CS354R

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MATERIALS AND TEXTURES

IMPROVING VISUAL FIDELITY

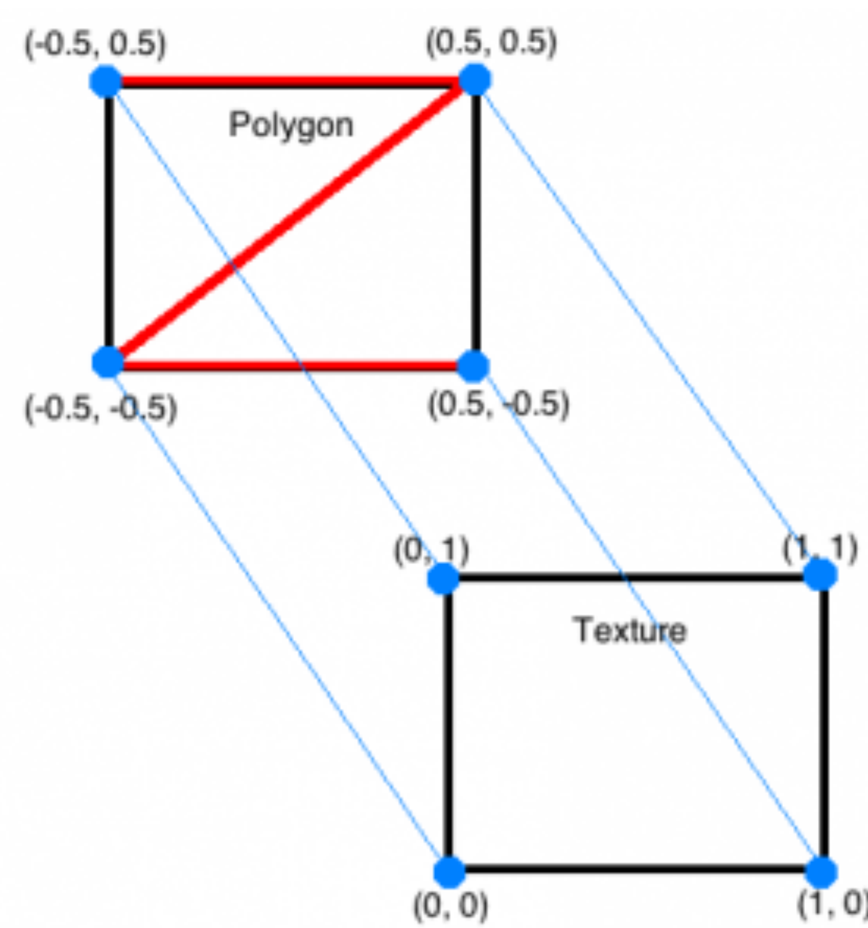
- Historically games relied on simple, local lighting models
- How did they get games to look like this?

TEXTURE MAPPING

- Take a “painted” image (texture) and wrap it around a 3D mesh (map) to add more detail
- Works for any shading parameters, not just color

BASIC MAPPING

- Textures live in a 2D space
  - Parameterize points in the texture with 2 coordinates: (s, t)
- Define the mapping from (x, y, z) in world space to (s, t) in texture space
- For polygons:
  - Specify (s, t) coordinates at vertices
  - Interpolate (s, t) for other points



BASIC TEXTURING CONCEPTS AND TERMS

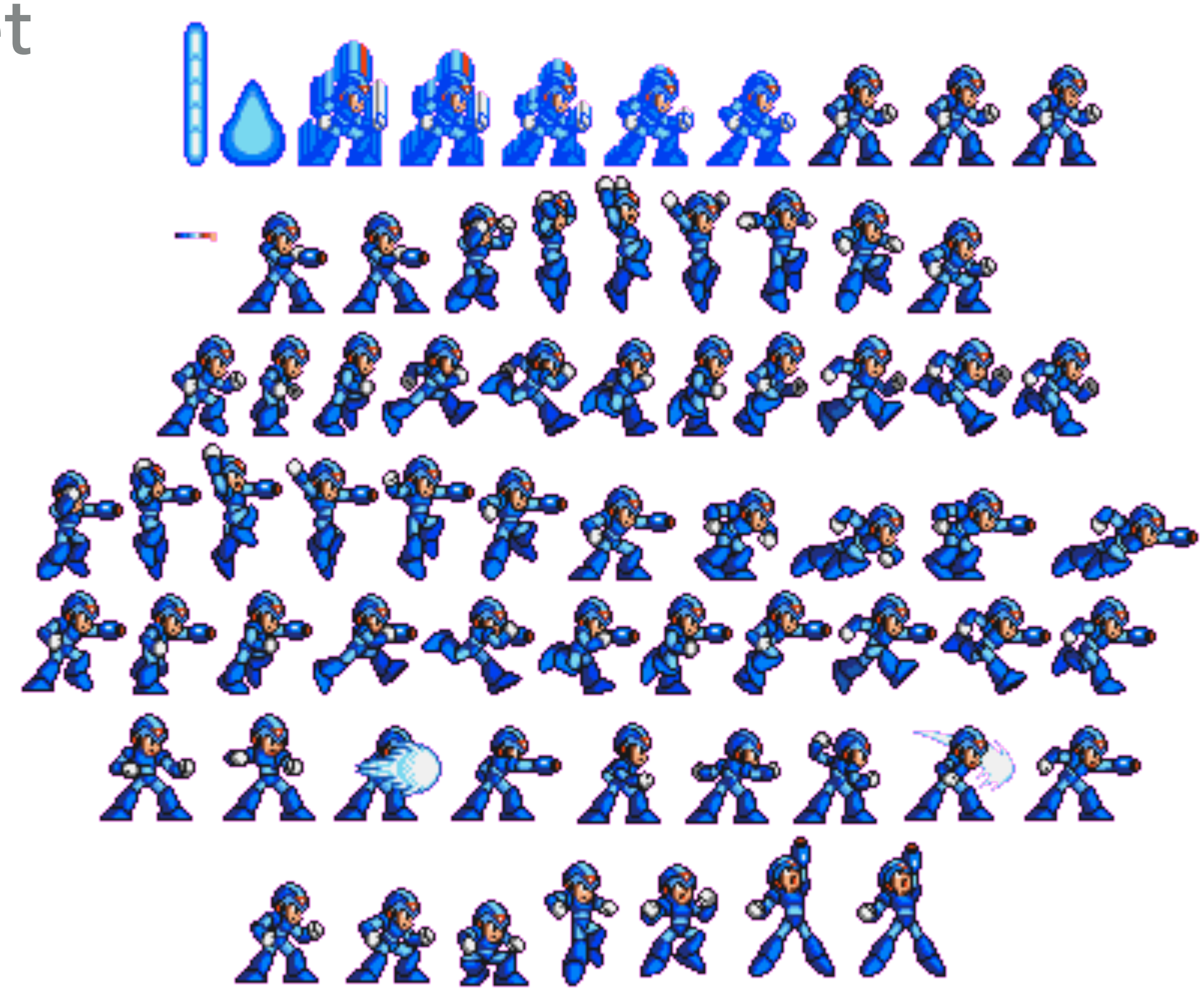
- Vertices are coordinates that define geometry
- Texture coordinates specified at vertices and interpolated across triangles
- Texture values for points mapping outside the texture image can be generated in various ways:
  - REPEAT, CLAMP, etc
- Width and height of texture images is often constrained
  - Powers of two
  - Sometimes required to be a square

TEXTURES IN GAMES

- Modern game engines provide a lot of texture support
  - High level of control for importing and editing
  - Varying resolutions to support hardware performance
  - Automatic texture atlasing
- Artist tools often included for texture management
  - Design texture images
  - Specify how to apply to object
  - Profiling to maintain good memory and performance bounds

TEXTURE ATLASING

- A packed set of textures (or sprites)
- 2D Example: a sprite sheet



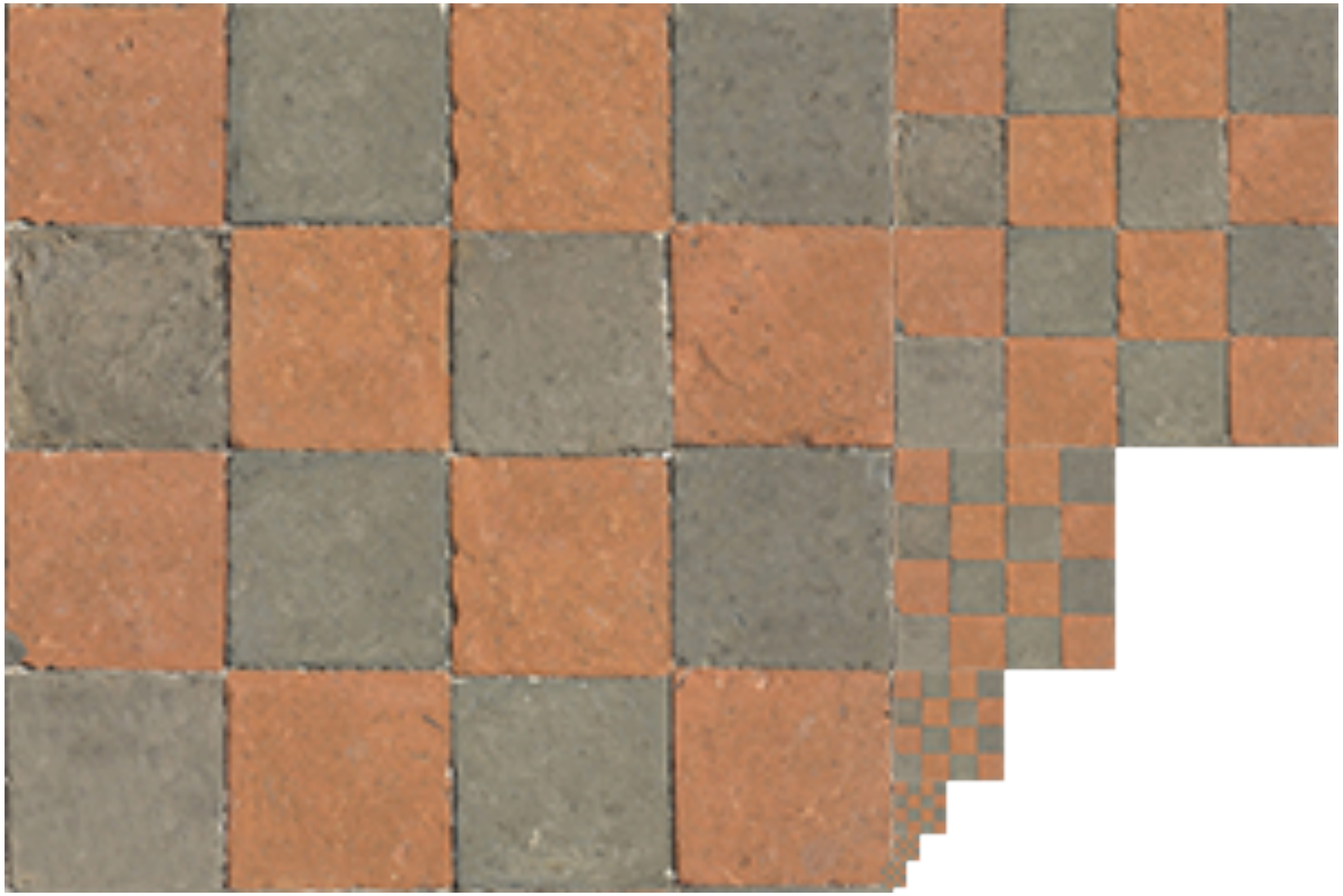
TEXTURE ATLASING

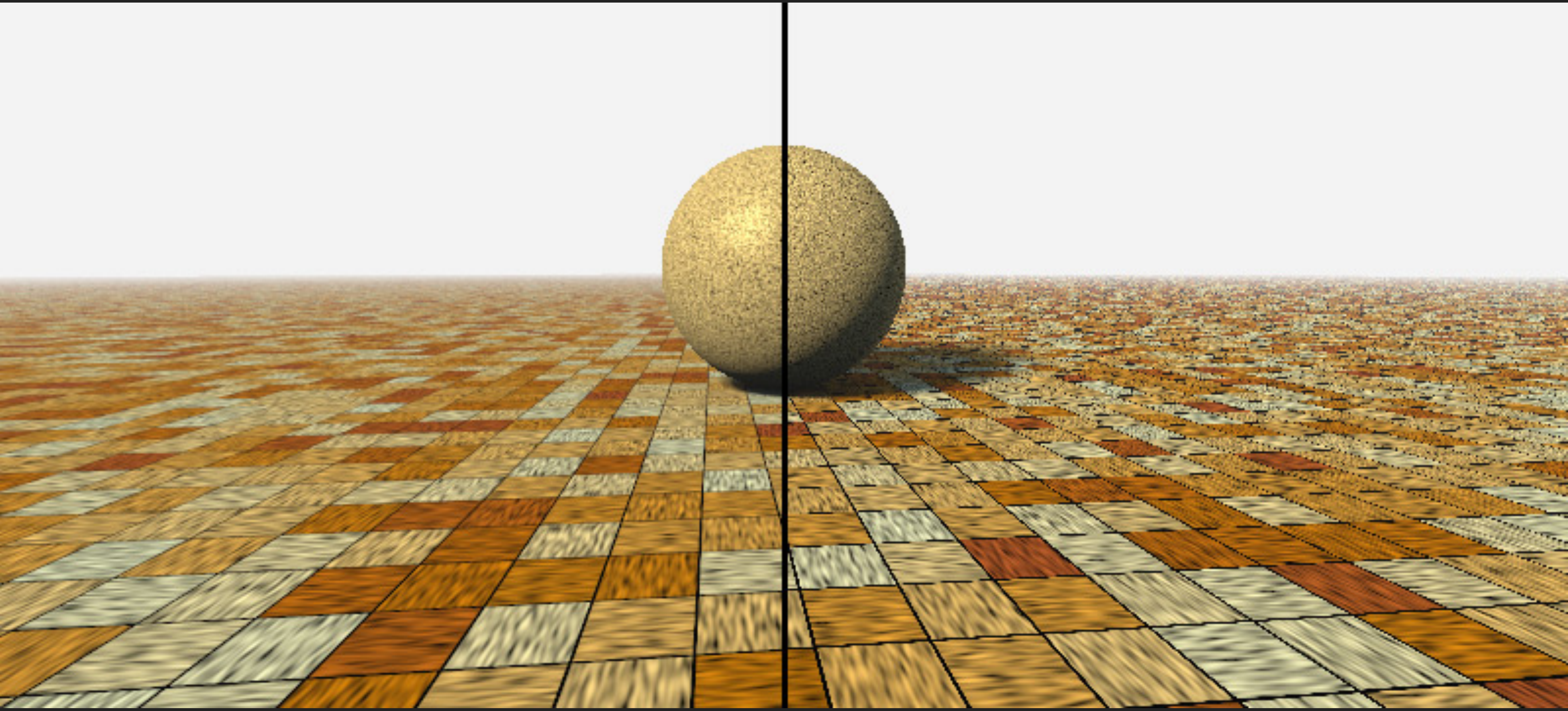
- Also used in 3D games!
- Artists pack the textures for many objects into one image
  - The texture coordinates for a given object may only index into a small part of the image
  - Care must be taken at sub-image boundary to achieve correct blending
  - Mipmapping is restricted
  - Best for objects that are at a known resolution

COMBINING TEXTURES

MIPMAPS

- Store multiple resolutions of same texture
  - Sample based on distance from camera

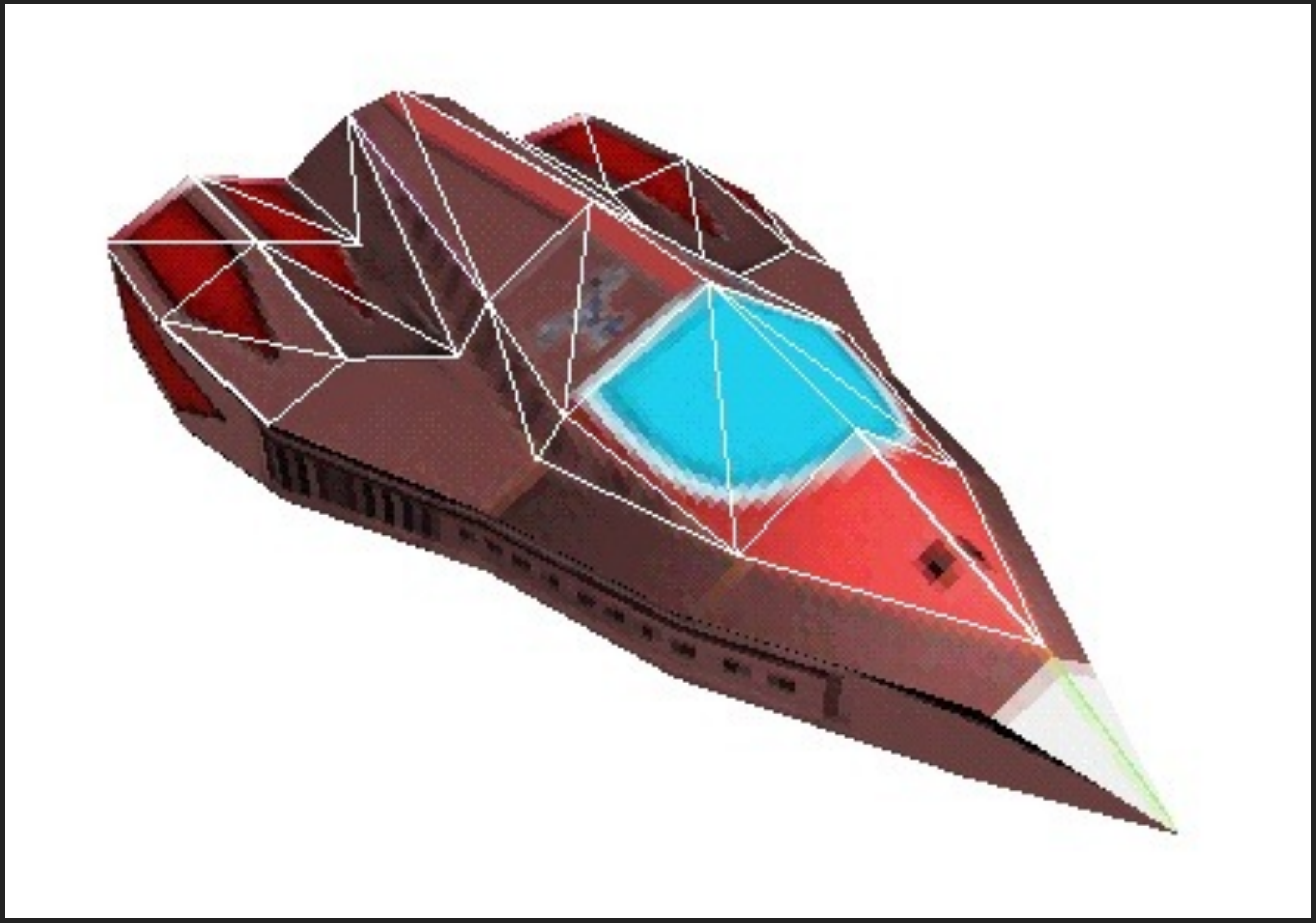


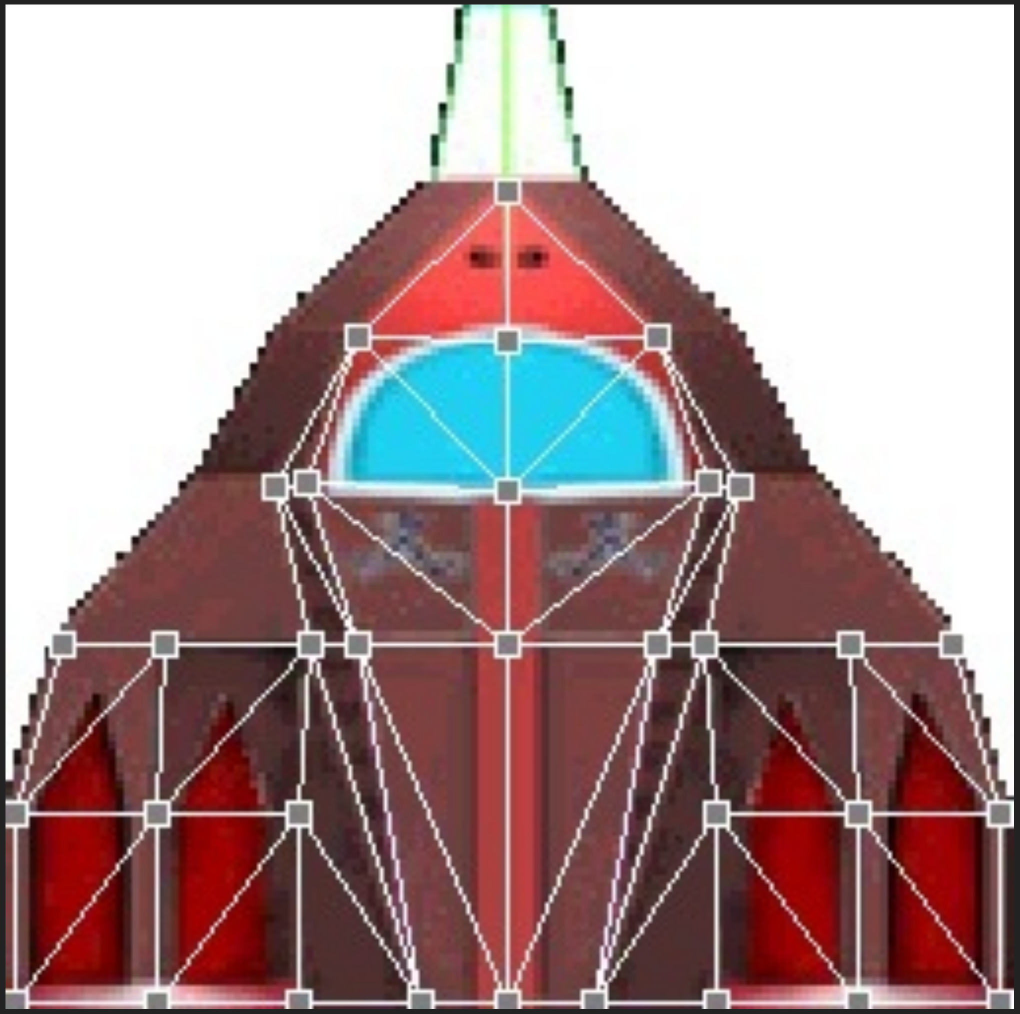


https://www.iquilezles.org/www/articles/filtering/filtering.htm

A LARGER EXAMPLE

3D EXAMPLE: TEXTURE TOOL





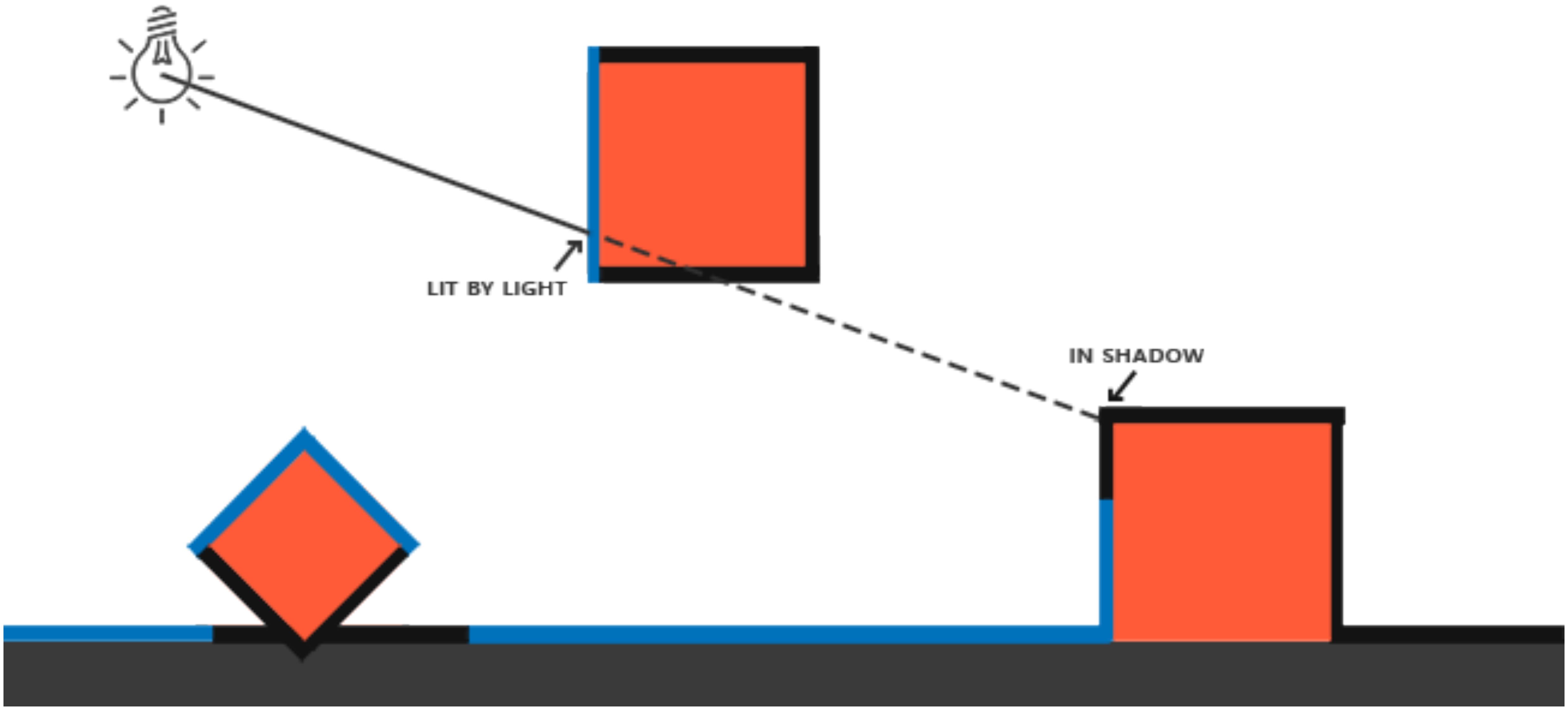
OTHER TEXTURING TECHNIQUES

- Animated textures
  - Texture matrix transforms texture in memory
  - Texture can slide, rotate, and stretch/shrink over surface
  - Useful for things like flame, swirling vortices, or pulsing entrances…
- Projective textures
  - Texture projected onto the scene as if from a slide projector
  - Used in light maps, shadow maps and decals

SHADOW MAPS

- Render shadows by determining if pixels are occluded from light sources
    1. Render scene from light source's point of view (multiple renders for multiple light sources)
    2. Store depth values of this scene as a texture (the shadow map)
    3. Render scene from camera's point of view and test if object coordinates are lit or unlit by light
- Must transform objects in scene into light source's coordinate system
- Check depth of object against depth of shadow map value to determine if object is occluded

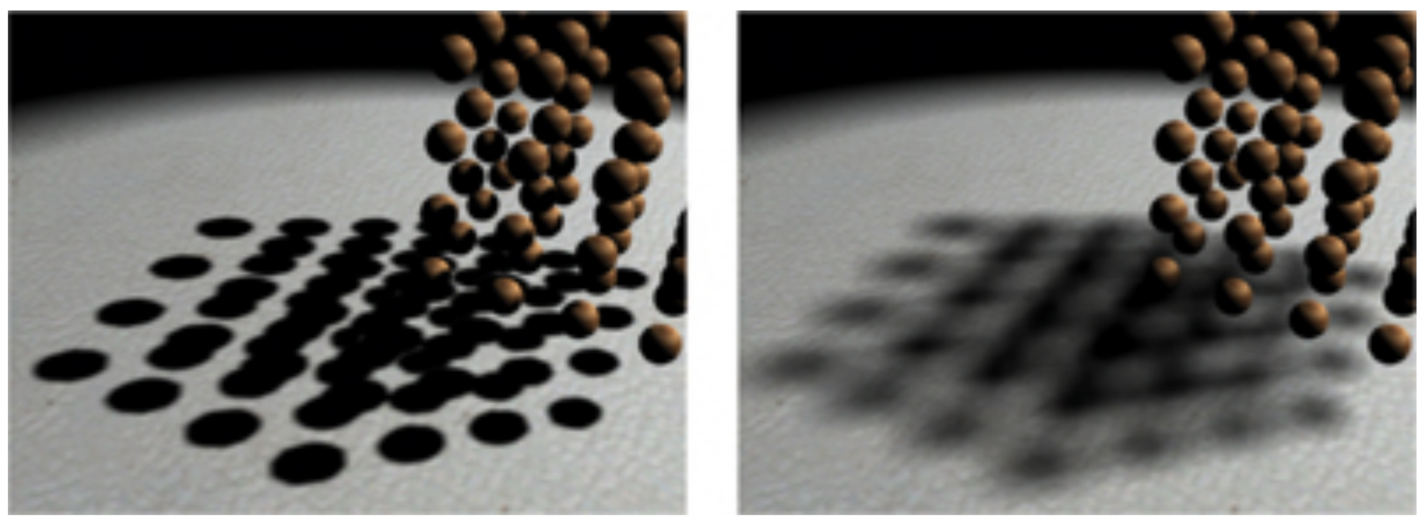
SHADOW MAP EXAMPLE



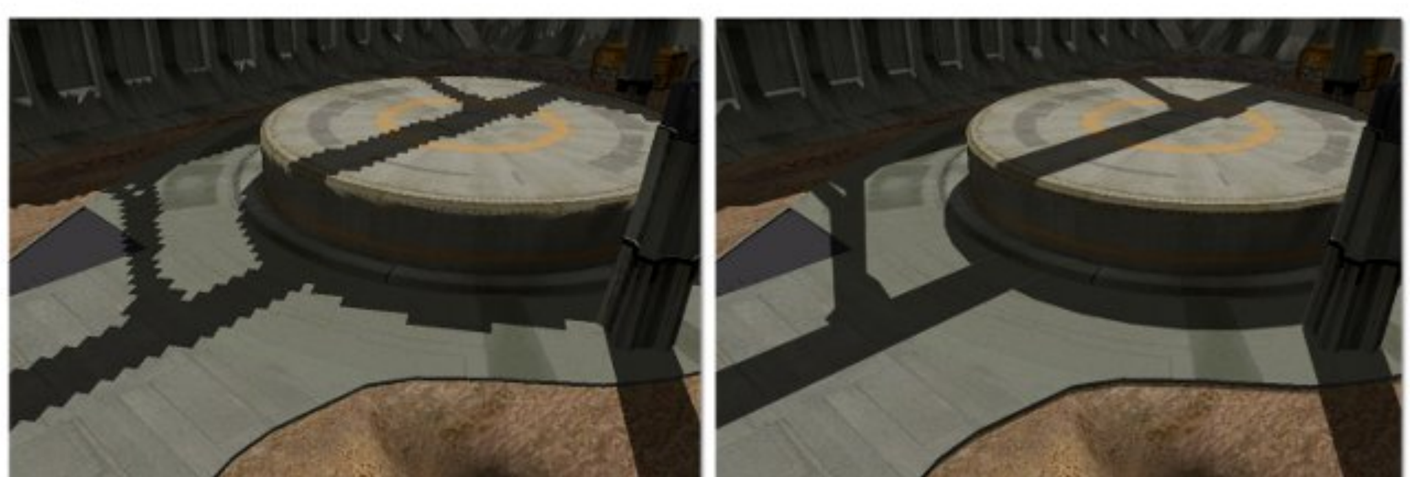
SHADOW MAP CHALLENGES

- Basic shadow mapping only generates hard shadows
  - Need additional processing for shadow penumbra
- Resolution of shadow map determines resolution of shadow
  - Aliasing and continuity issues
- Resource intensive
  - Need pre-baking or advanced techniques

SHADOW MAP CHALLENGES



Hard shadows vs shadows with penumbra



Aliased vs anti-aliased shadow maps

MSAA AND TEMPORAL ANTI-ALIASING

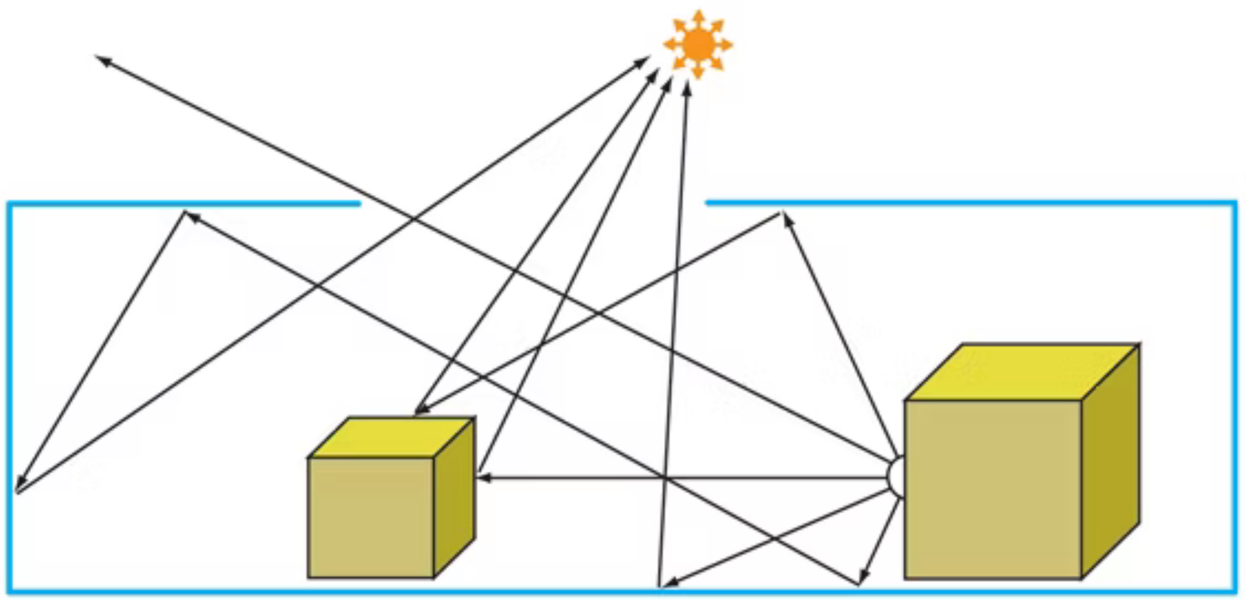
- Multisample anti-aliasing is a form of supersampling (oversampling to reduce loss of the signal)
  - Naive oversampling samples the entire image at higher resolution then reduces
  - Observation: aliasing occurs in specific areas rather than universally
  - Solution: only perform super sampling in areas with discontinuities in triangles/depth/etc
- Temporal anti-aliasing samples pixel over time to reduce temporal aliasing
  - Temporal aliasing occurs when objects move faster than frame speed
  - Apply filters based on multiple frames to soften effect

DLSS AND FSR

- DLSS (Deep learning Super Sampling) by NVidia
- FSR (FidelityFX Super Resolution) by AMD
- Deep learning approach to super sampling
    - Takes lower resolution image and upsamples it for higher resolution monitors
- Better scaling in resolution for “screen space” techniques
    - 4K resolution makes many screen space techniques impractical and/or less efficient
- Does not handle “high frequency” details such as text etc without extensive training

CONTROL DLSS VS DLSS 2.0 DEMO

MODELING LIGHT TRANSPORT



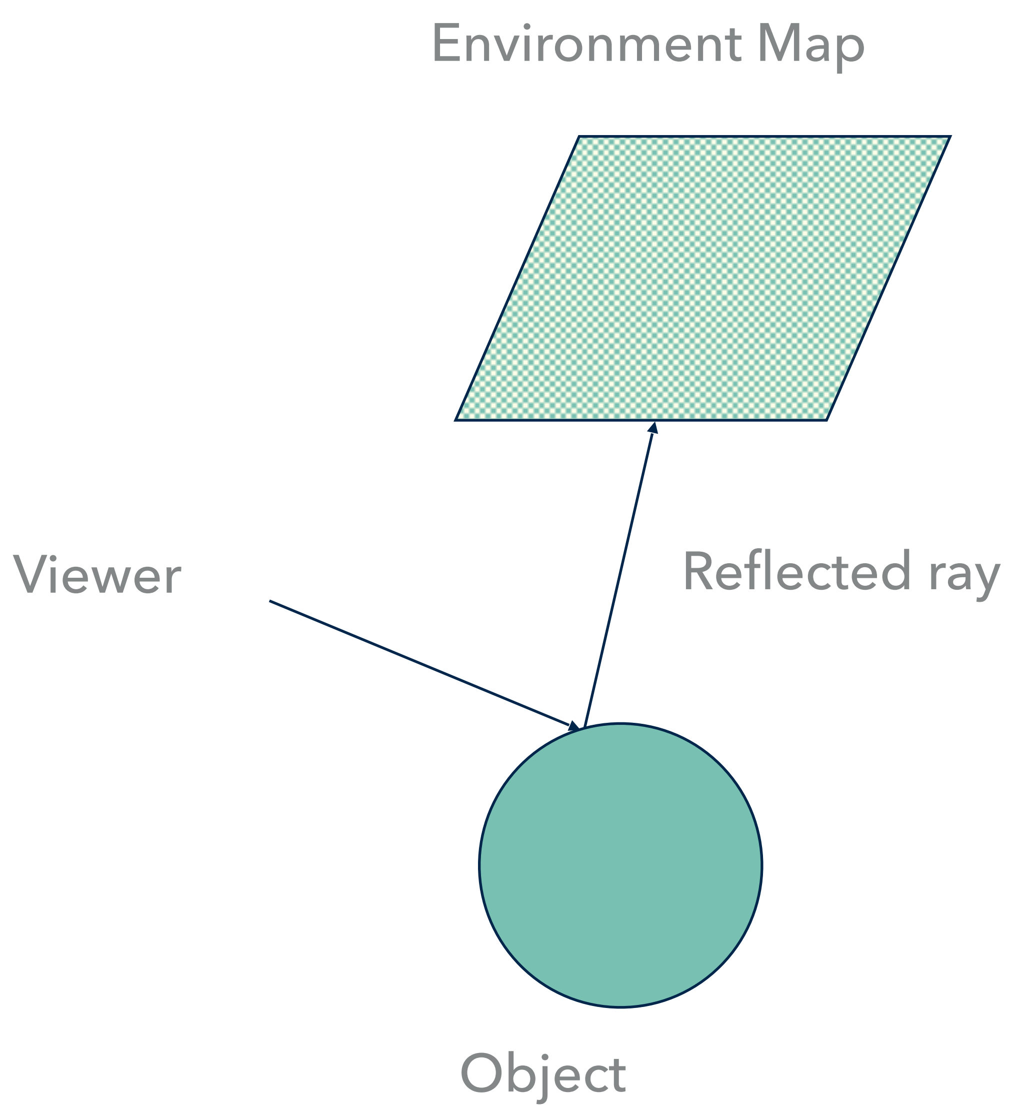
- Photons of light bounce around a “scene” based on their physical properties
- Modeling this transport of energy reconstructs visual output of the scene based on the lights and material properties of the scene objects
- Family of techniques known as “ray tracing” try to reconstruct this physics equation in a discrete/statistically valid way
    - Path tracers use Monte Carlo methods to converge in an unbiased way

RAY TRACING IN MODERN GAMES

- Ray tracing to create global illumination (GI) is increasingly common in Triple A games
  - Possible to create specific lighting features using targeted raytracing
  - Path tracing possible with RTX hardware/machine learning
- Many other techniques besides ray tracing still used to emulate GI

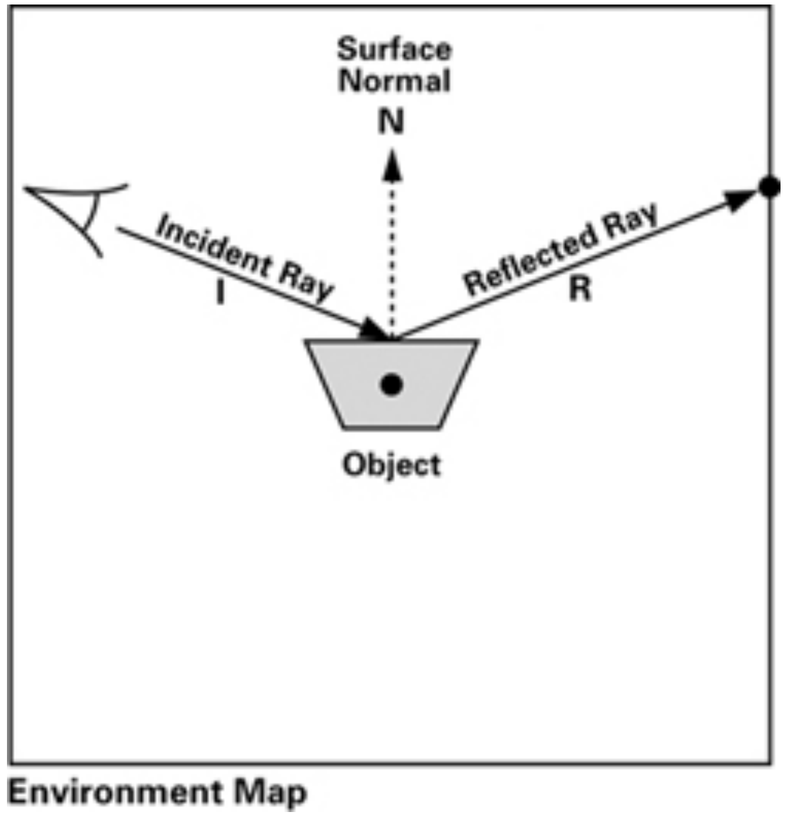
MOVING TOWARD GLOBAL ILLUMINATION

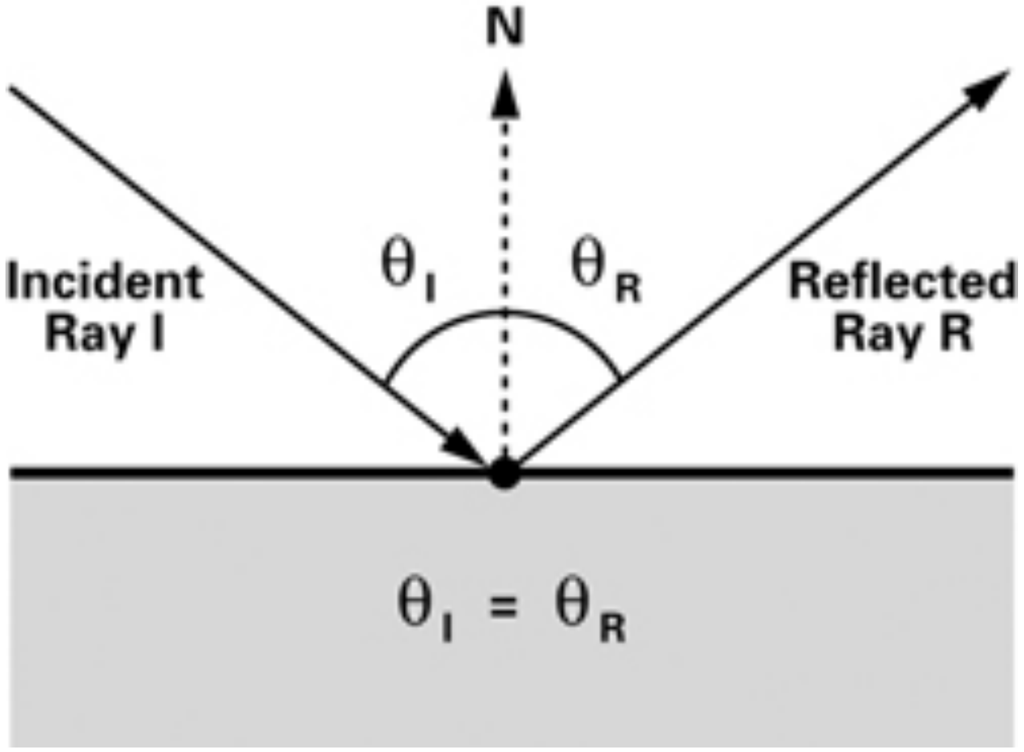
- Environment mapping produces reflections on shiny objects
- Texture is transferred in the direction of the reflected ray from the environment map onto the object



ENVIRONMENT MAPPING CONT'D

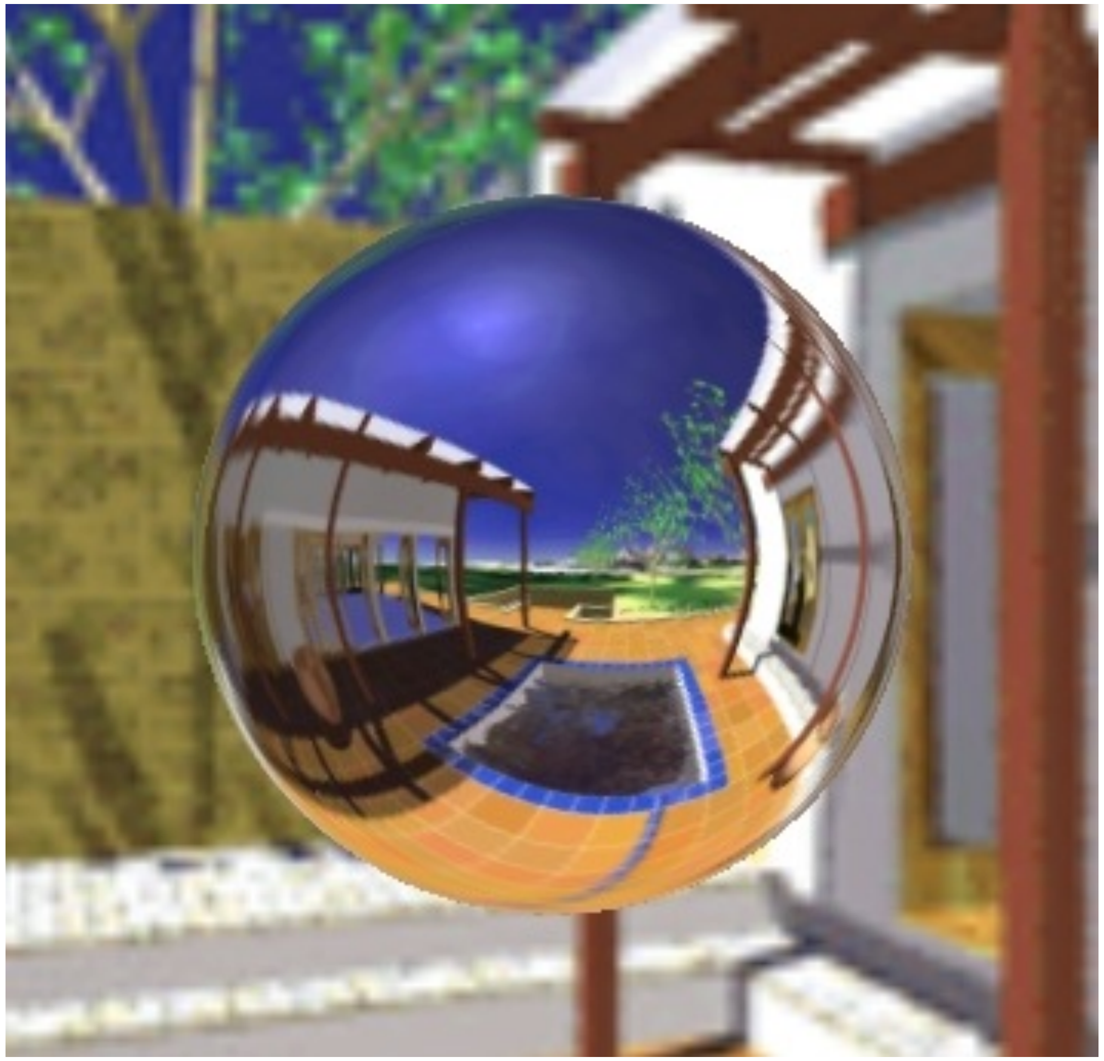
- Reflected ray: $R = I - 2(N \cdot I)N$

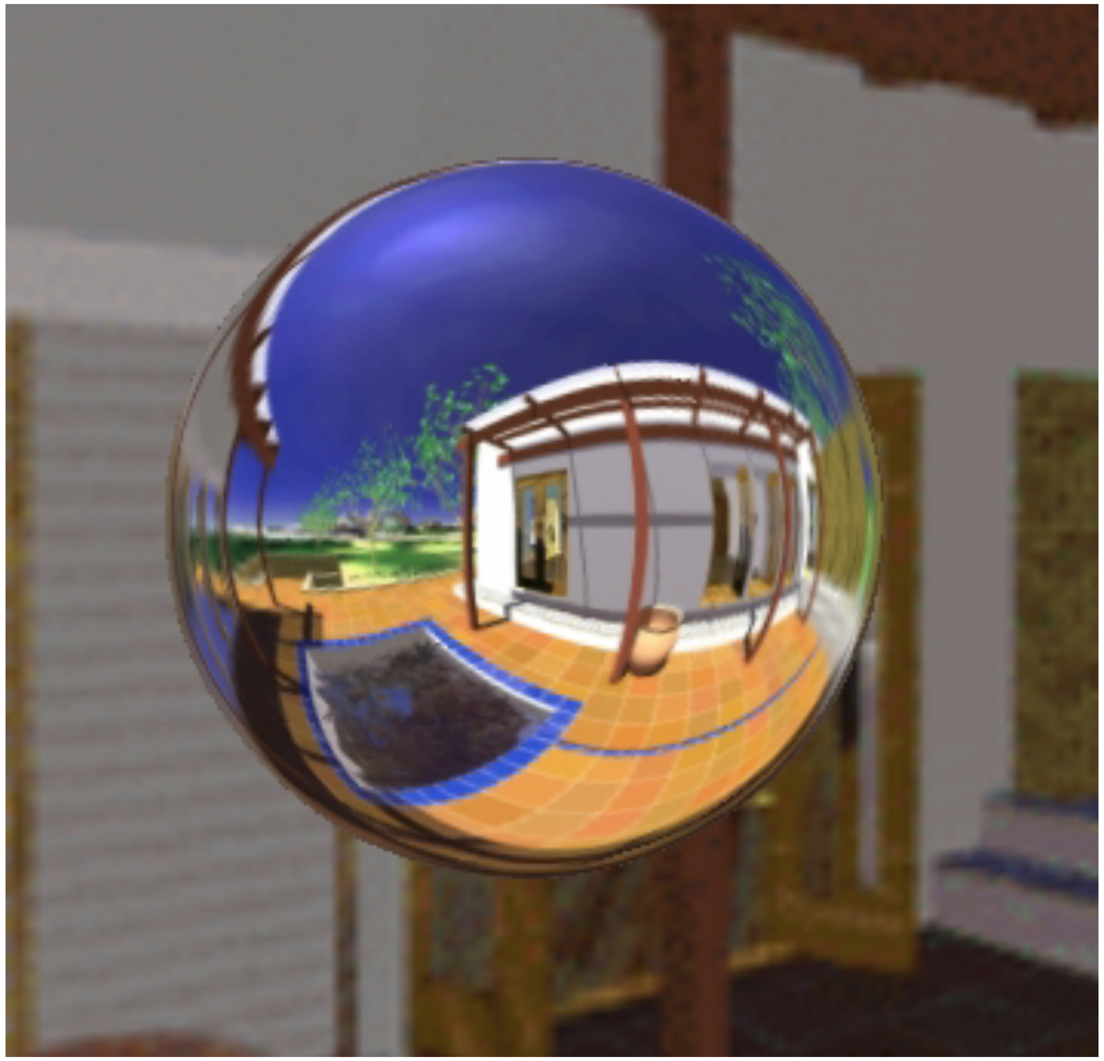




(NVidia CG Tutorial)

EXAMPLE

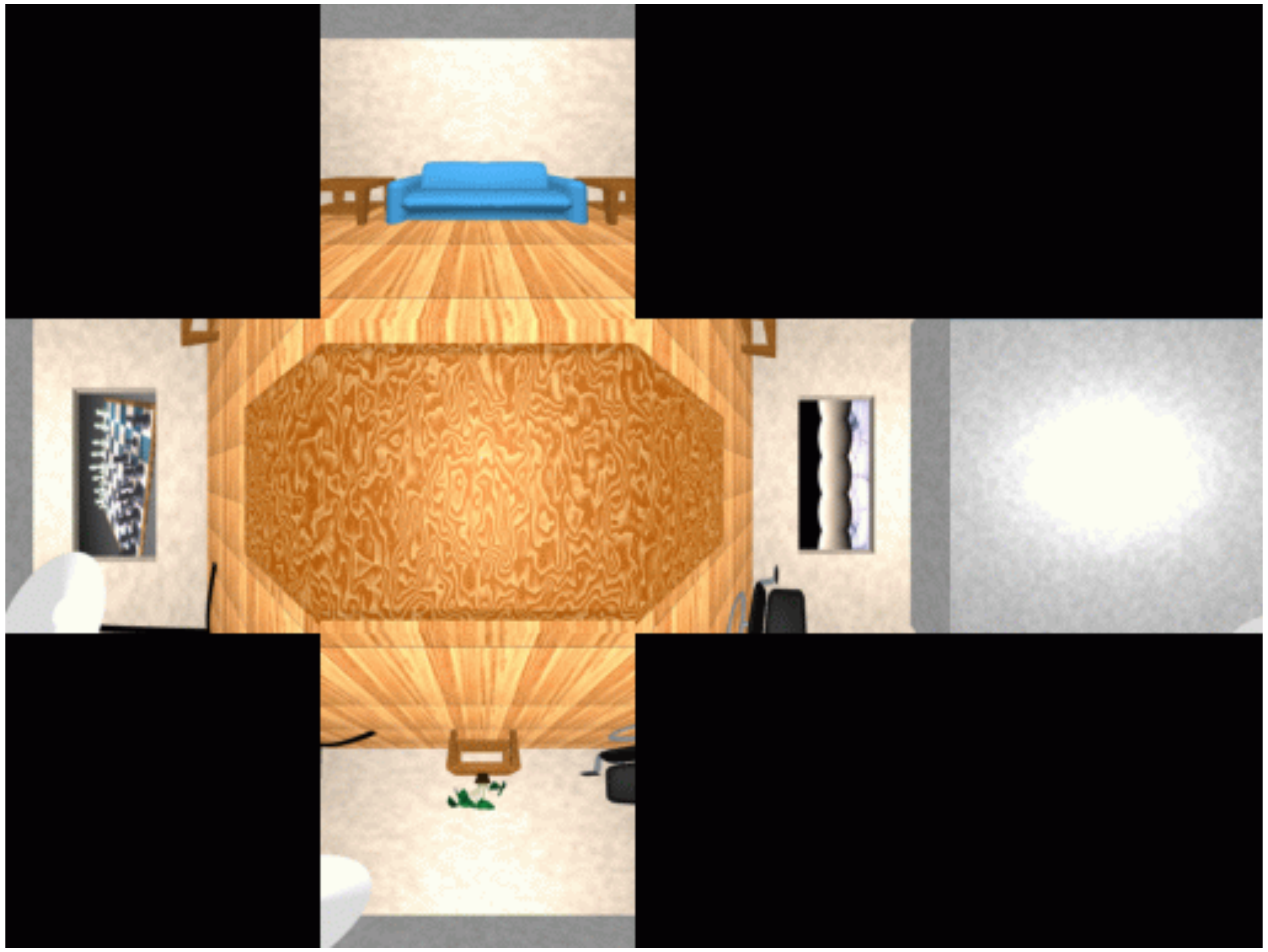




CUBE MAPPING

- The map resides on the surfaces of a cube around the object
  - Typically align the faces of the cube with the coordinate axes
- Can make map rendering arbitrarily complex as it's possible to do off-line
- For each face of the cube either:
  - Render the world from the center of the object with the cube face as the image plane
  - Or take 6 photos of a real environment with a camera in the object's position

CUBE MAP EXAMPLE

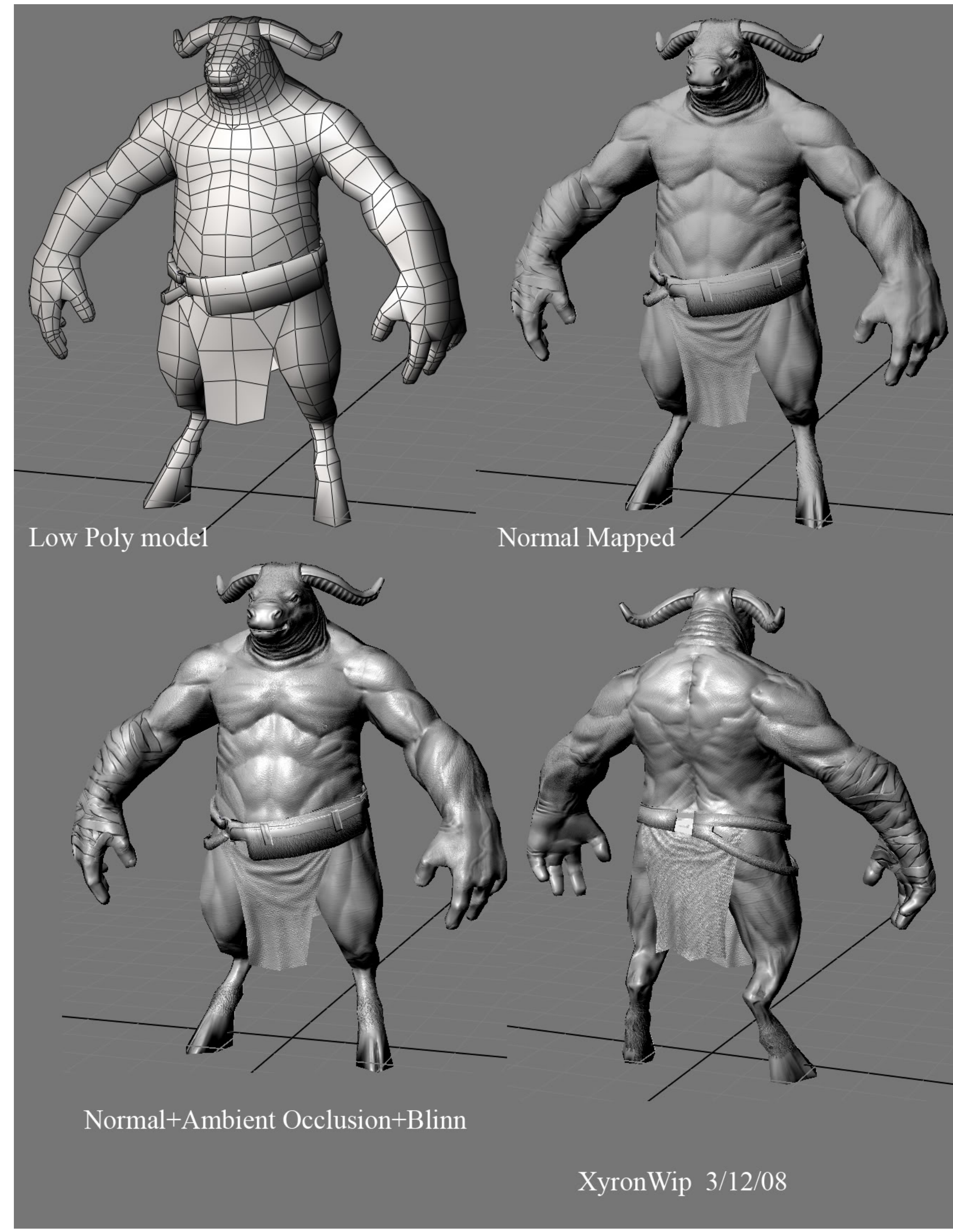


WHAT DO TEXTURES REPRESENT?

- Graphics hardware doesn't know what is in a texture
  - GPU applies a set of operations using values it finds in the texture, the existing value of the fragment (pixel), and maybe another color
  - The programmer decides what these operations are
- Examples:
  - Scalar luminance data (multiplies the fragment color)
  - Alpha data (multiplies the fragment's alpha channel)
  - Vector data (modifies the surface normals)
  - Depth data (determines distance from light source for shadow mapping)

TEXTURES IN DIGITAL ART

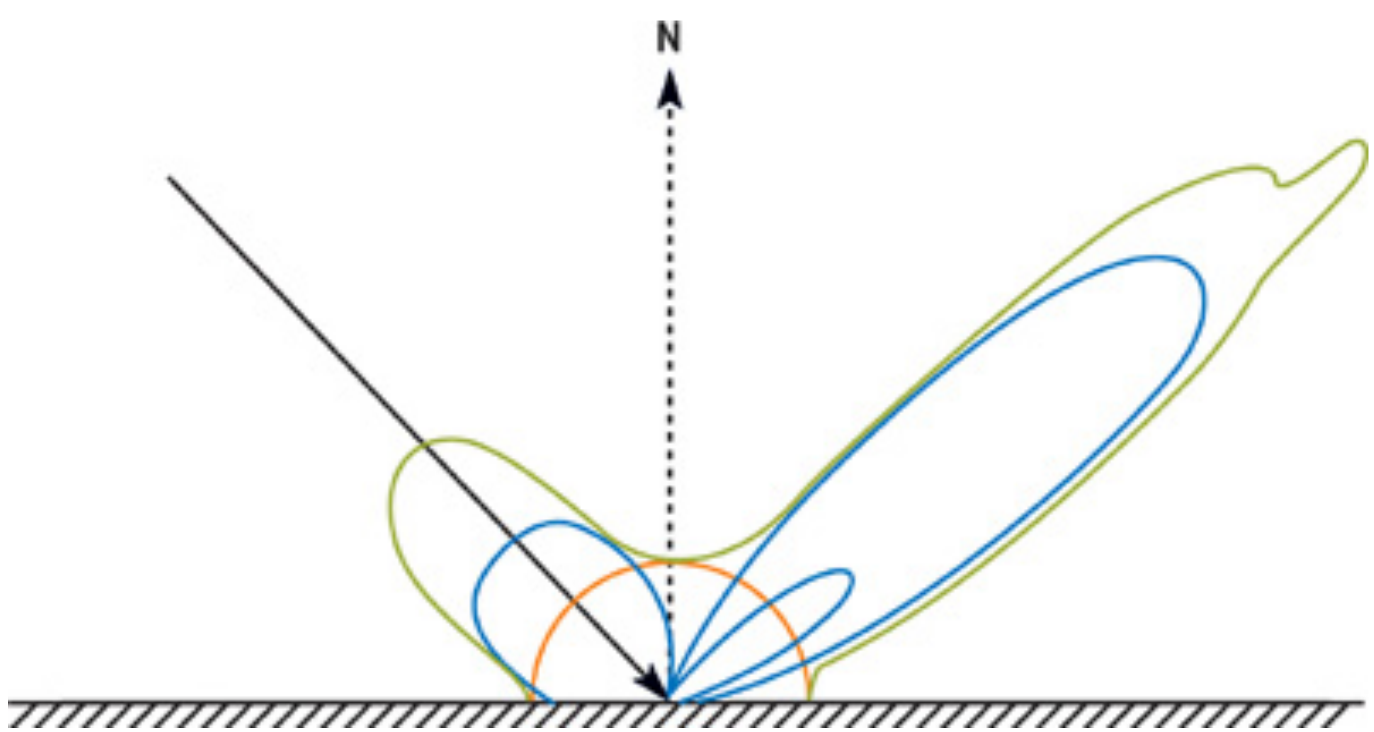
- Assets designed for modern graphics pipeline
  - Lower poly, higher textures
  - Multiple maps for multiple effects



(Arnab Roy, Maya)

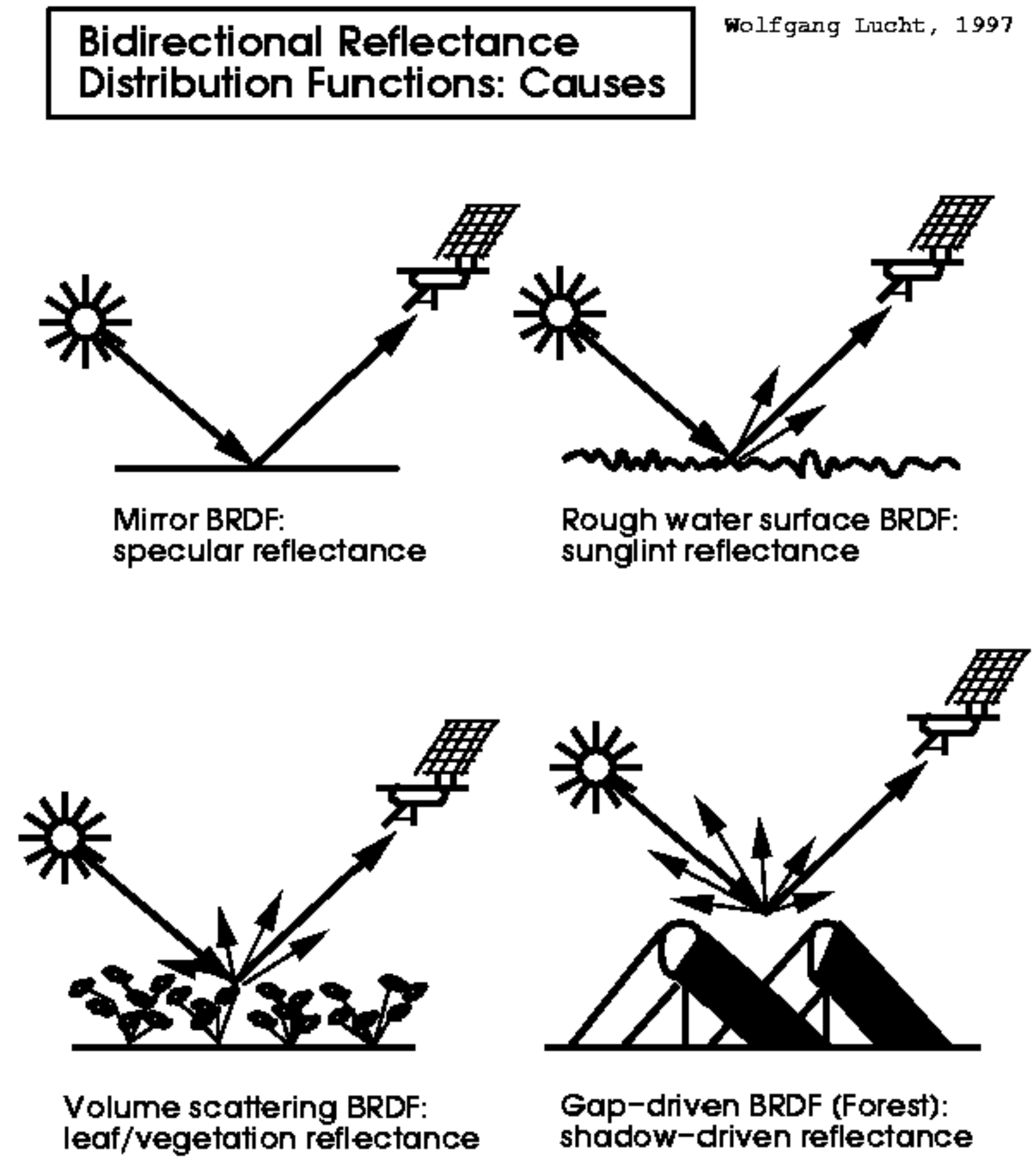
PHYSICALLY-BASED MATERIALS

- Textures provide more details but Phong lighting model inherently limited
  - Function is very approximate and not physically-based
- Can improve material model by using functions based on the physics of light



BRDFS

- Bidirectional reflectance distribution function
- Defines how a material reflects light based on the angle of observation
- Determines ratio of reflected radiance
    - Physically-based
    - Empirically studied by material sample

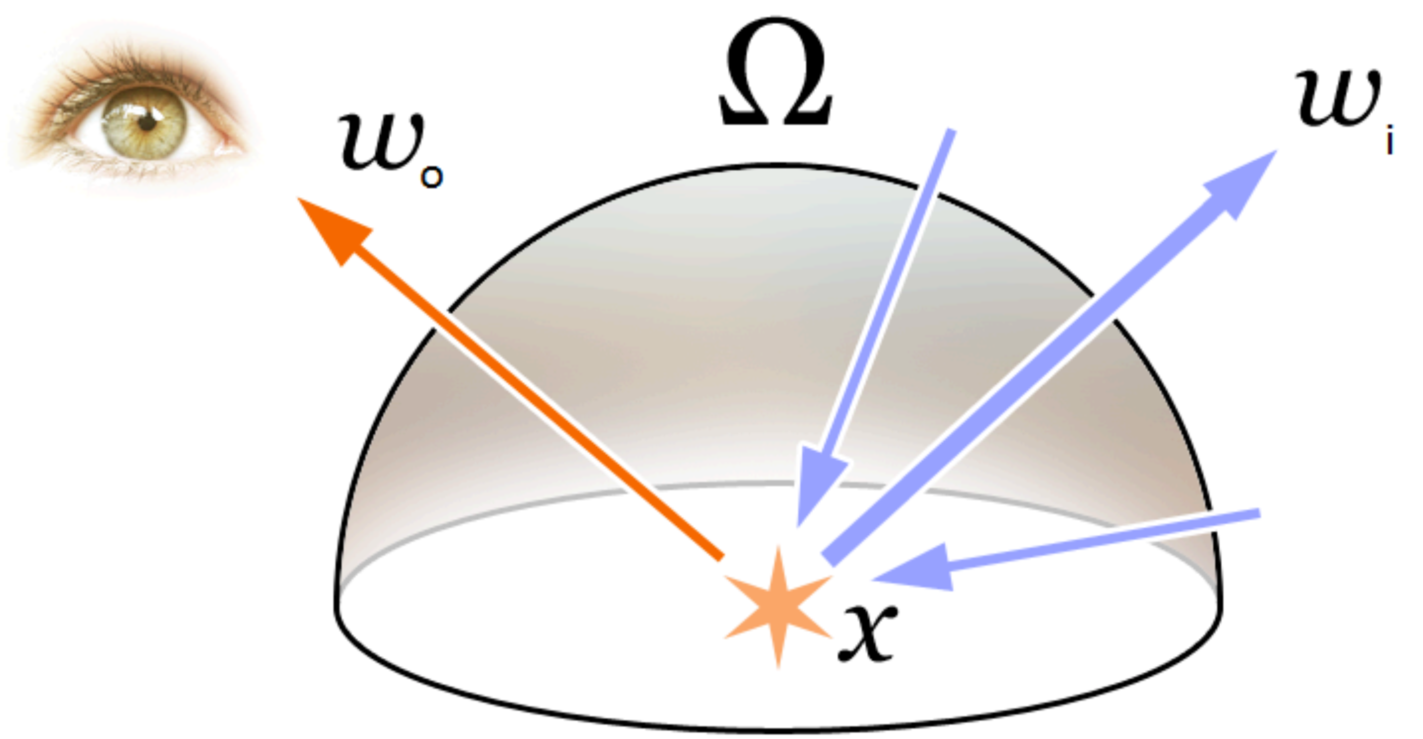


THE RENDERING EQUATION

- Describes radiance of light entering and leaving a point

$$L_o(\mathbf{x}, \omega_o, \lambda, t) = L_e(\mathbf{x}, \omega_o, \lambda, t) + \int_\Omega f_r(\mathbf{x}, \omega_i, \omega_o, \lambda, t) L_i(\mathbf{x}, \omega_i, \lambda, t) (\omega_i \cdot \mathbf{n}) \, d\omega_i$$

BRDF



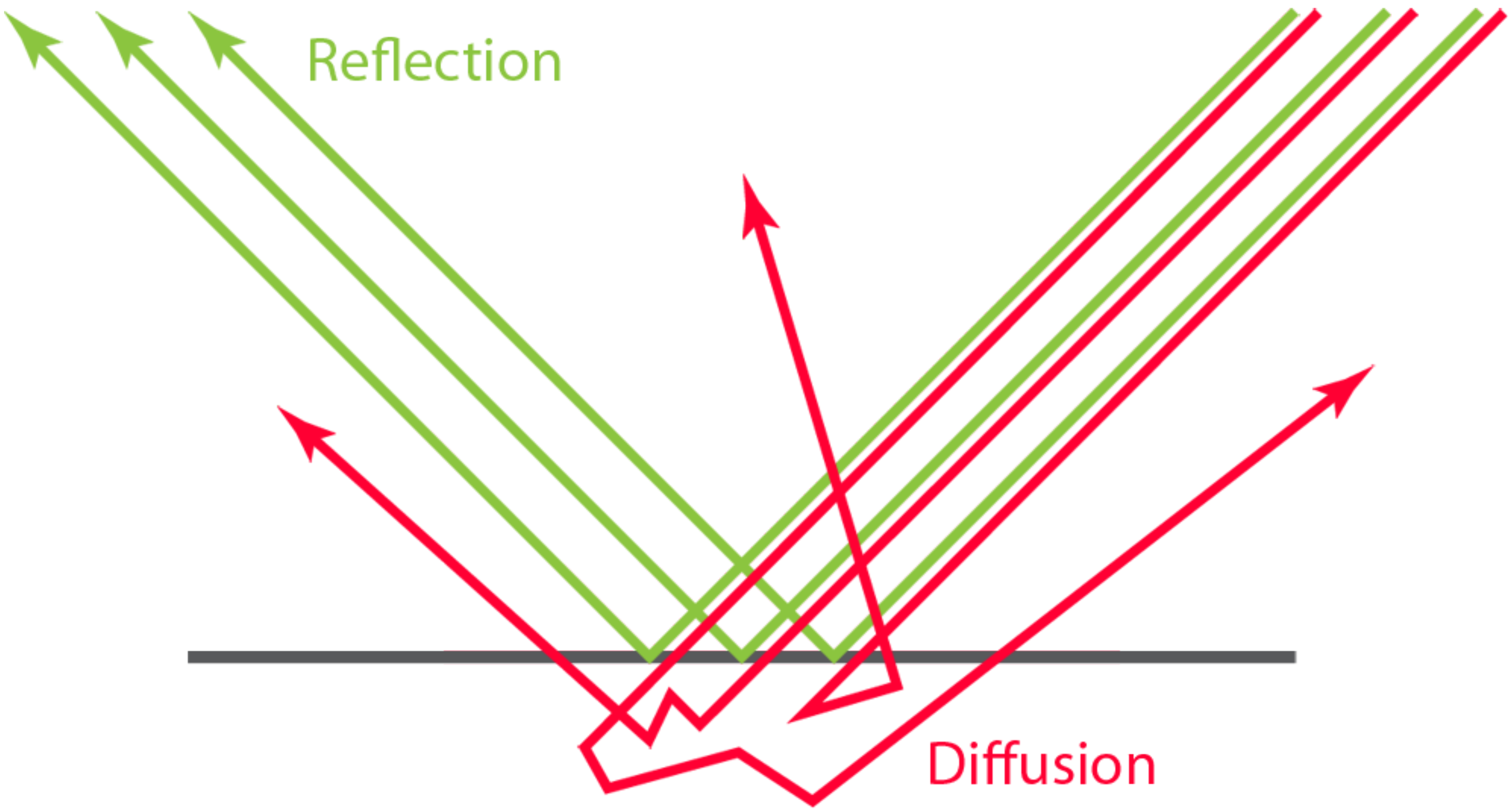
ADDITIONAL FUNCTIONS

- BTDF (bidirectional transmittance distribution function) models the scattering of transmitted light
- BSSRDF (bidirectional scattering-surface reflectance distribution function) model subsurface scattering and related effects
- BSDF (bidirectional scattering distribution function) encompasses BRDFs, BTDFs, and BSSRDFs

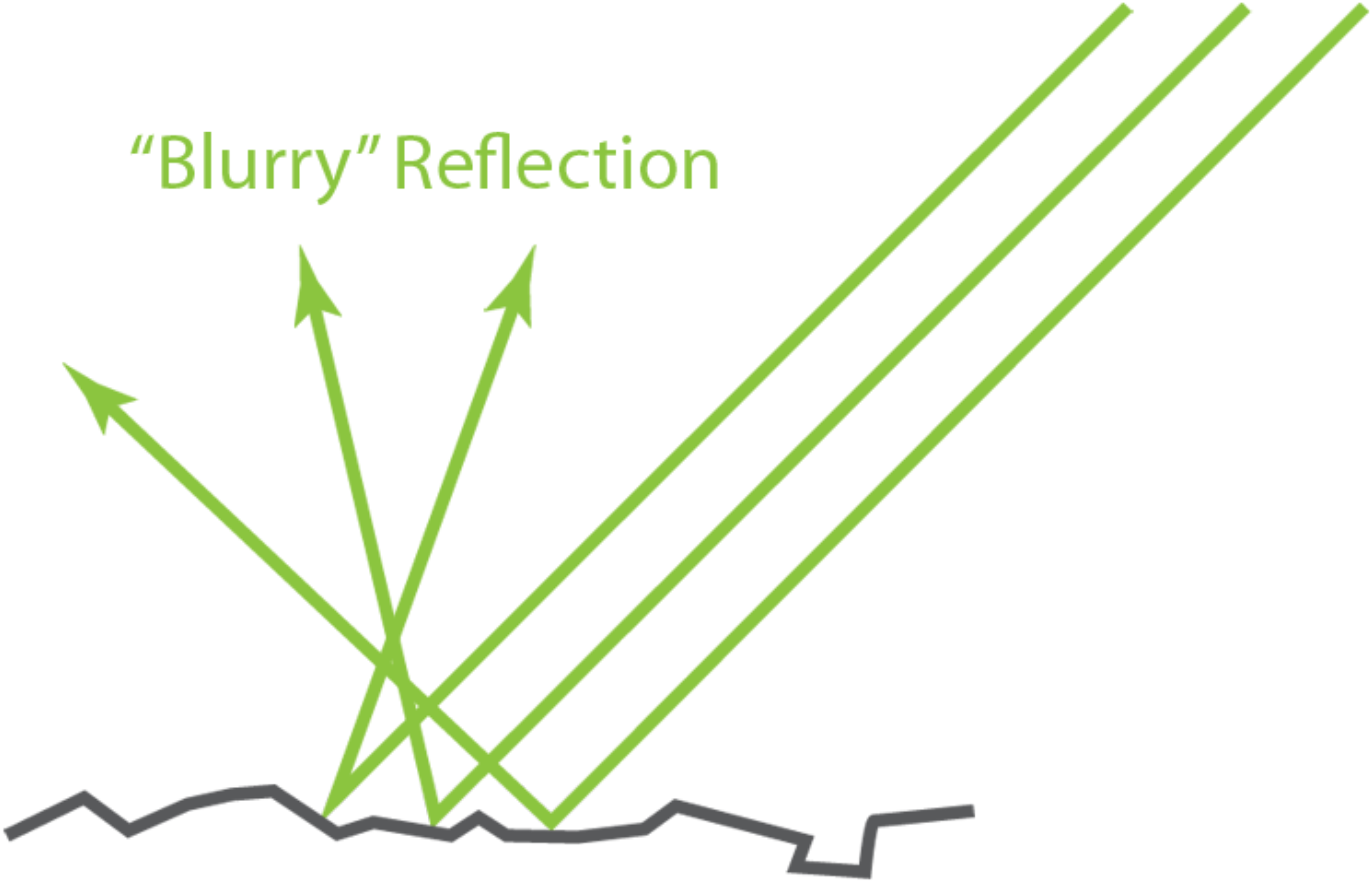
MATERIAL PARAMETERIZATION

- Base Color (Albedo)
  - Diffuse color based on scattering/absorption of light wavelengths
- Roughness
  - Amount of microsurfaces and imperfections on material's surface leading to light scatter
- Metallic
  - Degree of "metalness" including colored reflections and any diffusion from corrosion/dirt on surface
- Reflectance
  - Amount of reflected light on non-metallic surfaces

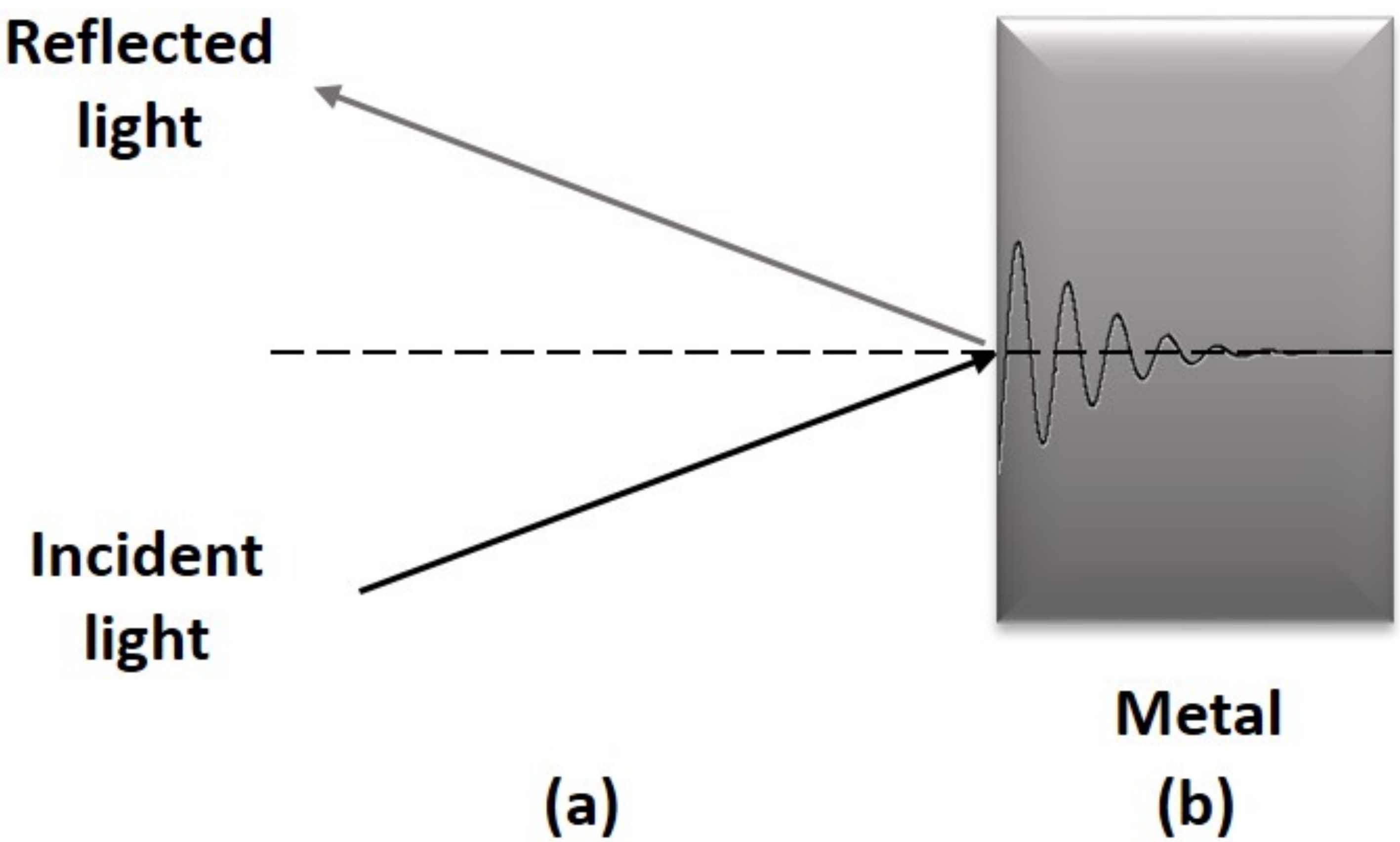
ALBEDO

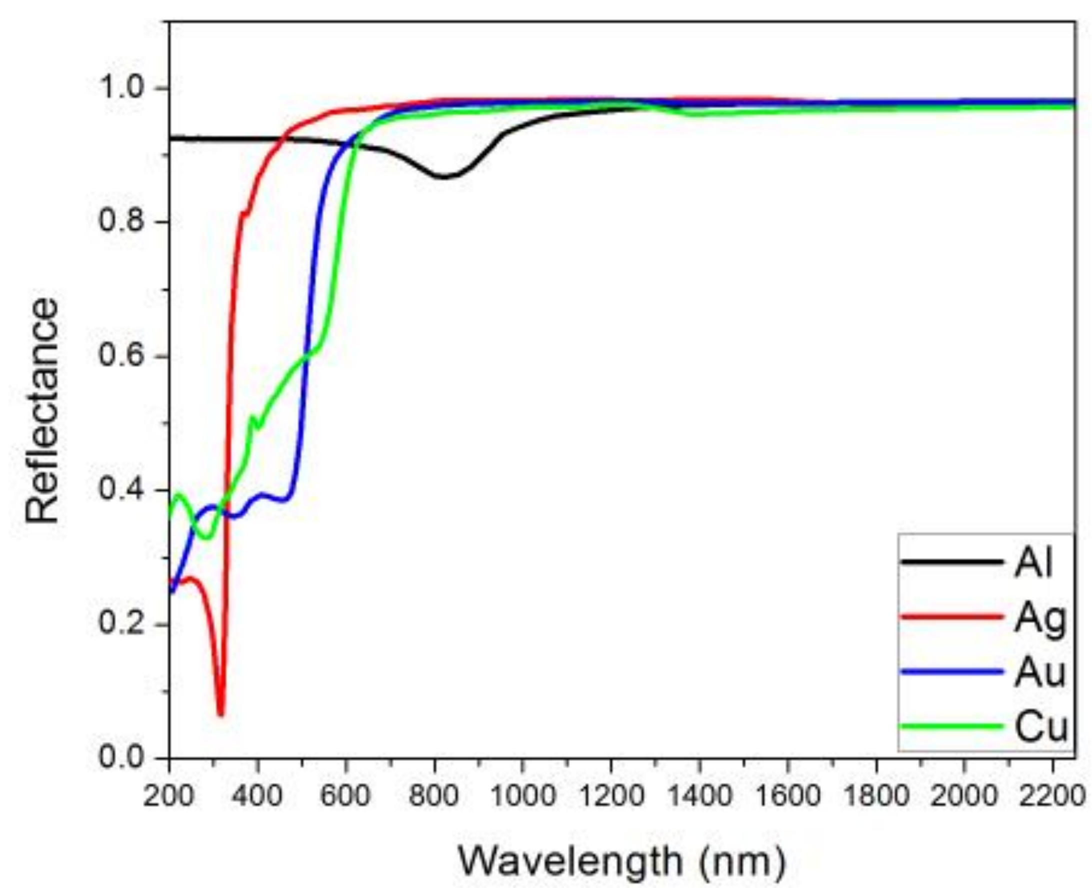


ROUGHNESS

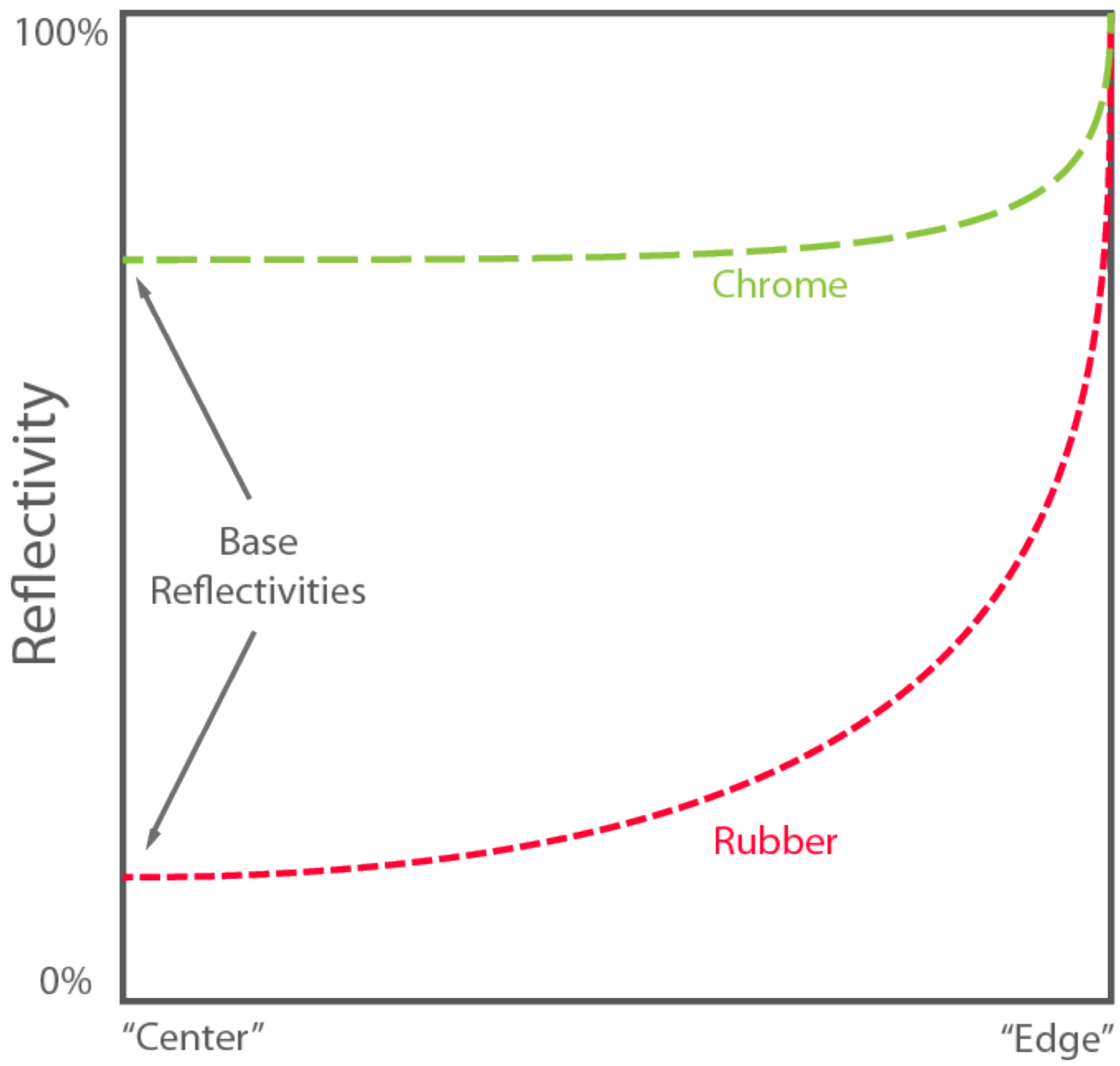


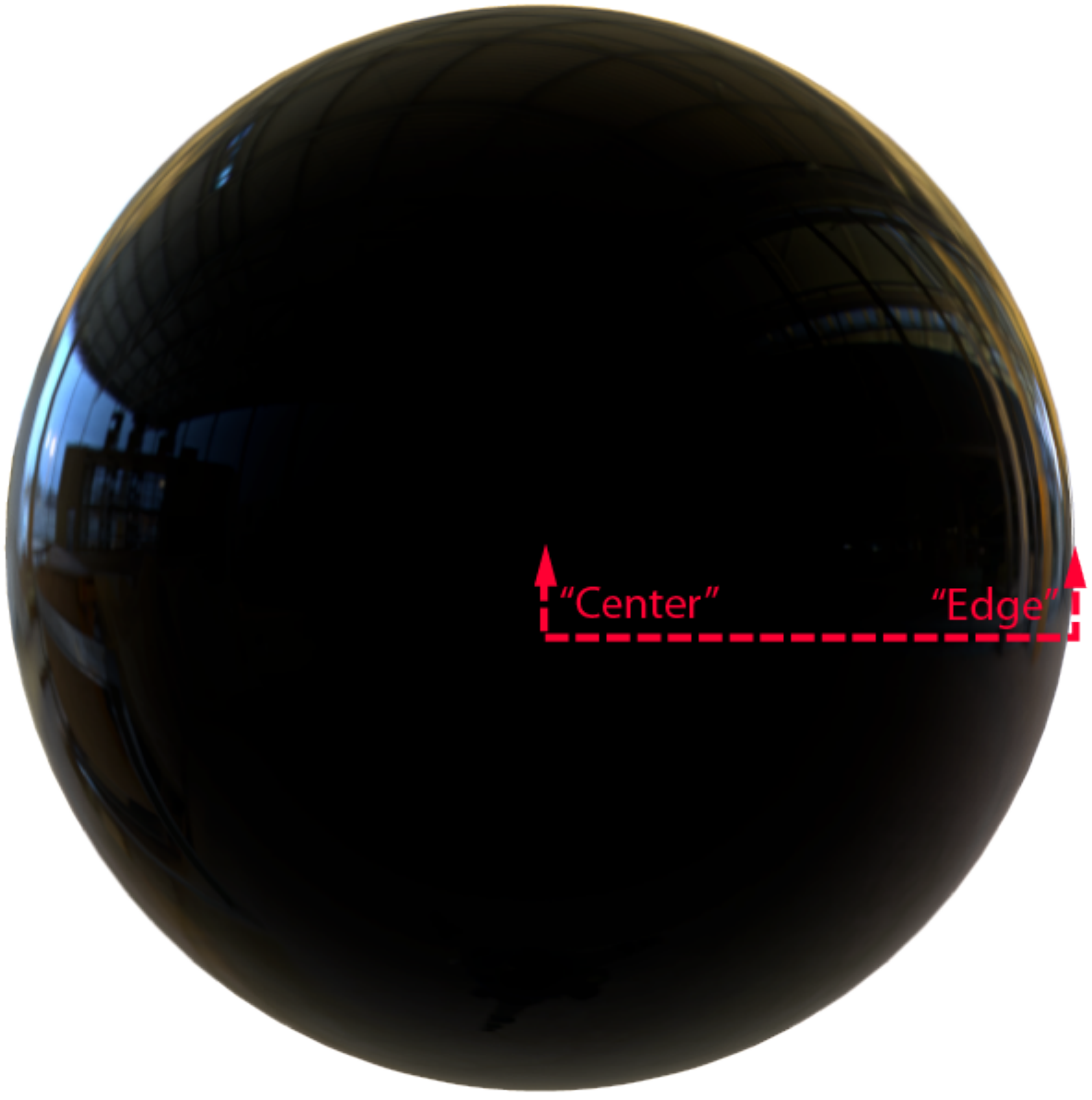
METALLIC


Reflected light
Incident light
Metal
(a)
(b)

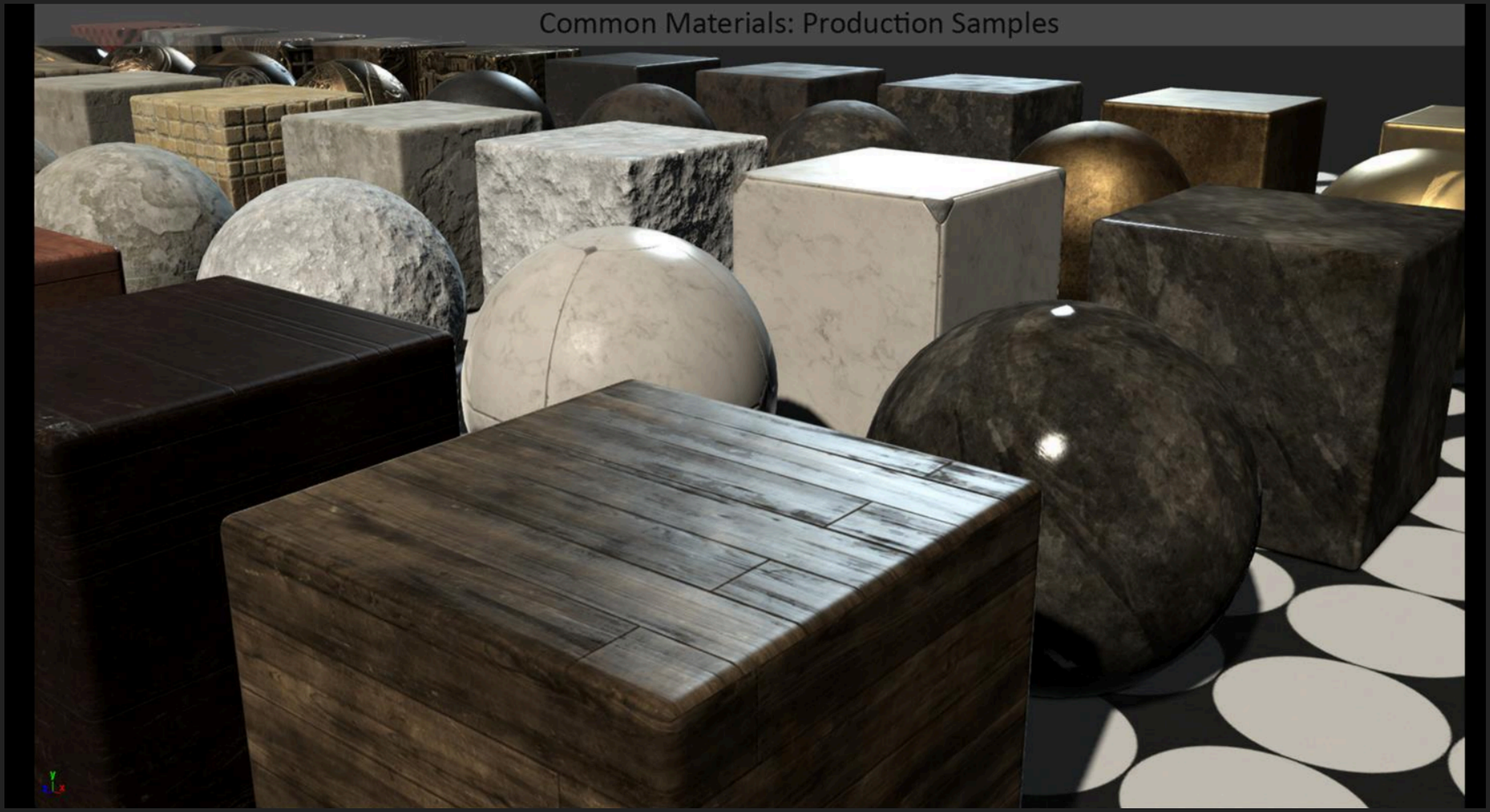

Reflectance
Wavelength (nm)
0.0
0.2
0.4
0.6
0.8
1.0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
Al
Ag
Au
Cu

REFLECTANCE





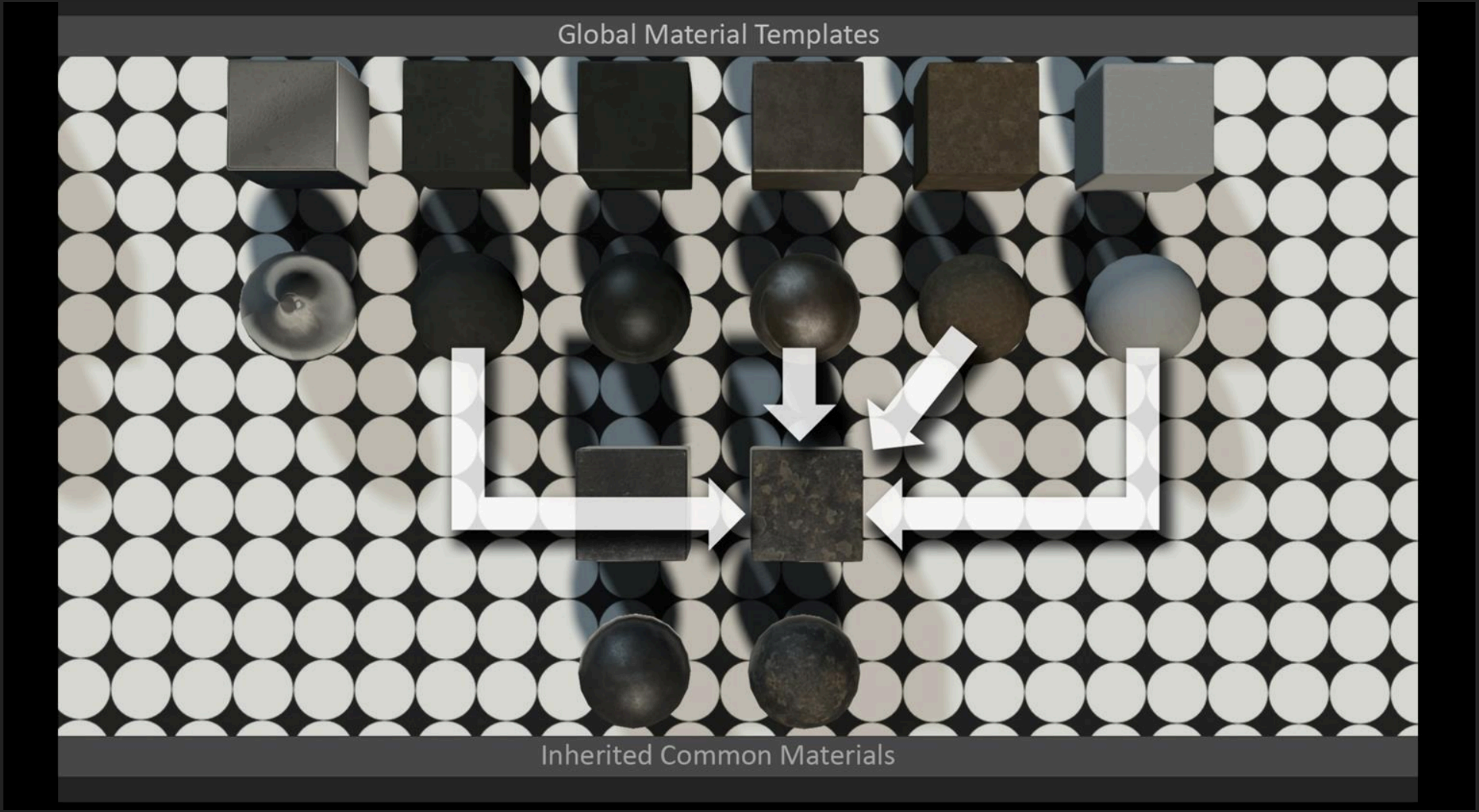
THE ORDER: 1886



MATERIAL TEMPLATES

- Store parameterization in base material
  - Changes from base material store on derived material
  - Global changes to base material change all derived material
- Material templates include:
  - Glasses
  - Masonry
  - Metals
  - Wood
  - etc
- Material compositing done using reference material and blend mask

MATERIAL TEMPLATING

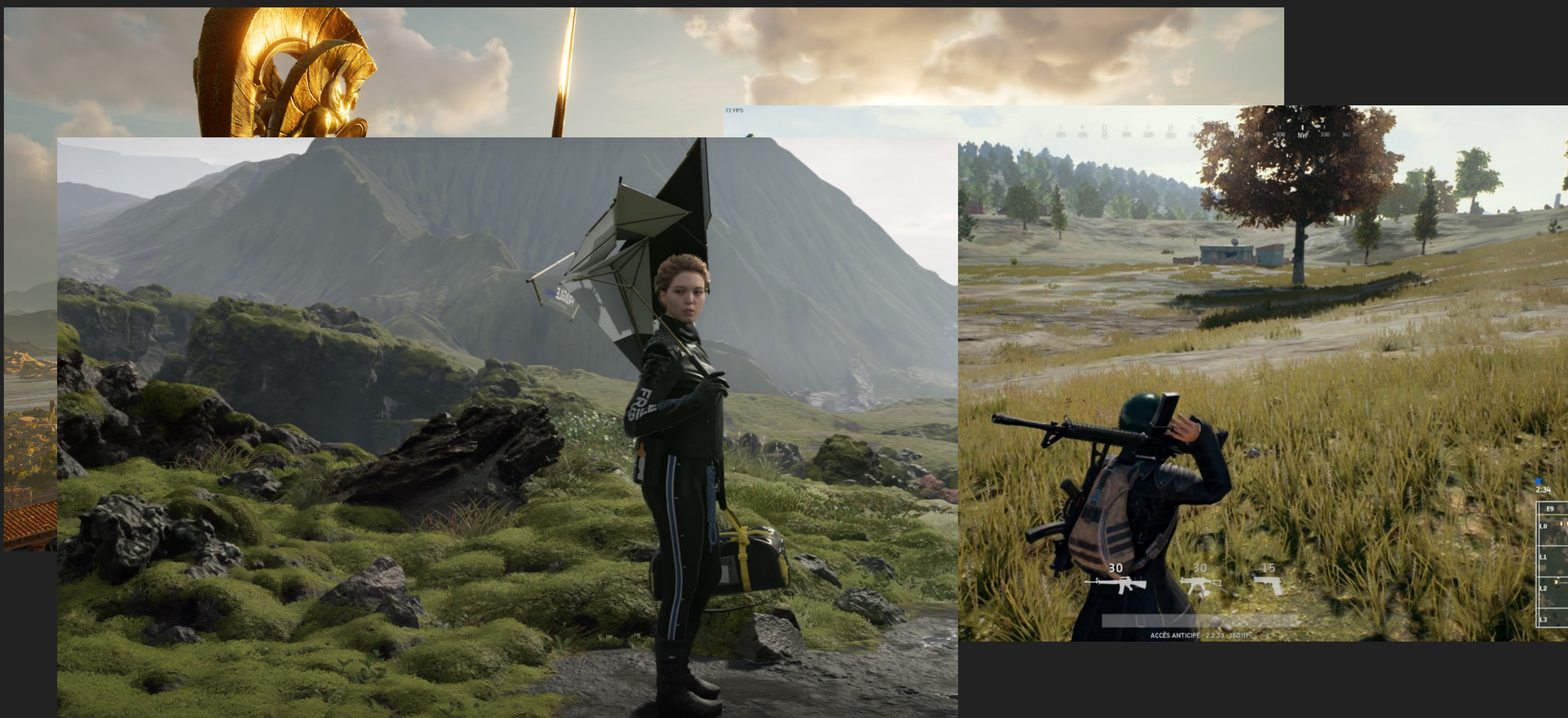


MATERIAL PIPELINE

- BRDFs provide a way for artists to interact with photorealistic lighting models and shader programming at a higher level
- Substance demo reel
    - https://www.youtube.com/watch?v=BYQpPK-qrTM
- Substance overview:
    - https://www.youtube.com/watch?v=y8q6-tgQjZc

GAMES THAT USE PBR MATERIALS…

- Industry standard so pretty much everyone…



YES, I MEAN EVERYONE

- Non-photorealistic rendering also benefits from PBR models!

SHADER CODE

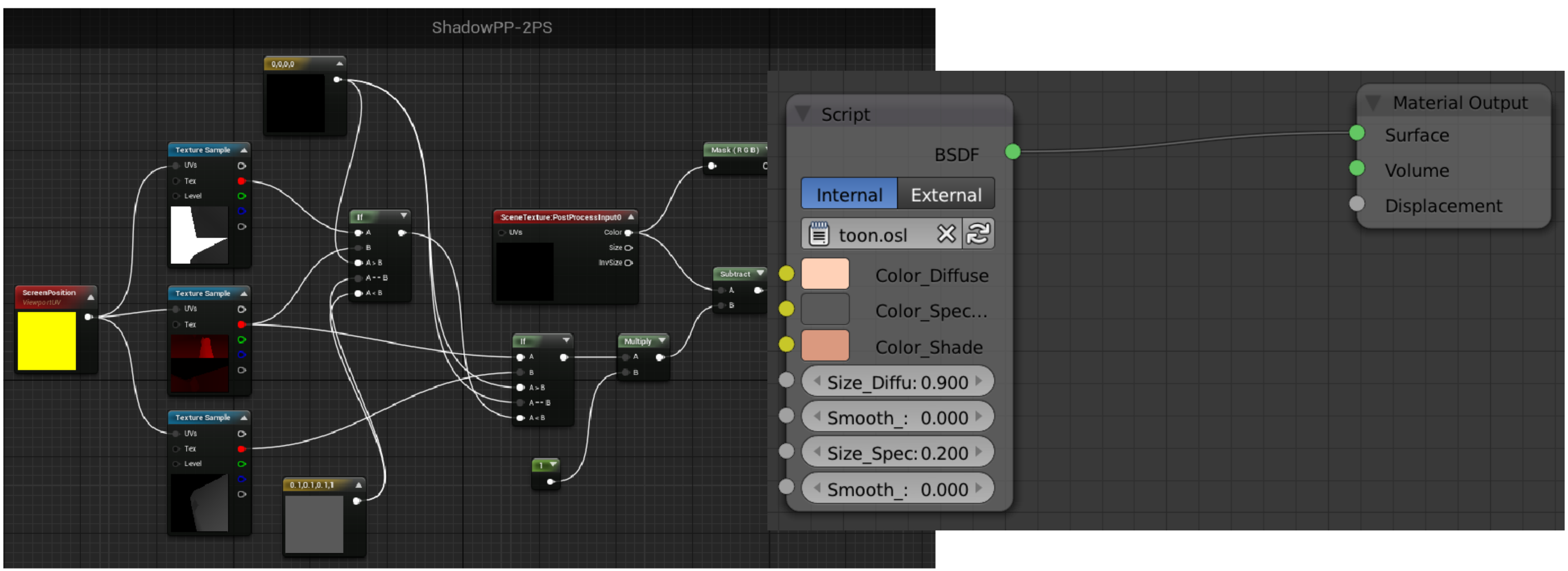
- Allows (relatively) easy writing of code to transform vertices, geometry, and pixels on the GPU
  - GLSL is language for OpenGL
  - HLSL is language for DirectX
- Setup for sending data to GPU done by graphics library
  - e.g. vertices to process, textures, lights, etc
- Programs on GPU run in parallel for every vertex, shape, pixel, etc being processed

SHADERS IN GODOT

- Godot provides its own language based on GLSL ES 3.0
  - Adds functionality
  - Reduces flexibility
  - Only supports vertex and fragment shaders
- Easier to set up and avoids low level issues
- Assumes some knowledge of shader programming in GLSL
- Access to compute shaders for allow for greater flexibility

MATERIAL SHADERS FOR ARTISTS

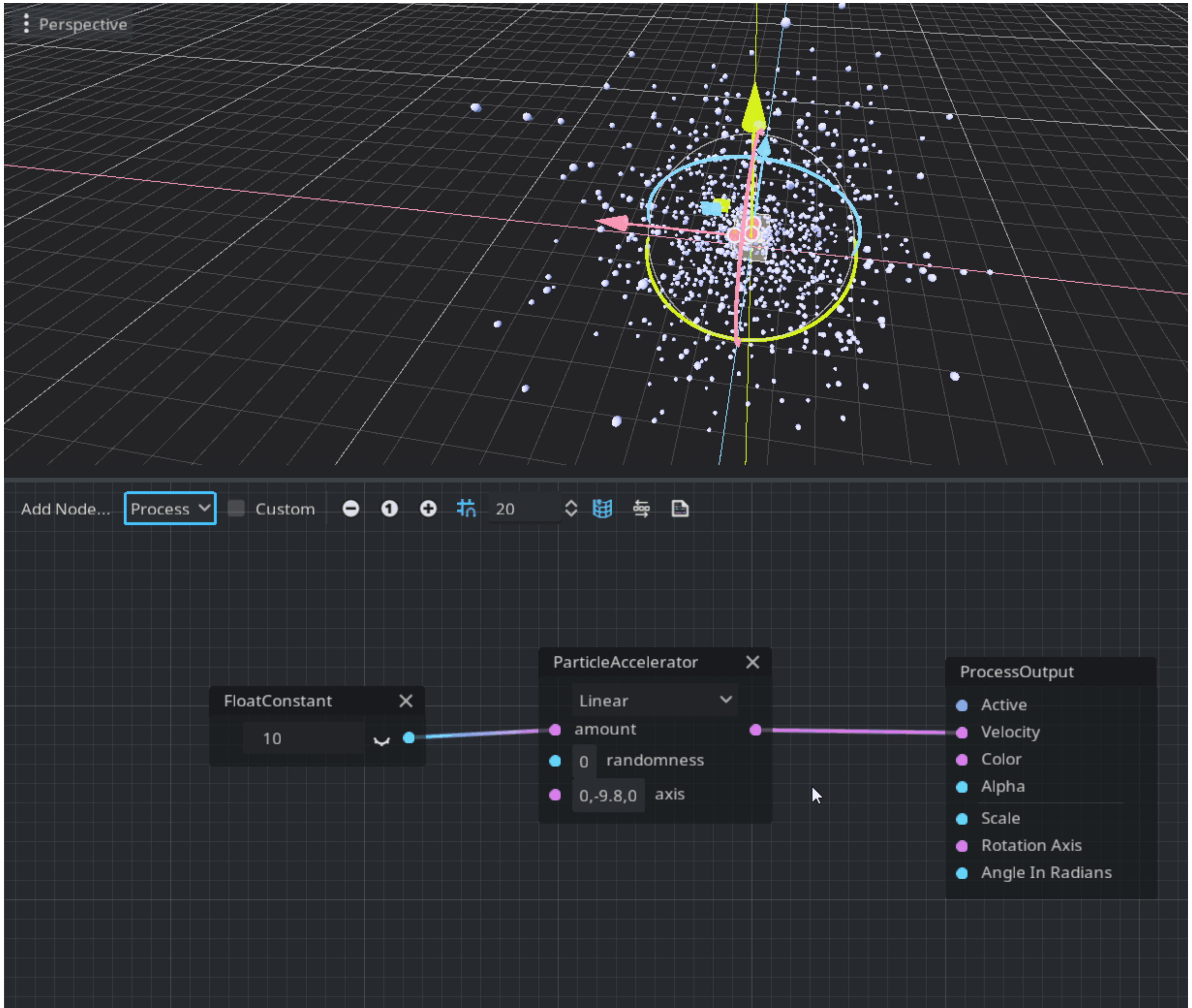
- Modern game engines and material programs provide interfaces for artists to work with shaders using visual scripting



VISUALSHADER IN GODOT

- VisualShader is Godot's node-based scripting language for shaders
  - Allows access to many, but not all, shader features
  - Provides a fast, visual way to create and debug shaders

PARTICLE EFFECT EXAMPLE IN VISUALSHADER



REFERENCES/RESOURCES

- [http://developer.download.nvidia.com/CgTutorial/cg_tutorial_chapter07.html]
- [https://learnopengl.com/Advanced-Lighting/Shadows/Shadow-Mapping]
- [https://developer.nvidia.com/gpugems/GPUGems3/gpugems3_ch08.html]
- [https://marmoset.co/posts/basic-theory-of-physically-based-rendering/]

REFERENCES/RESOURCES

- [https://eng.libretexts.org/Bookshelves/Materials_Science/Supplemental_Modules_(Materials_Science)/Optical_Properties/Metallic_Reflection]
- [https://godotengine.org/article/visual-shader-editor-back]
- [https://www.gdcvault.com/play/1020162/Crafting-a-Next-Gen-Material]