Advances in OpenGL ES

Session 505

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GPU Software

Introduction

- OpenGL ES offers the most direct access to graphics hardware on iOS
  - Allows lots of flexibility and power
    - Flexibility can be challenging to master
- Utilizing the API to its fullest can set your app apart
  - Make the difference between shipping something good or great

Agenda

What you will learn

- New in iOS 7
  - Instancing
  - Vertex texture sampling
  - sRGB texture formats
- Tuning and performance
  - Understand the GPU pipeline
  - Insight into feedback from GPU tools

A Note About Power Efficiency

Rendering, but not…

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- Manage frame rate
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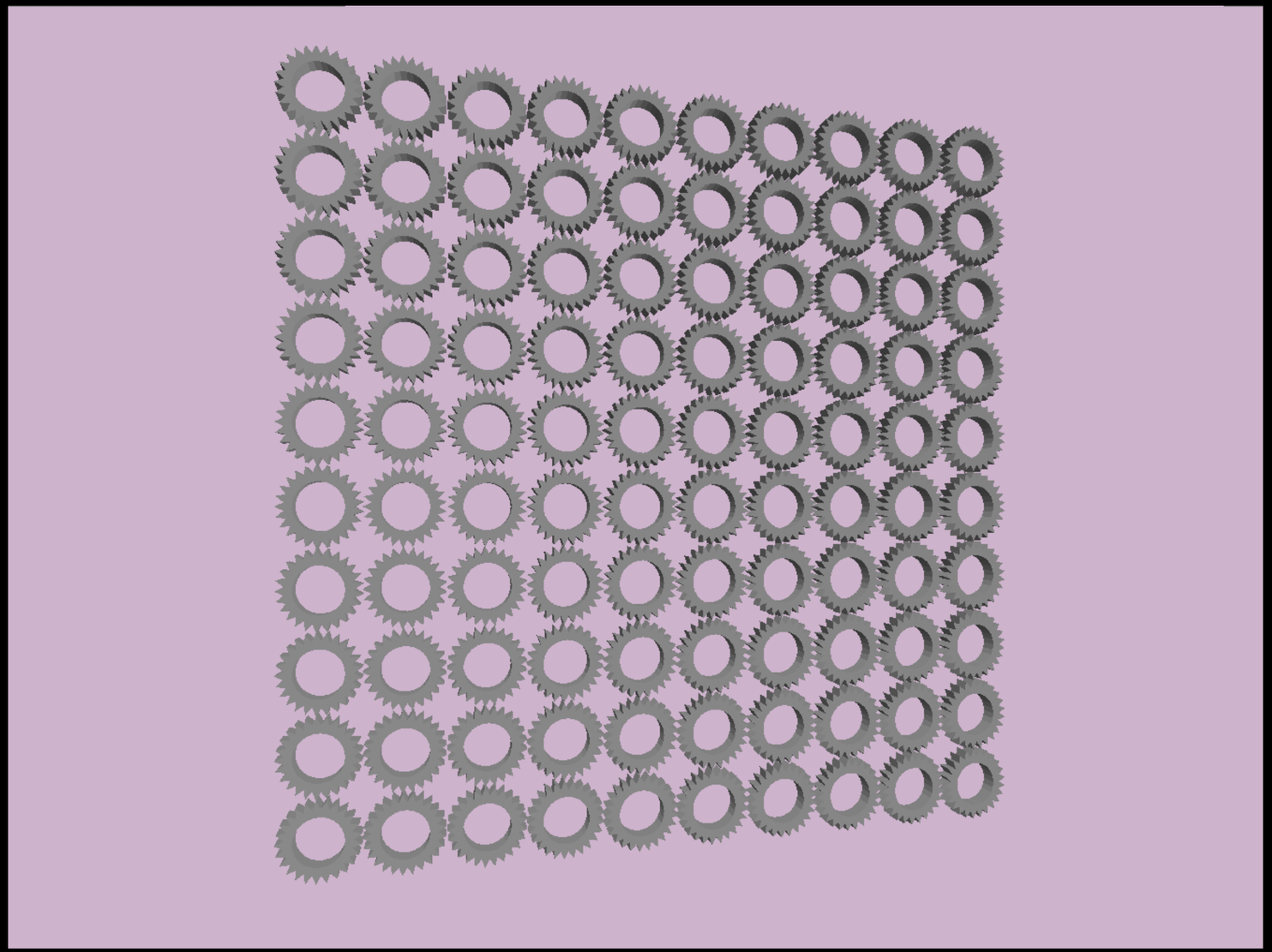
- Often unnecessary to render at all
  - Do not re-render a frame if it looks the same as the previous frame
    - No animation or movement
- Particularly important with the multilayered iOS 7 UI
  - UI can skip compositing if nothing has changed in a layer

Instancing

From one, come many…

Drawing Many Models



Drawing Many Models

Without instancing

```
for(x = 0; x < 10; x++)
{
    for(y = 0; y < 10; y++)
    {
      // Set uniform to position the gear
      glUniform4fv(mygearPosition[x][y]);

      // Draw the gear
      glDrawArrays(GL_TRIANGLES, 0, numGearVertices);
    }
}
```

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What Instancing Does

- Draw the same model many times
  - Different parameter for each instance
  - Single draw call
- Each instance can have different:
  - Position
  - Matrices
  - Texture coordinates

Instancing

Two forms

- Instanced arrays
  - `GL_APPLE_instanced_arrays`
  - Instance parameters in a vertex array
- Shader instance ID
  - `GL_APPLE_draw_instanced`
  - ID variable for instance drawn in vertex shader

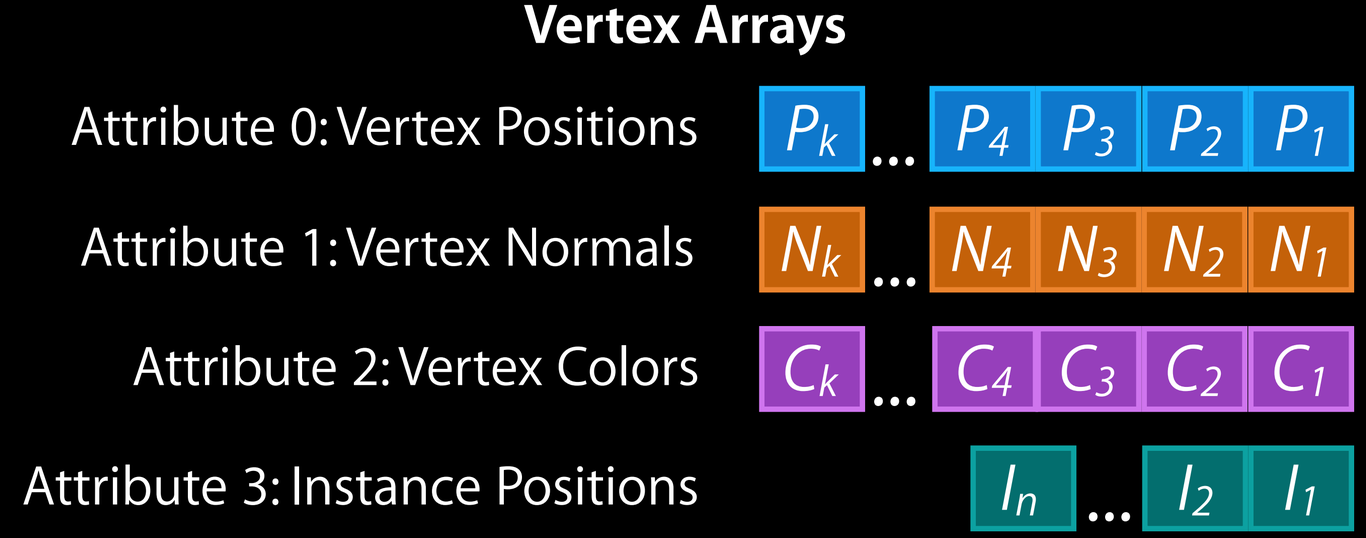
Instancing

Method 1: Instanced arrays

- `glVertexAttribDivisorAPPLE` indicates
  - Attribute array supplying instance data
  - Number of instances to draw before advancing to the next element in this array
- Draw with `glDrawArraysInstancedAPPLE` or `glDrawElementsInstancedAPPLE`
  - Same as `glDrawArrays` and `glDrawElements`, but extra parameter indicates number of instances to draw

Instancing

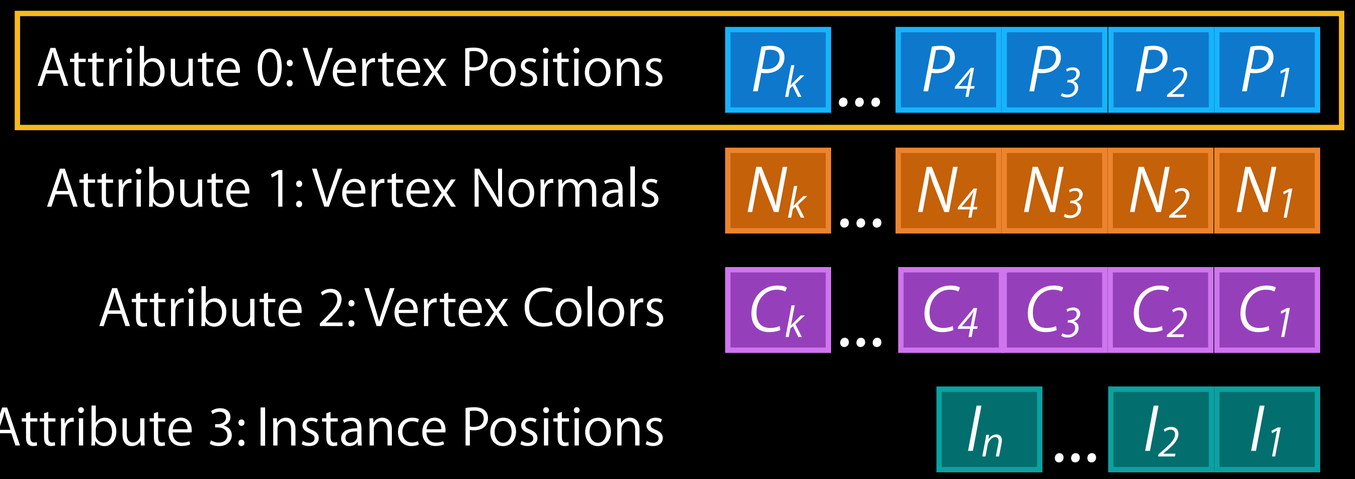
Method 1: Instanced arrays



Instancing

Method 1: Instanced arrays

```
glVertexAttribPointer(0, ... , positionOffset);
```



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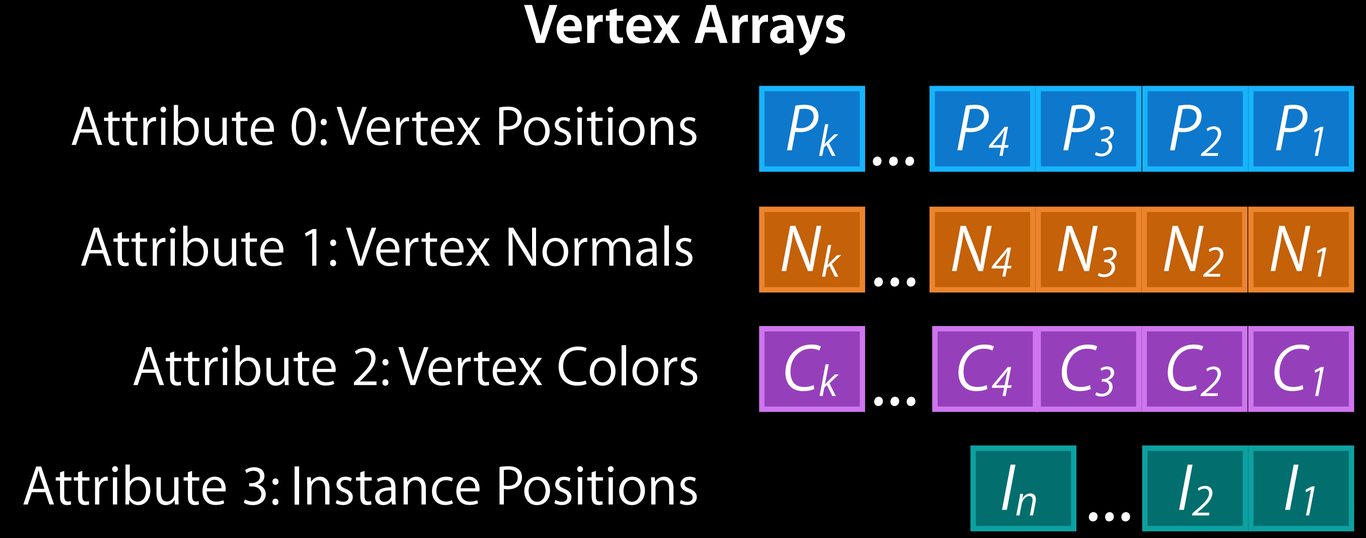

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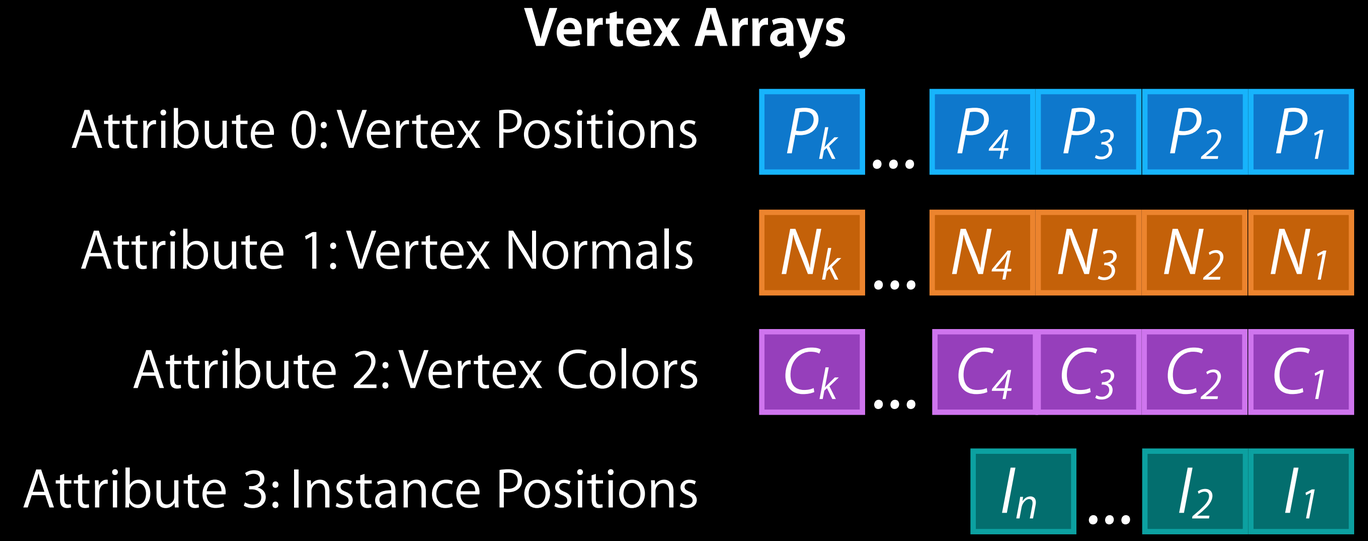

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glVertexAttribPointer(1, ... , normalOffset);
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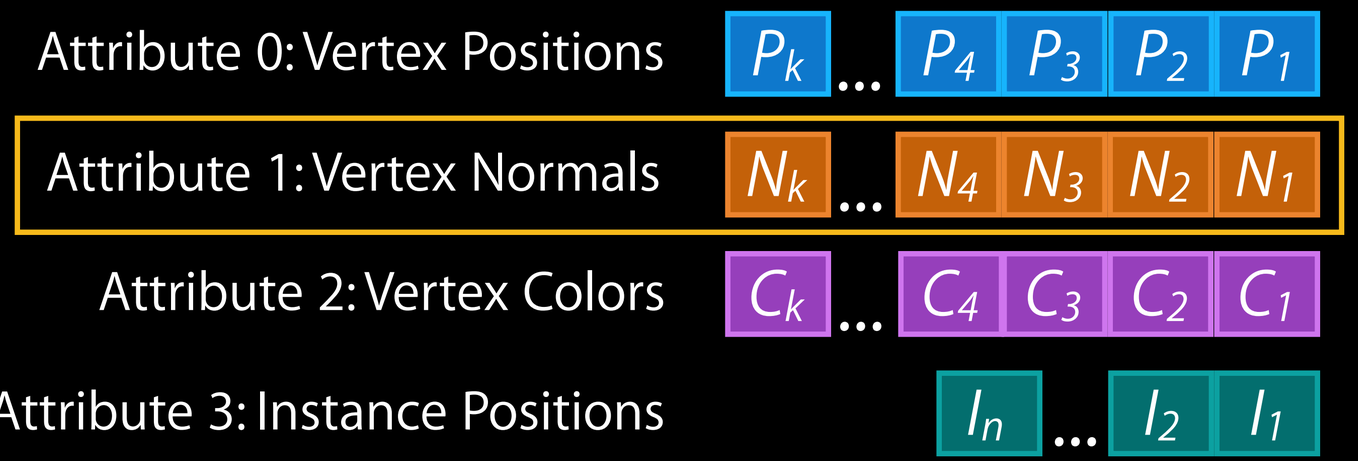

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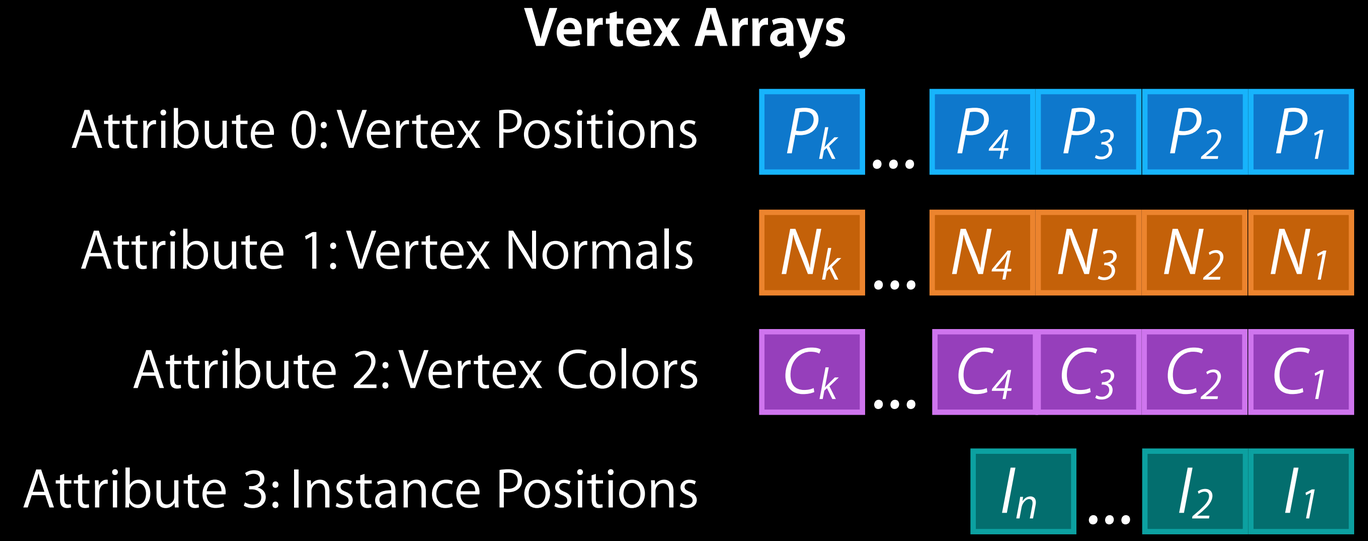

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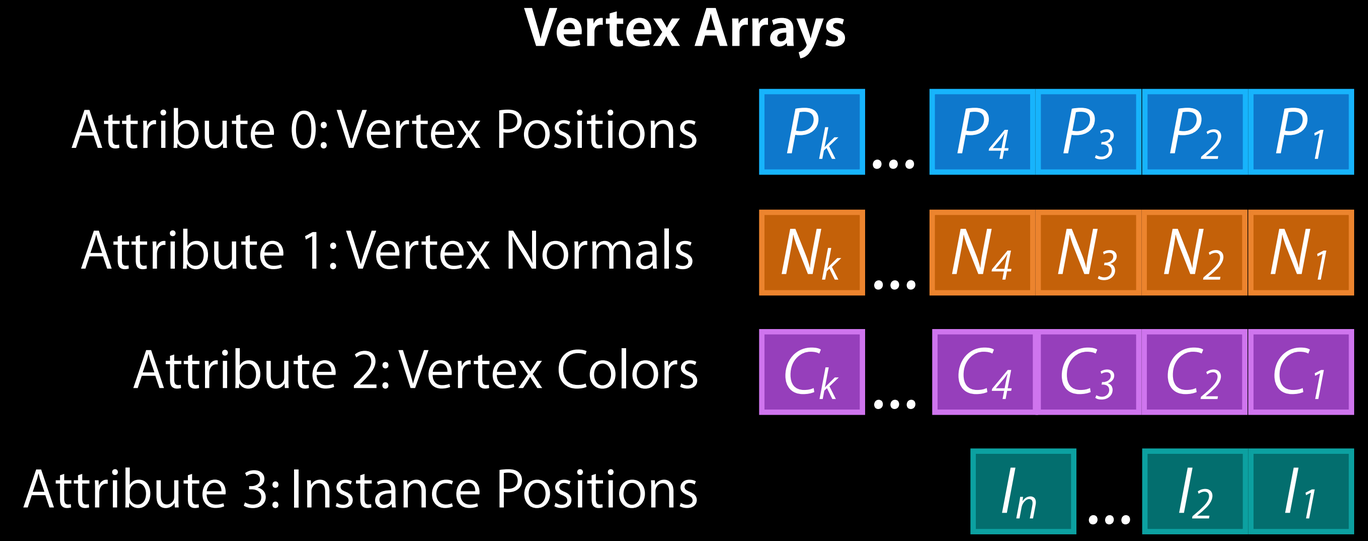

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glVertexAttribPointer(2, ... , colorOffset);
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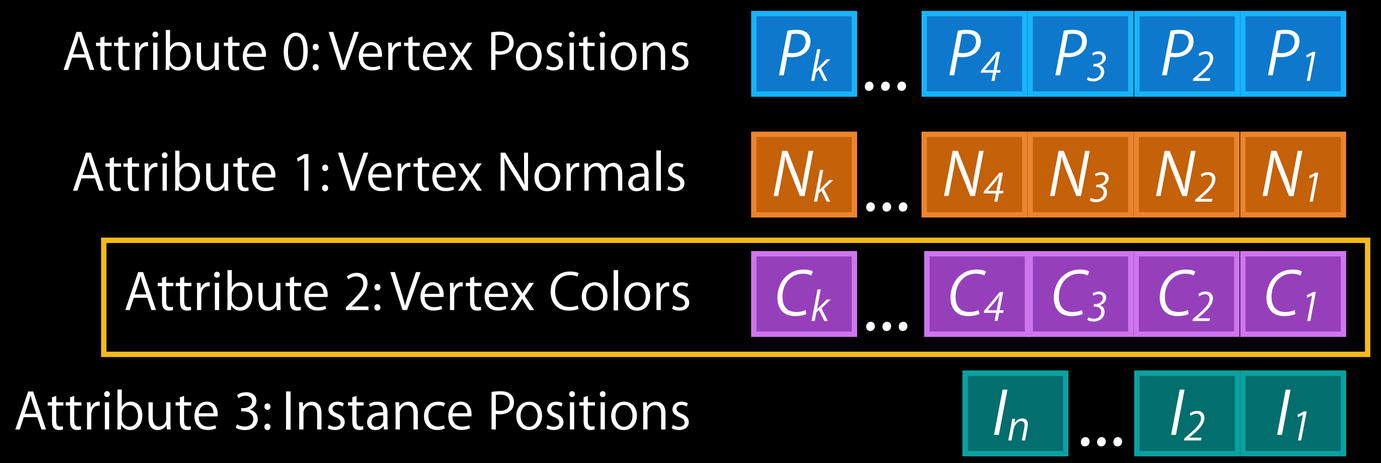

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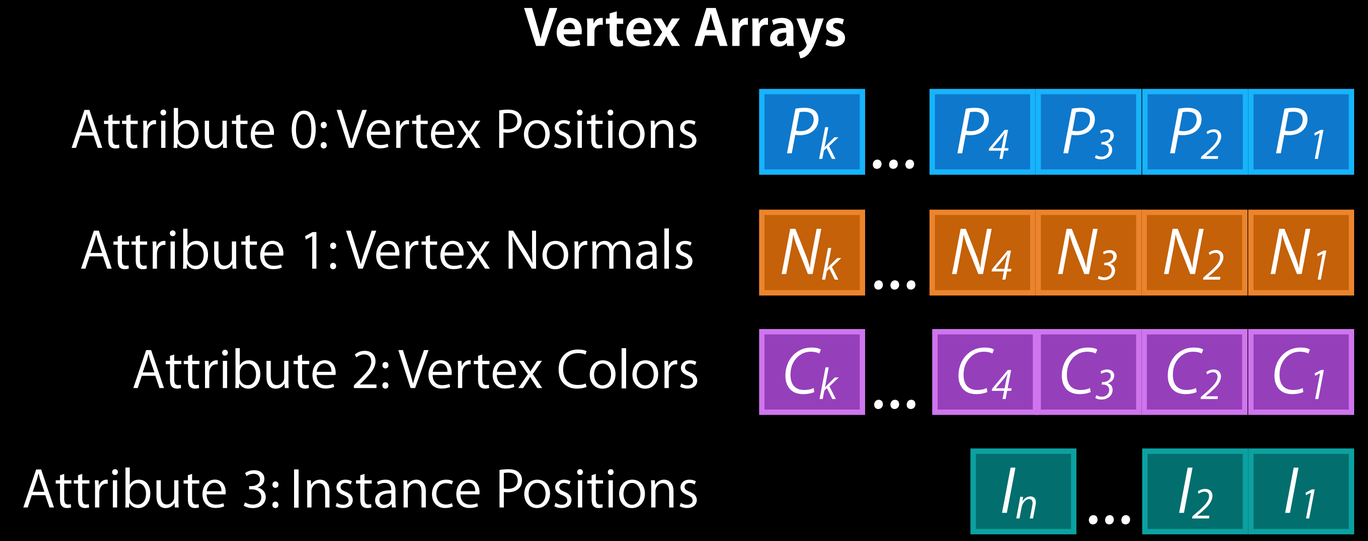

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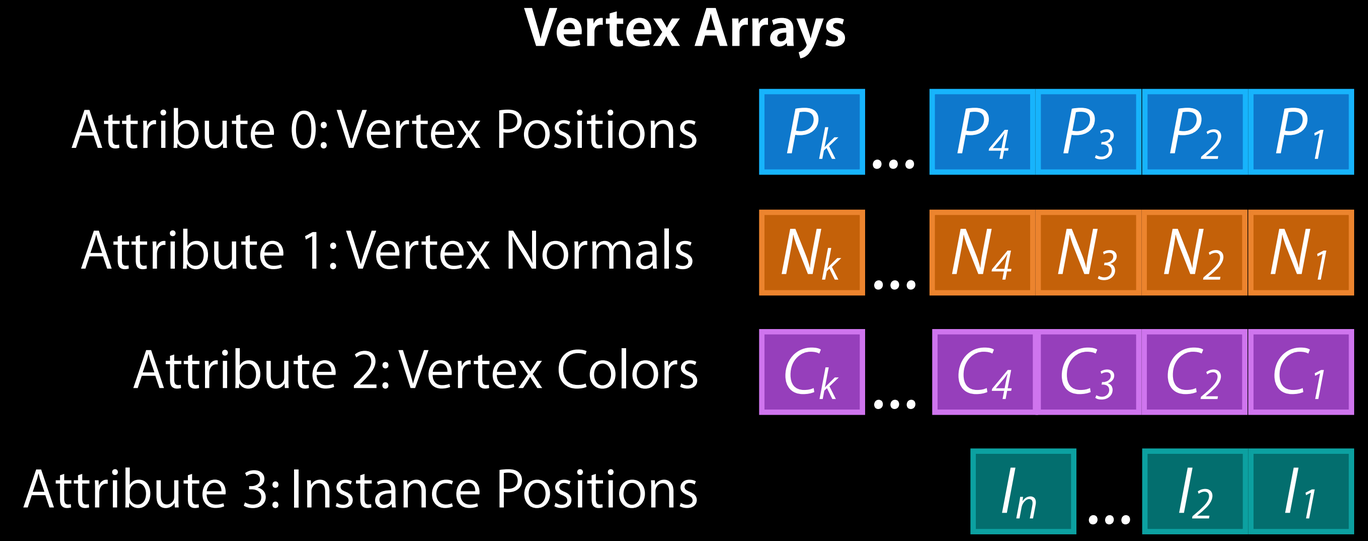

Instancing

Method 1: Instanced arrays

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glVertexAttribPointer(3, ..., instancePositionOffset);
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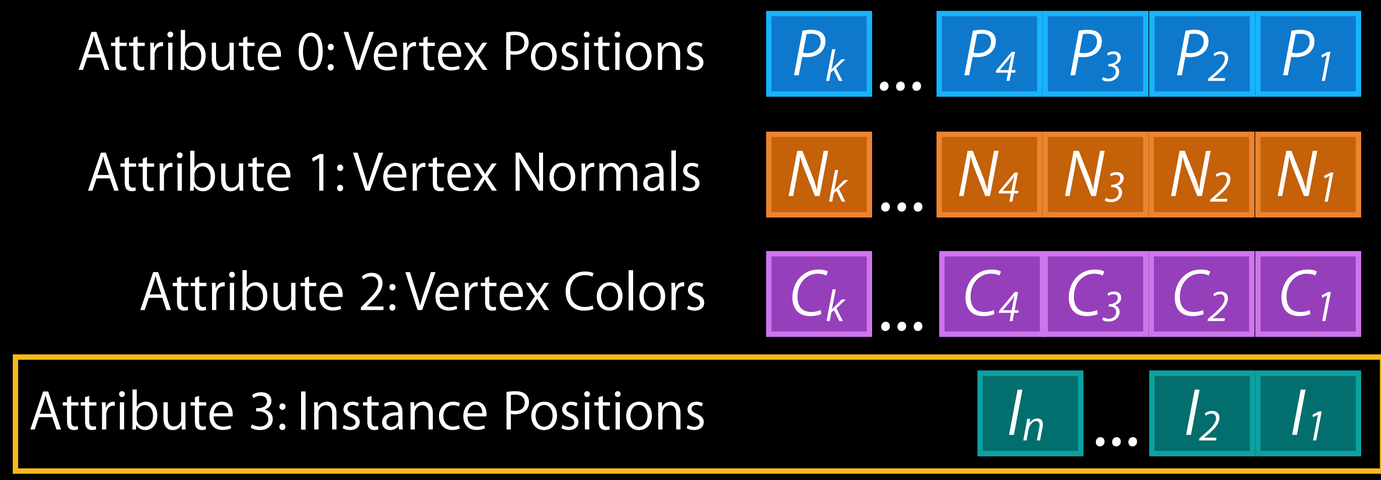
Vertex Arrays



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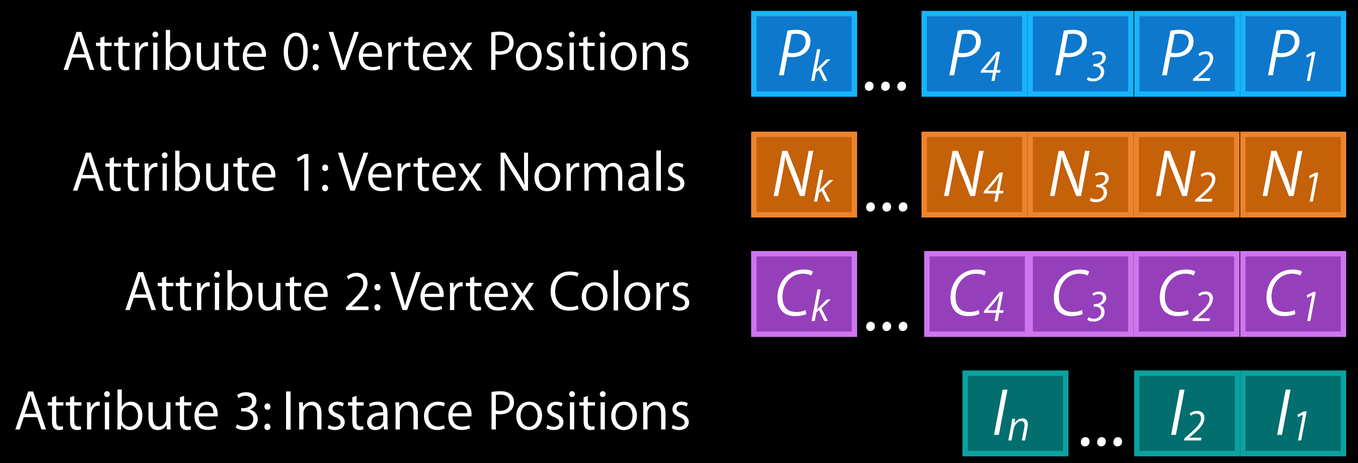

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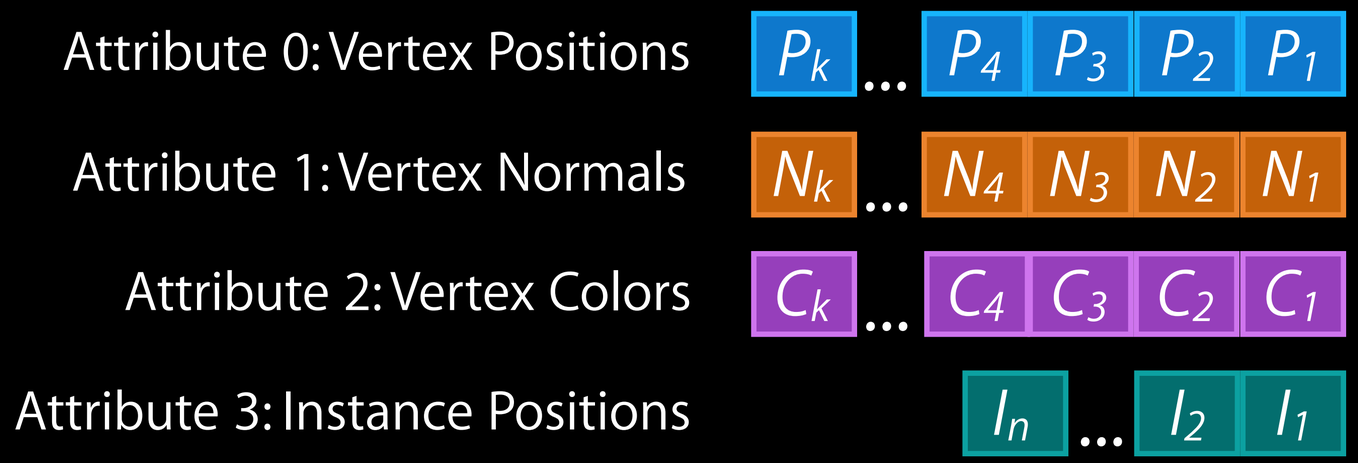

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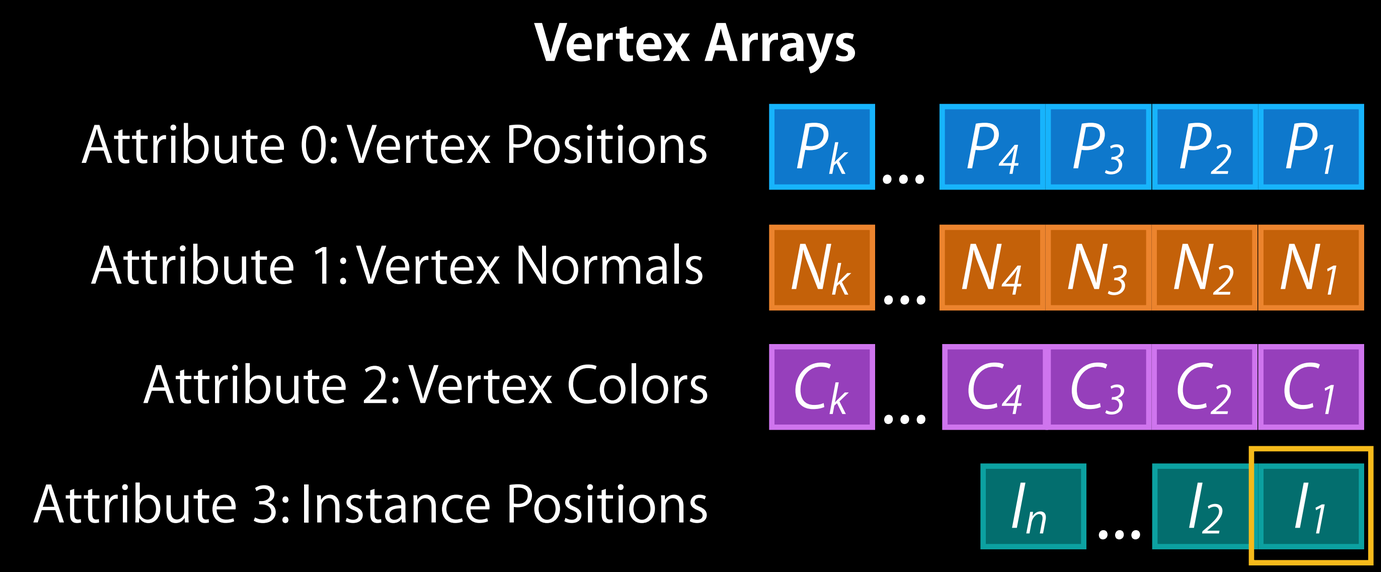

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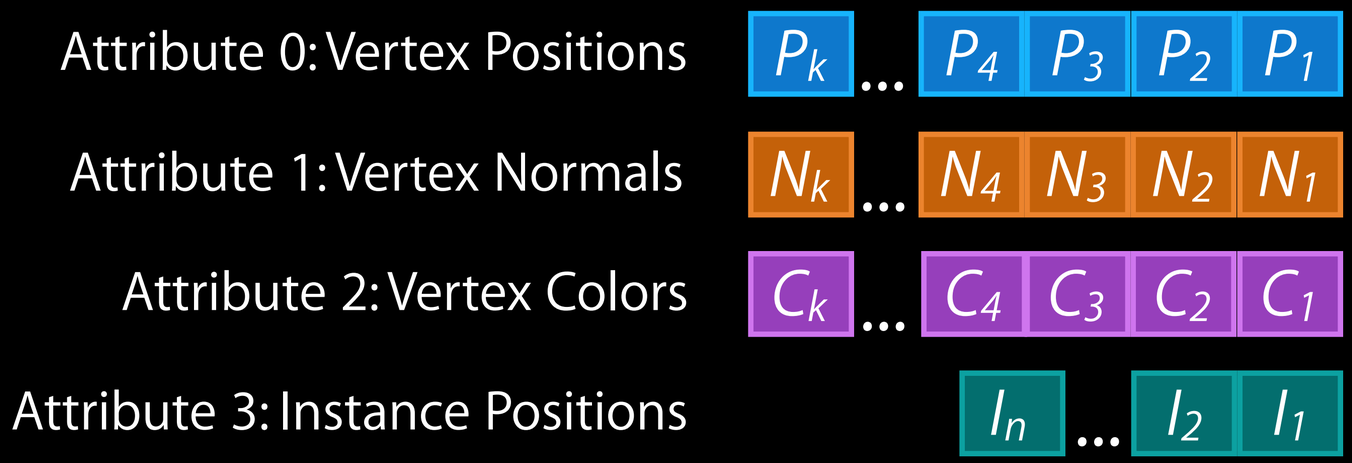

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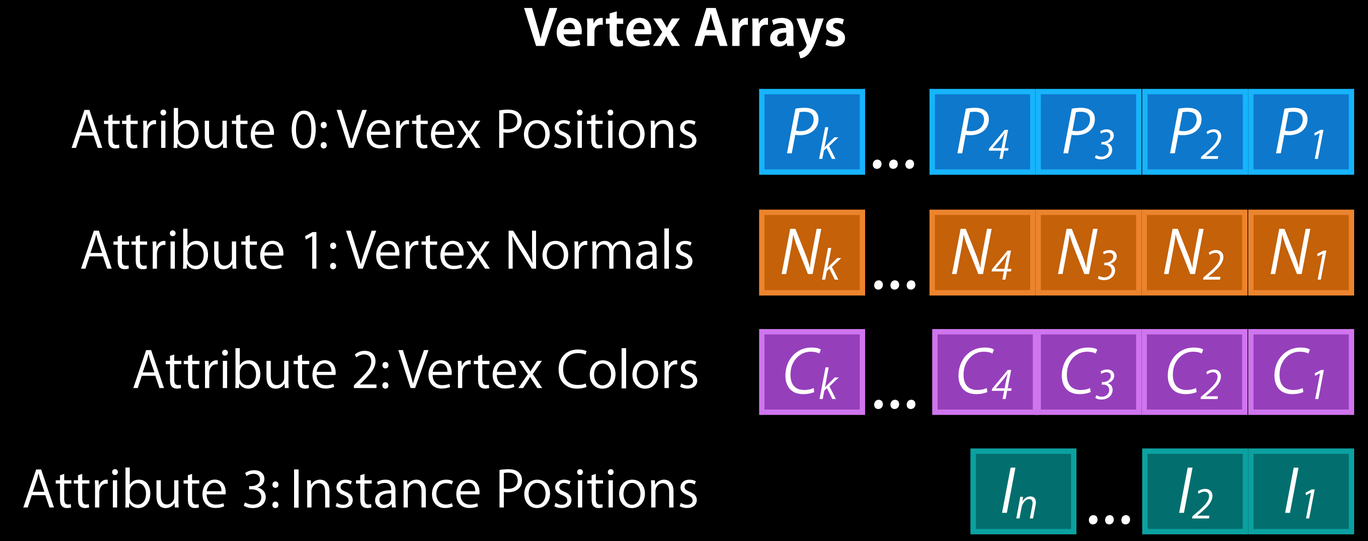

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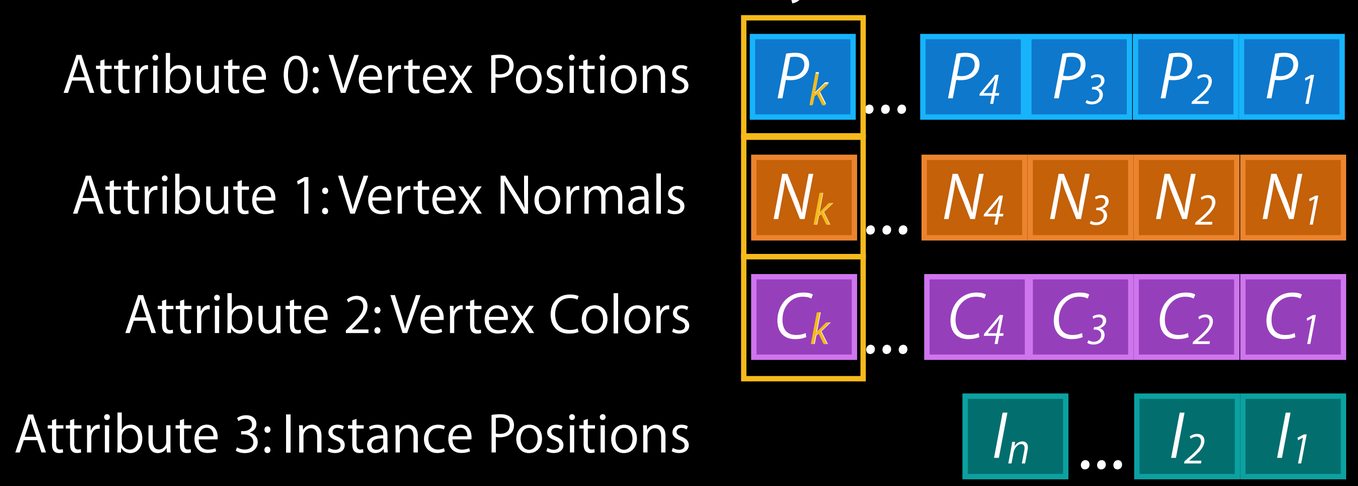

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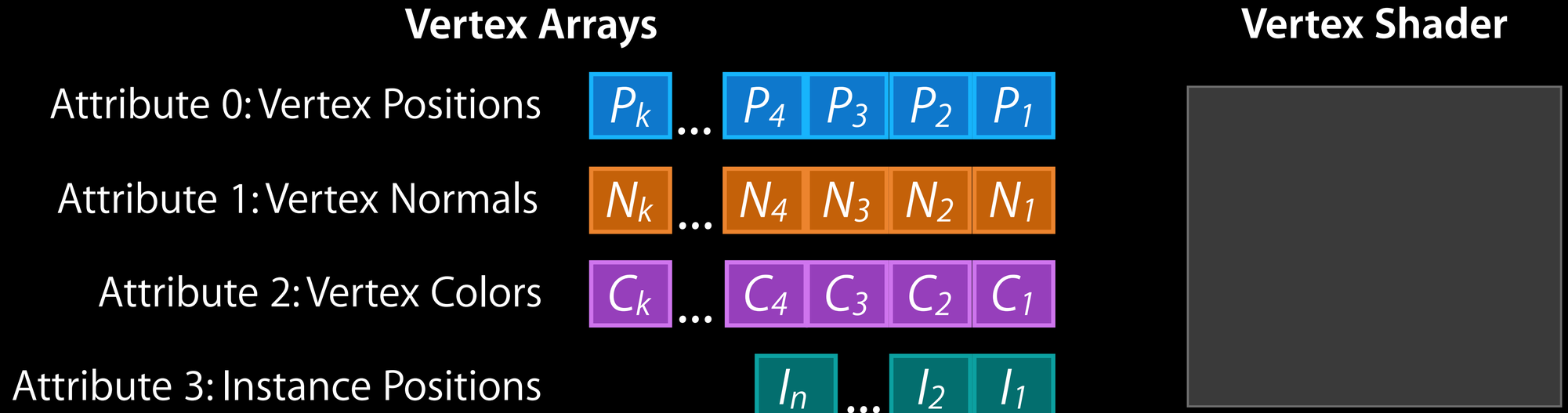

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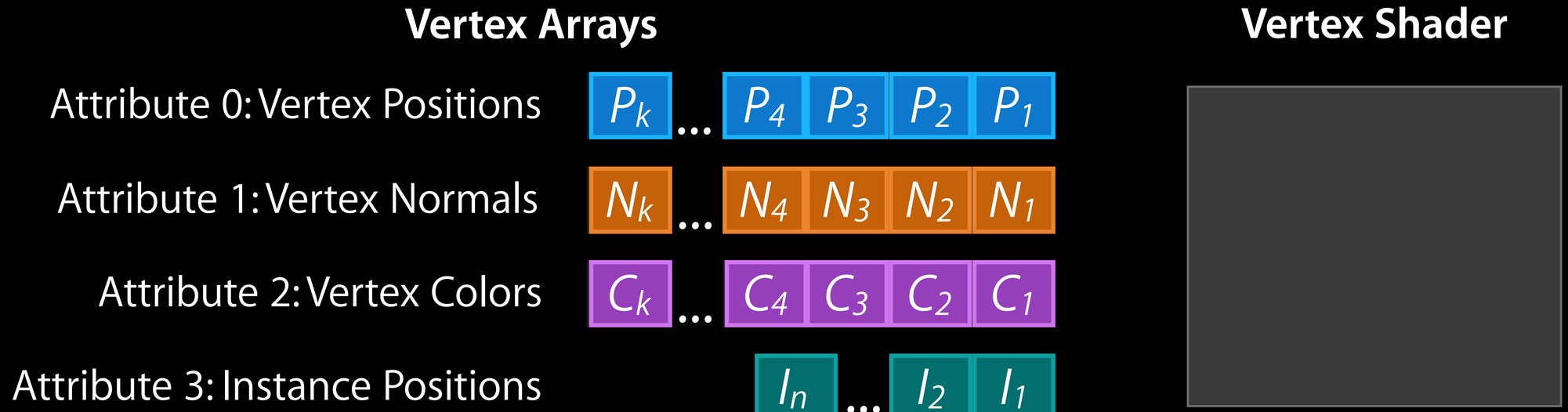

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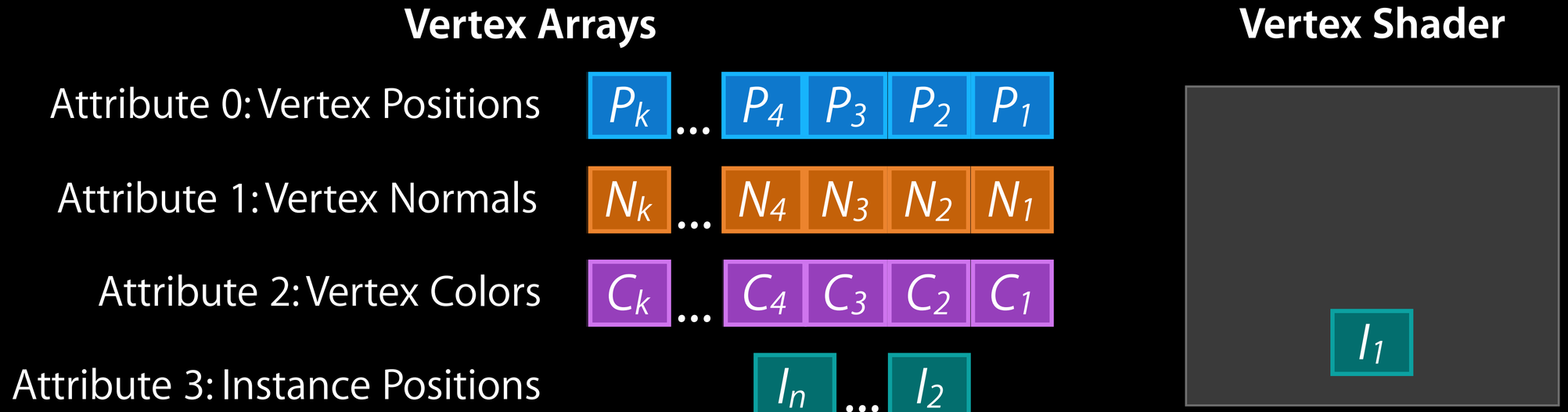

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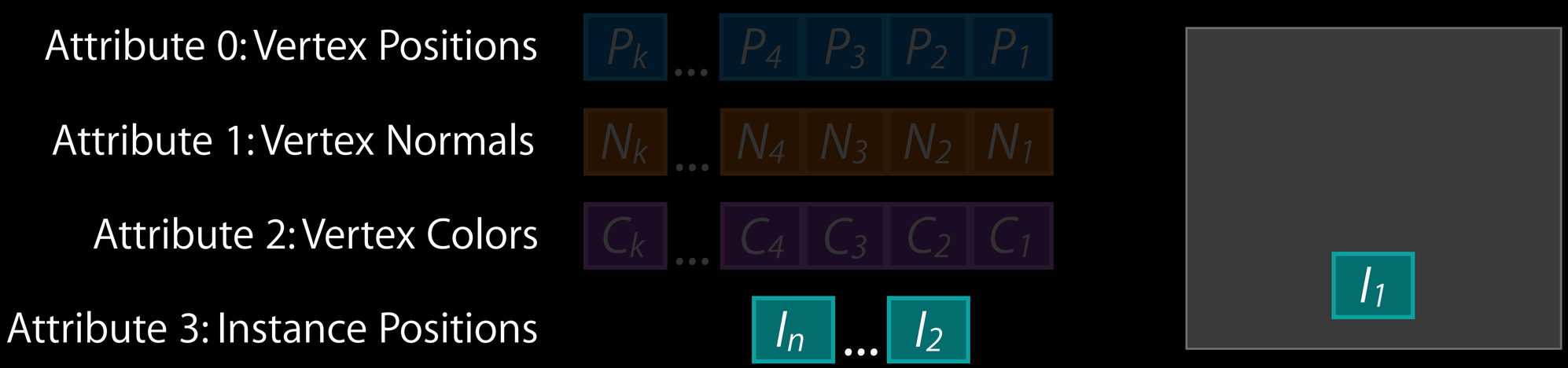

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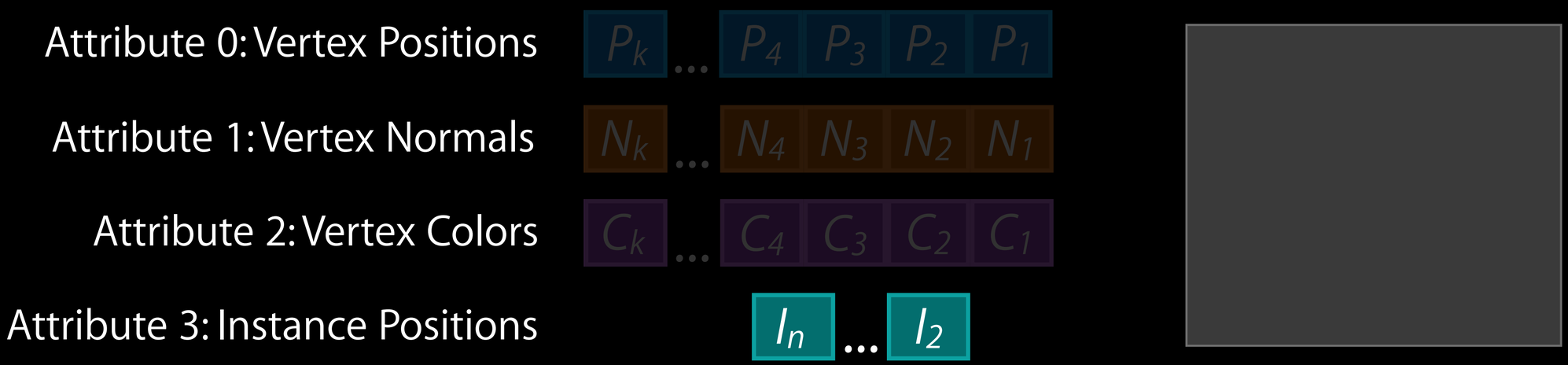

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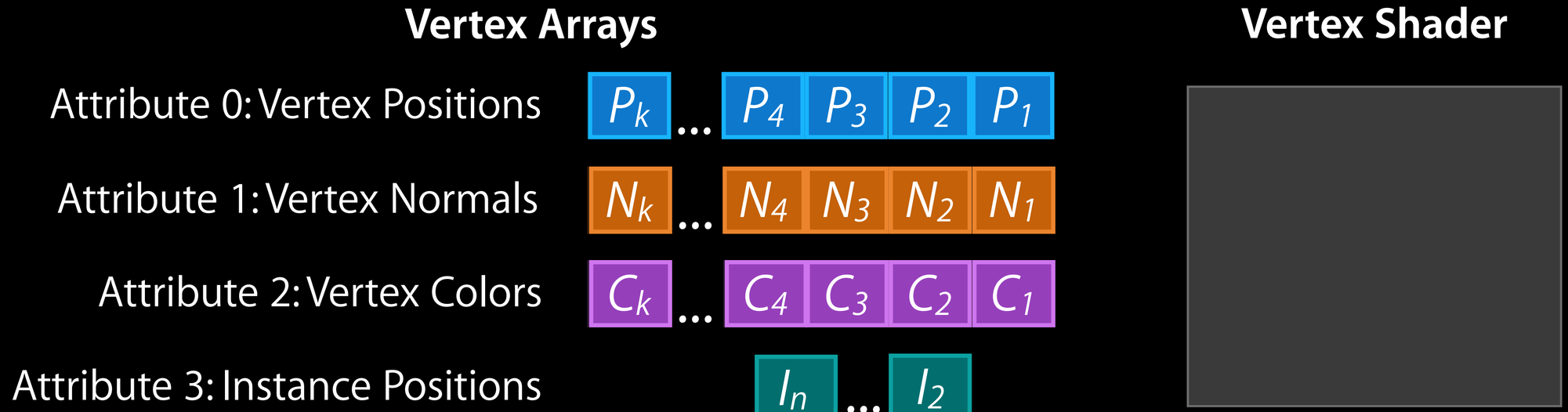

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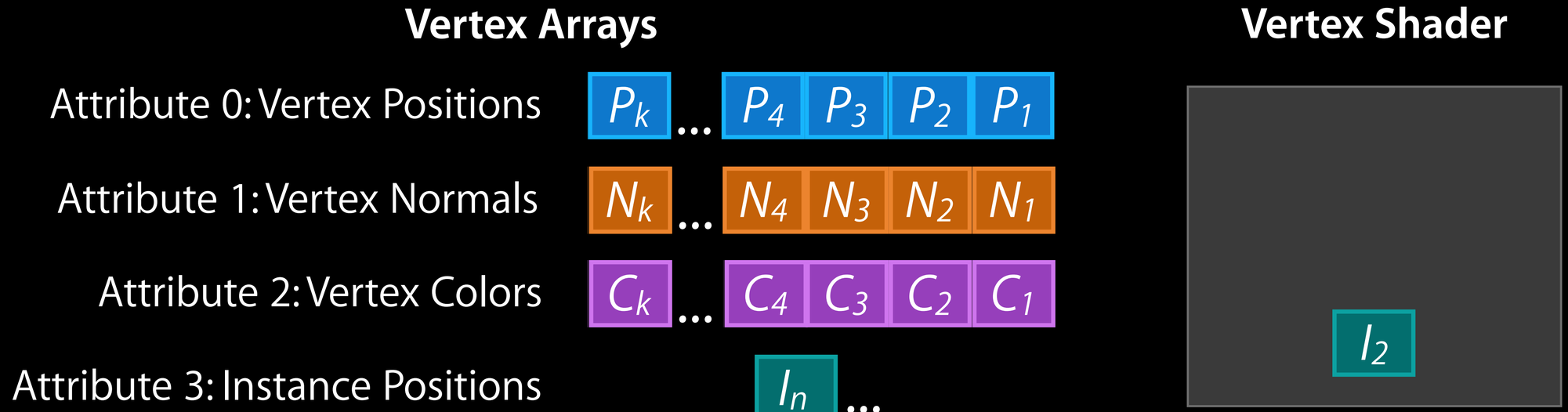

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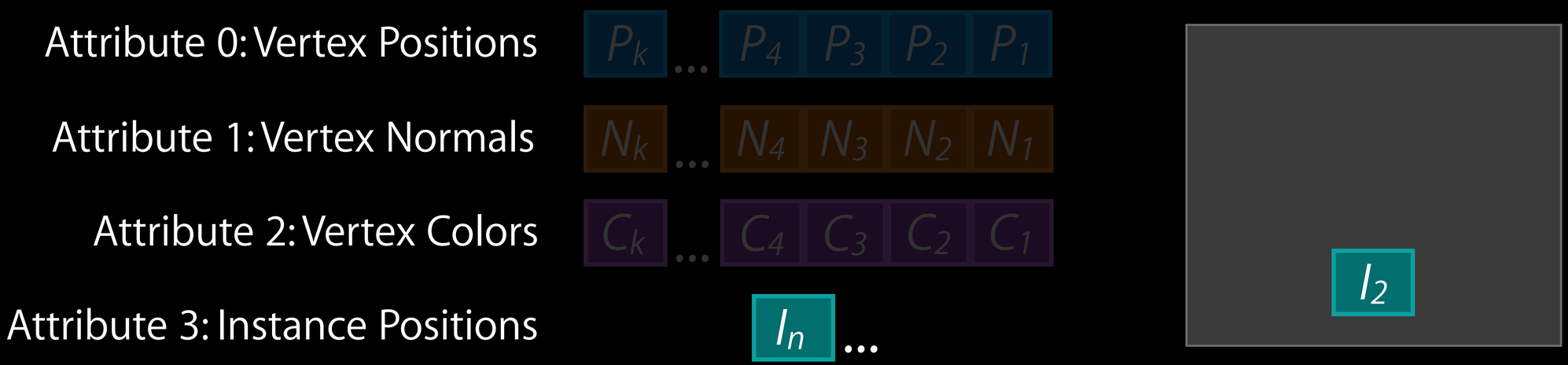

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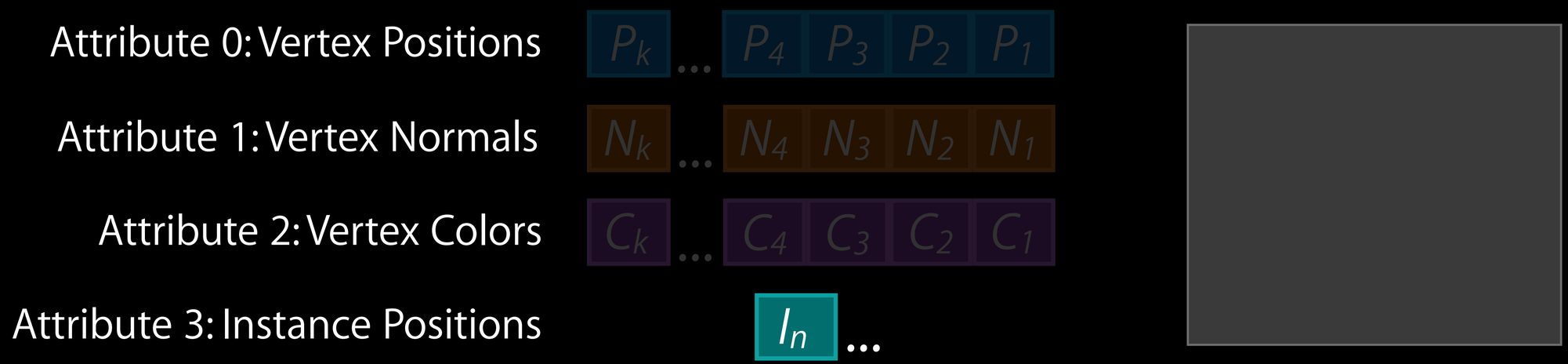

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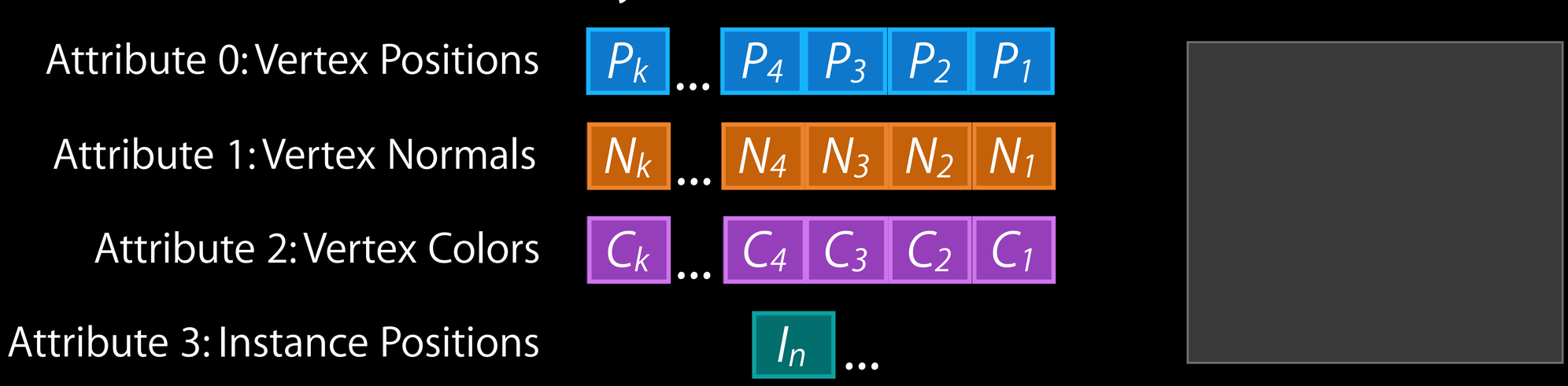

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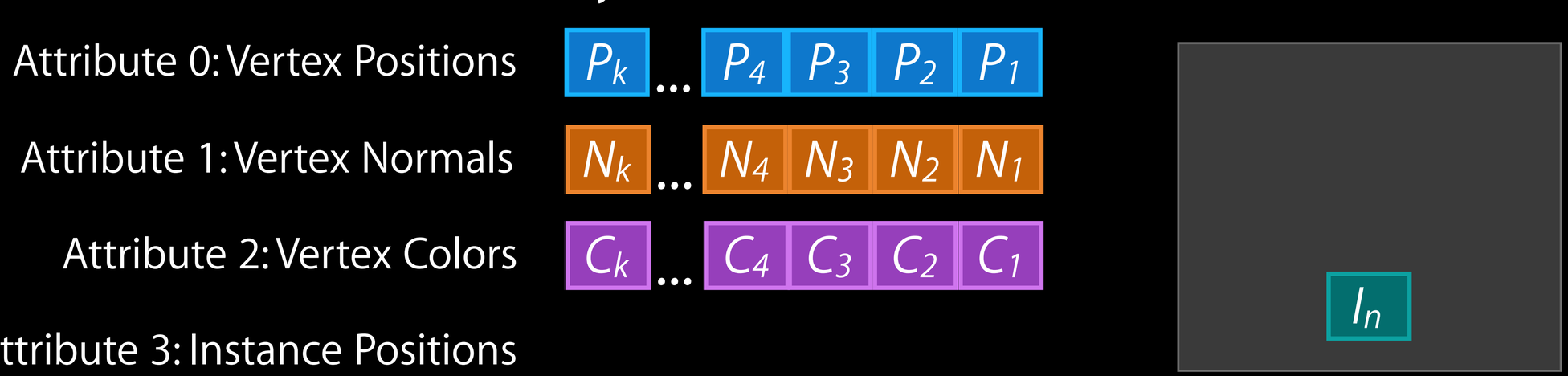

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Vertex Arrays

Attribute 0: Vertex Positions

Attribute 1: Vertex Normals

Attribute 2: Vertex Colors

Attribute 3: Instance Positions

Vertex Shader

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Vertex Shader

Instanced Arrays

API setup


```
// Setup per vertex position, normal, and color arrays on
//  indices 0, 1, and 2 for gear model same as usually

...

// Setup vertex array index 3 to contain per object positions
glVertexAttribPointer(3, ..., instancePositionOffset);

// Indicate that attribute 3 should increment 1 element each instance
glVertexAttribDivisorAPPLE(3, 1);

// Draw gear model 100 times
glDrawArraysInstancedAPPLE(GL_TRIANGLES, 0, NUM_GEAR_VERTS, 100);
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Instance Arrays

Vertex shader

```
// Per vertex and normal position
attribute vec4 pos;
attribute vec3 normal;
// Per instance position (maps to attribute index 3)
attribute vec4 instancePos;
...
void main()
{
    // Add vertex position to instance position
    vec4 tempPos = instancePos + pos;
    // Transform position to clip space and output to gl_Position

    ...

    gl_Position = tempPos;
}
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Instancing

Method 2: Instance ID

- Built-in `gl_InstanceIDAPPLE` variable in vertex shader
- ID incremented for each instance
- Can use ID to calculate unique info for instance
  - Calculate texture or position
  - Location of instance parameter in uniform array or texture
- Also uses `glDrawArraysInstancedAPPLE` or `glDrawElementsInstancedAPPLE`

Instancing

Method 2: Instance ID

```
glDrawArraysInstancedAPPLE(GL_TRIANGLES, 0, k, n);
```

Vertex Arrays

Attribute 0: Vertex Positions — P_k ... P_4 P_3 P_2 P_1

Attribute 1: Vertex Normals — N_k ... N_4 N_3 N_2 N_1

Attribute 2: Vertex Colors — C_k ... C_4 C_3 C_2 C_1

Vertex Shader

```
gl_InstanceID
```

Instancing

Method 2: Instance ID

```
glDrawArraysInstancedAPPLE(GL_TRIANGLES, 0, k, n);
```

Vertex Arrays

Attribute 0: Vertex Positions P_k ... P_4 P_3 P_2 P_1

Attribute 1: Vertex Normals N_k ... N_4 N_3 N_2 N_1

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Vertex Shader

```
gl_InstanceID
0
```

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Vertex Shader

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Vertex Shader

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```

Instancing

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Vertex Shader

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Vertex Arrays

Attribute 0: Vertex Positions

Attribute 1: Vertex Normals

Attribute 2: Vertex Colors

Vertex Shader

```
gl_InstanceID
```

n

Shader Instance ID

Vertex shader


```
uniform float gearSize;
attribute vec2 vertexPosition;

...

void main() {
    float instanceID = float(gl_InstanceIDAPPLE);
    instancePosition.x = mod(instanceID, 10) * gearSize;
    instancePosition.y = (floor(instanceID)/ 10) * gearSize;
    vec4 tempPos = vertexPosition.xy + instancePosition.xy;

    // Transform tempPos to clip space and output to gl_Position

    ...

    gl_Position = tempPos;
}
```

Shader Instance ID

Vertex shader


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uniform float gearSize;
attribute vec2 vertexPosition;

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}
```

Vertex Texture Sampling

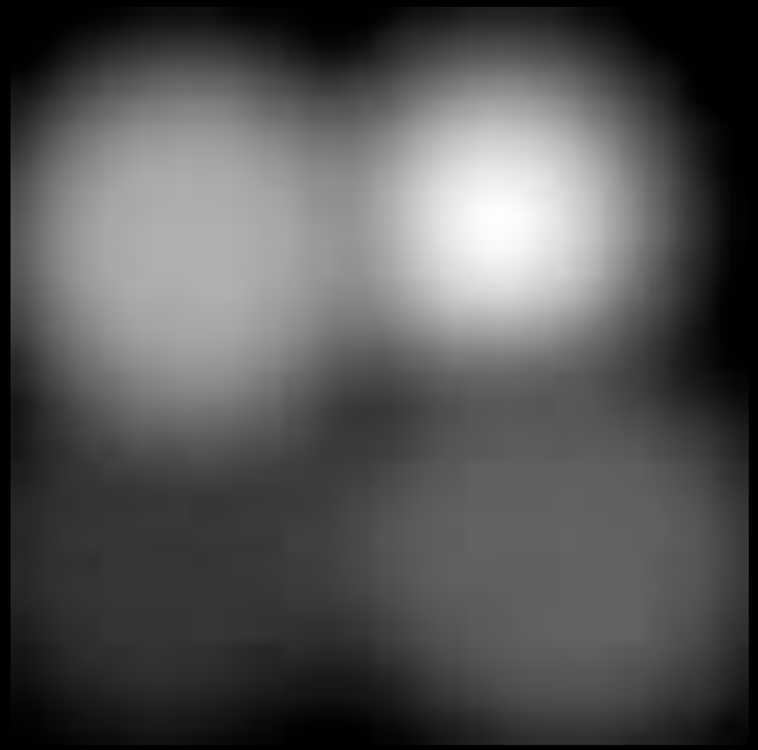
A texture in the vertex stage?

Vertex Texture Sampling

- Texture access in the vertex shader
- Many uses
  - Displacement mapping
  - Alternative to uniforms
- Generic data store with random access

A Simple Vertex Texture Sampling Example

Height mapping



A Simple Vertex Texture Sampling Example

```
attribute vec2 xzPos;
uniform sampler2D heightMap;

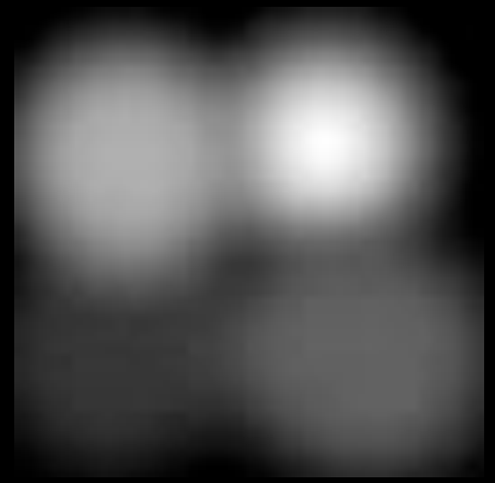
...

main()
{
    vec4 tempPos = texture2D(heightMap, xzPos);
    tempPos.xz = xzPos;

    // Transform tempPos to from model space to
    // clip space with modelviewProjection matrix

    ...

    // output to gl_Position
    gl_Position = tempPos;
}
```



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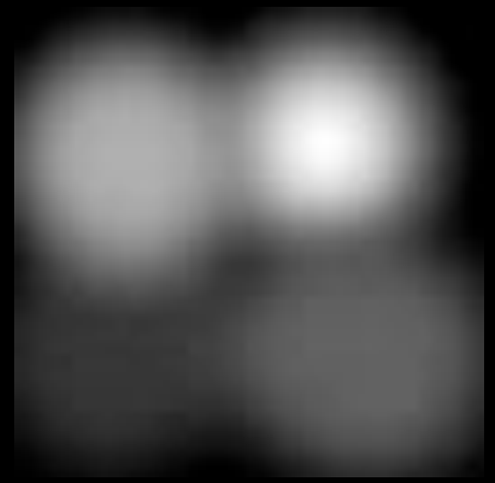

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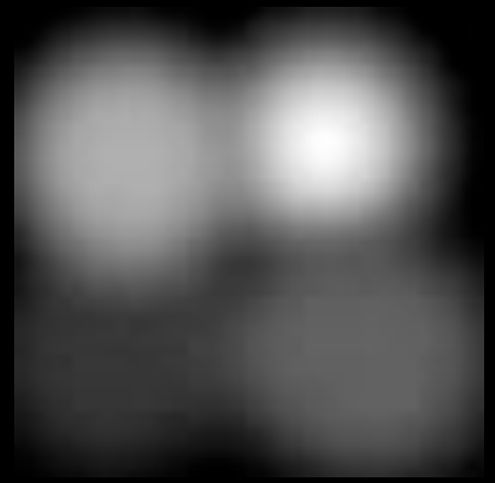

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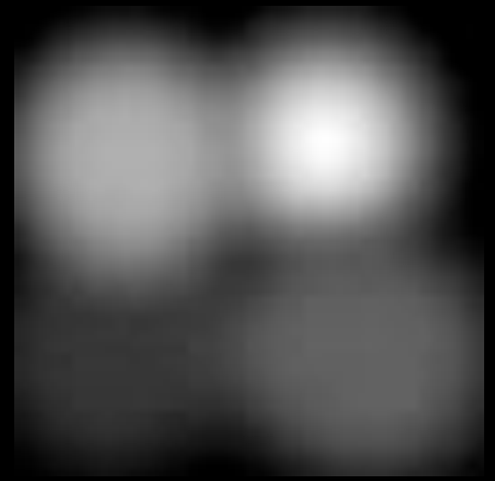

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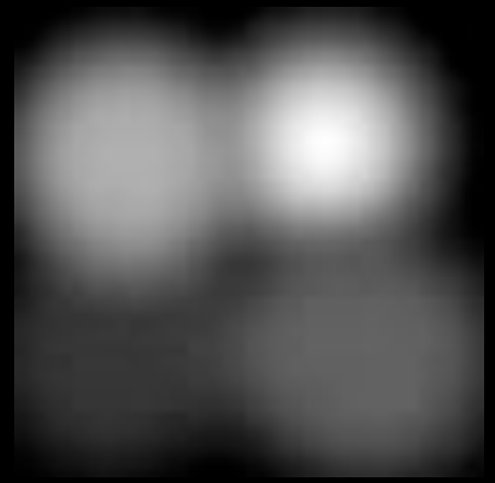

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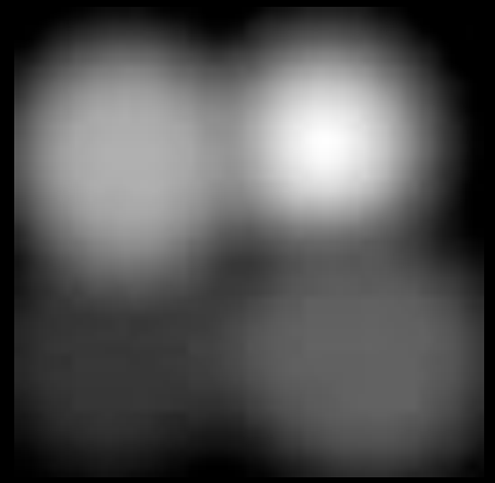

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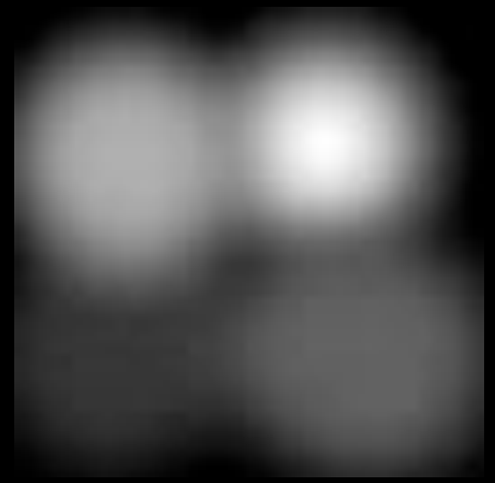

Vertex Texture Sampling for Generic Data

- Can store any kind of data in a texture for shader access
  - Large store of random access memory
  - Data normally passed via `glUniform`, passed via texture

Texture Sampling vs. Uniforms

- Larger storage than a uniform array
- Potentially less API calls to set data
  - Bind large number of uniforms as group
- A variety of types
  - `GL_UNSIGNED_BYTE`, `GL_HALF_FLOAT`, and `GL_FLOAT`
- Use with filtering and wrapping
  - Averages sequential values
- Render to texture
  - GPU can produce data

Demo

Instanced Asteroids

Instanced Asteroids

Instancing with shader instance ID

- Calculates transformation matrix in vertex shader
  - `gl_InstanceIDAPPLE` modded by a constant gives a spin value
    - cos and sin used to generate rotation matrix
  - `gl_InstanceIDAPPLE` also used to calculate position
    - Translation applied to rotation matrix
- Matrix calculations are done per vertex

Instanced Asteroids

Instancing with instanced arrays

- Two vertex arrays store positions and rotations
  - Calculated once at app startup
- Attribute divisor passes parameters for each asteroid
  - Not passed per vertex

Instanced Asteroids

Instance ID with texture sampling vs. instanced arrays

- Advantages of instance ID
  - Little memory or bandwidth required
  - Use GPU for computation

Instanced Asteroids

Instance ID with texture sampling vs. instanced arrays

- Advantages of instance ID
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- Advantages of instanced arrays
  - Generally faster than computing on GPU
  - Lots of flexibility in types

Instanced Asteroids

Instance ID with texture sampling vs. instanced arrays

- Advantages of instance ID
  - Little memory or bandwidth required
  - Use GPU for computation
- Advantages of instanced arrays
  - Generally faster than computing on GPU
  - Lots of flexibility in types
- Advantages of using instance ID with vertex texture sampling
  - Random access
  - Often logically simplest to store data
    - Look up tables, bone matrices

Instancing and Vertex Texture Sampling

Summary

- Instancing
  - Many models, single draw
  - Different parameters each instance
  - Performance gains
- Vertex texture sampling
  - Texture data access in vertex shader
  - Use with instance ID for per-instance parameters
- Available on all iOS 7 devices

sRGB

The other colorspace

sRGB Texture Formats

Gamma encoded texture formats

NEW

- sRGB is an alternate colorspace
- More perceptually correct
  - Matches gamma curve of displays
- Perceptually linear color mixing
  - Mixing with RGB weighs brighter colors more than darker ones

sRGB

Linear

sRGB Texture Formats

In the API

- New formats
  - `GL_SRGB_EXT           // External Format`
  - `GL_SRGB_ALPHA_EXT     // External Format`
  - `GL_SRGB8_ALPHA8_EXT   // Internal Format`
  - `GL_COMPRESSED_SRGB_PVRTC_..._APPLE // Compressed Formats`
- Noncompressed sRGB textures are renderable
  - Linear blending
  - Color calculations in shaders
- Check for `GL_EXT_sRGB` in the extension string
  - Not supported on iPhone 4

sRGB Texture Formats

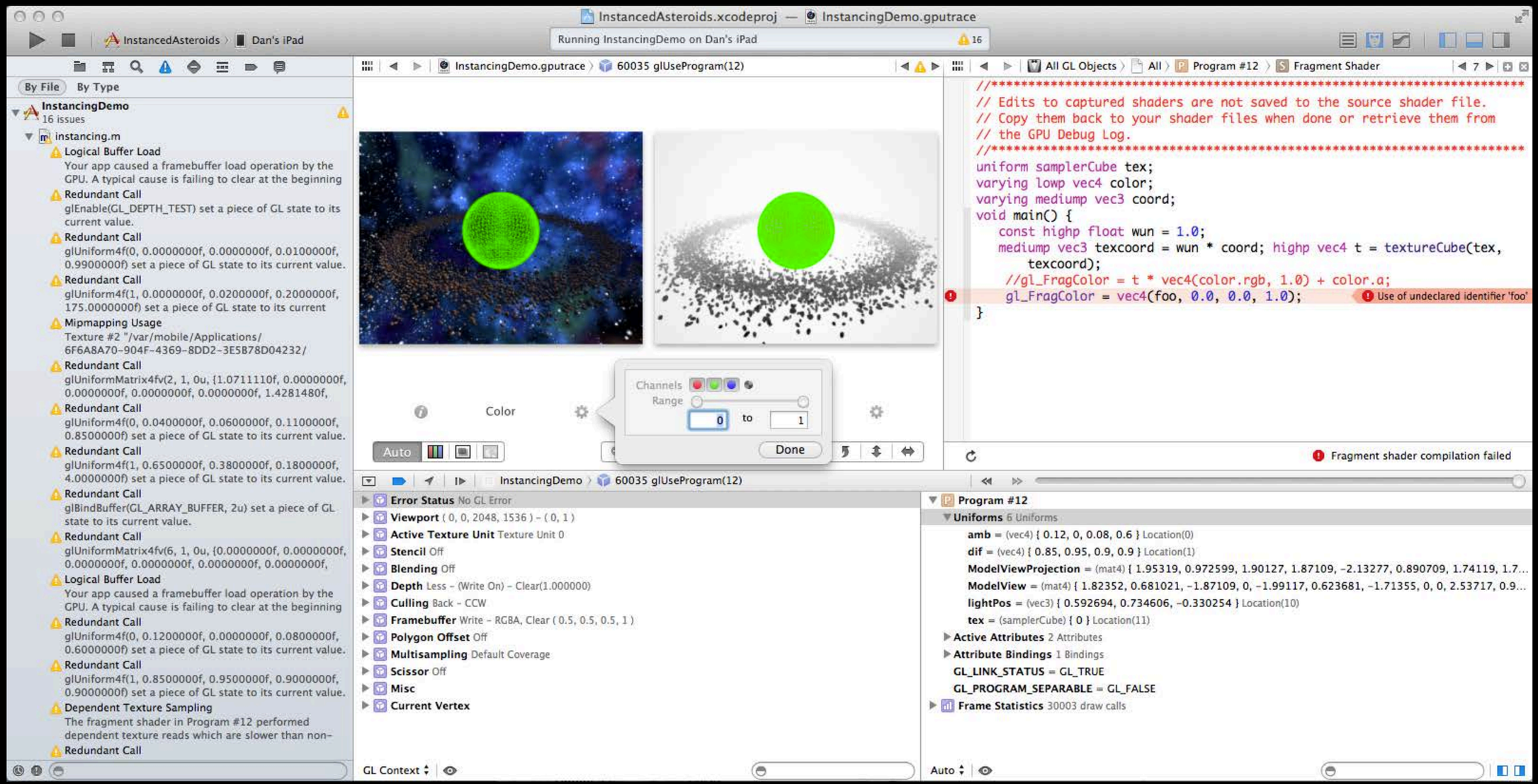
When they should be used

- The perceptually "correct" colorspace to use for mixing
- Author texture images with sRGB colorspace in mind
  - Otherwise may look different than intended
- Only use for color data

GPU Tools

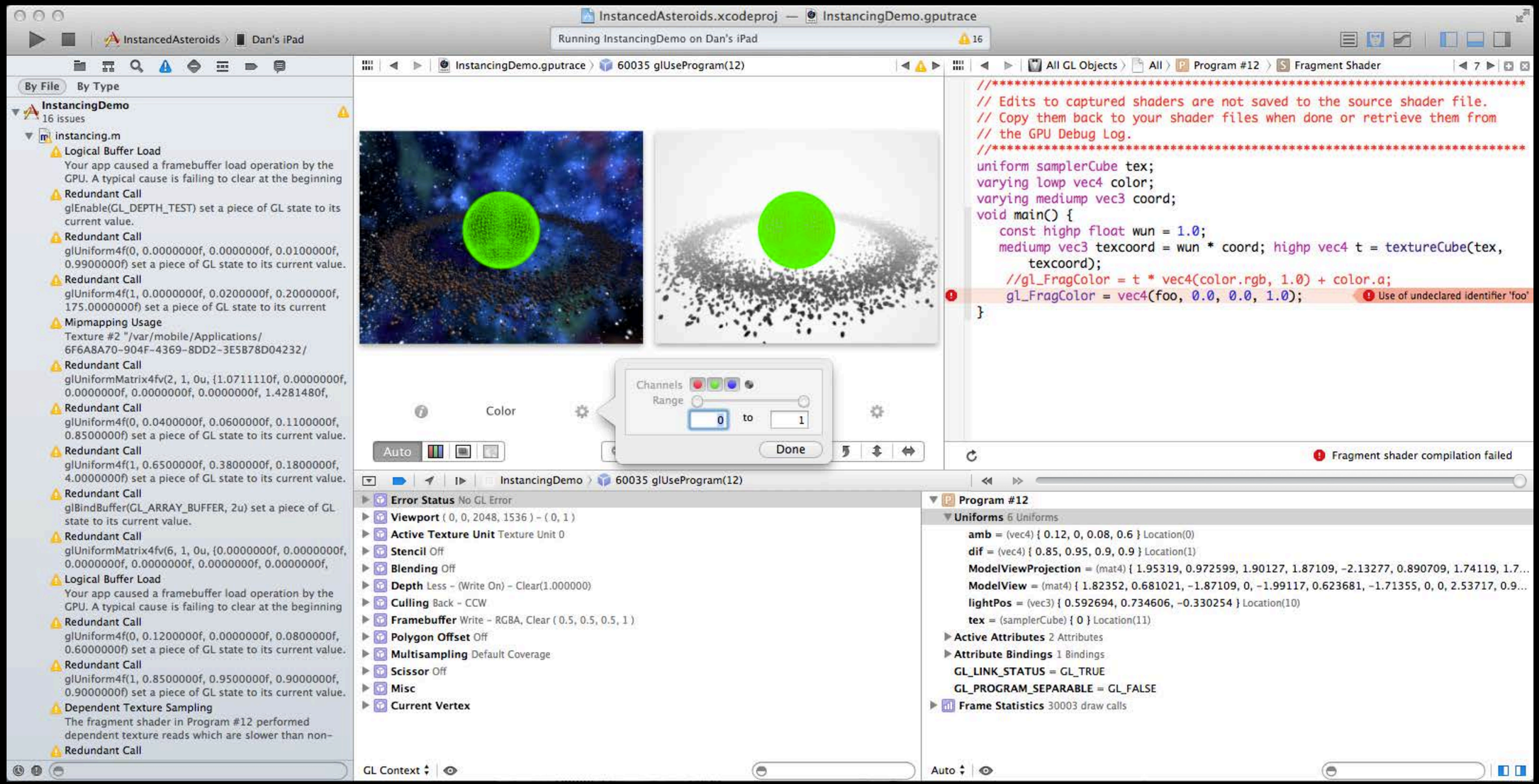
Building a solid foundation

OpenGL ES Frame Debugger



OpenGL ES Frame Debugger

Scrubber bar and Framebuffer view



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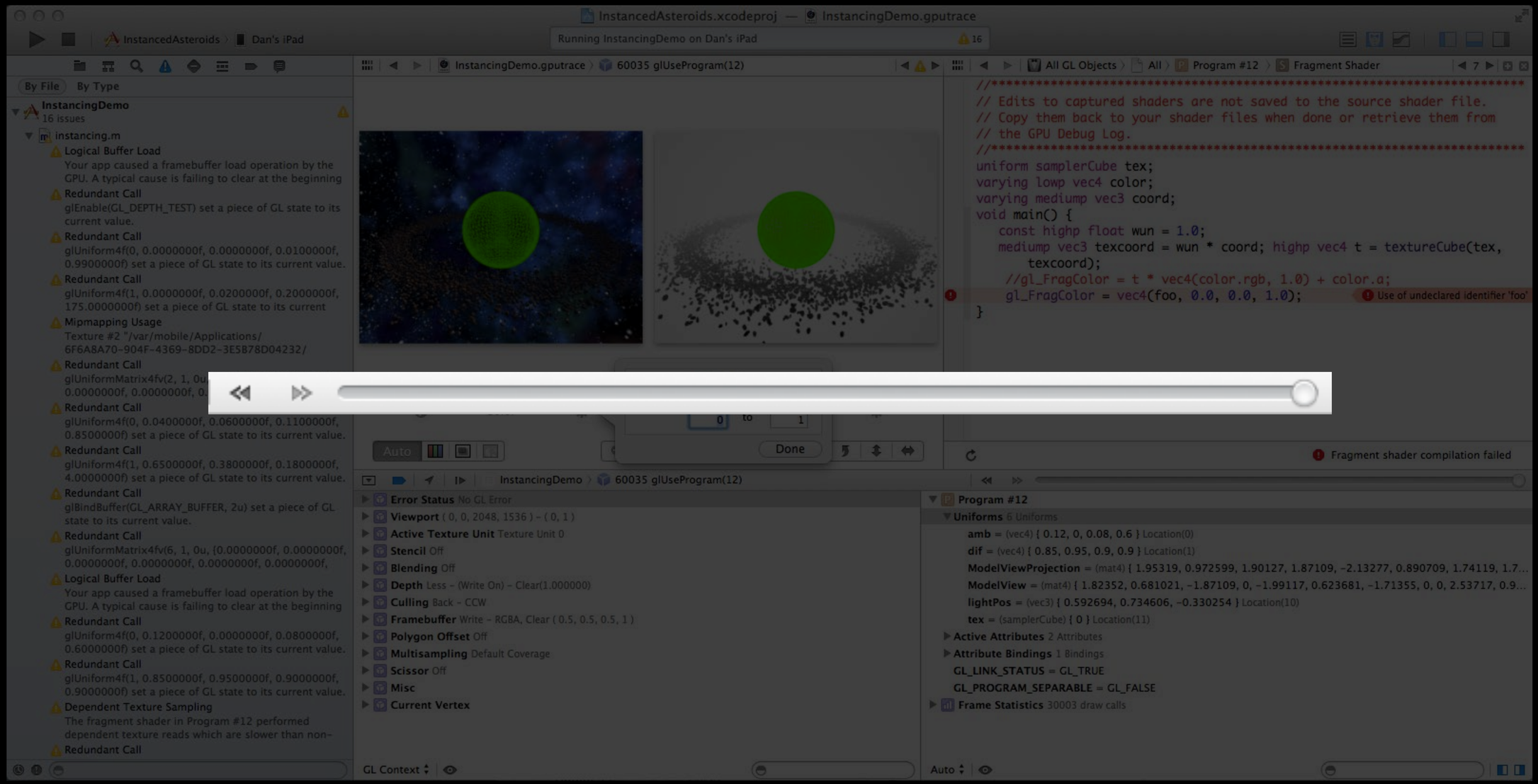

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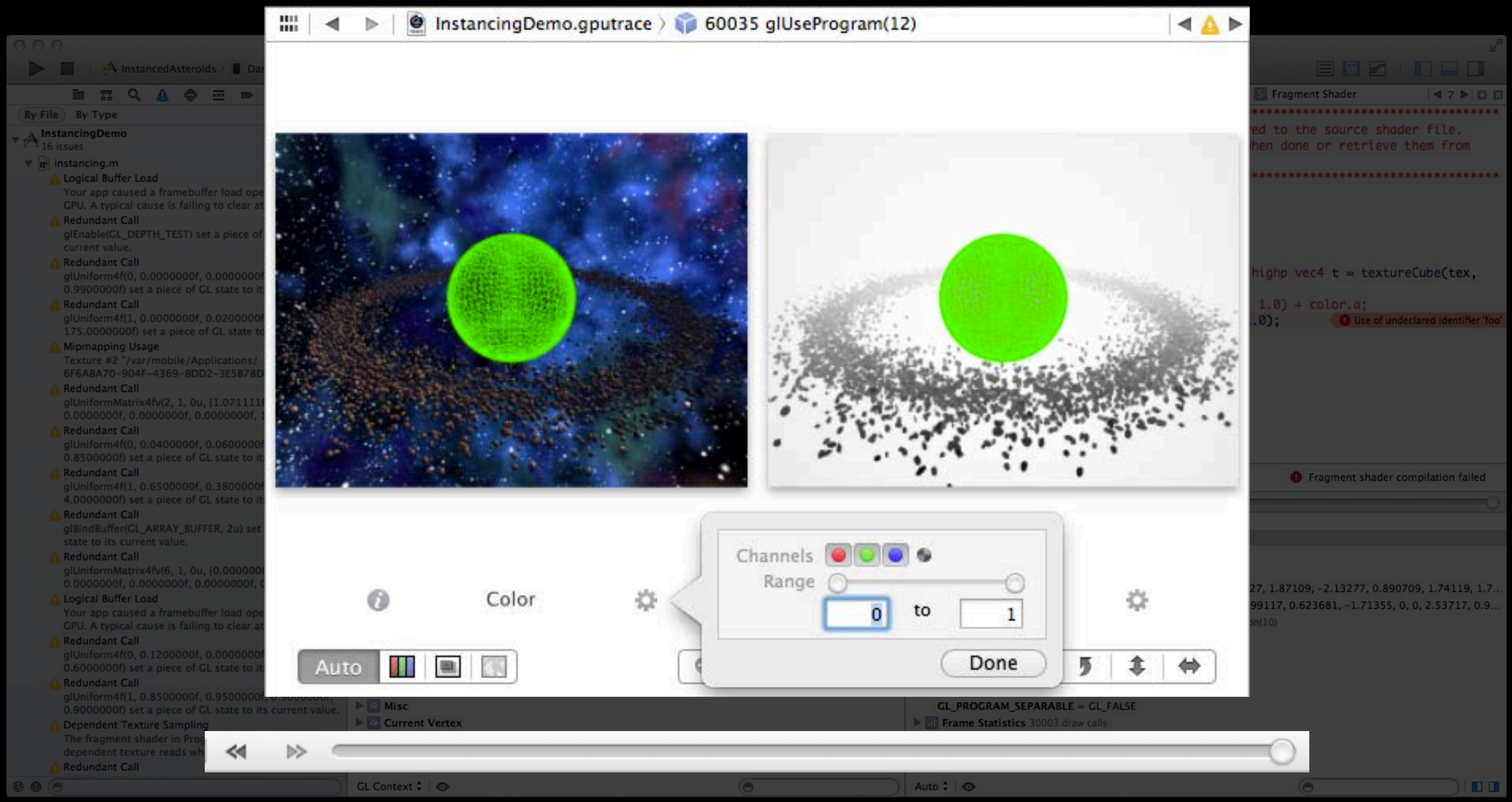

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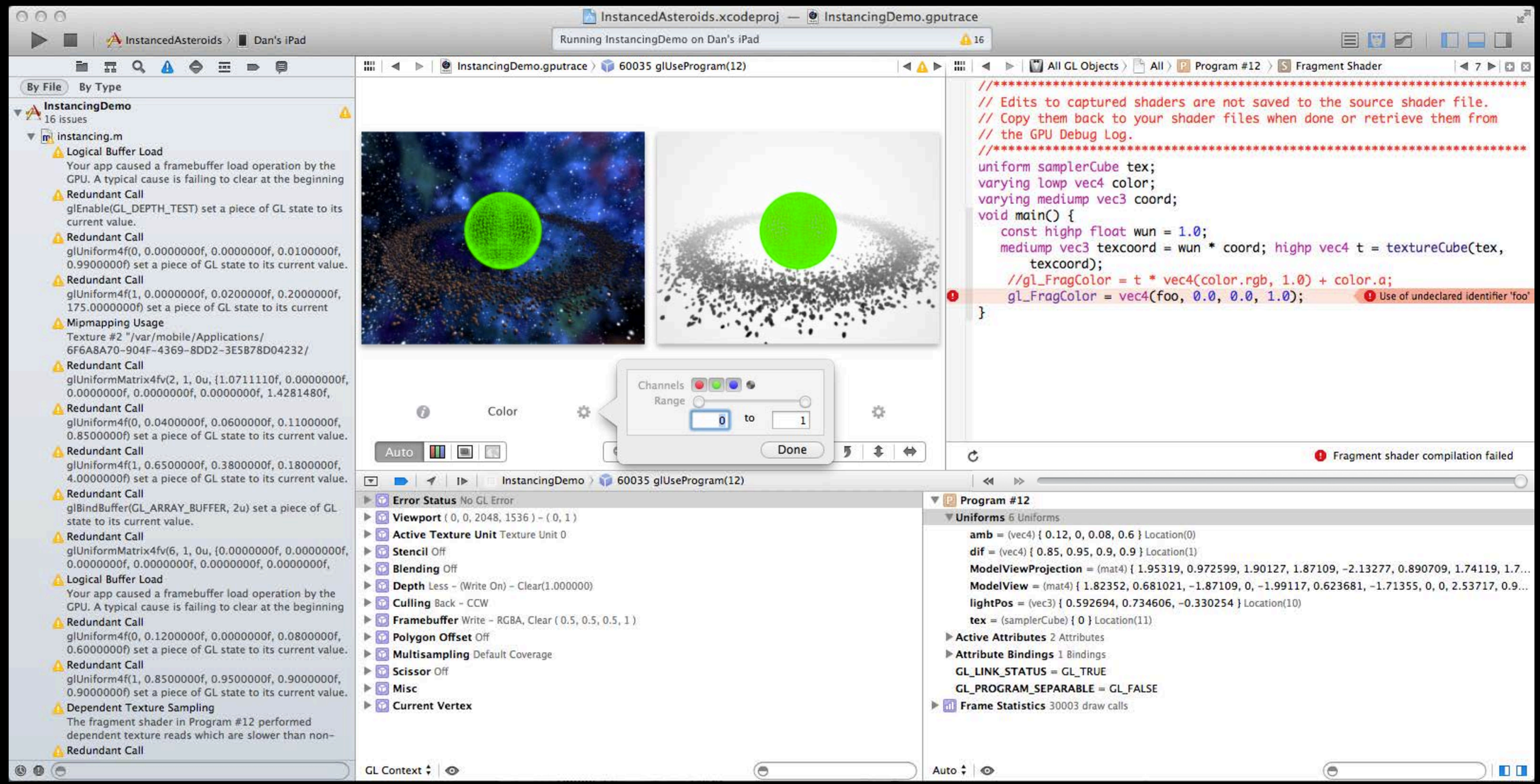
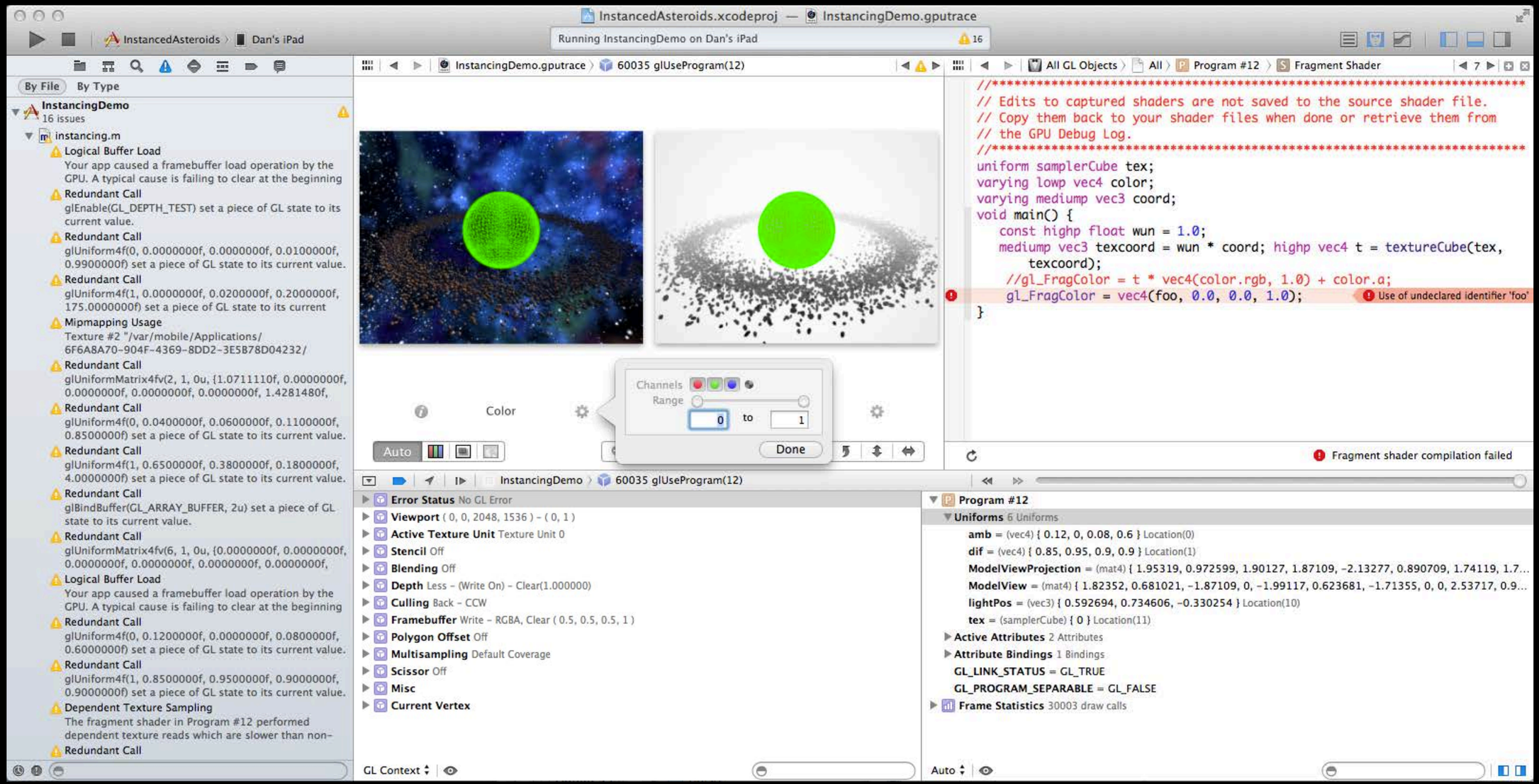


OpenGL ES Frame Debugger

GL context state and auto context view



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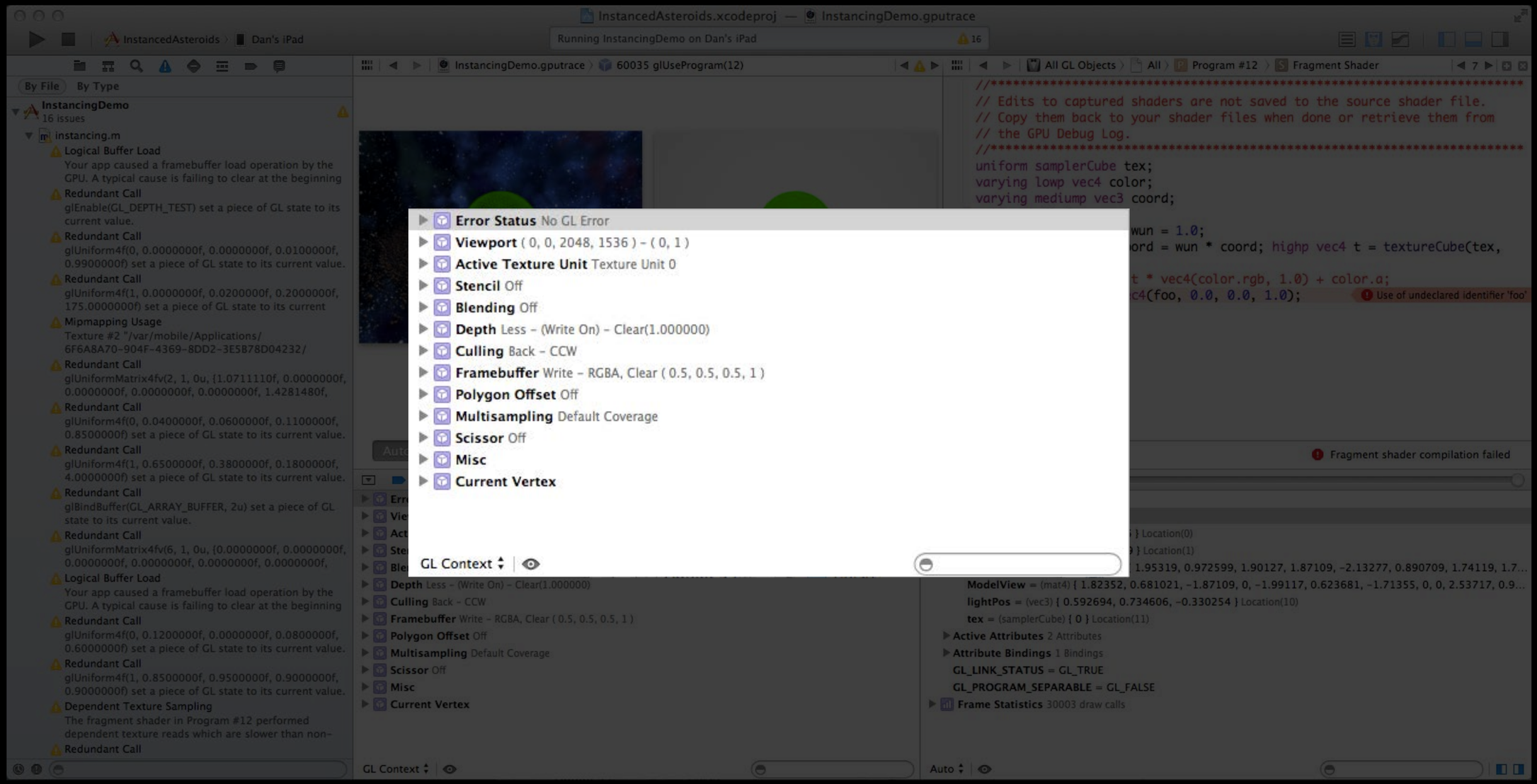

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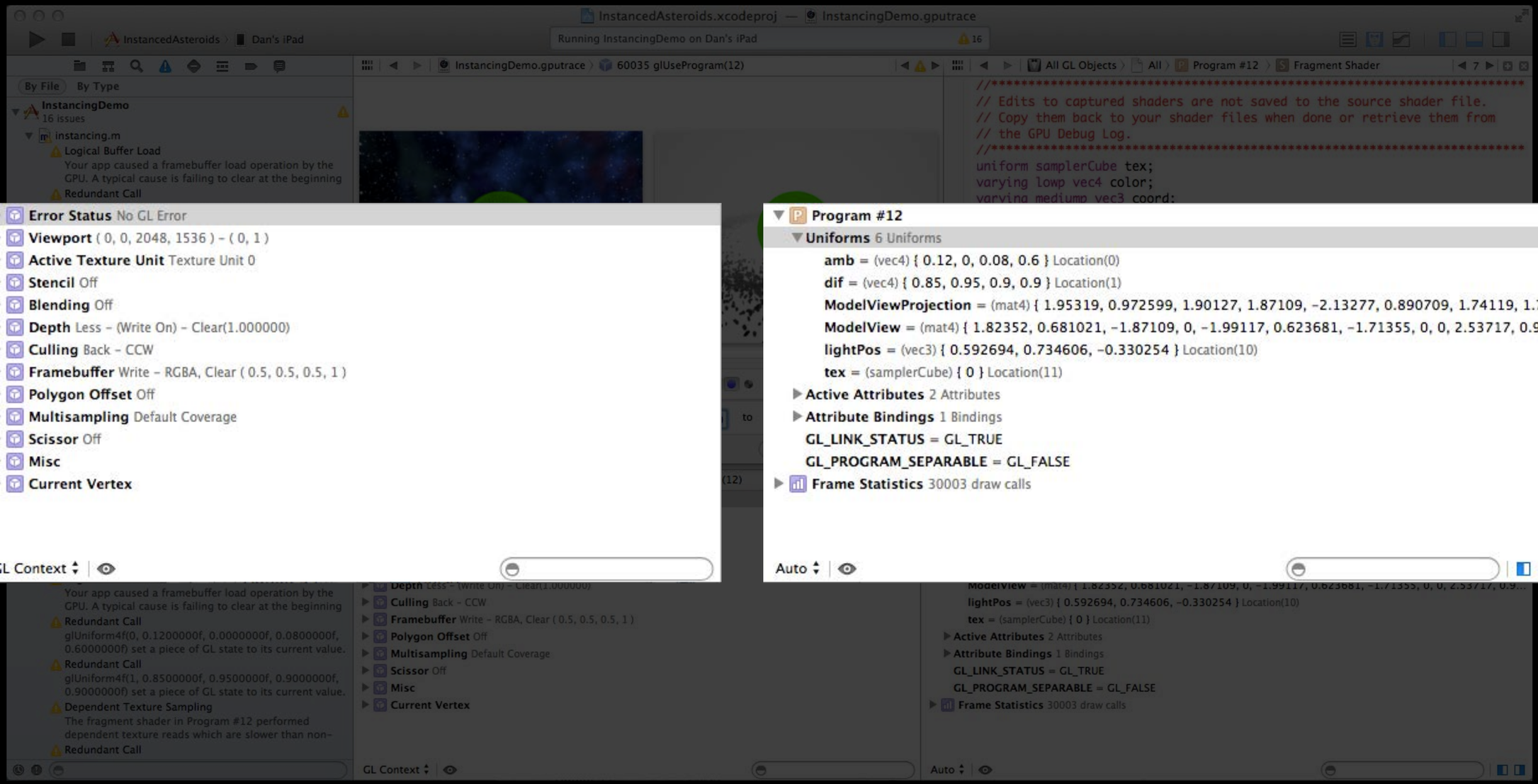

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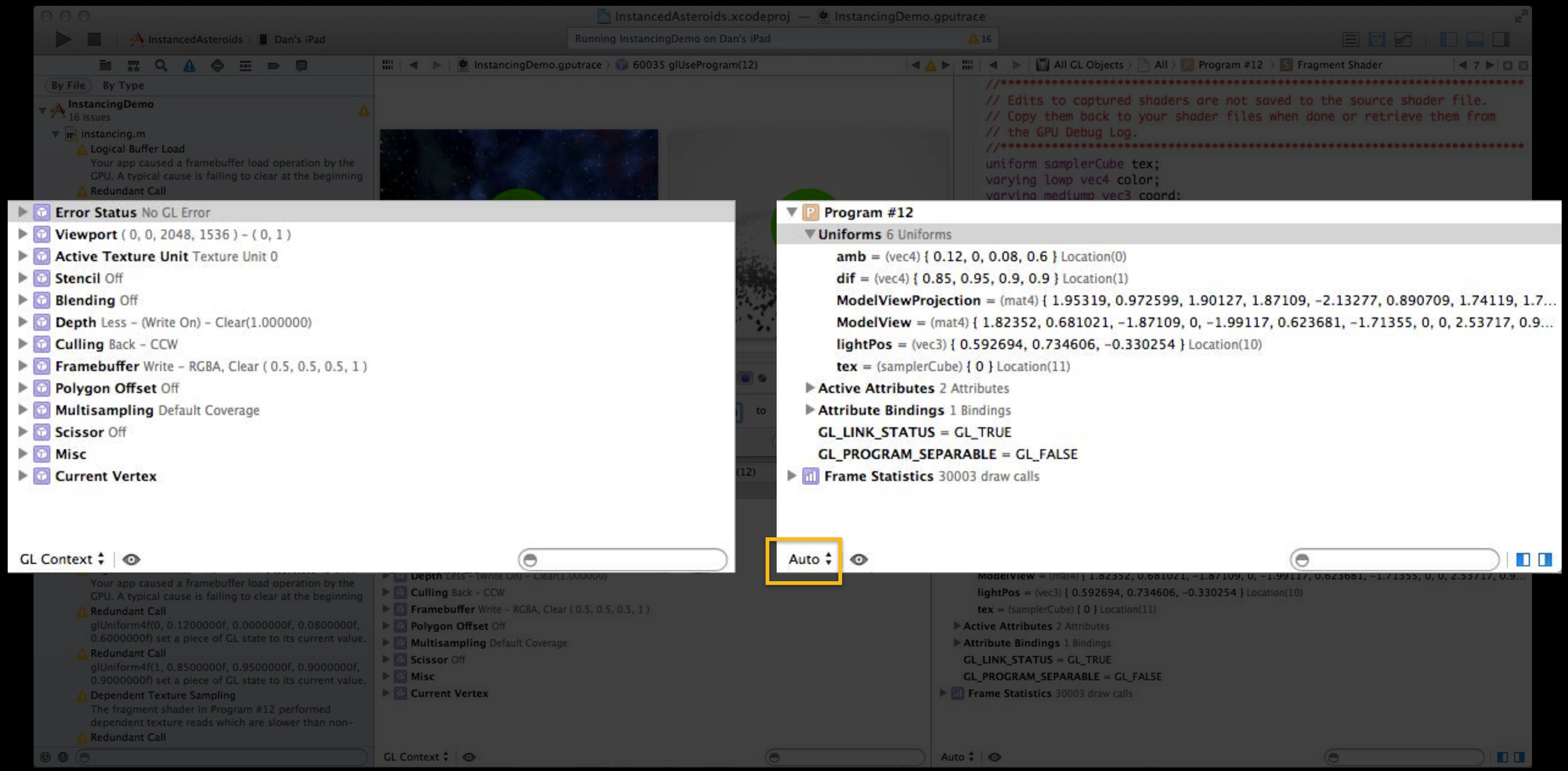

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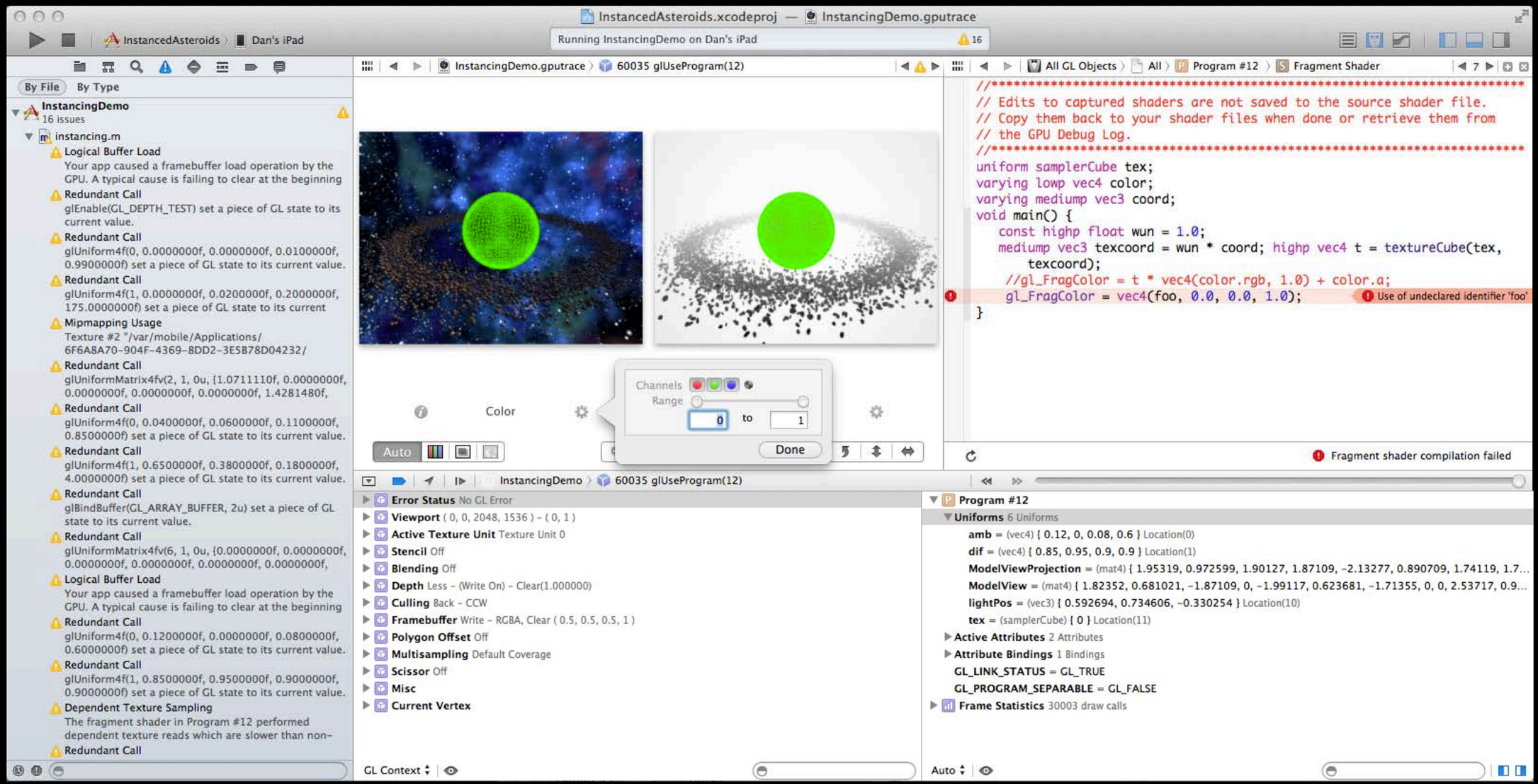
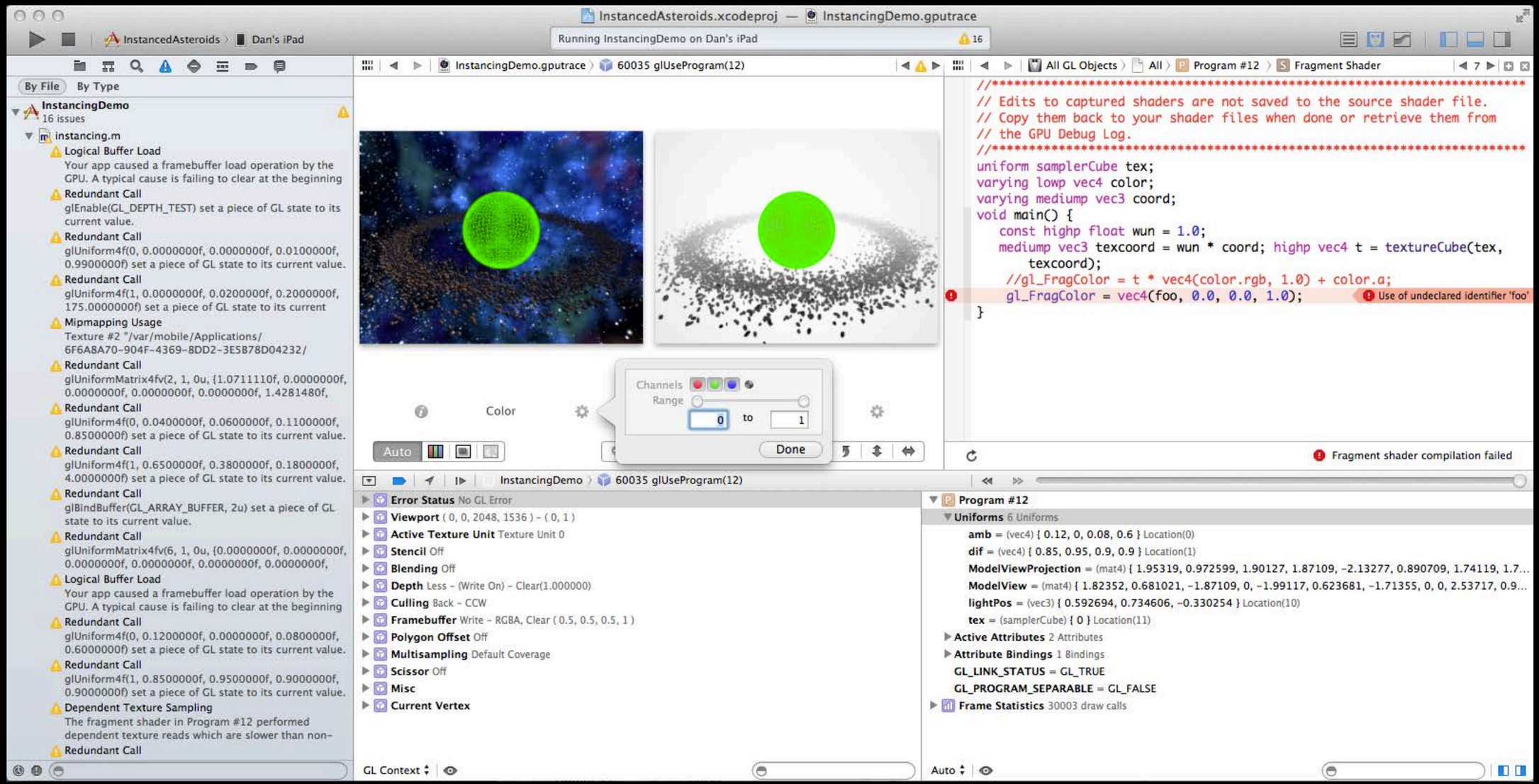


OpenGL ES Frame Debugger

Object view and Shader editor



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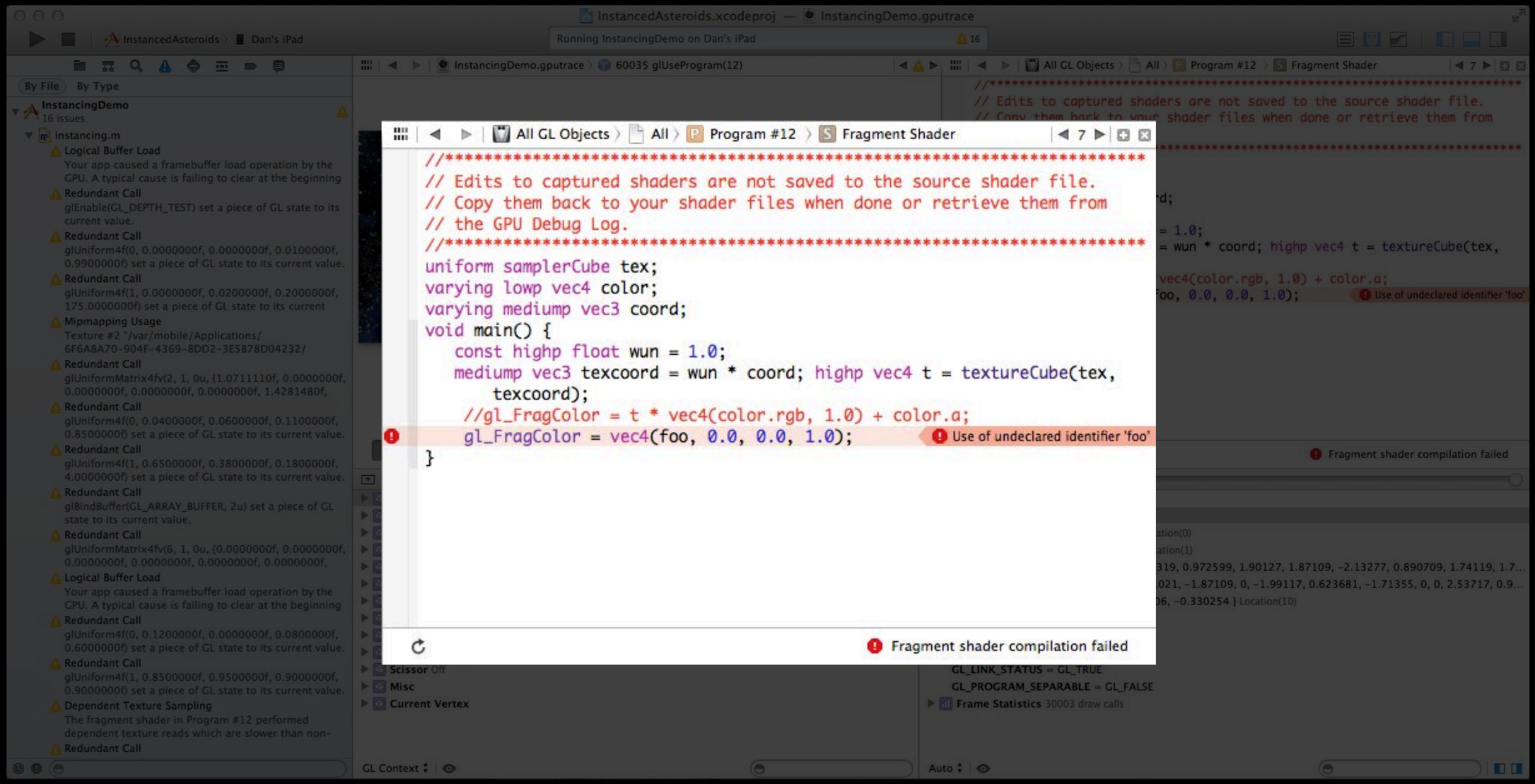

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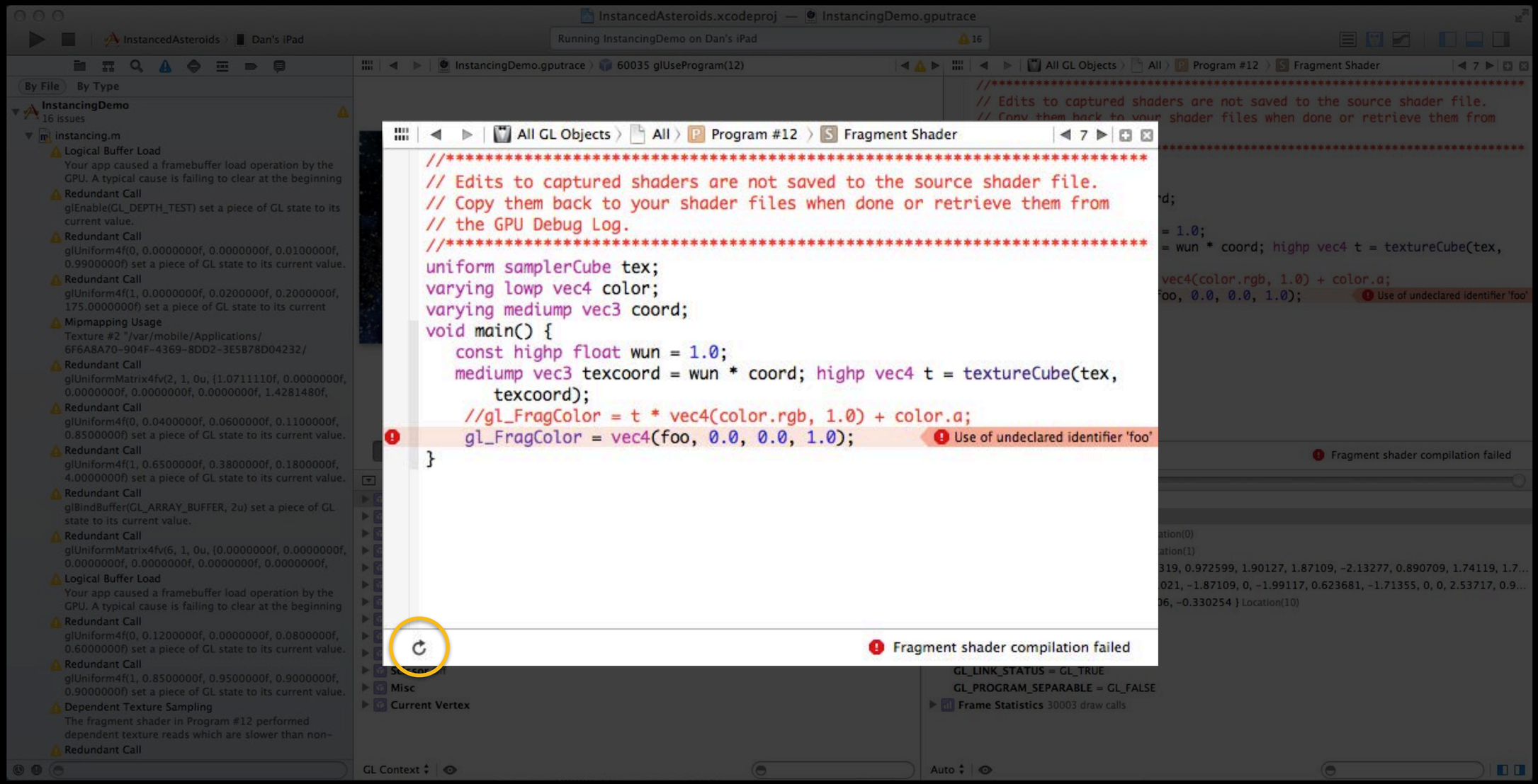

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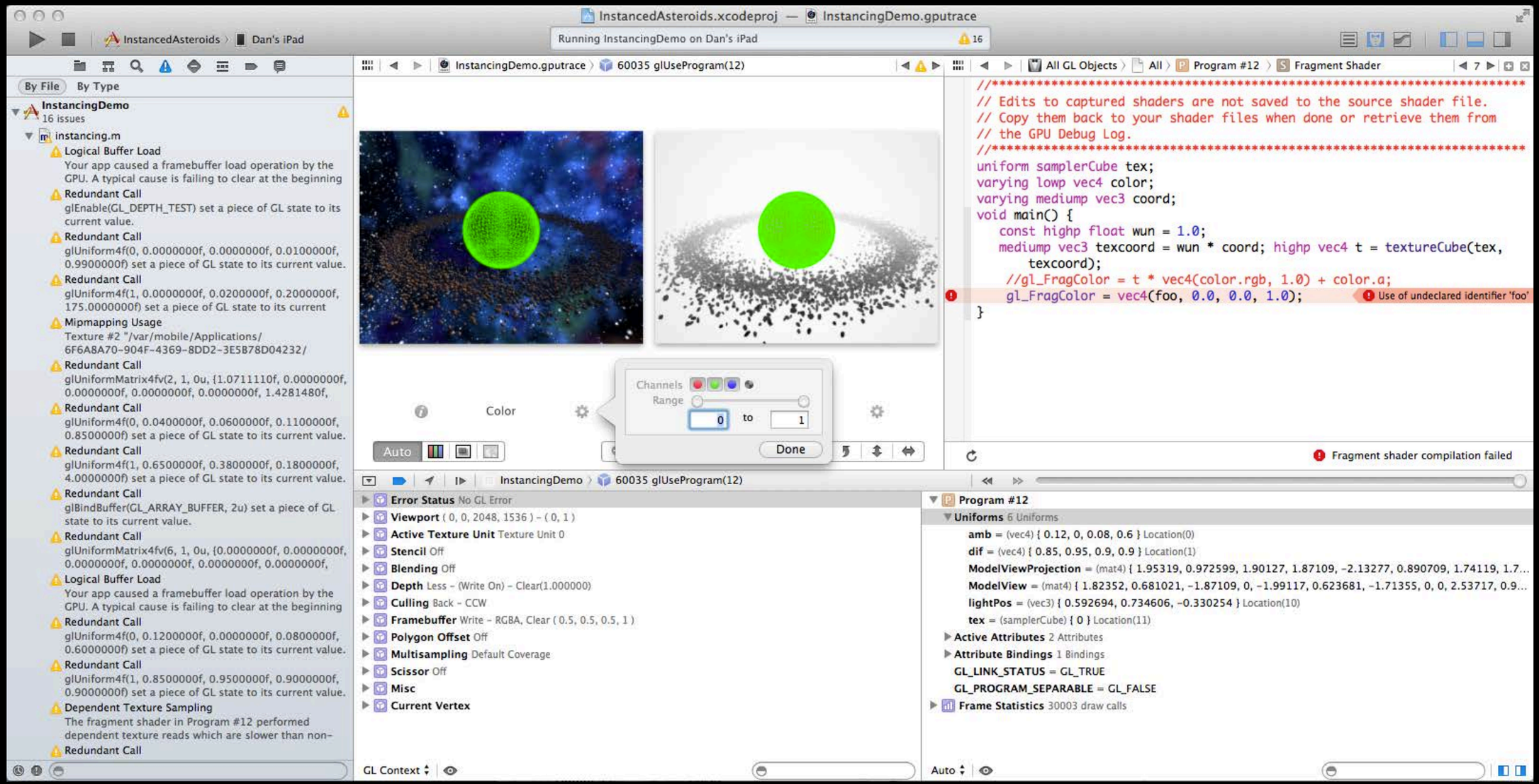
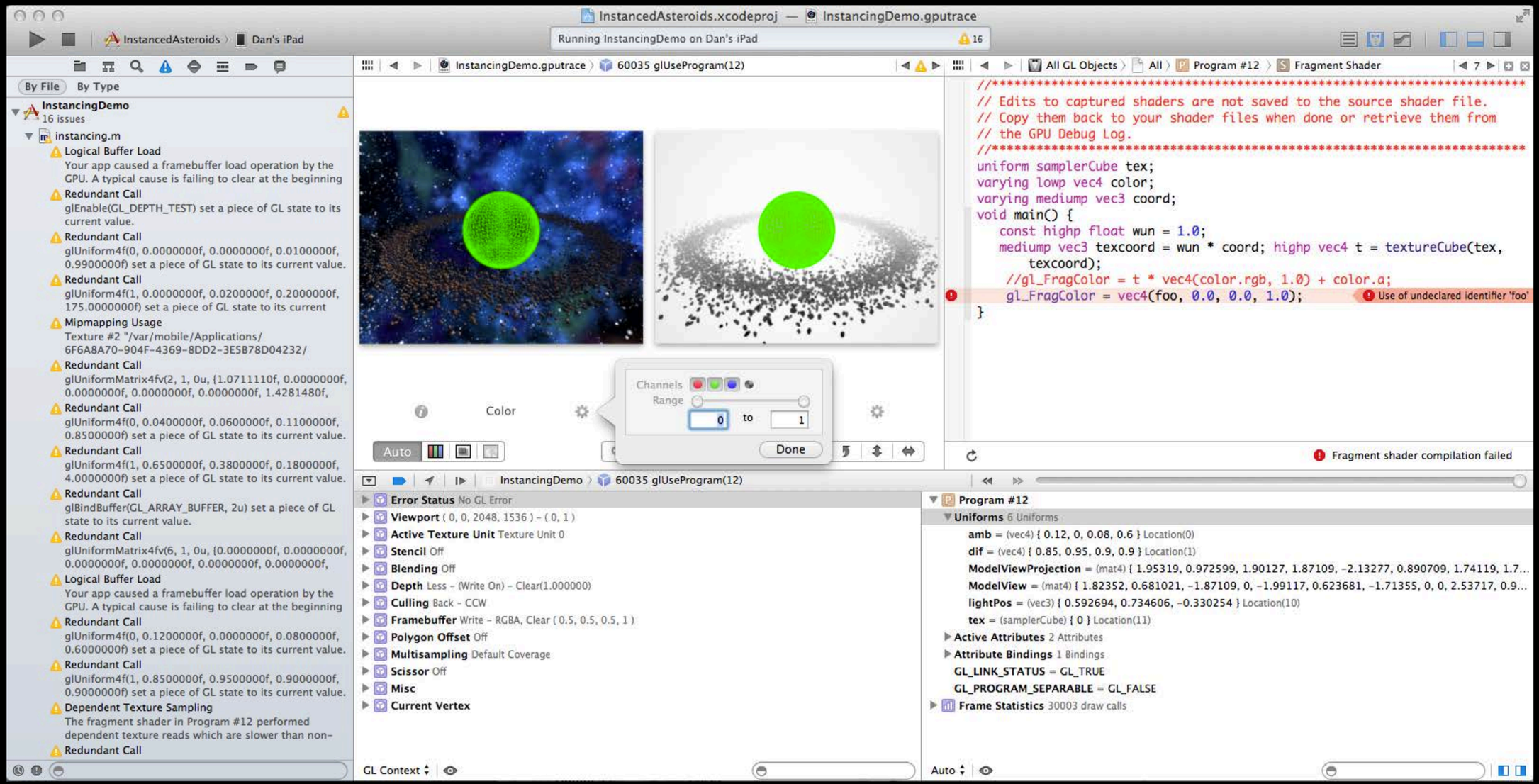


OpenGL ES Frame Debugger

GL issues navigator



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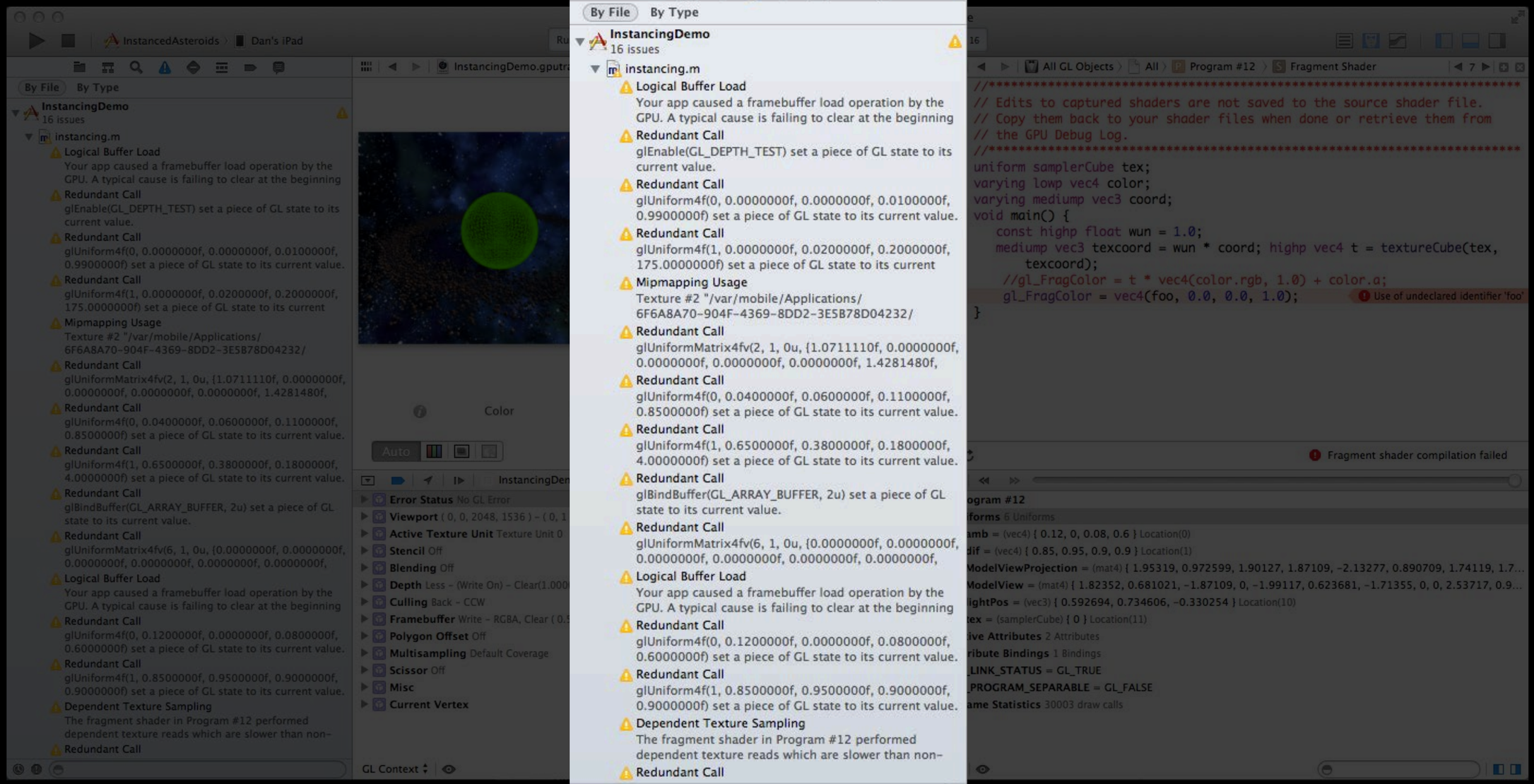

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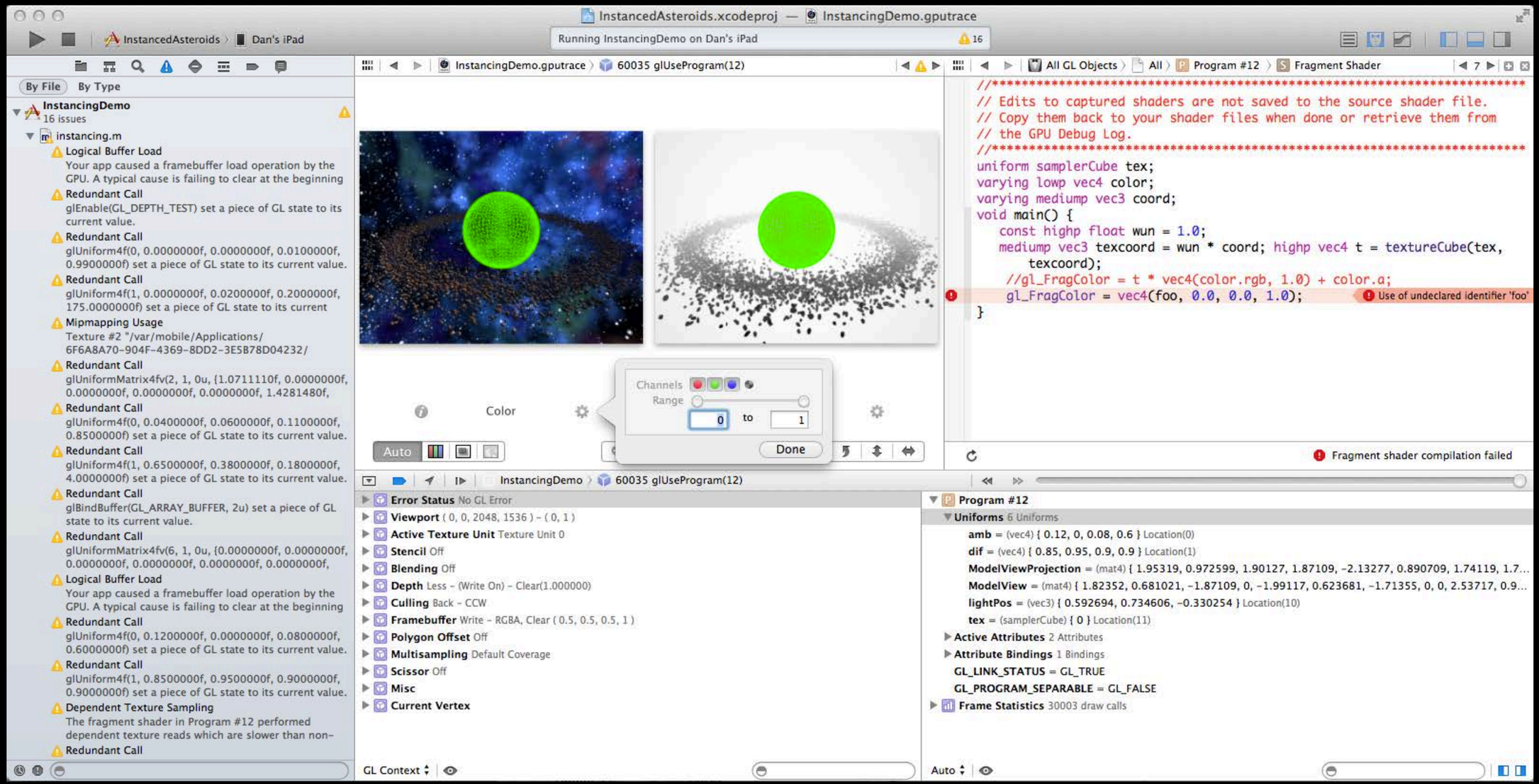
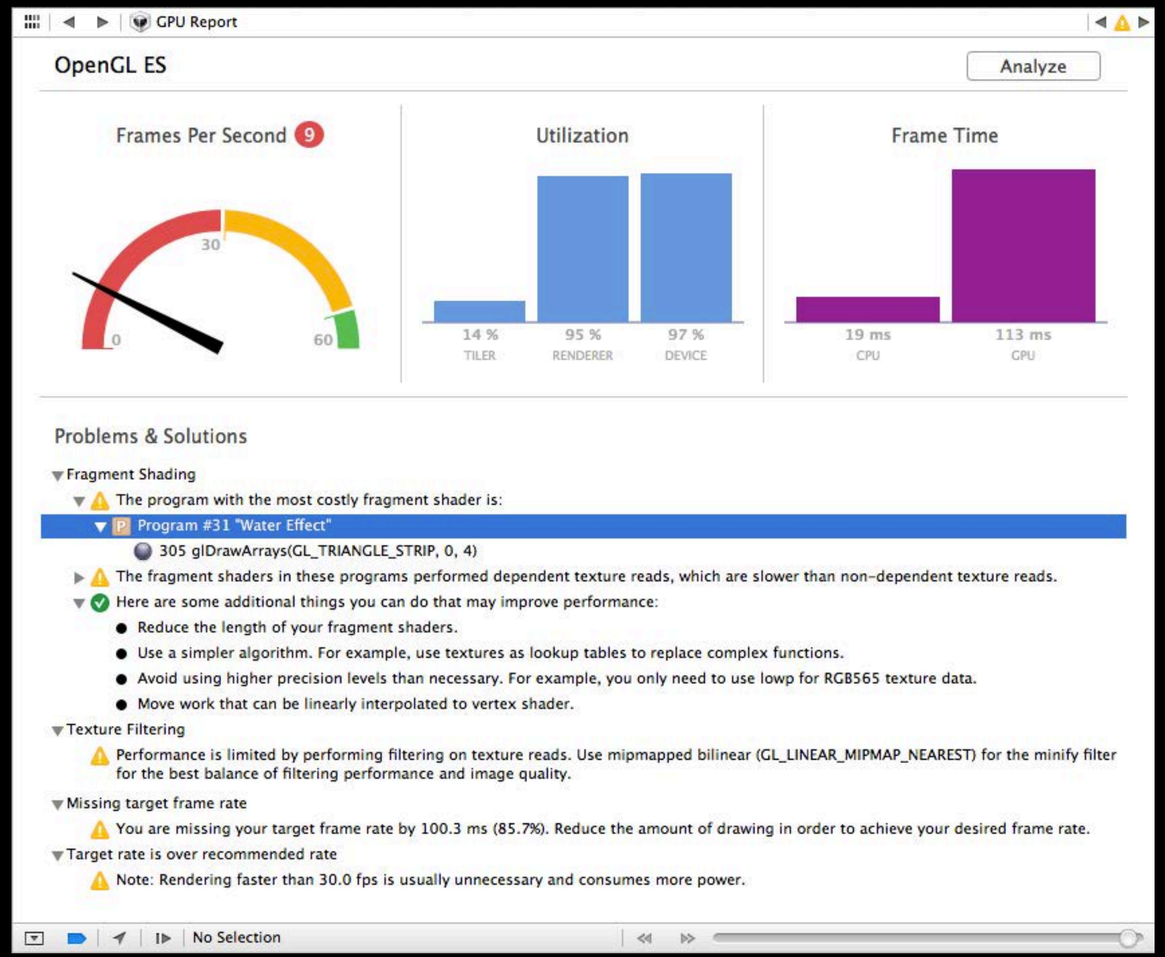


OpenGL ES Frame Debugger

OpenGL ES performance analysis



OpenGL ES Frame Debugger

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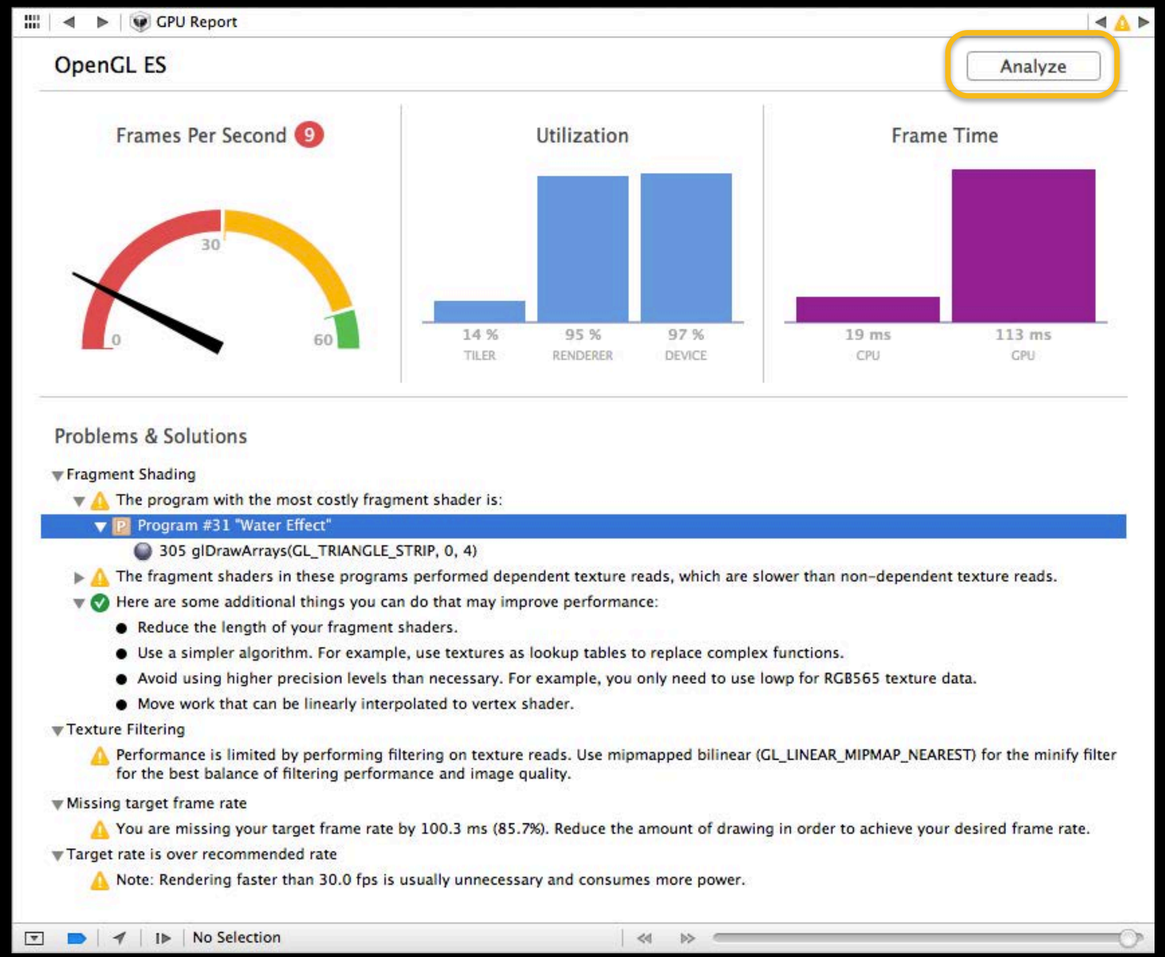
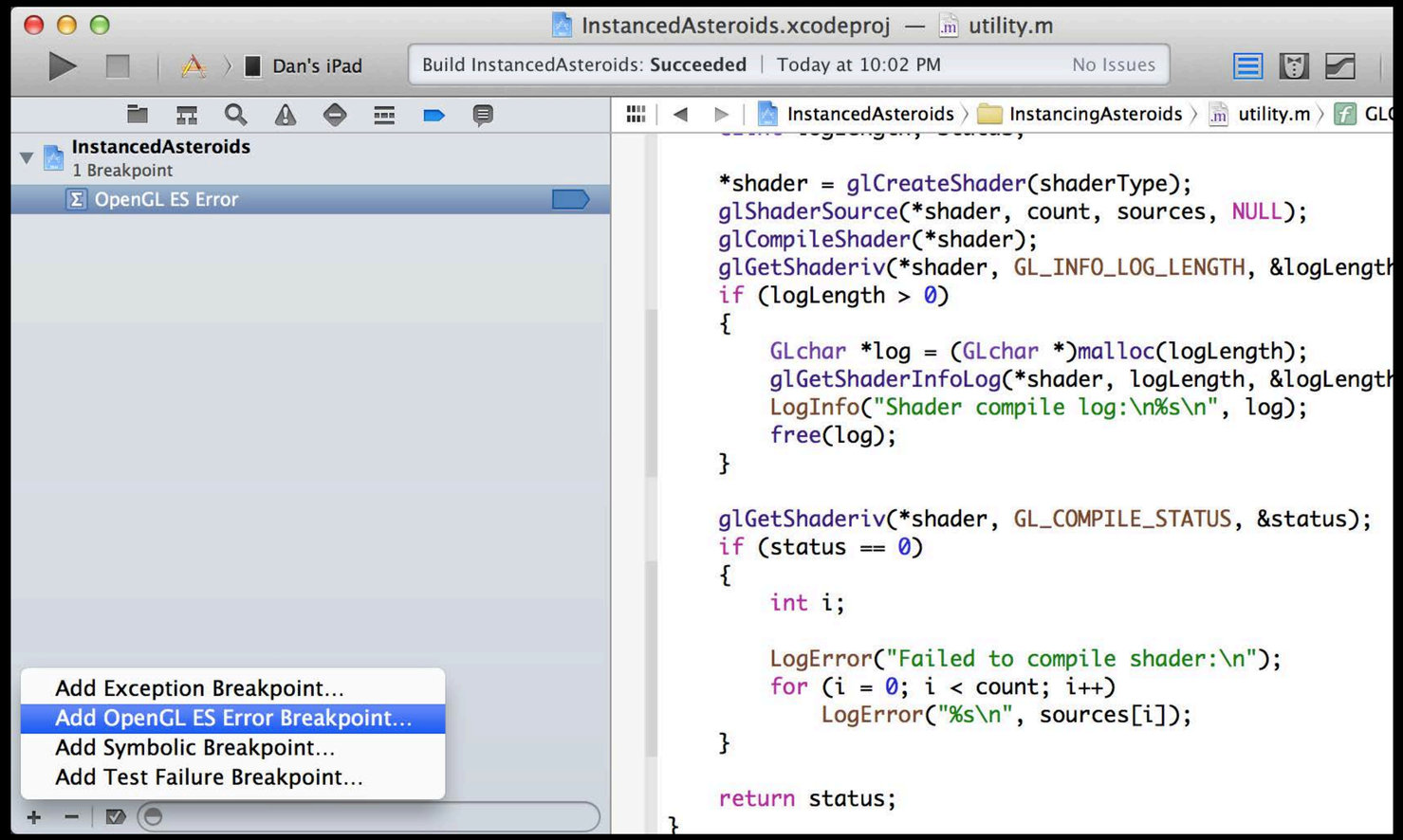
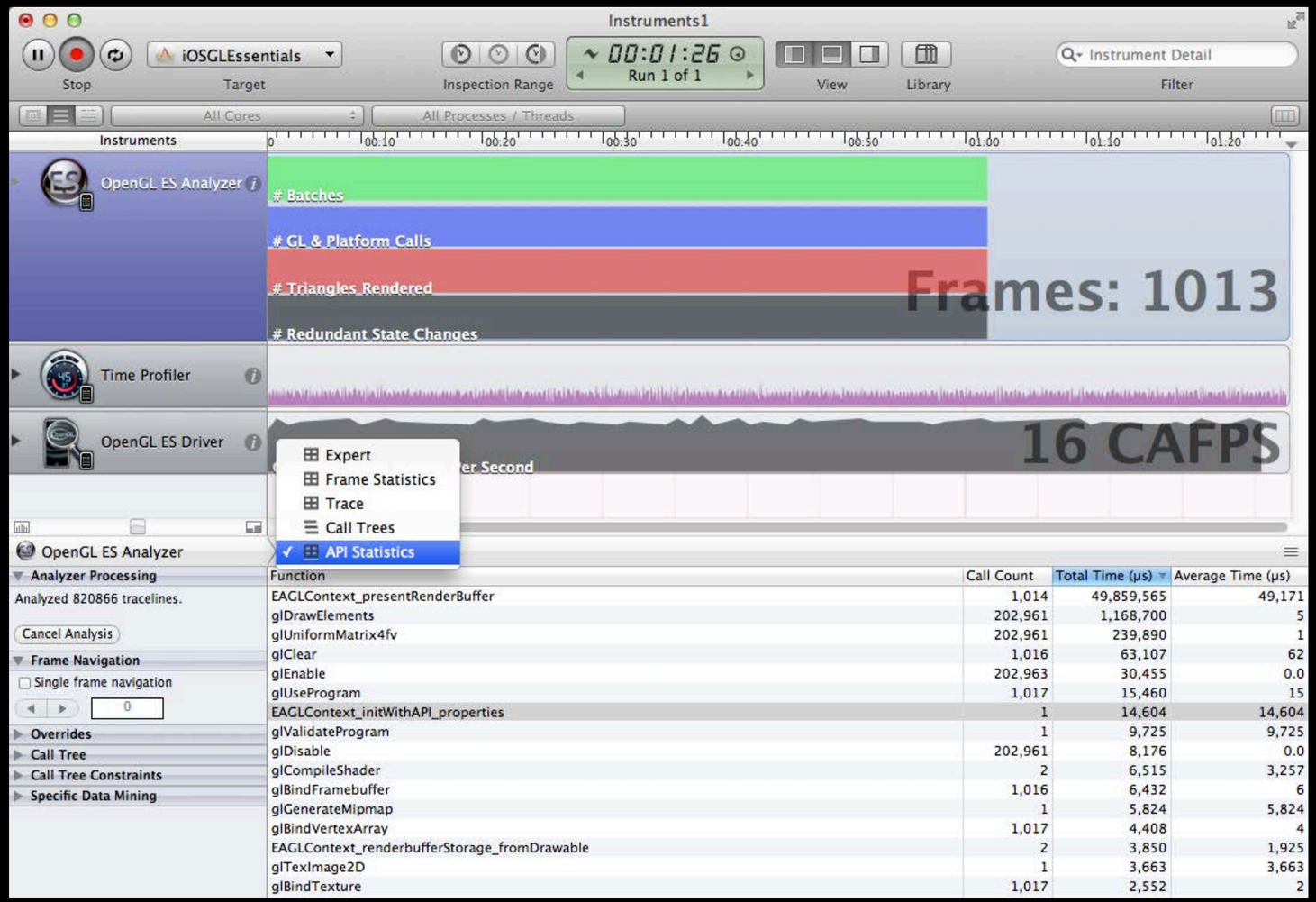


Xcode Breakpoints

Break on OpenGL ES error



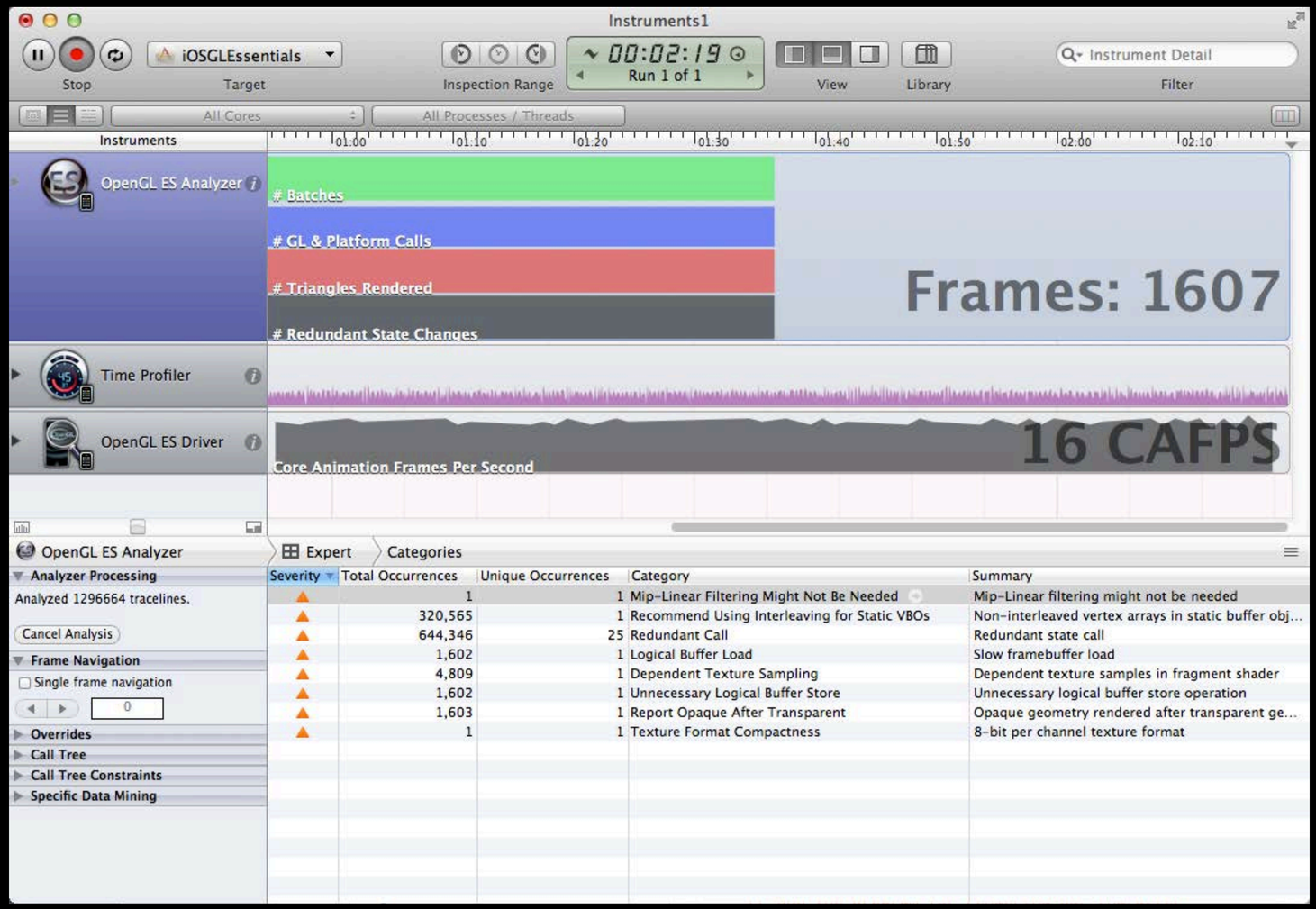
OpenGL ES Analyzer Instrument



Function	Call Count	Total Time (µs)	Average Time (µs)
EAGLContext_presentRenderBuffer	1,014	49,859,565	49,171
glDrawElements	202,961	1,168,700	5
glUniformMatrix4fv	202,961	239,890	1
glClear	1,016	63,107	62
glEnable	202,963	30,455	0.0
glUseProgram	1,017	15,460	15
EAGLContext_initWithAPI_properties	1	14,604	14,604
glValidateProgram	1	9,725	9,725
glDisable	202,961	8,176	0.0
glCompileShader	2	6,515	3,257
glBindFramebuffer	1,016	6,432	6
glGenerateMipmap	1	5,824	5,824
glBindVertexArray	1,017	4,408	4
EAGLContext_renderbufferStorage_fromDrawable	2	3,850	1,925
glTexImage2D	1	3,663	3,663
glBindTexture	1,017	2,552	2

OpenGL ES Analyzer Instrument

OpenGL ES expert



Maximizing GPU Performance

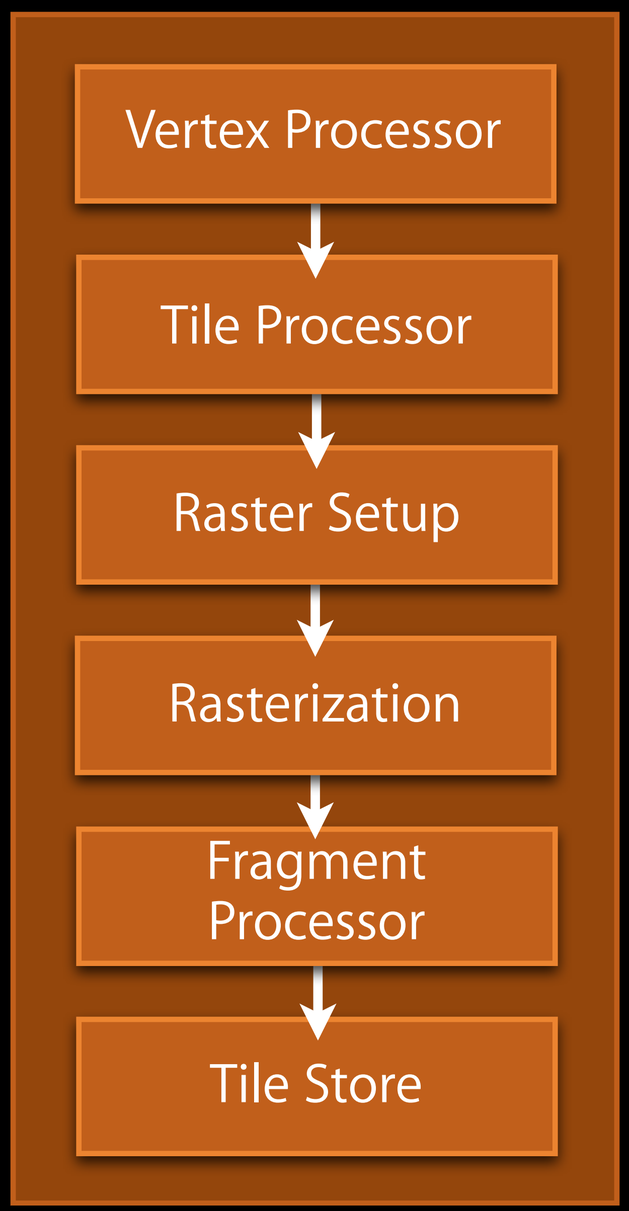
Understanding the GPU architecture

Tile-Based Deferred Renderer

High performance, low power

- TBDR Pipeline different than traditional streaming GPUs
- Optimizations to reduce processing load
  - Increases performance
  - Saves power
- Depends heavily on caches
  - Large transfers to unified memory costly
- Certain operations prevent optimizations or cause cache misses
  - Operations avoidable

The Tile-Based Deferred Rendering Pipeline



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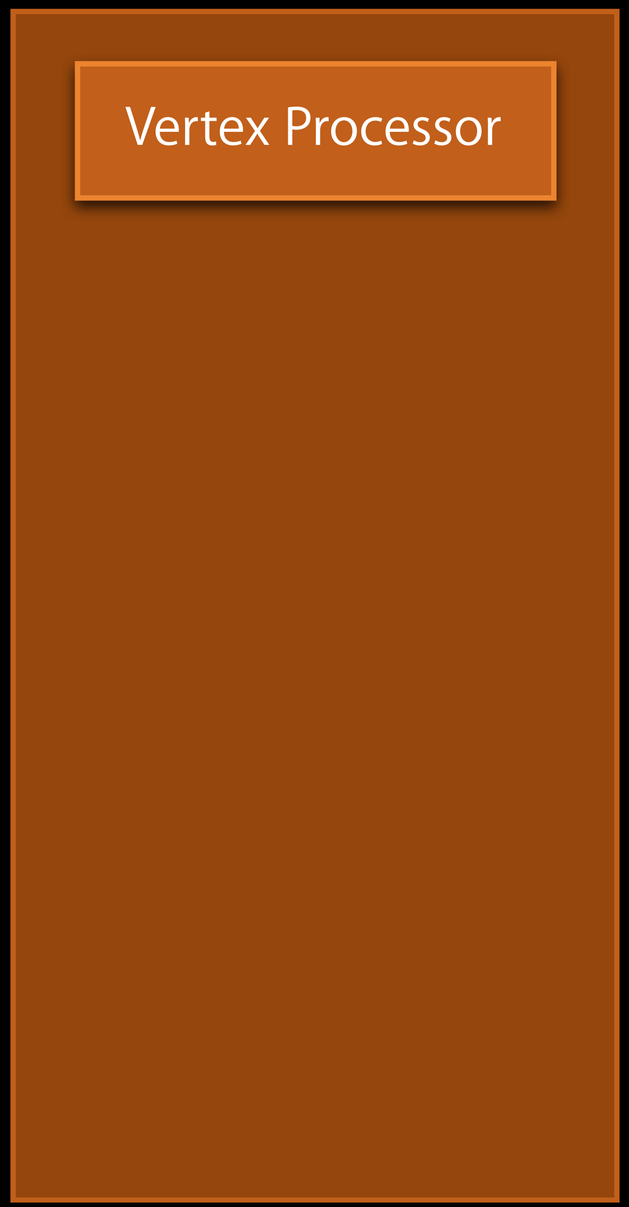
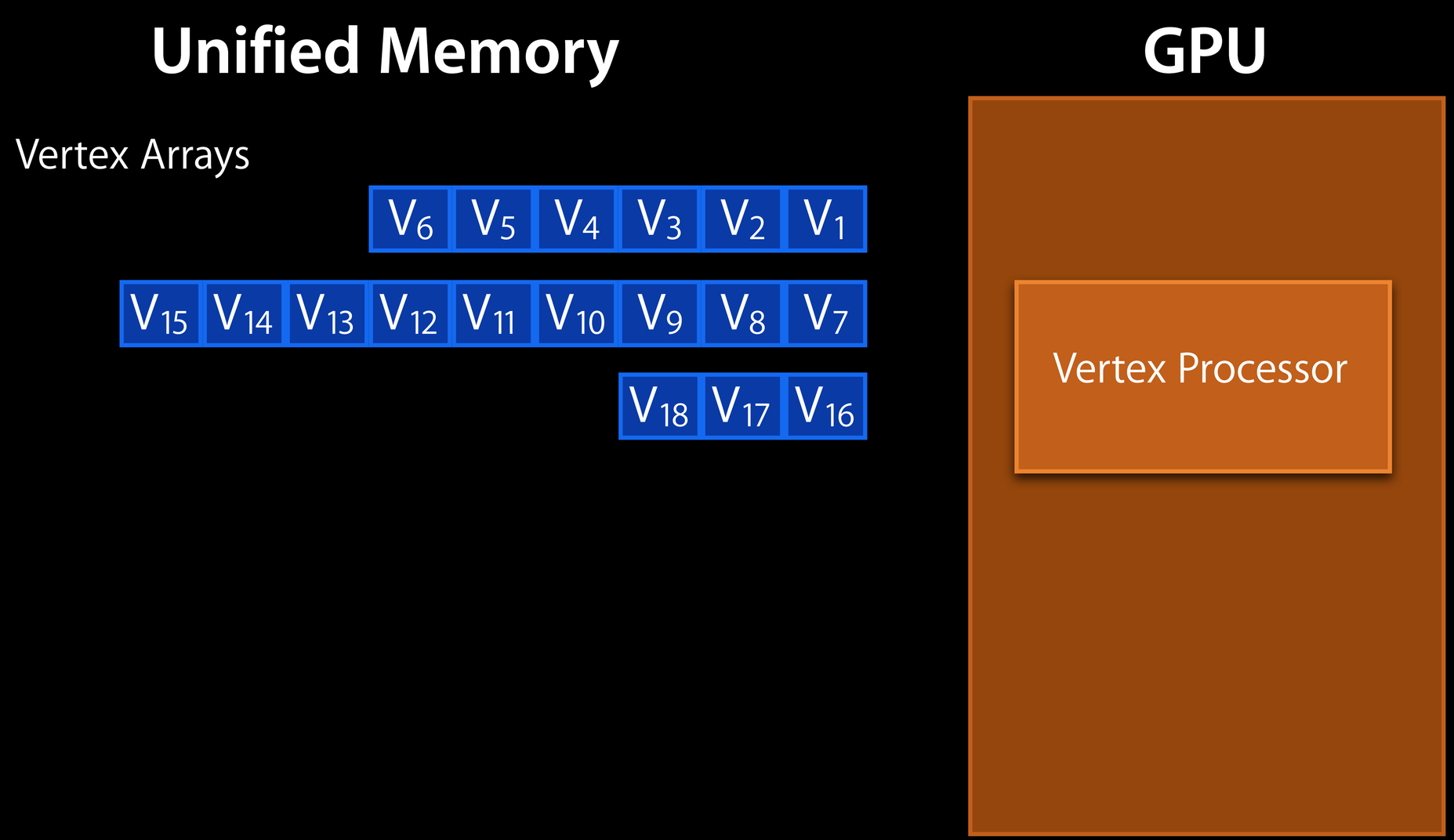


Vertex Shading

- Draw call submits vertices to GPU's vertex processor



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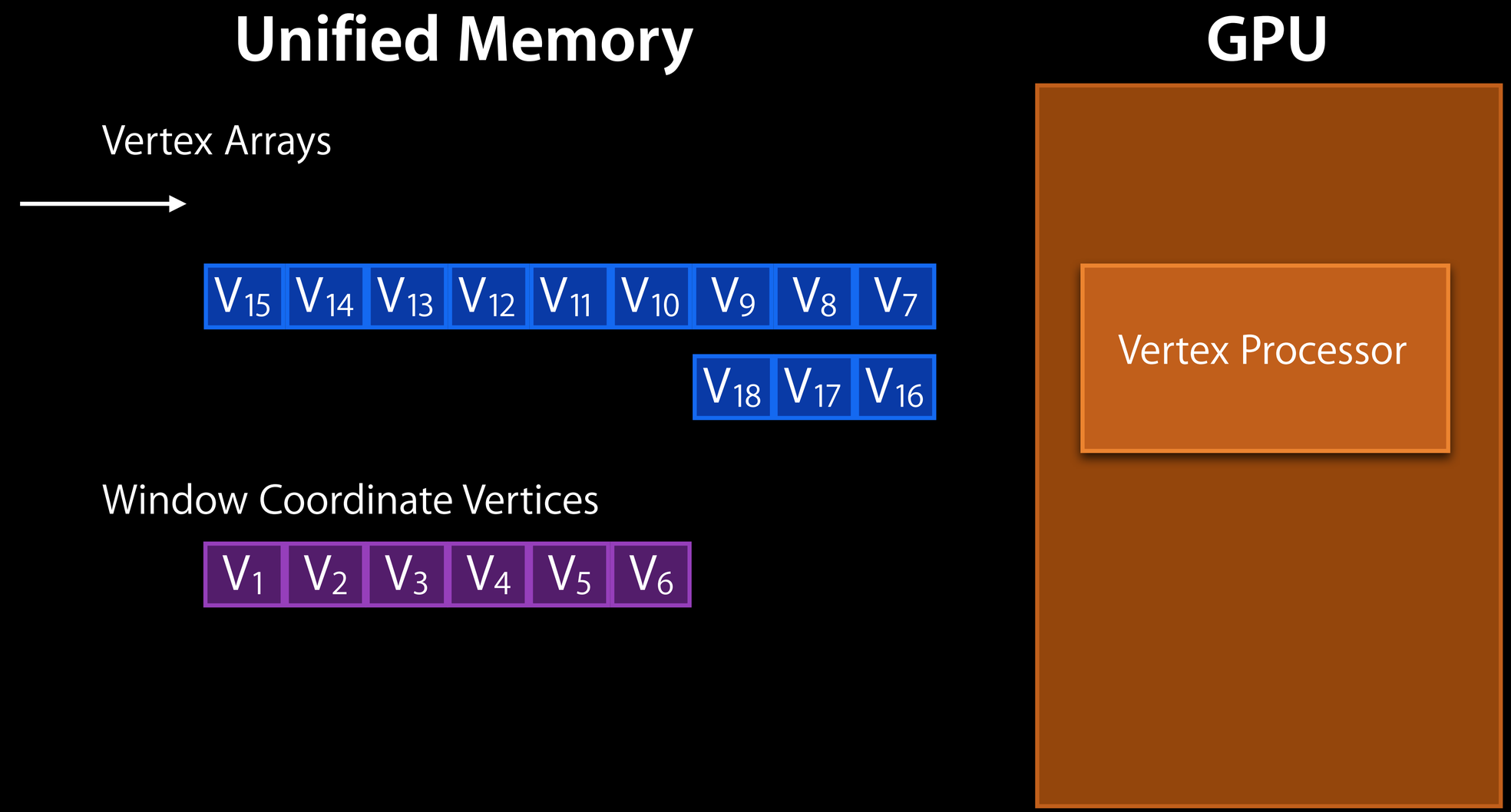
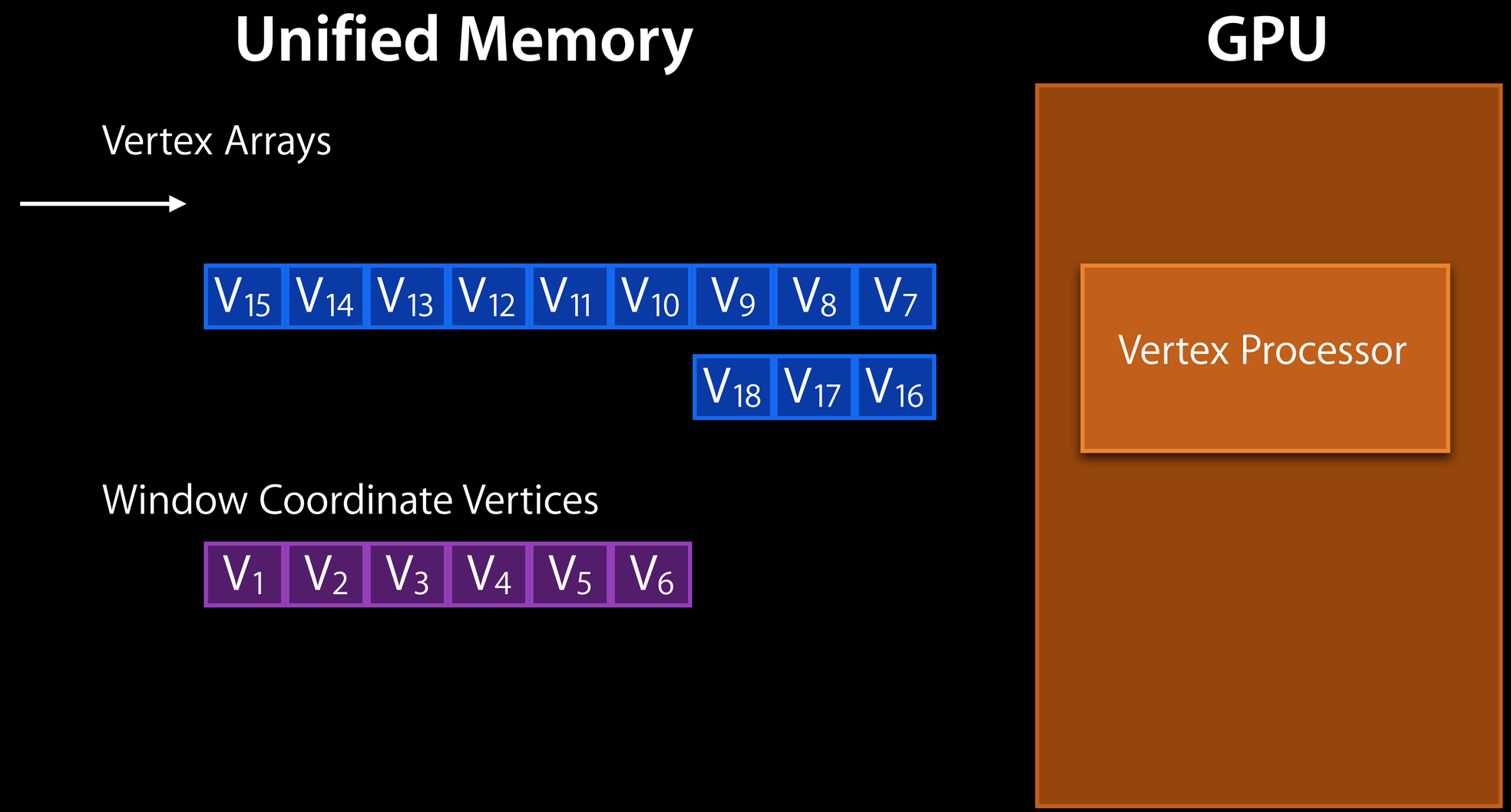


- Vertices shaded and transformed to window coords
- Shaded, transform vertices, stored out to unified memory



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Unified Memory

Vertex Arrays

Window Coordinate Vertices

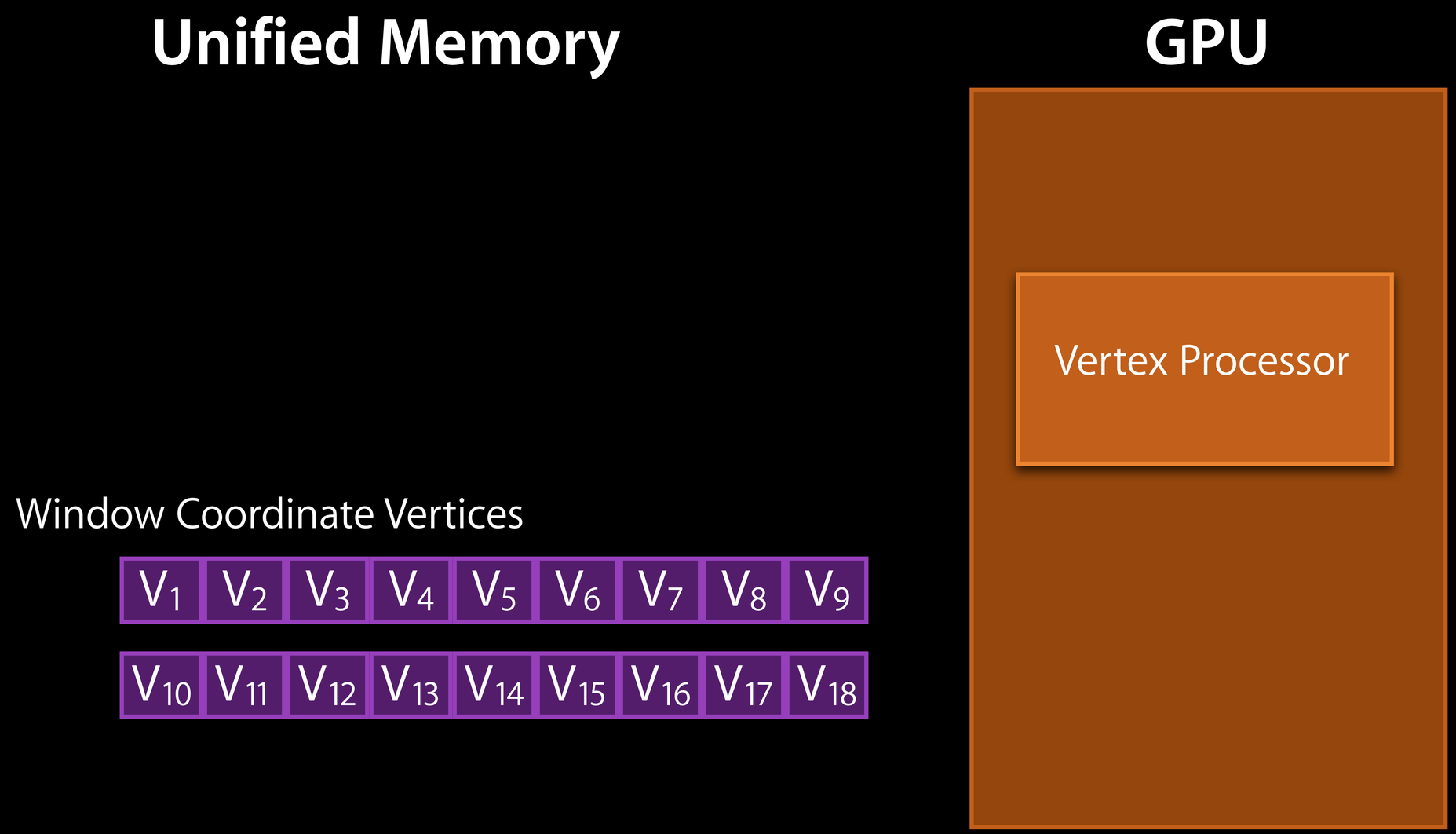
V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9

V_{10}	V_{11}	V_{12}	V_{13}	V_{14}	V_{15}	V_{16}	V_{17}	V_{18}

GPU

Vertex Processor

- A frames' worth of vertices stored
- Rasterization deferred until `presentRenderbuffer` or renderbuffer changed



Tiling Processor

Unified Memory

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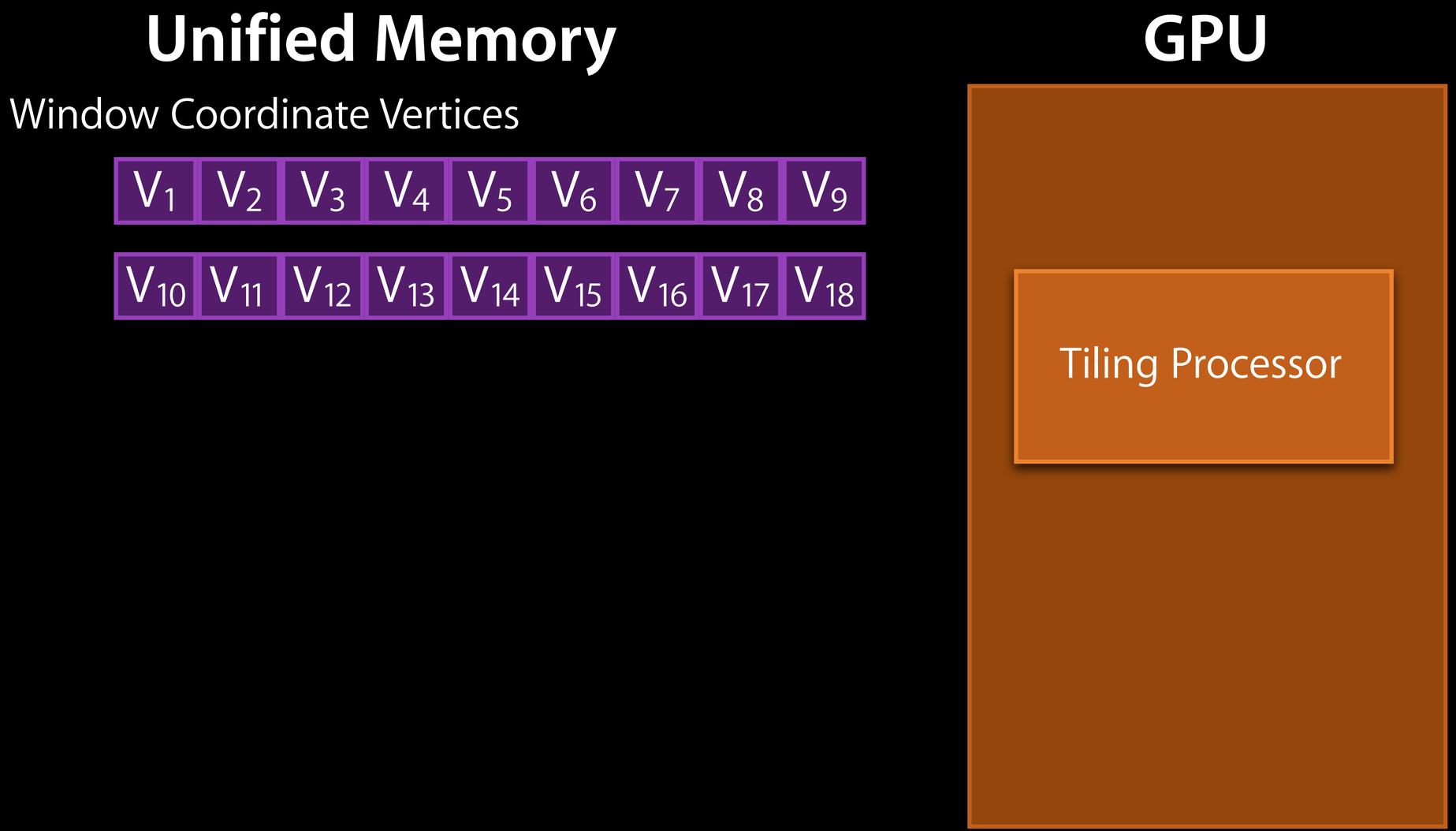
GPU

Tiling Processor

- Render buffers split into tiles
- Allows rasterization and fragment shading on embedded GPU memory



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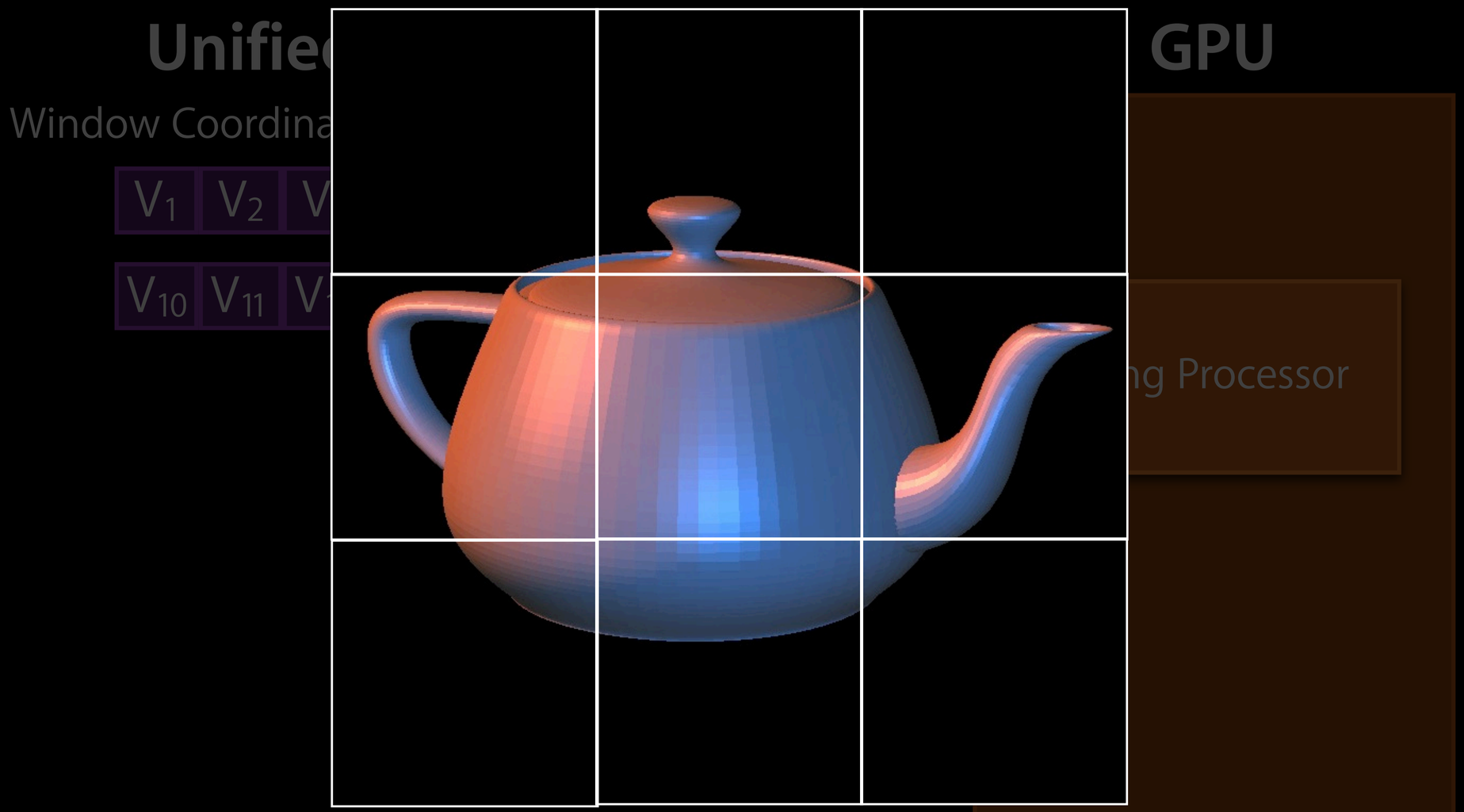

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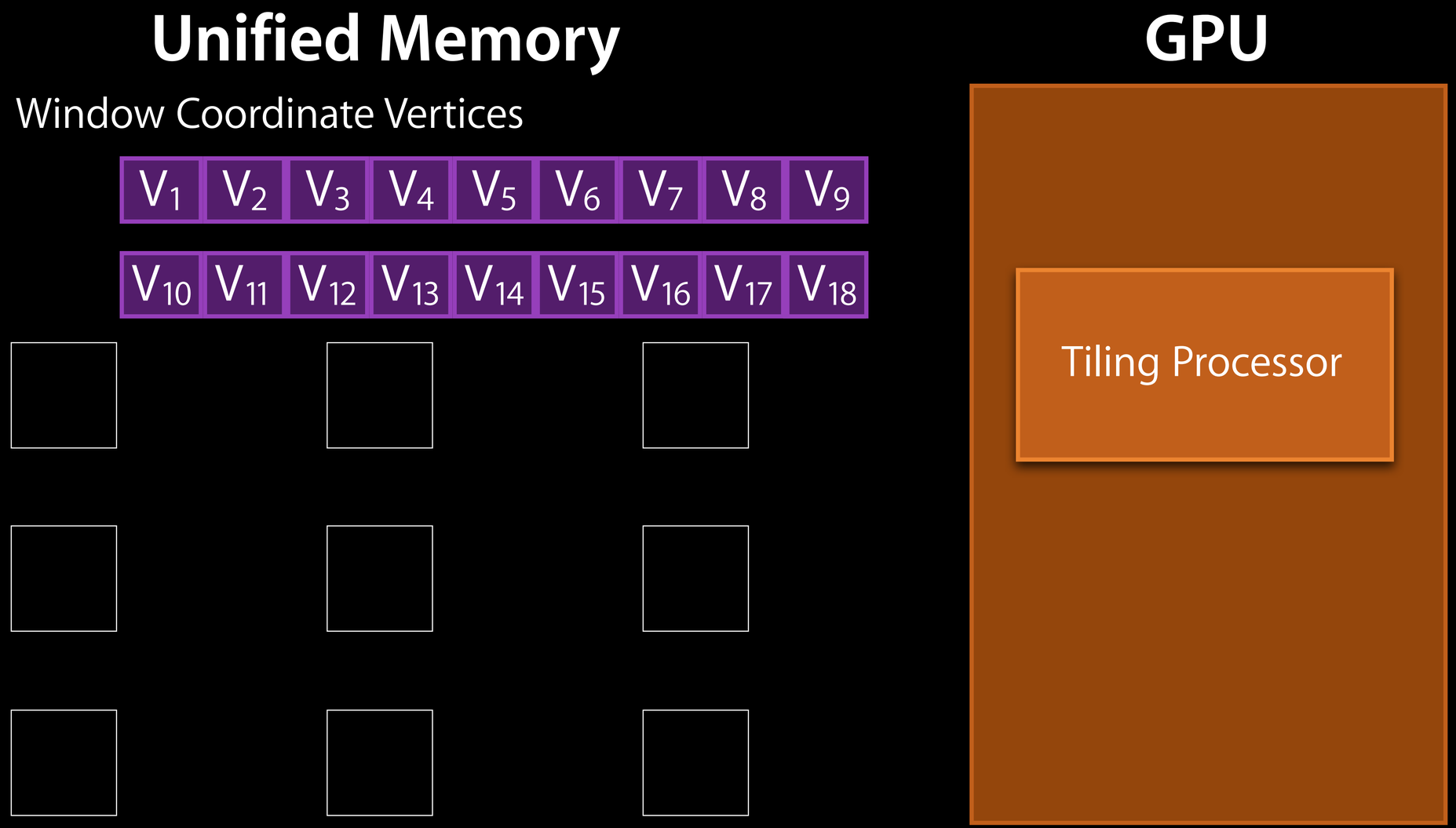
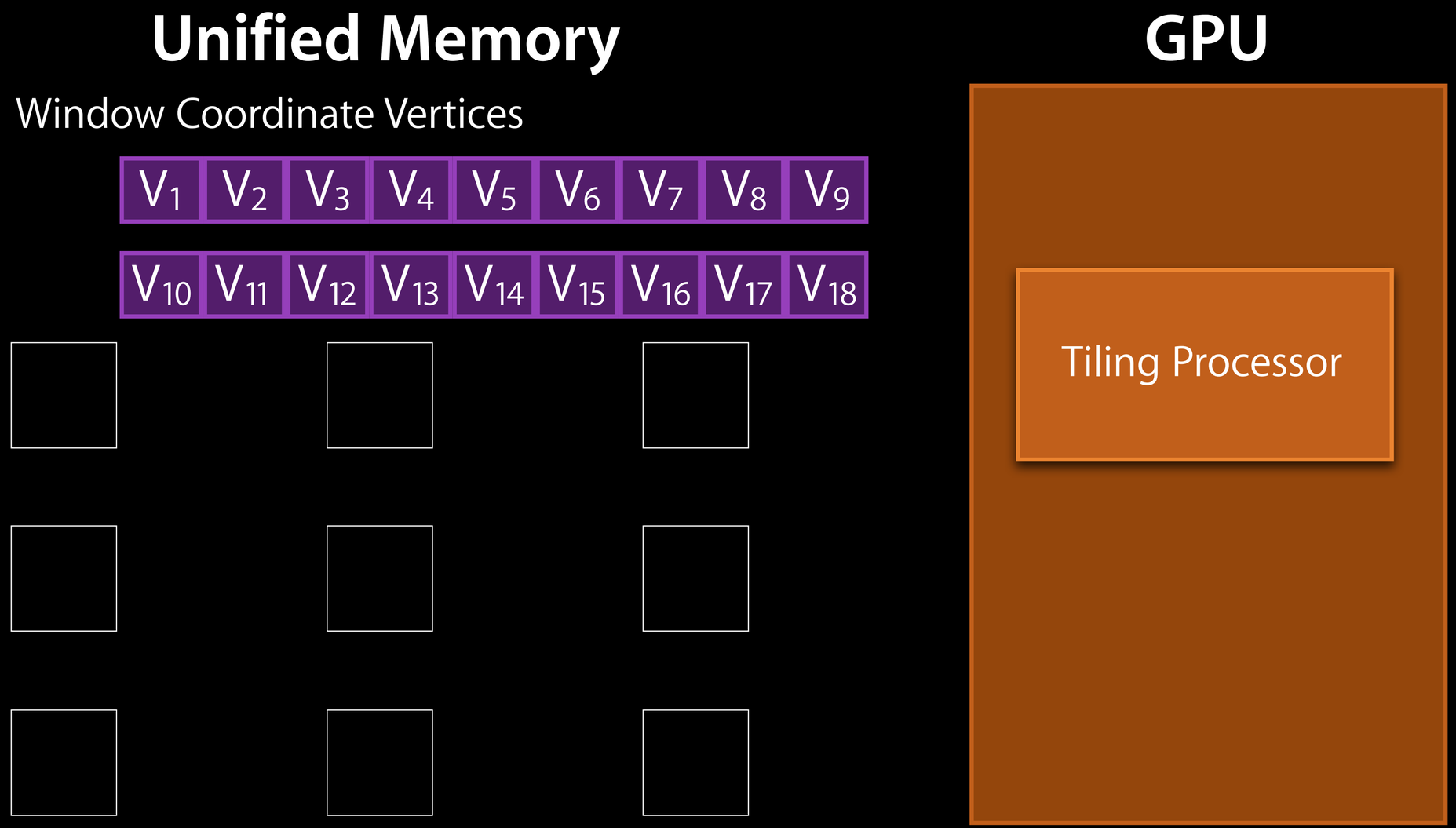


- Vertices processed in groups of triangles
- Tiling processor bins triangles into tiles in which they are located



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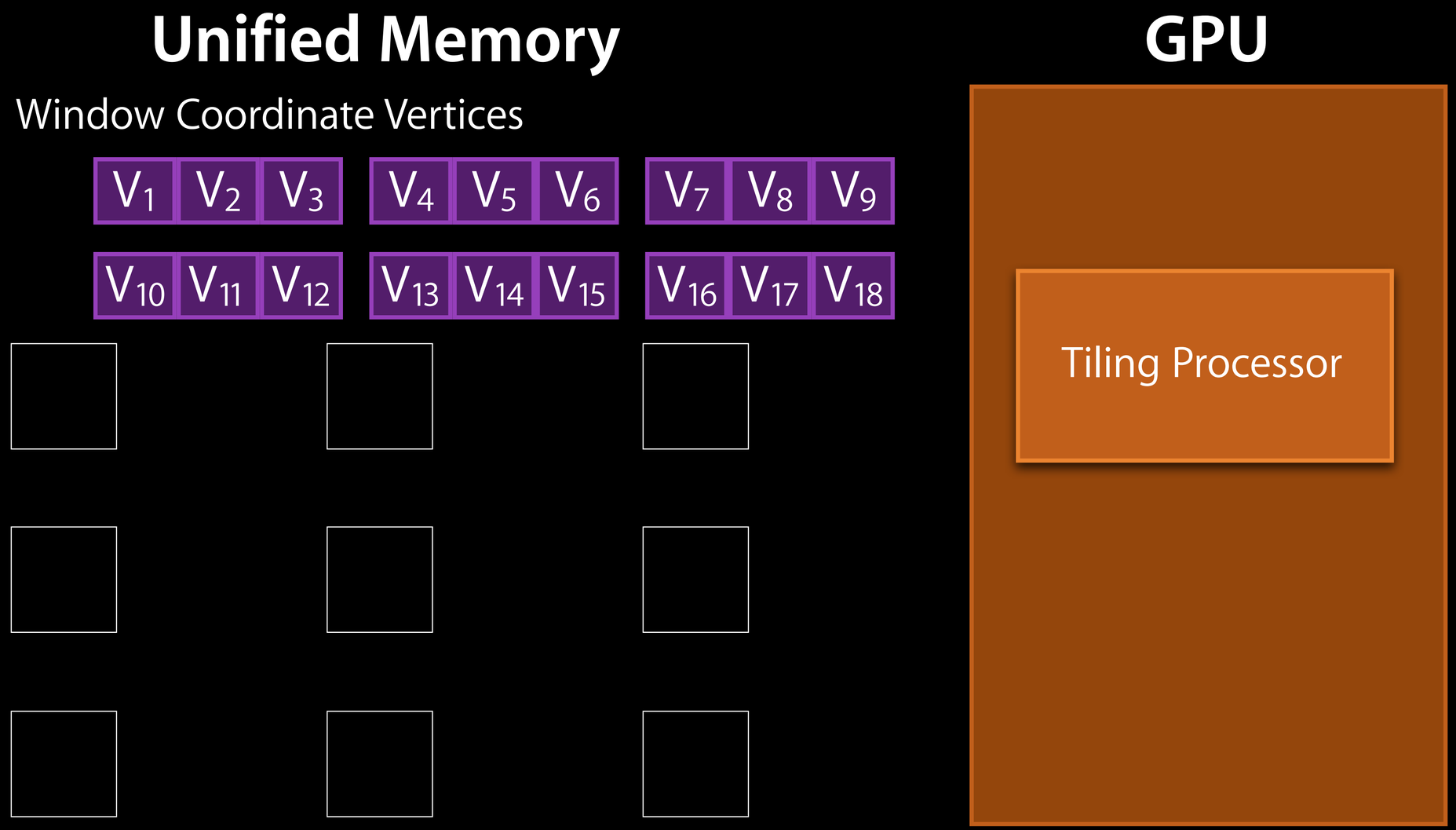

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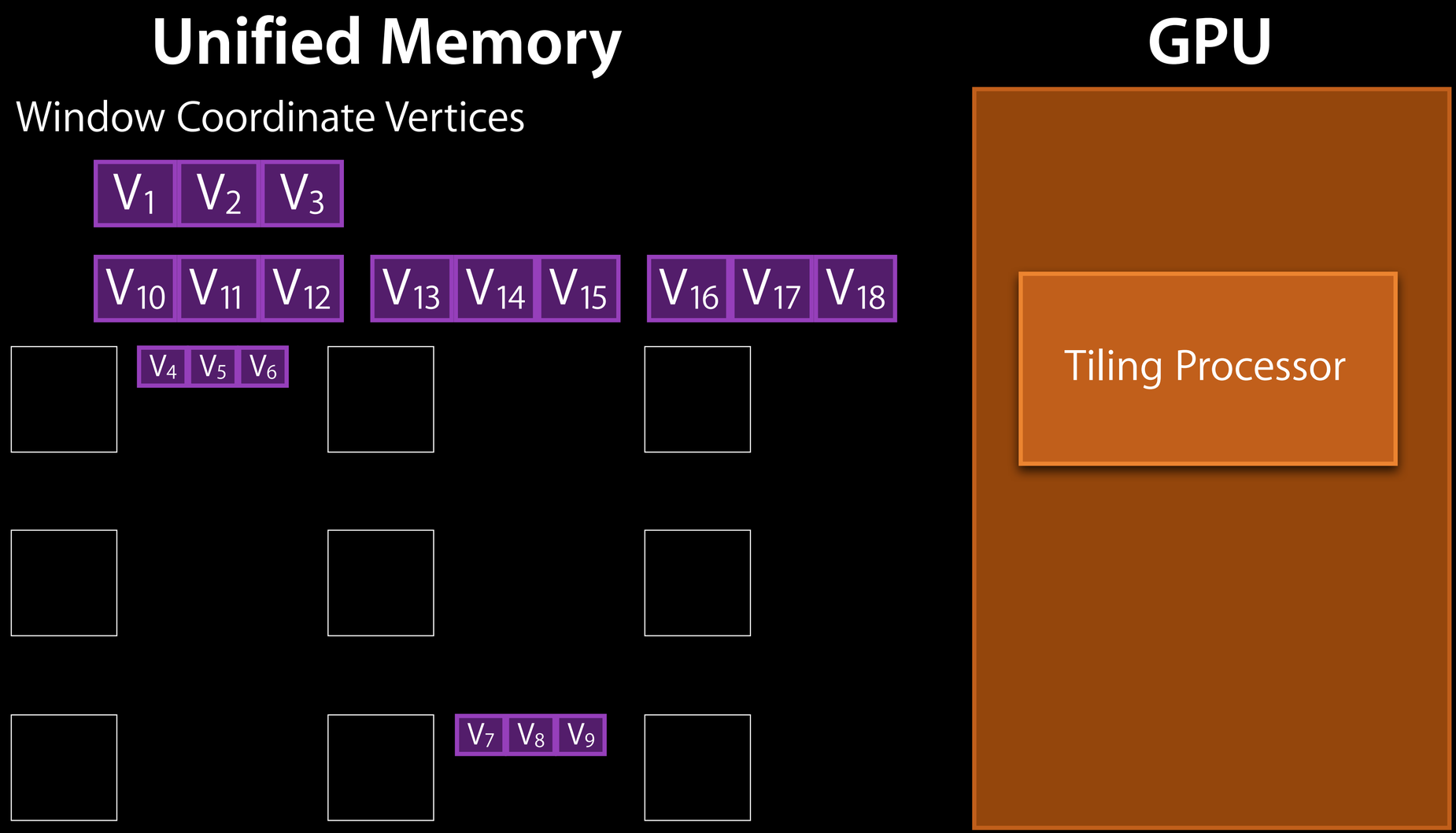
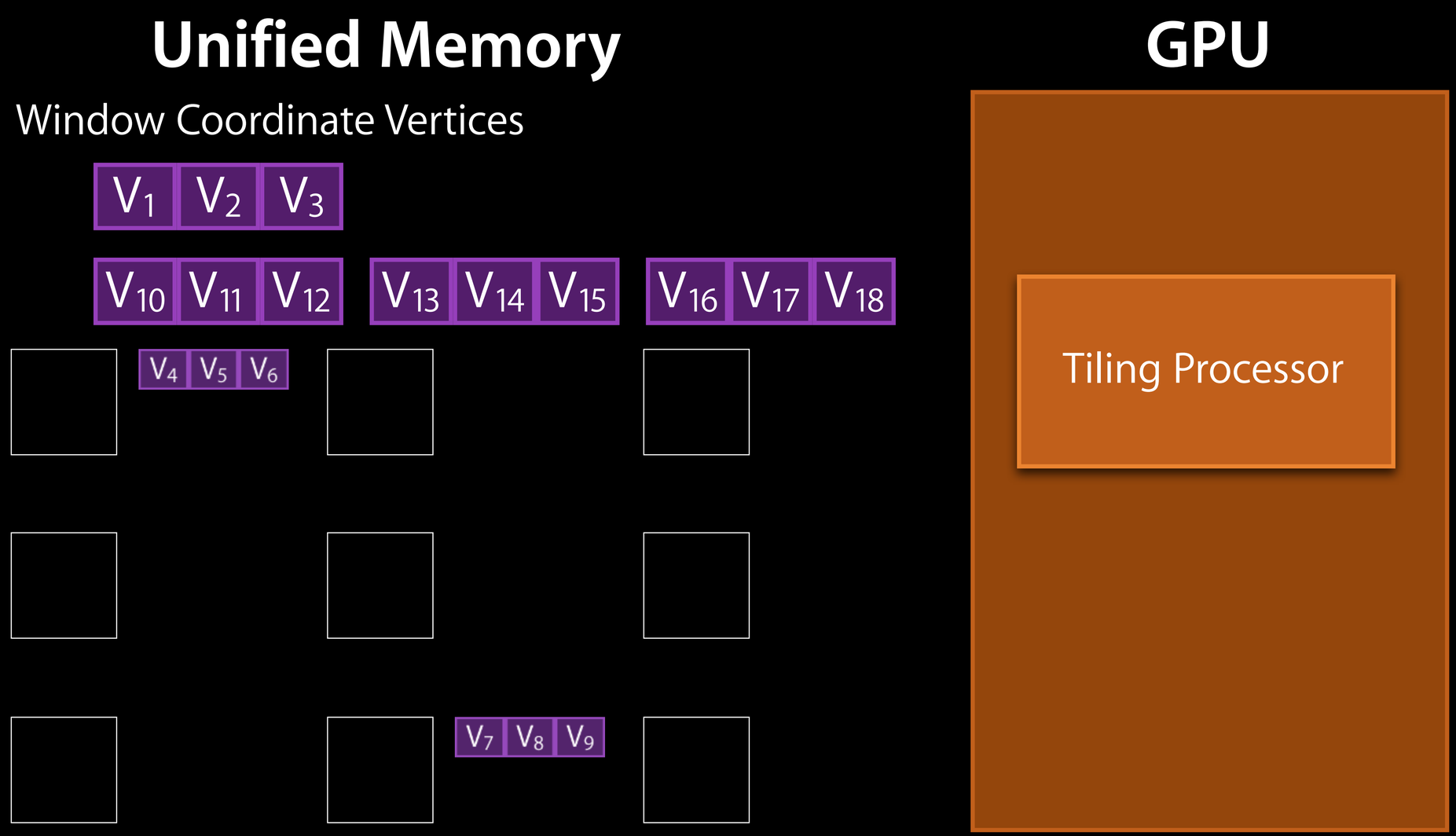


- GPU may bin a larger triangle into multiple tiles



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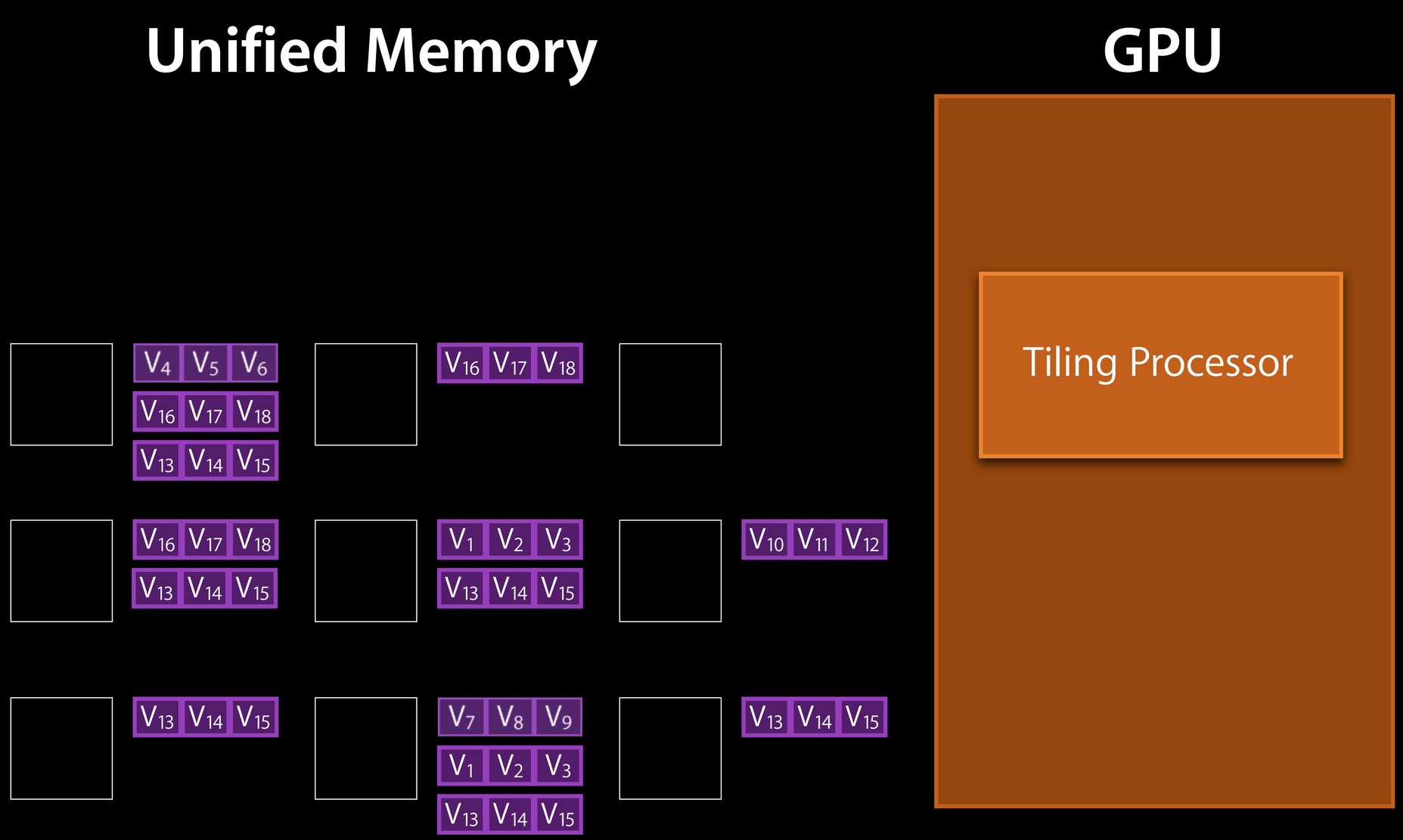
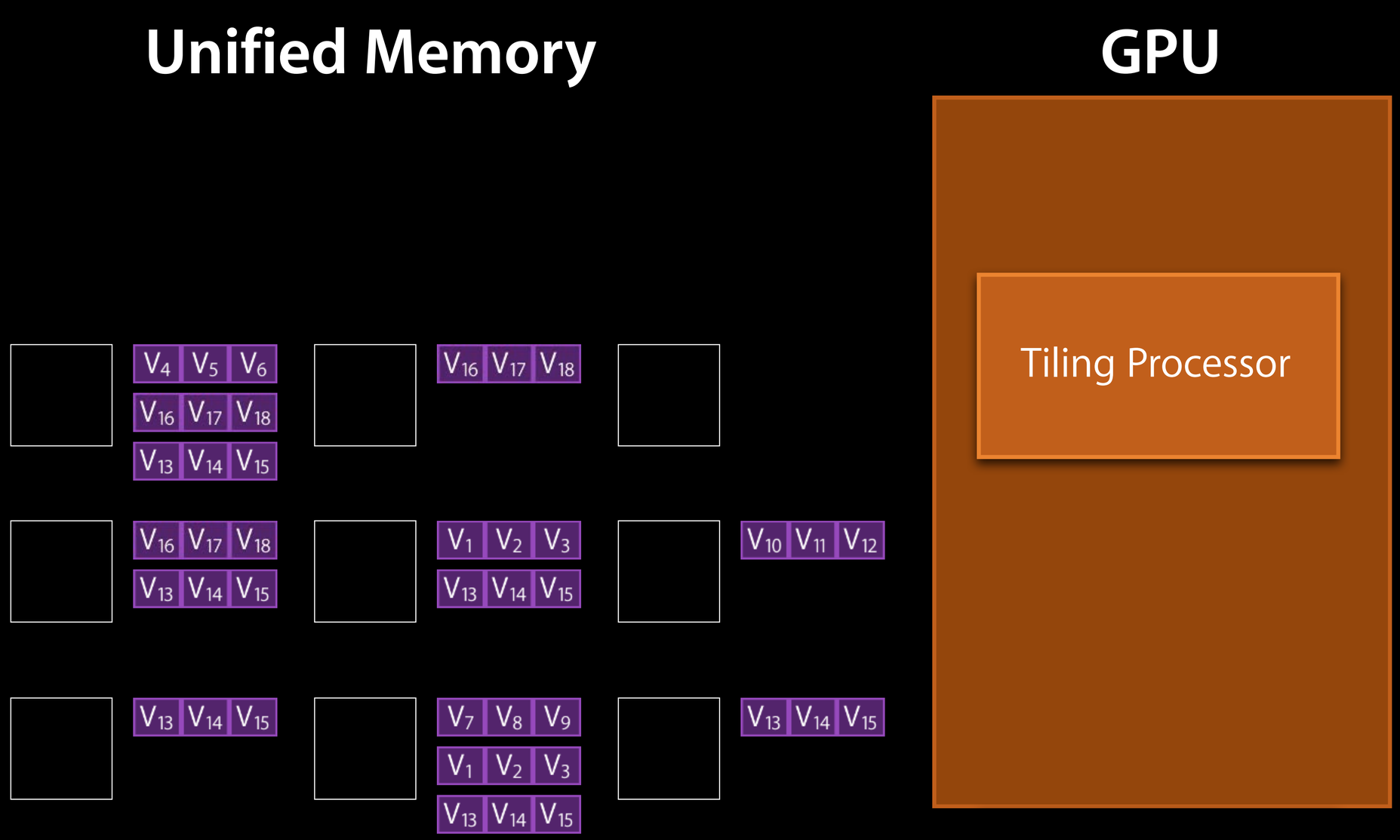


Raster Setup



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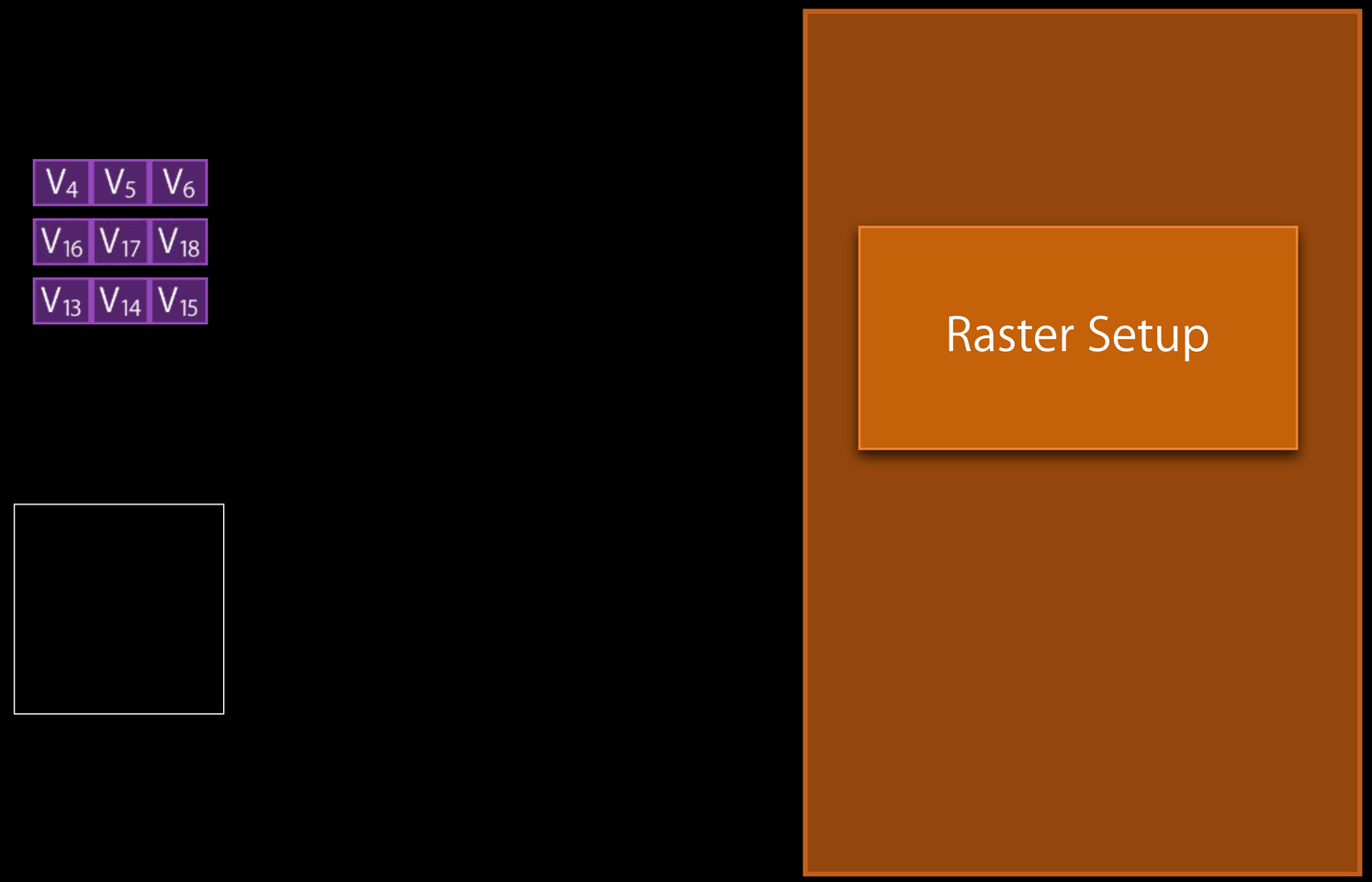

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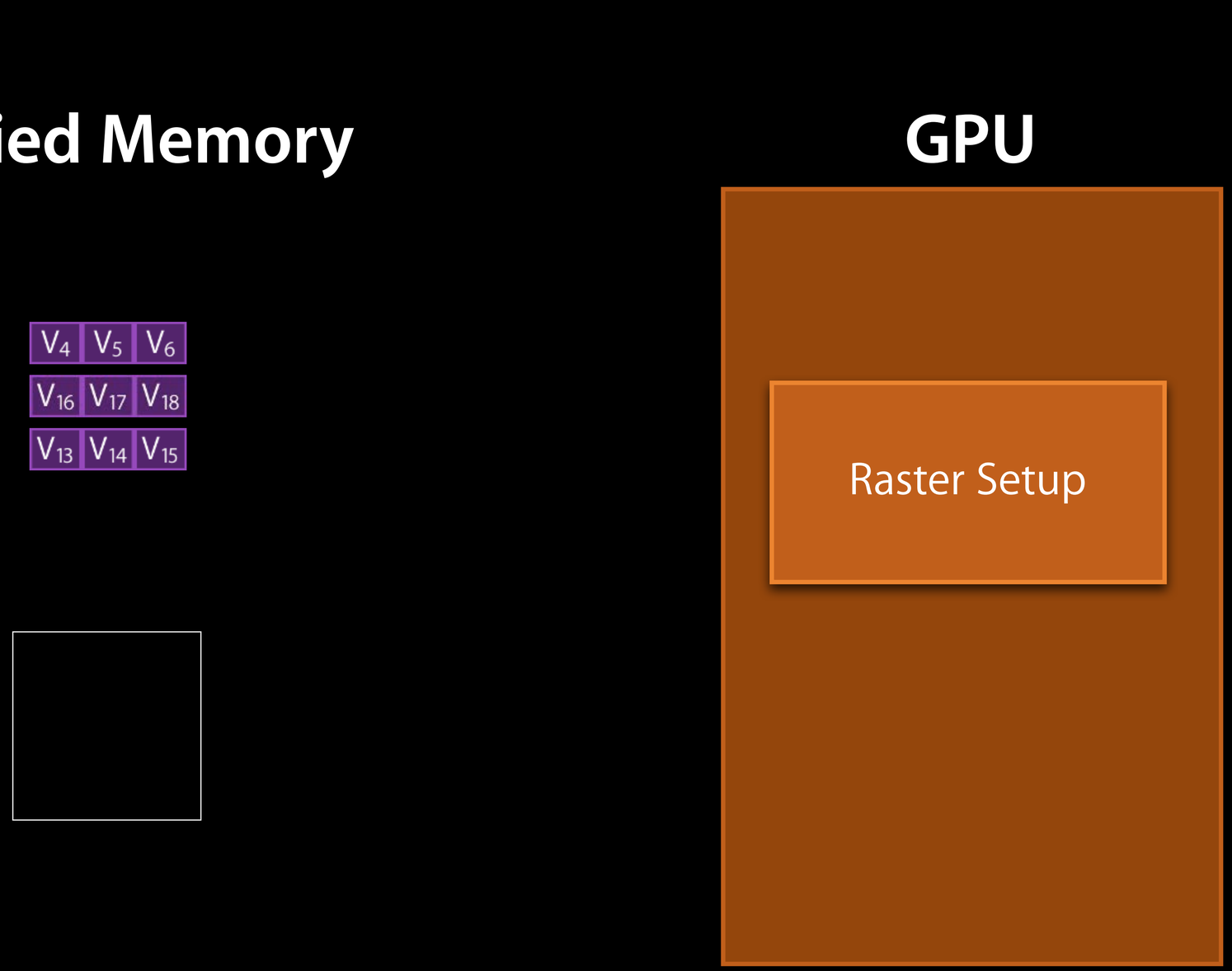

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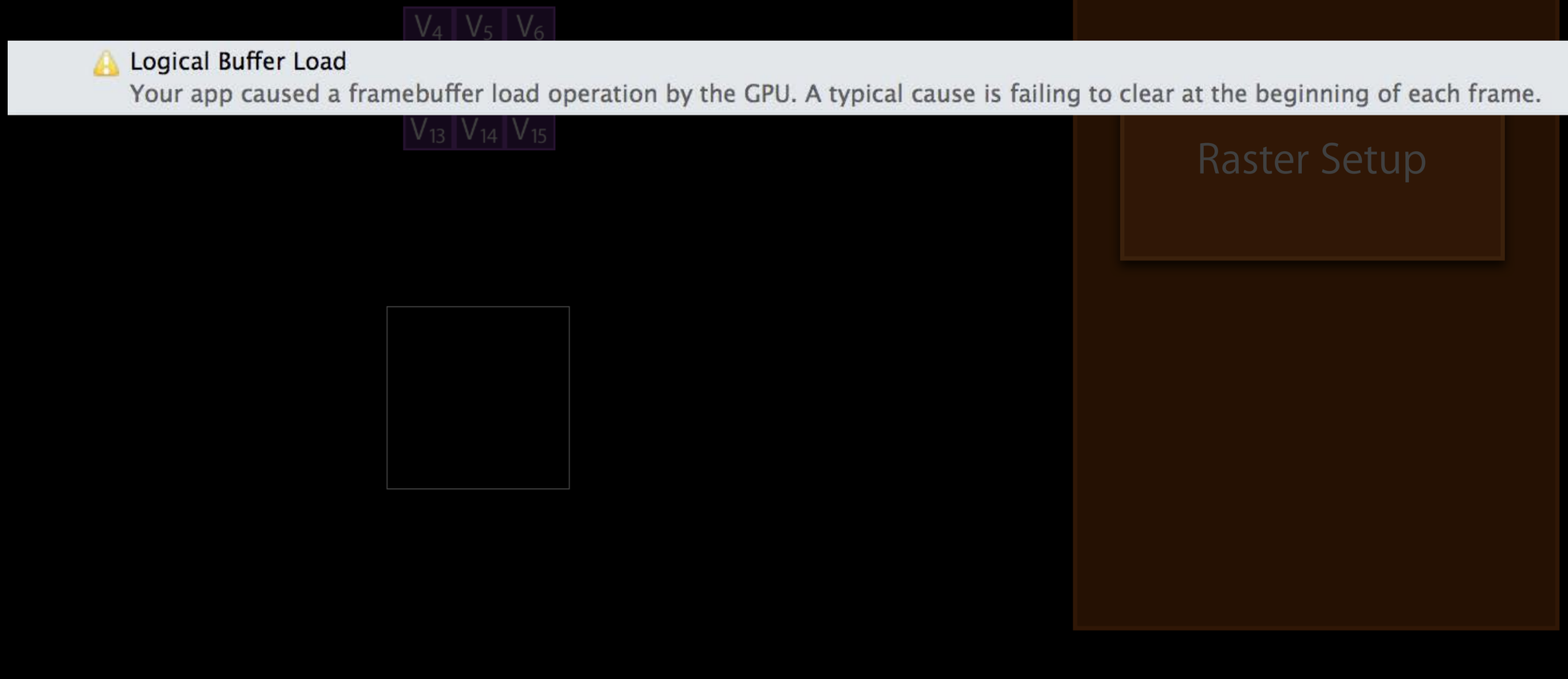
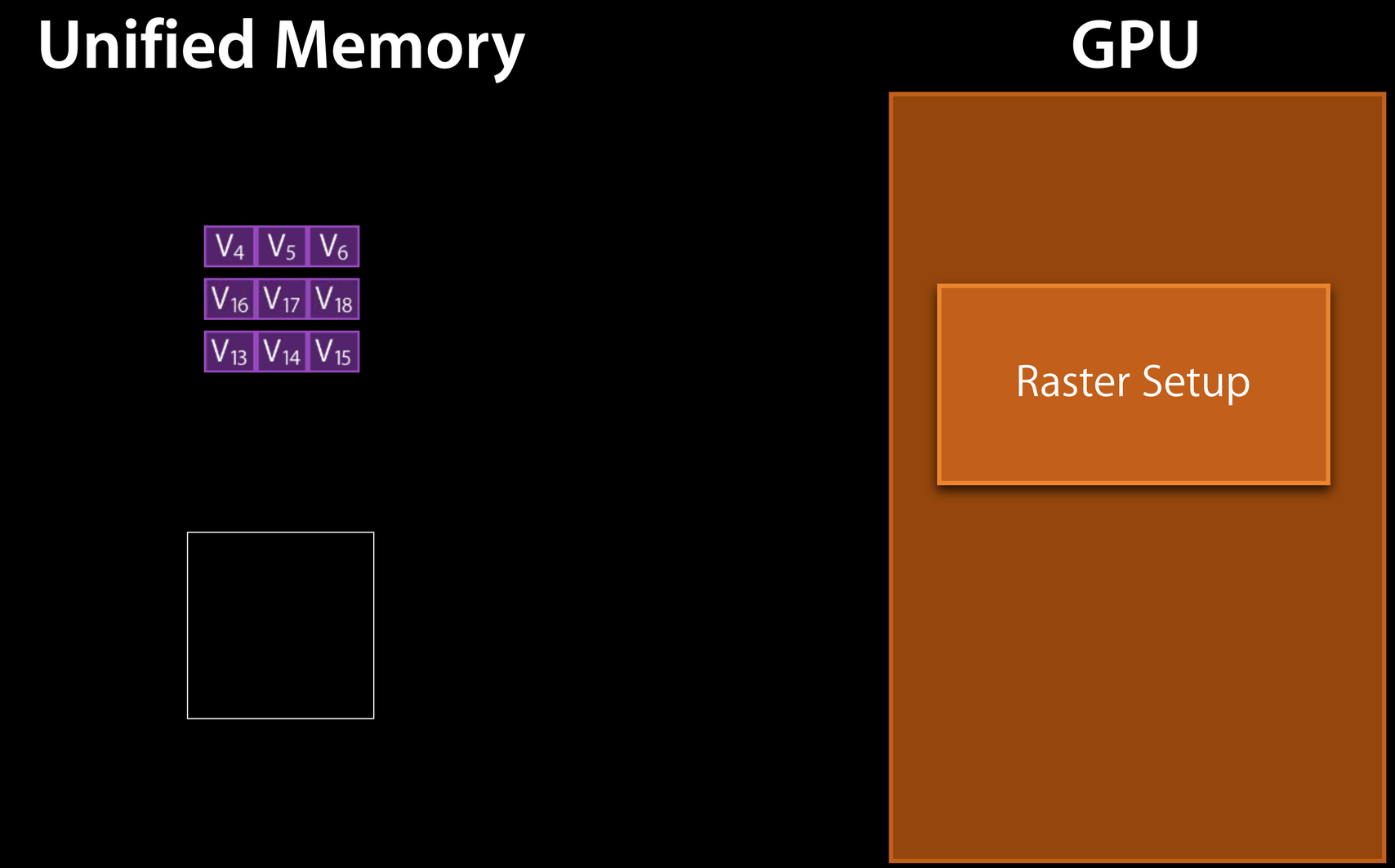


Logical Buffer Load

Your app caused a framebuffer load operation by the GPU. A typical cause is failing to clear at the beginning of each frame.

- Rasterizer uses tile-sized embedded memory



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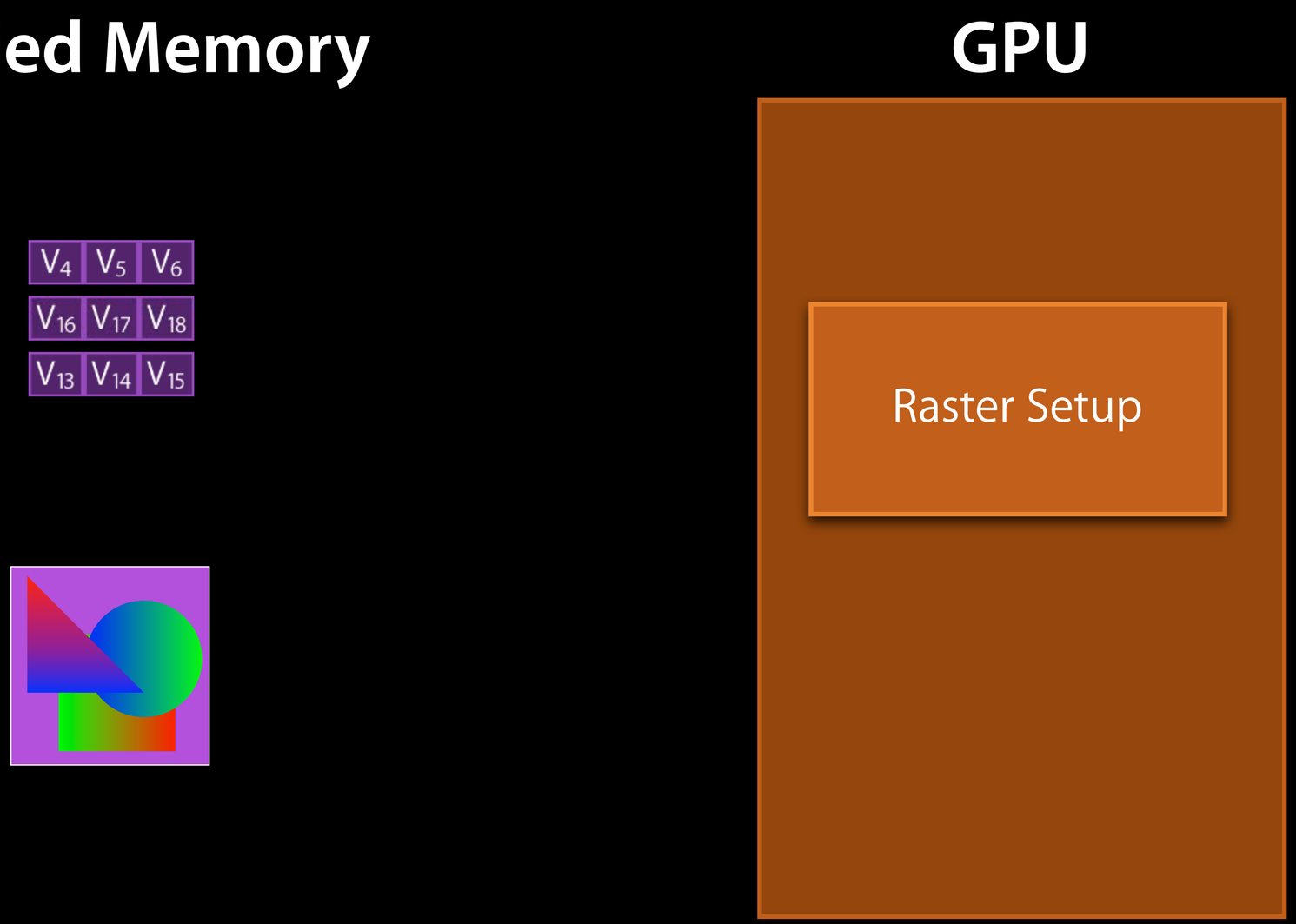
- If data is in render buffer, GPU must perform a costly load



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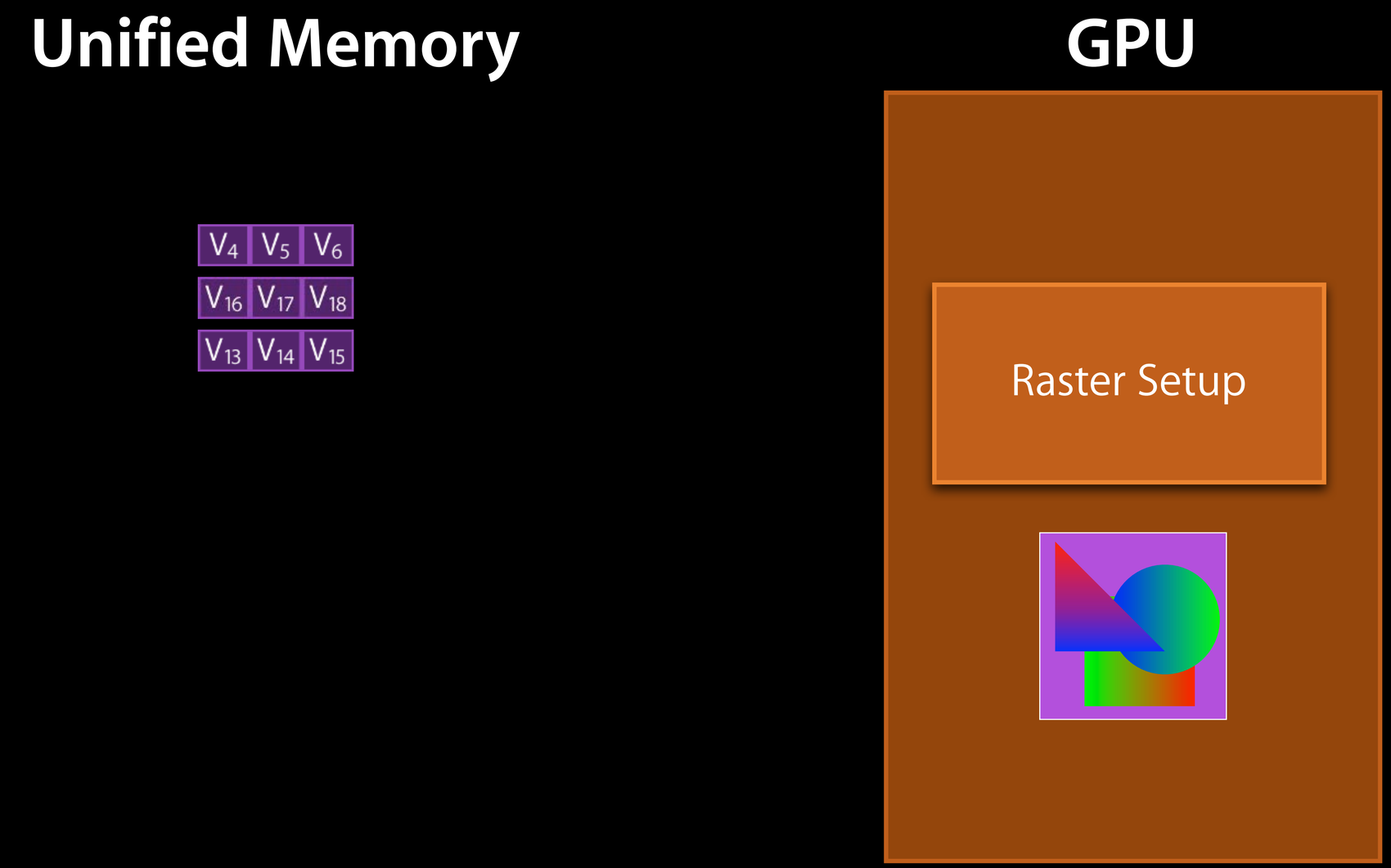
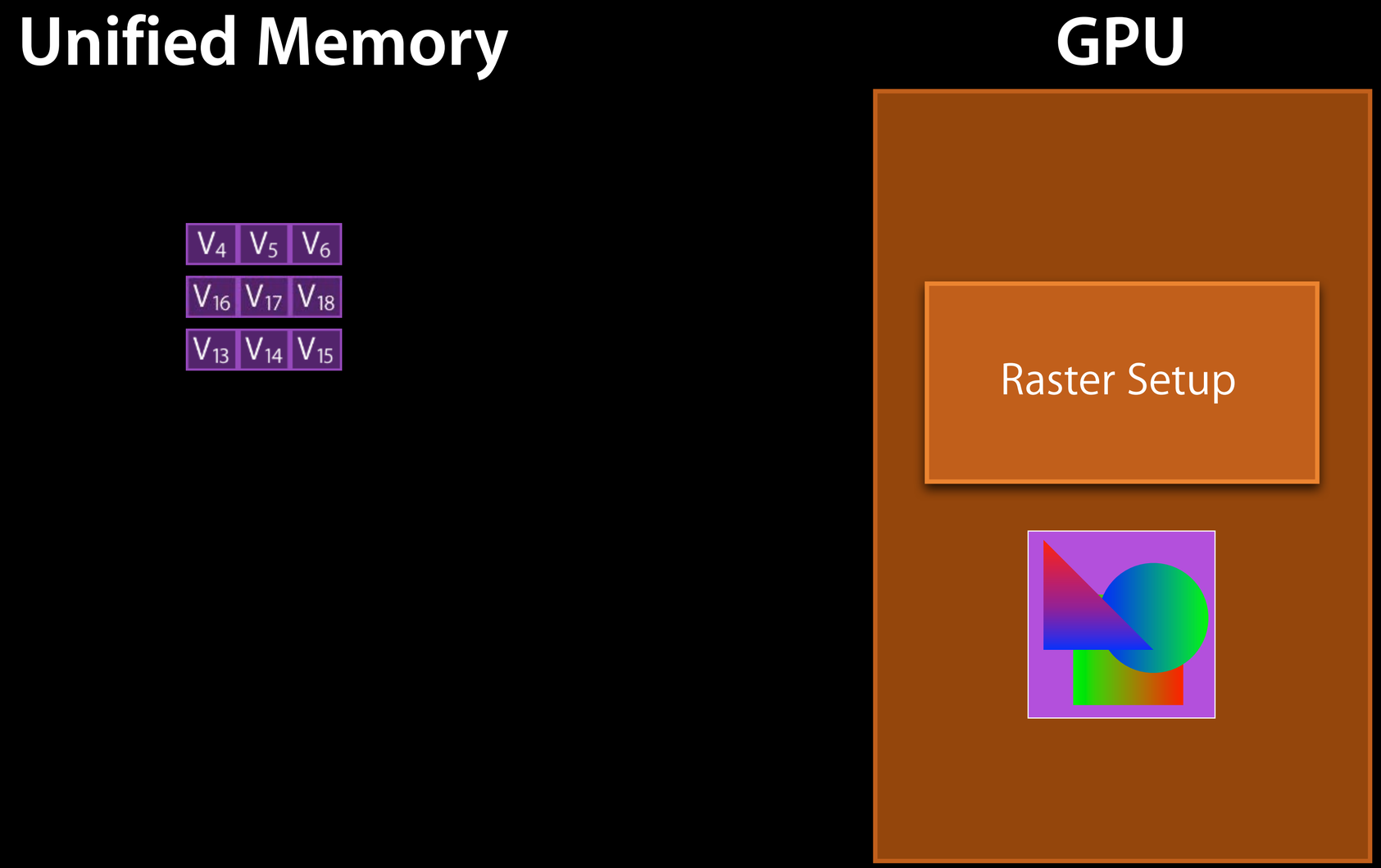


- If there is data in the depth buffer, GPU must load it also



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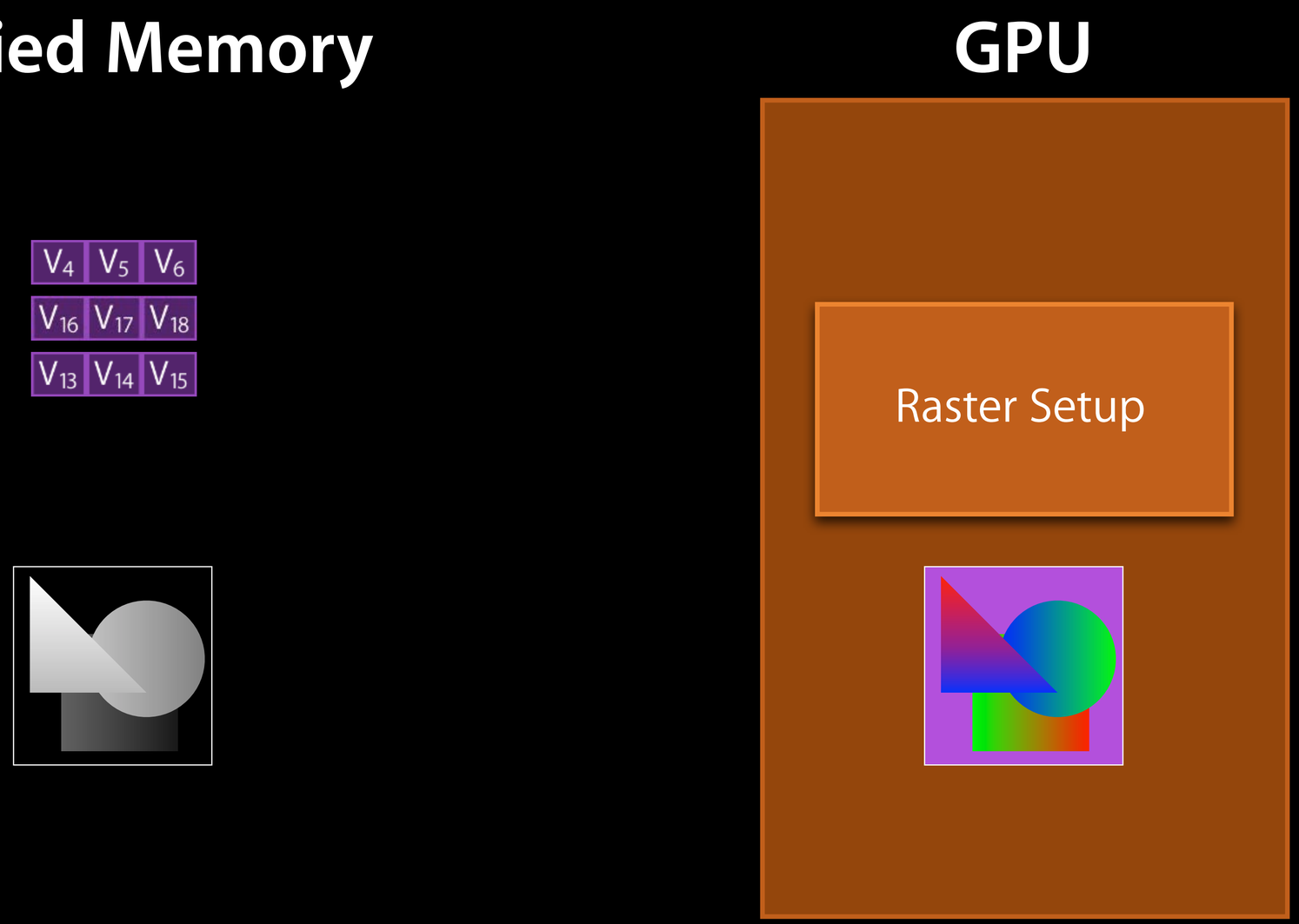

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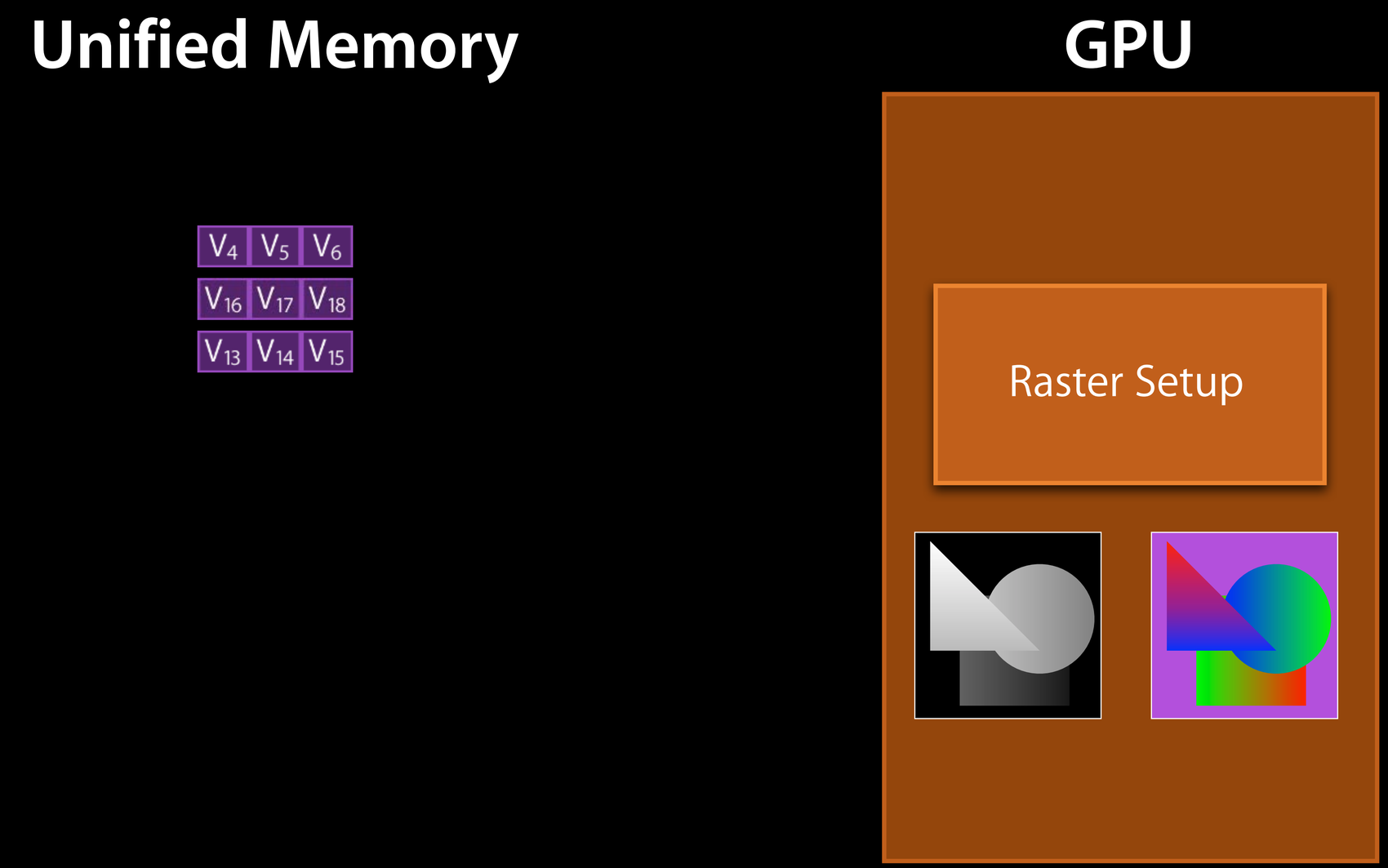
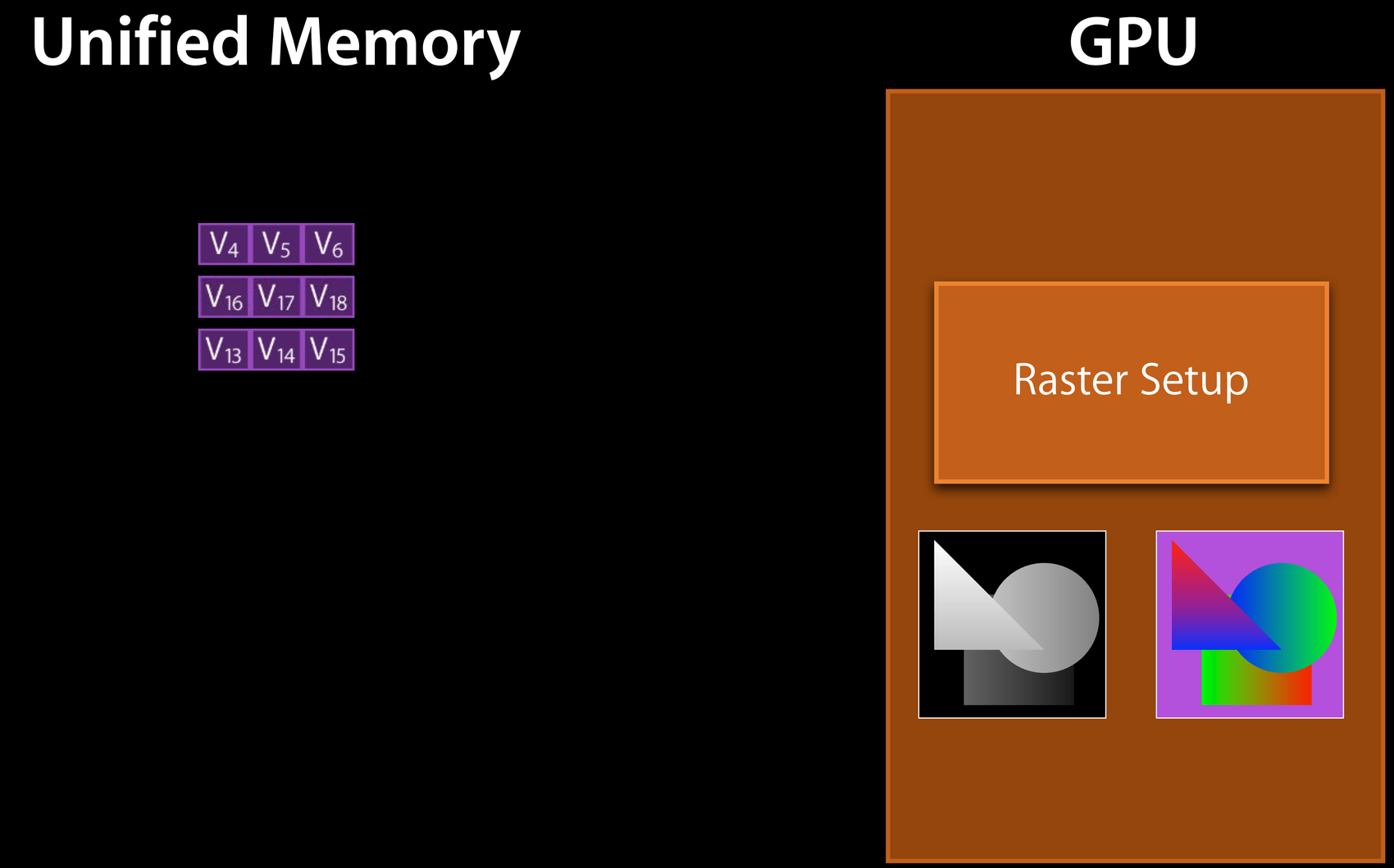
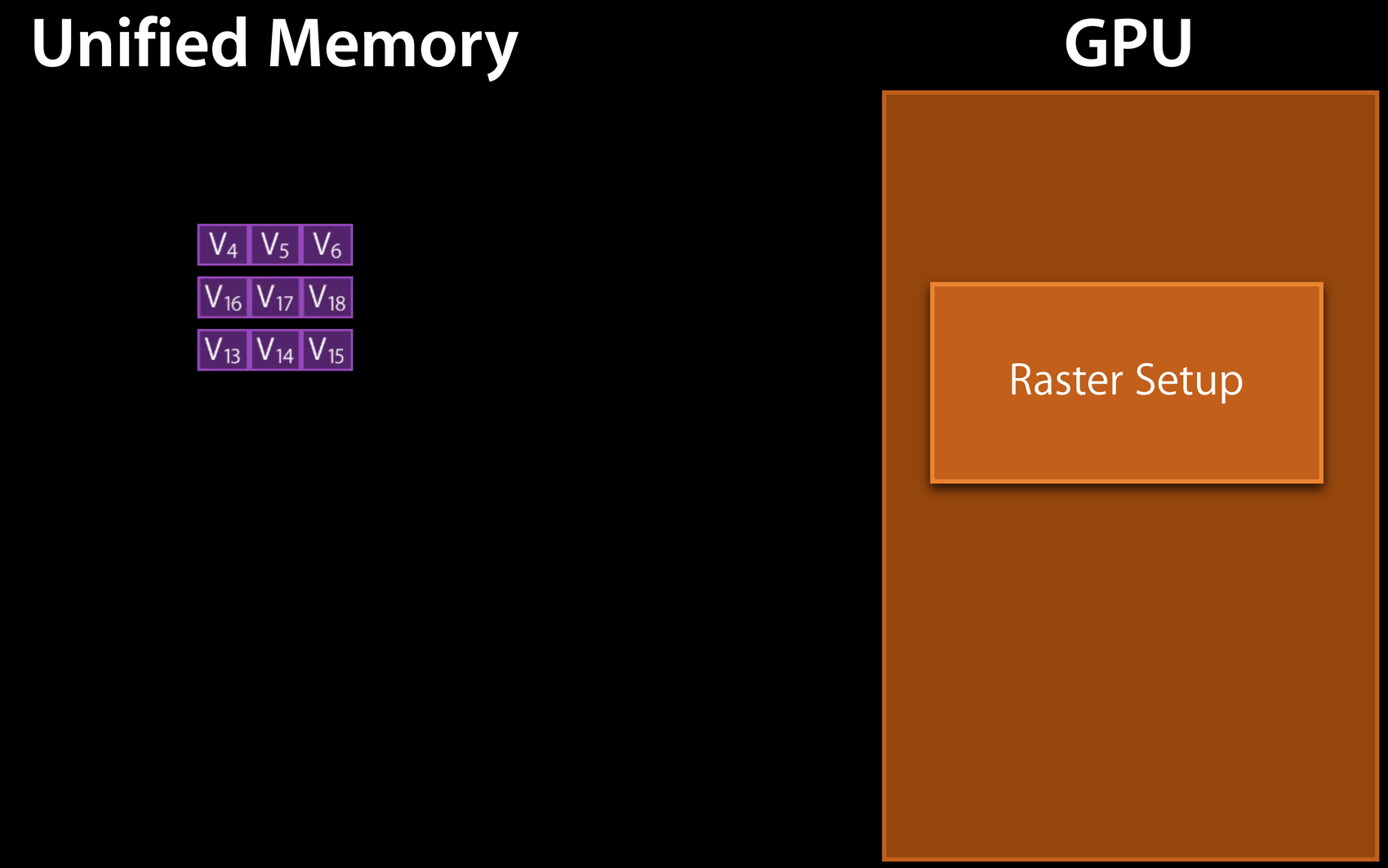


- Loading a tile is called a Logical Buffer Load
  - Developers can avoid these



- Calling `glClear` before rendering skips Logical Buffer Load



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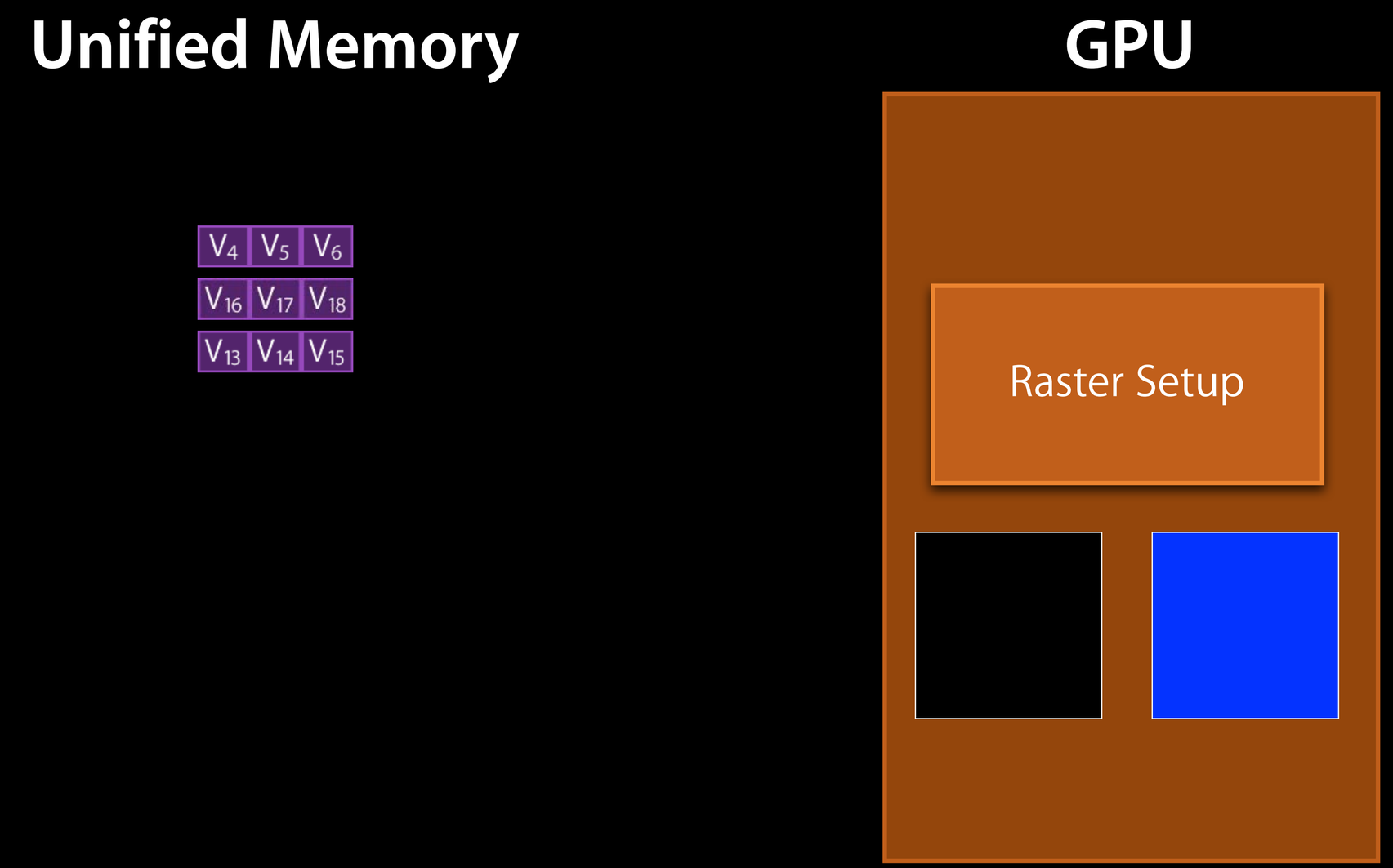
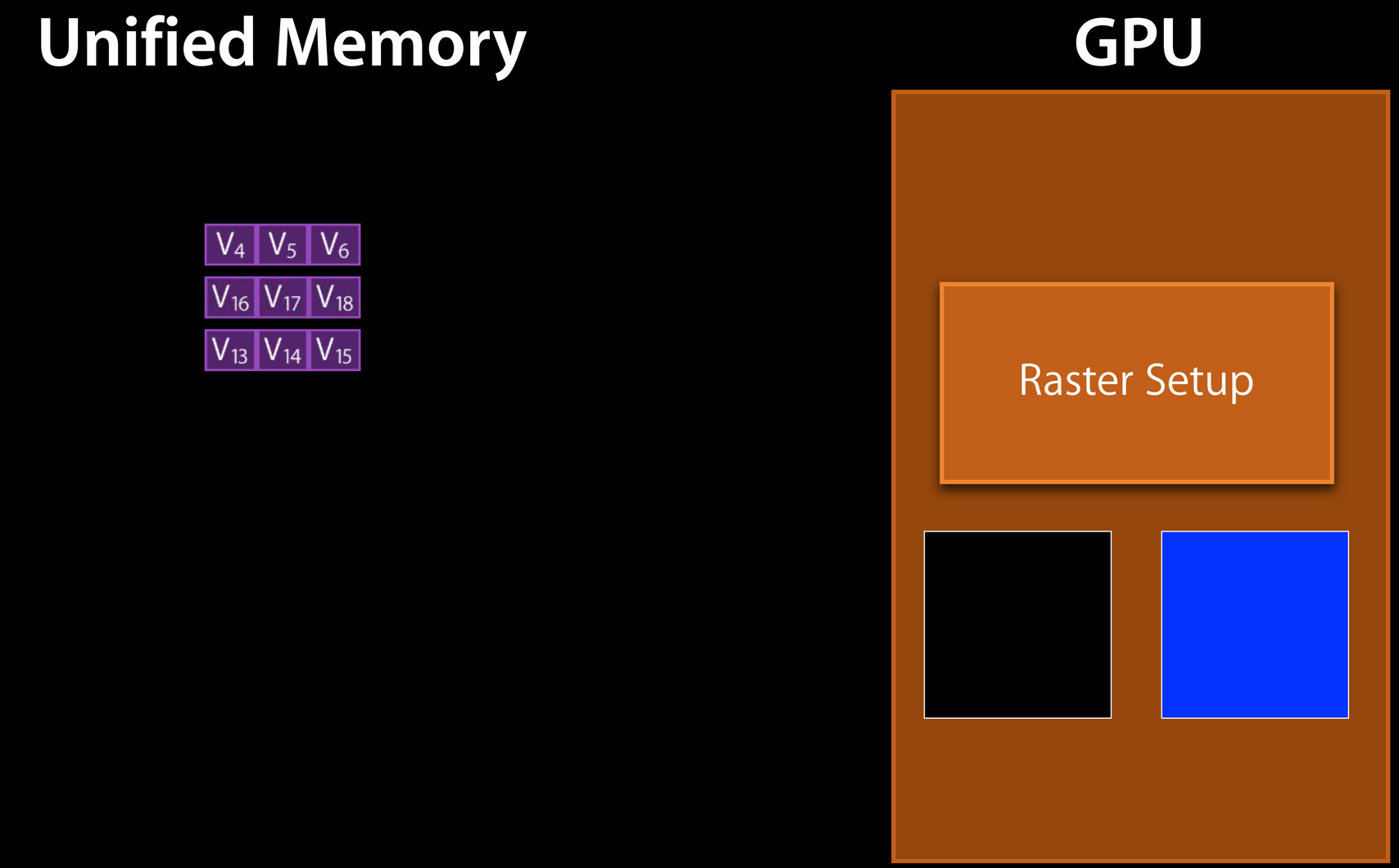
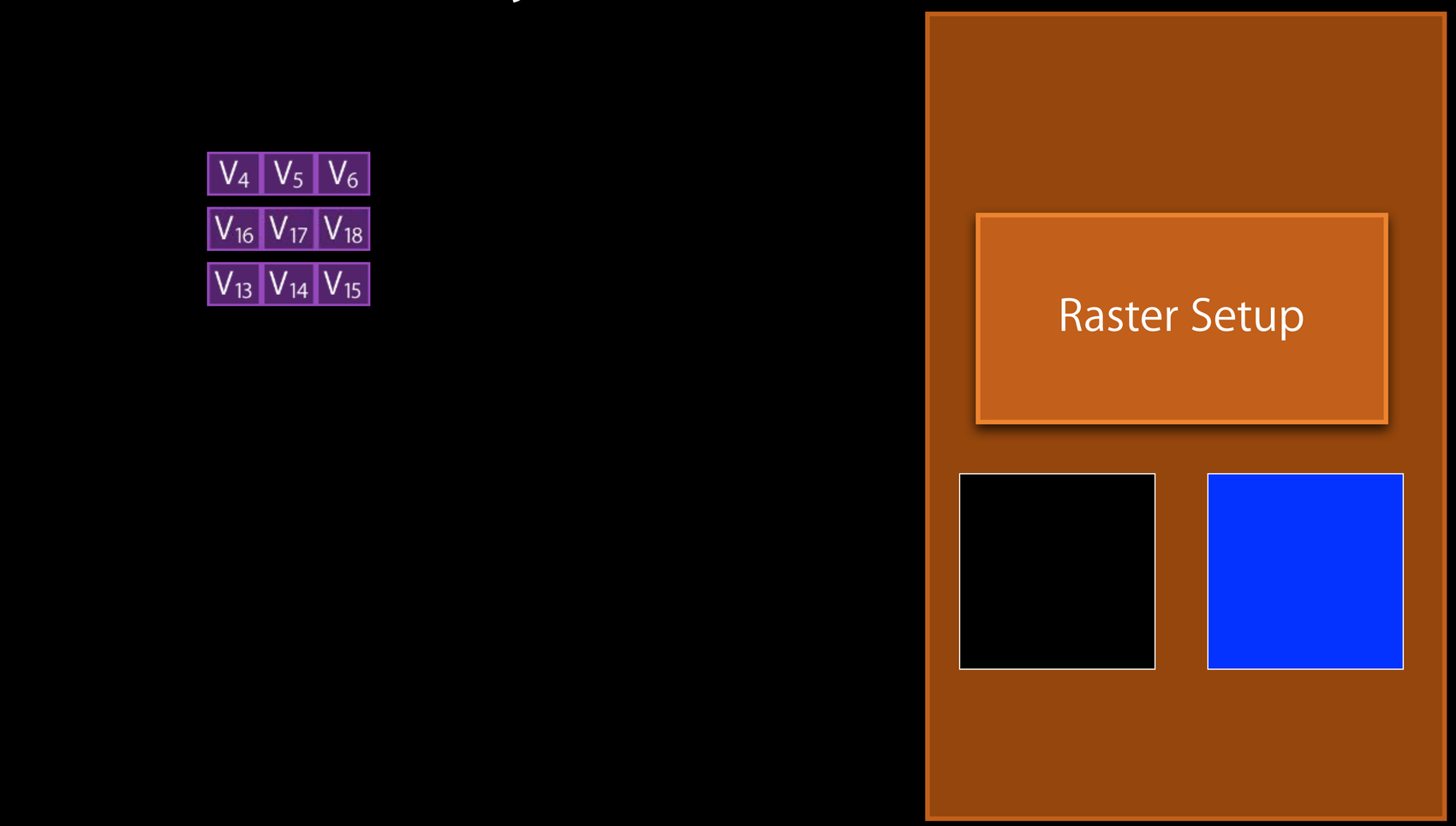
  - Can immediately rasterize to embedded memory



- Logical Buffer Loads also happen when switching render buffer



- Logical Buffer Loads also happen when switching render buffer
  - Render to texture, render to new buffer, render to texture again



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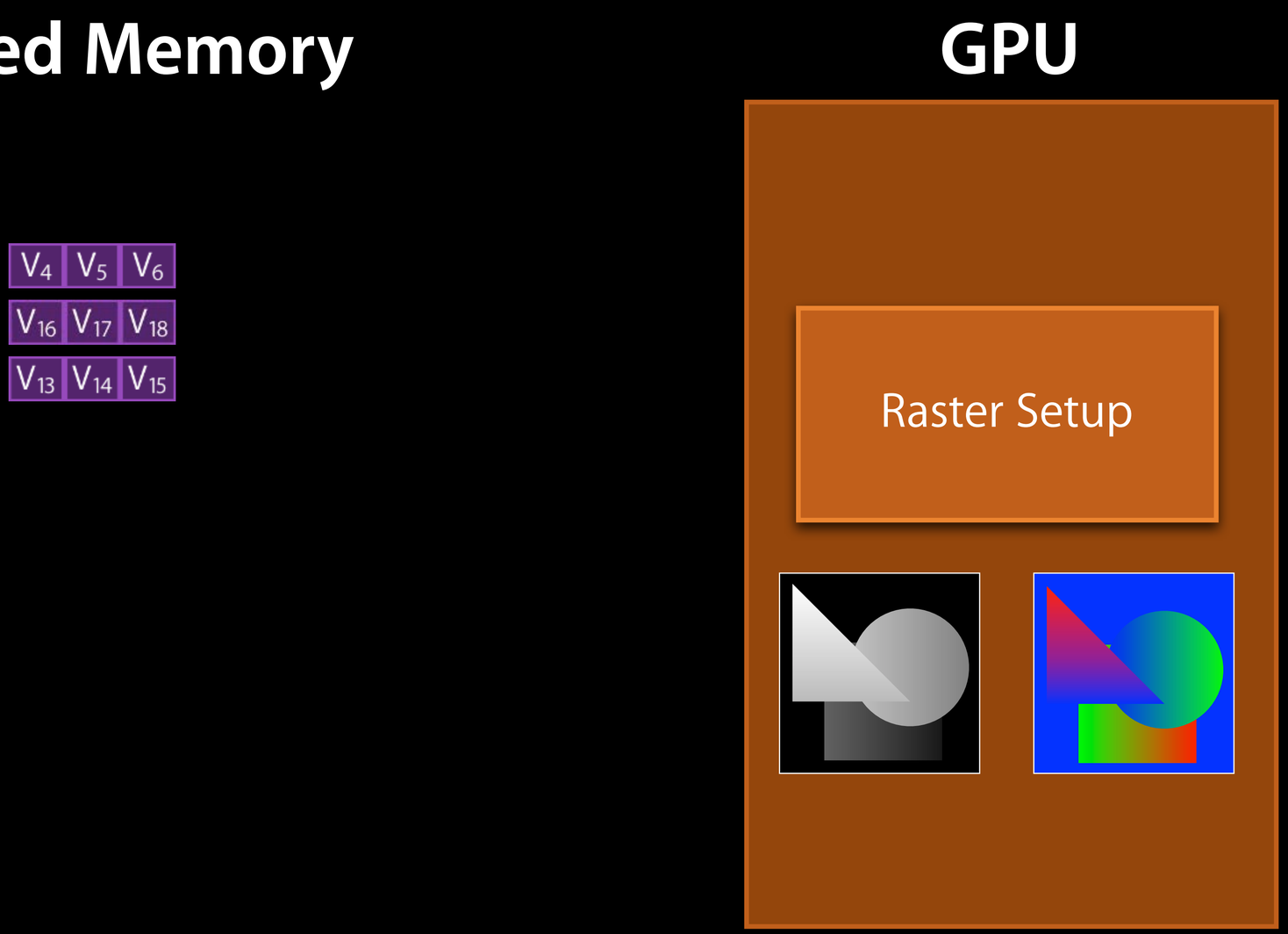

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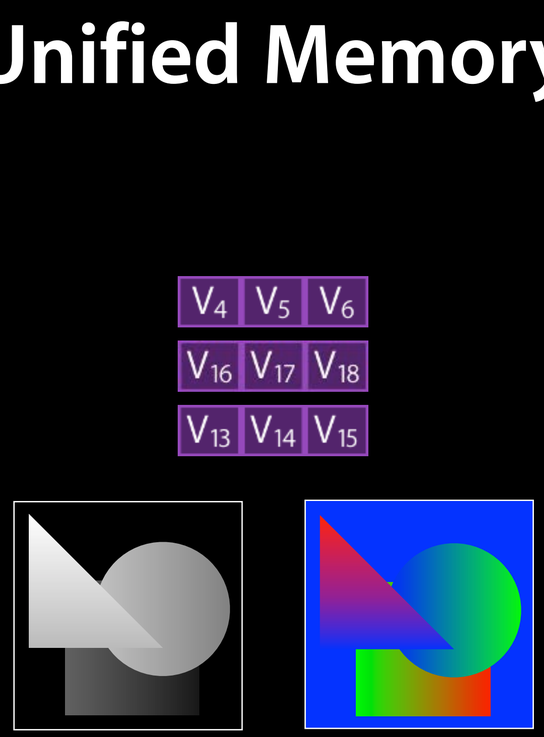

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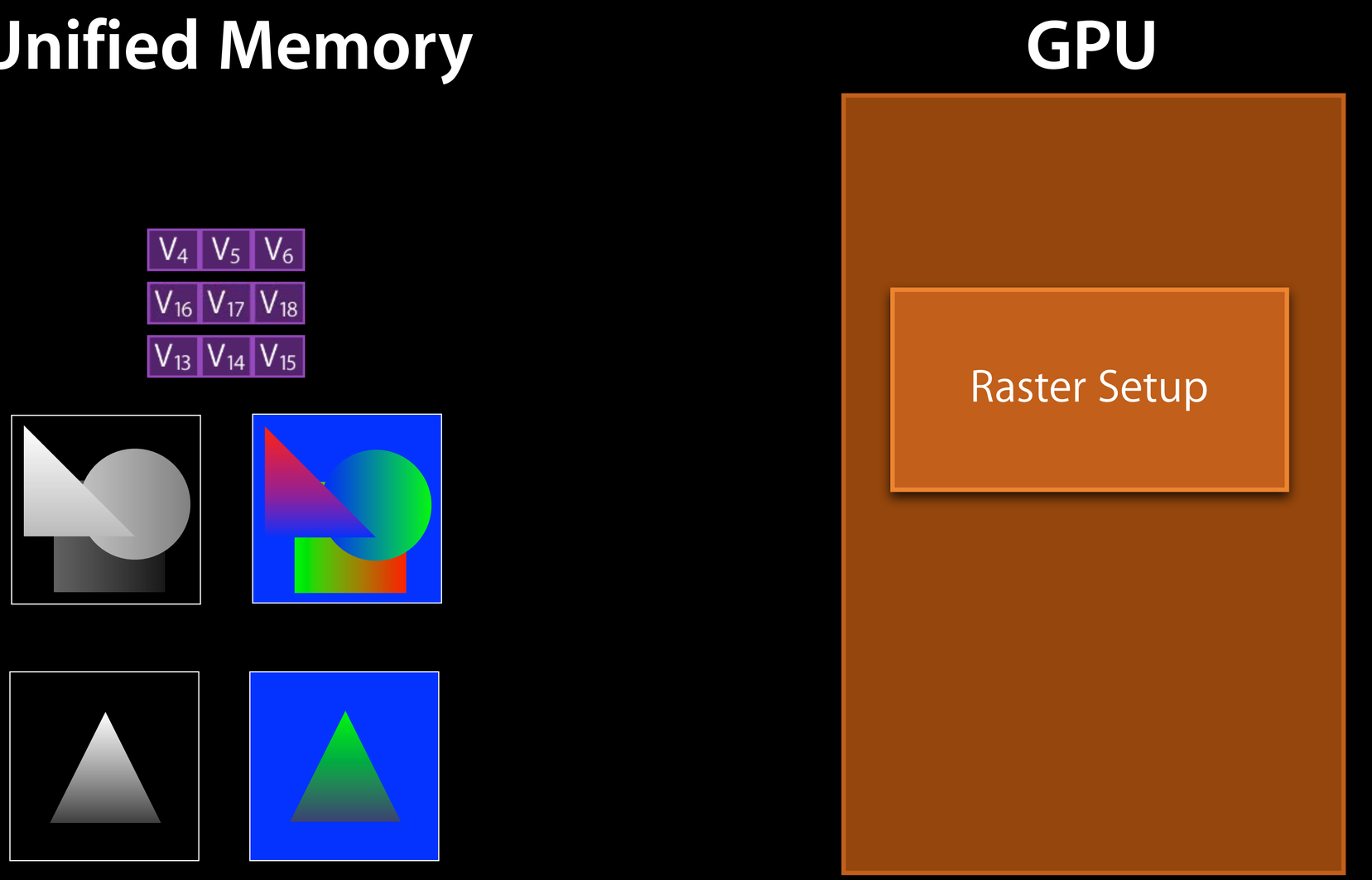

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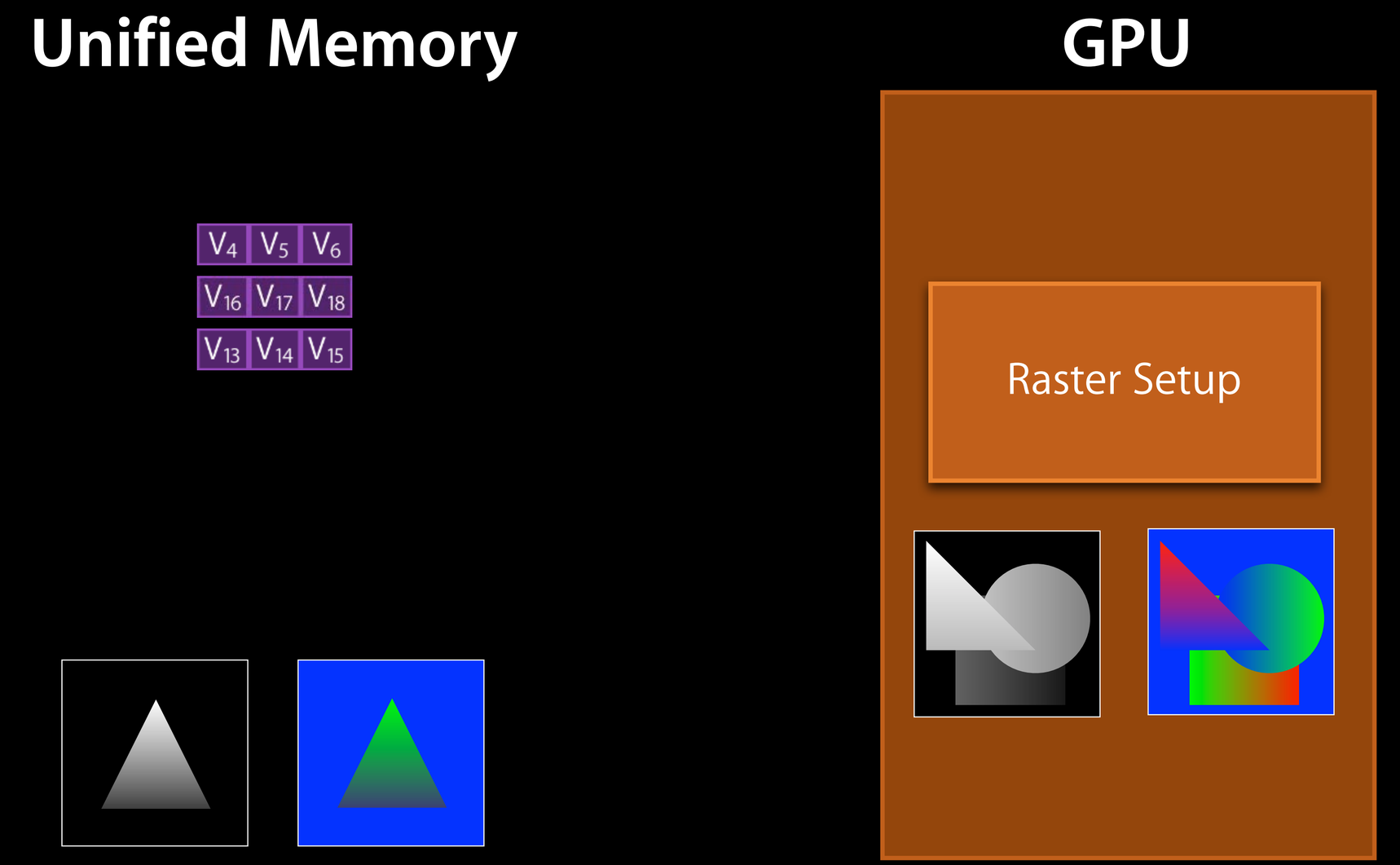
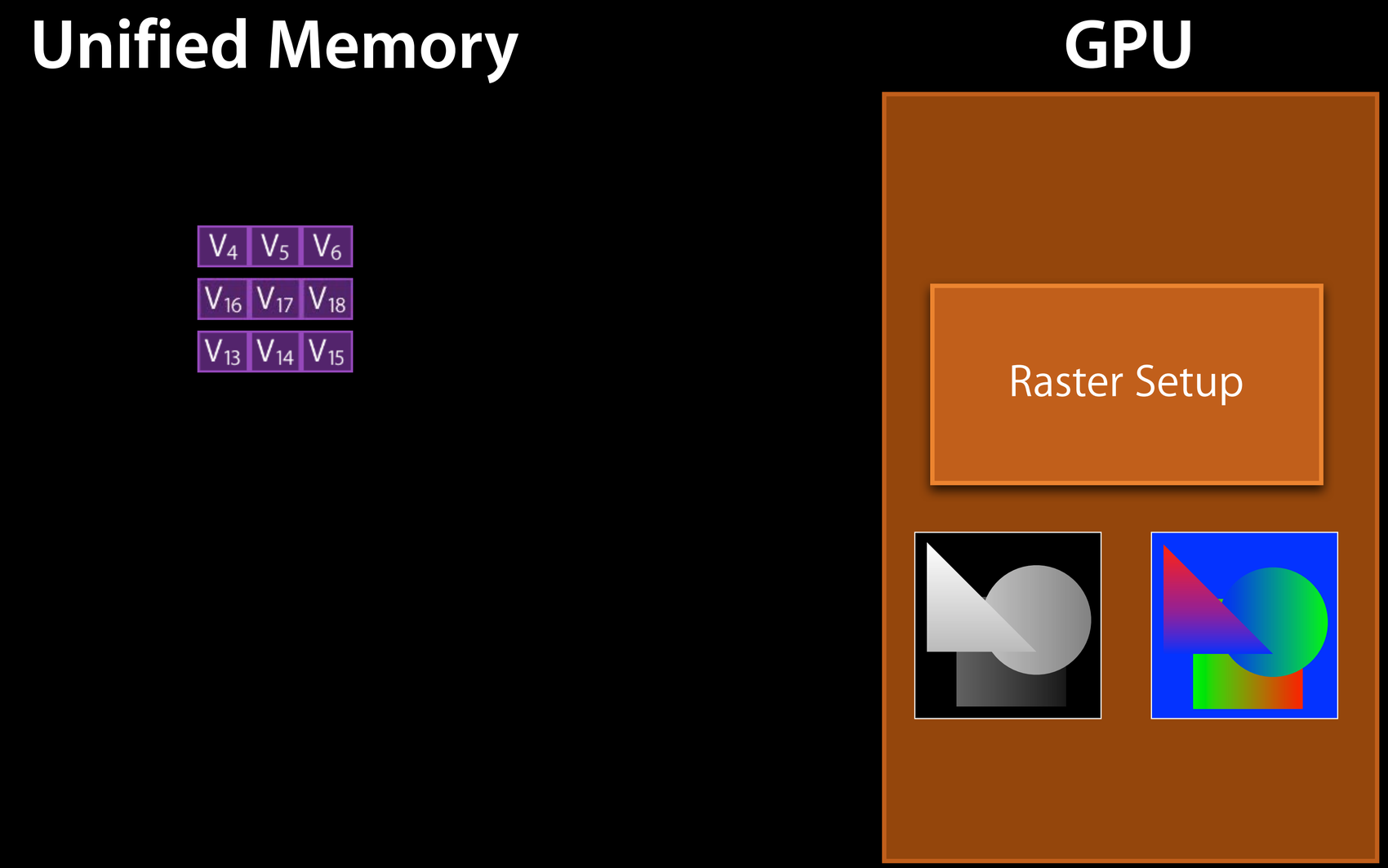
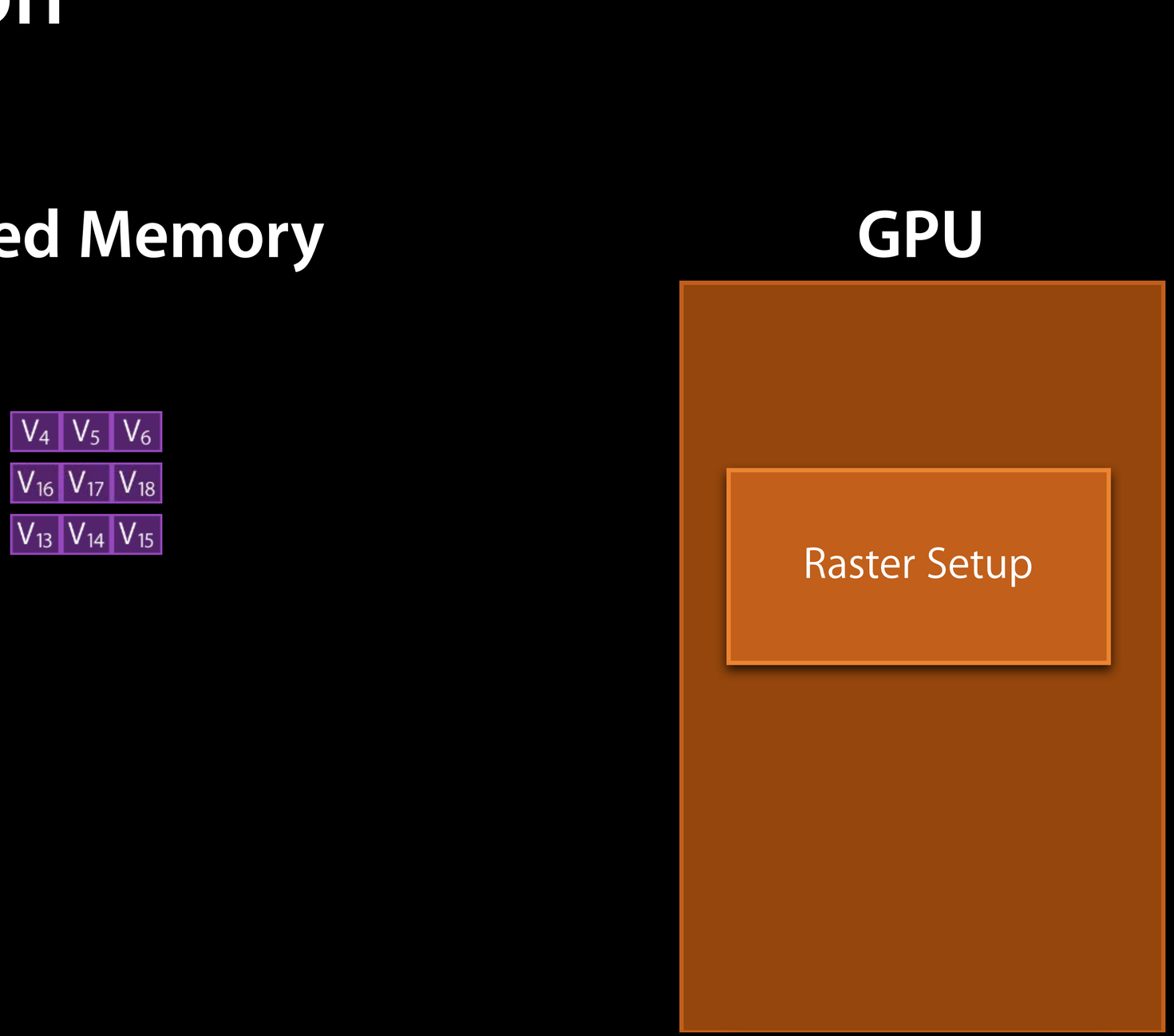


- Developers should avoid frequent switching of renderbuffers
  - Complete rendering to one buffer before switching to another



Rasterization



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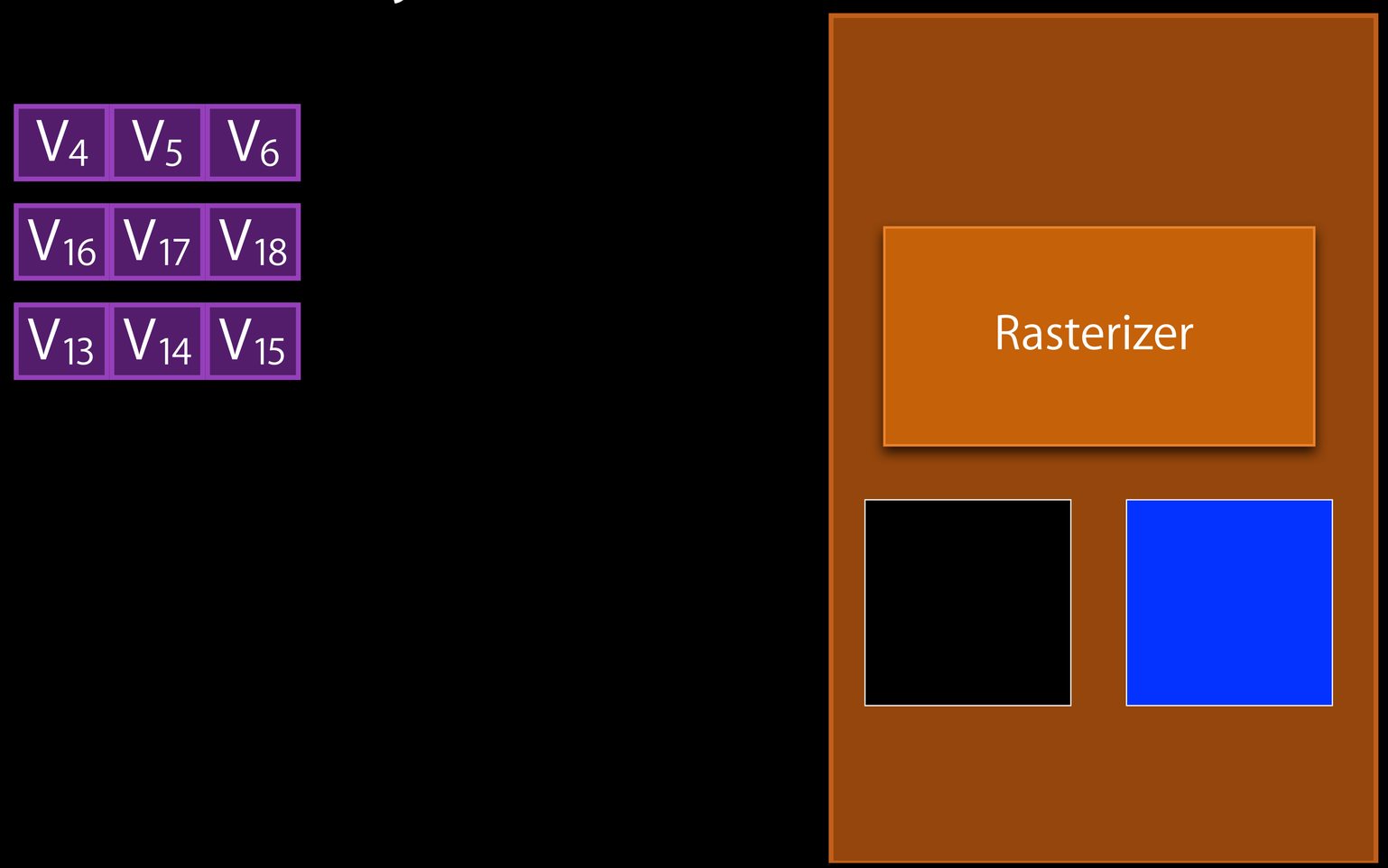
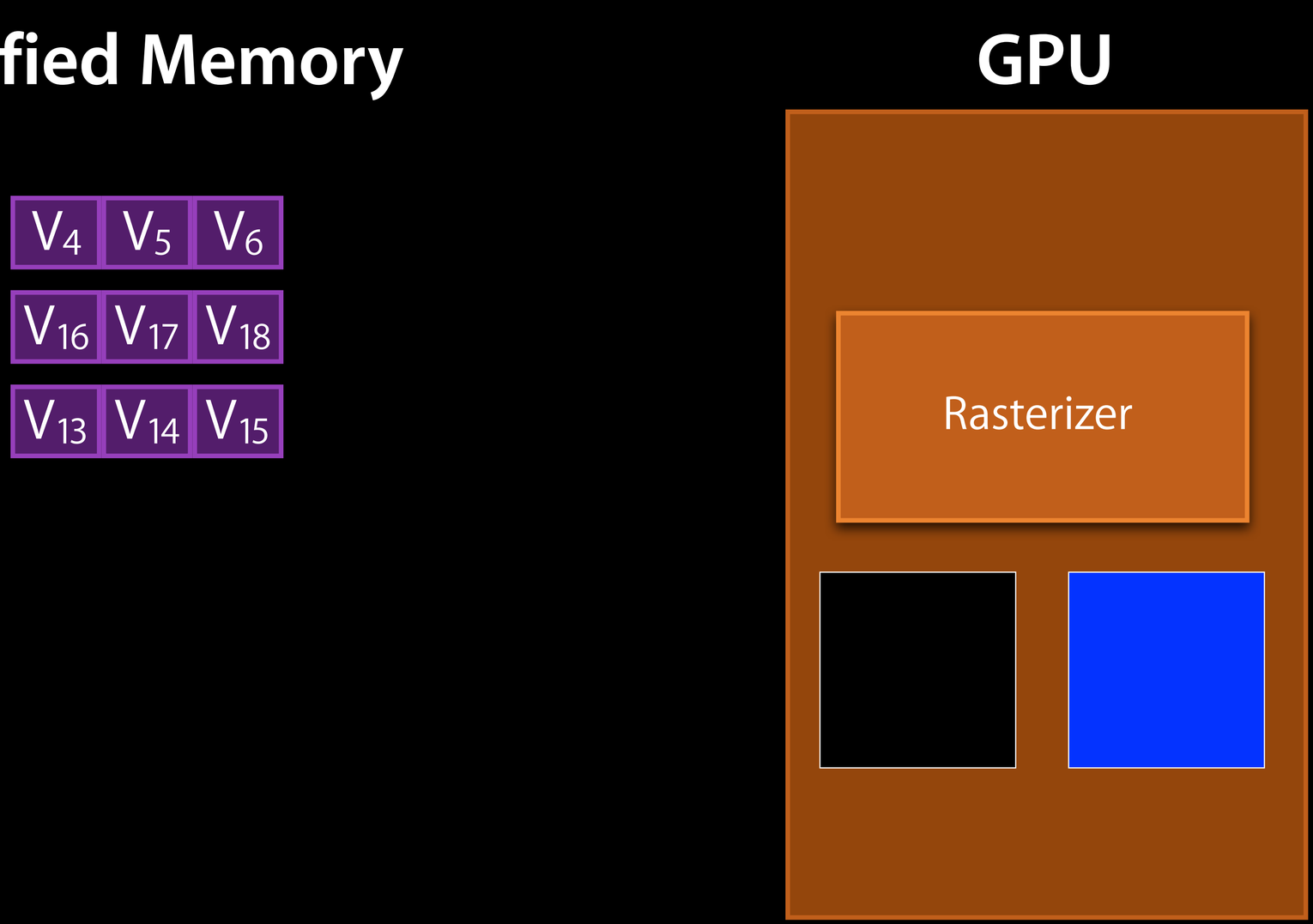


- GPU reads triangles assigned to tile
  - XY pixel coordinates and Z values generated



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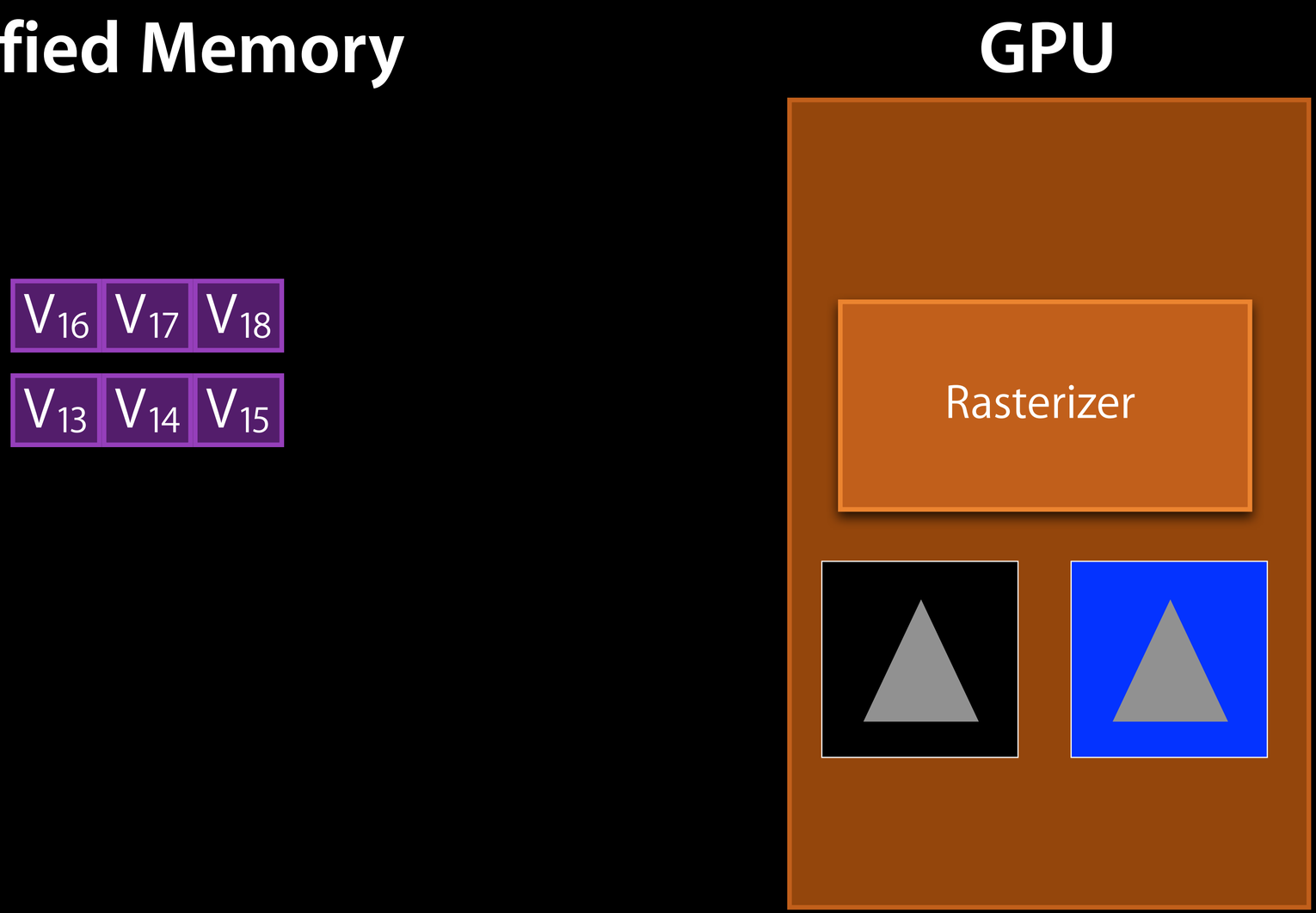
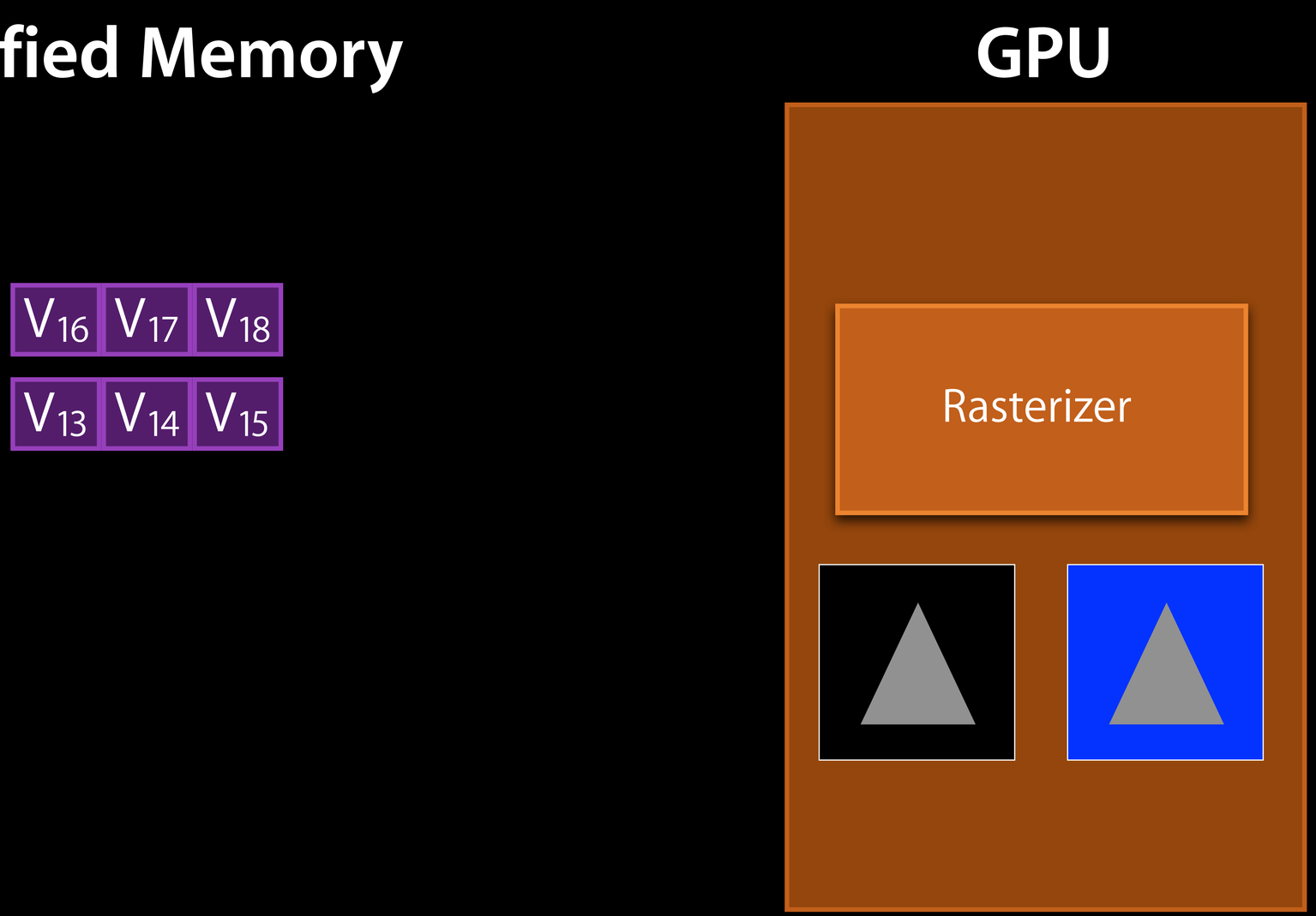
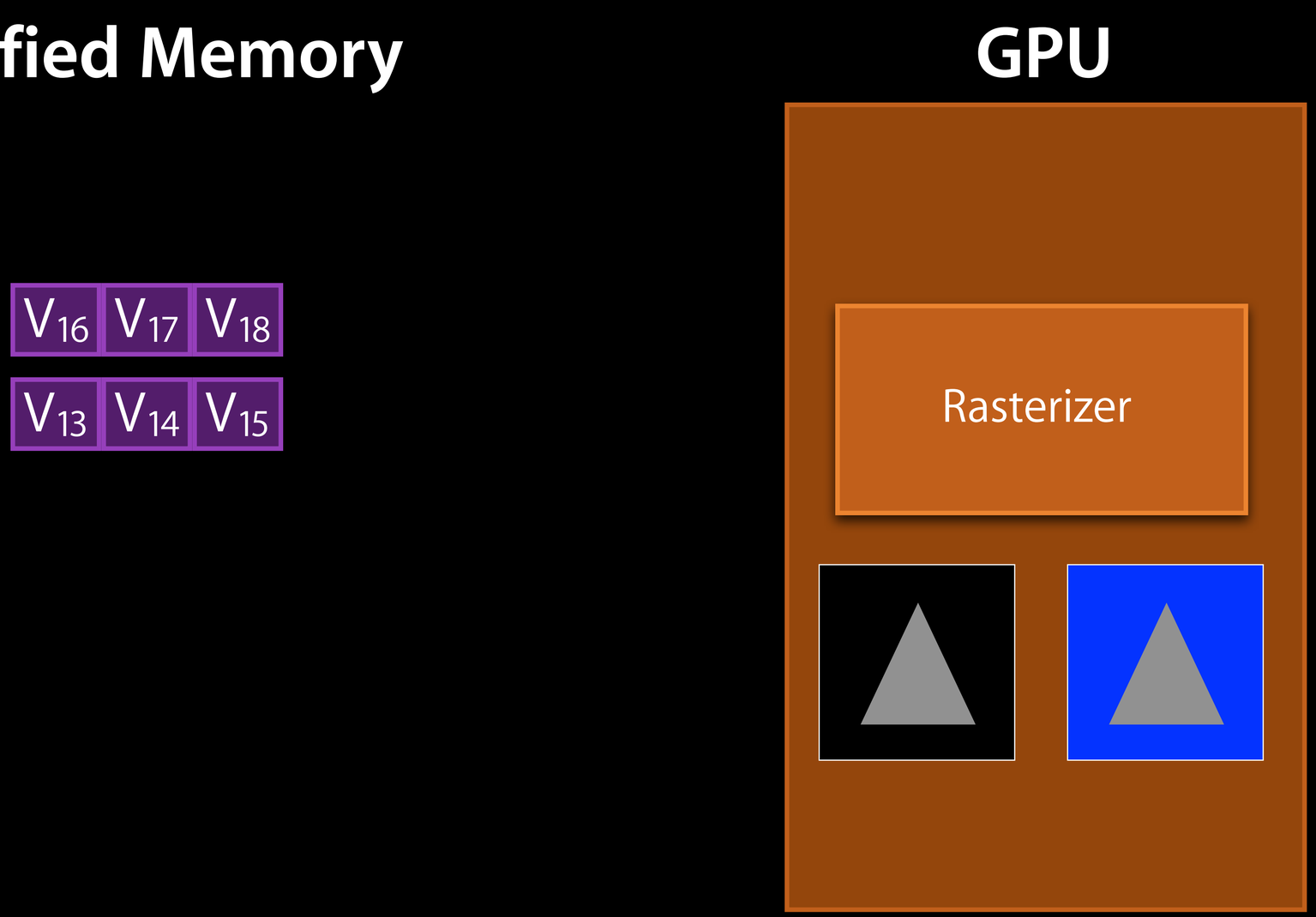


- Fragment shader not run yet
  - Positions and depth calculated only



- Hidden Surface Removal performed
  - GPU can reject fragments before shading them



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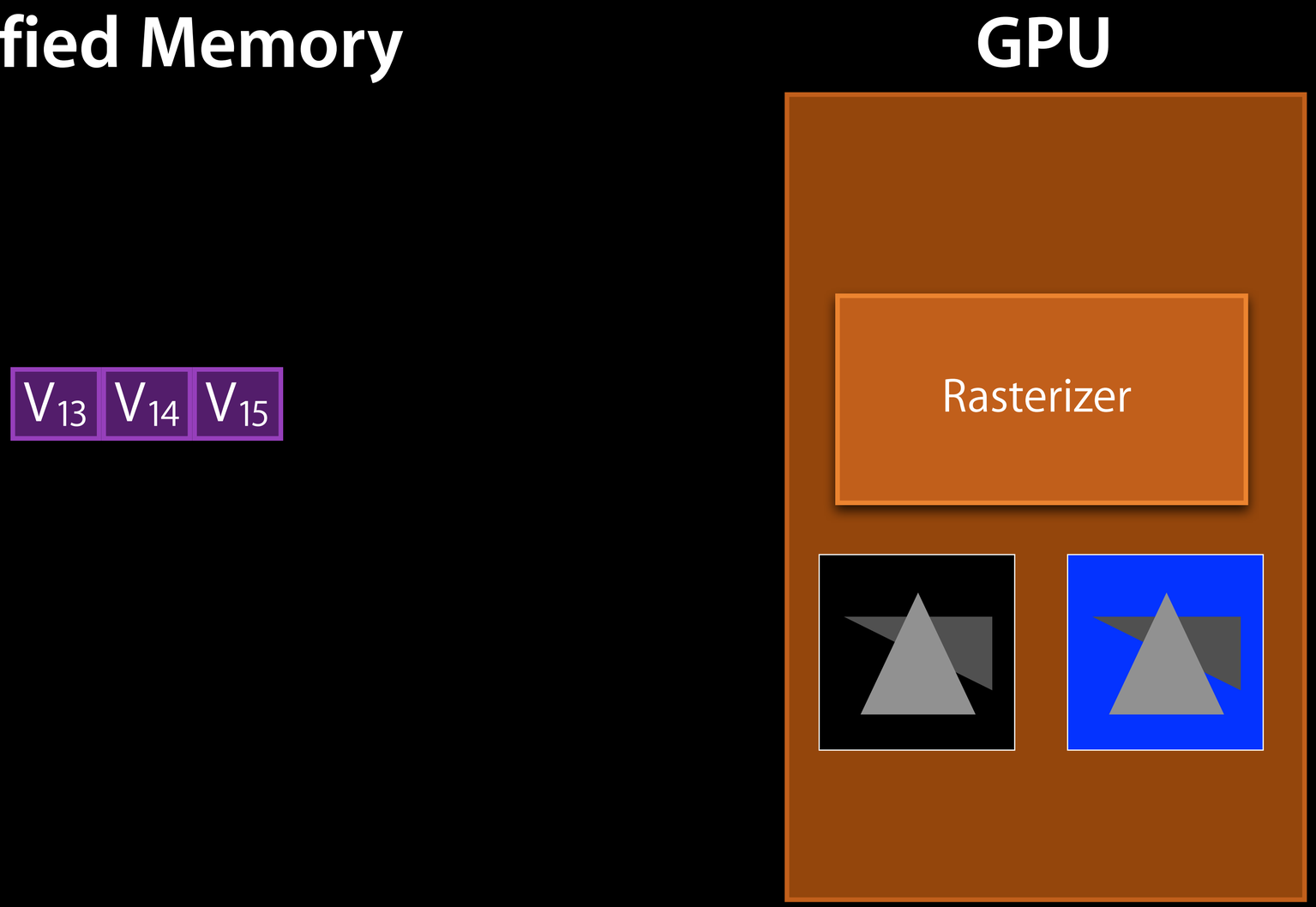
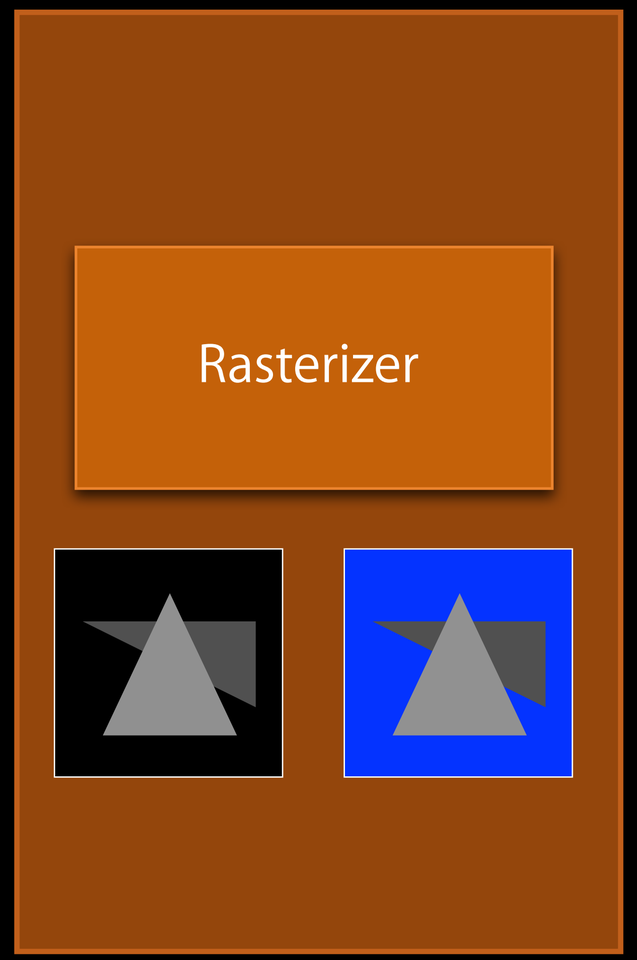


- Triangles of entire frame are present
  - Allows many fragments to be rejected

Unified Memory

GPU



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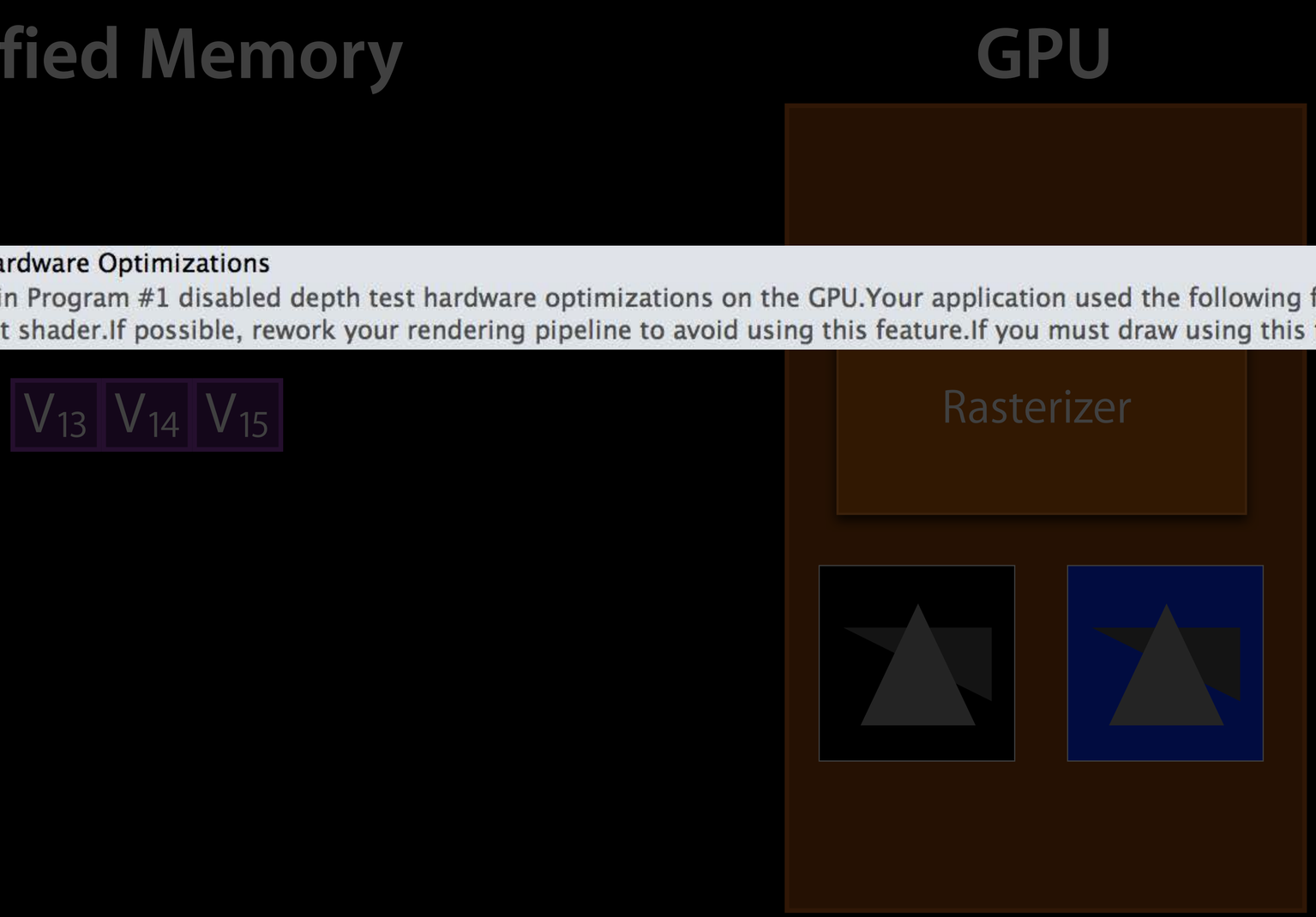
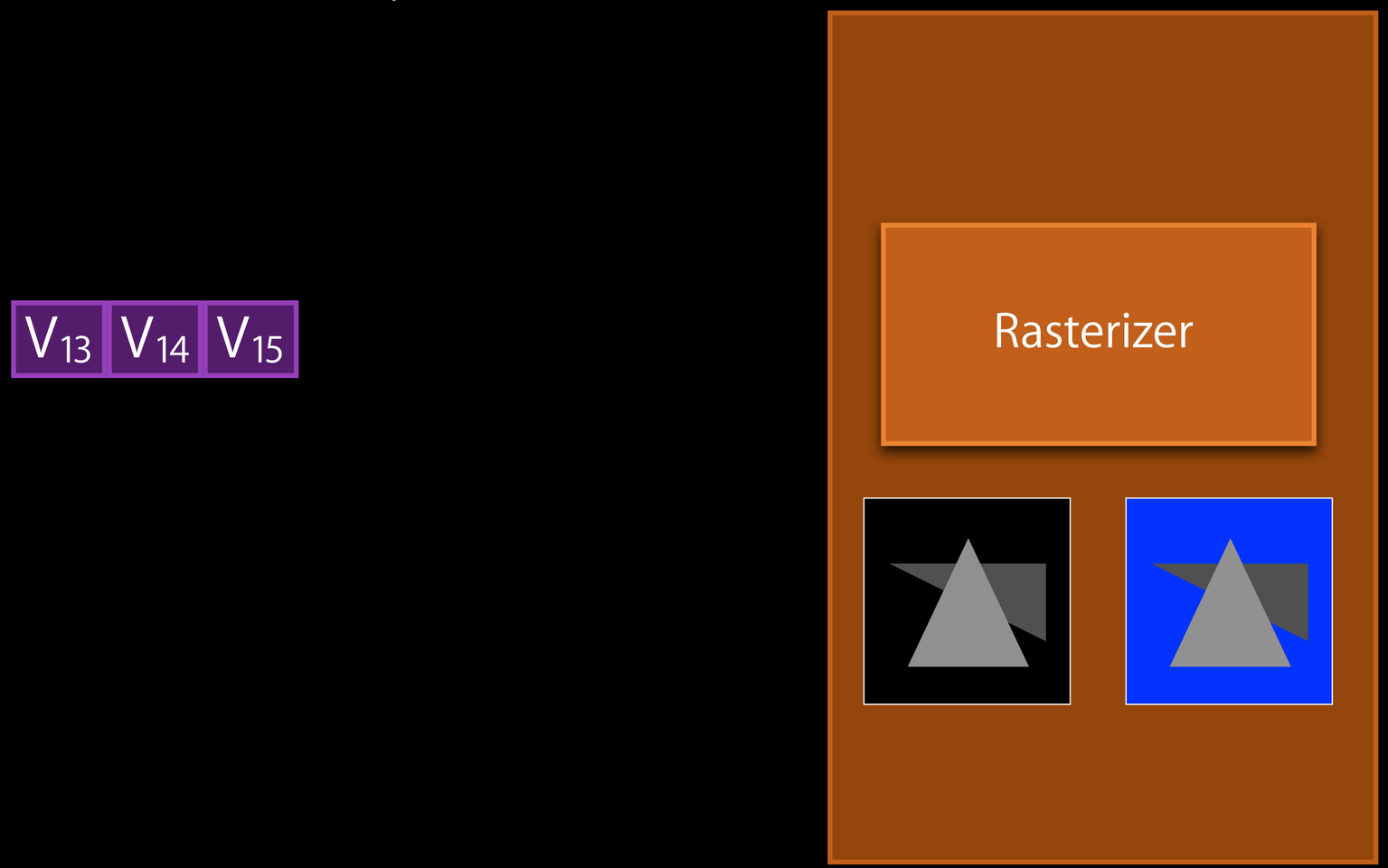


- Costly to enable blending or use `discard` in shader
  - Defeats the Hidden Surface Removal optimization



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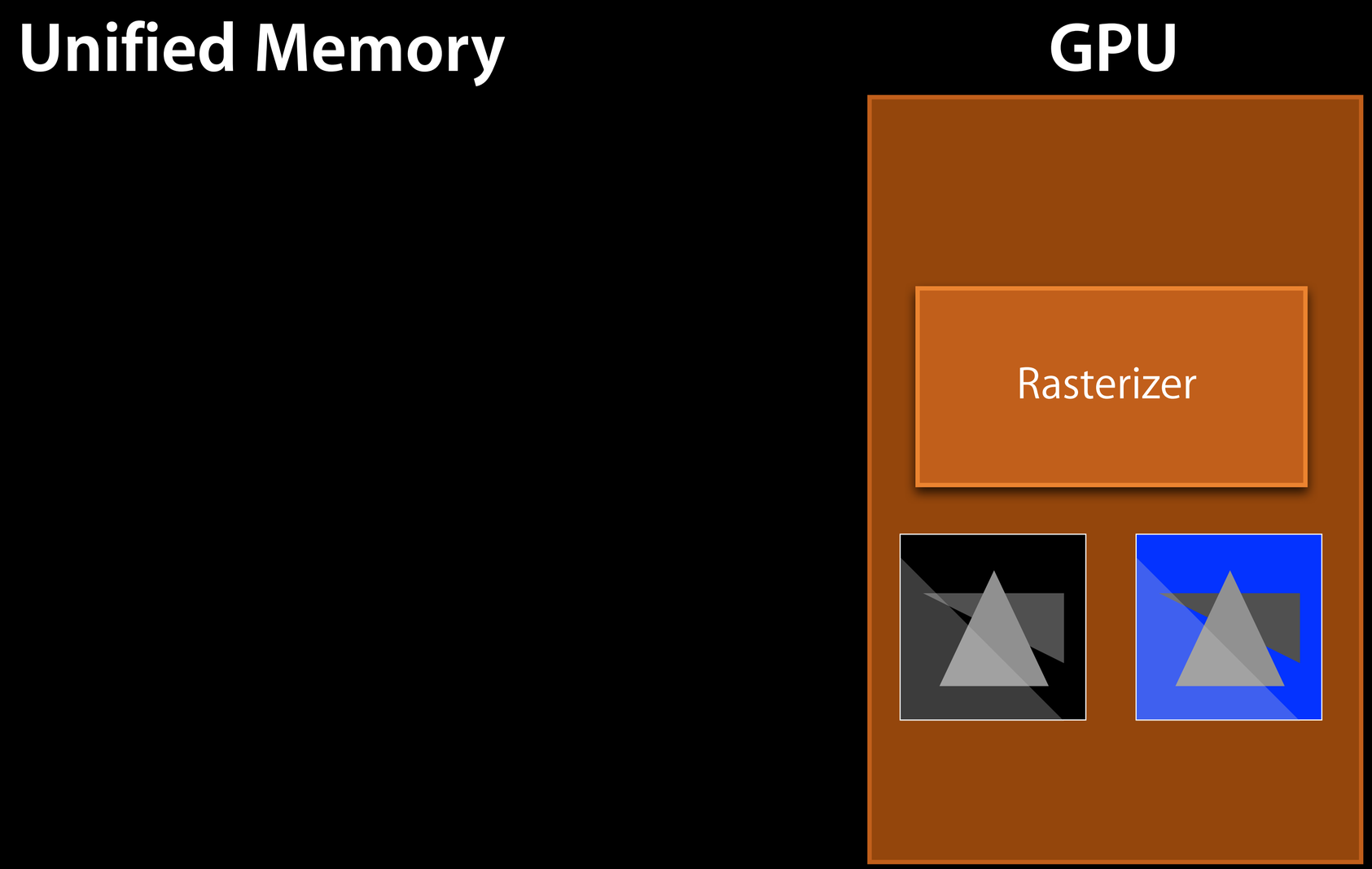
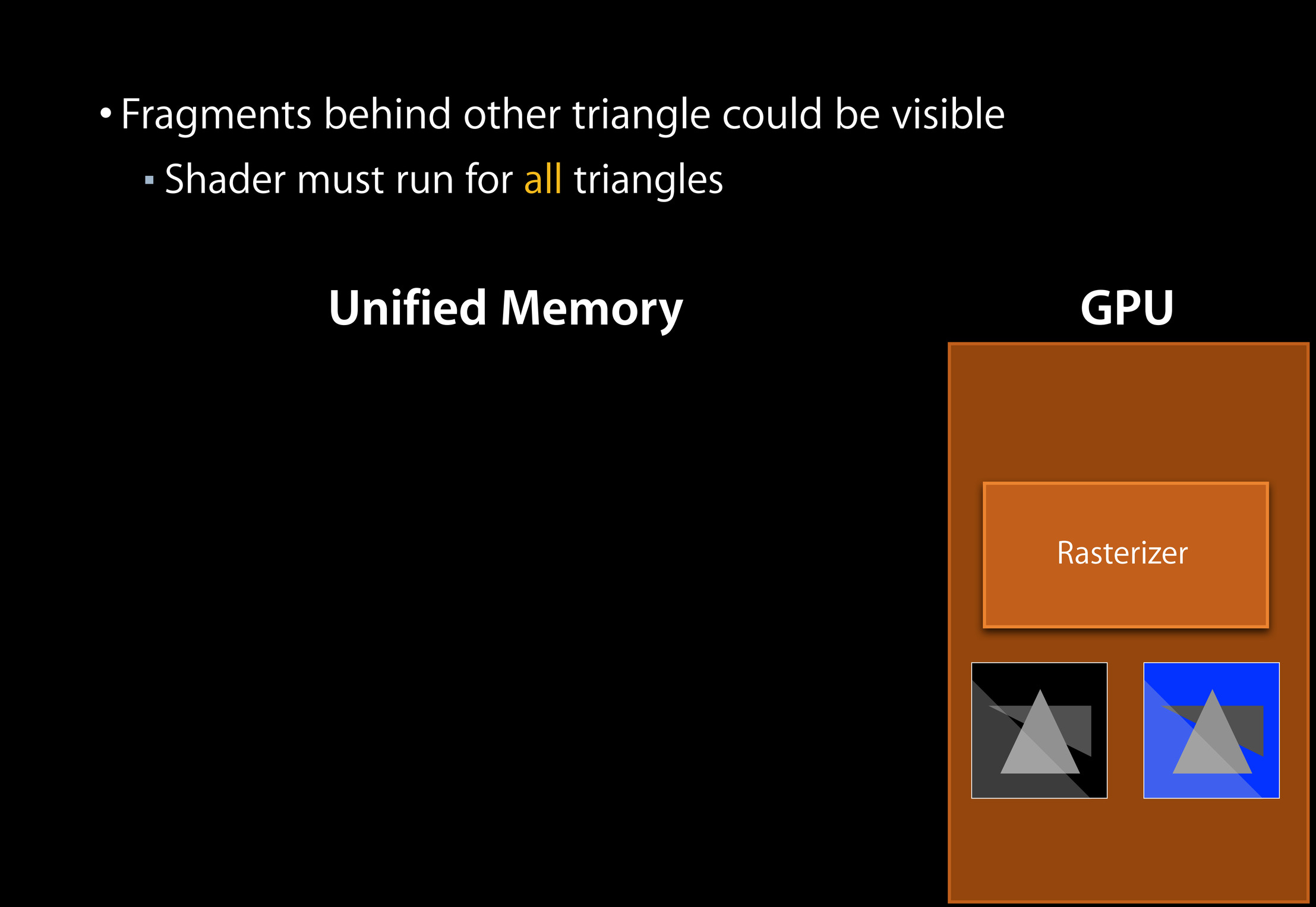


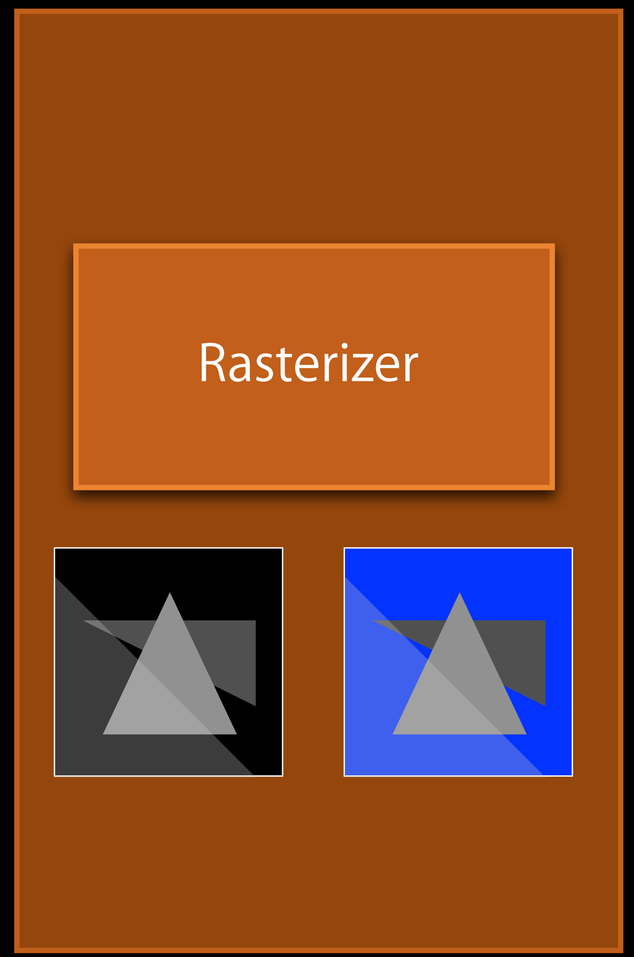
- Fragments behind other triangle could be visible
  - Shader must run for all triangles



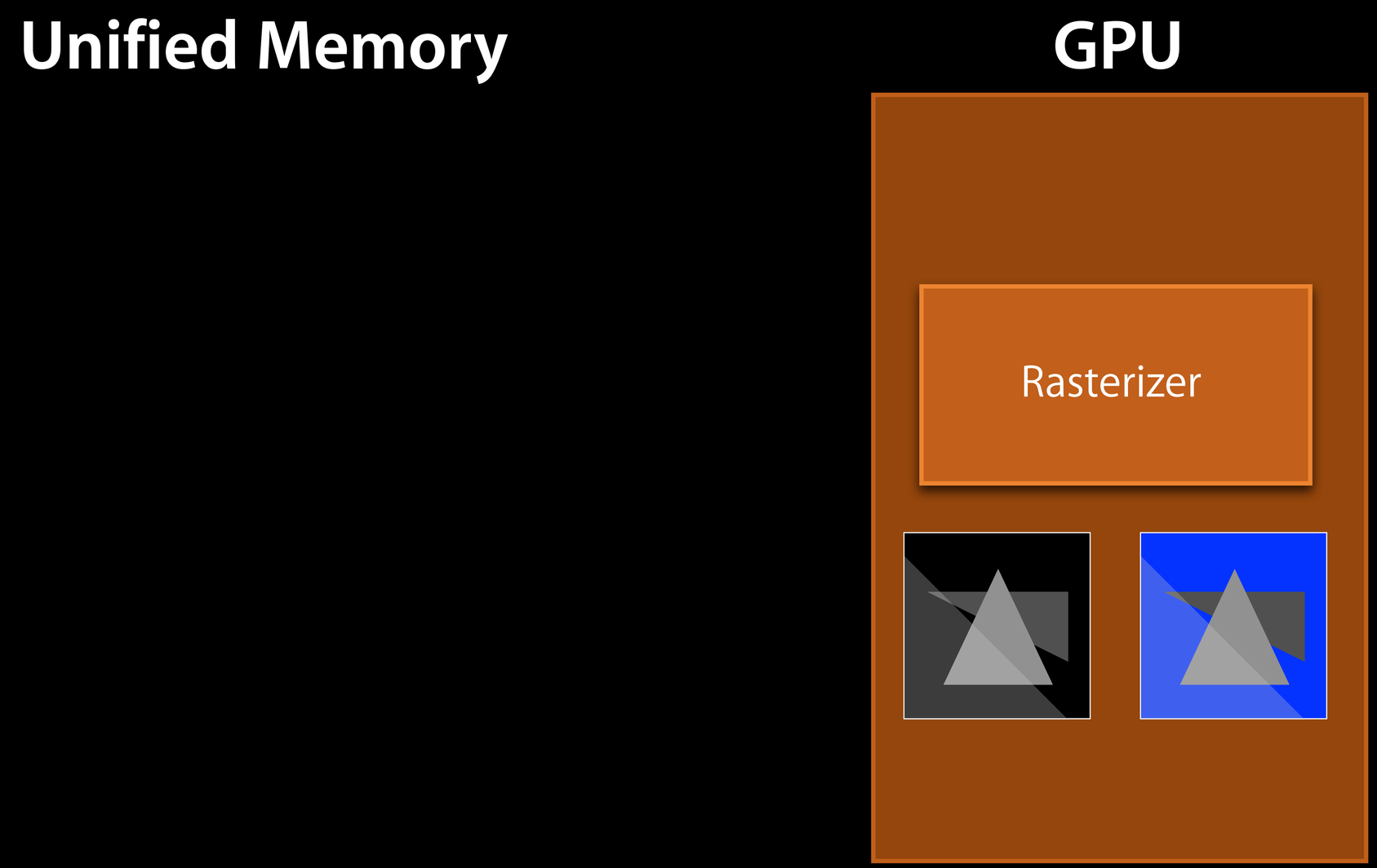
- No fragment shader savings without Hidden Surface Removal
  - Cost to performance and power

Unified Memory

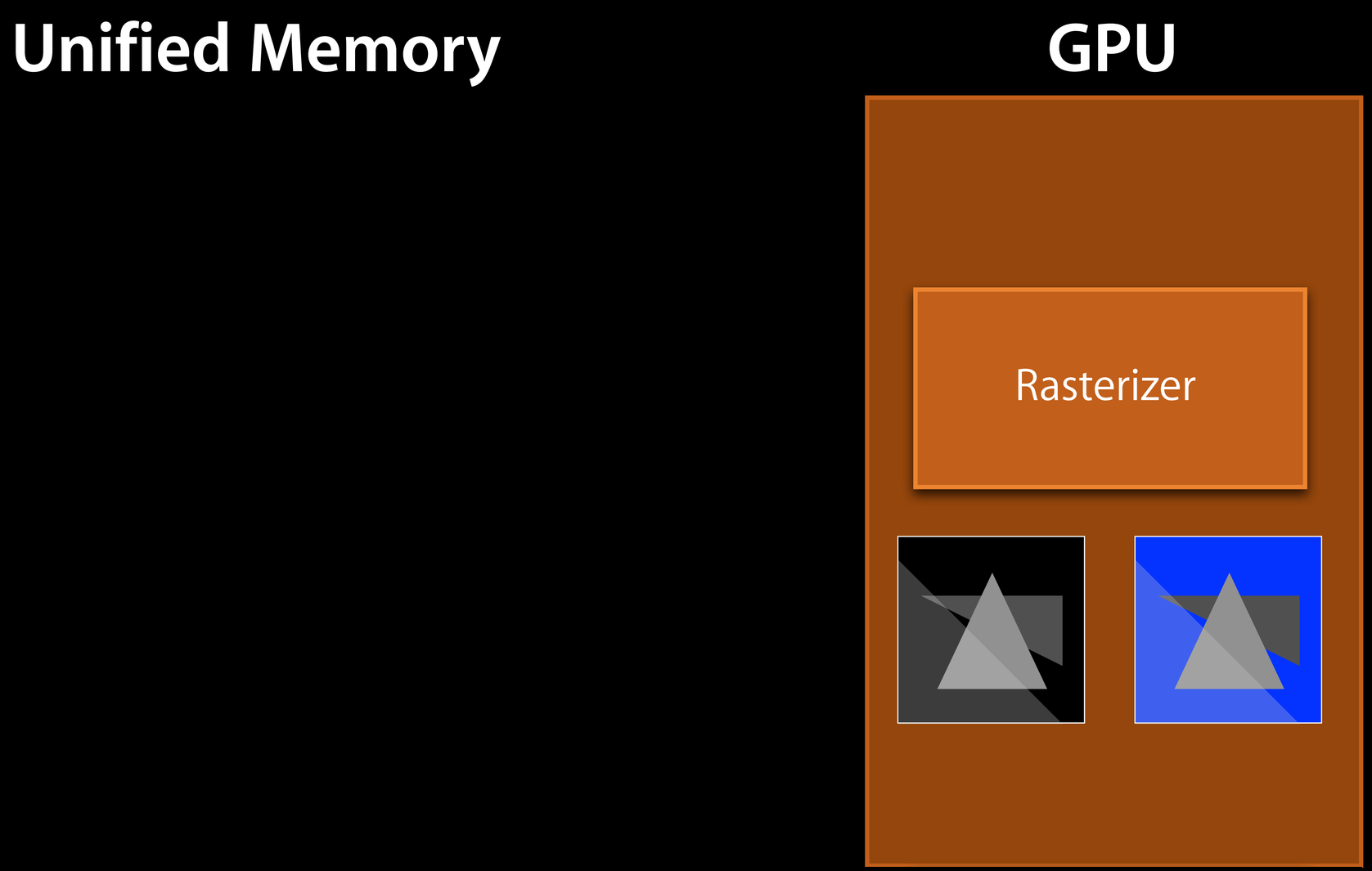
GPU



- Developers must be judicious of their use of `discard` and blending
  - Allow GPU to reject as many fragments as possible



Fragment Shading



Fragment Shading

Unified Memory

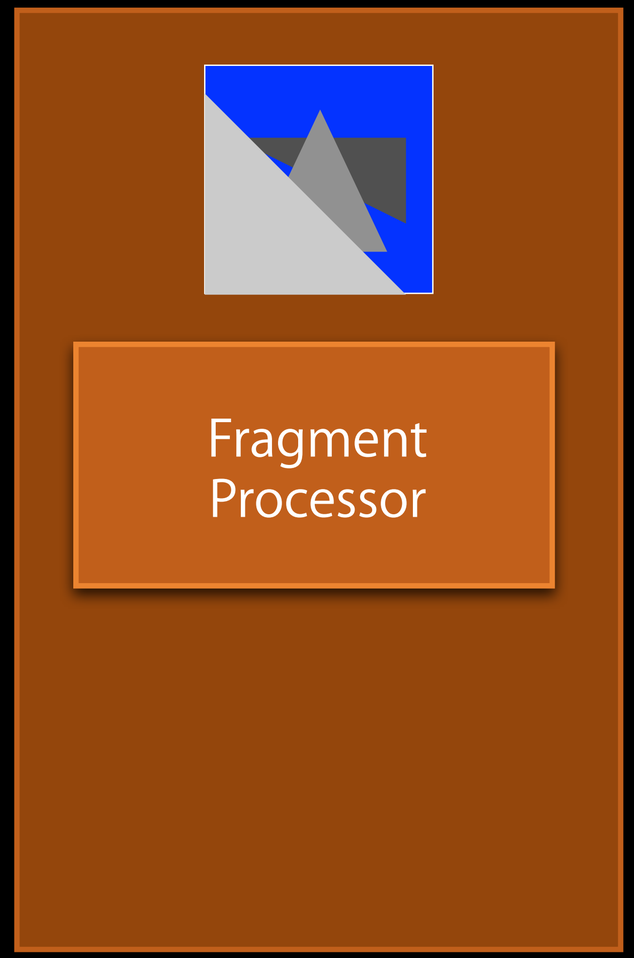
GPU

Fragment
Processor

- With Hidden Surface Removal algorithm
  - Only need to run fragment shader on each pixel once

Unified Memory

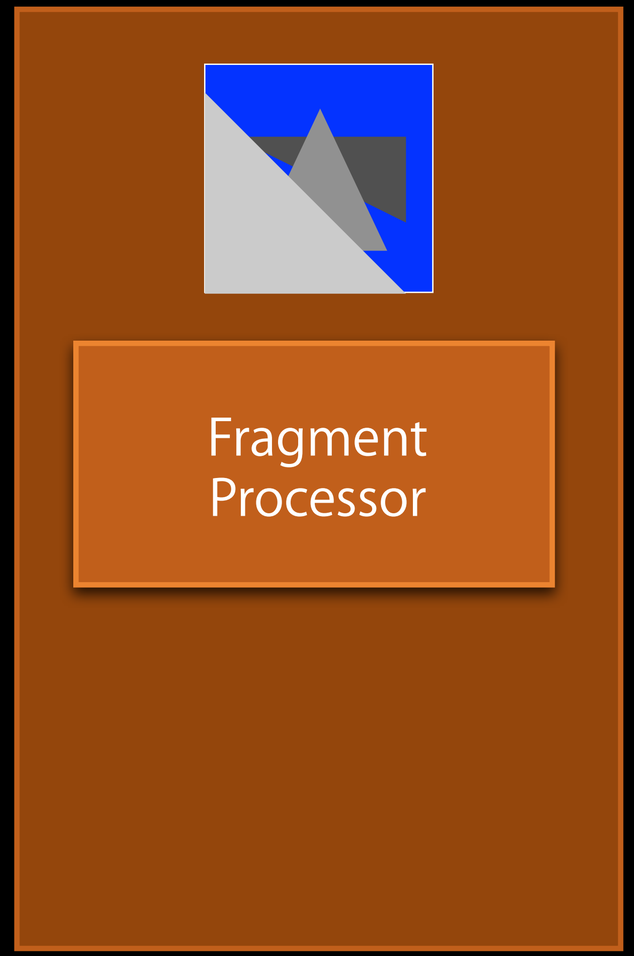
GPU



- Fragment processor shades and produces colored pixels
- Colors written to embedded tile memory on GPU

Unified Memory

GPU



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Unified Memory

GPU

Fragment Processor

Tile Storage

Unified Memory

GPU

Fragment Processor

Tile Storage

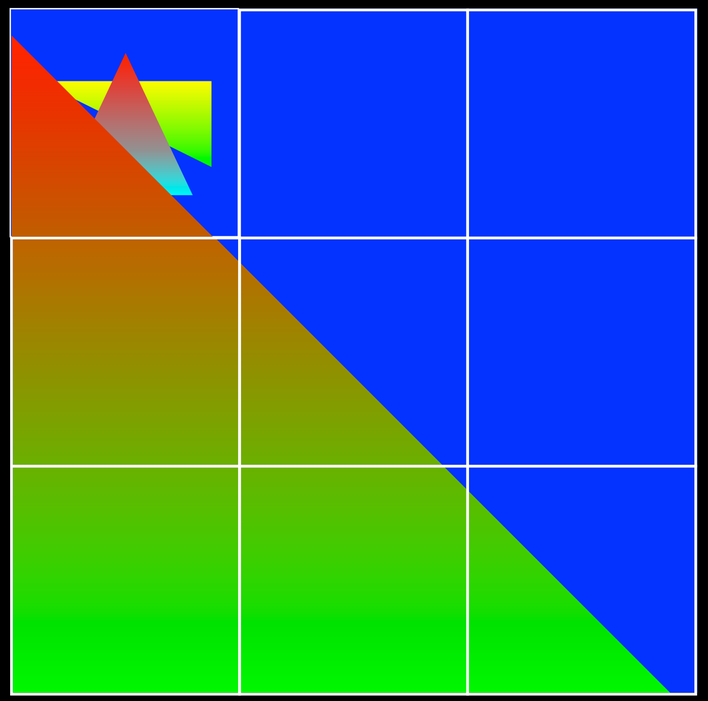
Unified Memory

GPU

Tile Store

Tile Storage

Unified Memory

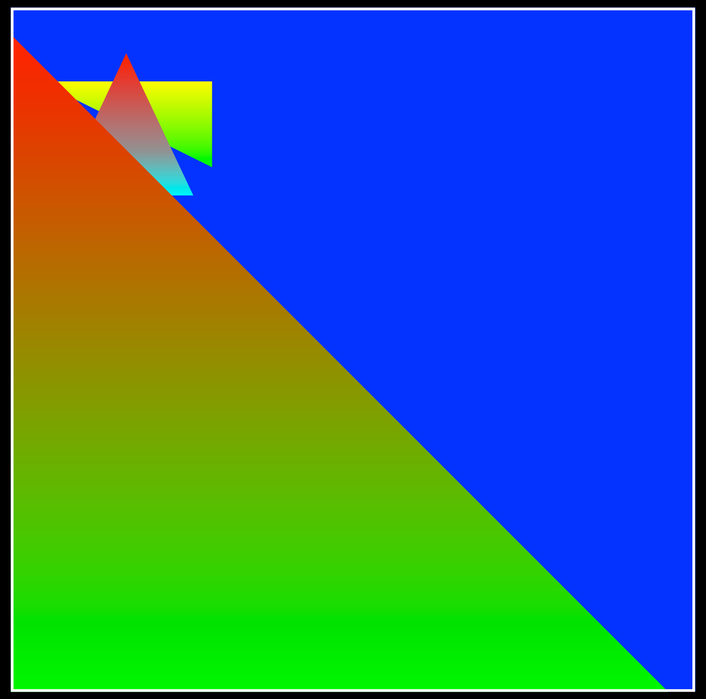


GPU

Tile Store

- Tile stored in unified memory
- Once all tiles processed, renderbuffer is ready for use

Unified Memory

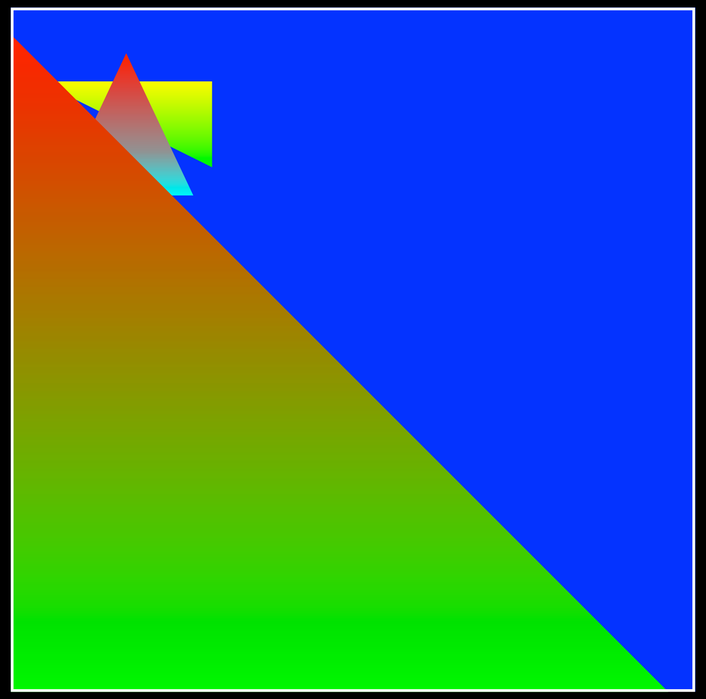


GPU

Tile Store

- Storing tile to unified memory called Logical Buffer Store
- Each frame needs at least one

Unified Memory



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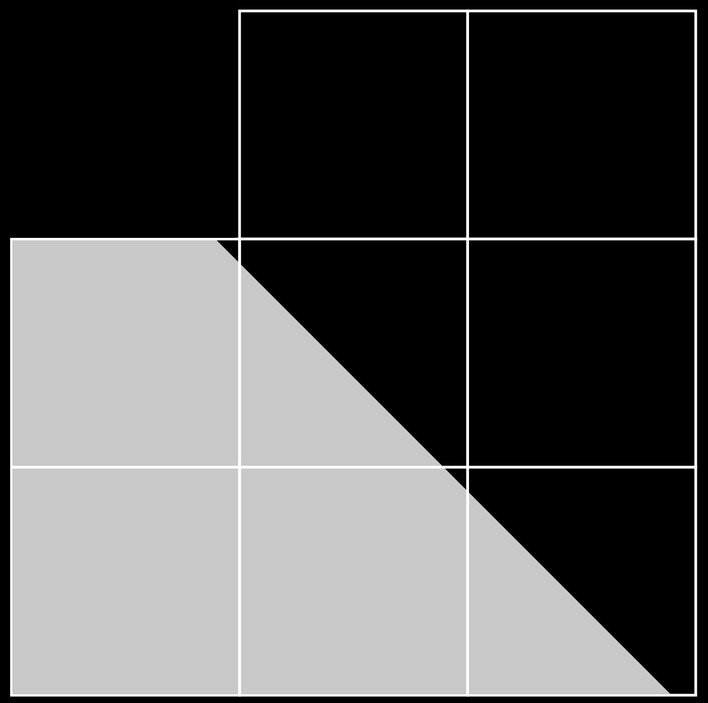
- Depth only needs to be stored for depth texture effects
  - Such as shadowing or Screen Space Ambient Occlusion



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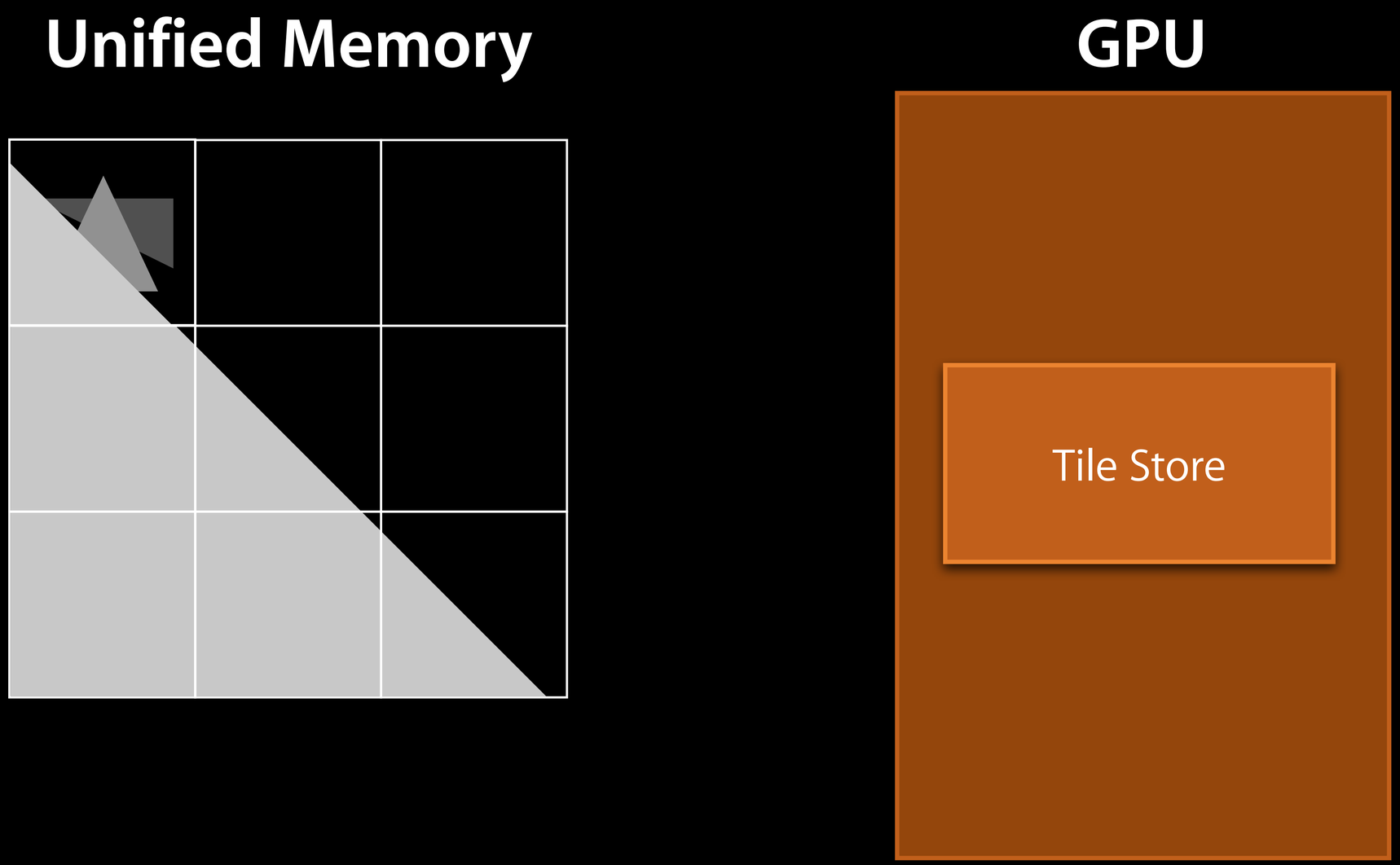
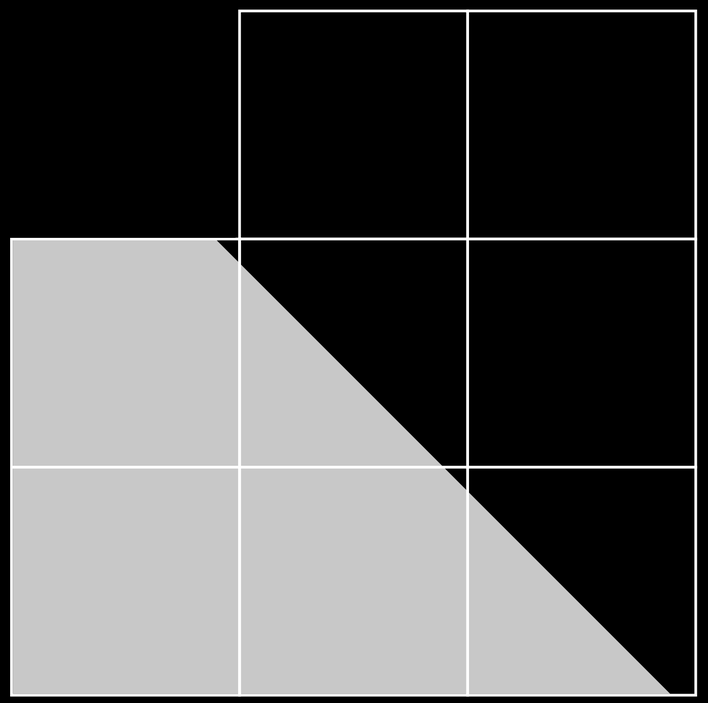


- Unless using such effect
  - Depth buffer storage unnecessary

Unified Memory



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- Developers can call `glDiscardFramebufferEXT` to skip Logical Buffer Store
- Depth buffer tile discarded after rendering complete

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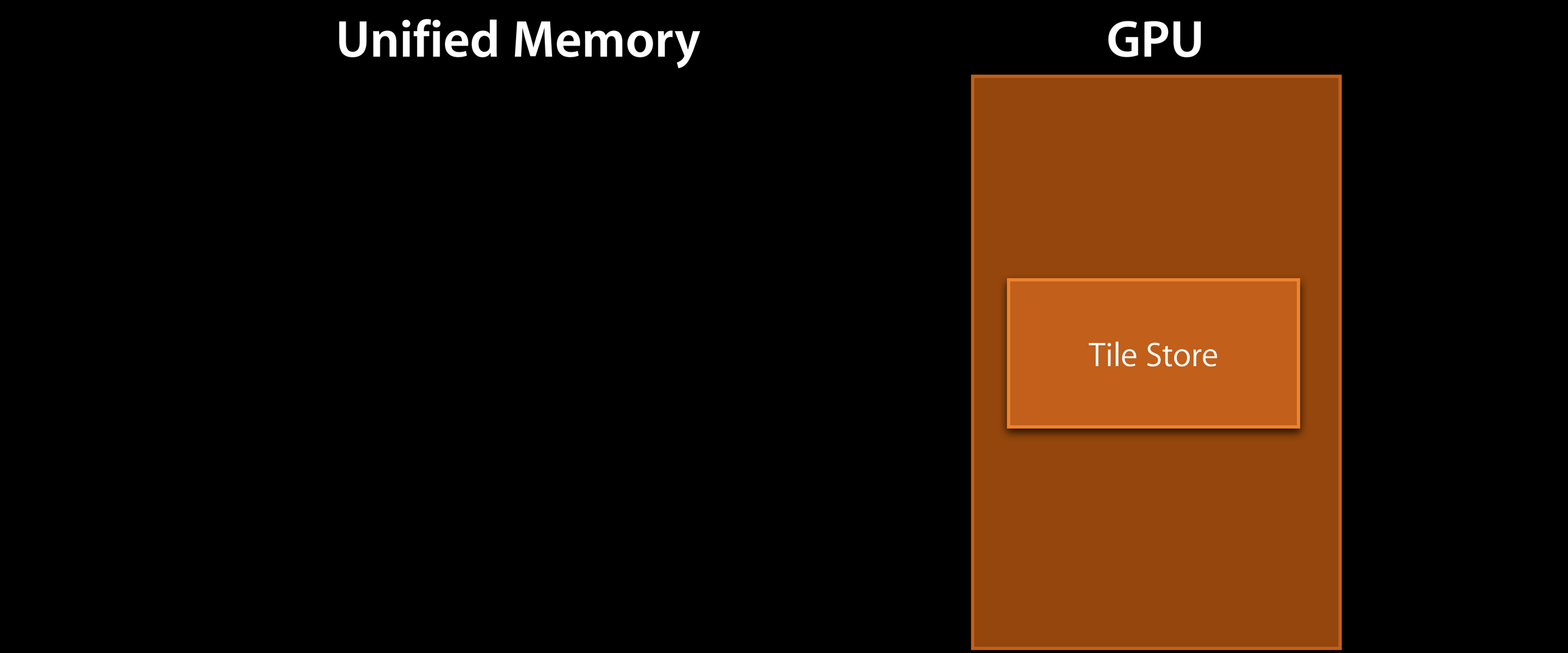
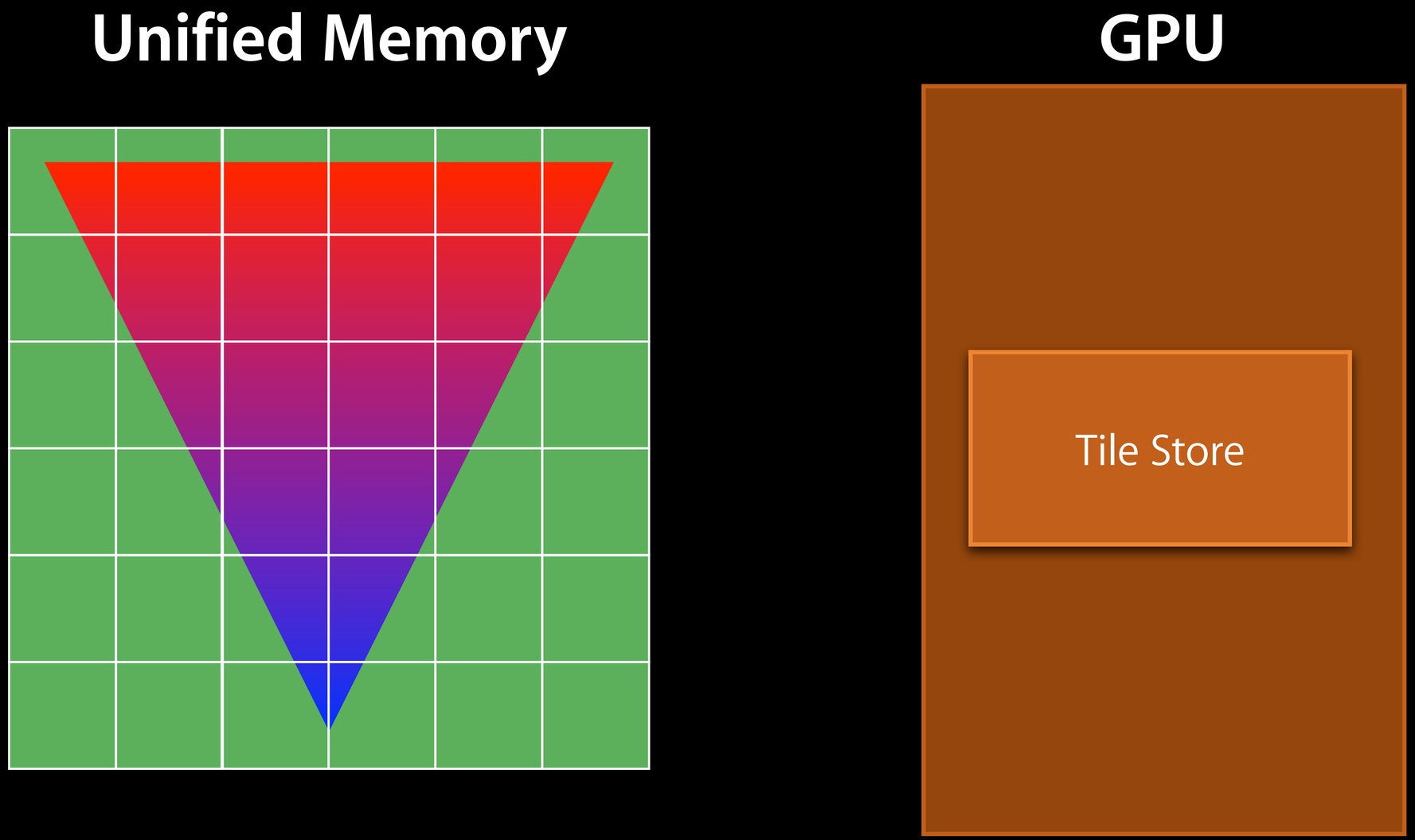
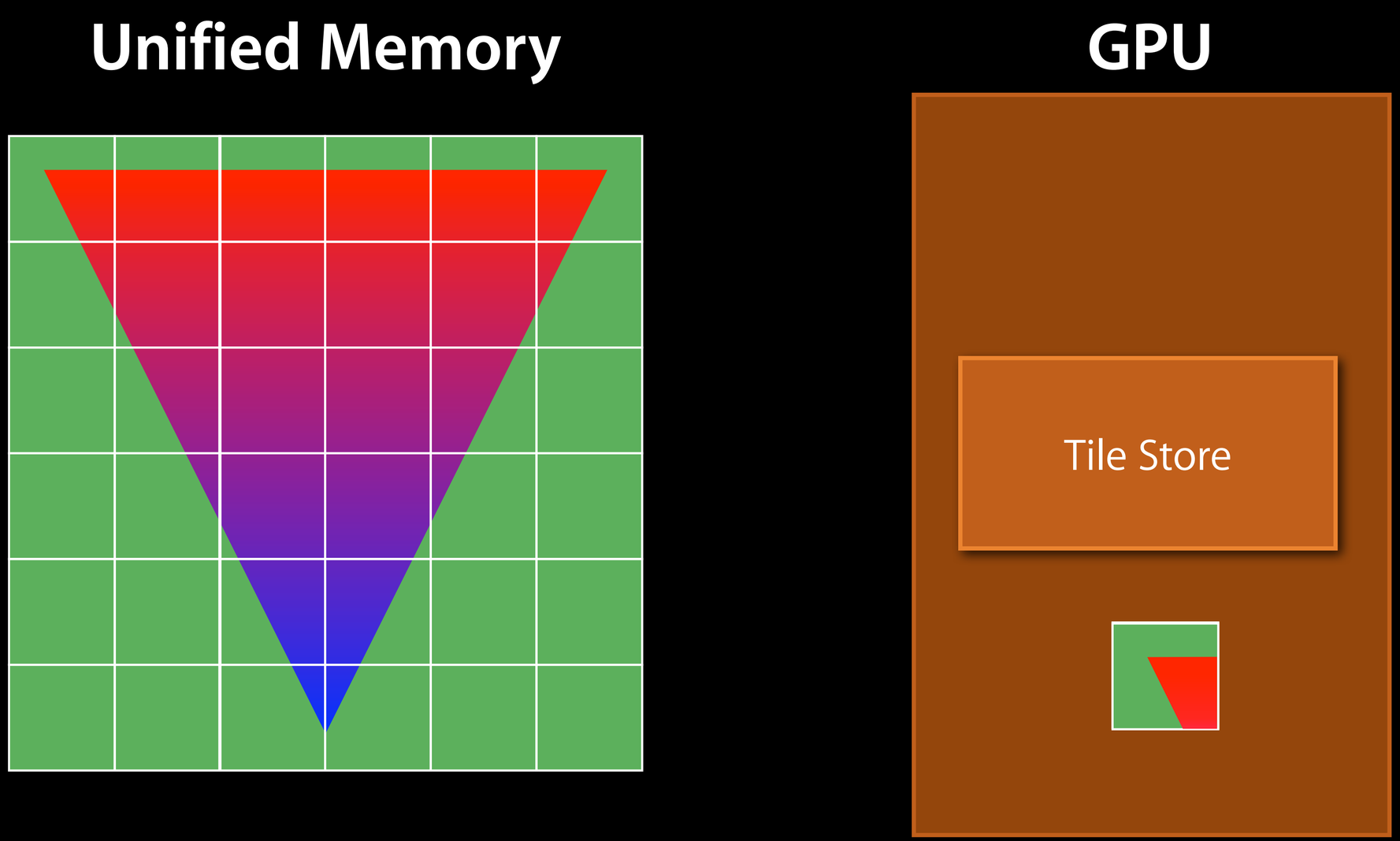


- Multisample anti-aliased renderbuffers have many more tiles
  - Developers do not need to store preresolved MSAA renderbuffer



- Only need color buffer MSAA buffer has been resolved to



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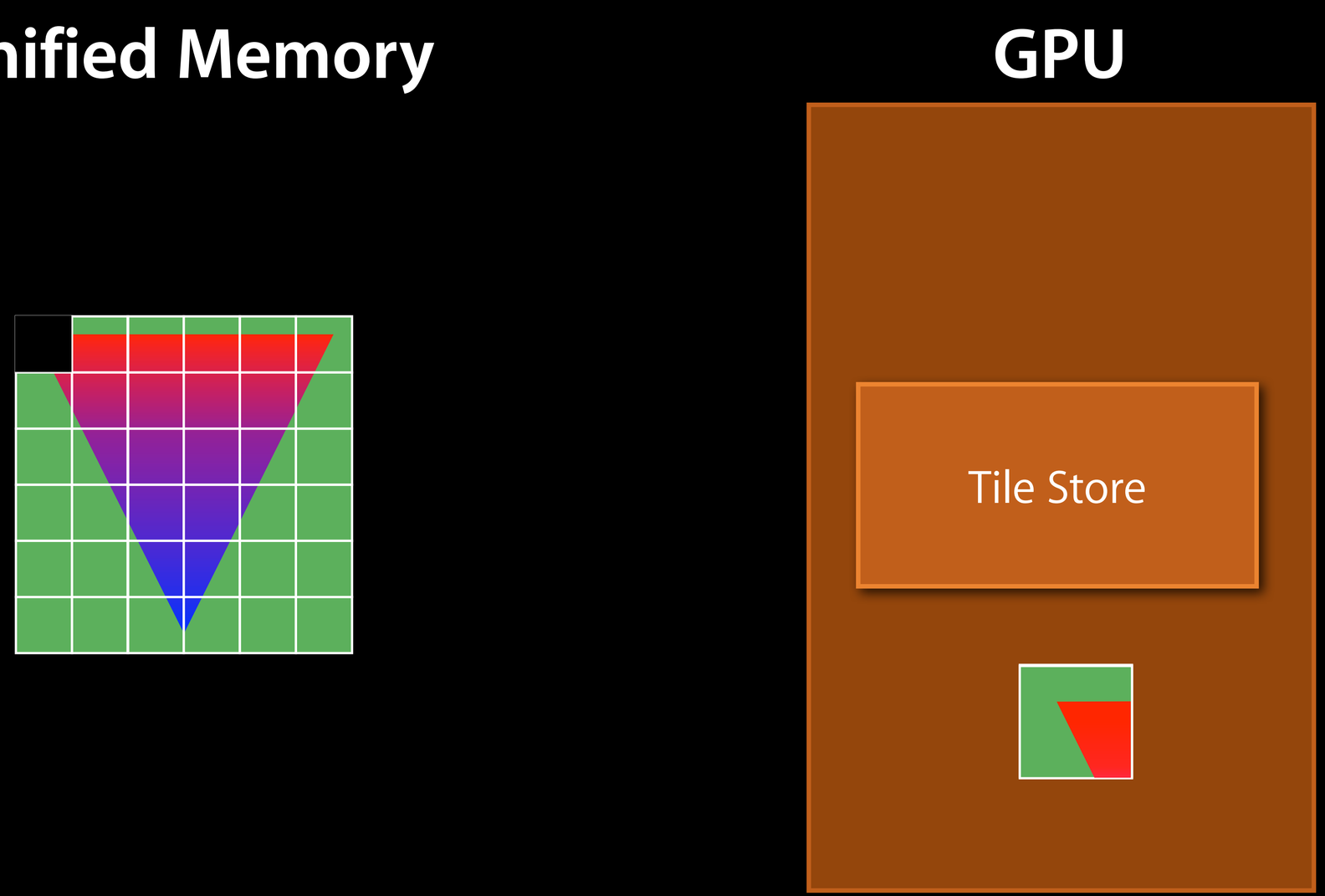

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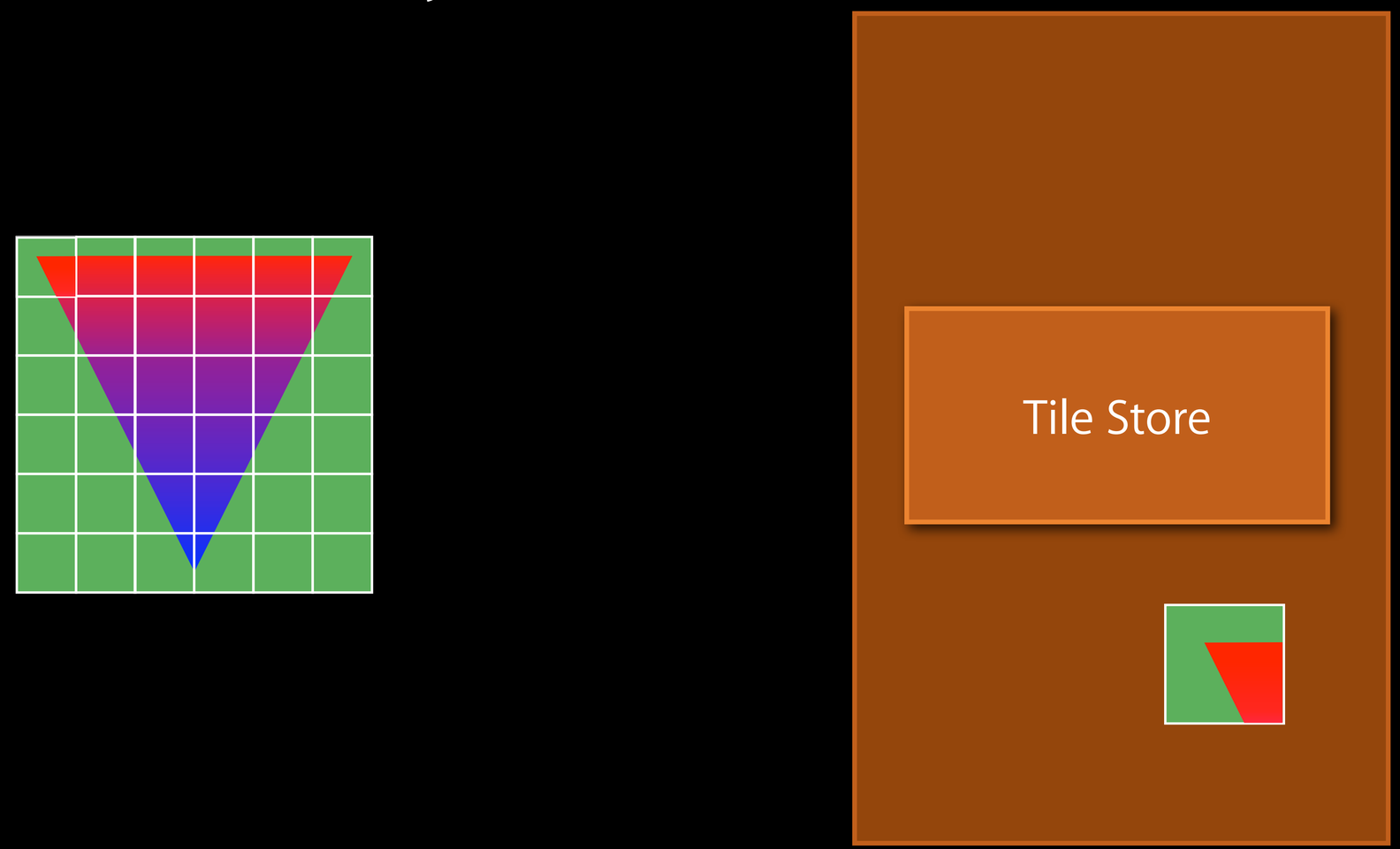
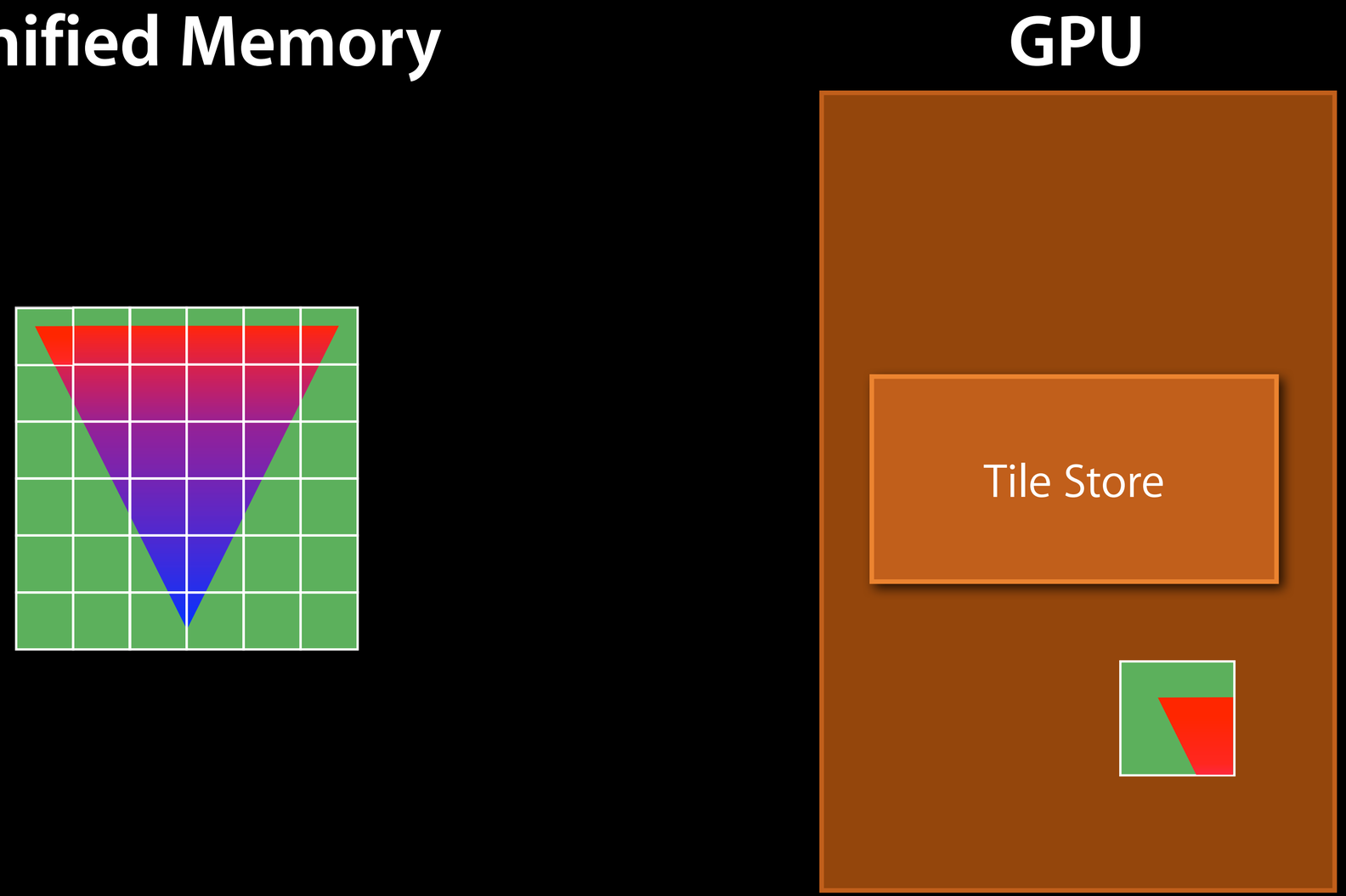


- Only need color buffer MSAA buffer has been resolved to
  - Call `glDiscardFramebufferEXT` on MSAA color buffer



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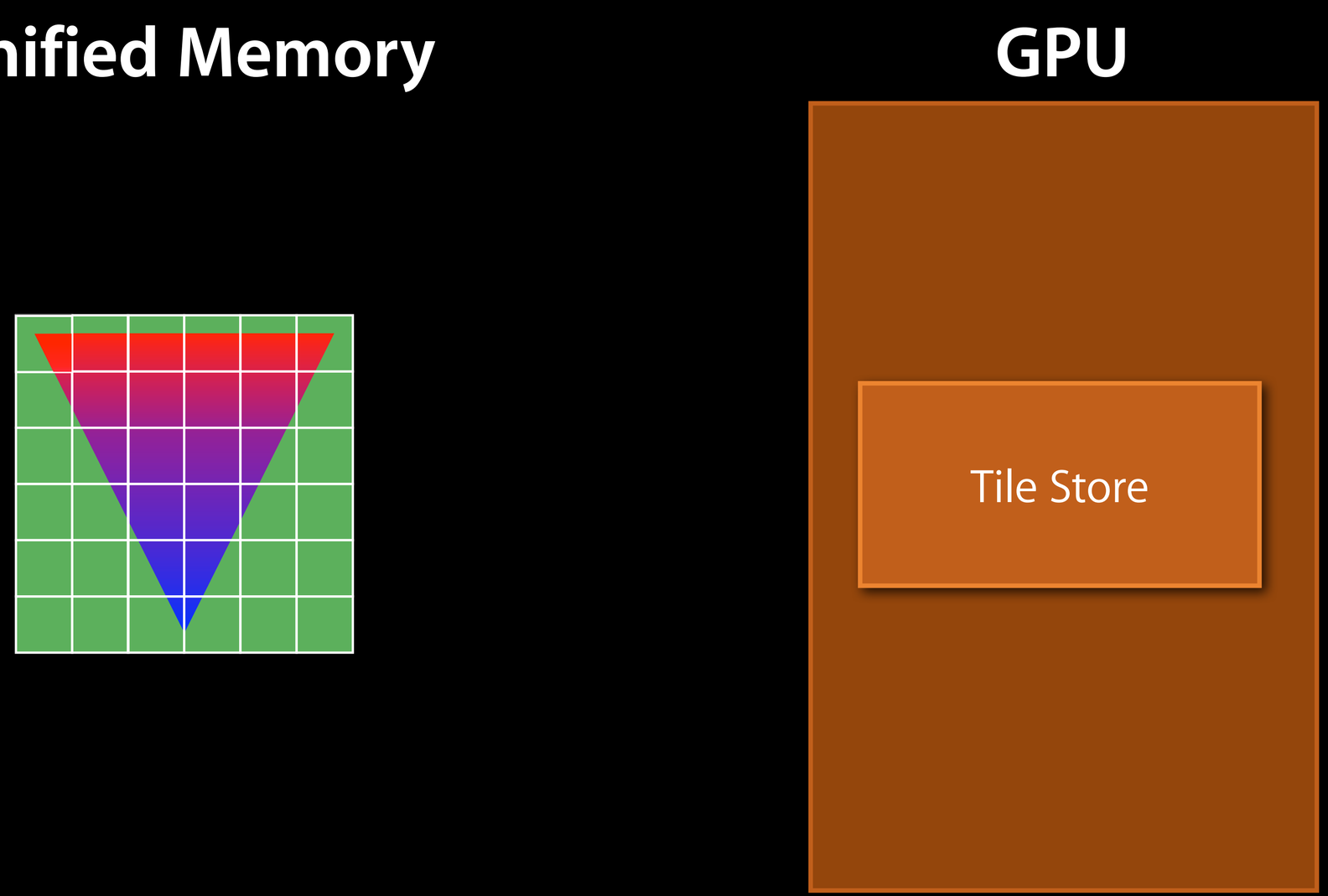

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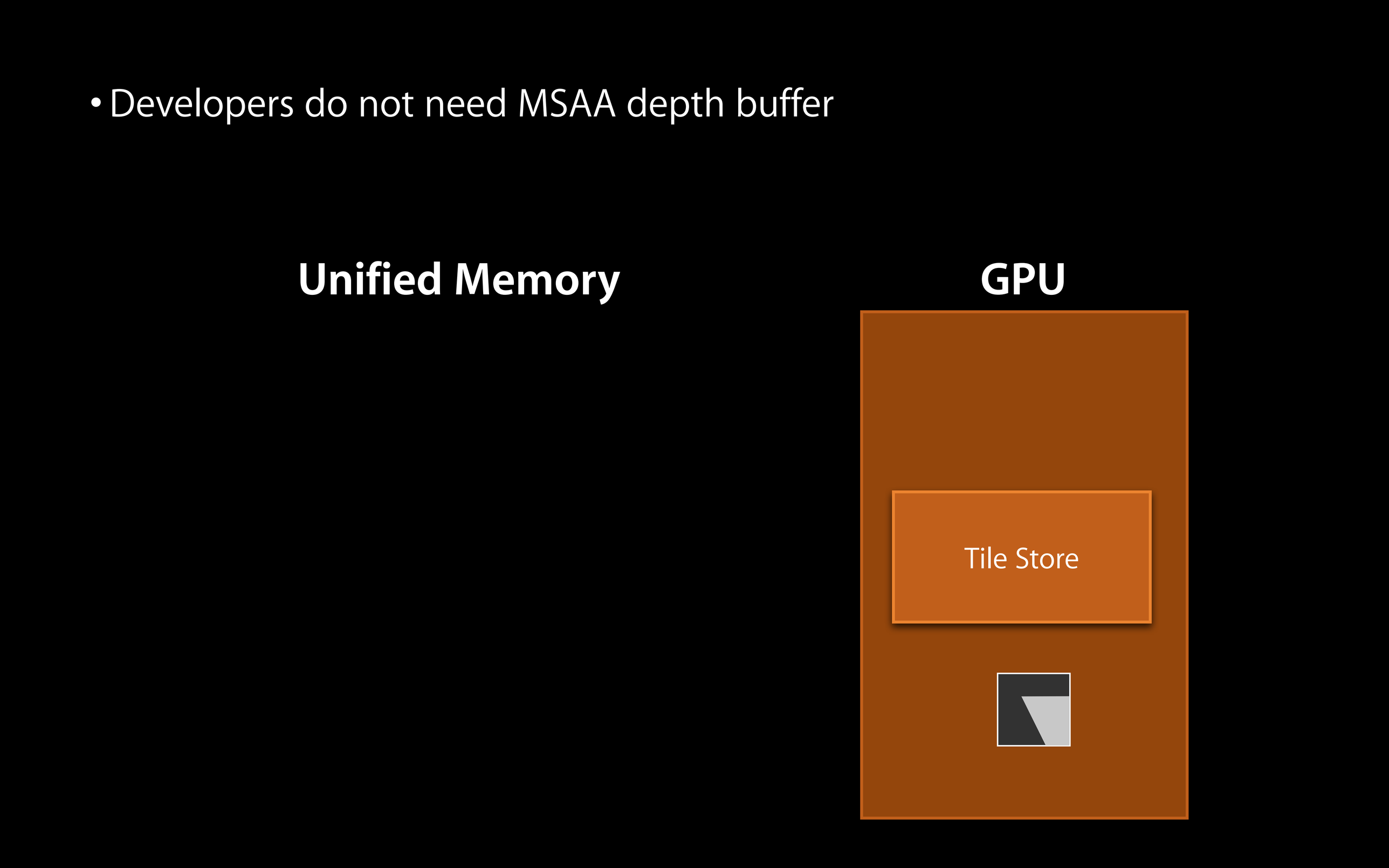
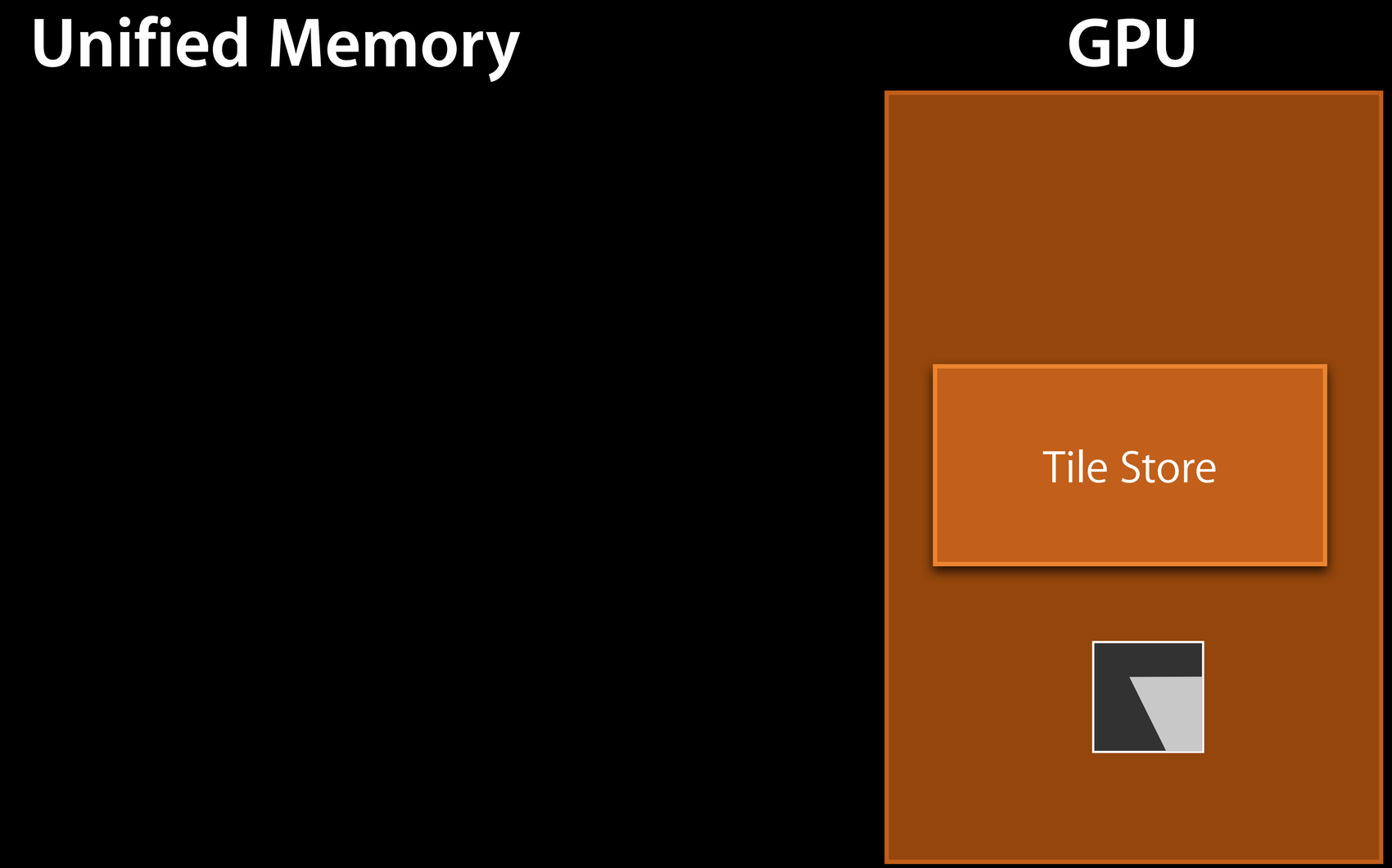


- Developers do not need MSAA depth buffer
  - Also call `glDiscardFramebufferEXT` on MSAA depth buffer



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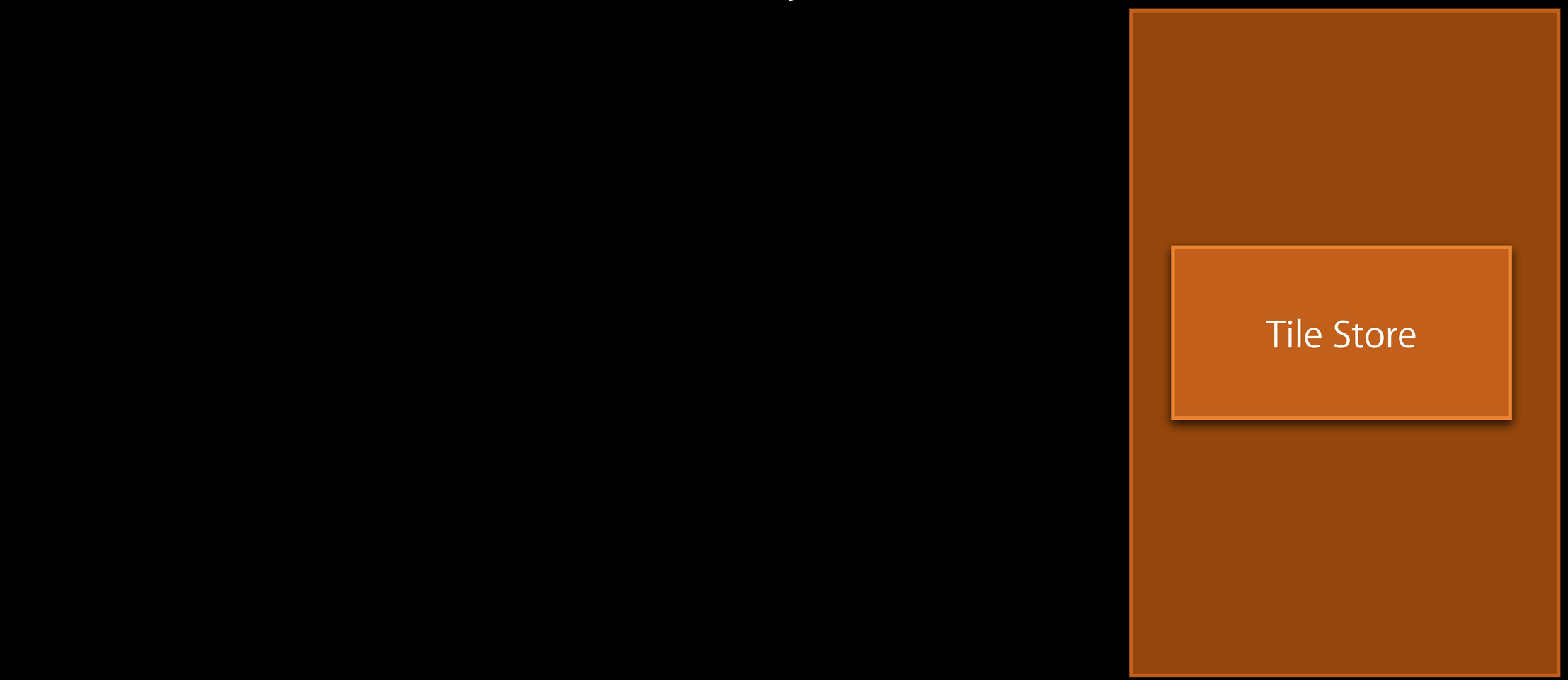


Taking TBDR into Consideration

Hidden Surface Removal

- Hidden Surface Removal a unique strength
  - Greatly reduces workload
  - Certain operation defeat HSR process
    - Enabling blending
    - Using `discard` in shader

Taking TBDR into Consideration

Using fragment discard and blending

- Draw all triangles using `discard` after drawing triangles that do not
  - Hidden Surface Removal used for triangles in opaque group

Taking TBDR into Consideration

Using fragment discard and blending

- Draw all triangles using `discard` after drawing triangles that do not
  - Hidden Surface Removal used for triangles in opaque group
- Trim geometry needing these operations
  - Worth adding more vertices to reduce fragments

Taking TBDR into Consideration

Logical Buffer Loads and Stores

- Transfers buffer between memory and GPU are expensive
- Avoid Logical Buffer Loads
  - Use `glClear` so GPU can skip them
  - Frequent renderbuffer switches cause tile thrashing
- Avoid Logical Buffer Stores
  - Use `glDiscardFramebufferEXT`
  - Especially for multisample anti-aliased buffers

Dependent Texture Sampling

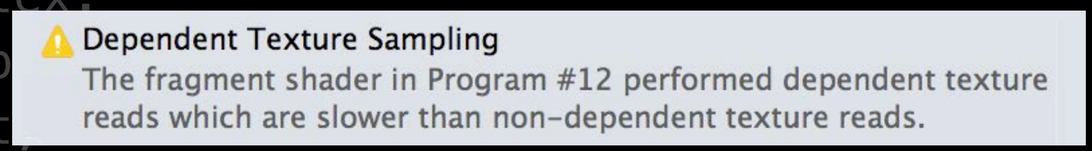
- Calculate texture coordinate in shader
  - Sample with `texture*` function

```
uniform sampler2D tex;
varying vec2 texCoo
varying vec2 offset;
...

main()
{
    vec2 offsetCoord = texCoord + offset;
    vec4 color = texture(tex, offsetCoord);

    ...

}
```



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uniform sampler2D tex;
varying vec4 packedTexCoords;

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main()
{
    vec4 color1 = texture2D(tex, packedTexCoords.xy);
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Dependent Texture Sampling

- High latency to sample texture in unified memory
  - GPU prefetches texture data for nondependent reads
    - Done in rasterization before shader executed
  - Cannot prefetch if coordinate calculated in shader
    - Shader stalls, waiting for texture data
- Minimize dependent texture samples
  - Hoist calculation
    - Perform coordinate calculation in vertex shader
    - Calculate in app and put in uniform

Dependent Texture Sampling

```
uniform sampler2D tex;
varying vec2 texCoord0;
varying vec2 texCoord1;

...

main()
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    vec4 color1 = texture2D(tex, texCoord0);
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Dynamic Branching

A simple example

```
attribute float testVal;
varying float outVal;

...

main()
{
```

⚠ Fragment Shader Dynamic Branching
The fragment shader in Program #14 "Light" contains dynamic branch instructions, which reduces the performance of the shader.

```
    {
        outVal = 1.0;
    }
    else
    {
        outVal = 0.0;
    }

    ...

}
```

Dynamic Branching

A simple example

```
attribute float testVal;
varying float outVal;

...

main()
{
    if(testVal > 1.0)
    {
        outVal = 1.0;
    }
    else
    {
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    ...
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```

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Dynamic Branching

- GPUs are highly parallel devices
  - Process multiple vertices and fragments simultaneously
- Special branch mode for execution
  - More latency to stay in sync
- If possible, calculate predicate outside of shader
  - Branches on uniforms do not incur same overhead

Dynamic Branching

- GPUs are highly parallel devices
  - Process multiple vertices and fragments simultaneously
- Special branch mode for execution
  - More latency to stay in sync
- If possible, calculate predicate outside of shader
  - Branches on uniforms do not incur same overhead
- Shaders using both Dependent Texture Sampling and Dynamic Branching are particularly costly

Minimizing CPU Overhead

Managing draw calls

Optimizing Draw Call Performance

- Most CPU overhead in draw calls
- More state set for draw, more expensive draw
  - State setting looks inexpensive
  - Work for state set deferred until draw

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⚠ Redundant Call
glBindTexture(GL_TEXTURE_2D, 1u) set a piece of GL state to its current value.

- Maximize efficiency of each draw

⚠ Inefficient State Update
glViewport(0, 0, 1024, 1024) sets a piece of GL state more than once before it is used by a clear or a draw call.

Optimizing Draw Call Performance

- Most CPU overhead in draw calls
- More state set for draw, more expensive draw
  - State setting looks inexpensive
  - Work for state set deferred until draw
- Maximize efficiency of each draw
- Reduce inefficient state setting
  - Shadow state
  - Sort state

Optimizing Draw Call Performance

- Some fixed overhead for draw
  - State validation
  - Call to driver

Optimizing Draw Call Performance

- Some fixed overhead for draw
  - State validation
  - Call to driver
- Minimize number of draw calls made
  - Object culling
  - Coalesce calls
    - Instancing
    - Vertex batching
    - Texture atlases

Texture Atlases

Bind and draw

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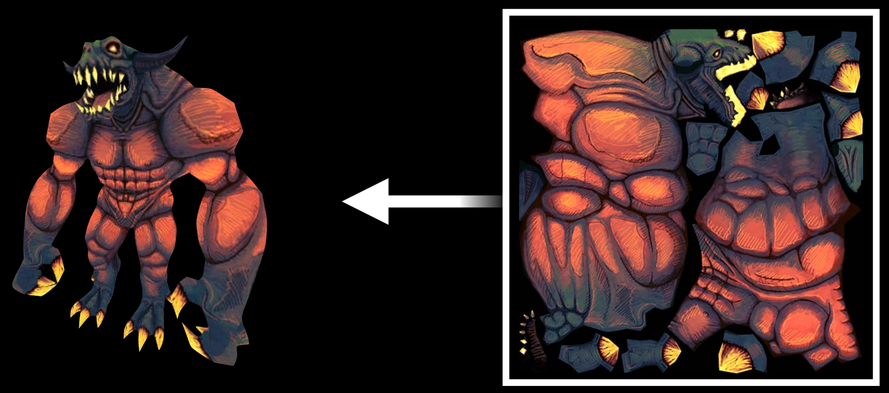

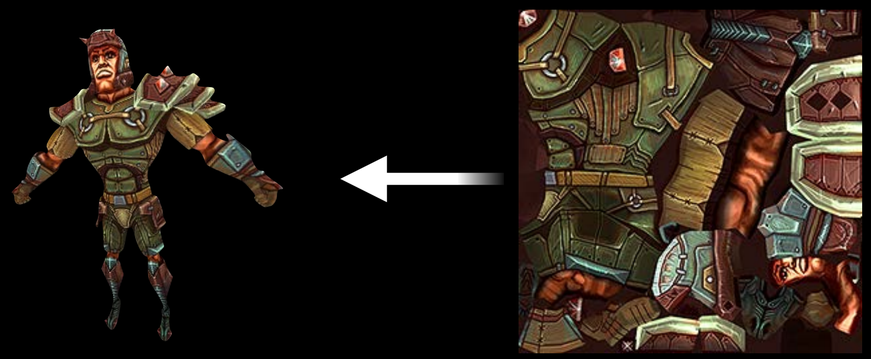

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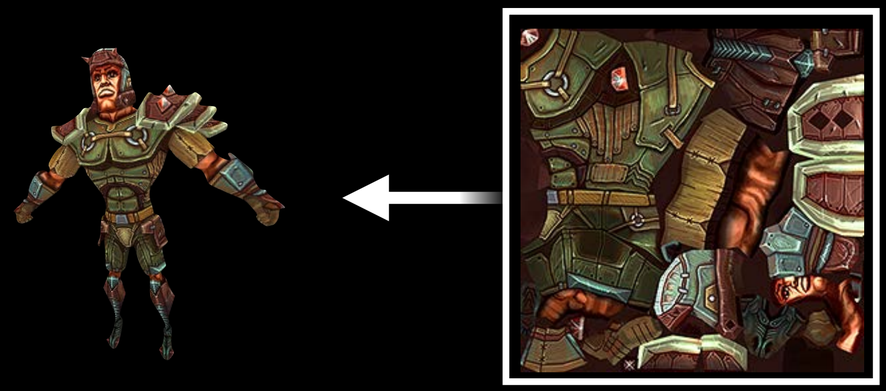

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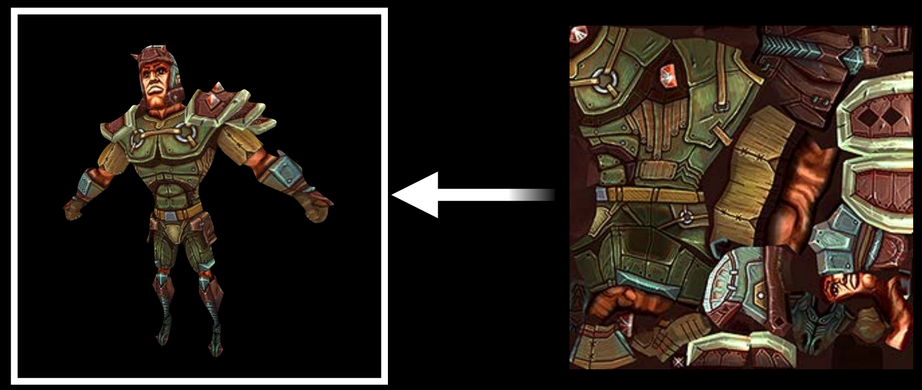

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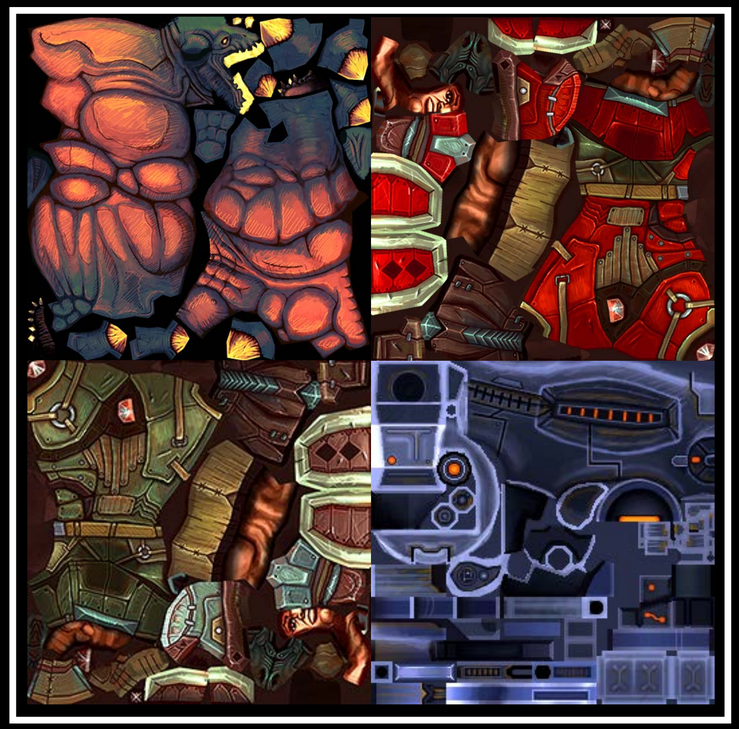

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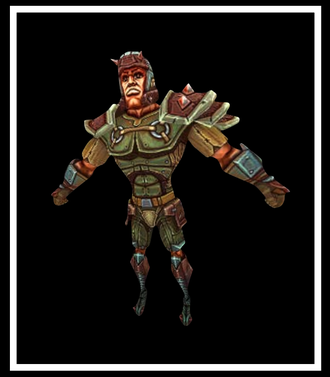

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Combining draws

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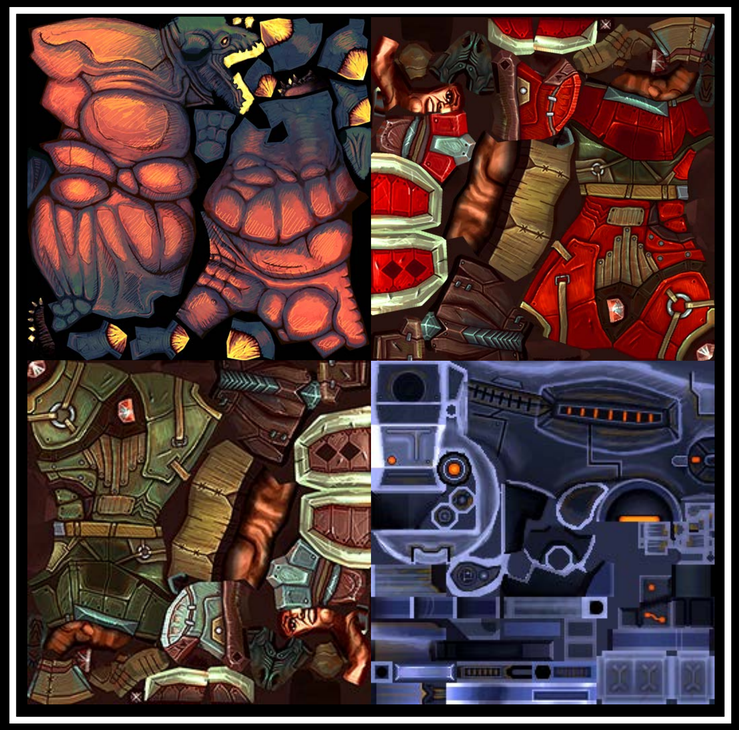

Texture Atlases

Combining draws

Texture Atlases

Sprite Kit texture atlas tool

- Combines images efficiently
- Produces property list denoting sub-images
  - Scale texture coordinates based on plist
- ‘TextureAtlas’ command line tool in Xcode

More Information

Allan Schaffer
Graphics and Game Technologies Evangelist
aschaffer@apple.com

Documentation
OpenGL ES Programming Guide for iOS
https://developer.apple.com/opengles

Apple Developer Forums
http://devforums.apple.com

Related Sessions

Introduction to Sprite Kit	Presidio Wednesday 11:30AM
What’s New in OpenGL for OS X	Marina Thursday 2:00PM

Labs

Sprite Kit Lab	Graphics and Games Lab B Thursday 9:00AM
OpenGL and OpenGL ES Lab	Graphics and Games Lab A Thursday 10:15AM

Summary

- Reduce draw call overhead
  - Use techniques including instancing and texture atlases
- Consider GPU's operation when architecting your renderer and in performance investigations
  - GPU tools help greatly
  - Tile-Based Deferred Rendering has some special consideration

WWDC2013