# **05** Forward and deferred shading

**CS5625** Spring 2022
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slides adapted from
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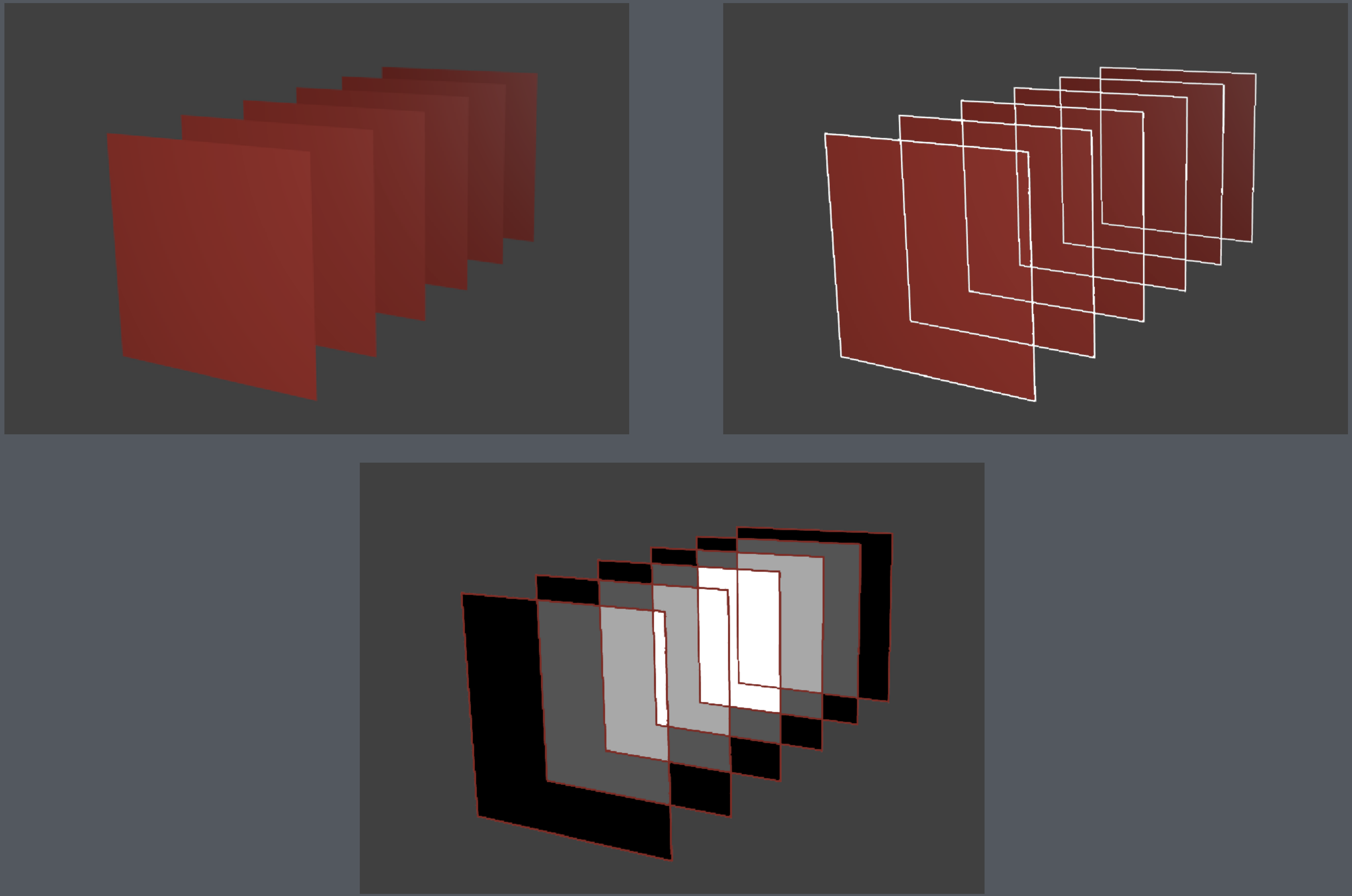
# Rendering: forward shading

```
for each object in the scene
   for each triangle in this object
      for each fragment f in this triangle

         gl_FragColor = shade(f)

         if (depth of f < depthbuffer[x, y])
            framebuffer[x, y] = gl_FragColor
            depthbuffer[x, y] = depth of f
         end if

      end for
   end for
end for
```

# Problem: Overdraw



# Problem: lighting complexity


*Just Cause 3* | Avalanche Studios

# Missed opportunity: spatial processing

**Fragments cannot talk to each other**

- a fundamental constraint for performance

**Many interesting effects depend on neighborhood and geometry**

- bloom
- ambient occlusion
- motion blur
- depth of field
- edge-related rendering effects

# Multi-pass rendering

**An old idea**

- going back at least to the 80s
- render something, store it, use the result to render something else
- used for dynamic reflections, shadows, etc.

**Deferred rendering is a particular type of multi-pass approach**

- store data in the image-space pixel grid
- store quantities that would be intermediate results in forward rendering
- use stored values in later pass(es) to compute final shading
- later passes can work on only some pixels, and can access data from other pixels

# Deferred shading approach

**First render pass**

- draw all geometry
- compute material- and geometry-related inputs to lighting model
- don't compute lighting
- write shading inputs to intermediate buffer

**Second render pass**

- don't draw geometry
- use stored inputs to compute shading
- write to output

**Post-processing pass** (optional, can also be used with fwd. rendering)

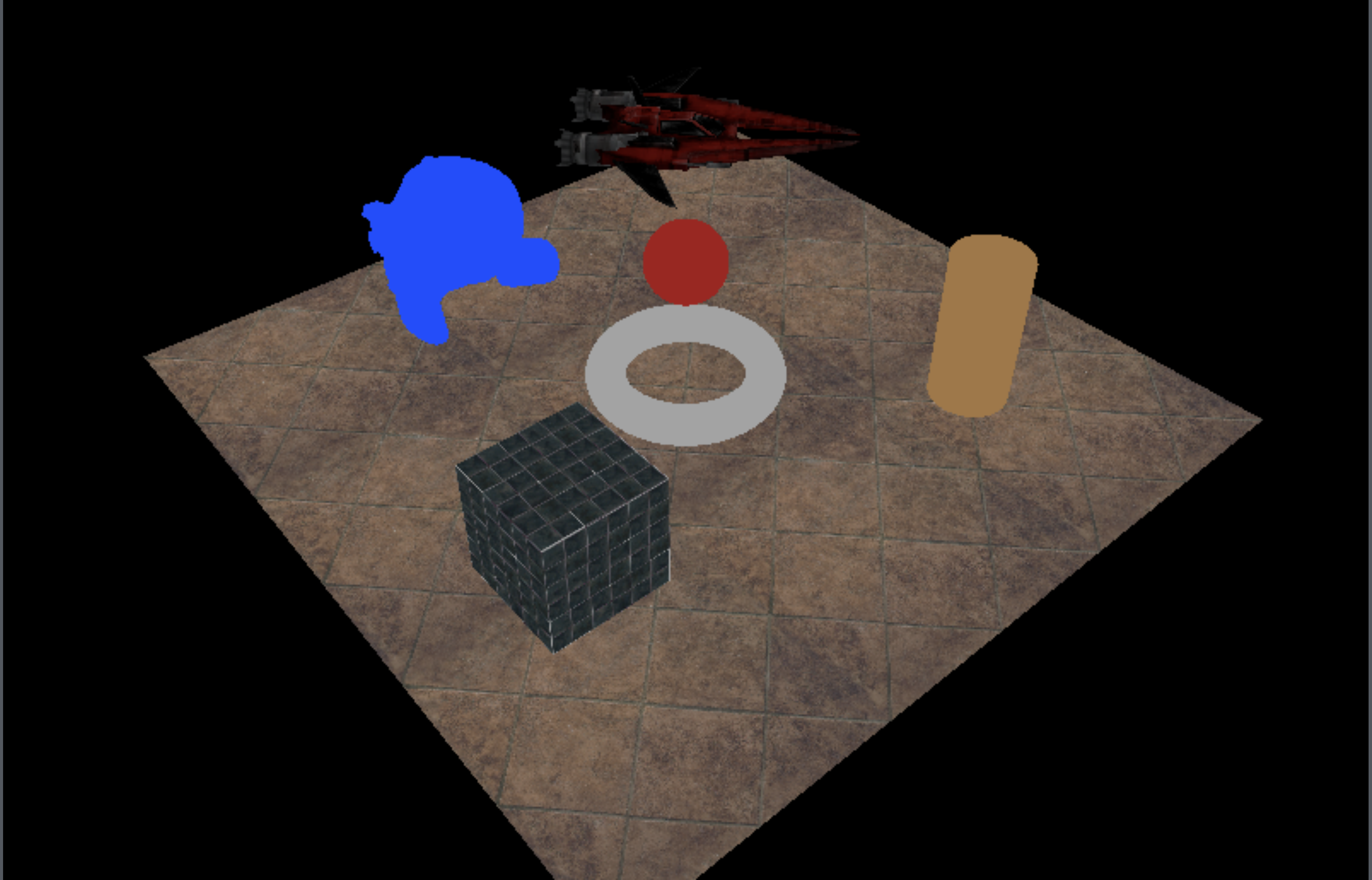
- process final image to produce output pixels

# Deferred shading step 1

```
for each object in the scene
    for each triangle in this object
        for each fragment f in this triangle

            gl_FragData[…] = material properties of f
            if (depth of f < depthbuffer[x, y])
                gbuffer[…][x, y] = gl_FragData[…]
                depthbuffer[x, y] = depth of f
            end if

        end for
    end for
end for
```

Here we’re making use of an OpenGL feature called “Multiple Render Targets” in which the familiar gl_FragColor is replaced by an array of values, each of which is written to a different buffer.

# First pass: output just the materials

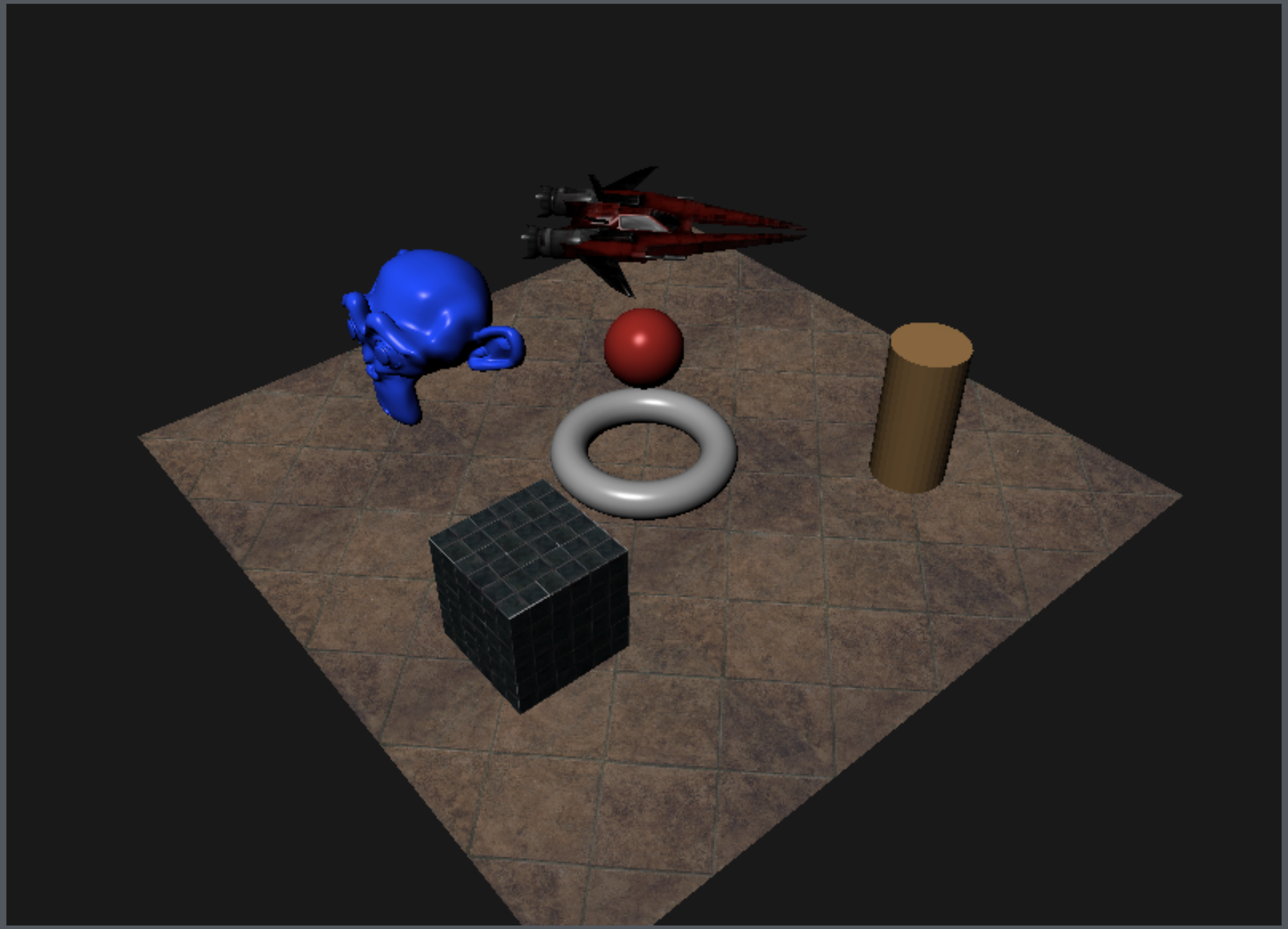


# Deferred Shading Step 2

```
for each fragment f in the gbuffer
   framebuffer[x, y] = shade (f)
end for
```

One improvement: shade (f) only executed for visible fragments.

Output is the same →

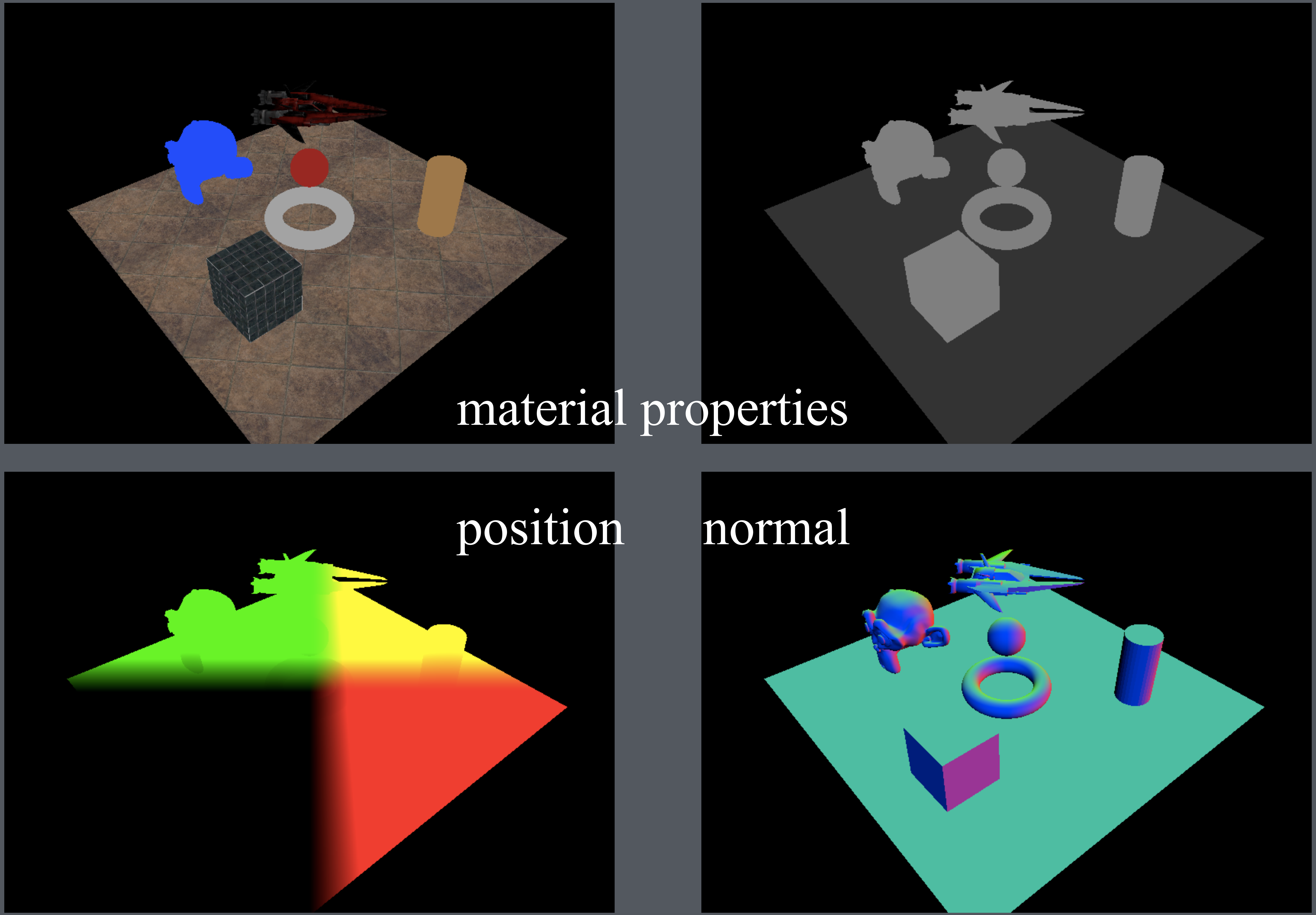


```
for each object in the scene
   for each triangle in this object
      for each fragment f in this triangle

         gl_FragData[…] = material properties of f
         if (depth of f < depthbuffer[x, y])
            gbuffer[…][x, y] = gl_FragData[…]
            depthbuffer[x, y] = depth of f
         end if

      end for
   end for
end for
```

```
for each fragment f in the gbuffer
   framebuffer[x, y] = shade (f)
end for
```

Here we're making use of an OpenGL feature called "Multiple Render Targets" in which the familiar gl_FragColor is replaced by an array of values, each of which is written to a different buffer.

# G-buffer: multiple textures



# The übershader

**Shader which computes lighting based on g-buffer: has code for all material/lighting models in a single huge shader.**

```
shade (f) {
    result = 0;
    if (f is Lambertian) {
        for each light
            result += (n . l) * diffuse;
        end for
    } else if (f is Blinn-Phong) {
        ...
    } else if (f is ...) {
        ...
    }
    return result;
}
```

# Übershader inputs

**Need access to all parameters of the material for the current fragment:**

- Blinn-Phong: kd, ks, n
- Microfacet: kd, ks, alpha
- etc.

**Also need fragment position and surface normal**

**Solution: write all that out from the material shaders:**

```
{outputs} = {f.material, f.position, f.normal}
if (depth of f < depthbuffer[x, y])
   gbuffer[x, y] = {outputs}
   depthbuffer[x, y] = depth of f
end if
```

# Deferred lighting

**Single-pass render has to consider all lights for every fragment**

- much wasted effort since only a few lights probably contribute
- batching geometry by which lights affect it is awkward
- straight 2-pass deferred has same problem

**With deferred shading, fragments can be visited in subsets**

- move loop over lights out of the shader: do a shading pass per light
- for each light, draw bounds of (significantly) affected volume
- only compute shading for fragments covered by that
- with depth/stencil games, can only shade fragments inside the volume

# Power of Deferred Shading

**Can do any image processing between step 1 and step 2!**

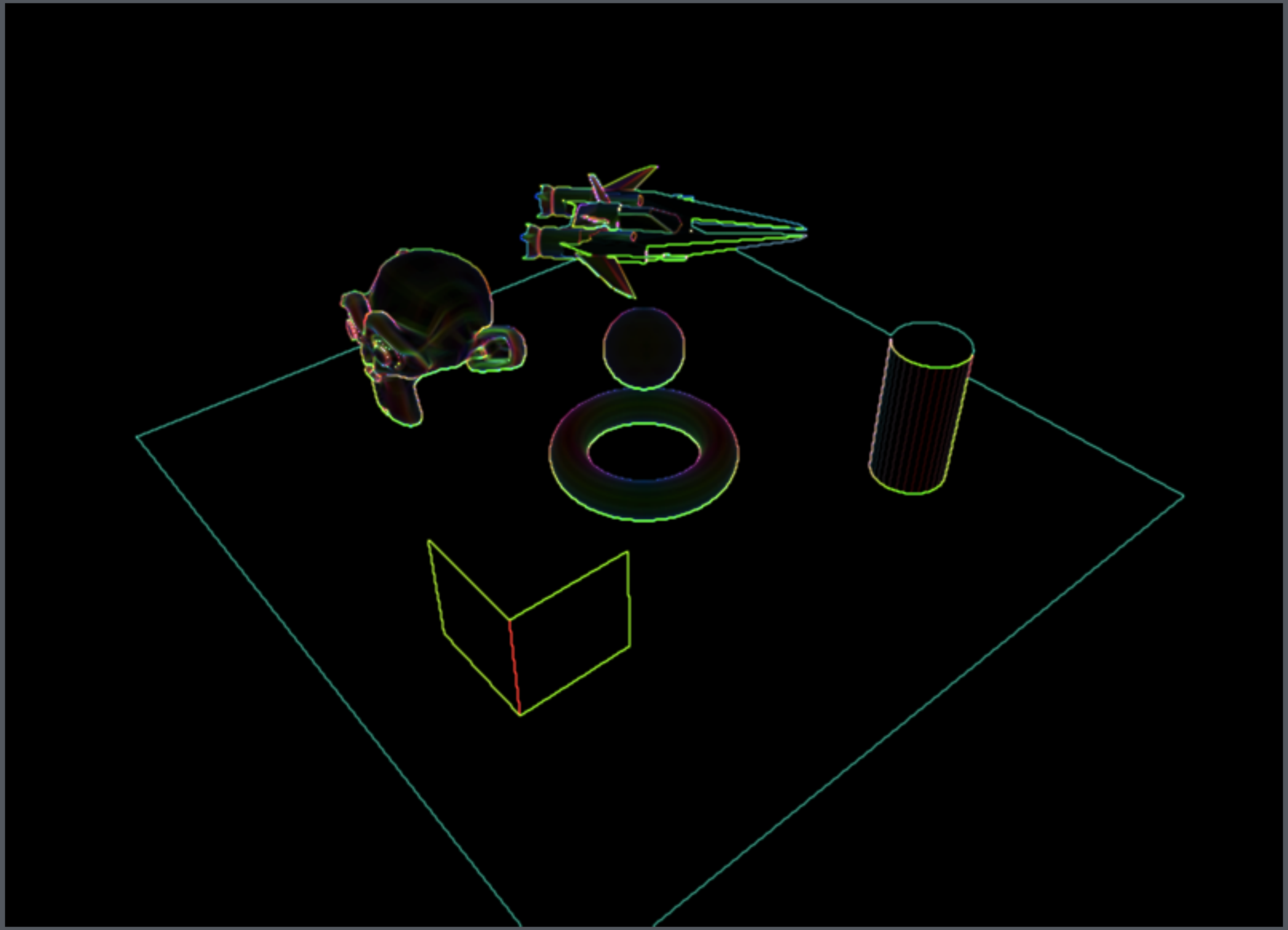
- Recall: step 1 = fill g-buffer, step 2 = light/shade
- Could add a step 1.5 to filter the g-buffer

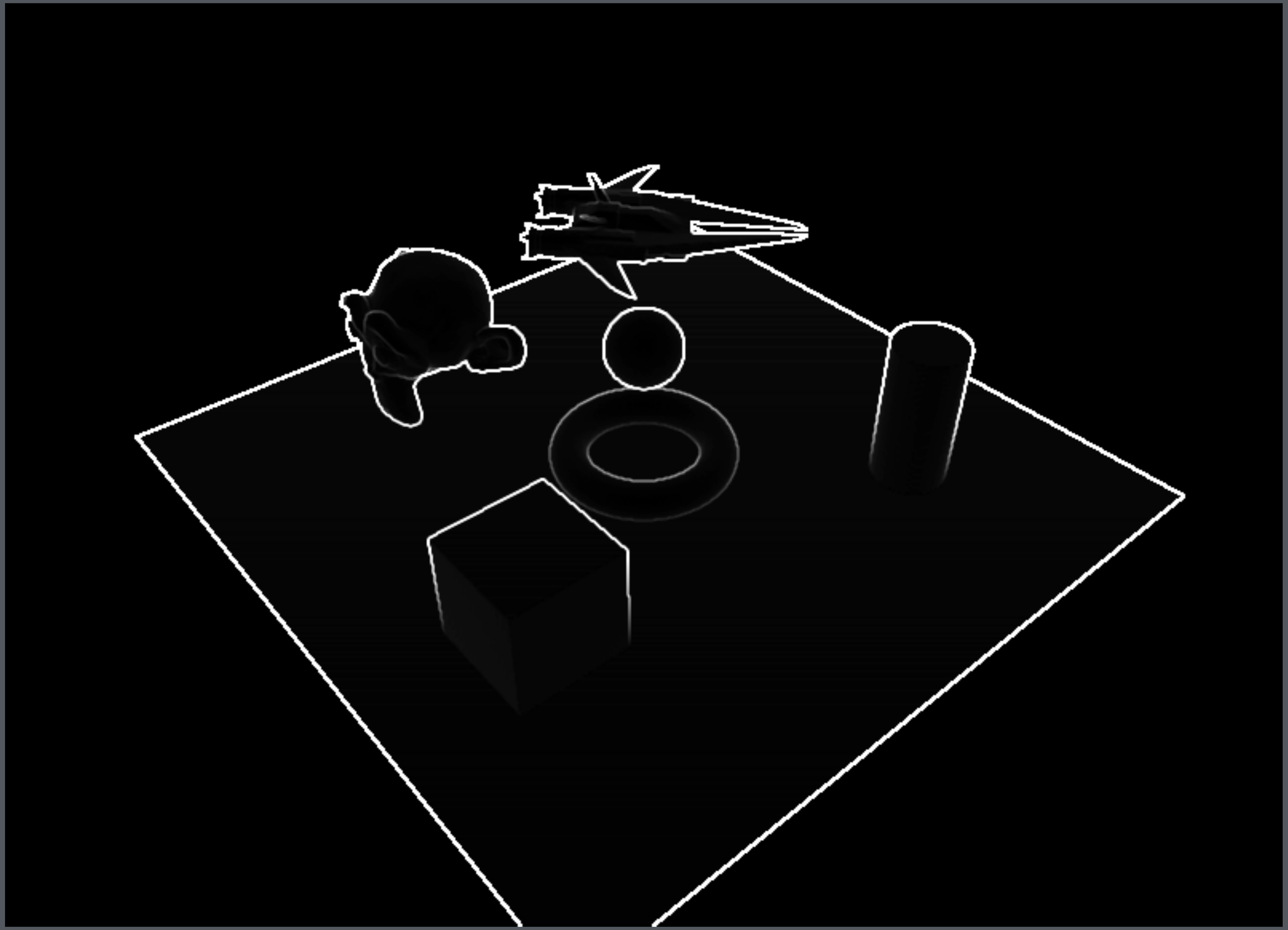
**Examples:**

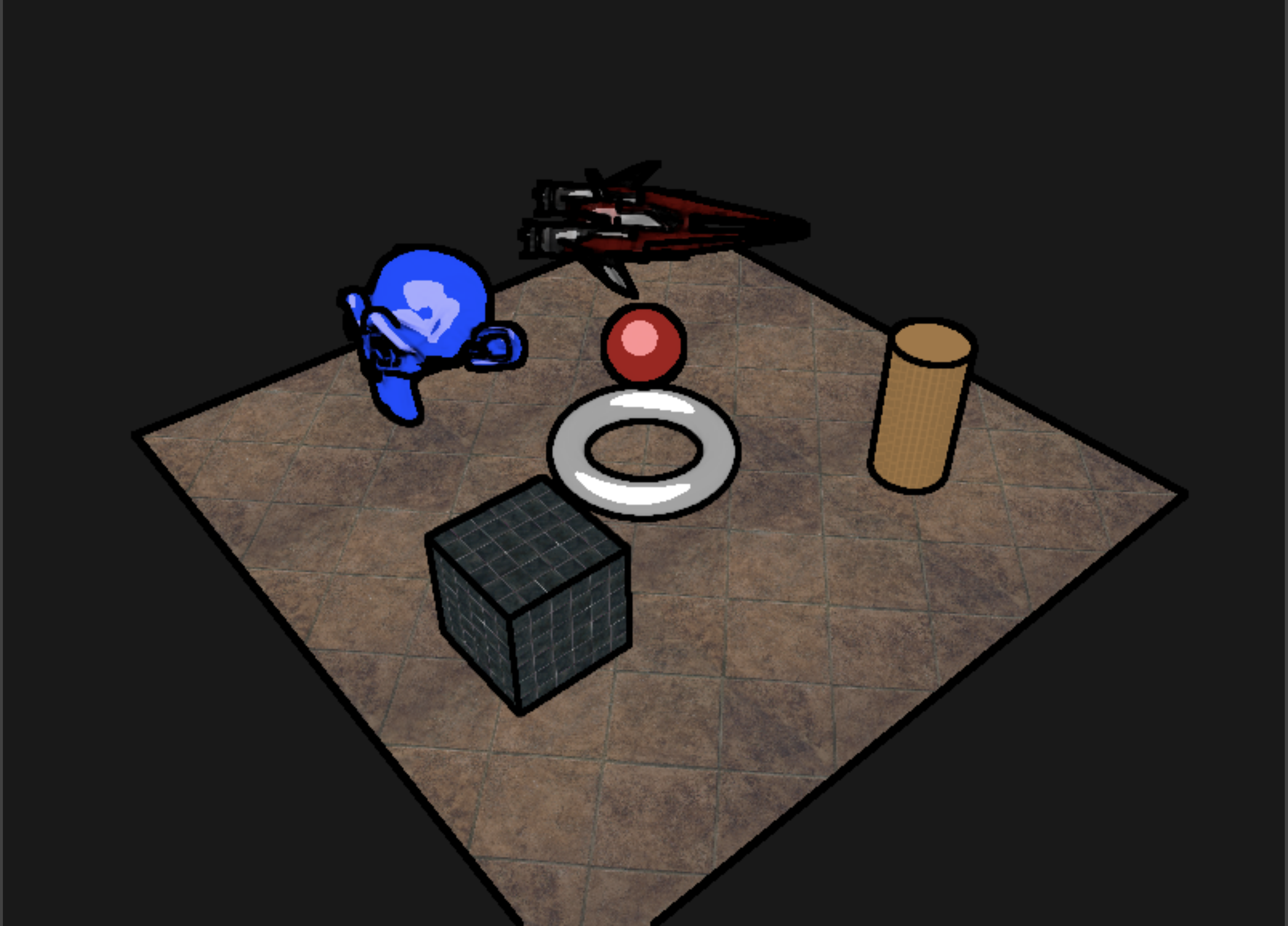
- silhouette detection for artistic rendering
- screen-space ambient occlusion
- denoising based on bilateral filter using geometric info

# Silhouette detection

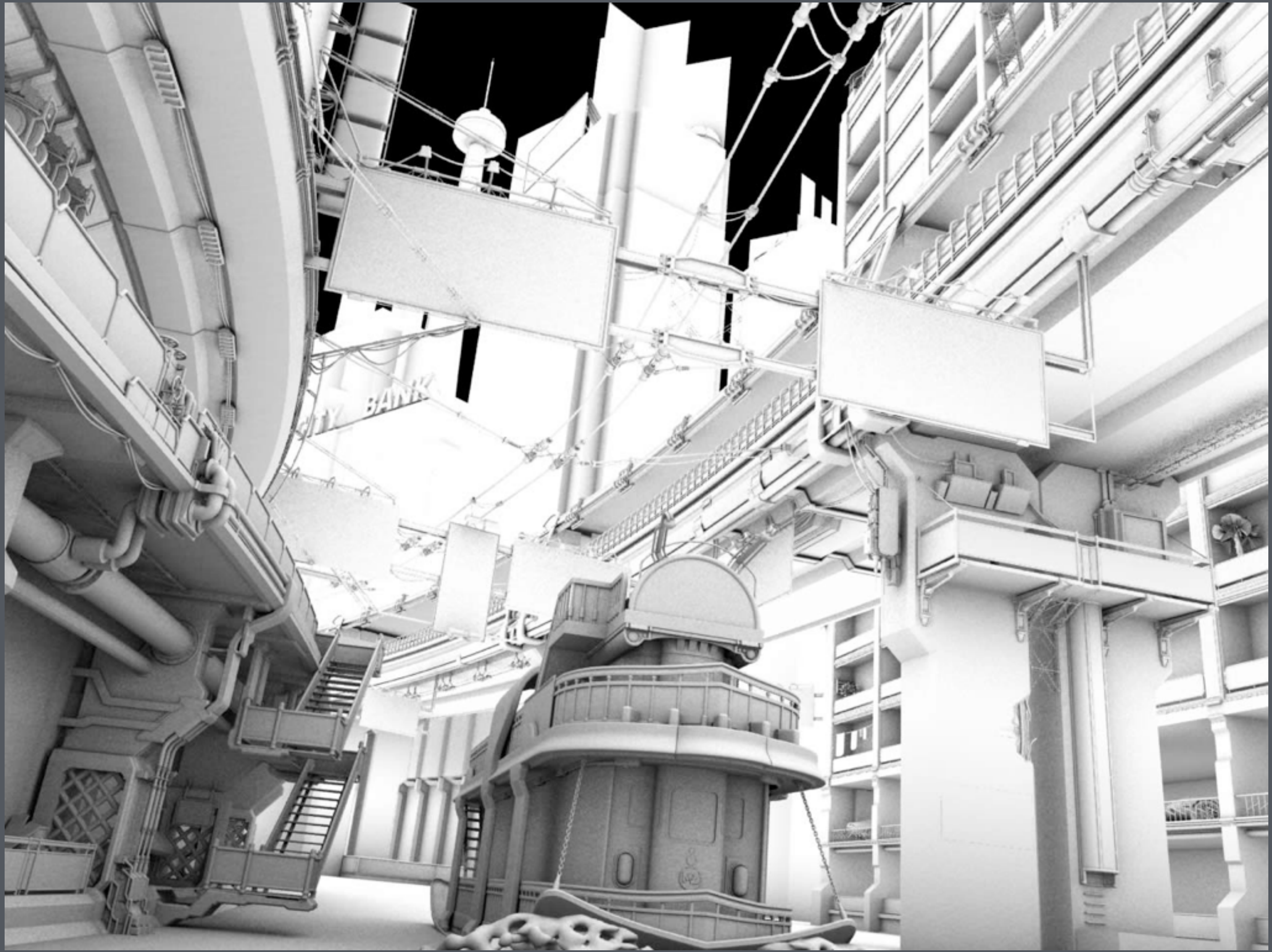
**By differentiating the depth buffer, can locate silhouettes and creases**







# Amient occlusion



# Denoising

[Mara et al. HPG 2017]

# Post-processing

**After pixel values are computed, often more processing is desired**

- effects that depend only on pixel values and depth (not normals, texture, etc.) are the same in forward or deferred mode
- pointwise color transforms: color grading, tone processing
- convolution filters: lens flare and bloom
- depth-dependent effects: atmospheric haze

# Color grading


*The Matrix* (Warner Bros.); comparison: Digital Media Academy

# Bloom

*Journey* | thatgamecompany

# Limitations of Deferred Shading

**Each pixel in the g-buffer can only store material and surface info for a single surface.**

- blending/transparency is difficult
- antialiasing is a different ball game

**For transparency: a “hybrid” renderer**

- deferred shading for opaque objects, forward shading for translucent objects
- allows translucent geometry to know about opaque geometry behind it

**For antialiasing: smart blurring**

- use what is in the g-buffers to blur along but not across edges

# Antialiasing

**Single shading sample per pixel**

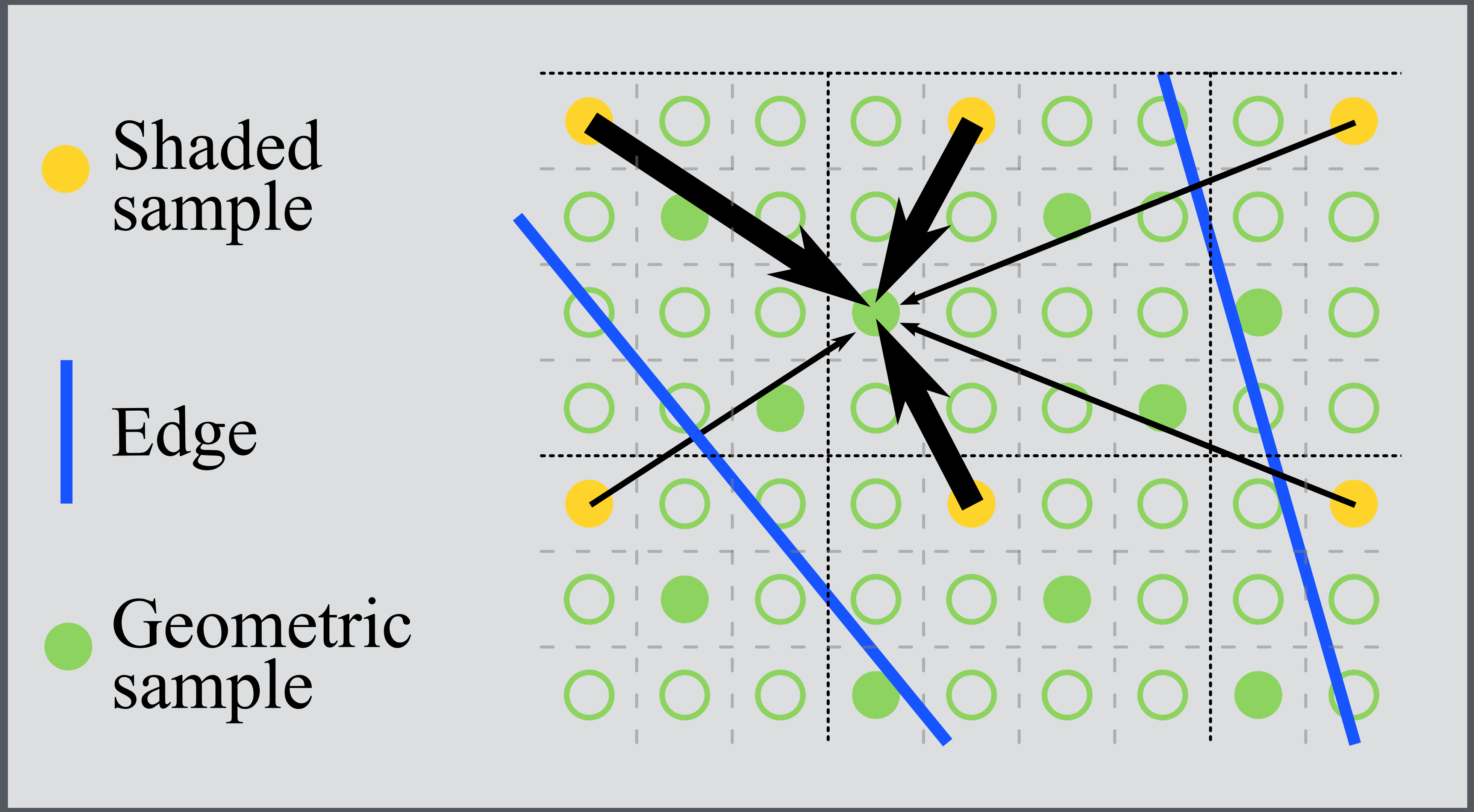
**Reconstruct by blending nearby samples**

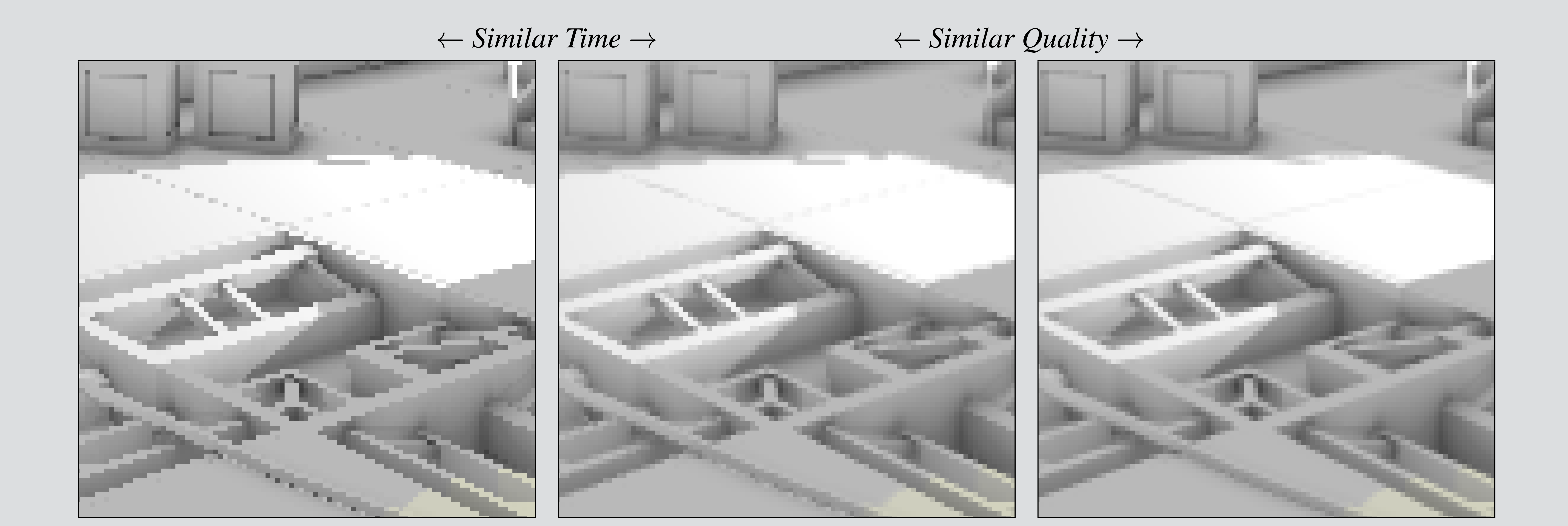
- select them by looking for edges
  (Morphological AA [Reshetov 09])
- learn about edges using multisample depth
  (Subpixel Reconstruction AA [Chajdas et al. 11])

# MLAA

[Reshetov 09]

# SRAA




(a) 1× Shading + Box (poor, fast)  (b) **NEW: 1× Shading + SRAA (good, fast)**  (c) 16× Shading + Box (good, slow)

[Chajdas et al. 11]

# Summary: Deferred Shading

**Pros**

- Store everything you need in 1st pass
  - normals, diffuse, specular, positions,...
  - G-buffer
- After z-buffer, can shade only what is visible

**Cons:**

- transparency (only get one fragment per pixel)
- antialiasing (multisample AA not easy to adapt)

**Standard game engines provide both forward and deferred paths**

# How to do all this in OpenGL

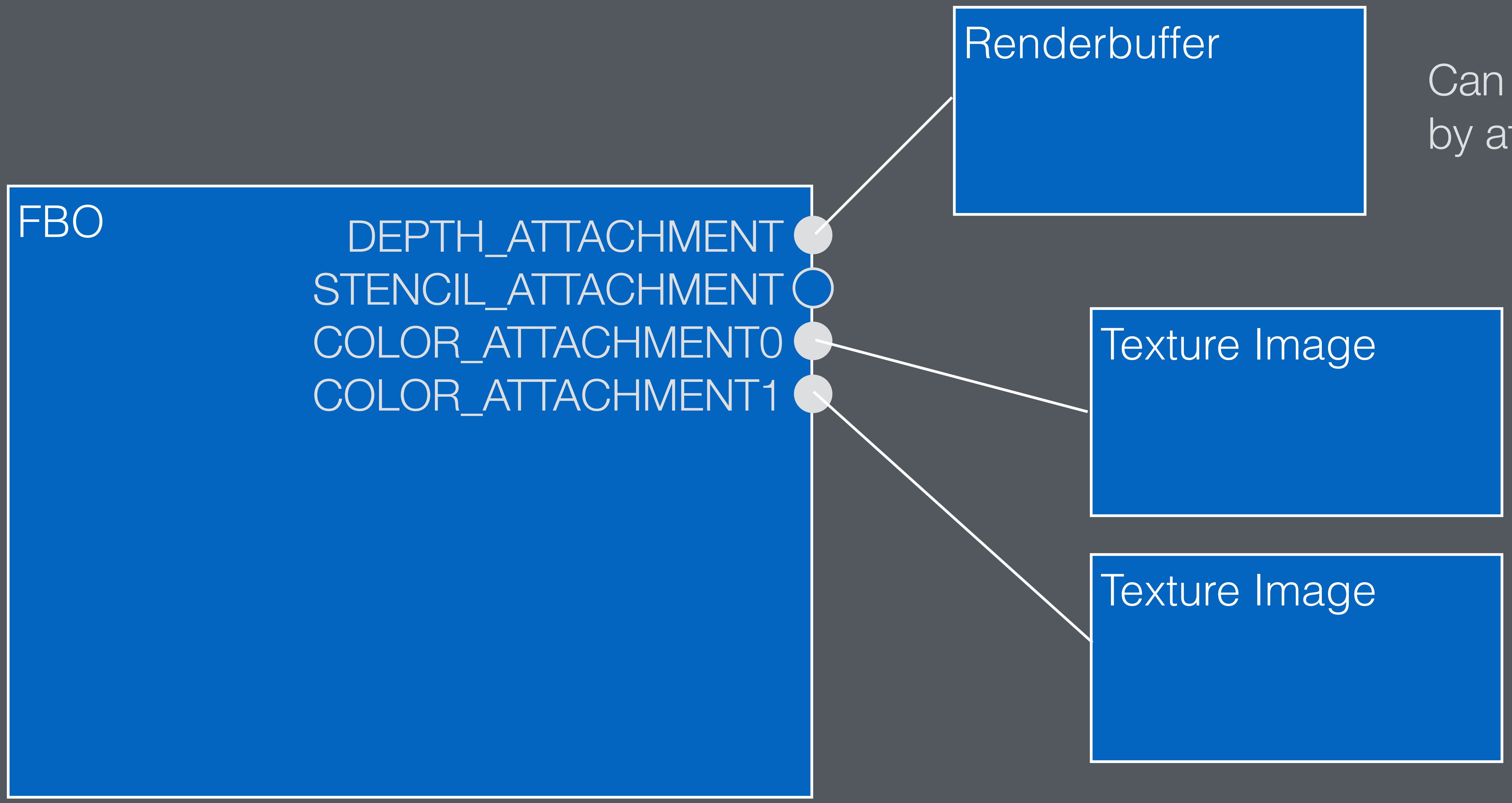
**When you first fire up OpenGL, all fragment shader output is written to the framebuffer that shows up in your window**

- this is the *default framebuffer*
- it actually can contain multiple buffers: front and back for double-buffering; left and right for stereo/HMD devices. You can control where fragment shader output goes using glDrawBuffer()

**For deferred shading and other multi-pass methods, you instead create a (non-default) *Framebuffer Object* (FBO)**

- you *attach* images to the FBO to receive fragment shader output
- color attachments (variable number) receive color data from gl_FragData[…] (gl_FragColor is just an alias for gl_FragData[0])
- a depth attachment is required for *z*-buffering to function; stencil attachments are also possible

# Framebuffer Object




Can only be used
by attaching to an FBO

Can be attached to an FBO, filled with data, and later sampled as a texture in another shading pass

All these images have to match in size!