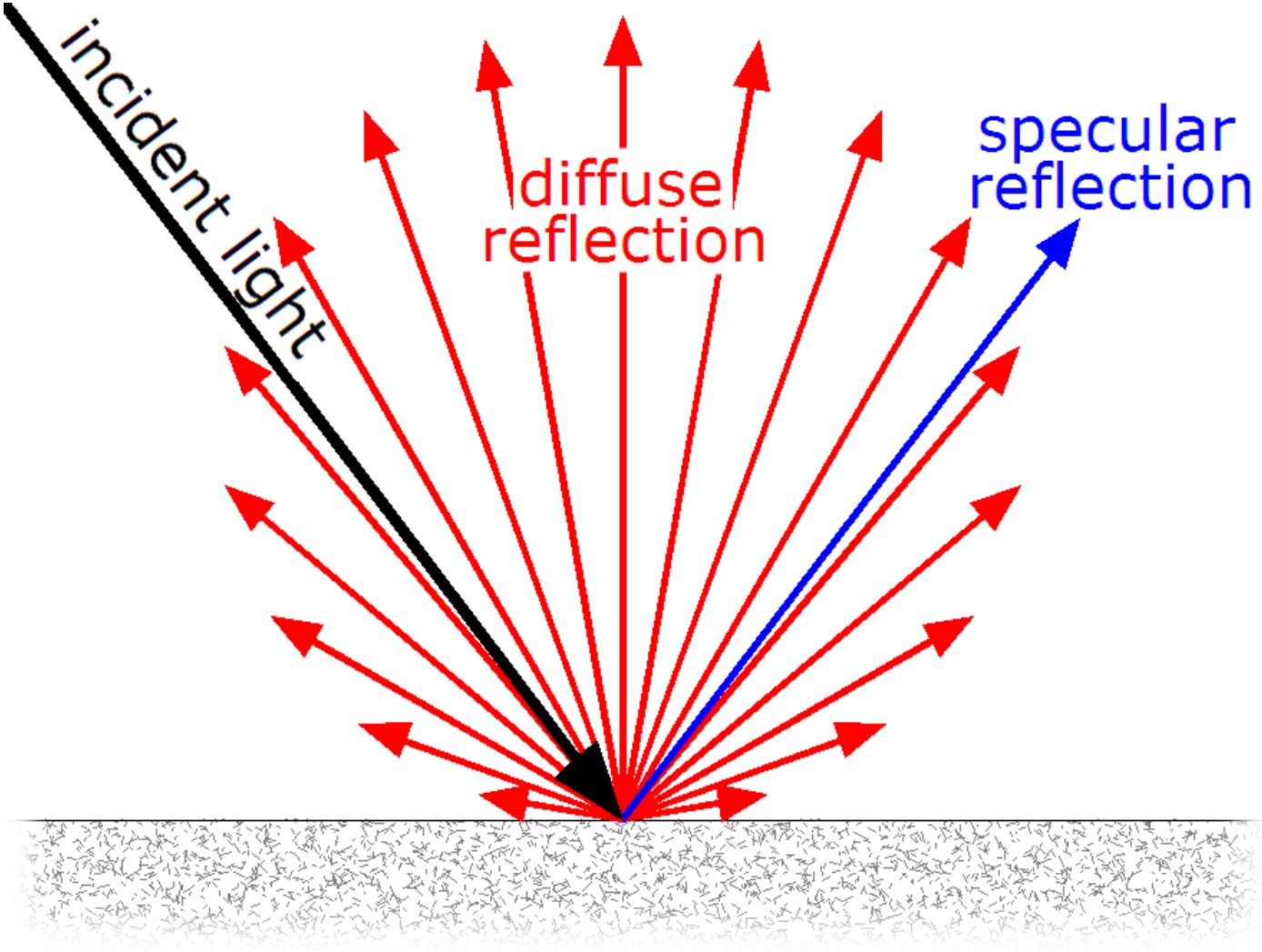
More light sources possible

Not supported by most game engines

Bounces



BRDF

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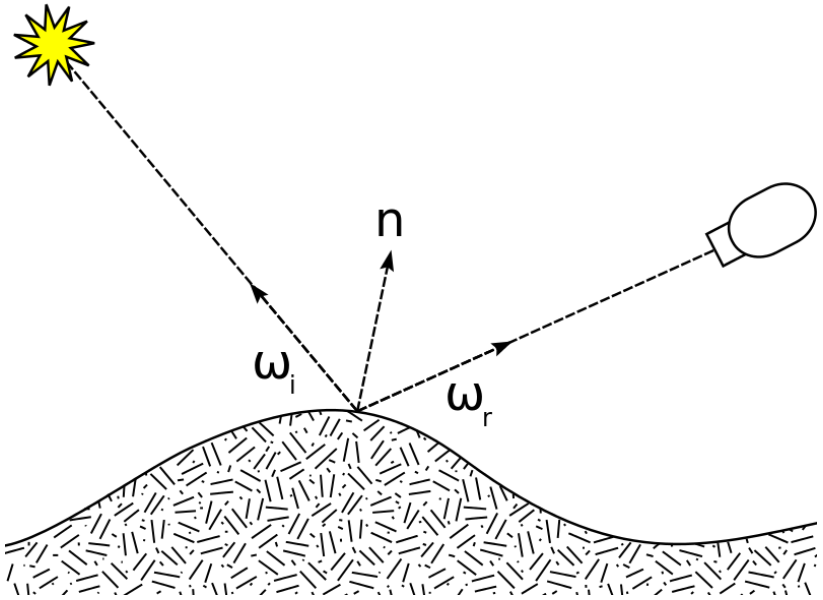
Bidirectional reflectance distribution function

- incoming light direction
- outgoing direction (for example to the camera)
- returns the ratio of reflected radiance

$$f_r(\omega_i, \omega_r)$$



Path Tracing

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foreach (pixel)

- bounce around a lot

Use BRDF at each collision

Very slow

- but useful to create reference images
- and for prerendered lighting informations

Realtime Lighting

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Consider only light rays from direct light sources

- First bounce

Use shadow maps

- Second bounce

Ignore further light bouncing

- No reflections
- No ambient light

Image-Based Lighting

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Put surroundings in cube map

- Use for example path tracing to generate the cube map

Ignore lights, instead sample cube map

A cube map is only correct for one position

Ignores dynamic objects

HDR

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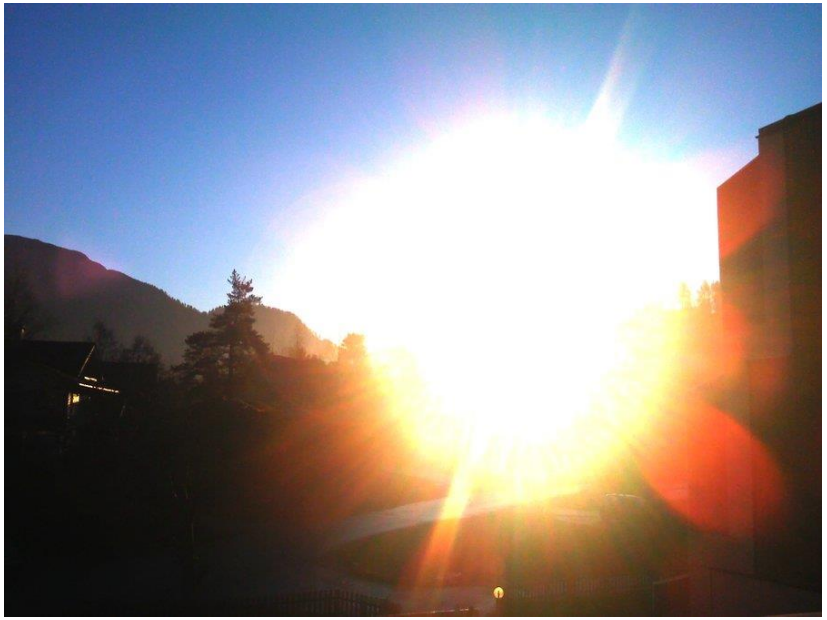
„High dynamic range“

Use more than 32 bits of data for one pixel



BRDF

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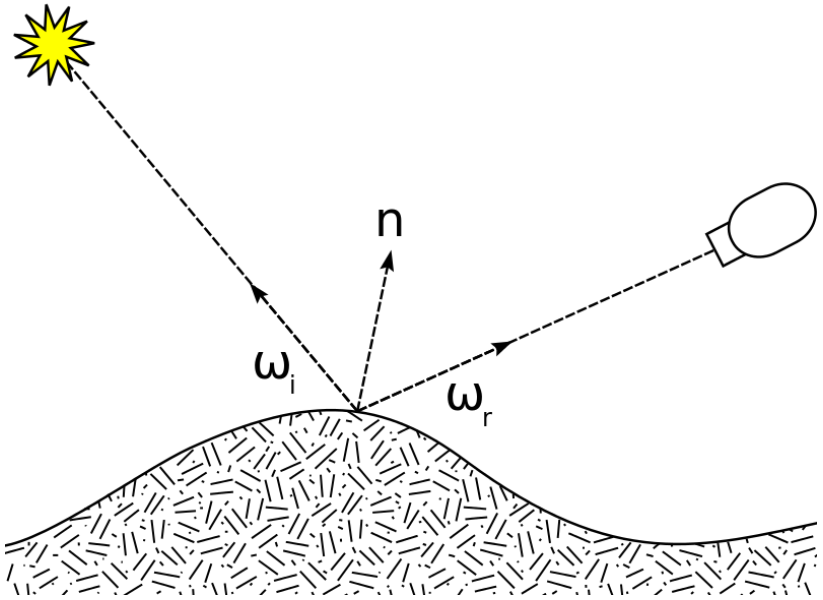

BRDF Shortcomings

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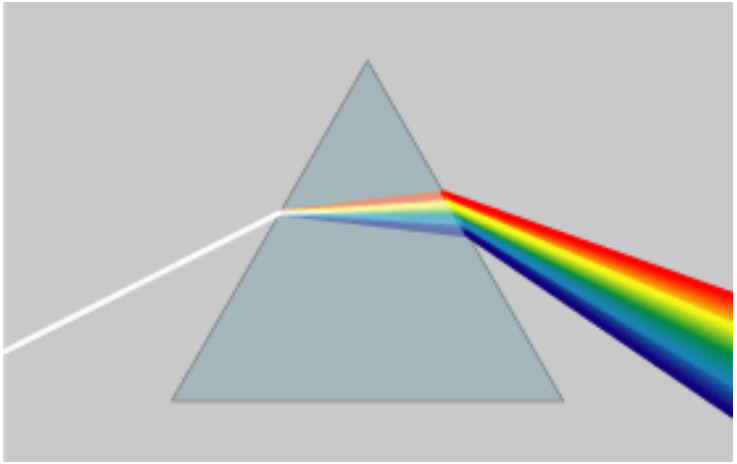
Subsurface-Scattering

Wavelength dependence



BRDF

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Only positive light

$$f_r(\omega_i, \omega_r) \geq 0$$

BRDF

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Inverted

$$f_r(\omega_i, \omega_r) = f_r(\omega_r, \omega_i)$$

BRDF

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Energy conserving

$$\forall \boldsymbol{\omega_i}, \int_{\Omega} \boldsymbol{f_r(\omega_i, \omega_r) cos(\theta_r) d\omega_r} \leq \mathbf{1}$$

Phong Lighting

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color = ambient + diffuse + specular

Phong Lighting

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color = ~~ambient~~ + diffuse + specular

Gamma

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sRGB

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See Exercise 1

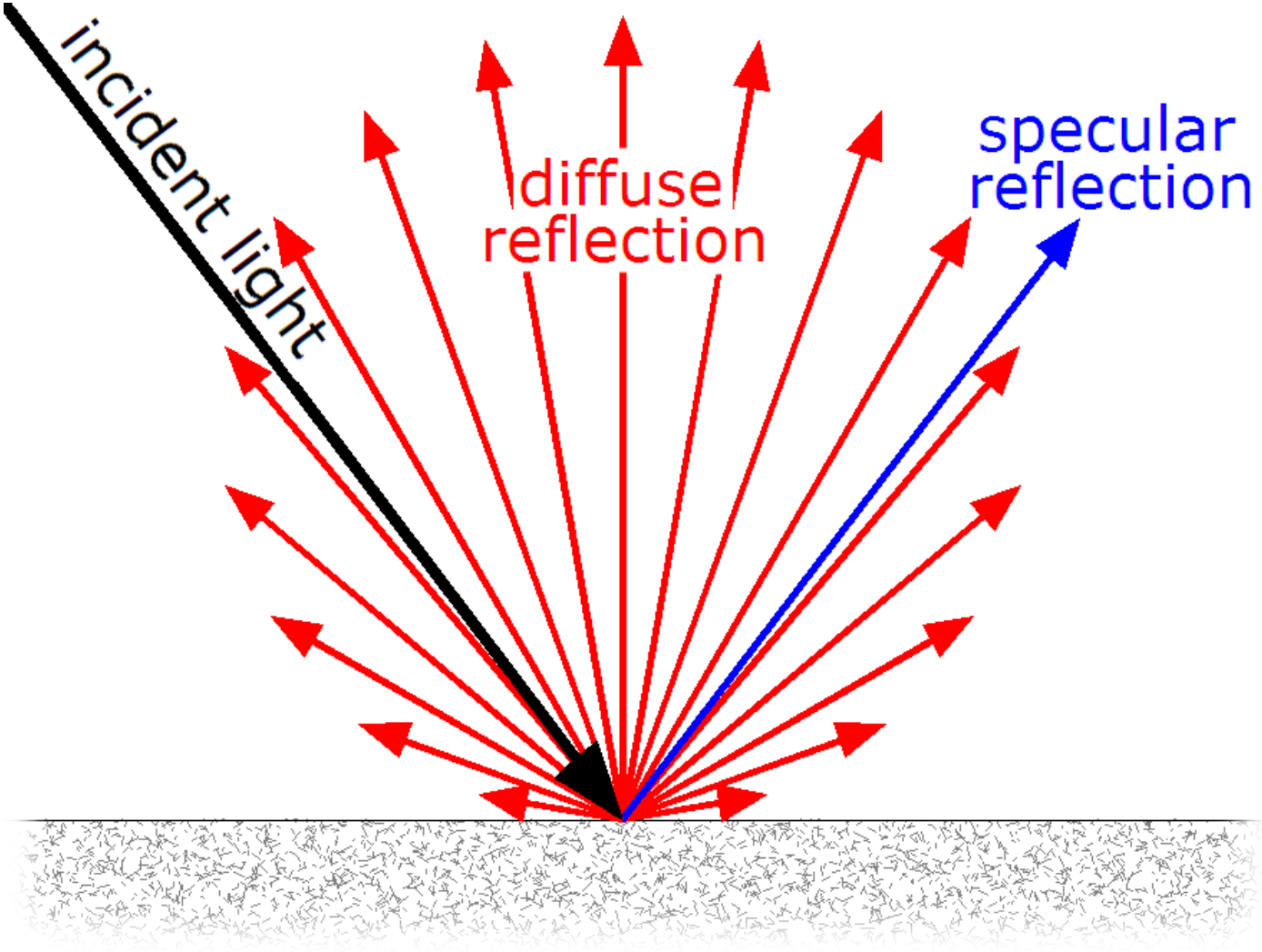
Transform textures to linear (pow 2.2)

- Or use sRGB texture reading (also allows proper filtering)

Lighting calculations in linear space (gamma 1)

Then transform for sRGB (pow 1 / 2.2)

Diffuse & Specular



Diffuse

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Lambertian reflectance / Phong diffuse

I = L*N

Good enough for modern engines

- Used for example in Unreal Engine 4

Specular

Brick

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angle(normal, light) = angle(normal, camera)

Brick

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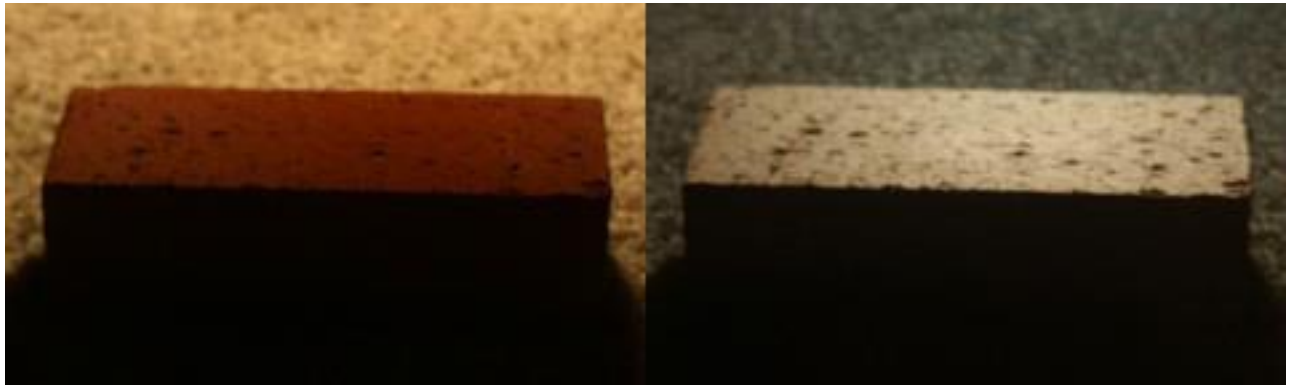
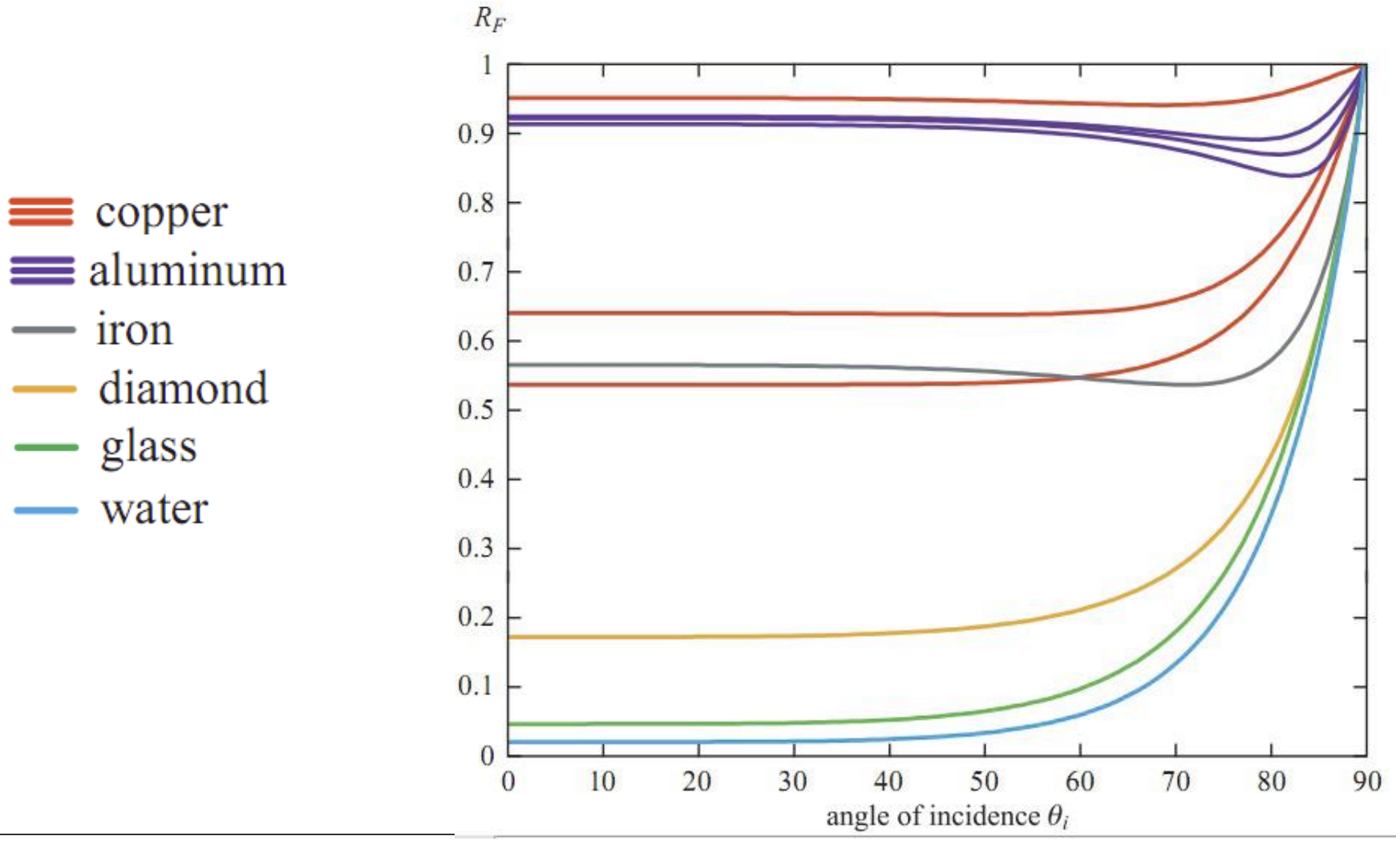
angle(normal, light) = angle(normal, camera)



Fresnel


copper
aluminum
iron
diamond
glass
water
R_F
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
angle of incidence θ_i

Fresnel

Schlick Approximation

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Schlick(spec, light, normal) = spec + (1 - spec) (1 - (light*normal))^5

Microfacet Model

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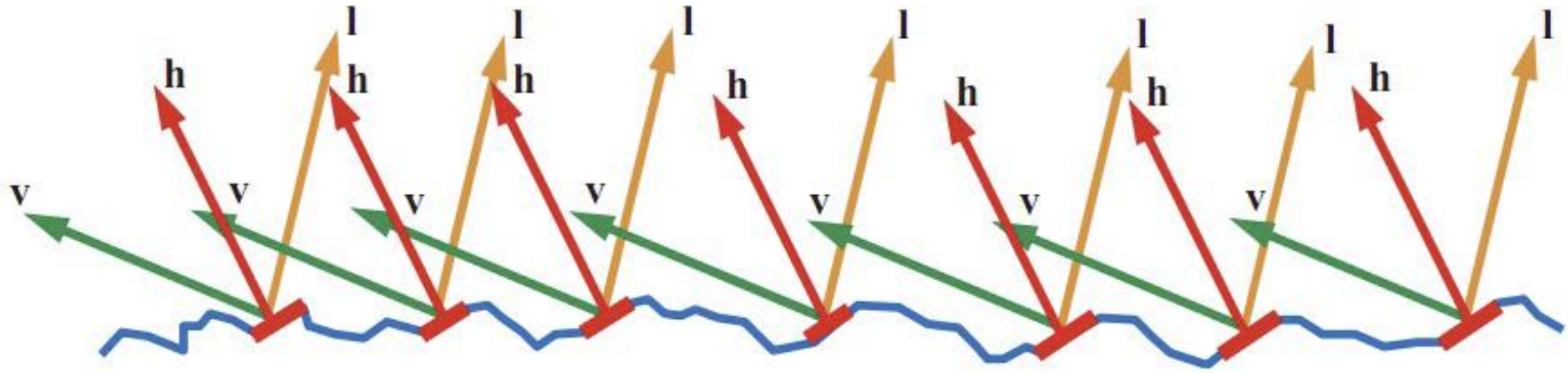

Microfacet BRDF

$$f(l,v) = \frac{F(l,h)G(l,v,h)D(h)}{4(n \cdot l)(n \cdot v)}$$

Normal Distribution

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D(h)

Portion of microfacets pointing to h

$$D_{tr}(m) = \frac{\alpha_{tr}^2}{\pi\left((n \cdot m)^2(\alpha_{tr}^2 - 1) + 1\right)^2}$$

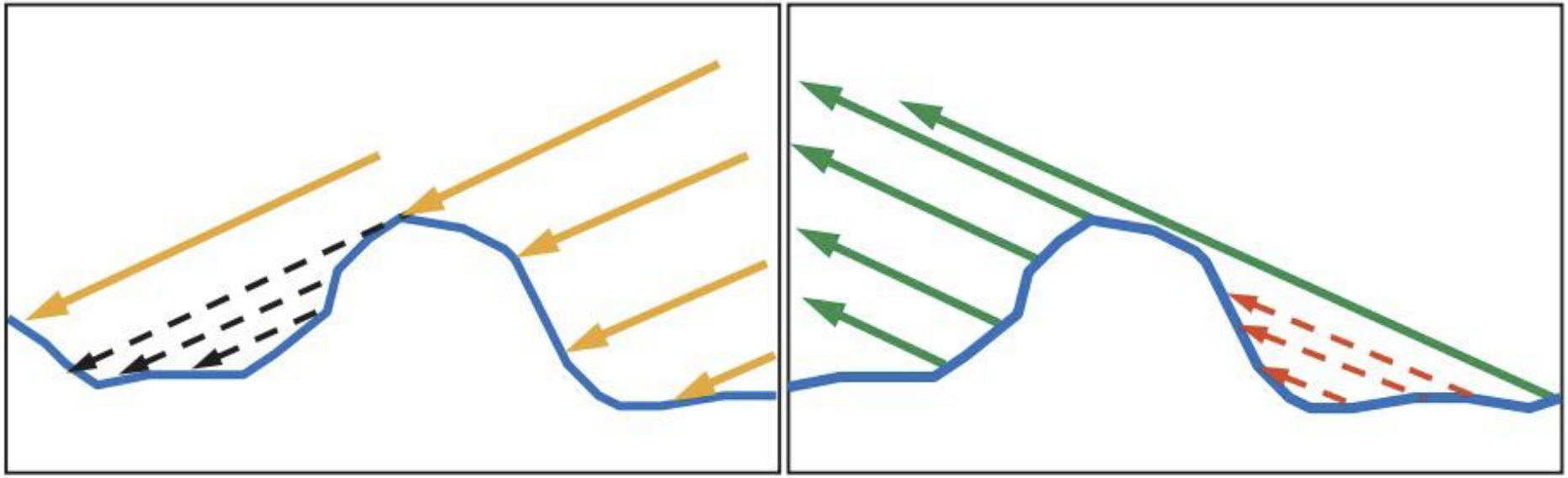
Trowbridge-Reitz (GGX)

α: Roughness

Geometry Factor

- **G(l, v, h)**
- **Cook-Torrance:**

$$G_{ct}(l,v,h) = \min\left(1, \frac{2(n\cdot h)(n\cdot v)}{(v\cdot h)}, \frac{2(n\cdot h)(n\cdot l)}{(v\cdot h)}\right)$$



Physically Based Rendering

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In practice:

- Gamma correction
- Microfacet BRDF
- Lots of Cube Maps

Polarization of Reflected Light

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Specular Reflection

- Polarization does not change

Diffuse Reflection

- Polarization is randomized

Cardboard

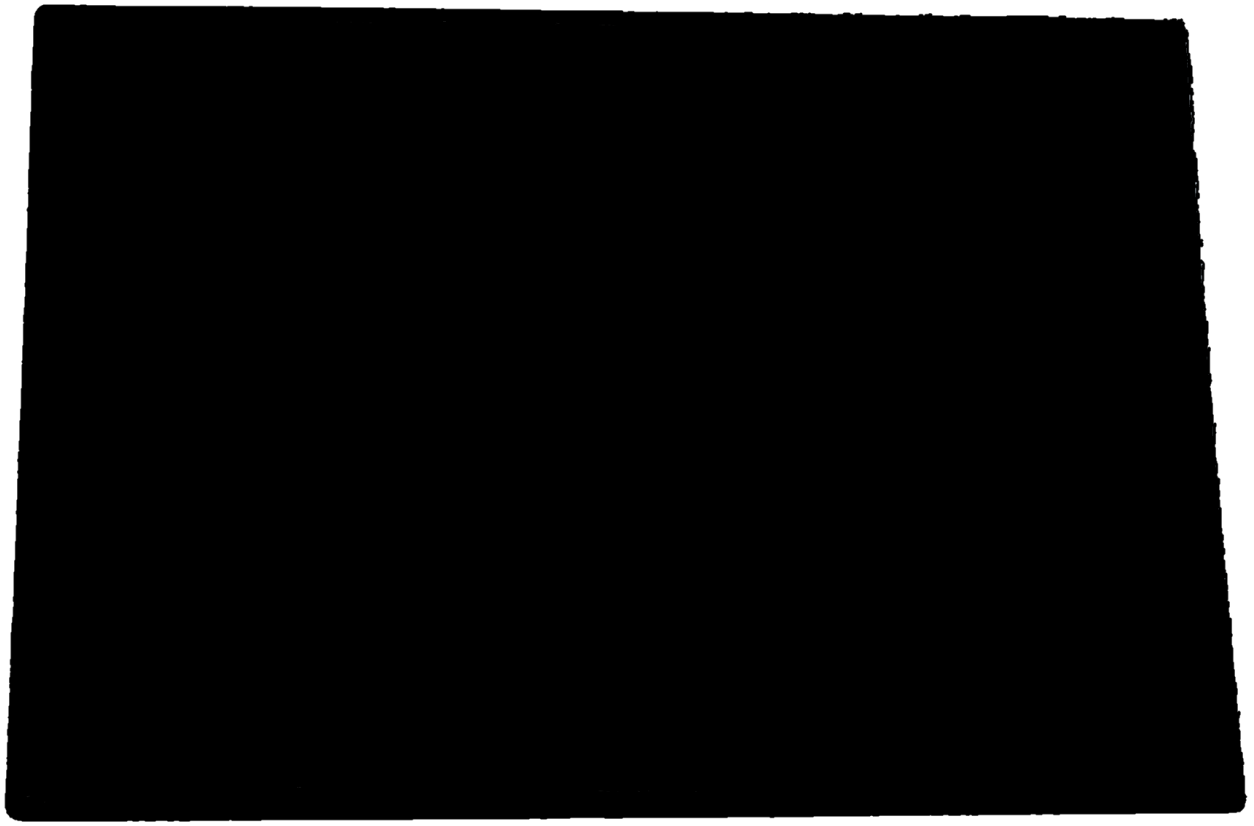
Cardboard Diffuse

Cardboard Specular

Metal

Metal Specular

Metal Diffuse



Metals and Dielectrics

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Metals:

- No diffuse
- High Specular

Dielectrics

- Diffuse
- Low Specular

Note: Specular value is specified at low angles

Textures

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Typical Setup

- Diffuse texture
- Specular texture
- Roughness texture
- Normal Map

Incorporating Image Based Lighting

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Precalculate Cube Maps

- Lots of Cube Maps
- Manually placed in level editor

Cube Maps

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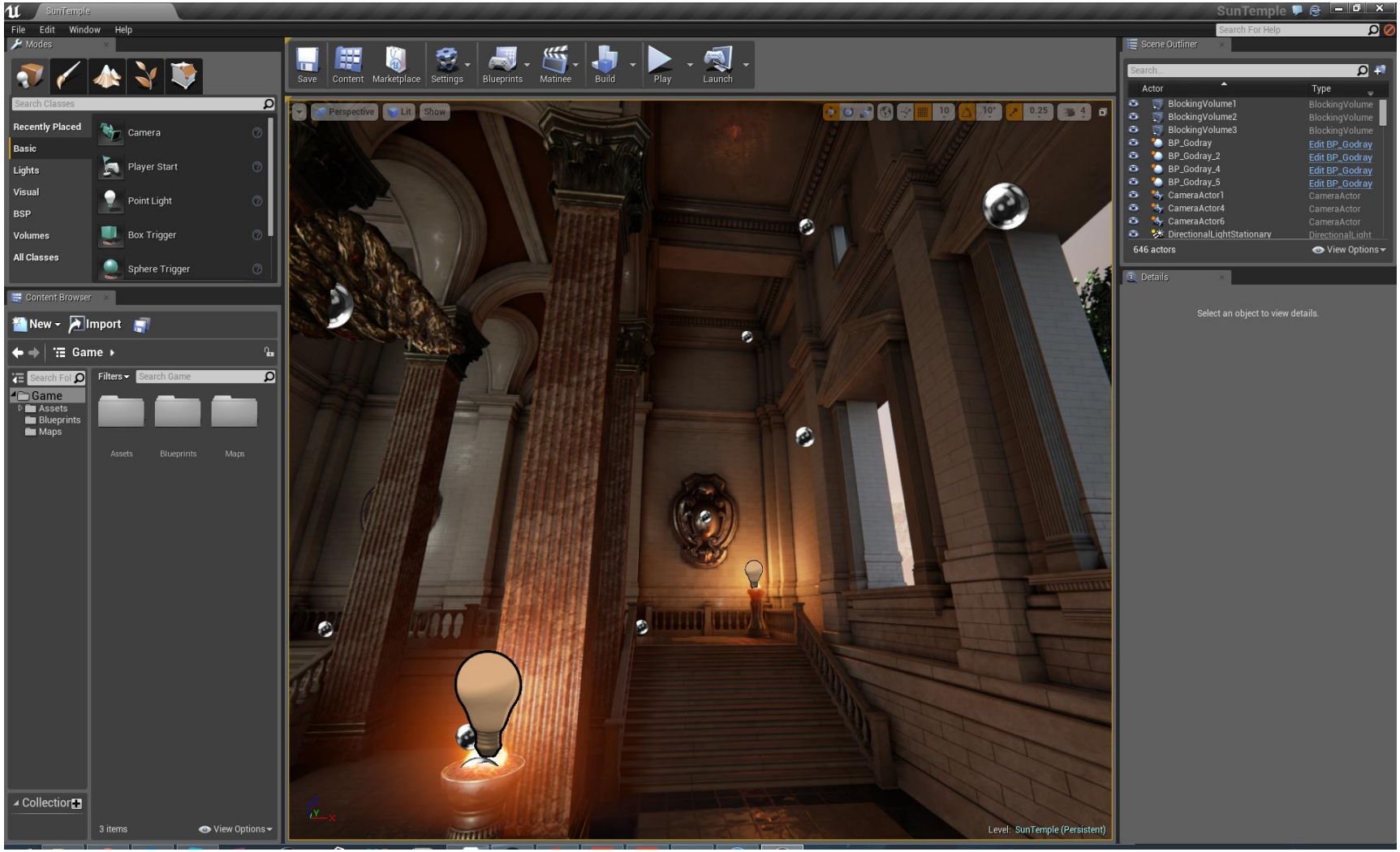

Cube Maps

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Can be interpolated

- Which is a rough approximation

Can not capture dynamic objects

Reflection Rendering

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As done in Unreal Engine 4, Killzone Shadow Fall,…

Deferred Rendering Pass

Raytrace depth buffer

If no hit

- Interpolate local cube maps

If no hit

- Use global cube map

Ambient Occlusion

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Small notches are normally shadowed

- Unless lit directly

Calculations need very exact light bounces

Screen Space Ambient Occlusion

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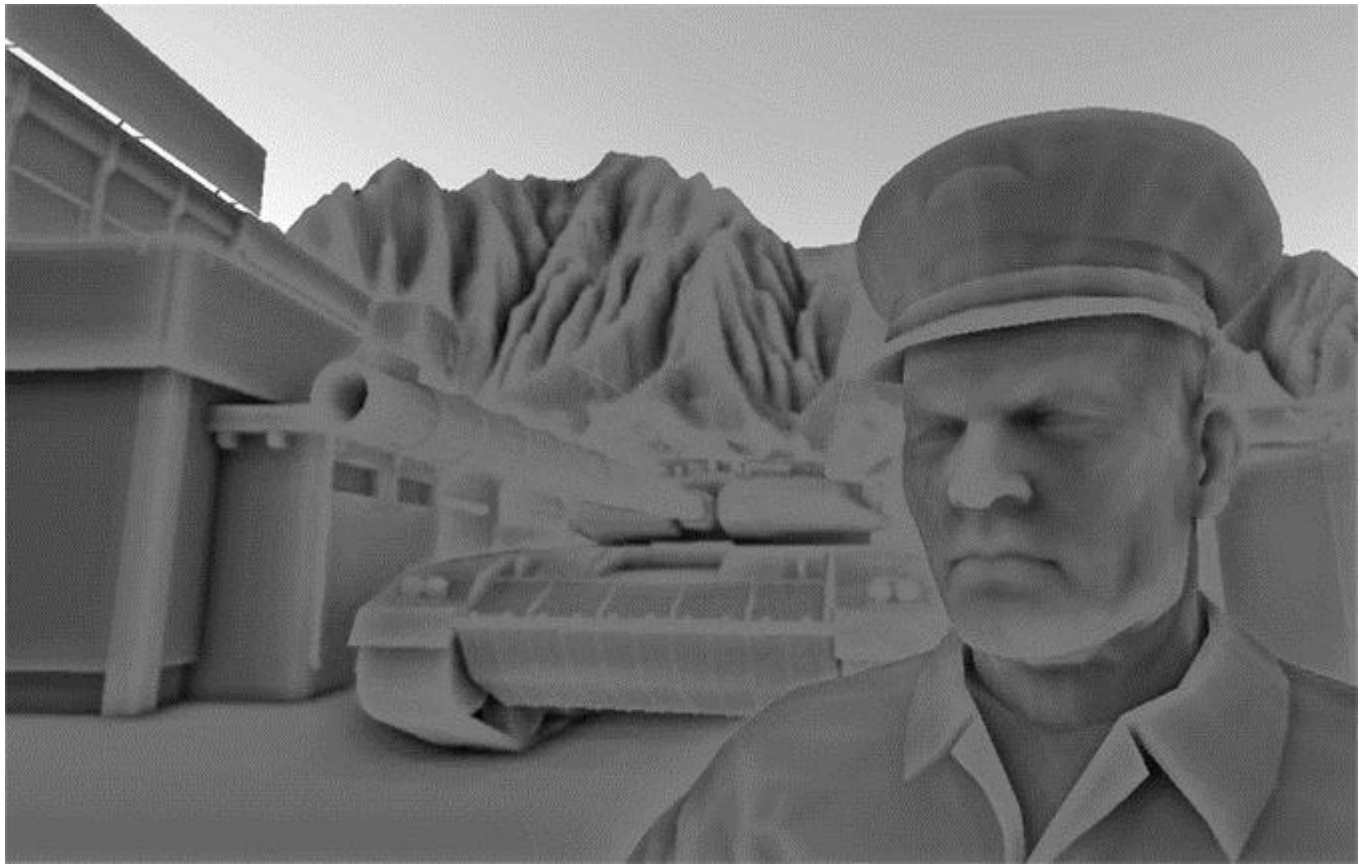
Filter after rendering

Darken at sharp normal changes



Global Illumination

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„Ambient light“

Spherical Harmonic Lighting

Voxel Cone Tracing

…

Summary

GPU Internals

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NVidia GeForce GT 6600, 2004

Memory

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Memory bandwidth is extremely important

- Textures
- Framebuffer
- Depth Buffer

Memory access times not very important

- Most data is streamed
- Access times can be hidden by switching tasks

Memory

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Gigantic discrepancy from low-end to high-end

- GeForce 720 starts at 14.4 GB/s
- PS4: 176 GB/s
- GeForce 780 Ti: 336 GB/s
- GeForce GTX 980: 224 GB/s

Vertex and Fragments Shaders

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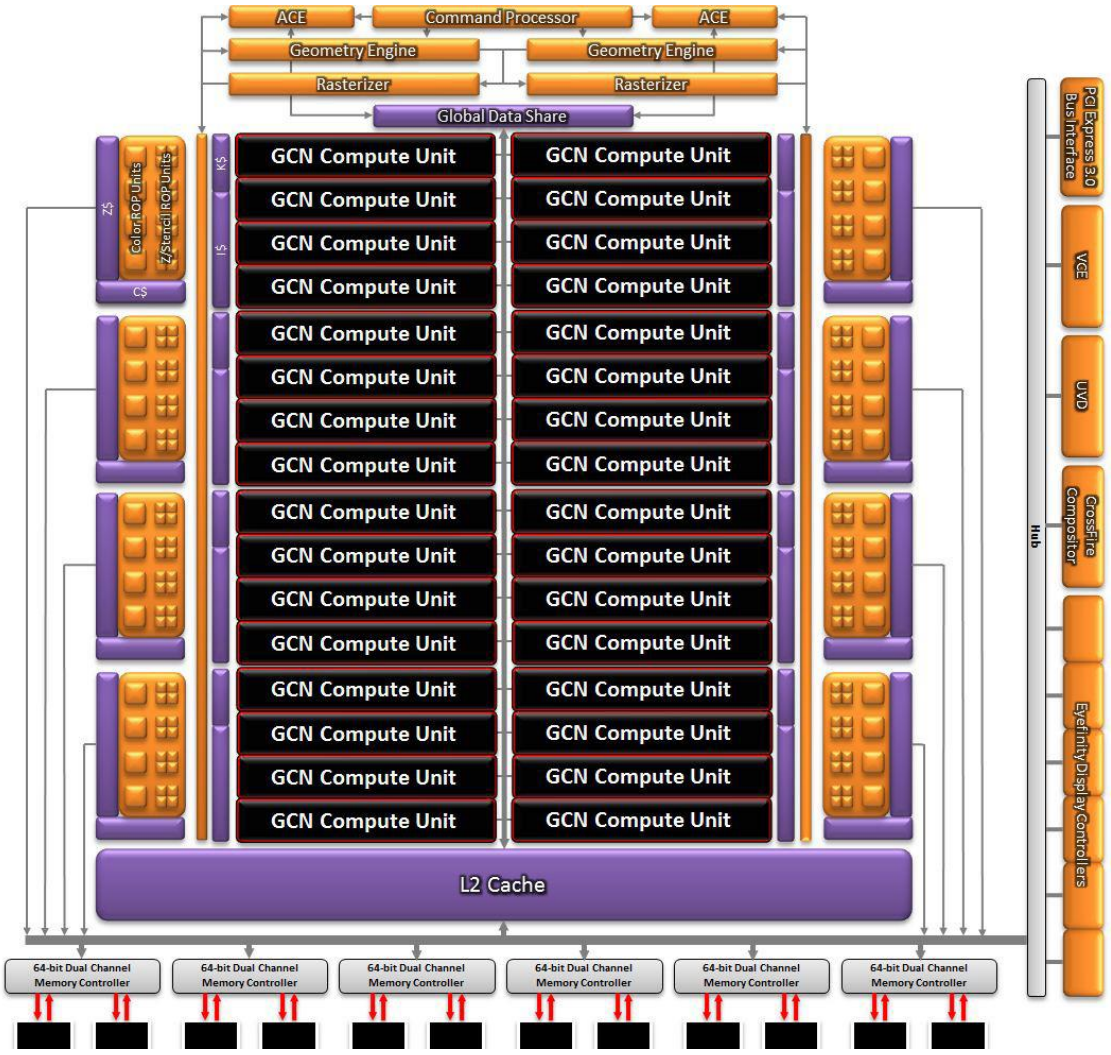
Run on the same hardware

Dynamically scheduled


ACE
Command Processor
ACE
Geometry Engine
Geometry Engine
Rasterizer
Rasterizer
Global Data Share
GCN Compute Unit
L2 Cache
Z$
Color ROP Units
Z/Stencil ROP Units
C$
K$
I$
Hub
PCI Express 3.0 Bus Interface
VCE
UVD
CrossFire Compositor
Eyefinity Display Controllers
64-bit Dual Channel Memory Controller

SMT

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Also used in CPUs (Hyperthreading)

Switch to different thread when stalled (for example waiting for memory)

SIMD

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Compiler can put calculations on multiple vertices/pixels in one instruction

Problem: Flow control

- Wrong paths pseudo-executed
  - Can be efficient when all vertices/pixel in one pack take the same paths

Shader variants

- „Typically when you create a simple surface shader, it internally expands into 50 or so internal shader variants” (Shader Compilation in Unity 4.5)

Parallelization

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Small work packages can prevent parallelization

- Performance dip for tiny triangles

CPU <-> GPU

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Biggest performance trap

Minimize state changes

Minimize draw calls

Send little data to the GPU

If possible never read data from the GPU

Summary