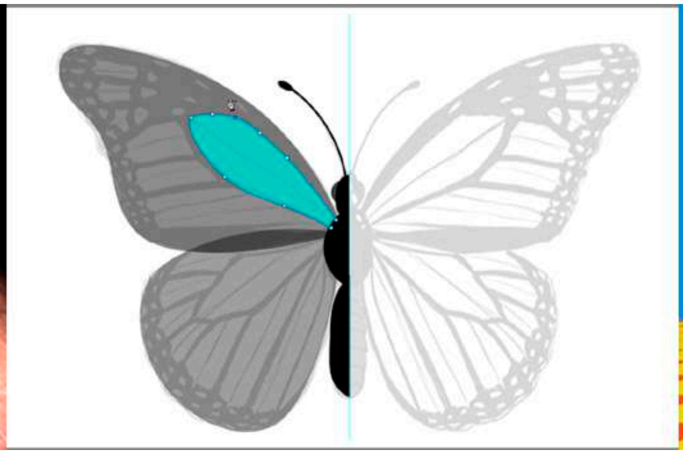
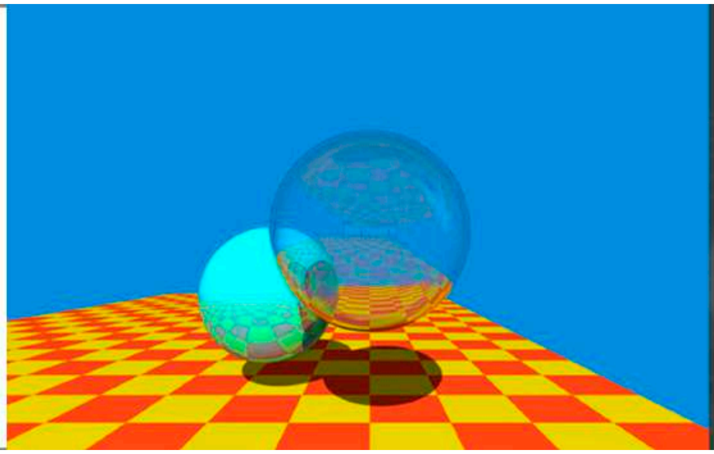
Introduction to Computer Graphics

GAMES101, Lingqi Yan, UC Santa Barbara

Lecture 8:

Shading 2
(Shading, Pipeline and Texture Mapping)

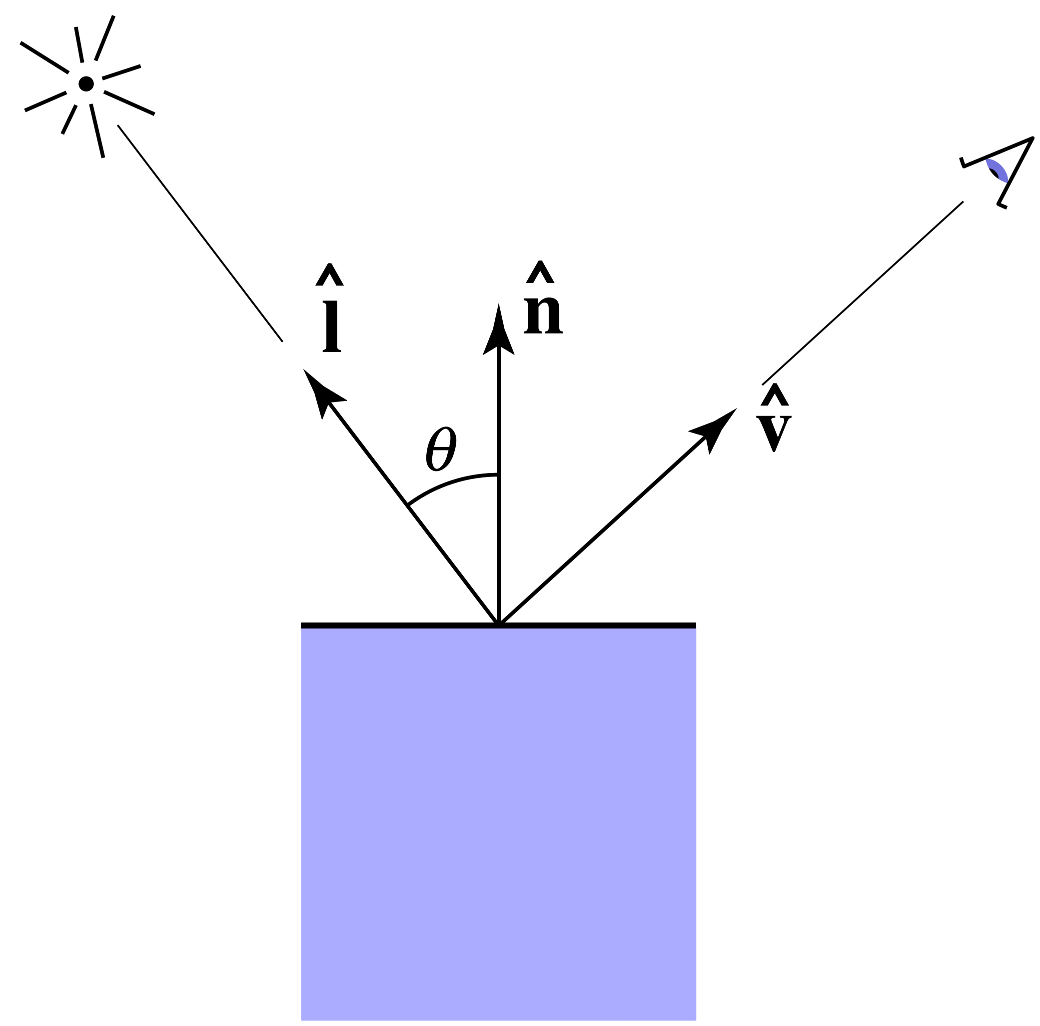





Announcements

- Homework 2
  - 45 submissions so far
  - Upside down? No problem
  - Active discussions in the BBS, pretty good
- Next homework is for shading
- Today's topics
  - Easy, but a lot

Last Lecture

- Shading 1
  - Blinn-Phong reflectance model
    - Diffuse
    - Specular
    - Ambient
  - At a **specific shading point**

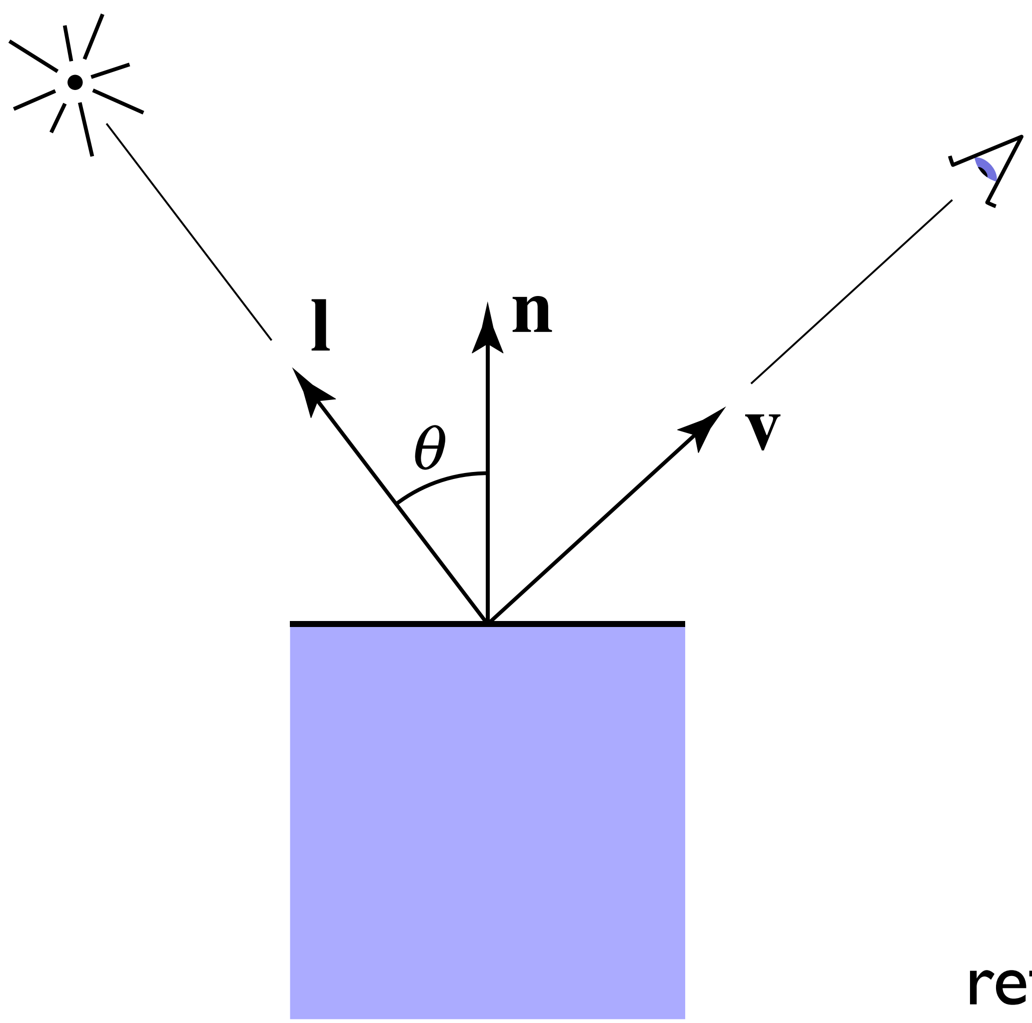


Today

- Shading 2
  - Blinn-Phong reflectance model
    - Specular and ambient terms
  - Shading frequencies
  - Graphics pipeline
  - Texture mapping
  - Barycentric coordinates

Recap: Lambertian (Diffuse) Term

Shading independent of view direction



energy arrived
at the shading point

$$L_d = k_d \, (I/r^2) \max(0, \mathbf{n} \cdot \mathbf{l})$$

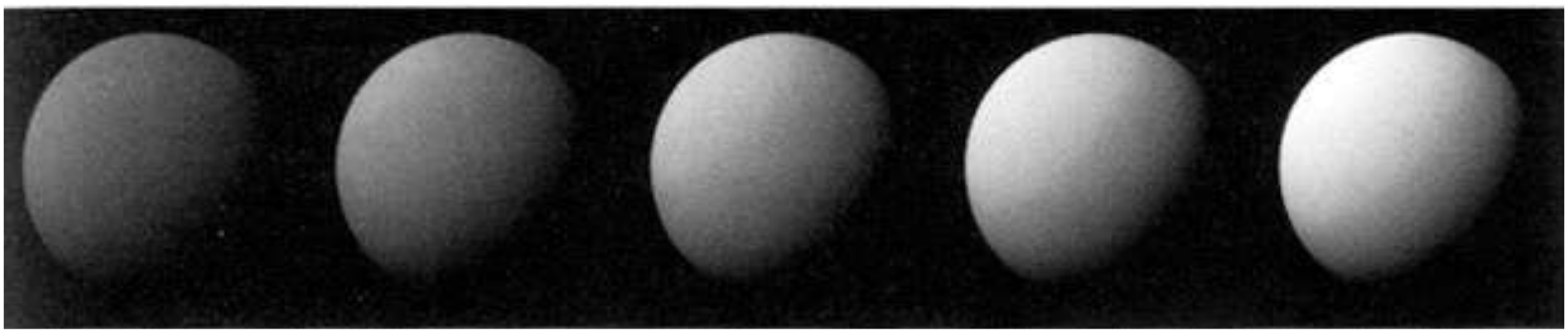
diffusely
reflected light

diffuse
coefficient
(color)

energy received
by the shading point

Recap: Lambertian (Diffuse) Term

Produces diffuse appearance



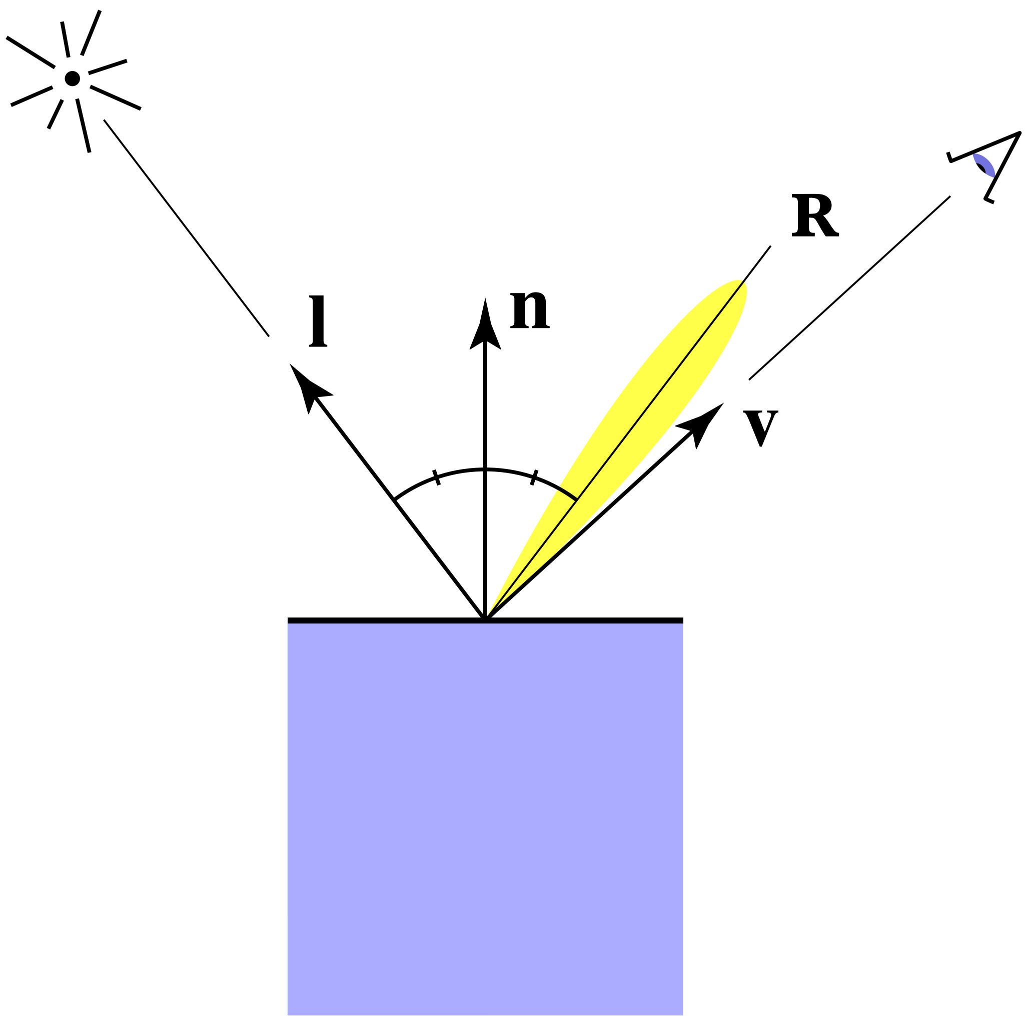
$k_d \longrightarrow$

[Foley et al.]

Specular Term (Blinn-Phong)

Intensity depends on view direction

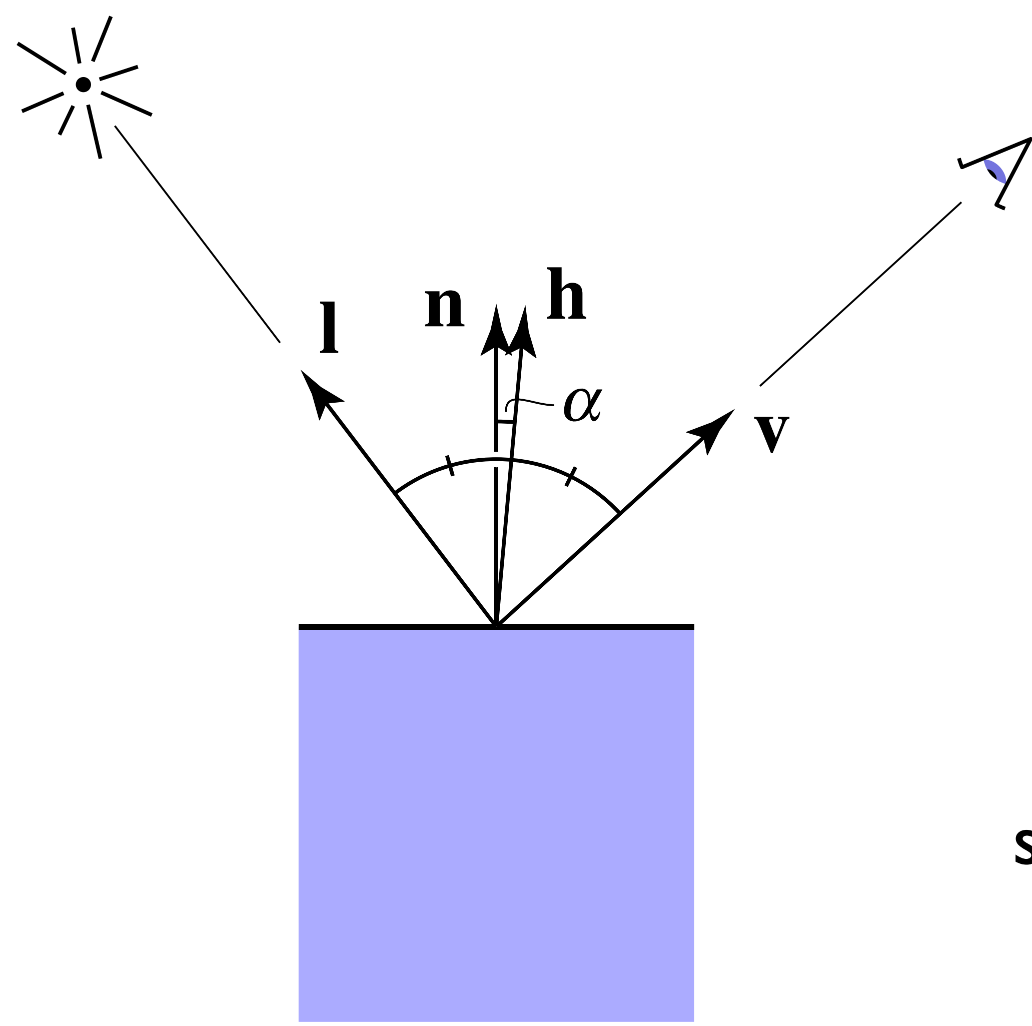
- Bright near mirror reflection direction



Specular Term (Blinn-Phong)

V close to mirror direction ⇔ **half vector** near normal

- Measure "near" by dot product of unit vectors



$$\mathbf{h} = \text{bisector}(\mathbf{v}, \mathbf{l})$$

(半程向量)

$$= \frac{\mathbf{v} + \mathbf{l}}{\|\mathbf{v} + \mathbf{l}\|}$$

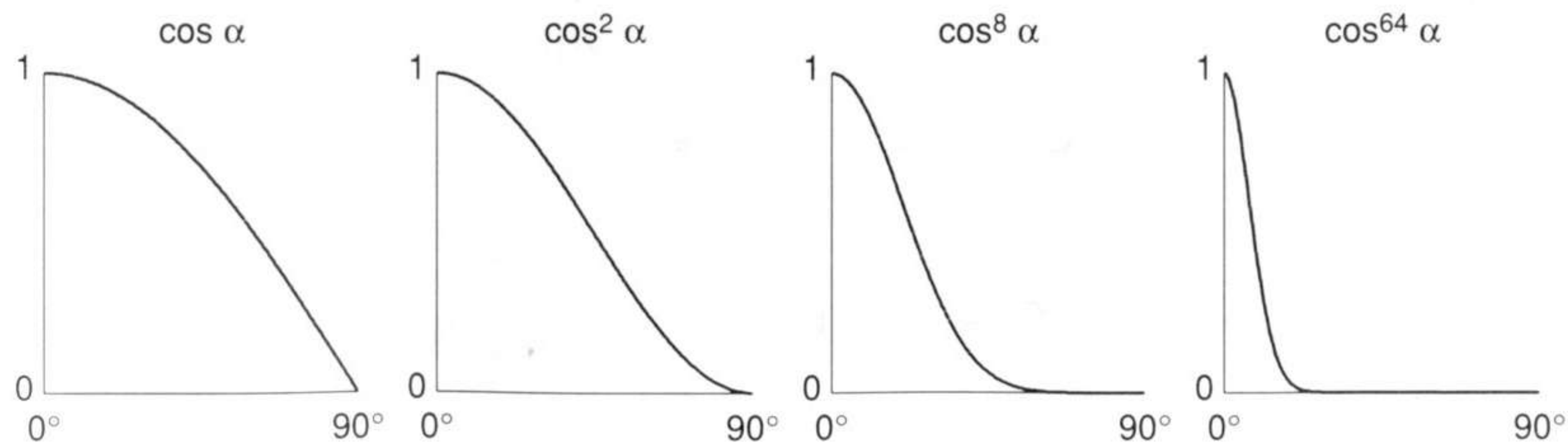
$$L_s = k_s \, (I/r^2) \max(0, \cos\alpha)^p$$
$$= k_s \, (I/r^2) \max(0, \mathbf{n} \cdot \mathbf{h})^p$$

specularly reflected light (L_s)

specular coefficient (k_s)

Cosine Power Plots

Increasing p narrows the reflection lobe

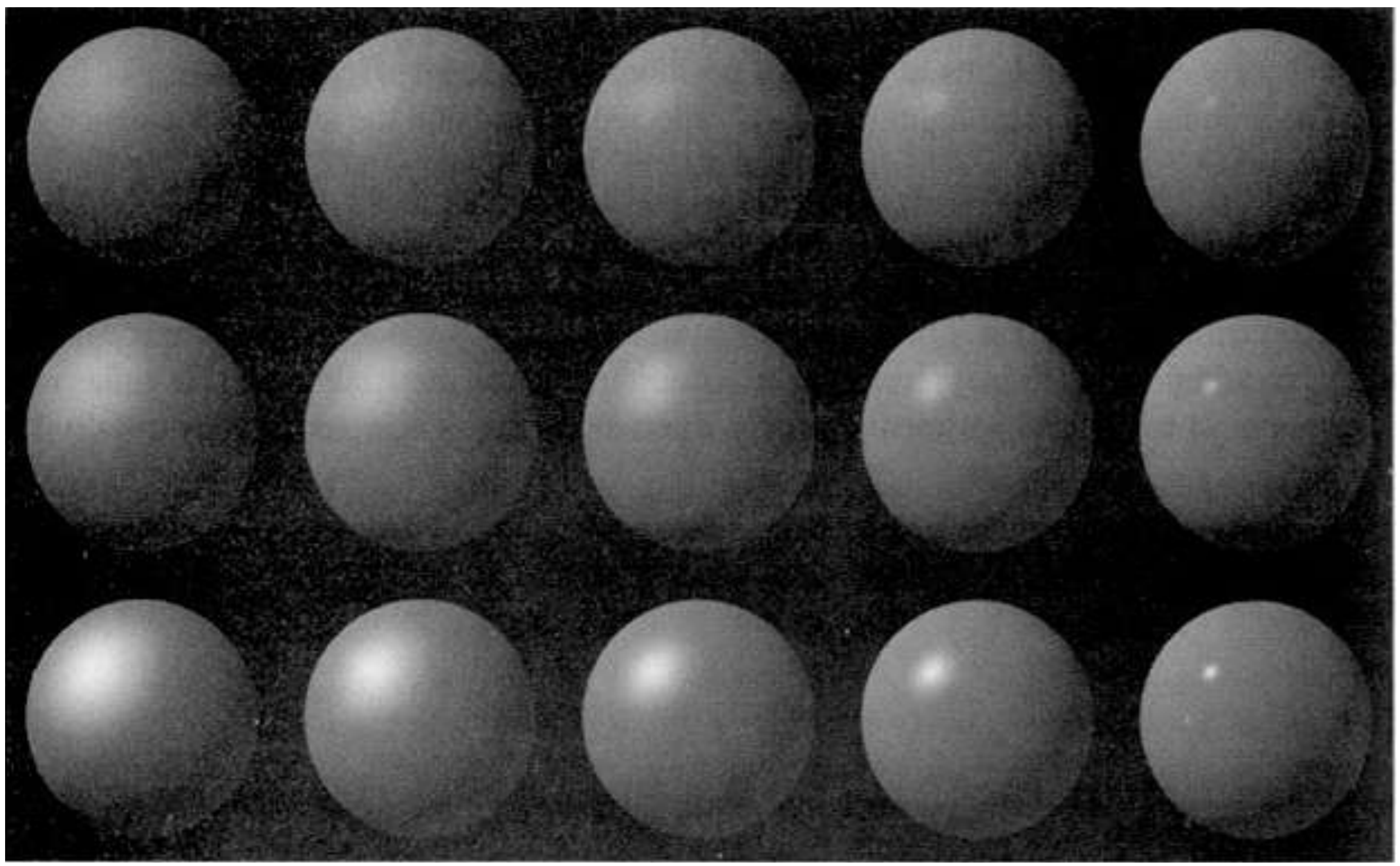


[Foley et al.]

Specular Term (Blinn-Phong)

Blinn-Phong

$$L_s = k_s \, (I/r^2) \max(0, \mathbf{n} \cdot \mathbf{h})^p$$



k_s ↓

p →

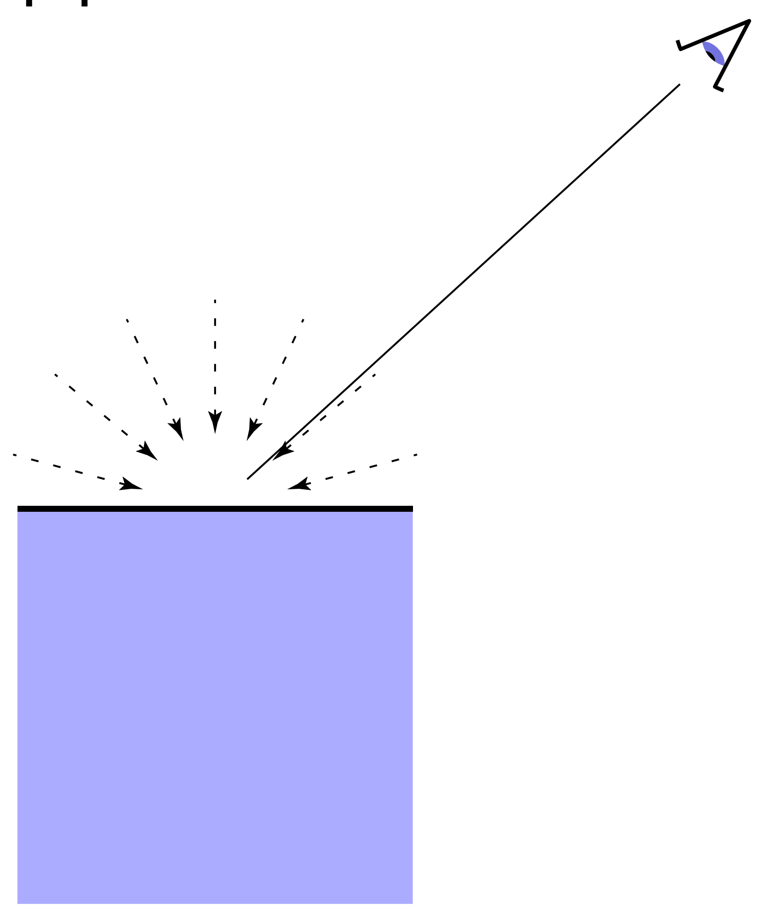
Note: showing
Ld + Ls together

[Foley et al.]

Ambient Term

Shading that does not depend on anything

- Add constant color to account for disregarded illumination and fill in black shadows
- This is approximate / fake!

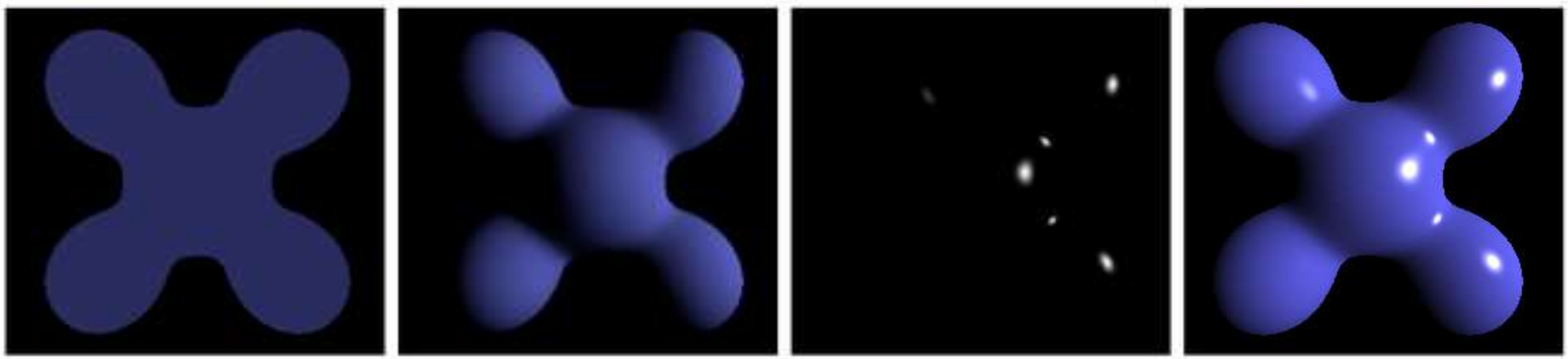


$$L_a = k_a \, I_a$$

ambient coefficient

reflected ambient light

Blinn-Phong Reflection Model



Ambient + Diffuse + Specular = Blinn-Phong Reflection

$$
\begin{aligned}
L &= L_a + L_d + L_s \\
&= k_a\, I_a + k_d\,(I/r^2)\max(0, \mathbf{n}\cdot\mathbf{l}) + k_s\,(I/r^2)\max(0, \mathbf{n}\cdot\mathbf{h})^p
\end{aligned}
$$

Questions?

Shading Frequencies

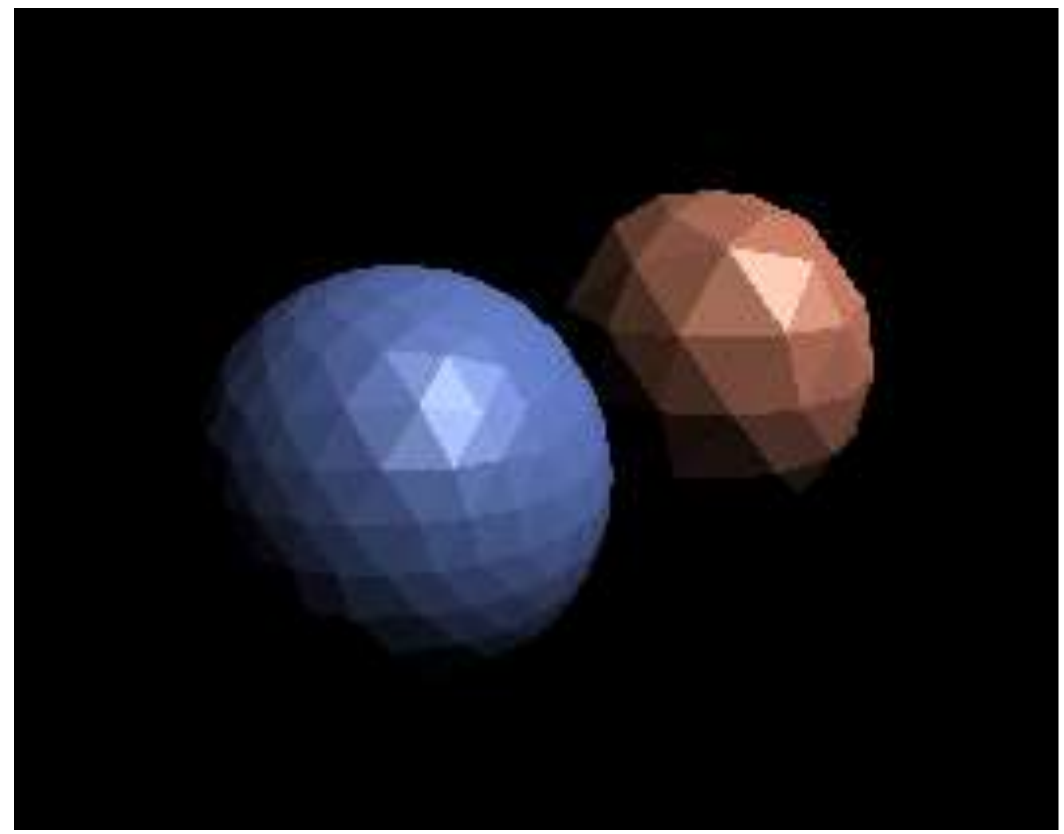
Shading Frequencies

What caused the shading difference?

Shade each triangle (flat shading)

Flat shading

- Triangle face is flat — one normal vector
- Not good for smooth surfaces



Shade each vertex (Gouraud shading)

Gouraud shading

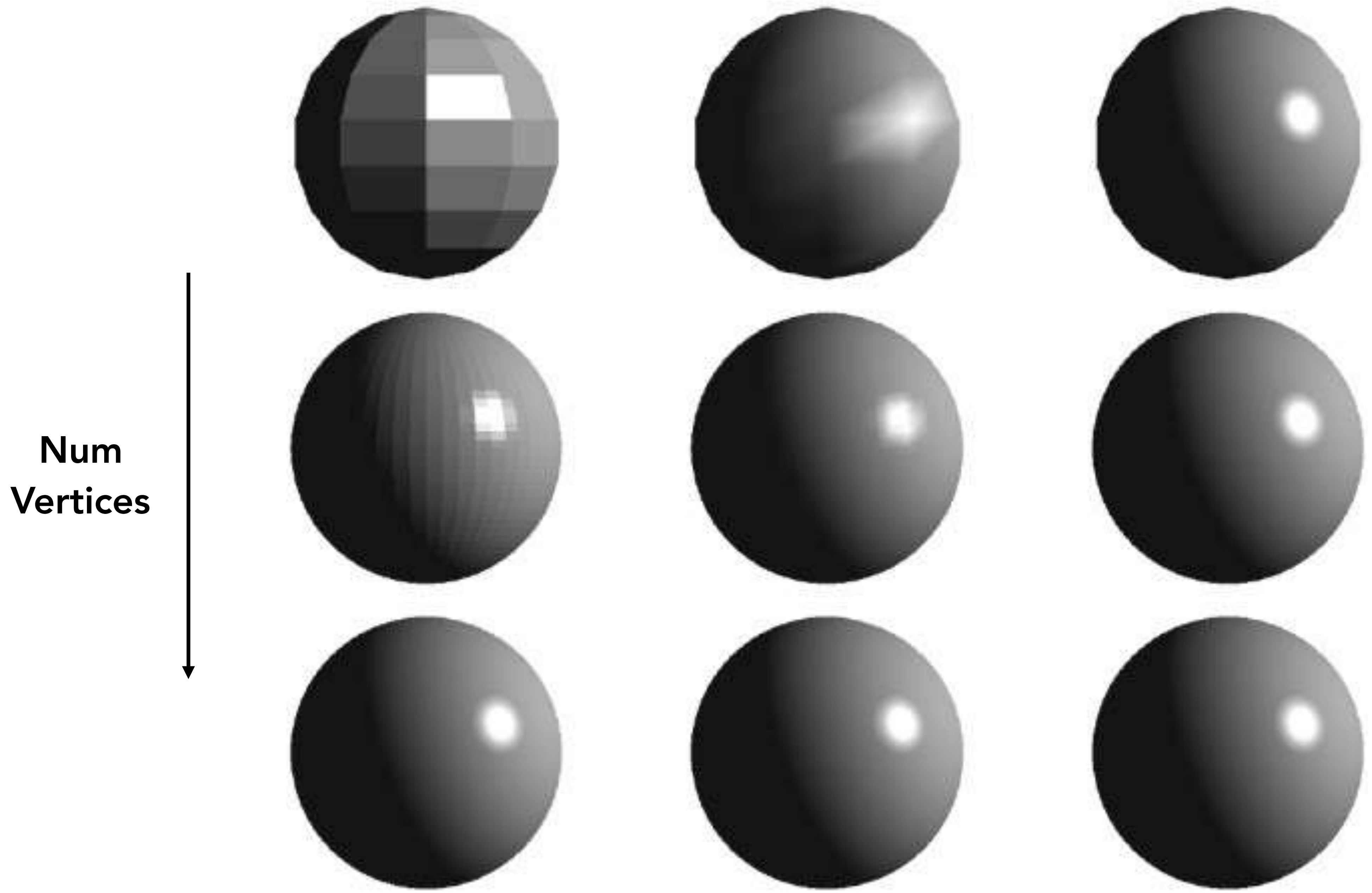
- Interpolate colors from vertices across triangle
- Each vertex has a normal vector (how?)

Shade each pixel (Phong shading)

Phong shading

- Interpolate normal vectors across each triangle
- Compute full shading model at each pixel
- Not the **Blinn-Phong Reflectance Model**

Shading Frequency: Face, Vertex or Pixel



Shading freq. : Face Vertex Pixel

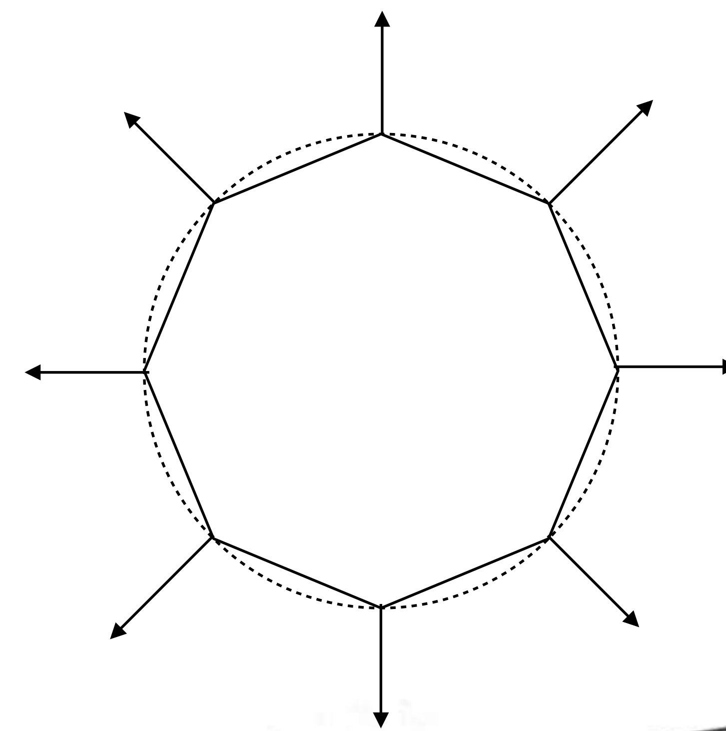
Shading type : Flat Gouraud Phong

Image credit: Happyman, http://cg2010studio.com/

Defining Per-Vertex Normal Vectors

Best to get vertex normals from the underlying geometry

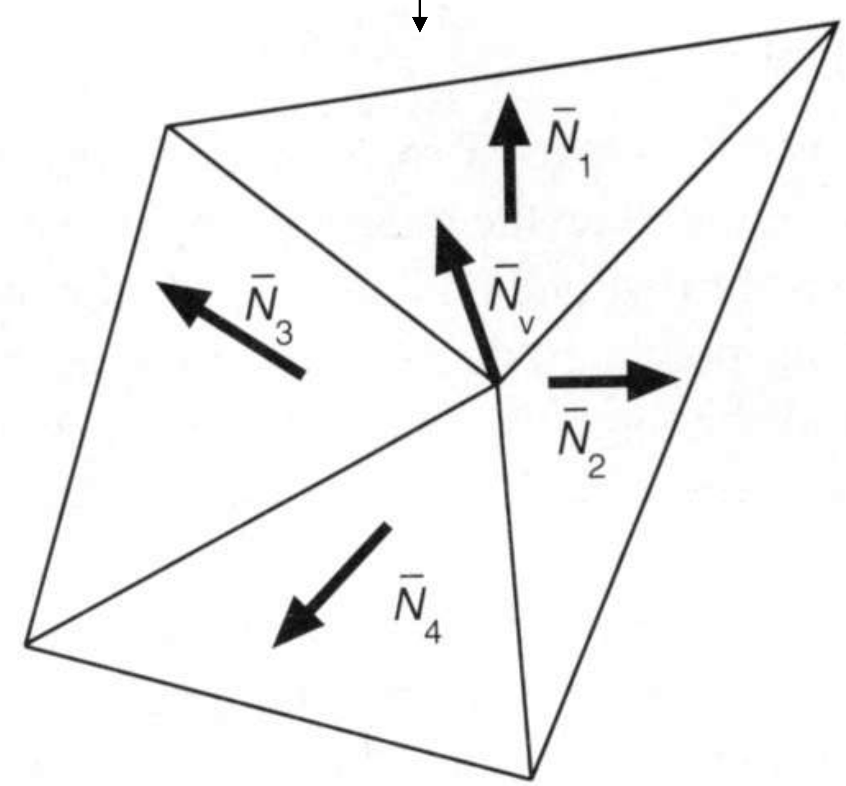
- e.g. consider a sphere



Otherwise have to infer vertex normals from triangle faces

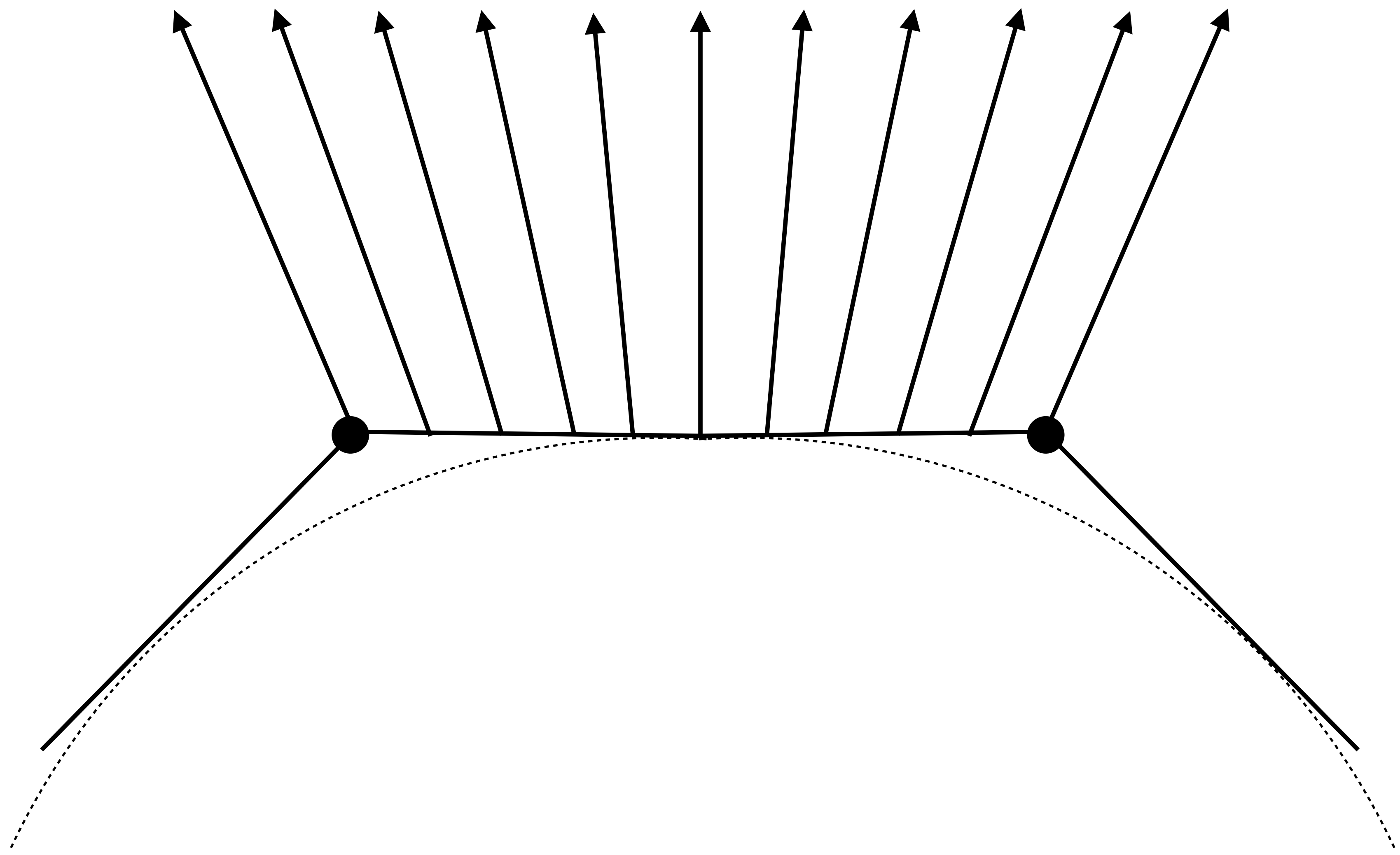
- Simple scheme: **average surrounding face normals**

$$N_v = \frac{\sum_i N_i}{\|\sum_i N_i\|}$$



Defining Per-Pixel Normal Vectors

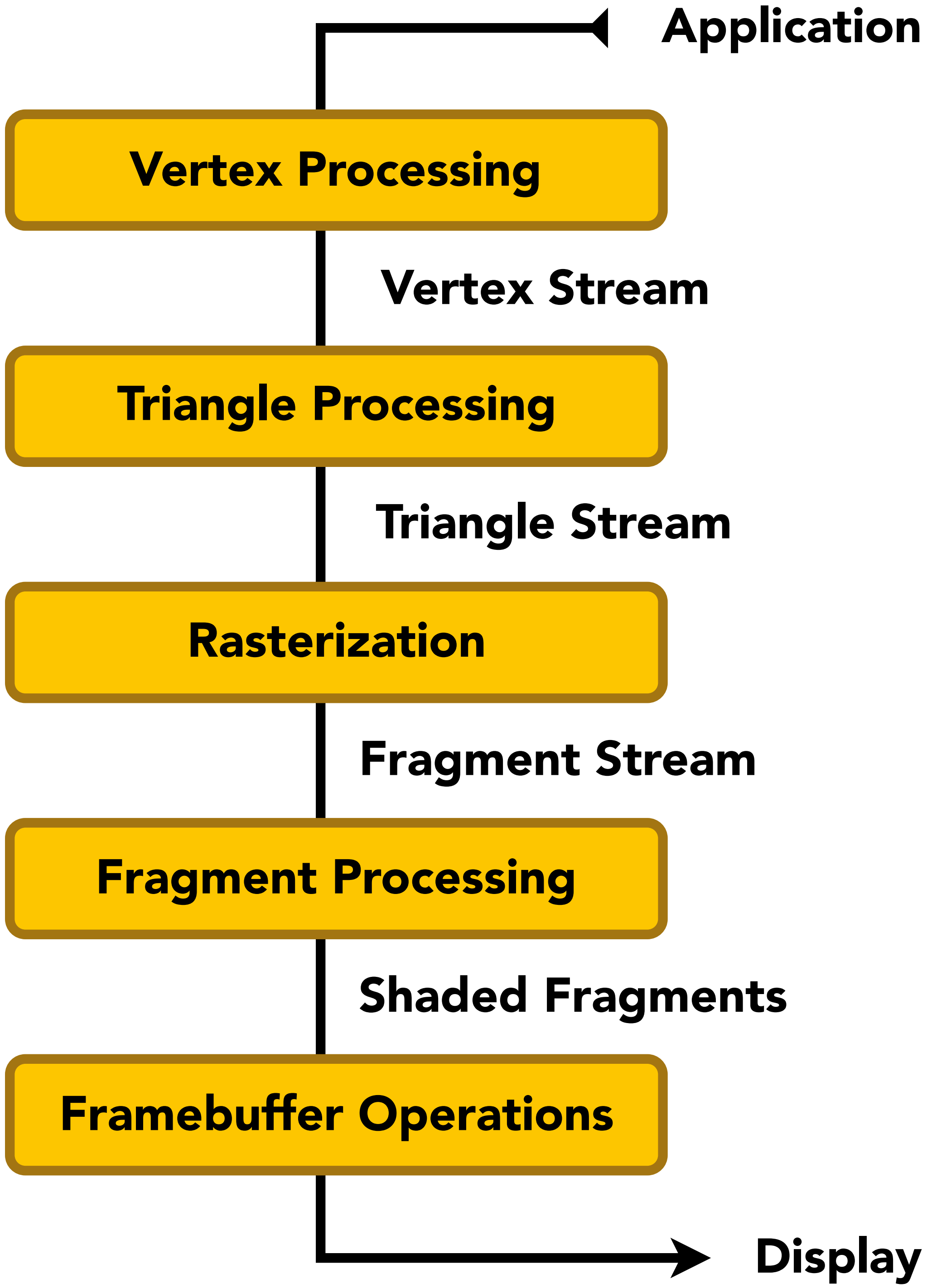
Barycentric interpolation (introducing soon) of vertex normals

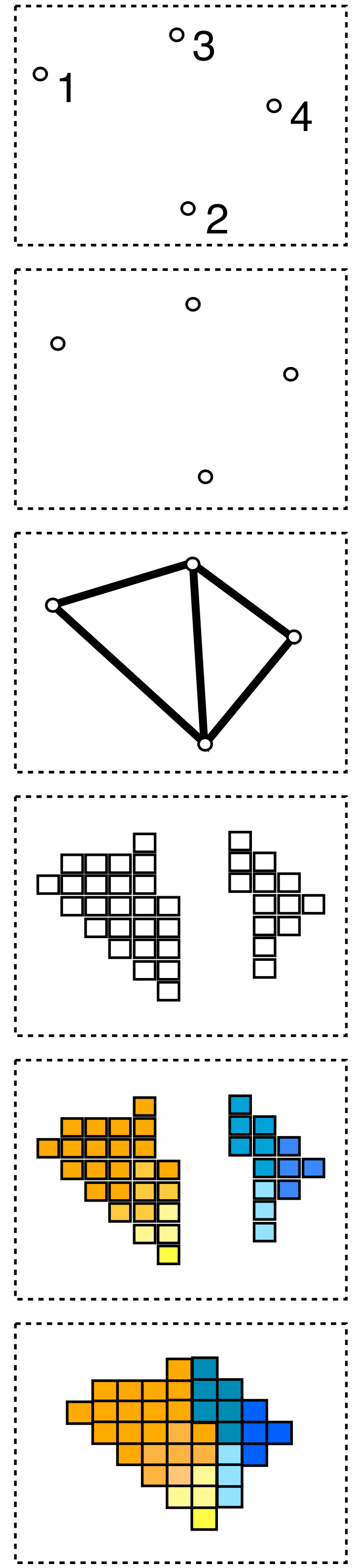


Don't forget to normalize the interpolated directions

Graphics (**Real-time Rendering**) Pipeline

Graphics Pipeline





Input: vertices in 3D space

Vertices positioned in screen space

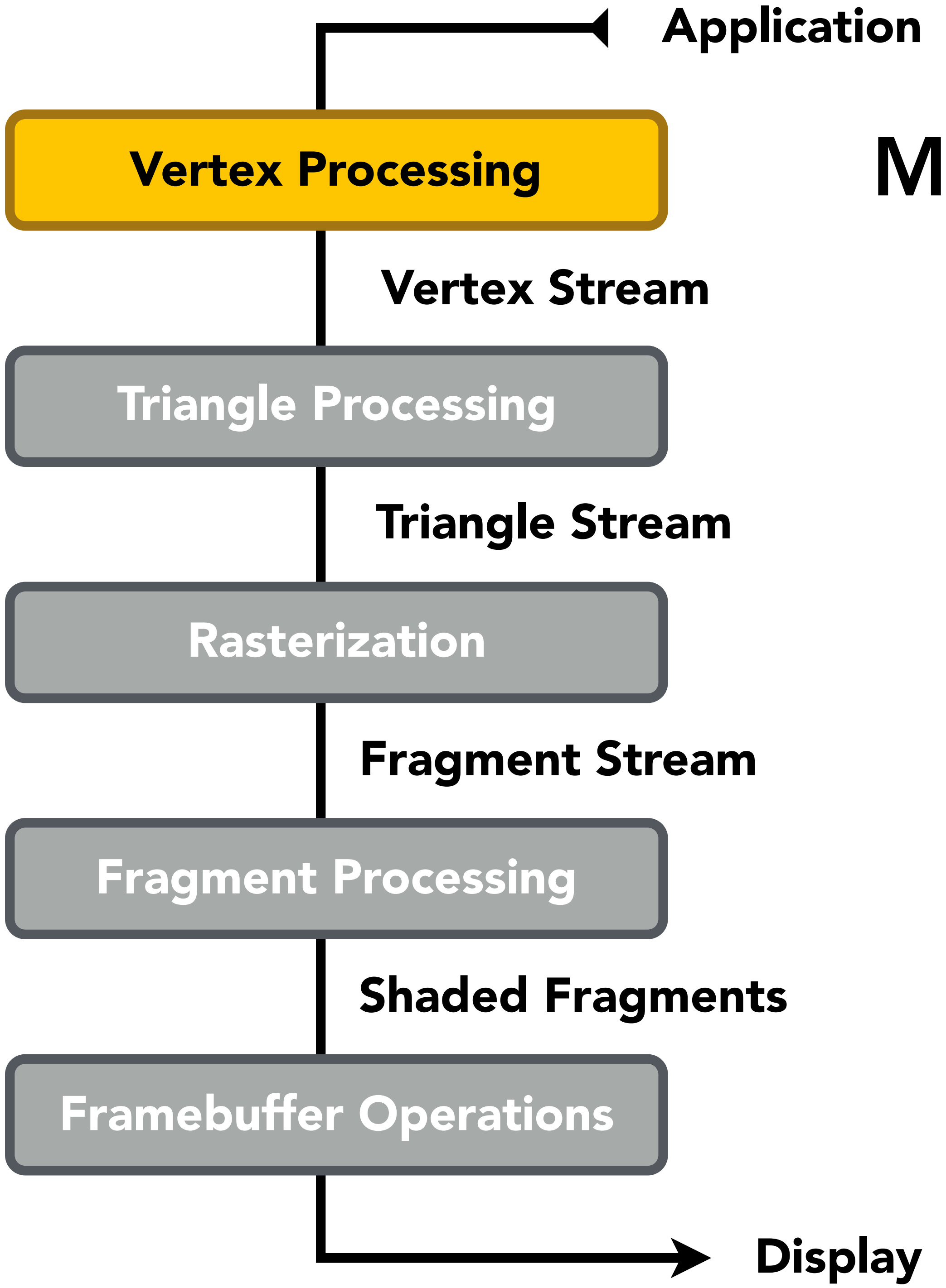
Triangles positioned in screen space

Fragments (one per covered sample)

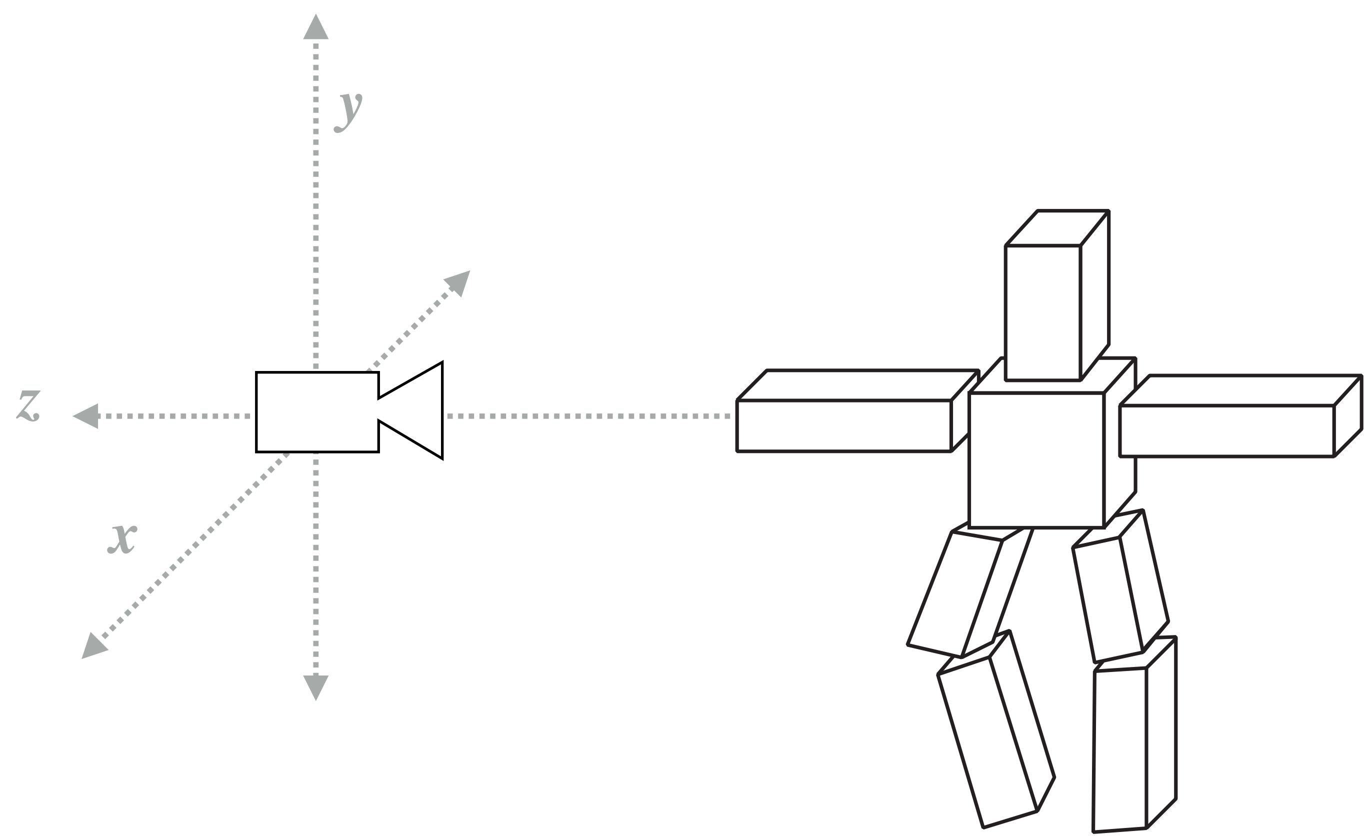
Shaded fragments

Output: image (pixels)

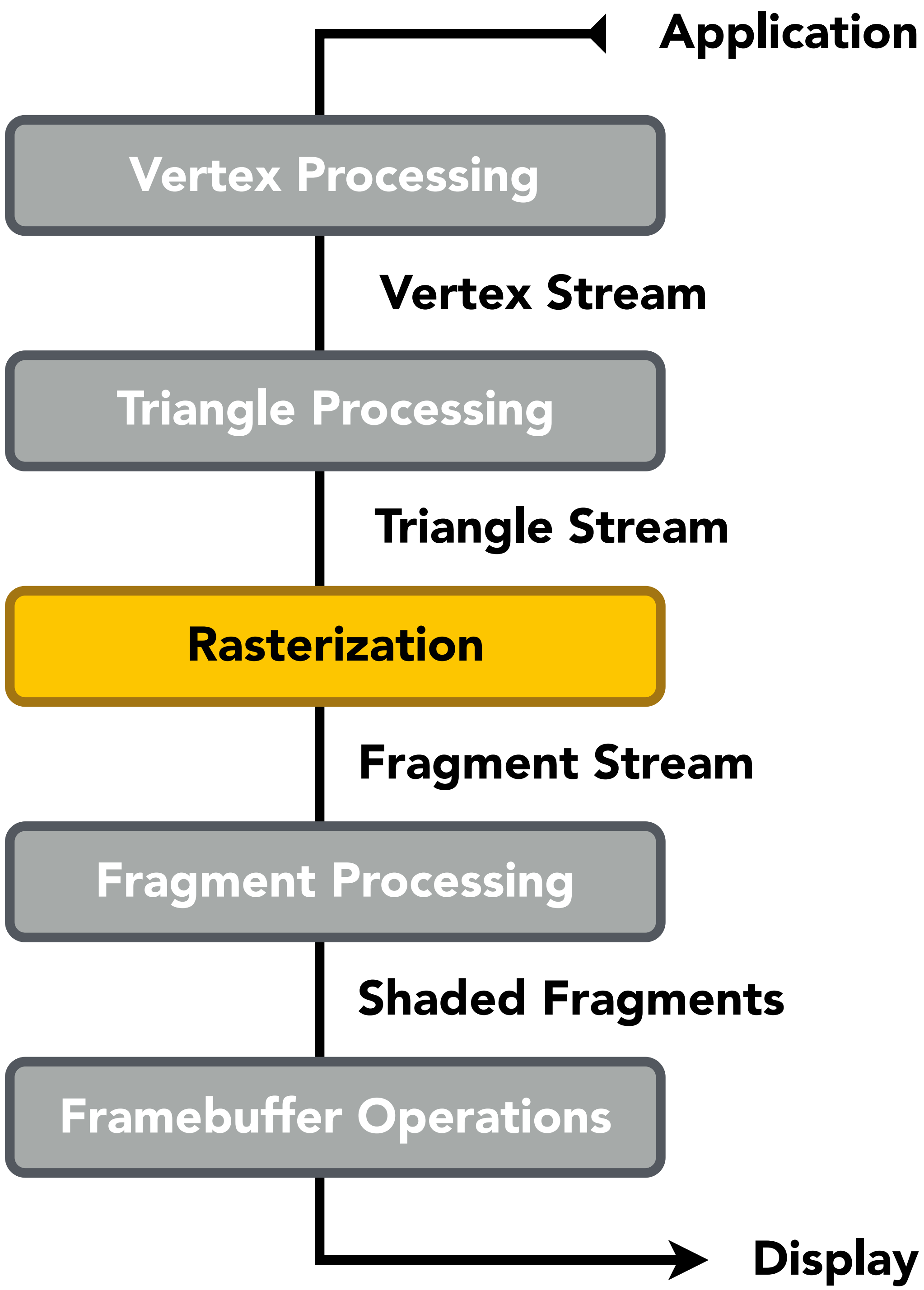
Graphics Pipeline



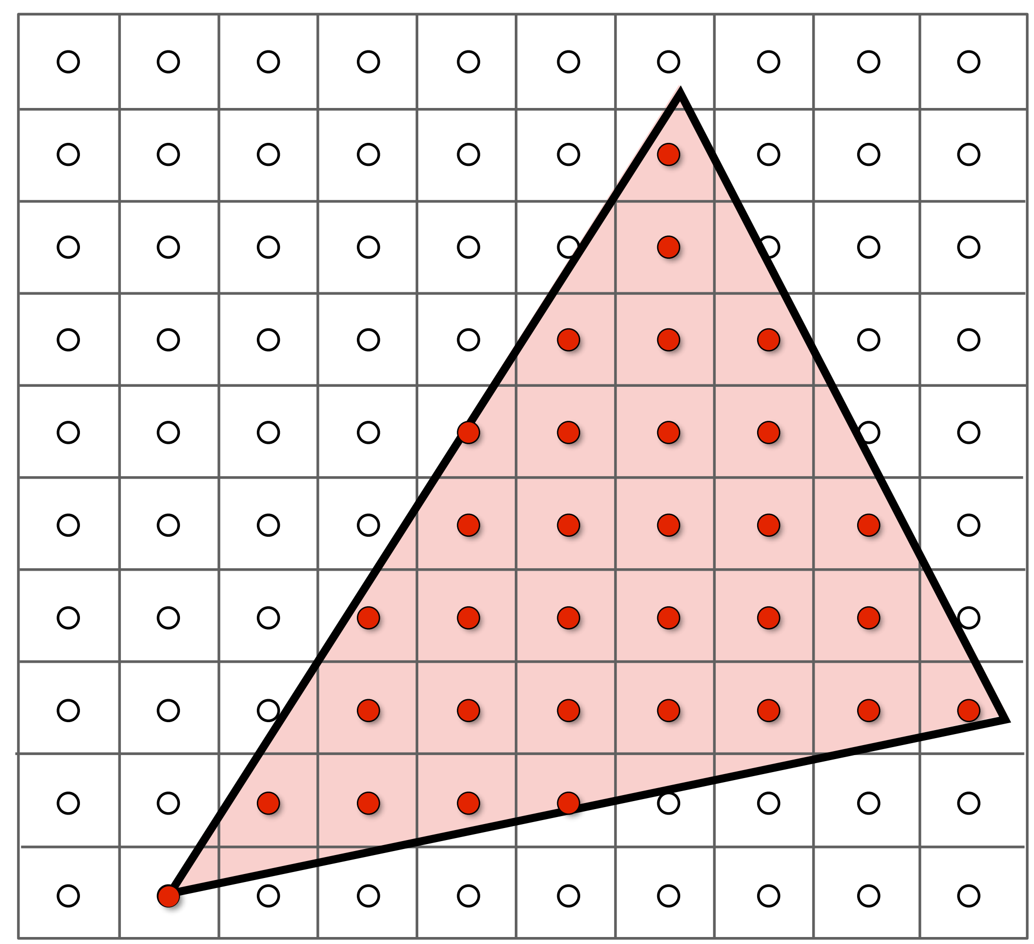
Model, View, Projection transforms



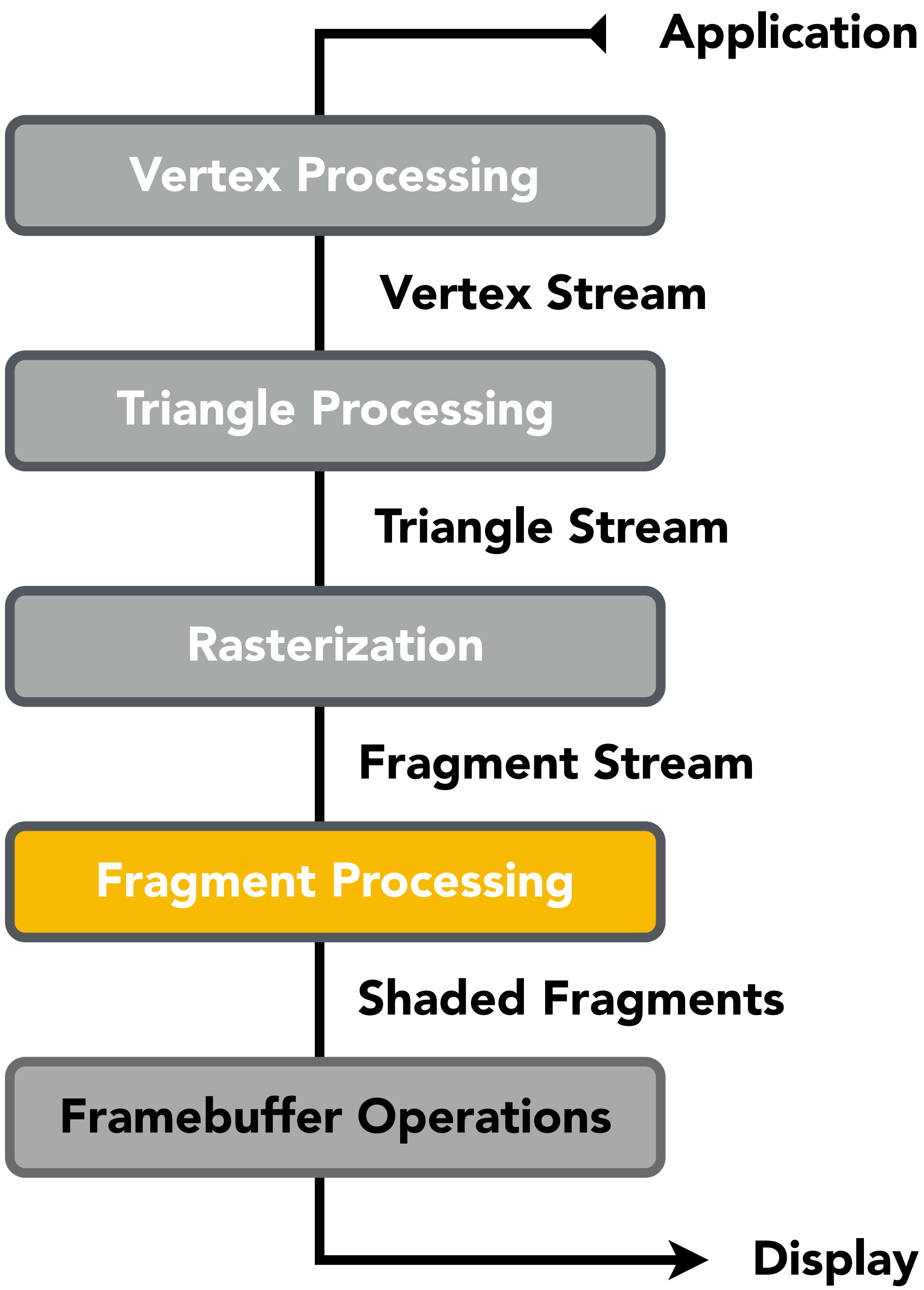
Graphics Pipeline



Sampling triangle coverage

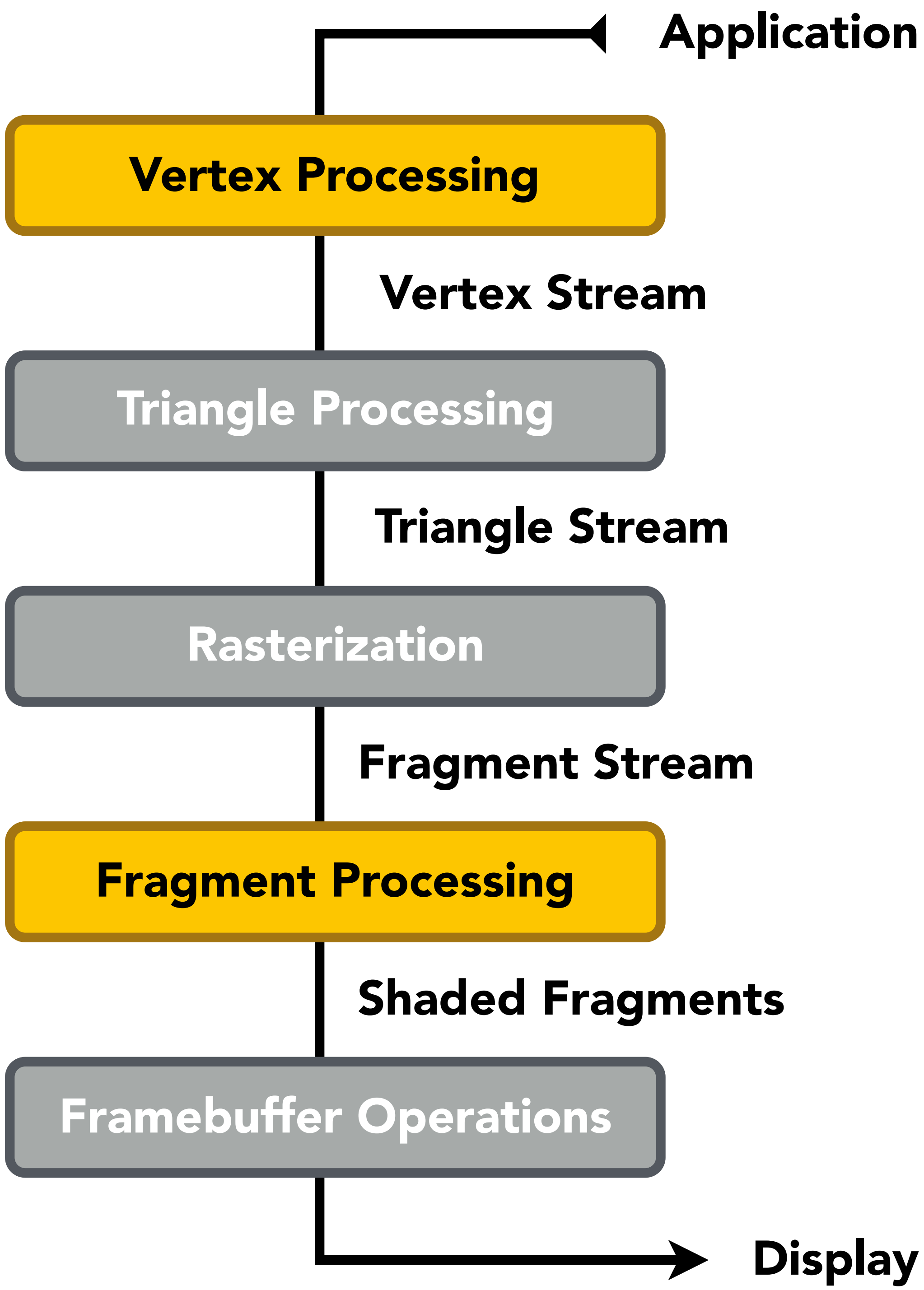


Rasterization Pipeline

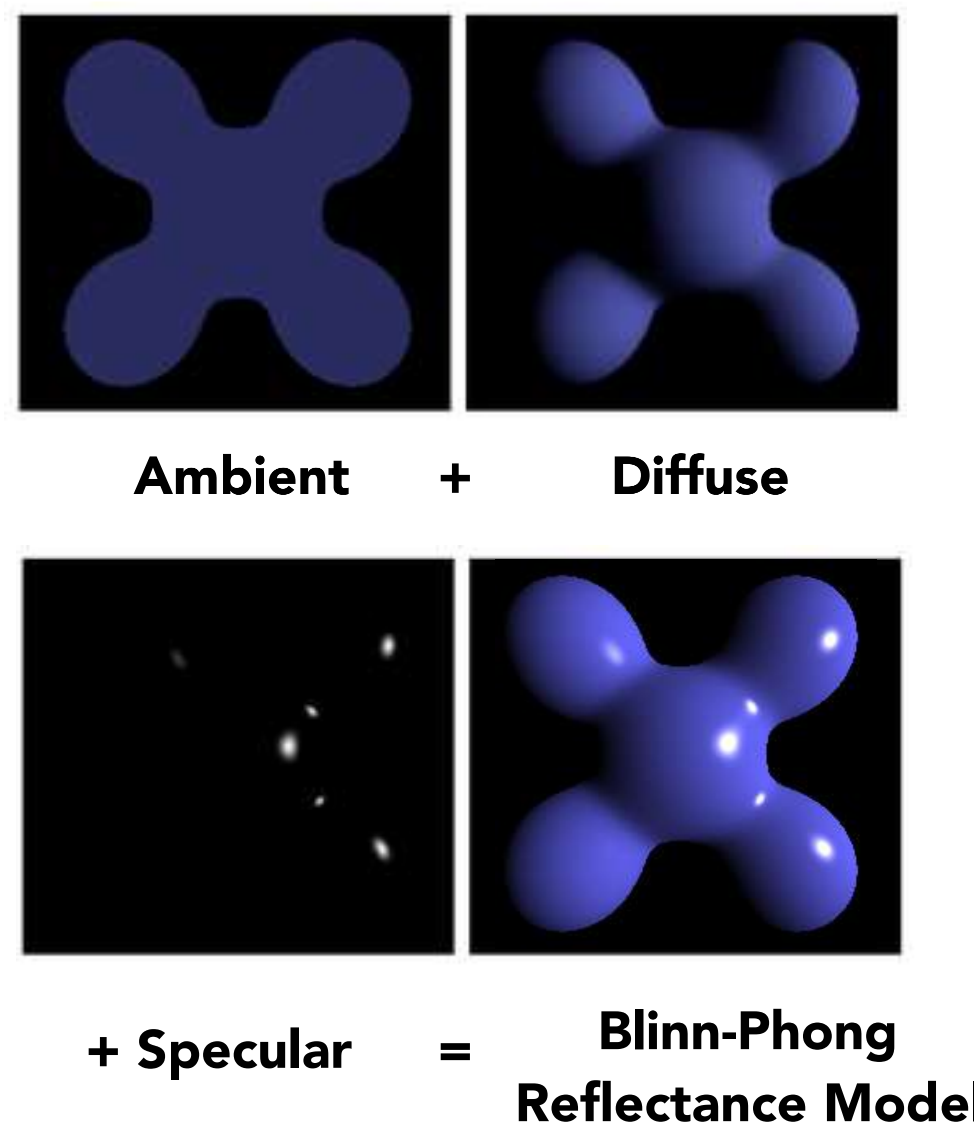


Z-Buffer Visibility Tests

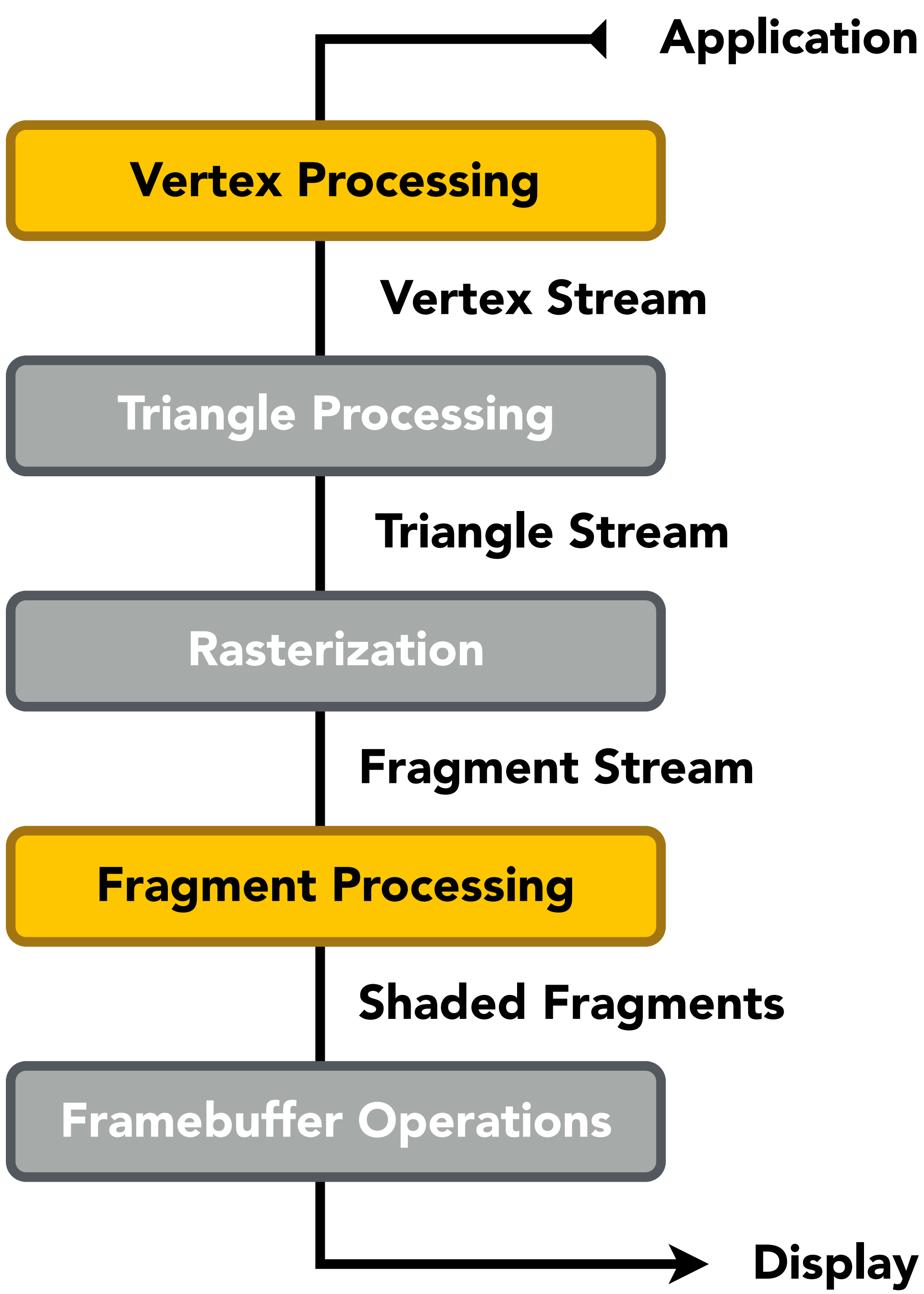
Graphics Pipeline



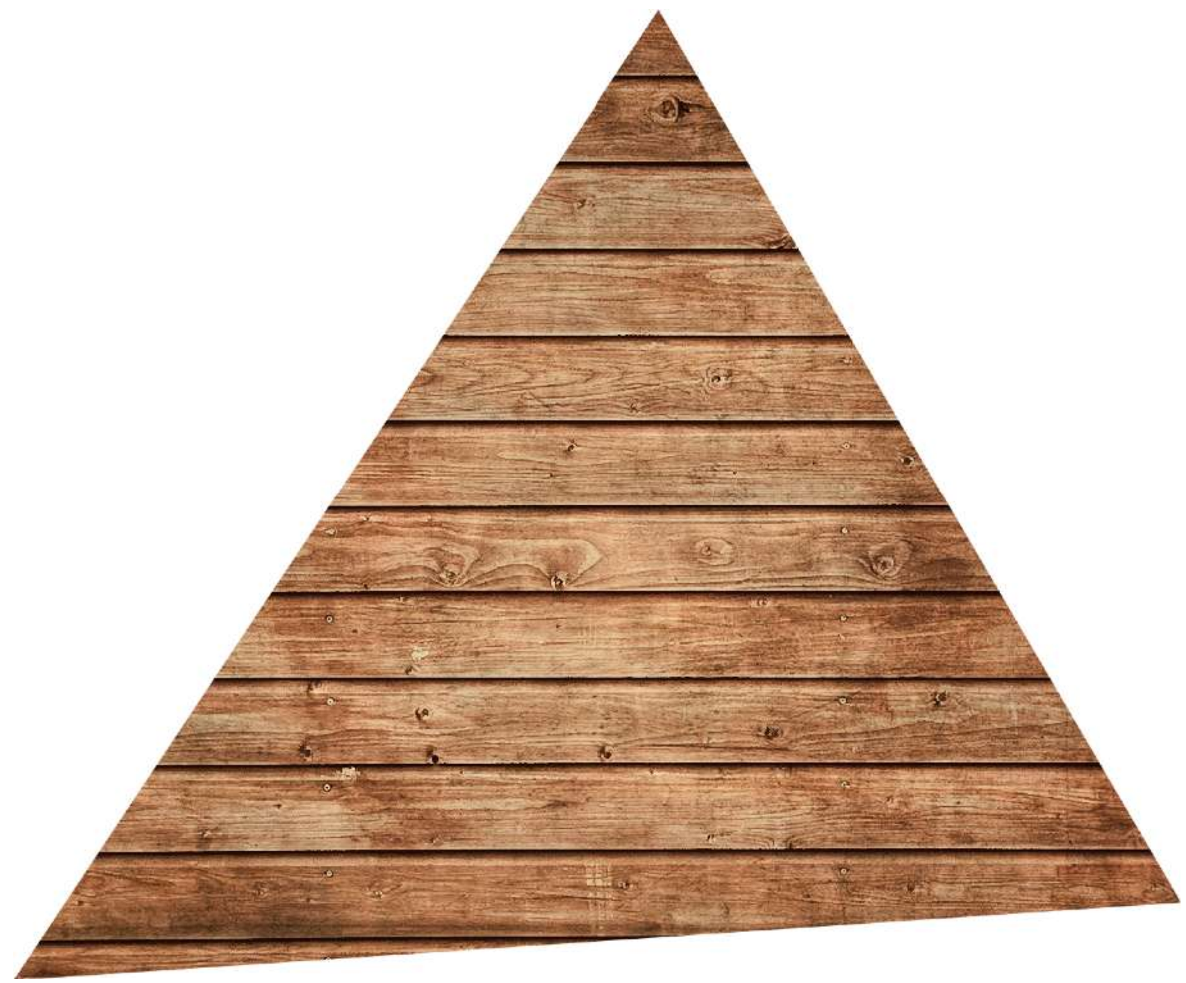
Shading



Graphics Pipeline



Texture mapping
(introducing soon)



Shader Programs

- Program vertex and fragment processing stages
- Describe operation on a single vertex (or fragment)

Example GLSL fragment shader program

```
uniform sampler2D myTexture;
uniform vec3 lightDir;
varying vec2 uv;
varying vec3 norm;

void diffuseShader()
{
  vec3 kd;
  kd = texture2d(myTexture, uv);
  kd *= clamp(dot(–lightDir, norm), 0.0, 1.0);
  gl_FragColor = vec4(kd, 1.0);
}
```

- **Shader function executes once per fragment.**
- **Outputs color of surface at the current fragment's screen sample position.**
- **This shader performs a texture lookup to obtain the surface's material color at this point, then performs a diffuse lighting calculation.**

Shader Programs

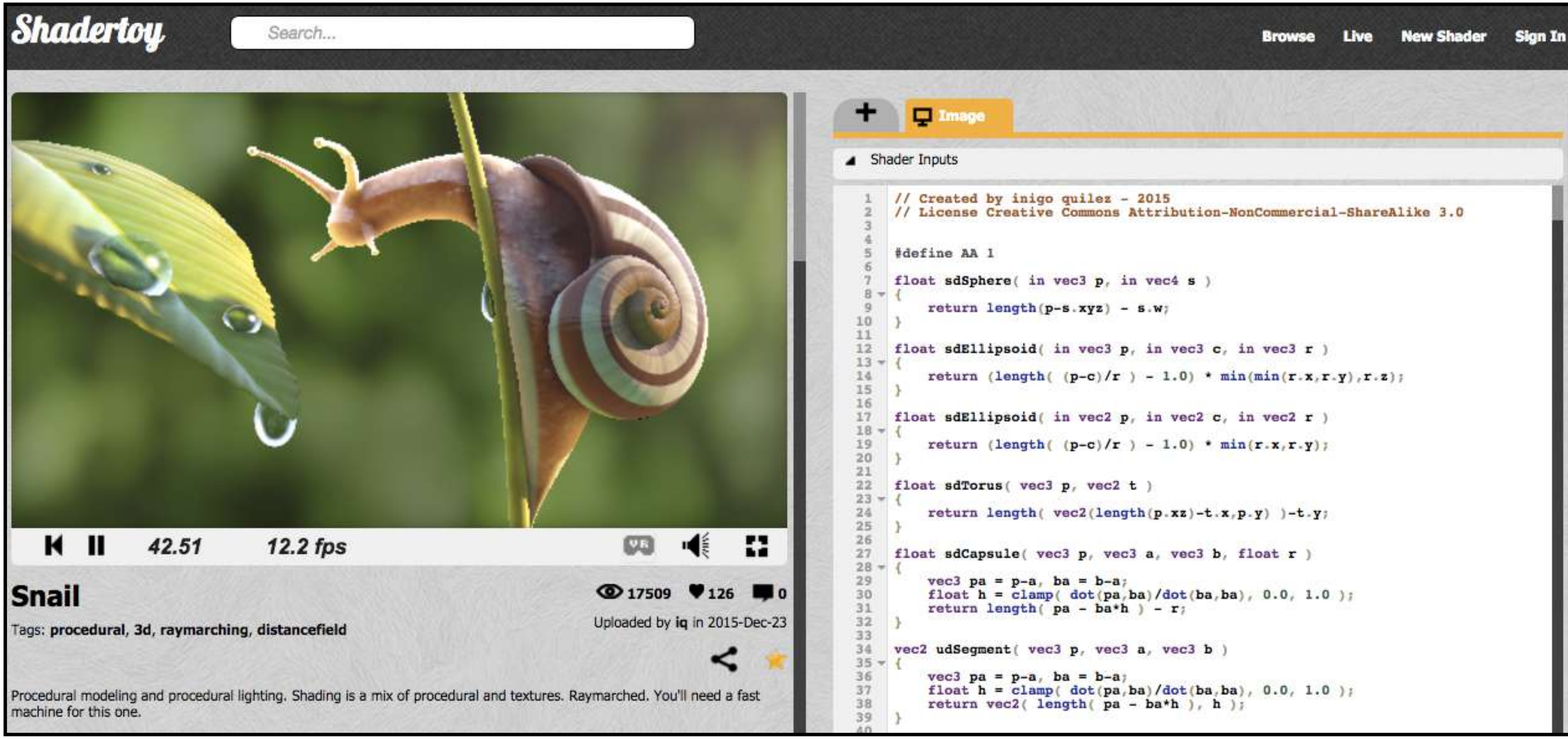
- Program vertex and fragment processing stages
- Describe operation on a single vertex (or fragment)

Example GLSL fragment shader program

```
uniform sampler2D myTexture;     // program parameter
uniform vec3 lightDir;           // program parameter
varying vec2 uv;                 // per fragment value (interp. by rasterizer)
varying vec3 norm;               // per fragment value (interp. by rasterizer)

void diffuseShader()
{
  vec3 kd;
  kd = texture2d(myTexture, uv);                    // material color from texture
  kd *= clamp(dot(–lightDir, norm), 0.0, 1.0);      // Lambertian shading model
  gl_FragColor = vec4(kd, 1.0);                     // output fragment color
}
```

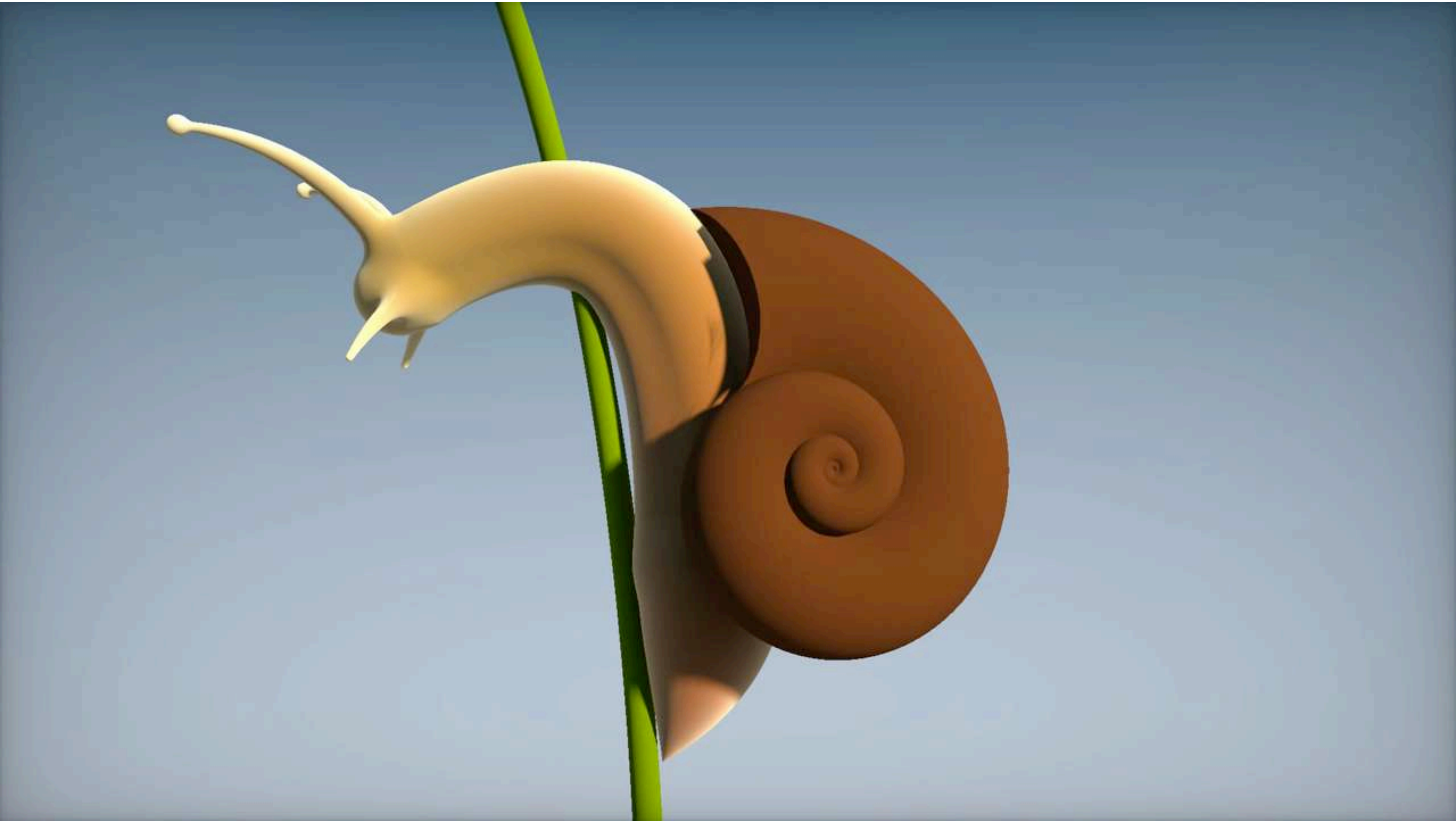
Snail Shader Program



Inigo Quilez

Procedurally modeled, 800 line shader.
http://shadertoy.com/view/ld3Gz2

Snail Shader Program



Inigo Quilez, https://youtu.be/XuSnLbB1j6E

Goal: Highly Complex 3D Scenes in Realtime

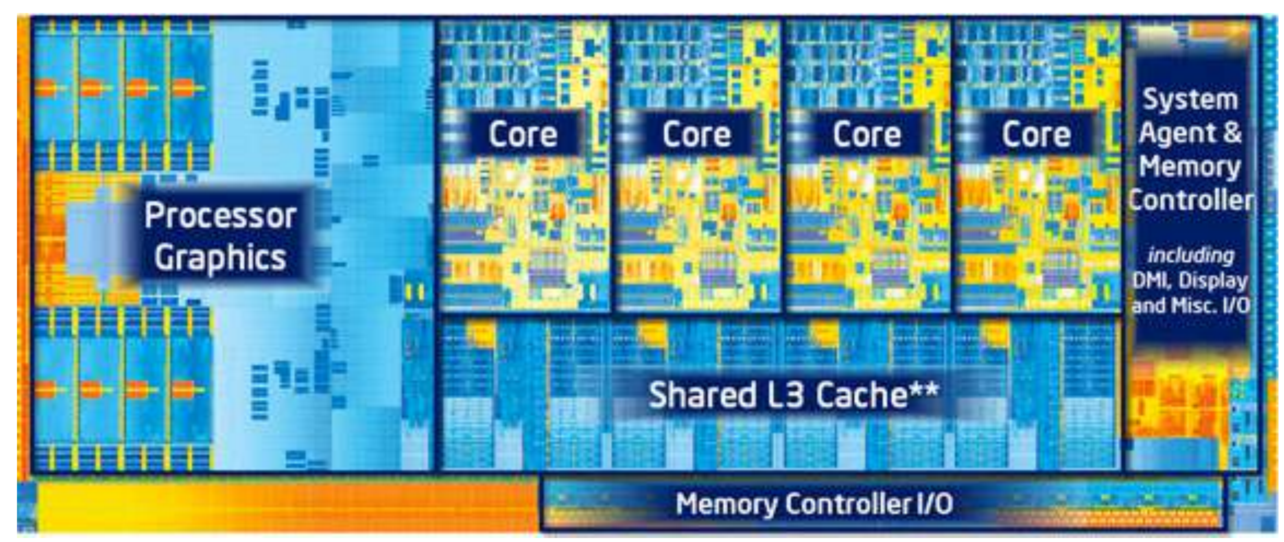
- **100's of thousands to millions of triangles in a scene**
- **Complex vertex and fragment shader computations**
- **High resolution (2-4 megapixel + supersampling)**
- **30-60 frames per second (even higher for VR)**

Unreal Engine Kite Demo (Epic Games 2015)

Graphics Pipeline Implementation: GPUs

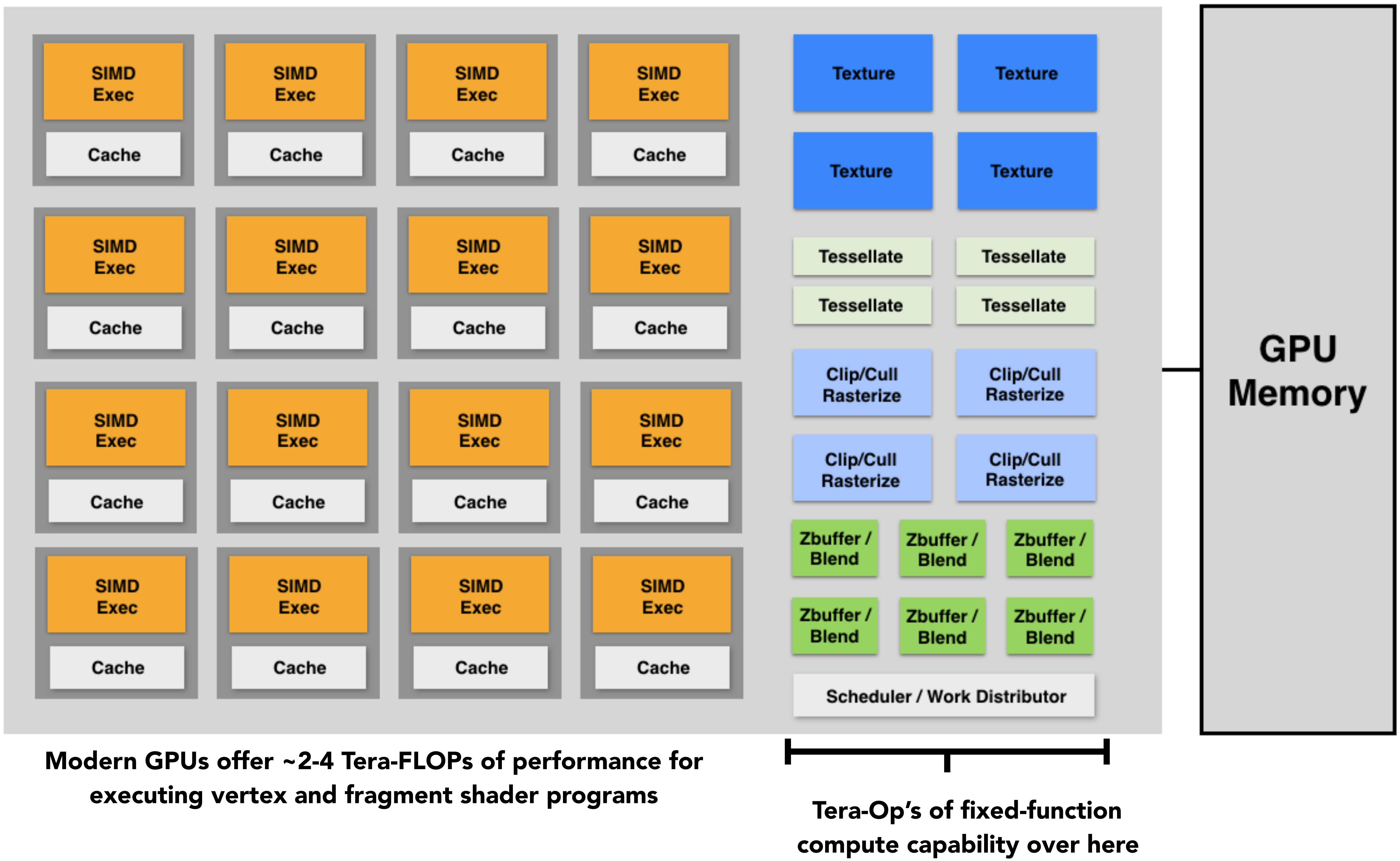
Specialized processors for executing graphics pipeline computations

Discrete GPU Card
(NVIDIA GeForce Titan X)



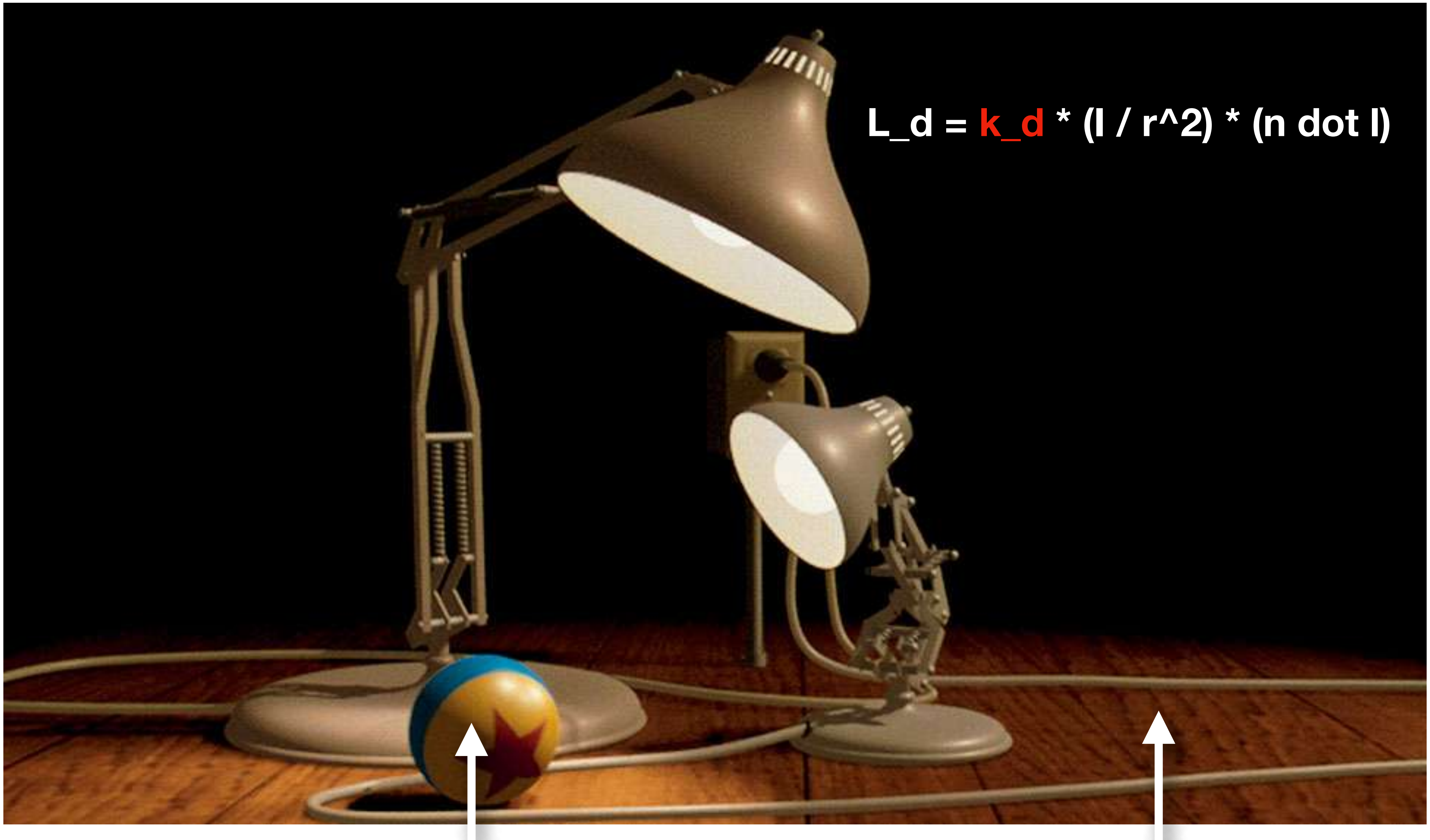
Integrated GPU:
(Part of Intel CPU die)

GPU: Heterogeneous, Multi-Core Procesor



Texture Mapping

Different Colors at Different Places?



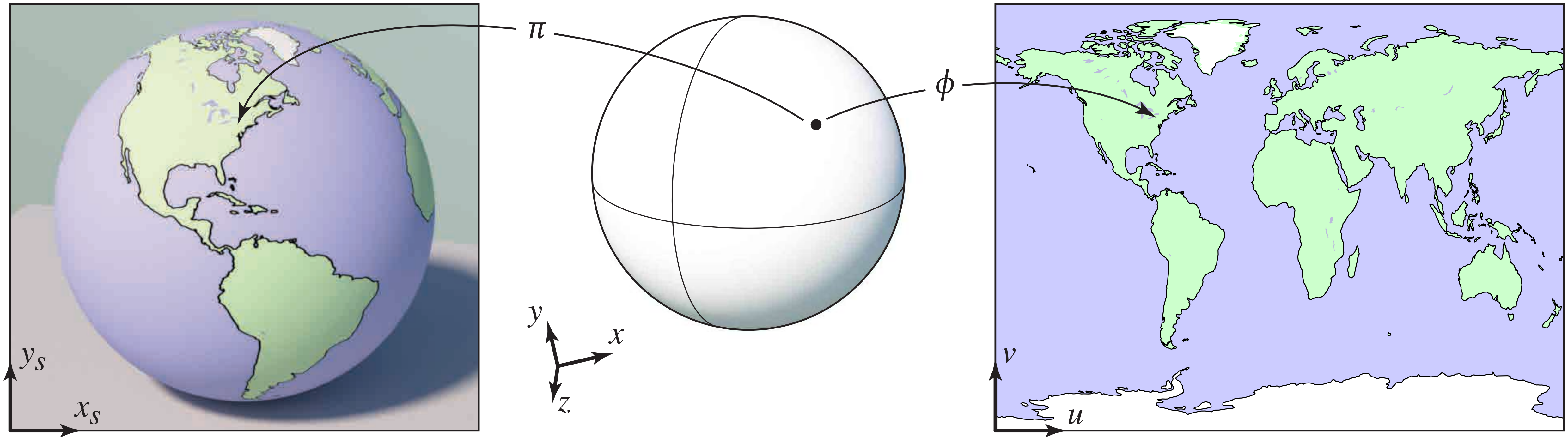
Pattern on ball

Wood grain on floor

Surfaces are 2D

Surface lives in 3D world space

Every 3D surface point also has a place where it goes in the 2D image (**texture**).



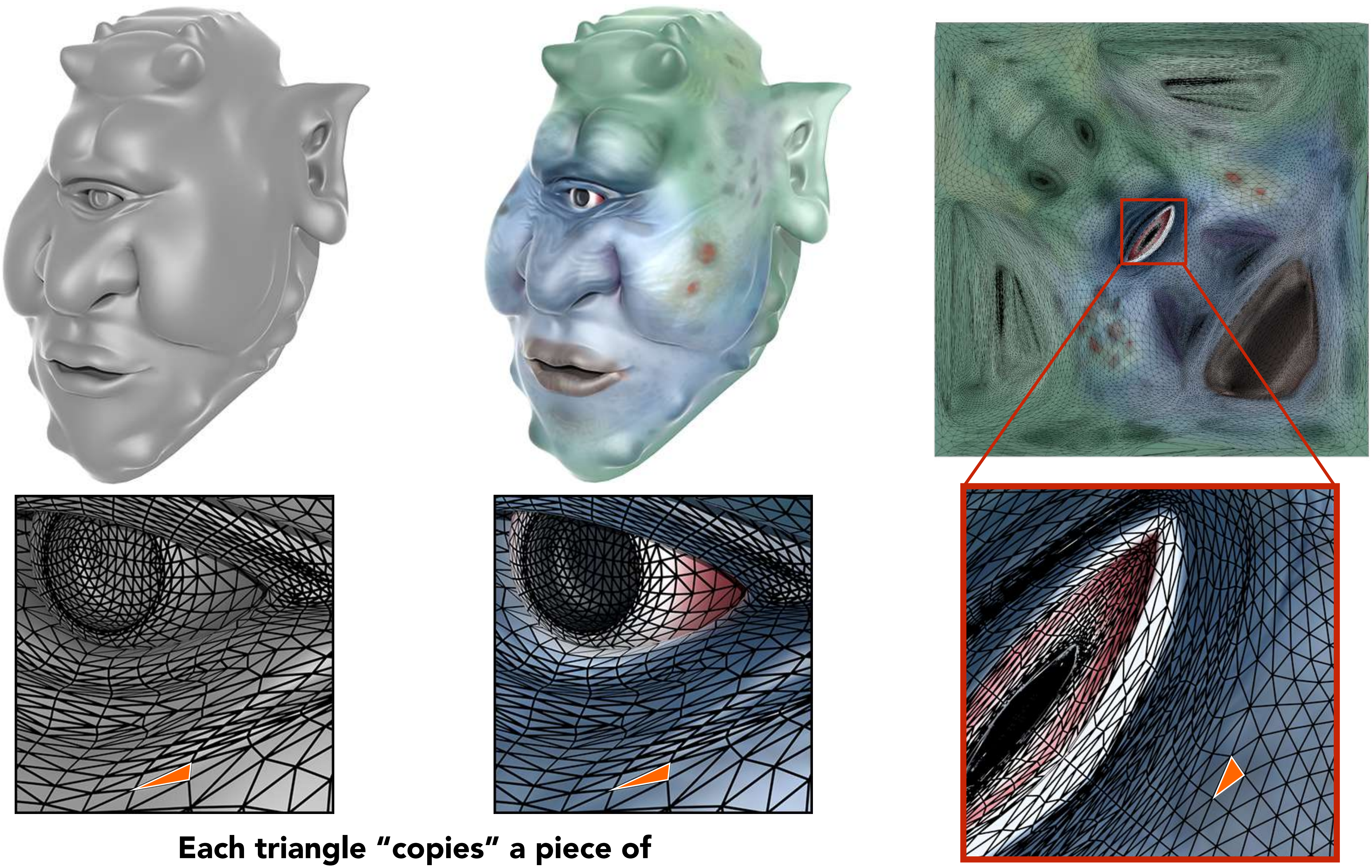
Screen space

World space

Texture space

Texture Applied to Surface

Rendering without texture **Rendering with texture** **Texture**



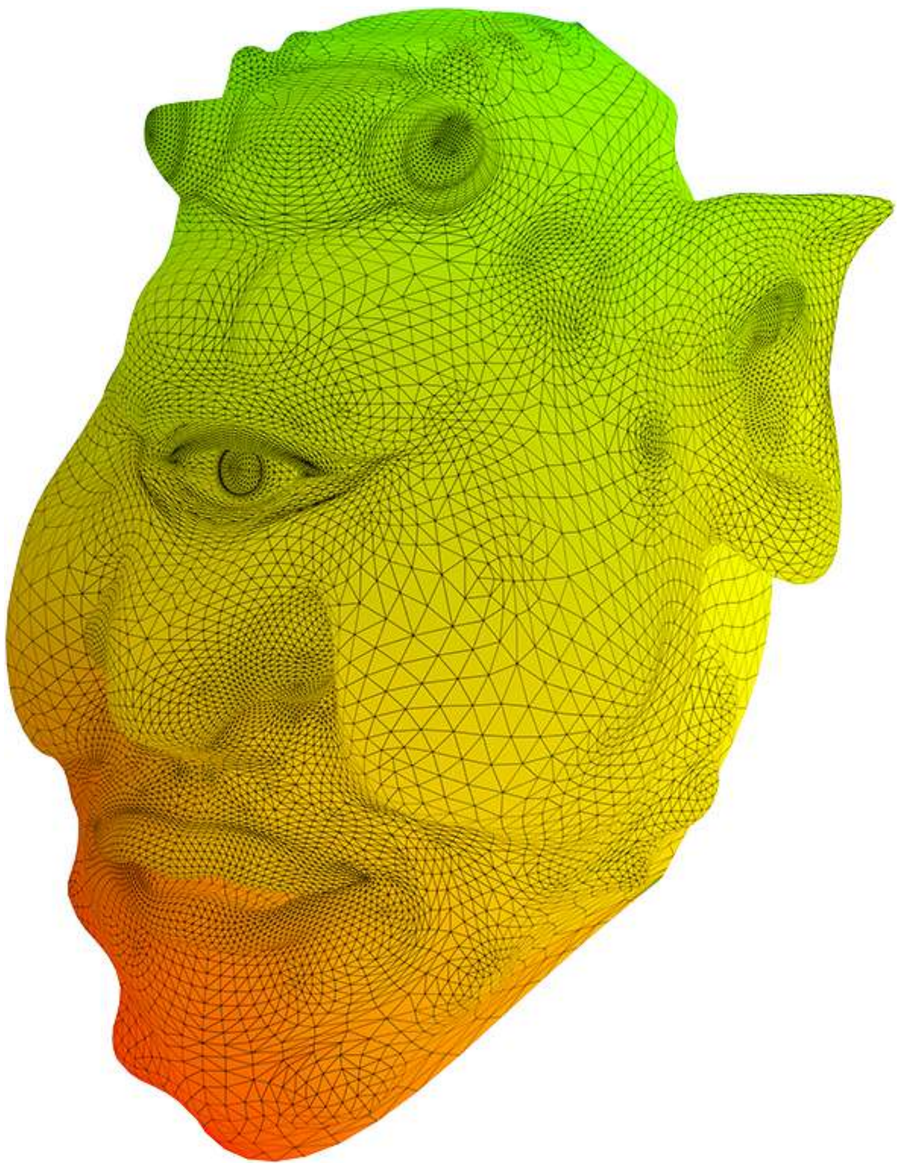
Zoom

Each triangle "copies" a piece of the texture image to the surface.

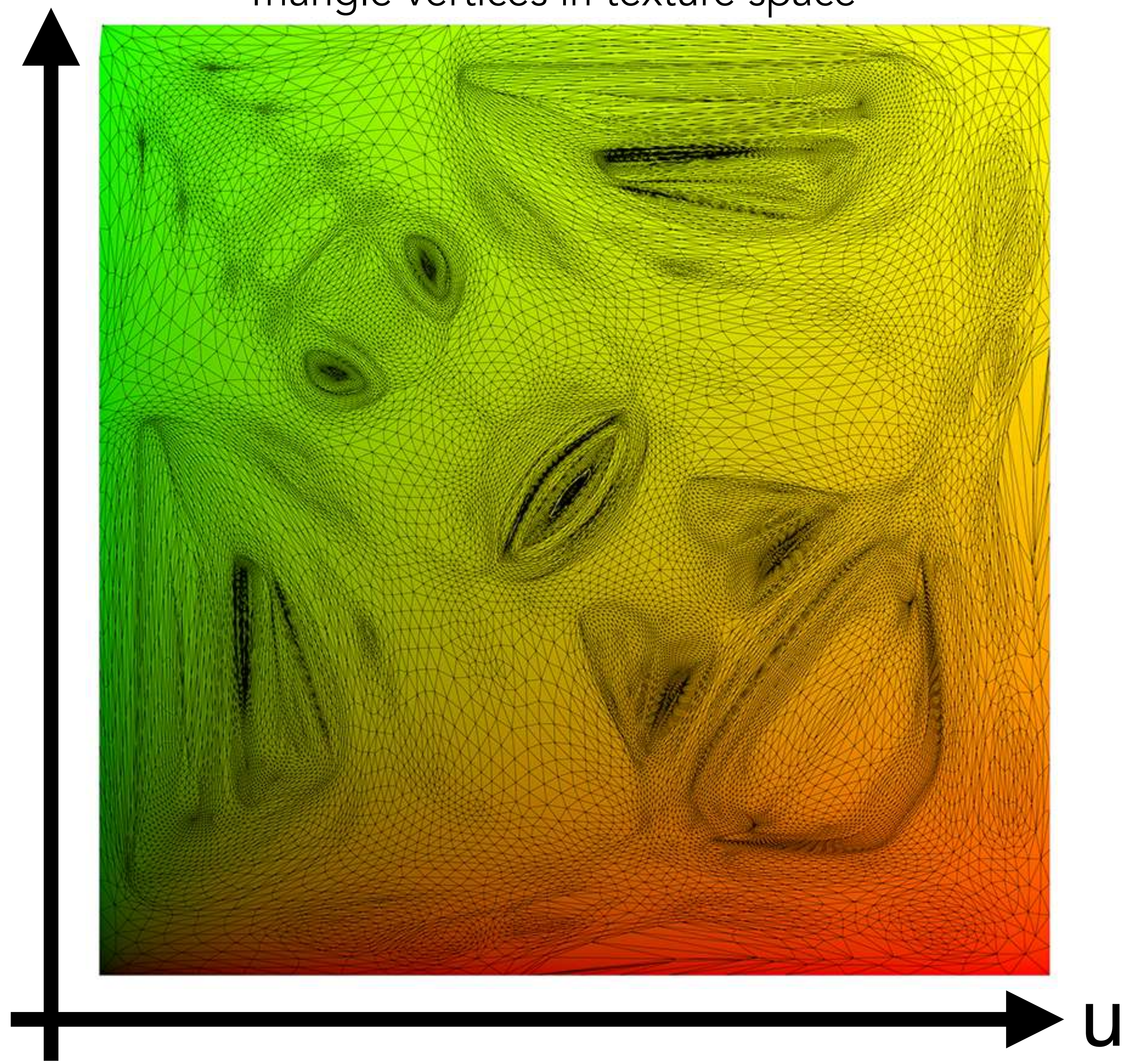
Visualization of Texture Coordinates

Each triangle vertex is assigned a texture coordinate (u,v)

Visualization of texture coordinates

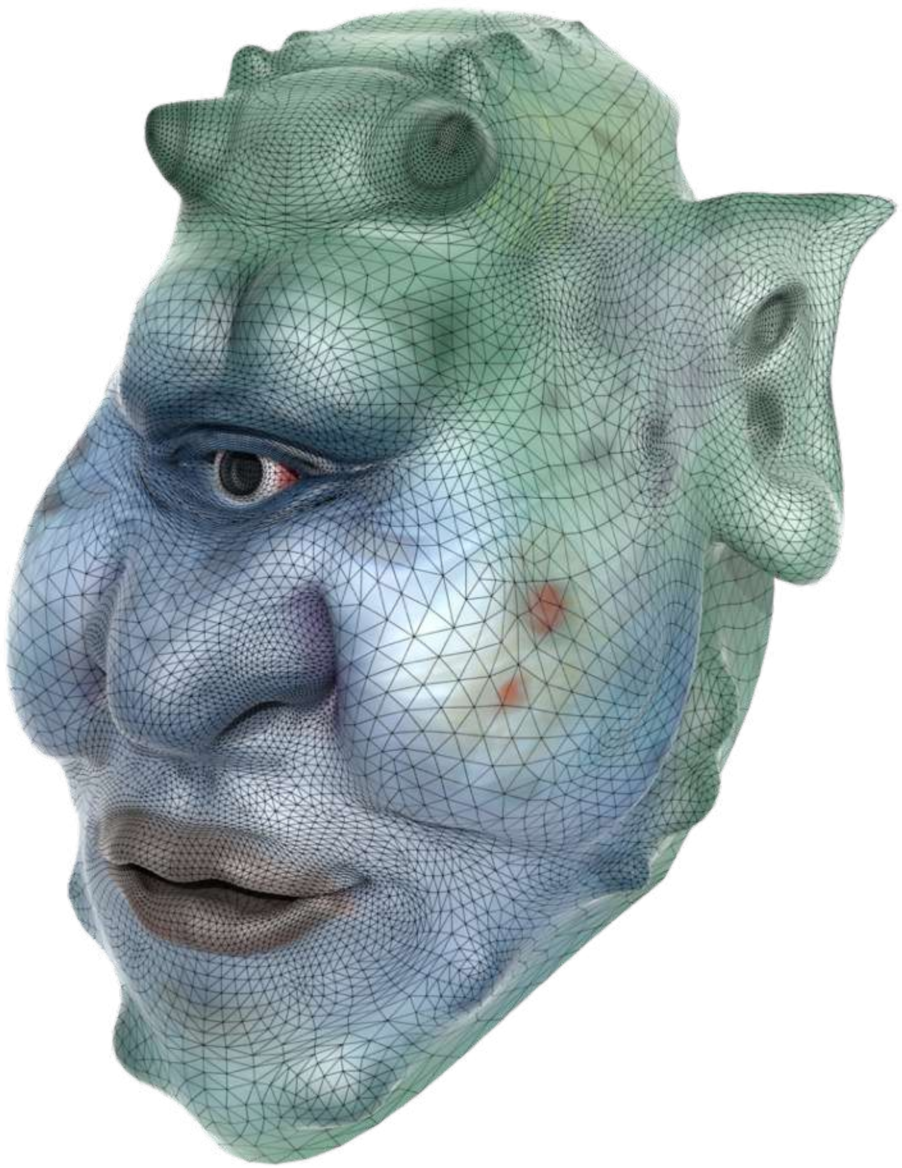


Triangle vertices in texture space

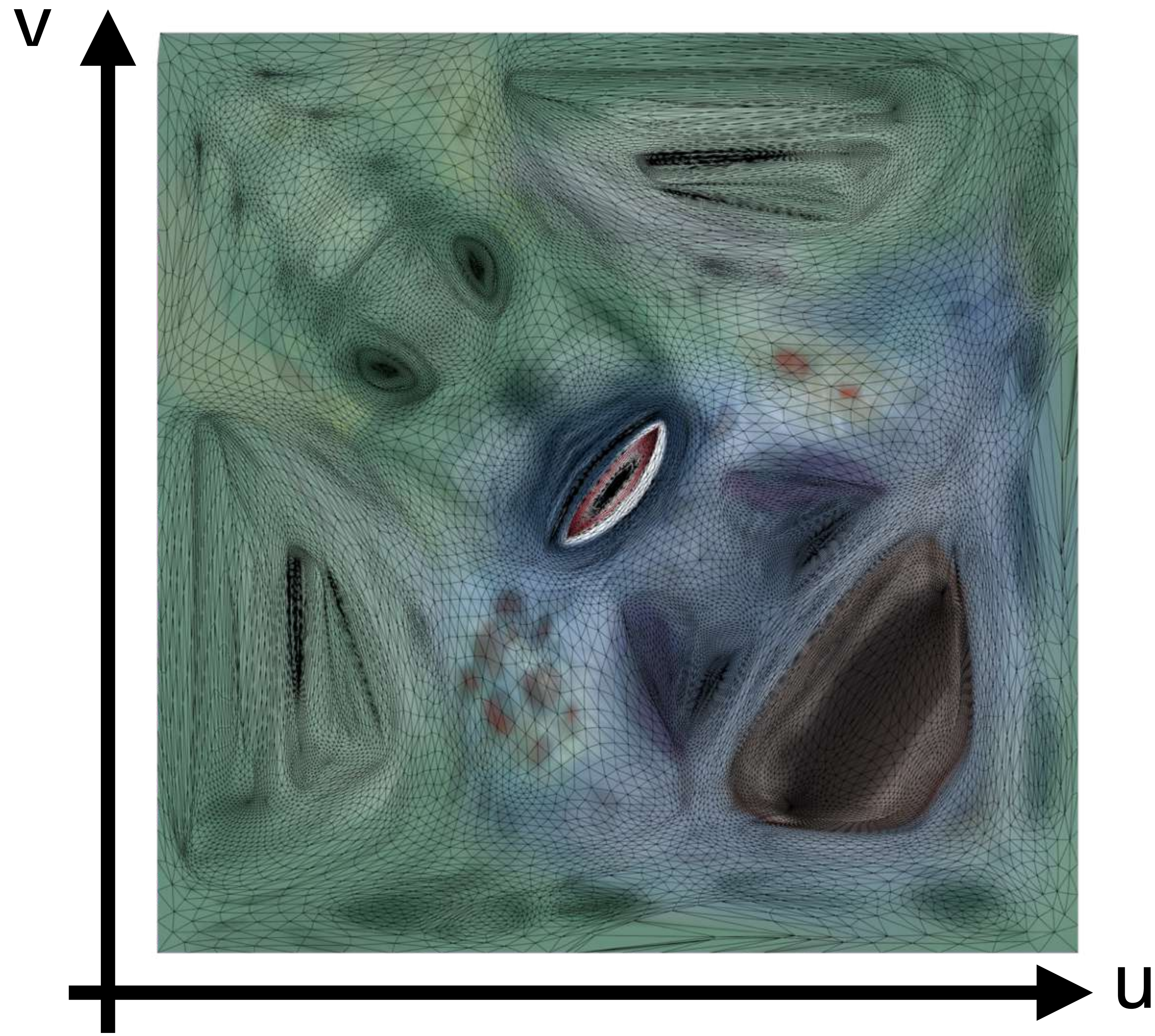


Texture Applied to Surface

Rendered result

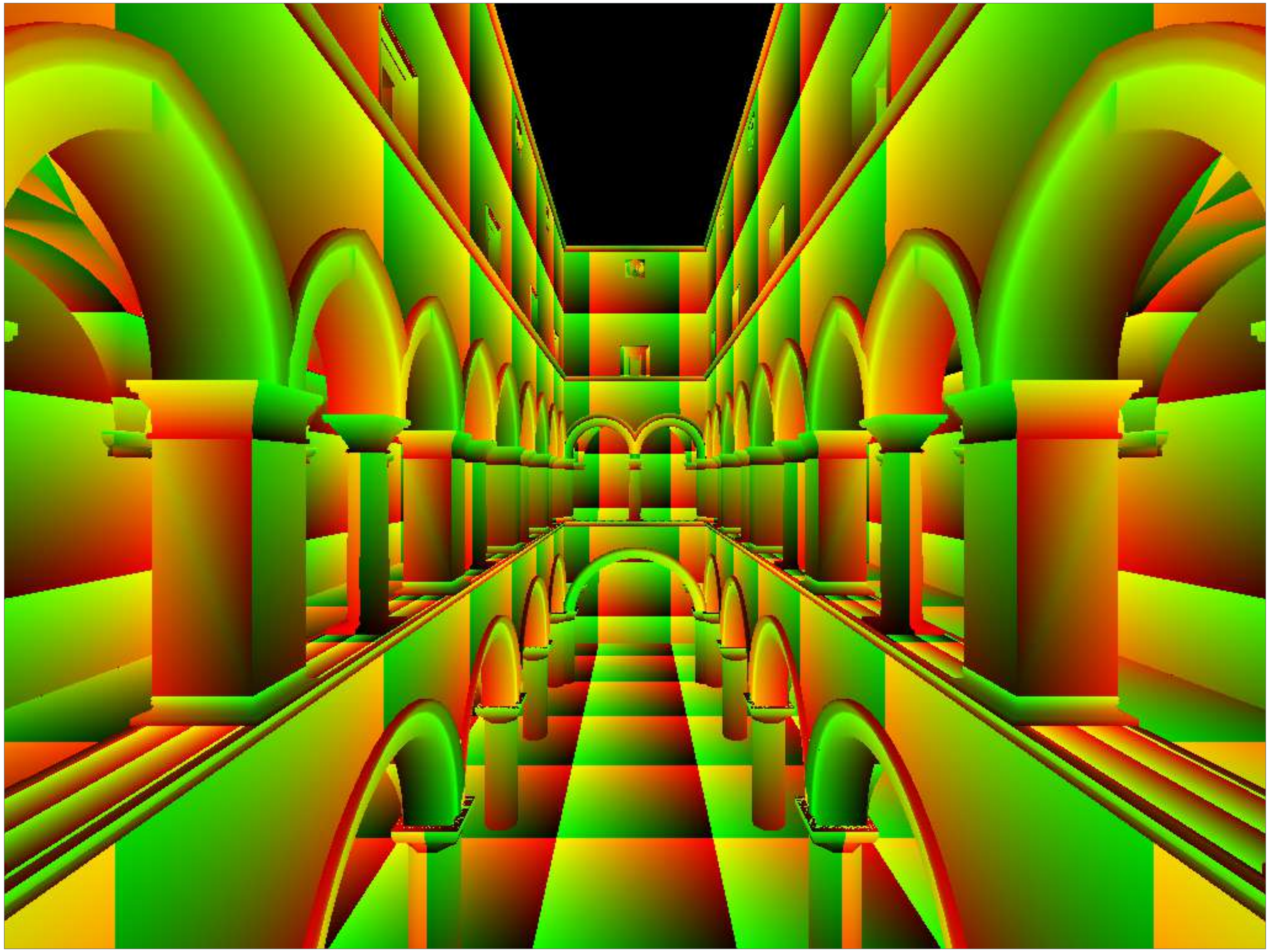


Triangle vertices in texture space

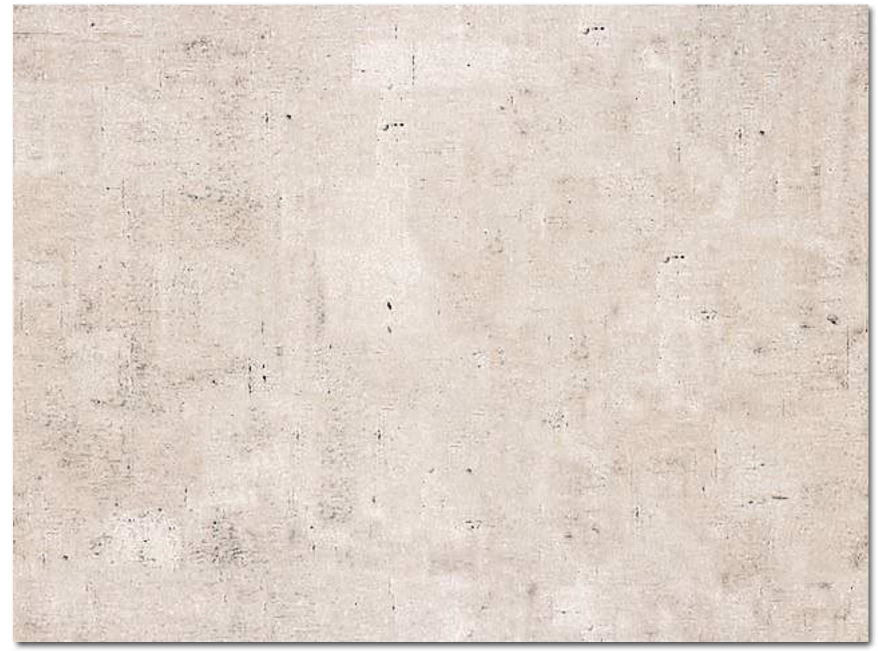


Textures applied to surfaces

Visualization of texture coordinates



Textures can be used multiple times!



example textures
used / **tiled**

Thank you!

(And thank Prof. Ravi Ramamoorthi and Prof. Ren Ng for many of the slides!)