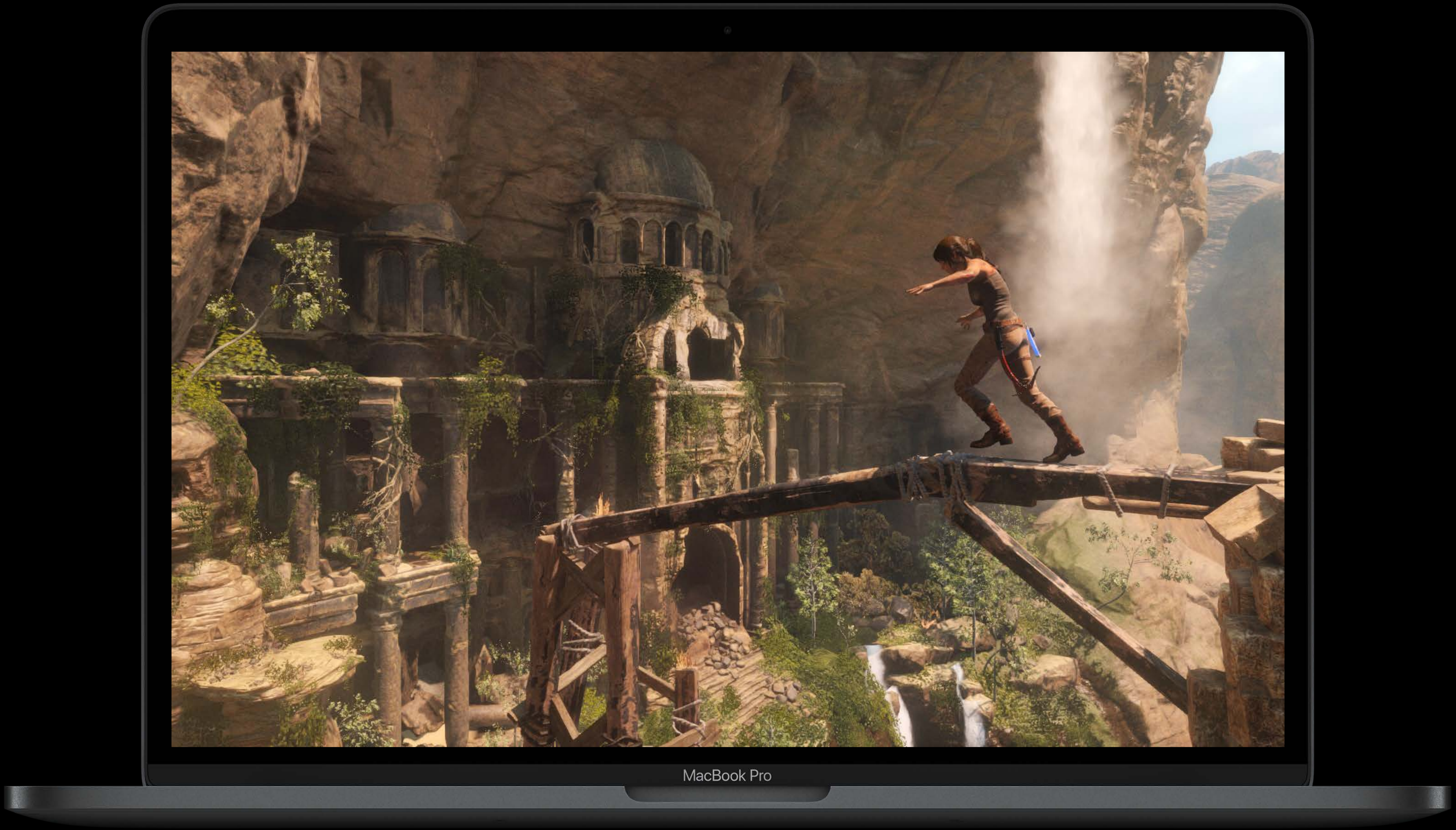
#WWDC18

Metal for Game Developers

Session 607

Brian Ross, GPU Software (macOS)
Michael Imbrogno, GPU Software (iOS)


INSIDE
playdead.com/inside
MENU


MacBook Pro

Agenda

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Harnessing Parallelism

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Taking Explicit Control

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Building GPU-Driven Pipelines

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Bringing Fortnite to Metal

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Scalable multi-threaded encoding is key

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Metal makes multi-threaded CPU command generation easy and fast

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Metal makes multi-threaded CPU command generation easy and fast

Metal automatically parallelizes GPU tasks

Single-Thread Rendering

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Increased latency

Multi-Threaded Rendering

MTLCommandBuffer

Multi-Threaded Rendering

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Multi-Threaded Rendering

MTLCommandBuffer

```swift
// Create multiple command buffers
let commandBuffer1 = commandQueue.makeCommandBuffer()!
let commandBuffer2 = commandQueue.makeCommandBuffer()!

// Enqueue to define desired GPU execution order
commandBuffer1.enqueue()
commandBuffer2.enqueue()

// Dispatch encoding on separate threads
queue.async(group: group) {
    encodeGBufferPass( commandBuffer2, … )
    commandBuffer2.commit()
}
queue.async(group: group) {
    encodeDeferredShadingPass( commandBuffer1, … )
    commandBuffer1.commit()
}
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Multi-Threaded Rendering

MTLCommandBuffer

Multi-Threaded Rendering

Without MTLParallelRenderCommandEncoder

Multi-Threaded Rendering

With MTLParallelRenderCommandEncoder

```swift
// Create parallel encoder and subordinate render command encoder objects
let parallelRenderEncoder = commandBuffer.makeParallelRenderCommandEncoder(renderPassDesc)!
let renderEncoder1 = parallelRenderEncoder.makeRenderCommandEncoder()!
let renderEncoder2 = parallelRenderEncoder.makeRenderCommandEncoder()!

// Encode different portions of G-Buffer pass (in any order) on separate threads
queue.async(group: group) {
    encodeGBufferTerrain(renderEncoder2)
}
queue.async(group: group) {
    encodeGBufferObjects(renderEncoder1)
}

// Notify when encoding complete and end the parallel encoder
group.notify(queue: queue) {
    parallelRenderEncoder.endEncoding()
}
```

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Asynchronous compute and render

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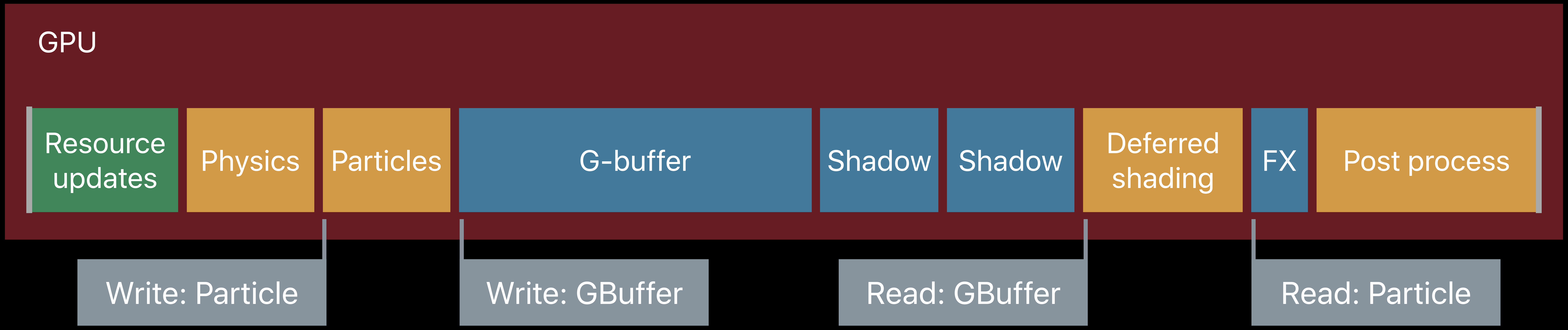
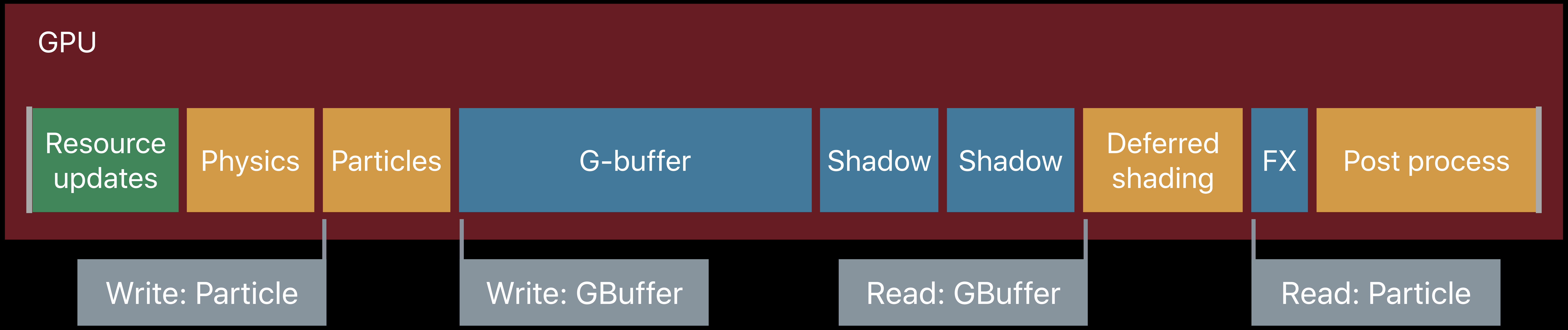


GPU Parallelism

Asynchronous compute and render



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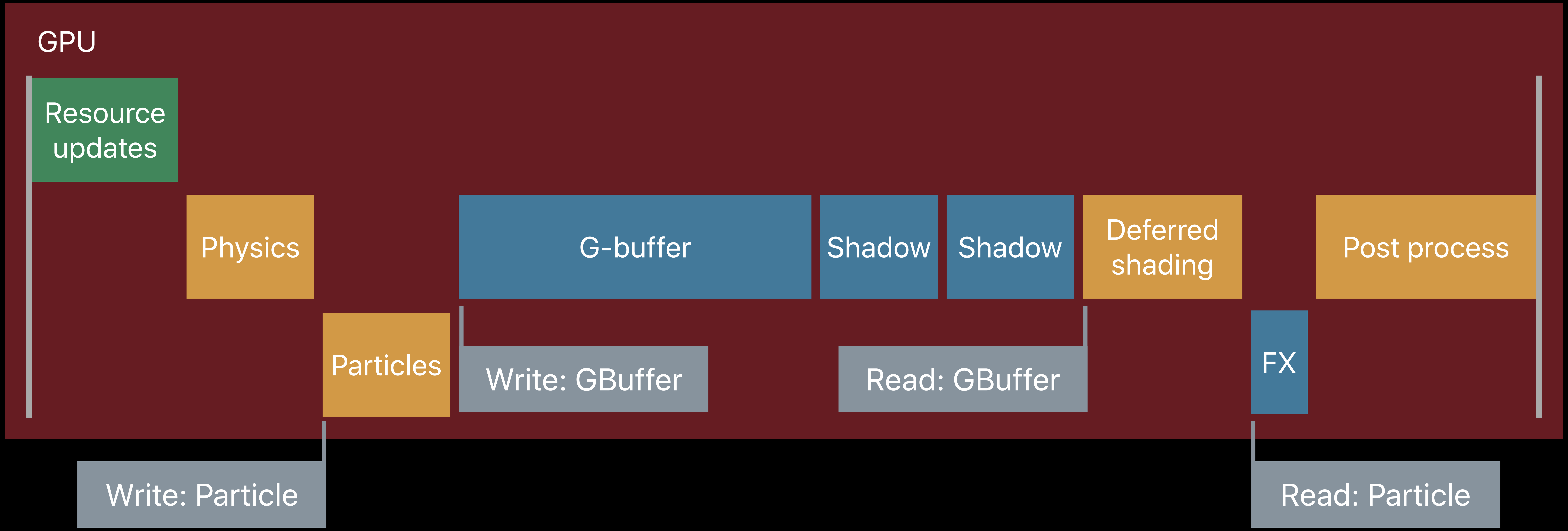

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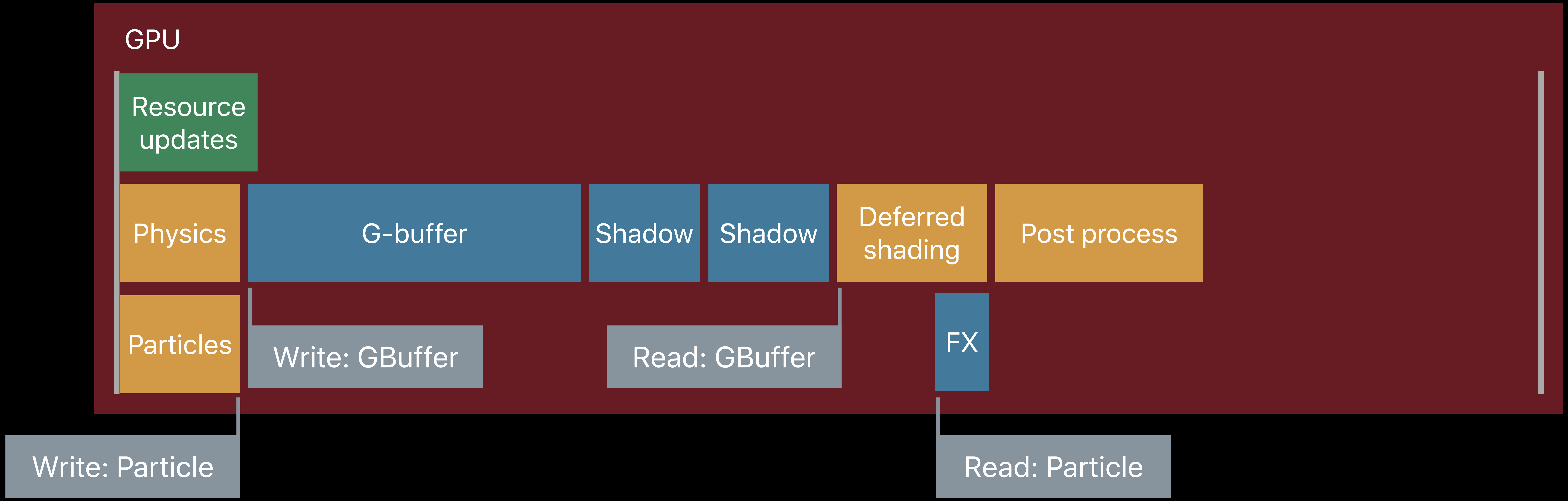

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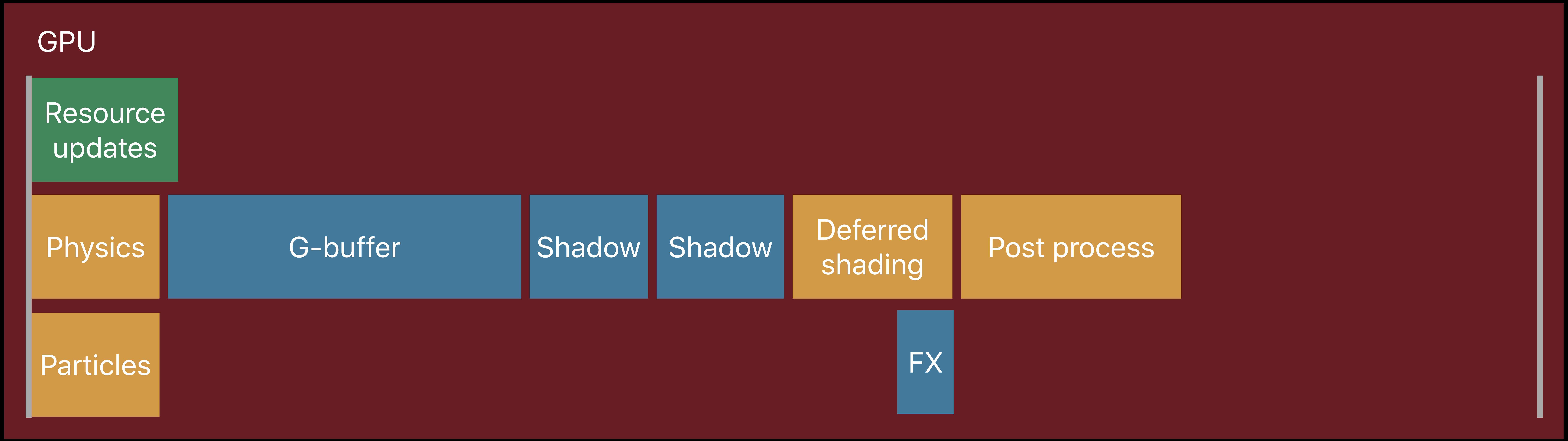

Taking Explicit Control

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Allocate resources cheaply using heaps

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Metal offers more direct approaches for even less overhead

Disable Metal’s automatic reference counting

Allocate resources cheaply using heaps

Control GPU parallelism with fences and events

Resource Heaps

MTLHeap

Control time of memory allocation

Fast reallocation and aliasing of resources

Cheaper resource binding

Simple API

Resource Heaps

MTLHeap

Resource Heaps

MTLHeap

Resource Heaps

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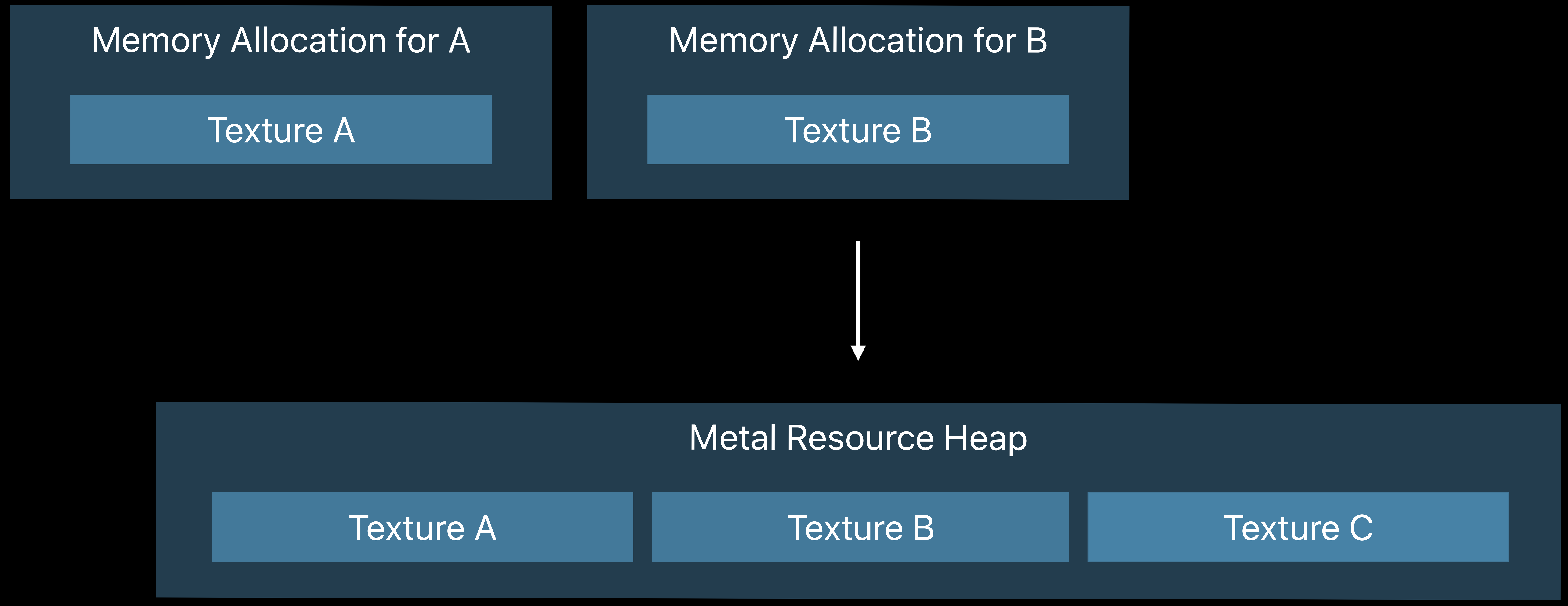
MTLHeap



Resource Heaps
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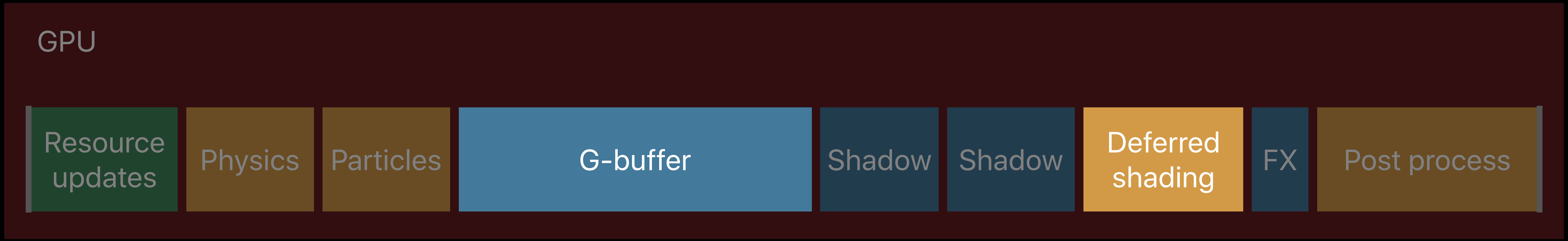
Resource Heaps

Without dependency tracking

MTLFence and MTLEvent

Explicit execution order



MTLFence and MTLEvent

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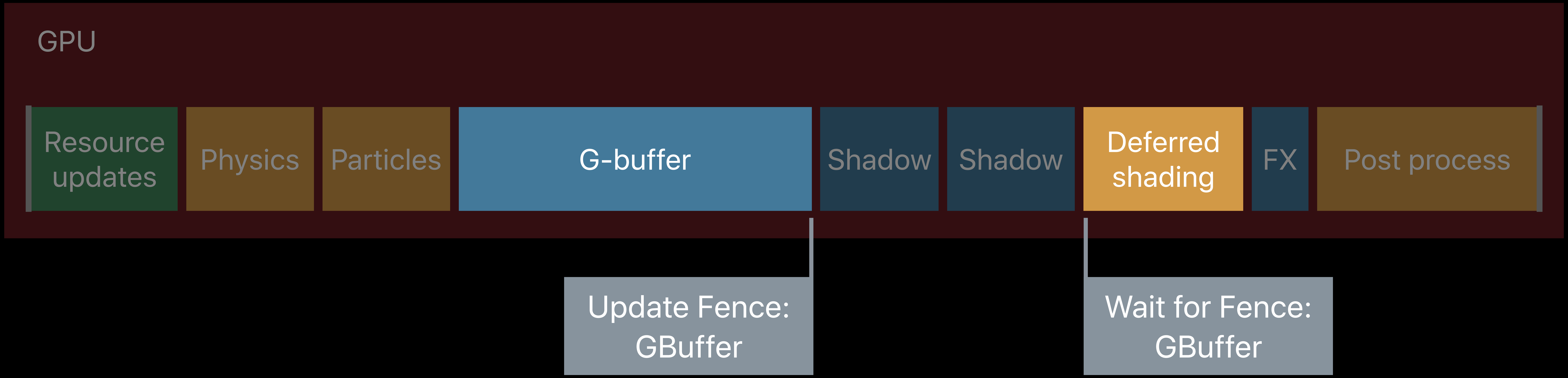

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// G-Buffer pass creates a temporary target to render output
let temporaryRenderTarget = heap.makeTexture(gBufferTextureDescriptor)

// Render into our temporary render target and return encoder for later use
let renderEncoder = renderSceneIntoRenderTarget(temporaryRenderTarget)!

// Update the G-Buffer fence now that we encoded our scene
renderEncoder.updateFence(gBufferFence after: .fragment)


// Deferred Shading pass uses render target and return encoder for later use
let computeEncoder = computeDeferredShading(temporaryRenderTarget)

// Deferred shading pass needs to wait for fence
computeEncoder.waitForFence(gBufferFence)

// After this point we can re-use the render target in a post-process pass
temporaryRenderTarget.makeAliasable()
let depthOfFieldTarget = heap.makeTexture(depthOfFieldTextureDescriptor)
computeDepthOfField(depthOfFieldTarget)
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Building GPU-Driven Pipelines

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Games are moving more and more logic onto GPU

- Efficient processing of large datasets
- Growing scene graph complexity

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Games are moving more and more logic onto GPU

- Efficient processing of large datasets
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Metal 2 enables you to move entire render loop to the GPU

- Argument Buffers—offload parameter management
- Indirect Command Buffers—offload rendering loop

Argument Buffers

Shader example

```
struct Material
{
    float              roughness;
    float              intensity;
    texture2d<float> surfaceTexture;
    texture2d<float> specularTexture;
    sampler            textureSampler;
};

kernel void my_kernel(constant Material &material [[buffer(0)]], ...)
{
    ...
}
```

Argument Buffers

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```

Argument Buffers

Modifying materials from GPU

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struct Material
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    float              roughness;
    float              intensity;
    texture2d<float> surfaceTexture;
    texture2d<float> specularTexture;
    sampler            textureSampler;
};

kernel void my_kernel(device Material &material [[buffer(0)]], ...)
{
    material.surfaceTexture = getDetailedTexture(...);
}
```

Argument Buffers

Modifying materials from GPU

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    float              roughness;
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Argument Buffers
Arrays of materials

```
struct Material
{
    float              roughness;
    float              intensity;
    texture2d<float> surfaceTexture;
    texture2d<float> specularTexture;
    sampler            textureSampler;
};

fragment float4 my_shader(device Material *material [[buffer(0)]], ...)
{
    return calculateMaterial( material[instanceID] );
}
```

Argument Buffers

Arrays of materials

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    float             roughness;
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Argument Buffers

Arrays of materials

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fragment float4 my_shader(device Material *material [[buffer(0)]], ...)
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```

Argument Buffers

New arguments

```
struct Material
{
    float                 roughness;
    float                 intensity;
    texture2d<float>      surfaceTexture;
    texture2d<float>      specularTexture;
    sampler               textureSampler;
    render_pipeline_state pipelineState;
    command_buffer        commandBuffer;
};
```

Argument Buffers

New arguments

```
struct Material
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    float                  roughness;
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    sampler                textureSampler;
    render_pipeline_state  pipelineState;
    command_buffer         commandBuffer;
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```

Indirect Command Buffers (ICB)

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Allows GPU to build draw calls

- Massively parallel generation of commands

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Reuse ICB in multiple frames

- Modify contents

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Remove expensive CPU and GPU synchronization

Game Rendering Loop

Traditional running on CPU

Game Rendering Loop

Traditional running on CPU

Game Rendering Loop

Traditional running on CPU

Game Rendering Loop

Mixed CPU and GPU work

Game Rendering Loop

Mixed CPU and GPU

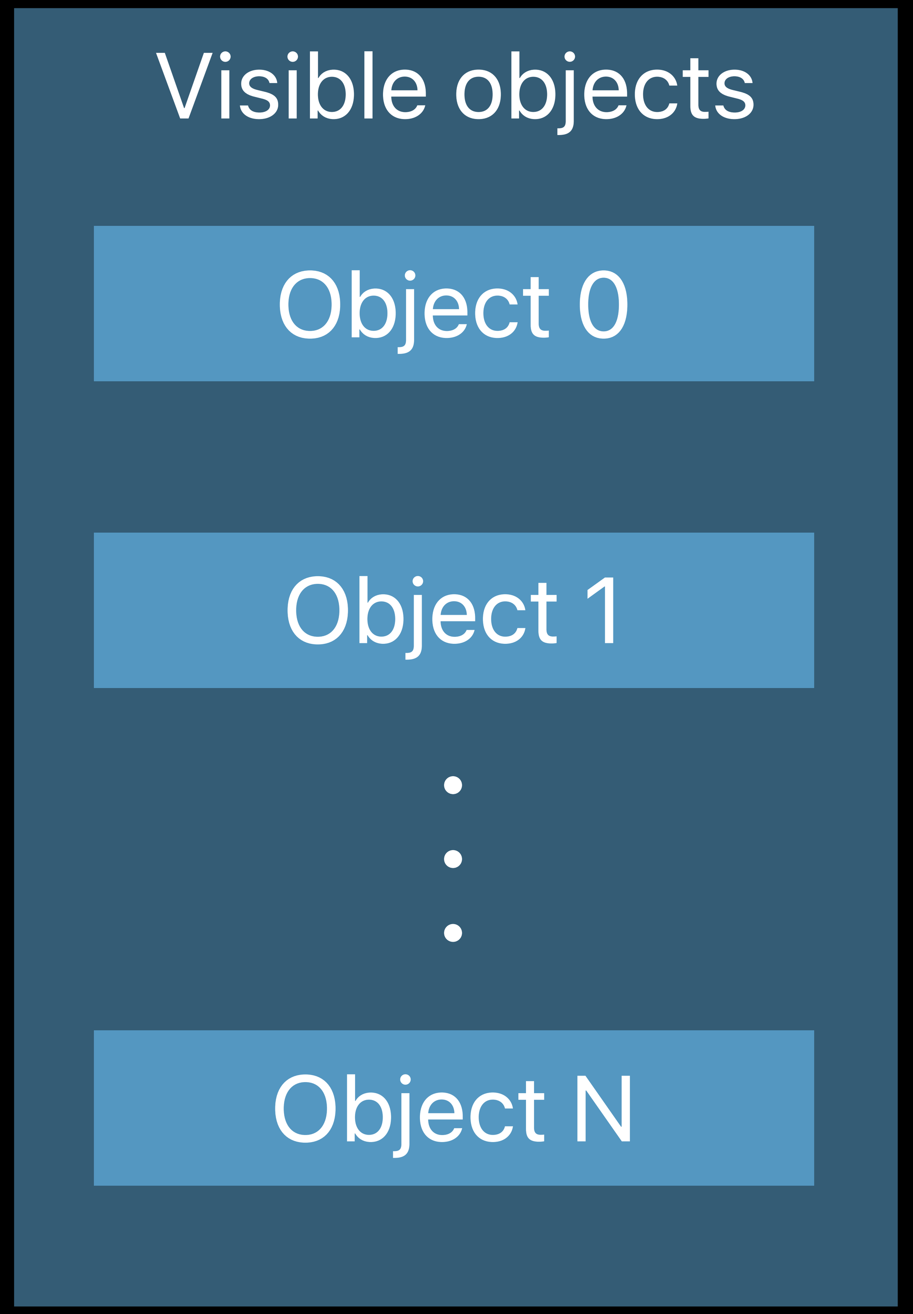
Game Rendering Loop

GPU Driven rendering loop

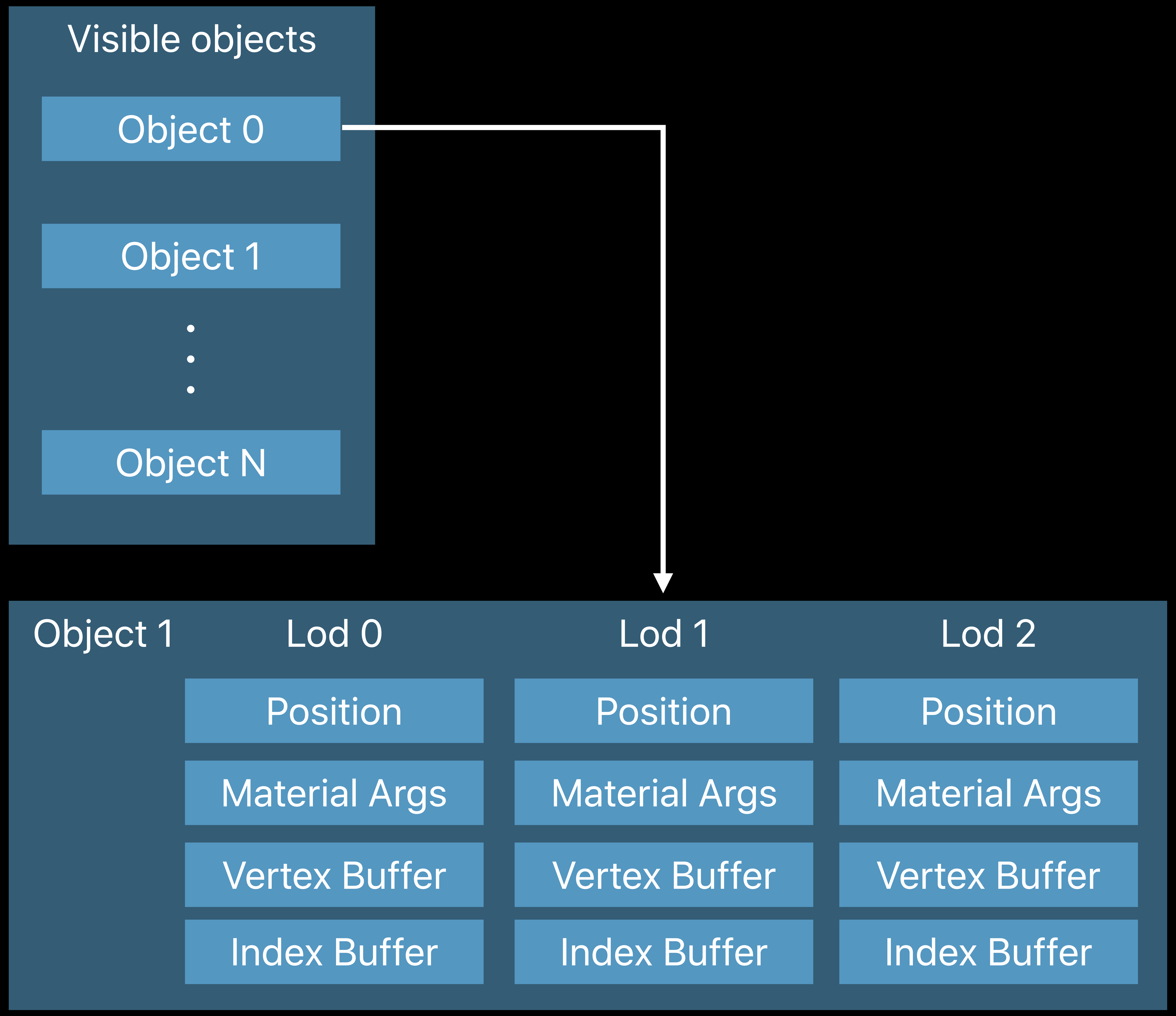
Game Rendering Loop

GPU Driven rendering loop

GPU Rendering Loop



GPU Rendering Loop



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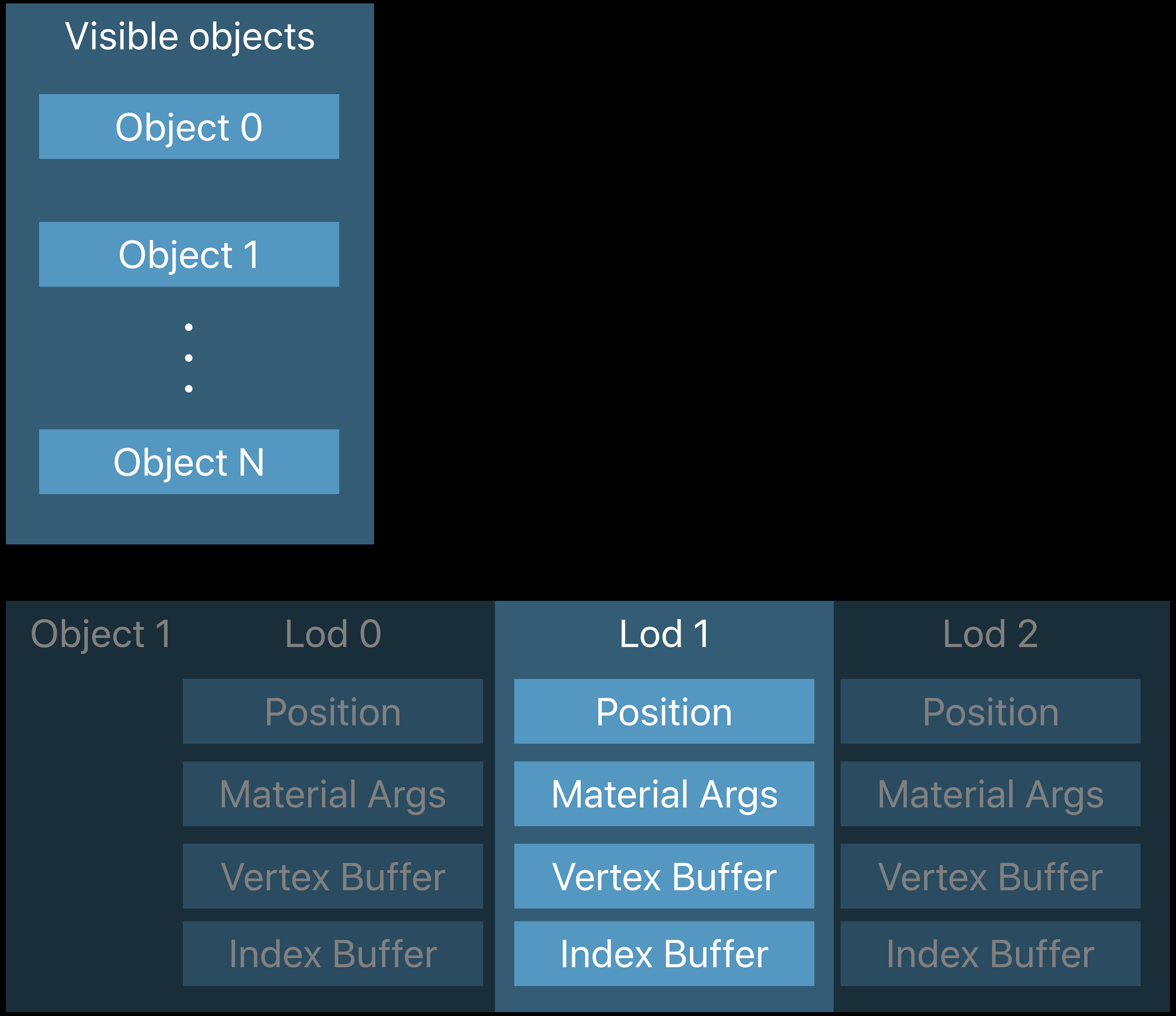

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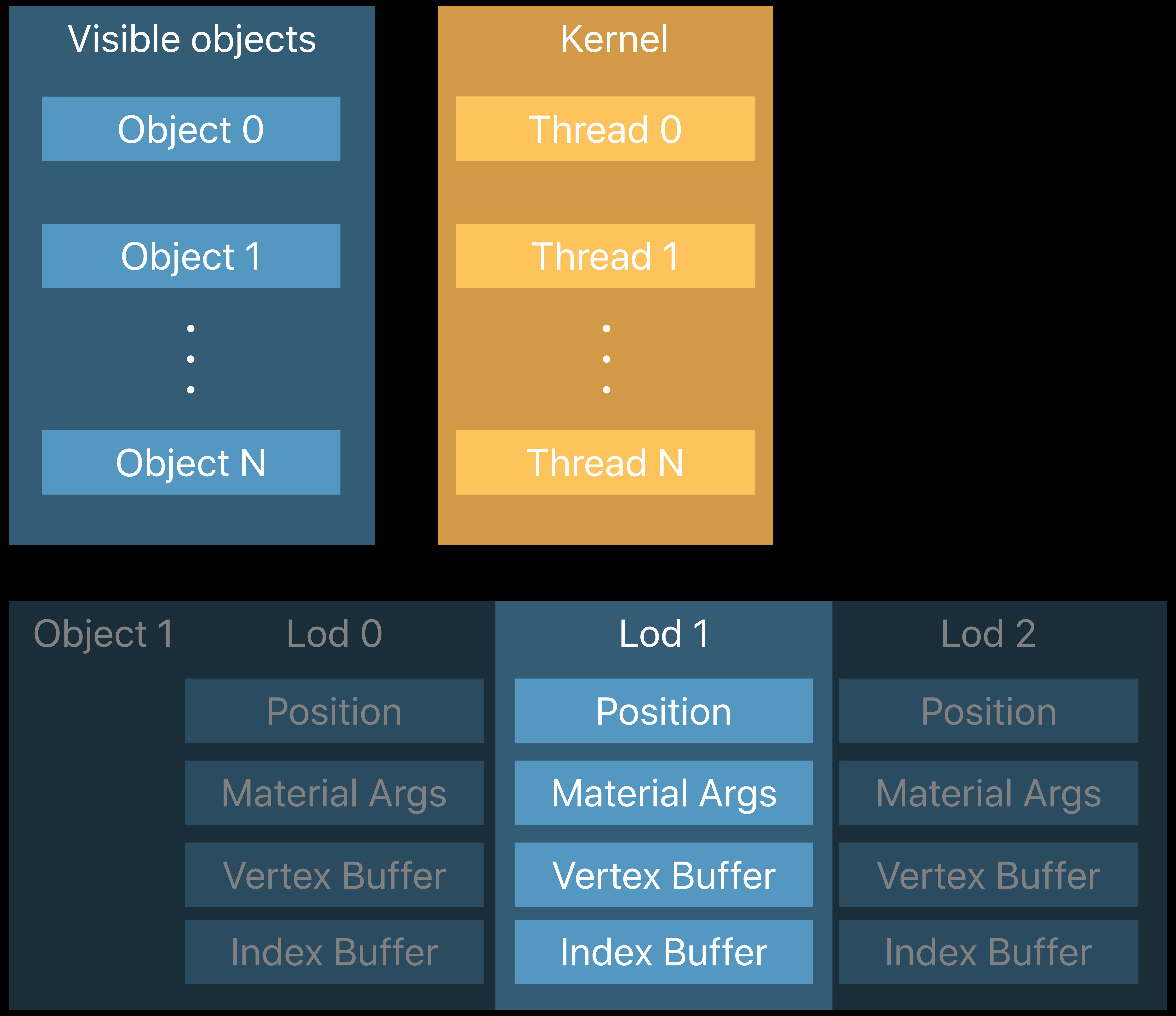

GPU Rendering Loop

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GPU Rendering Loop

Encoding Drawcall Example

```
kernel void encodeDrawcall(device Objects        *obj  [[buffer(0)]],
                           device command_buffer  icb  [[buffer(1)]],
                           uint                   index  [[thread_index_in_grid]])
{
    // Select the render command index based on thread ID
    render_command cmd( icb, index );

    // Encode PSO and buffer arguments for each object
    cmd.set_pipeline_state( obj[index].shader );
    cmd.set_vertex_buffer( obj[index].geometry, 0);
    cmd.set_fragment_buffer( obj[index].material, 0);

    // Issue the drawcall
    cmd.draw(triangle, obj[index].vertexStart, obj[index].vertexCount,
                       obj[index].instanceCount, obj[index].baseInstance);
}
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Executing ICB Example

```
// Create an Indirect Command Buffer
let desc = MLTIndirectCommandBufferDescriptor()
desc.commandTypes = [.draw, .patches]
let icb = device.newIndirectCommandBuffer(with: desc, maxCommandCount:1000, options…)!

// Dispatch compute kernel to encode Indirect Command Buffer
computeEncoder.dispatchThreadGroups(…)

// Optimize the Indirect Command Buffer across specified range
blitEncoder.optimizeCommandsInBuffer(icb, with: NSRange(10..<900))

// Execute with indirect range buffer
renderEncoder.executeCommandsInBuffer(in: icb, indirectBuffer:rangeBuffer, …)
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desc.commandTypes = [.draw, .patches]
let icb = device.newIndirectCommandBuffer(with: desc, maxCommandCount:1000, options…)!

// Dispatch compute kernel to encode Indirect Command Buffer
computeEncoder.dispatchThreadGroups(…)

// Optimize the Indirect Command Buffer across specified range
blitEncoder.optimizeCommandsInBuffer(icb, with: NSRange(10..<900))

// Execute with indirect range buffer
renderEncoder.executeCommandsInBuffer(in: icb, indirectBuffer:rangeBuffer, …)
```


SCHOOL BUS
SCHOOL BUS
EMERGENCY EXIT
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EMERGENCY EXIT
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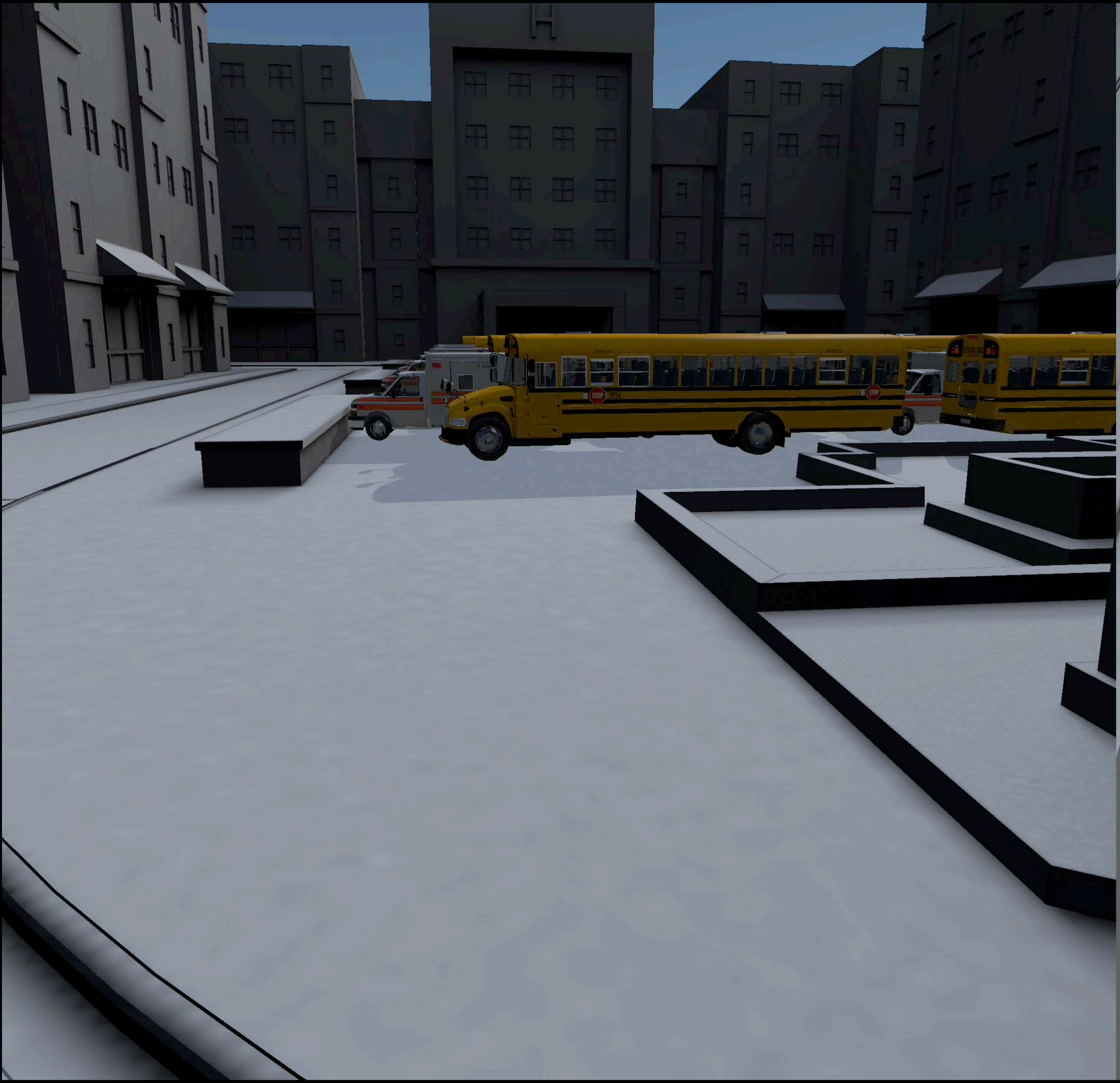
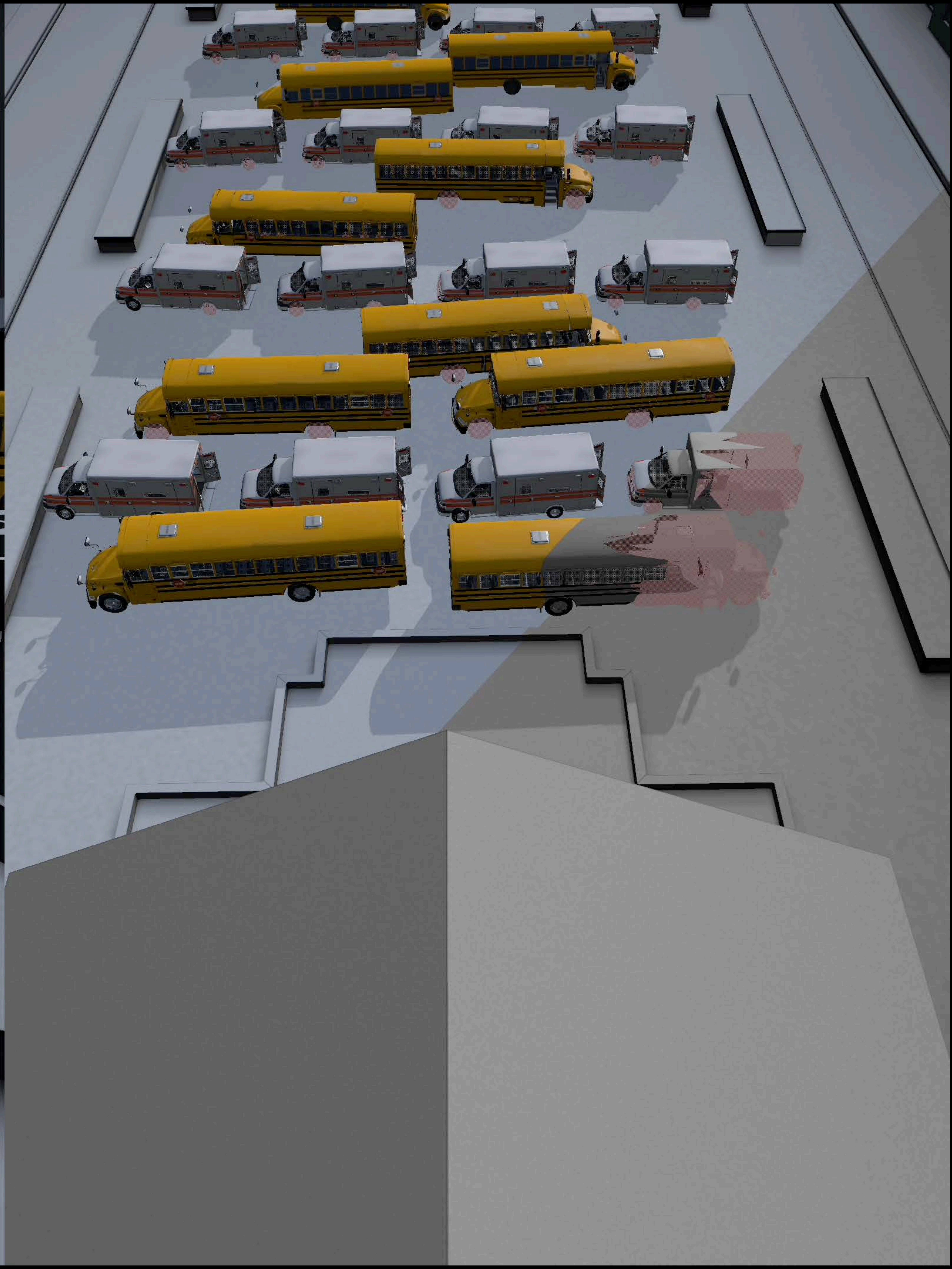

Optimizing for the A11 Bionic GPU

Tile-Based Deferred Rendering (TBDR)

High performance, low power

Tile-Based Deferred Rendering (TBDR)

High performance, low power

Tightly integrated with Metal

Tile-Based Deferred Rendering (TBDR)

High performance, low power

Tightly integrated with Metal

A11 Bionic takes TBDR to the next level


A11 GPU
System Memory
Vertex Stage
Tiled Vertex Buffer
Fragment Stage
Tile Z/S Buffer
Depth/Stencil Buffer
Tile Memory
Imageblock
Threadgroup Memory
Framebuffer
Tile Stage


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Framebuffer

Metal 2 Features on A11

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Programmable Blending	Combine render passes using attachments

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Imageblocks	Control pixel layouts from the shading language

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Persistent Threadgroup Memory	Share data across draws and dispatches

Metal 2 Features on A11

Programmable Blending	Combine render passes using attachments
Imageblocks	Control pixel layouts from the shading language
Tile Shading	Interleave graphics and compute in the render pass
Persistent Threadgroup Memory	Share data across draws and dispatches
Multi-Sample Color Coverage Control	Efficient custom resolves within the render pass

Programmable Blending

Metal provides read-write access to pixels in tile memory

- Implement custom blend operations

Programmable Blending

Metal provides read-write access to pixels in tile memory

- Implement custom blend operations

Combine passes that read-write the same pixels

- Eliminates system memory bandwidth between passes
- Optimizes deferred shading

Deferred Shading

Without Programmable Blending

Deferred Shading
Without Programmable Blending

Deferred Shading

With Programmable Blending

Deferred Shading

With Programmable Blending and Memoryless Render Targets

```
typedef struct {
    float4 albedo [[color(0)]];
    float4 normal [[color(1)]];
    float  depth  [[color(2)]];
    float4 accum  [[color(3)]];
} GBuffer;

fragment GBuffer ApplyLight(VertexOutput in [[stage_in]], GBuffer gBuffers, …)
{
    float3 p = ReconstructViewPosition(gBuffers.depth);
    half3  n = gBuffers.normal.rgb;
    half4 lighting = CalculateLighting(p, n, gBuffers.albedo, …);
    GBuffer output = gBuffers;
    output.accum += lighting;
    return output;
}
```

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typedef struct {
    float4 albedo [[color(0)]];
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Imageblocks

Flexible per-pixel storage in tile memory

- Layout declared in shading language

```
struct GBufferPixel {
    rgba8unorm<half3> albedo;
    rg11b10f<half3>   normal;
    float             depth;
};

struct MultiLayerAlphaBlendPixel {
    rgba8unorm<half4> color[4];
    half              depths[4];
};
```

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```

Imageblocks

Flexible per-pixel storage in tile memory

- Layout declared in shading language

Change pixel layout within a pass

- Merge render passes with different layouts

```
struct GBufferPixel {
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    rg11b10f<half3>   normal;
    float             depth;
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Deferred Shading

With Imageblocks

Deferred Shading and Multi-Layer Alpha Blending

With changing Imageblocks

Deferred Shading and Multi-Layer Alpha Blending

With changing Imageblocks

Tile Shading

New programmable stage in the render pass

- Dispatch a configurable threadgroup per tile

Tile Shading

New programmable stage in the render pass

- Dispatch a configurable threadgroup per tile

Interleave render and compute processing

- Read rendering results directly from tile memory

Tiled Forward Shading

Mixes render and compute

Tiled Forward Shading

Mixes render and compute

Tiled Forward Shading

Combine passes with Tile Shading

Tiled Forward Shading

Combine passes with Tile Shading

Persistent Threadgroup Memory

Threadgroup memory available to render passes

- Available to fragment and tile shaders
- Buffer contents persist for the lifetime of tile

Persistent Threadgroup Memory

Threadgroup memory available to render passes

- Available to fragment and tile shaders
- Buffer contents persist for the lifetime of tile

Share data across pixels

- Communicate tile-scoped data between draws and tile dispatches

Tiled Forward Shading

Using Tile Shading

Tiled Forward Shading

Using Tile Shading and Persistent Threadgroup Memory

```
kernel void CullLights(imageblock<FragData> all_frag_data,
                       device Light *all_lights [[buffer(0)]],
                       threadgroup float2 depth_bounds [[threadgroup(0)]],
                       threadgroup uint32_t &active_light_mask [[threadgroup(1)]], …) {
    active_light_mask = 0;
    for (int i = 0; i < MAX_LIGHTS; ++i) {
        if (IntersectLightWithTileFrustum(all_lights[i], depth_bounds, …) {
            active_light_mask = (1u << i);
        }
    }
}
fragment float4 ForwardShade(VertexInputs stage_in [[stage_in]],
                             FragData frag_data [[imageblock_data]],
                             device Light *all_lights [[buffer(0)]],
                             threadgroup uint32_t &active_light_mask [[threadgroup(1)]]) {
    …
}
```

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    …
}
```

Deferred Shading and Multi-Layer Alpha Blending

With changing Imageblocks requires Tile Shading

Deferred Shading and Multi-Layer Alpha Blending

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Multi-Sample Color Coverage Control

Multi-Sample Color Coverage Control

MSAA is efficient on A-series GPUs

- Samples stored in tile memory for fast blending and resolves

Multi-Sample Color Coverage Control

MSAA is efficient on A-series GPUs

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MSAA is more efficient on A11

- Tracks unique colors in a pixel

Multi-Sample Color Coverage Control

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MSAA is more efficient on A11

- Tracks unique colors in a pixel

Tile shading gives control over color coverage

- Resolve in-place, in fast tile memory

Multi-Sample Rendering with Transparent Particles

Without Color Coverage Control

Multi-Sample Rendering with Transparent Particles

With Tile Shading and Color Coverage Control

```
// Tile shader that resolves in-place using color coverage control

struct FragData {
    half4 color;
};
kernel void InPlaceResolve(imageblock<FragData> img_blk_colors,
                           ushort2 tid [[thread_position_in_threadgroup]]) {
    half4 resolved_color = half4(0);
    for (int c = 0; c < img_blk_colors.get_num_colors(tid); ++c) {
        half4 color = img_blk_colors.data(tid, c, image_block_data_rate::color)->color;
        resolved_color += color * popcount(img_blk_color.get_color_coverage_mask(tid, c));
    }
    resolved_color /= img_blk_colors.get_num_samples();
    ushort output_sample_mask = 0xF;
    img_blk_colors.write(FragData{resolved_color}, tid, output_sample_mask);
}
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}
```

Fortnite: Battle Royale

Shipping an Unreal Engine 4 console game on iOS with Metal

Nick Penwarden, Epic Games

Technical Challenges

One map, larger than 6km^2

Time-of-day, destruction, player-built structures

100 players

50,000+ replicating actors

Crossplay with console and desktop players

One Game, All Platforms

Crossplay means we are limited in our ability to scale down the game

If it affects gameplay, we can't change it

If a player can hide behind an object, we must render it

Metal

Draw call performance allows us to render complex scenes with thousands of dynamic objects

Access to hardware features, e.g. programmable blending, allows for big wins on the GPU

Feature set lets us support artist authored materials, physically based rendering, dynamic lighting and shadows, GPU particle simulation

Rendering Features Used on iOS

Movable directional light with cascaded shadow maps

Movable skylight

Physically based materials

HDR and Tonemapping

GPU particle simulation

Artist authored materials with vertex animation


Mac (High)


Mac (Mid)

iOS (iPhone 8+)

Scalability

Scalability across platforms

- Minimum LOD for meshes
- Character LODs, animation update rates, etc.

Defined three performance buckets, assigned devices based on performance

- Low (iPhone 6s, iPad Air 2, iPad mini 4)
- Mid (iPhone 7, iPad Pro)
- High (iPhone 8, iPhone X, iPad Pro 2nd Gen)

Resolution

Backbuffer resolution is what the UI renders at, determined by contentScaleFactor

3D resolution is separate, upscaled before rendering UI (adds some cost)

Preferred scaling backbuffer, only scaled 3D separately on iPhone 6s, iPad Air 2, and iPad (5th gen)

Tuned per-device

Shadows

Dynamic shadows have a large impact on both GPU and CPU perf

Low
No Shadows

Mid
1 cascade, 1024x1024

High
2 cascades, 1024x1024, 25% further out

Foliage

Grass and foliage scales; both density and cull distance

Low
No foliage

Mid
30% density vs. console

High
100% density vs. console

Memory

Memory doesn't always correlate with performance

- iPhone 8 has less physical memory than iPhone 7+ but is faster

Low memory devices

- No foliage, no shadows, 16k max GPU particles, reduced pool for cosmetics, reduced texture memory pool

High memory devices

- Foliage, shadows, 64k max GPU particles, increased pool for cosmetics, increased texture memory pool

Memory Optimizations

Streaming

- Split POIs into streaming levels

Textures

- Used ASTC optimizing for size
- Removed/reduced non-streaming textures
- Adjusted streaming pool
- Content optimization

Meshes

- Per-platform min LOD, cooked out unused LODs
- Cooked out meshes culled by low detail mode
- Don’t load grass/foliage on low memory devices
- Content optimization

Materials

- Cook out medium and high quality variants
- Disable feature permutations we don’t use, e.g. dynamic point lights
- Reduce unique materials in content
- Removed editor-only properties

Audio

- Per-platform variation culling
- Per-platform downsampling
- Per-platform compression quality
- Quality node
- Content optimization

Framerate Targets

30fps at the highest visual fidelity possible

However...

Maxing out the CPU and GPU generates heat which causes the device to downclock

We also want to conserve battery life

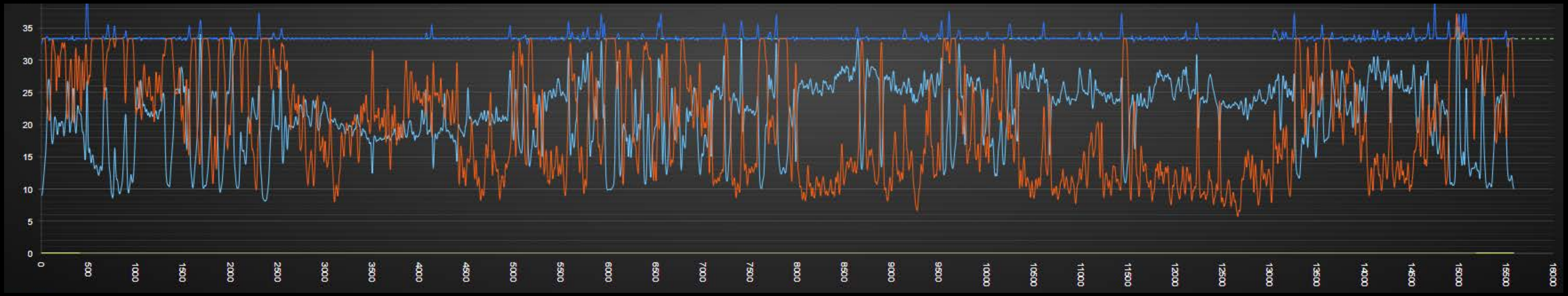
So we target 60fps for the environment but vsync at 30fps

Performance Tracking

Capture environment performance at a selection of POIs over time

Daily 100 player playtests to capture dynamic performance

- Key performance stats tracked
- Instrumented profiles gathered from one device
- Replays saved off for later investigation



Metal

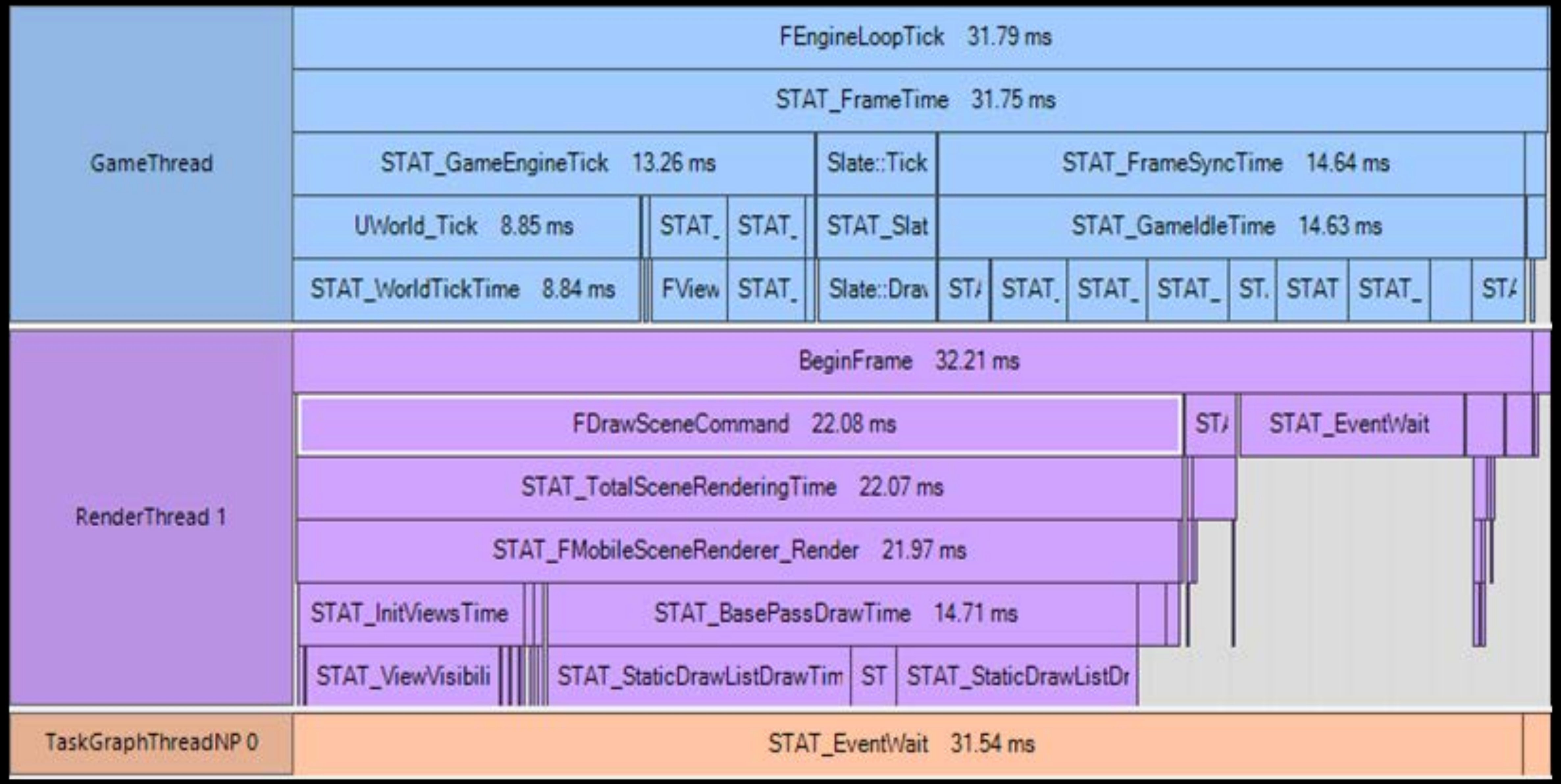
Threading

On most iOS devices, we have two cores to work with

Game thread: Input, networking, simulation

Rendering thread: culling and drawing the scene, all Metal work

One task thread for async tasks, mostly streaming



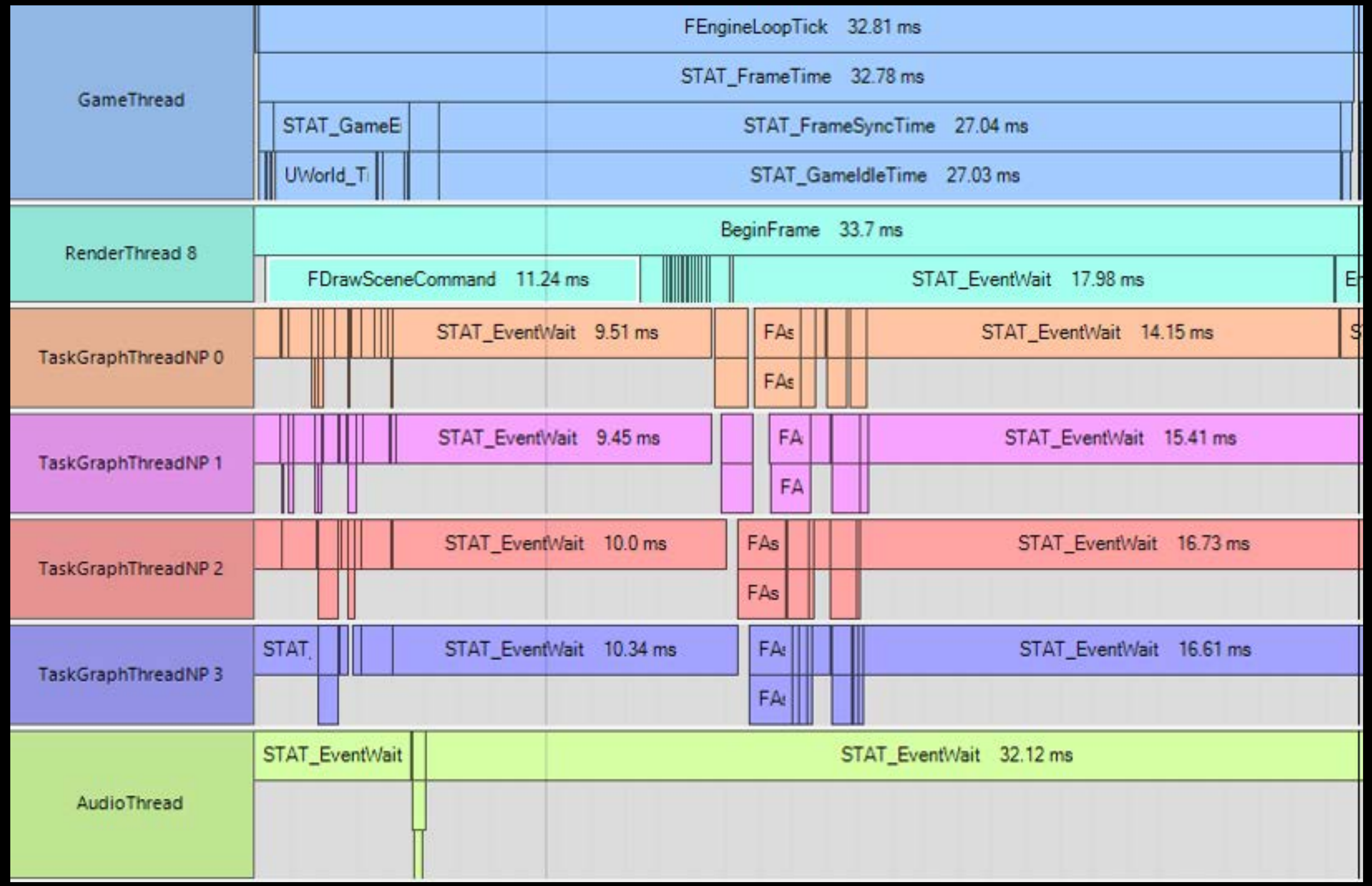
From an iPhone 6s

Threading

On iPhone 8 and X we have two "fast" and four "efficient" cores

We add three more task threads for

- Parallel animation evaluation
- Particle simulation
- Physics tasks
- Async scene queries
- Texture streaming
- Scene culling for rendering
- And a dedicated audio thread



From an iPhone X

Draw Calls

Draw calls were our main performance bottleneck

Metal’s performance really helped here, 3–4x faster than OpenGL, allowed us to ship without more aggressive work to reduce draw calls

Pulled in cull distance on decorative objects

Added HLODs to combine draw calls

Draw Calls

	CityOverlook		CityStreets	
	Draw Calls	CPU Time (ms)	Draw Calls	CPU Time (ms)
iPhone 8+	1281	4.7	605	2.73
iPhone 7+	1246	7.11	544	4.22

Hierarchical LOD

Combine draw calls for a group of meshes

Allow us to render the entire map while skydiving

Even on the ground, POIs are visible from up to 2km away

Added mid-range HLODs to further reduce draw calls in complex scenes like Tilted Towers

Pipeline State Objects

Minimize how many are created at runtime to prevent hitching

Follow best practices

- Compile functions offline
- Build library offline
- Group functions into a single library you can ship with your game

Ideally create all of the PSOs you need at load time

Pipeline State Objects

What if the set of PSOs you *might* need is large?

- Artist authored shaders x Lighting scenarios x RT formats x MSAA x Stencil state (e.g. LOD dithering) x Input layout x Scalability level x and more
- Minimize permutations where you can!
  - Sometimes a dynamic branch is fine

Pipeline State Objects

Identify the most common subset you are likely to need and create those at load

We use automation to run the game and gather PSOs used by device across the map, load cosmetics, fire weapons, etc.

We also store PSOs created during daily playtests

Not perfect, but…

- Number of PSOs created during gameplay is in the single digits on average
- We only create a small subset of the permutation matrix on load

Resource Allocation

Creating resources on the fly can hitch due to streaming or creation of dynamic objects

Treat resource allocation like memory allocation and use the same strategies to minimize "malloc" and "free"

We use a binned allocation strategy for smaller allocations

Programmable Blending

Optimization to reduce the number of resolves and restores for features that need to read the depth buffer, e.g. decals and soft particle blending

During forward pass, write linear depth to alpha channel (we render to FP16 render target)

During decal and translucent passes, if needed, read [[color(0)]] .a as linear depth

Programmable Blending

MSAA resolve happens before postprocessing and tonemapping

Bilinear filtering of HDR values can lead to very aliased edges, e.g. dark ceiling in shadow against a bright sky

10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10
0.1	10	10	10	10	10	10	10
0.1	0.1	0.1	10	10	10	10	10
0.1	0.1	0.1	0.1	0.1	10	10	10
0.1	0.1	0.1	0.1	0.1	0.1	0.1	10
0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

10	10	10	10
2.575	7.525	10	10
0.1	0.1	2.575	7.525
0.1	0.1	0.1	0.1

0.909	0.909	0.909	0.909
0.72	0.883	0.909	0.909
0.091	0.091	0.72	0.883
0.091	0.091	0.091	0.091

100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100
0.1	100	100	100	100	100	100	100
0.1	0.1	0.1	100	100	100	100	100
0.1	0.1	0.1	0.1	0.1	100	100	100
0.1	0.1	0.1	0.1	0.1	0.1	0.1	100
0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

100	100	100	100
25.08	75.03	100	100
0.1	0.1	25.08	75.03
0.1	0.1	0.1	0.1

0.99	0.99	0.99	0.99
0.962	0.987	0.99	0.99
0.091	0.091	0.962	0.987
0.091	0.091	0.091	0.091

Programmable Blending

Solution

- Pre-tonemap before resolve
- Perform the normal MSAA resolve
- The first postprocessing pass reverses the "pre-tonemap"

Use programmable blending for the pre-tonemap pass to avoid resolving the MSAA color buffer to memory!

100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100
0.1	100	100	100	100	100	100	100
0.1	0.1	0.1	100	100	100	100	100
0.1	0.1	0.1	0.1	0.1	100	100	100
0.1	0.1	0.1	0.1	0.1	0.1	0.1	100
0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

0.99	0.99	0.99	0.99
0.962	0.987	0.99	0.99
0.091	0.091	0.962	0.987
0.091	0.091	0.091	0.091

0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
0.091	0.99	0.99	0.99	0.99	0.99	0.99	0.99
0.091	0.091	0.091	0.99	0.99	0.99	0.99	0.99
0.091	0.091	0.091	0.091	0.091	0.99	0.99	0.99
0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.99
0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091
0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091

0.99	0.99	0.99	0.99
0.316	0.765	0.99	0.99
0.091	0.091	0.316	0.765
0.091	0.091	0.091	0.091

Future Metal Work

Parallel Rendering

On macOS we generate command buffers in parallel

- Not using parallel command encoders right now, separate command buffers easier to integrate in existing parallel rendering architecture
- Parallel command encoders would be needed on iOS

Experiment with parallel rendering on iOS

- For example, rendering thread on fast core versus four encoding threads on efficient cores

Metal Heaps

Use MTLHeap instead of buffer sub-allocation

Would also reduce hitches due to texture streaming

Requires precise fences, particularly which stages read which resources

- Full barriers between passes underutilize the GPU
- Requires some rework of our rendering architecture to make this bulletproof

Continue to Push High End Graphics on iOS

Metal 2 for Game Rendering

Summary

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Leverage multi-core CPUs

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Control memory and GPU concurrency for advanced performance needs

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Move CPU work to the GPU

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Control memory and GPU concurrency for advanced performance needs

Move CPU work to the GPU

Control tile memory on A11 for high performance and extended playtime

More Information

https://developer.apple.com/wwdc18/607

Metal for Games Lab	Technology Lab 5	Thursday 12:00PM

WWDC18