Graphics and Games

#WWDC15

What's New in Metal, Part 2

Session 607

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Anna Tikhonova GPU Software Frameworks Engineer

Metal at WWDC

What's New in Metal, Part 1

- Metal in Review
- New Features
- Metal and App Thinning

What's New in Metal, Part 2

- Introducing MetalKit
- Metal Perfomance Shaders

Metal Performance Optimization Techniques

- Metal System Trace Tool
- Metal Best Practices

Metal at WWDC

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MetalKit

Utility functionality for Metal Apps

MetalKit

NEW

MetalKit

NEW

MetalKit provides efficient implementations for commonly used scenarios

- Less effort to get up and rendering
- Increased performance and stability

MetalKit

Overview

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MetalKit View

- Unified view class for rendering Metal scenes

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Texture Loader

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Model I/O Integration

- Load and manage mesh data for Metal rendering

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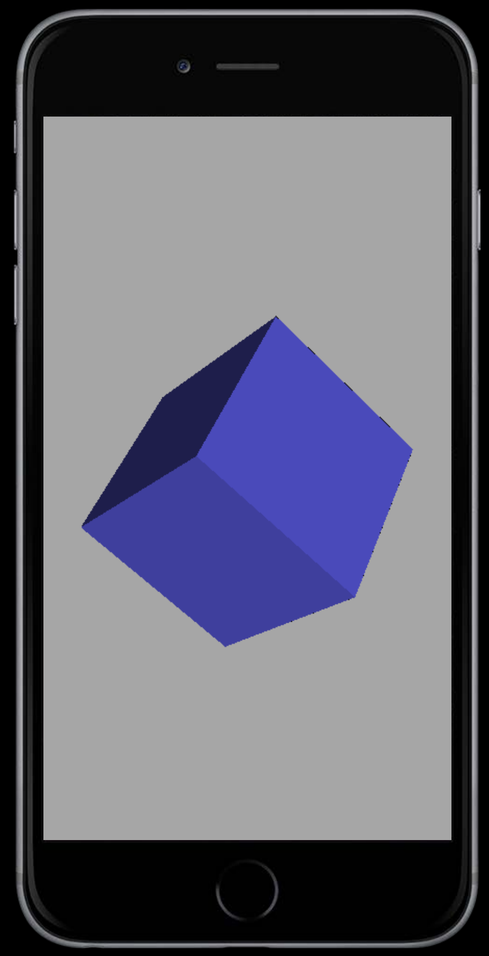
Simplest way to get Metal rendering on screen



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Unified between iOS and OS X

- Subclass of UIView for iOS
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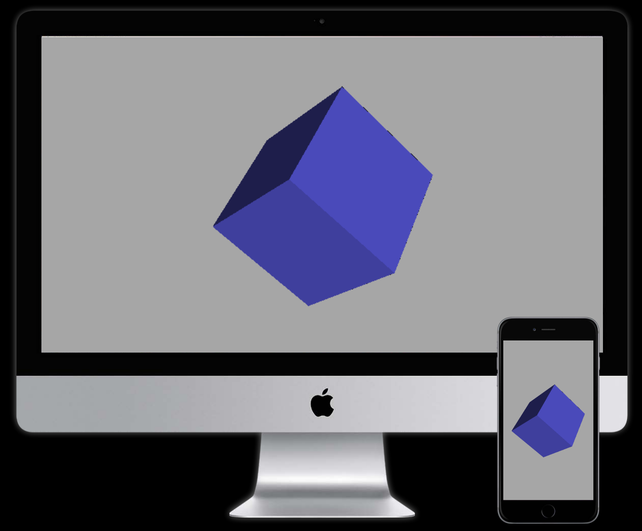

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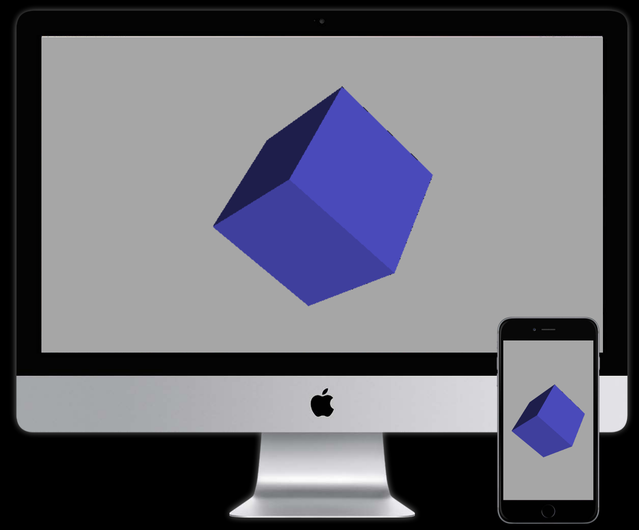
Manages render targets

- Creates render pass descriptors



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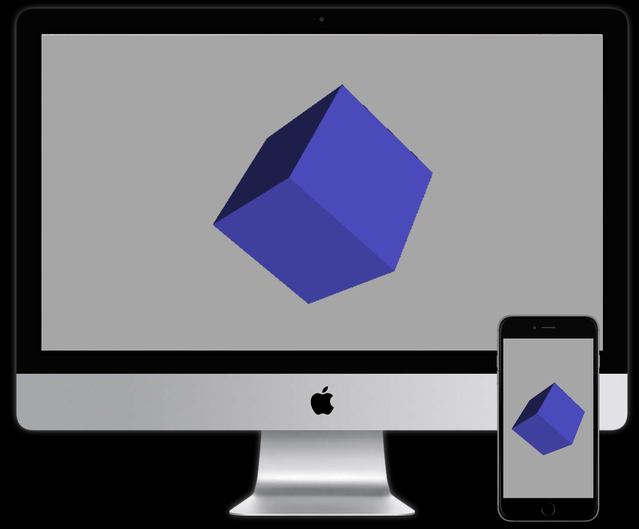
Multiple draw loop modes supported

- Timer, event, or explicitly driven draw loop



MetalKit View Setup

Approaches to using MTKView

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A. Implement a delegate

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B. Subclass MTKView

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```
- (void)drawRect:(CGRect)rect
- (void)layoutSubviews
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- OS X

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MetalKit View Setup

Initializing view properties

```
- (void)viewDidLoad
{
    MTKView *view = (MTKView *)self.view;

    view.delegate = self;

    view.device = device;

    view.colorPixelFormat = MTLPixelFormatBGRA8Unorm_sRGB;
    view.depthStencilPixelFormat = MTLPixelFormatDepth32Float_Stencil8;
    view.sampleCount = 4;
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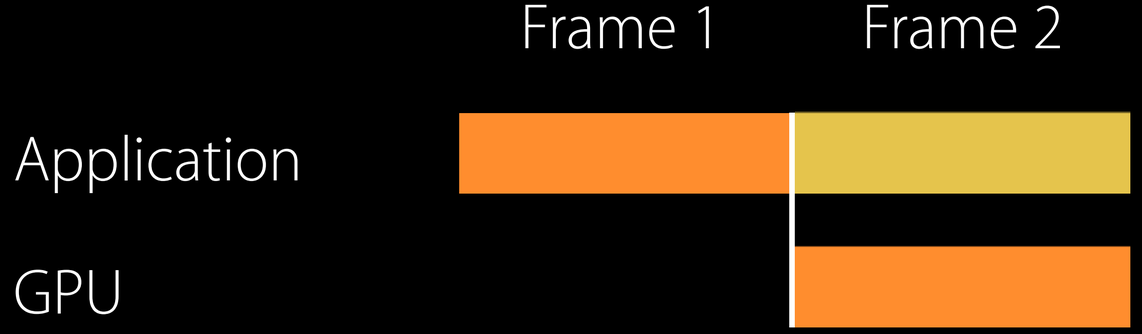

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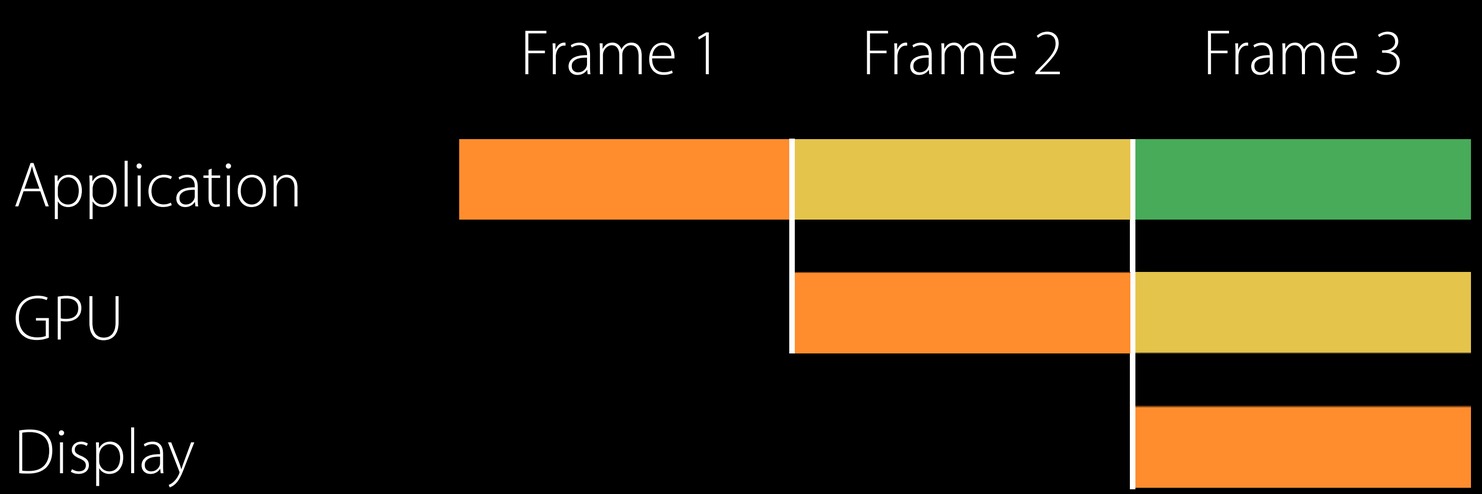

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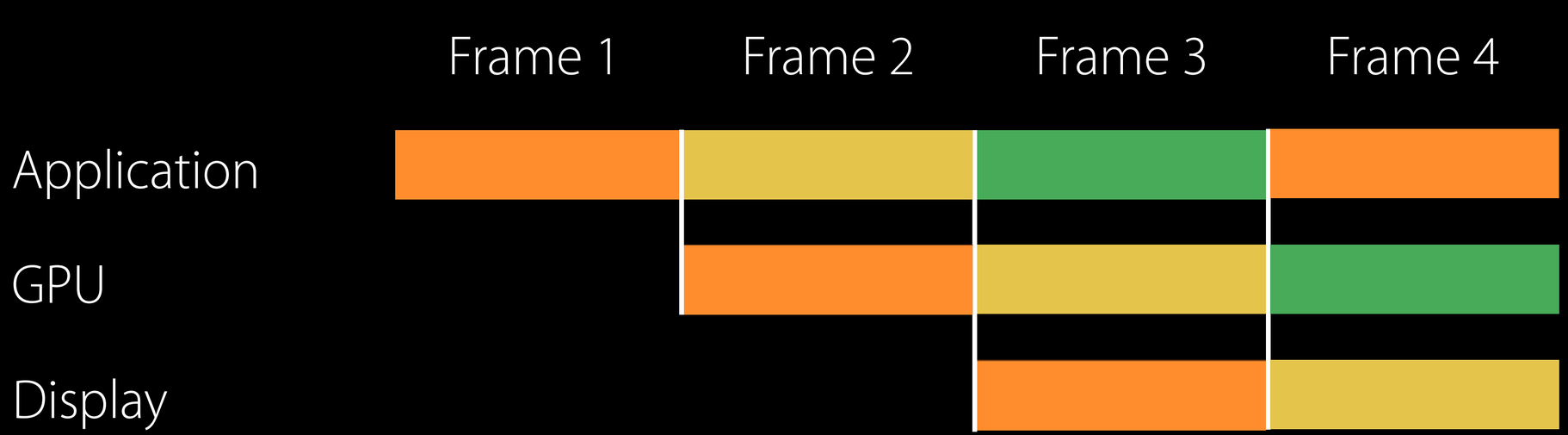

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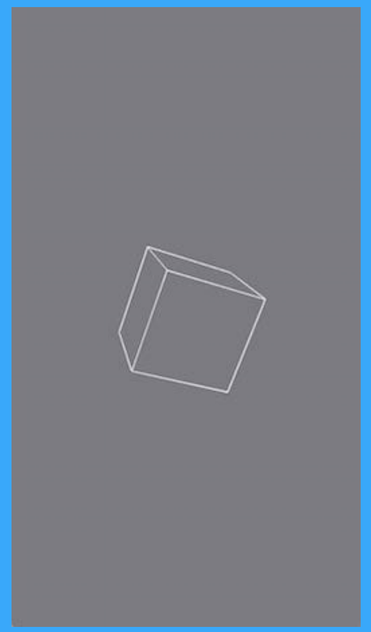

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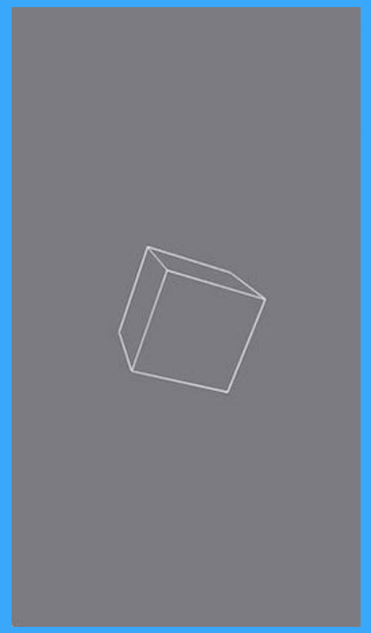

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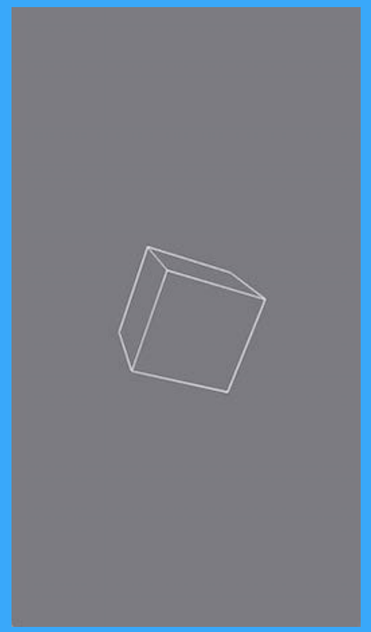

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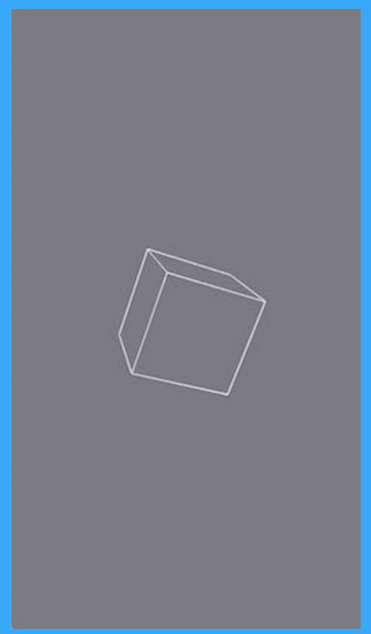

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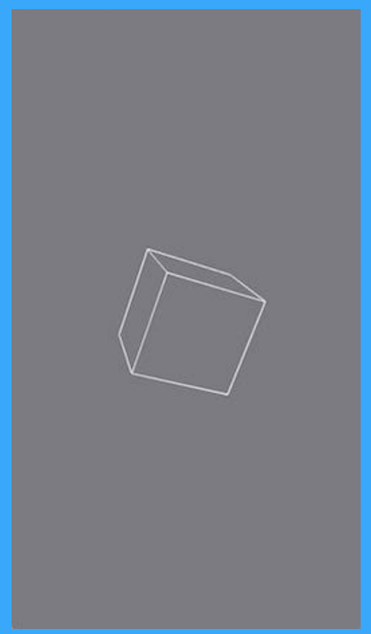

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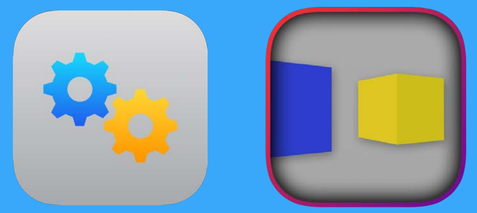

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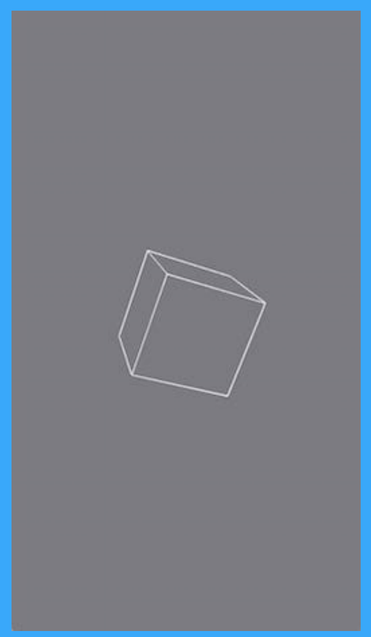

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MetalKit Texture Loader

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Texture loading made simple

- Give a reference, get a Metal texture

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Texture loading made simple

- Give a reference, get a Metal texture

Fast and fully featured

- Asynchronously decodes files and creates textures
- Support for common image file formats including JPG, TIFF, and PNG
- Also support for PVR and KTX texture file formats

Texture Loader

Basic usage

1. Initialize with Metal device

```
MTKTextureLoader *textureLoader =
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2. Load texture

```
[textureLoader textureWithContentsOfURL:fileURL
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- Static ambient occlusion
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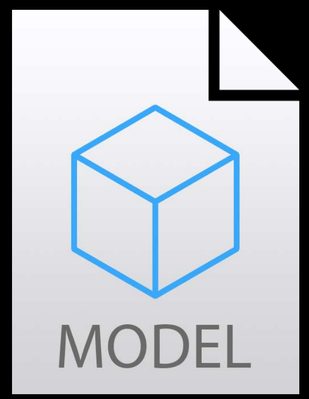
Allows you to focus on your rendering code

MetalKit and Model I/O

Utilities to efficiently use Model I/O with Metal

- Optimized loading of Model I/O meshes into Metal buffers
- Encapsulation of mesh data for Metal
- Functions to prepare mesh data for Metal pipelines

Rendering a Model I/O Asset



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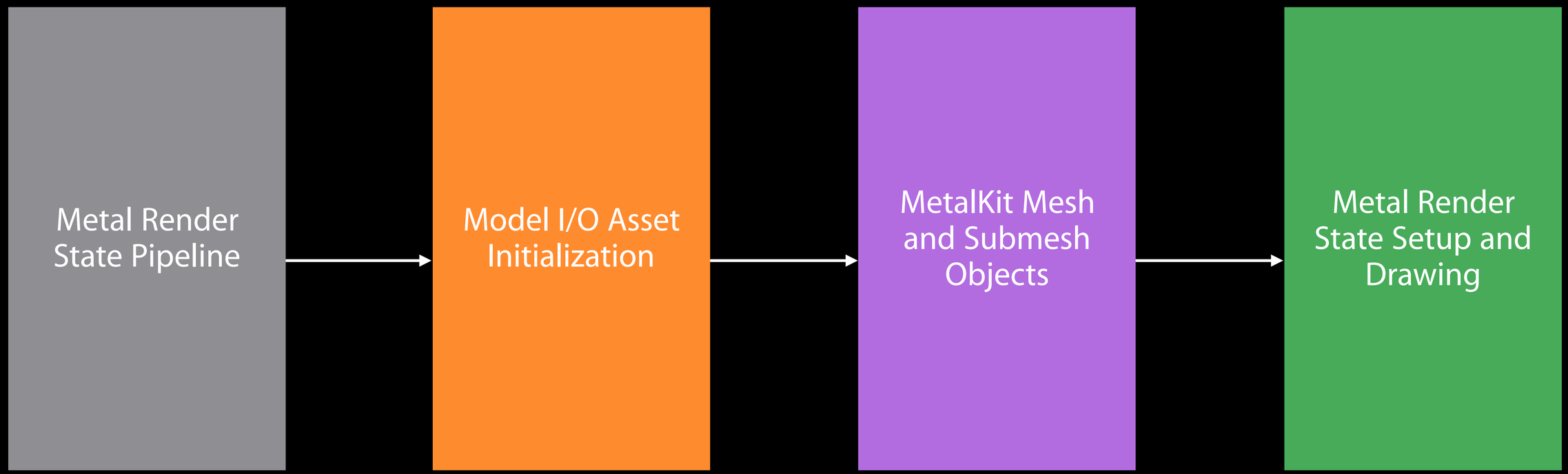

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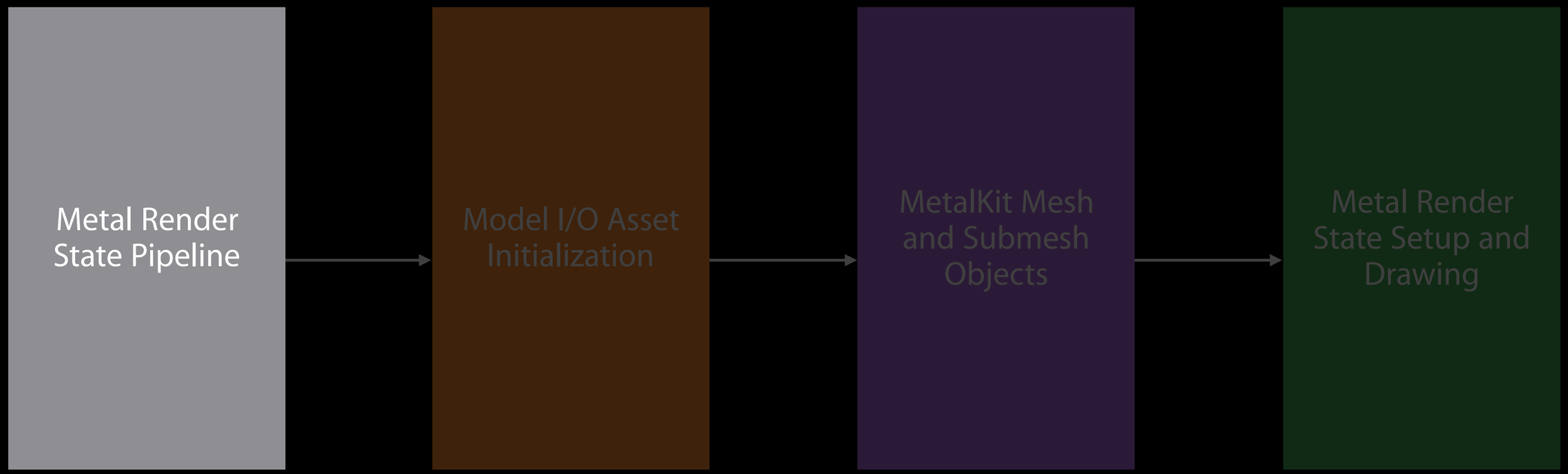

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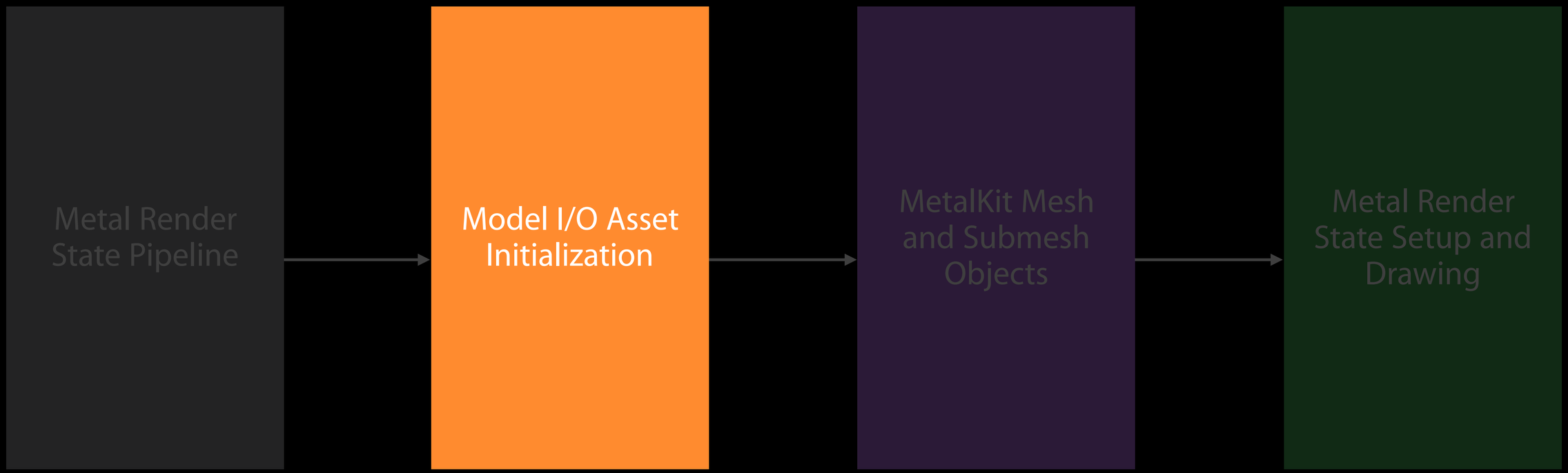

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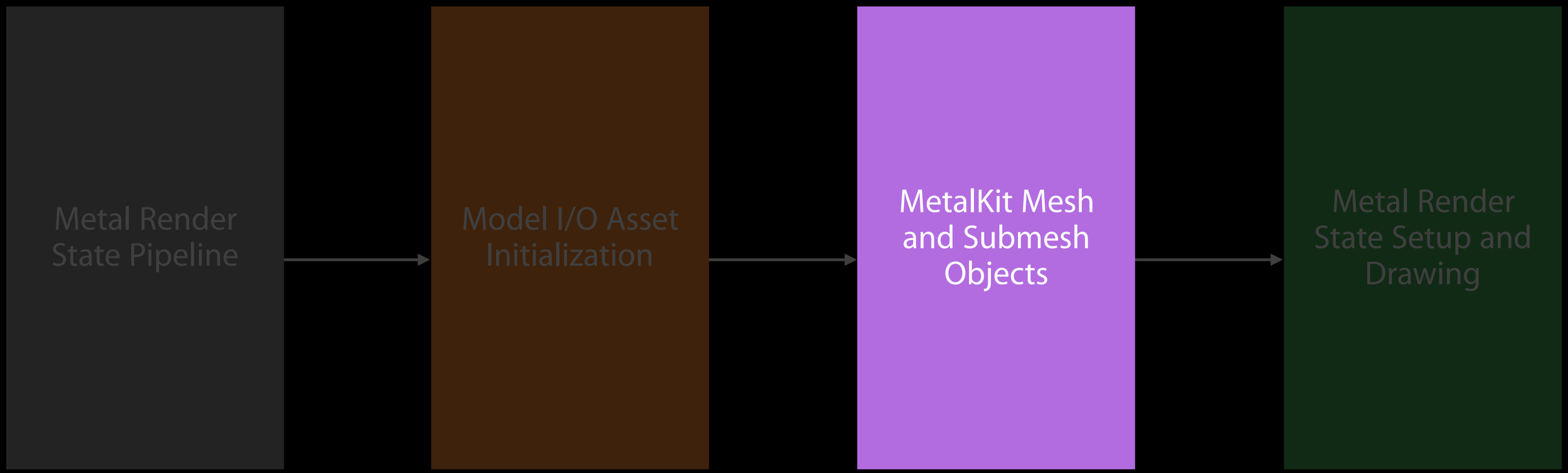

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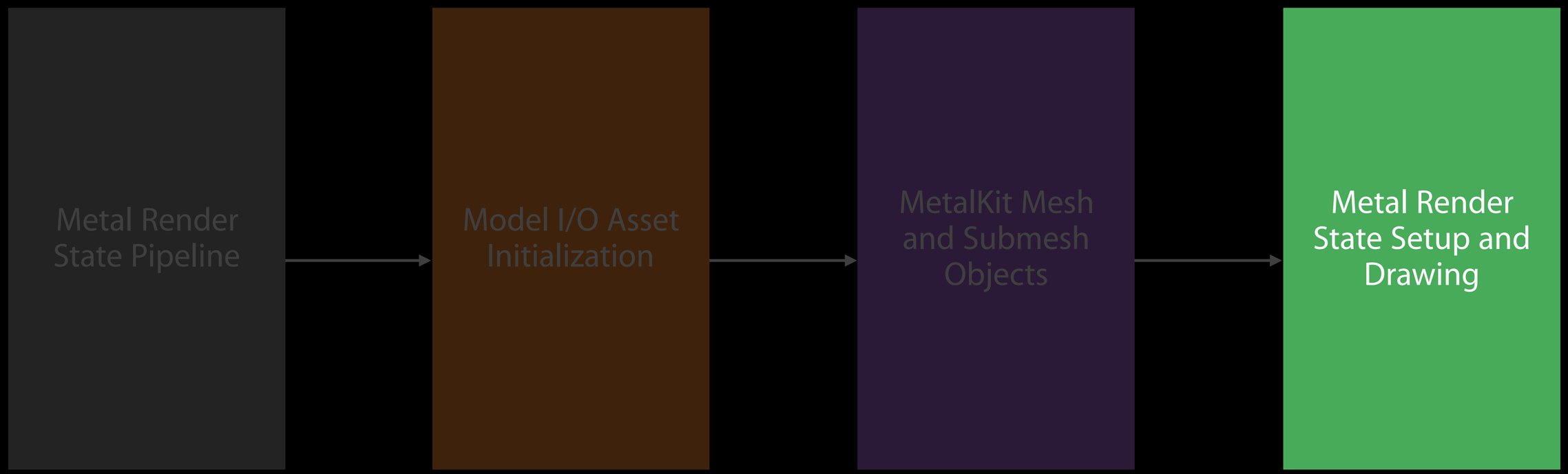
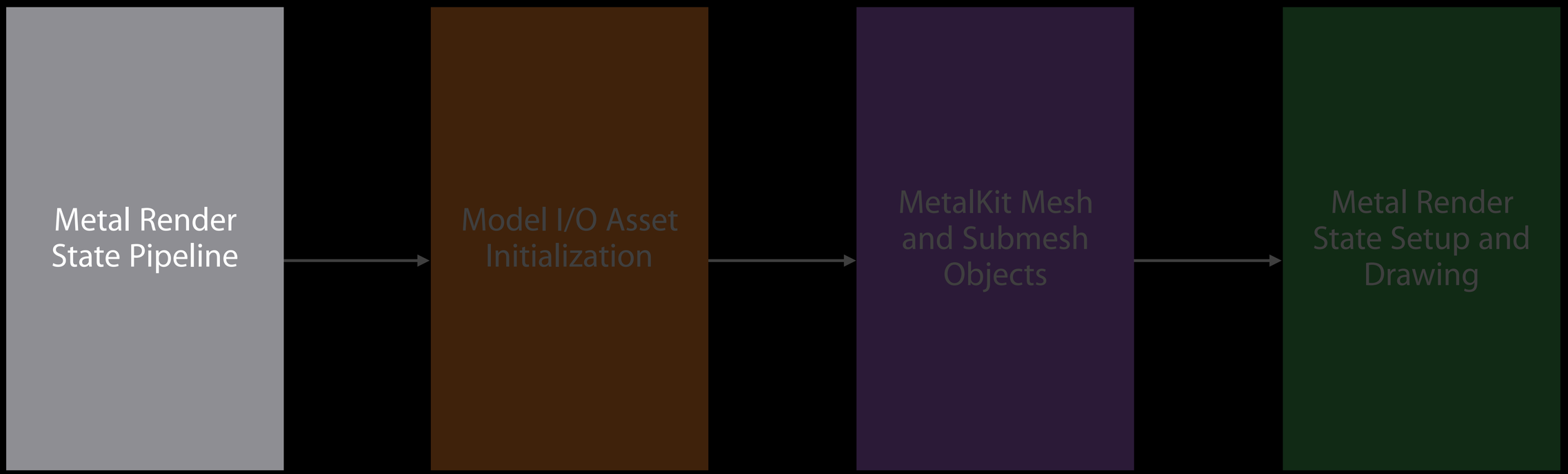


Setup for Model Rendering

Pipeline setup



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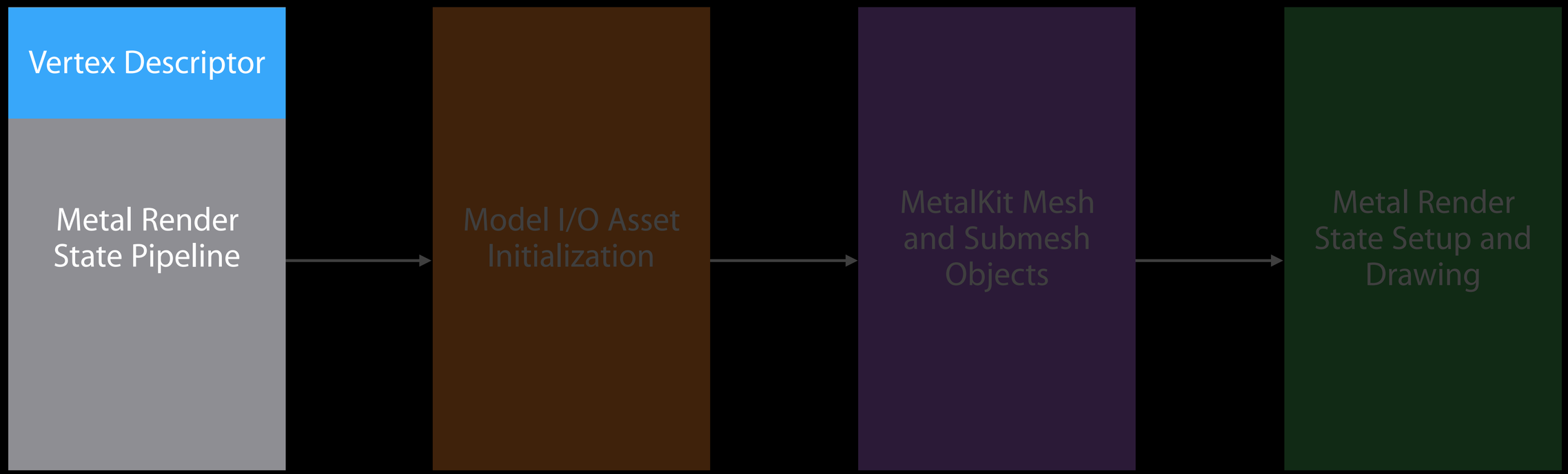

Vertex Shader

Setting up Per-Vertex Inputs

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struct VertexInput {
    float3  position [[ attribute(0) ]];
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vertex VertexOutput
vertexFunction(VertexInput current [[ stage_in ]])
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```

Vertex Shader

Setting up Per-Vertex Inputs

```
struct VertexInput {
    float3  position [[ attribute(0) ]];
    float4  color    [[ attribute(1) ]];
    float2  texUV    [[ attribute(2) ]];
};

vertex VertexOutput
vertexFunction(VertexInput current [[ stage_in ]])
{
   ...
}
```

Vertex Shader

Setting up Per-Vertex Inputs

```
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    float4  color    [[ attribute(1) ]];
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vertexFunction(VertexInput current [[ stage_in ]])
{
   ...
}
```

Vertex Shader

Setting up Per-Vertex Inputs

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struct VertexInput {
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    float4  color    [[ attribute(1) ]];
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};

vertex VertexOutput
vertexFunction(VertexInput current [[ stage_in ]])
{
   ...
}
```

```
struct VertexInput {
    float3  position [[ attribute(0) ]];
    float4  color    [[ attribute(1) ]];
    float2  texUV    [[ attribute(2) ]];
};
```

```
struct VertexInput {
    float3  position [[ attribute(0) ]];
    float4  color    [[ attribute(1) ]];
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};
```

```
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    float3  position [[ attribute(0) ]];
    float4  color    [[ attribute(1) ]];
    float2  texUV    [[ attribute(2) ]];
};
```

```
struct VertexInput {
    float3  position [[ attribute(0) ]];
    float4  color    [[ attribute(1) ]];
    float2  texUV    [[ attribute(2) ]];
};
```

Vertex Descriptor

```
struct VertexInput {
    float3  position [[ attribute(0) ]];
    float4  color    [[ attribute(1) ]];
    float2  texUV    [[ attribute(2) ]];
};
```

```
MTLVertexDescriptor *metalVertexDesc = [MTLVertexDescriptor new];
```

Vertex Descriptor

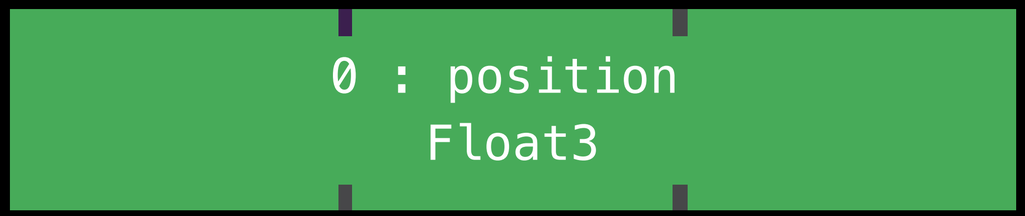
```
struct VertexInput {
    float3  position [[ attribute(0) ]];
    float4  color    [[ attribute(1) ]];
    float2  texUV    [[ attribute(2) ]];
};
```

```
metalVertexDesc.attributes[0].format = MTLVertexFormatFloat3;
metalVertexDesc.attributes[0].offset = 0;
```

Vertex Descriptor

```
struct VertexInput {
    float3  position [[ attribute(0) ]];
    float4  color    [[ attribute(1) ]];
    float2  texUV    [[ attribute(2) ]];
};
```

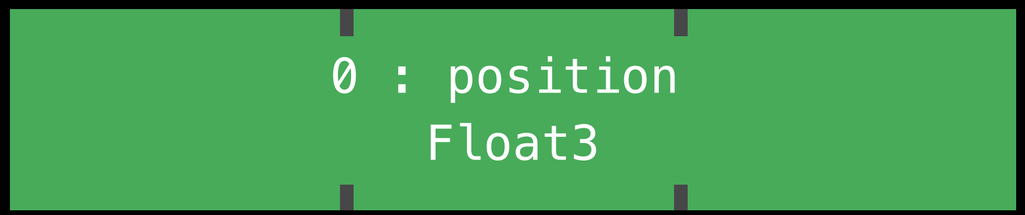
```
metalVertexDesc.attributes[0].format = MTLVertexFormatFloat3;
metalVertexDesc.attributes[0].offset = 0;
```



Vertex Descriptor

```
struct VertexInput {
    float3  position [[ attribute(0) ]];
    float4  color    [[ attribute(1) ]];
    float2  texUV    [[ attribute(2) ]];
};
```

```
metalVertexDesc.attributes[1].format = MTLVertexFormatUChar4Normalized;
metalVertexDesc.attributes[1].offset = 12;
```



Vertex Descriptor

```
struct VertexInput {
    float3  position [[ attribute(0) ]];
    float4  color    [[ attribute(1) ]];
    float2  texUV    [[ attribute(2) ]];
};
```

```
metalVertexDesc.attributes[1].format = MTLVertexFormatUChar4Normalized;
metalVertexDesc.attributes[1].offset = 12;
```

Vertex Descriptor

```
struct VertexInput {
    float3  position [[ attribute(0) ]];
    float4  color    [[ attribute(1) ]];
    float2  texUV    [[ attribute(2) ]];
};
```

```
metalVertexDesc.attributes[1].format = MTLVertexFormatUChar4Normalized;
metalVertexDesc.attributes[1].offset = 12;
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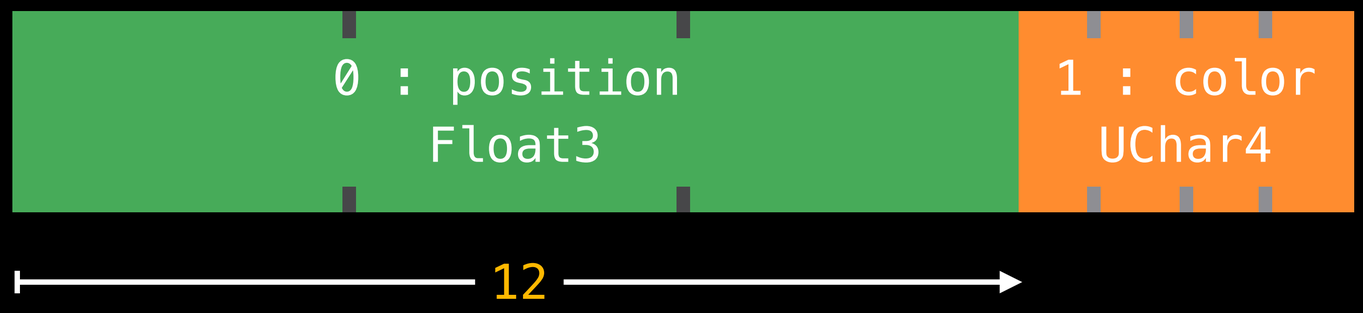
Vertex Descriptor

```
struct VertexInput {
    float3  position [[ attribute(0) ]];
    float4  color    [[ attribute(1) ]];
    float2  texUV    [[ attribute(2) ]];
};
```

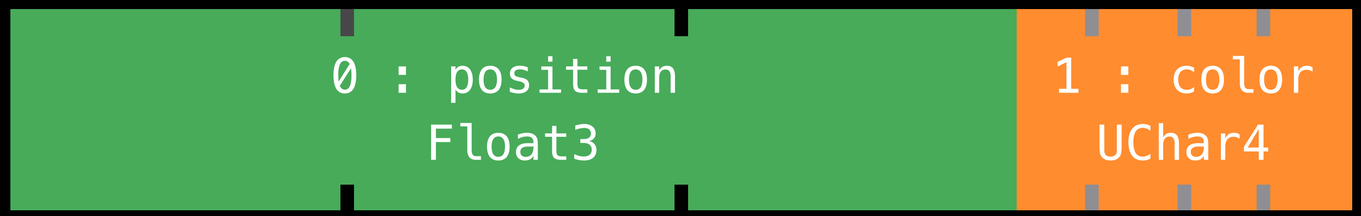
```
metalVertexDesc.attributes[1].format = MTLVertexFormatUChar4Normalized;
metalVertexDesc.attributes[1].offset = 12;
```



Vertex Descriptor

```
struct VertexInput {
    float3  position [[ attribute(0) ]];
    float4  color    [[ attribute(1) ]];
    float2  texUV    [[ attribute(2) ]];
};
```

```
metalVertexDesc.attributes[2].format = MTLVertexFormatHalfFloat2;
metalVertexDesc.attributes[2].offset = 16;
```



Vertex Descriptor

```
struct VertexInput {
    float3  position [[ attribute(0) ]];
    float4  color    [[ attribute(1) ]];
    float2  texUV    [[ attribute(2) ]];
};
```

```
metalVertexDesc.attributes[2].format = MTLVertexFormatHalfFloat2;
metalVertexDesc.attributes[2].offset = 16;
```

Vertex Descriptor

```
struct VertexInput {
    float3  position [[ attribute(0) ]];
    float4  color    [[ attribute(1) ]];
    float2  texUV    [[ attribute(2) ]];
};
```

```
metalVertexDesc.attributes[2].format = MTLVertexFormatHalfFloat2;
metalVertexDesc.attributes[2].offset = 16;
```

Vertex Descriptor

```
struct VertexInput {
    float3  position [[ attribute(0) ]];
    float4  color    [[ attribute(1) ]];
    float2  texUV    [[ attribute(2) ]];
};
```

```
metalVertexDesc.attributes[2].format = MTLVertexFormatHalfFloat2;
metalVertexDesc.attributes[2].offset = 16;
```

Vertex Descriptor

```
struct VertexInput {
    float3  position [[ attribute(0) ]];
    float4  color    [[ attribute(1) ]];
    float2  texUV    [[ attribute(2) ]];
};
```

```
metalVertexDesc.layouts[0].stride = 20;
```

Vertex Descriptor

```
struct VertexInput {
    float3  position [[ attribute(0) ]];
    float4  color    [[ attribute(1) ]];
    float2  texUV    [[ attribute(2) ]];
};
```

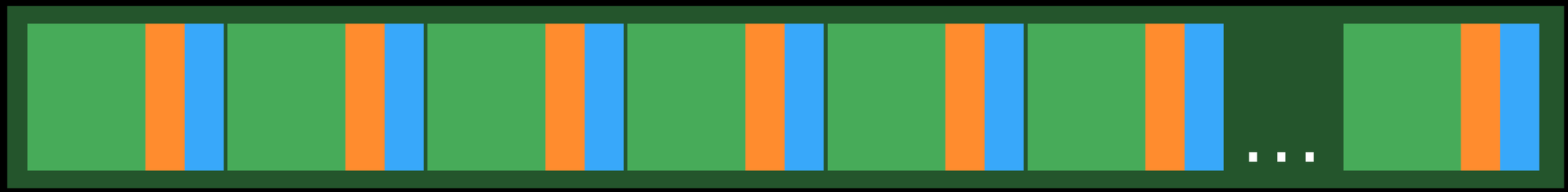
```
metalVertexDesc.layouts[0].stride = 20;
```

Vertex Array Layout

Vertex Array Layout

Vertex Array Layout

Vertex Array Layout



Building the Pipeline

```
renderPipelineDescriptor.vertexDescriptor = metalVertexDesc;
MTLRenderStatePipeline *pipeline =
    [device.newRenderPipelineStateWithDescriptor:renderPipelineDescriptor
                                           error:error];
```

Building the Pipeline

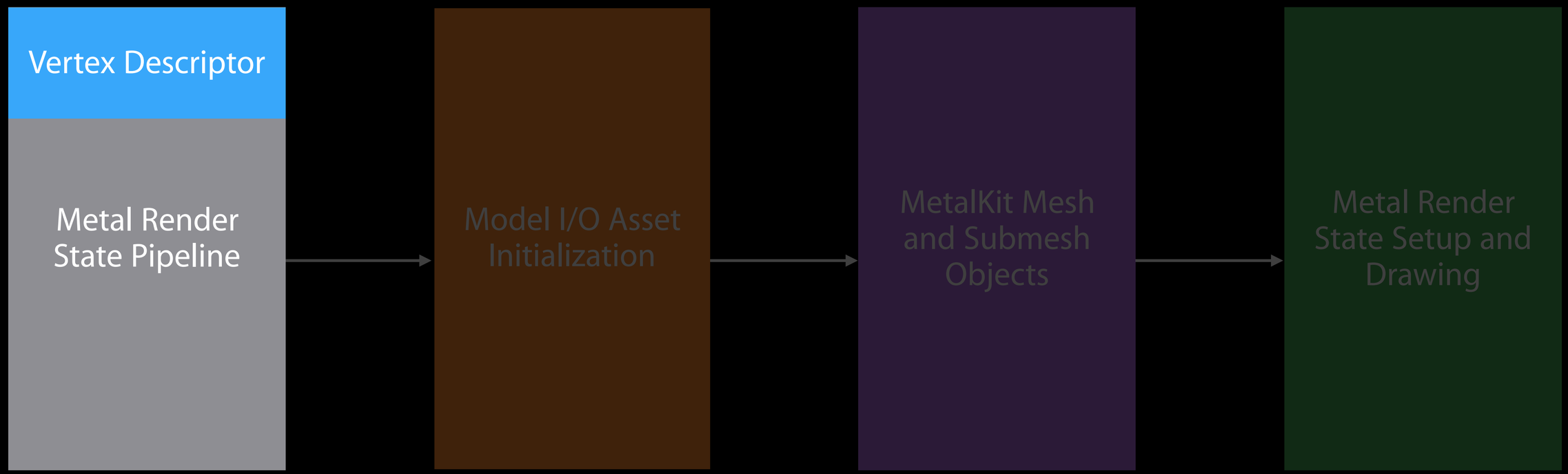
```
renderPipelineDescriptor.vertexDescriptor = metalVertexDesc;
MTLRenderStatePipeline *pipeline =
    [device.newRenderPipelineStateWithDescriptor:renderPipelineDescriptor
                                           error:error];
```

Building the Pipeline

```
renderPipelineDescriptor.vertexDescriptor = metalVertexDesc;
MTLRenderStatePipeline *pipeline =
    [device.newRenderPipelineStateWithDescriptor:renderPipelineDescriptor
                                           error:error];
```

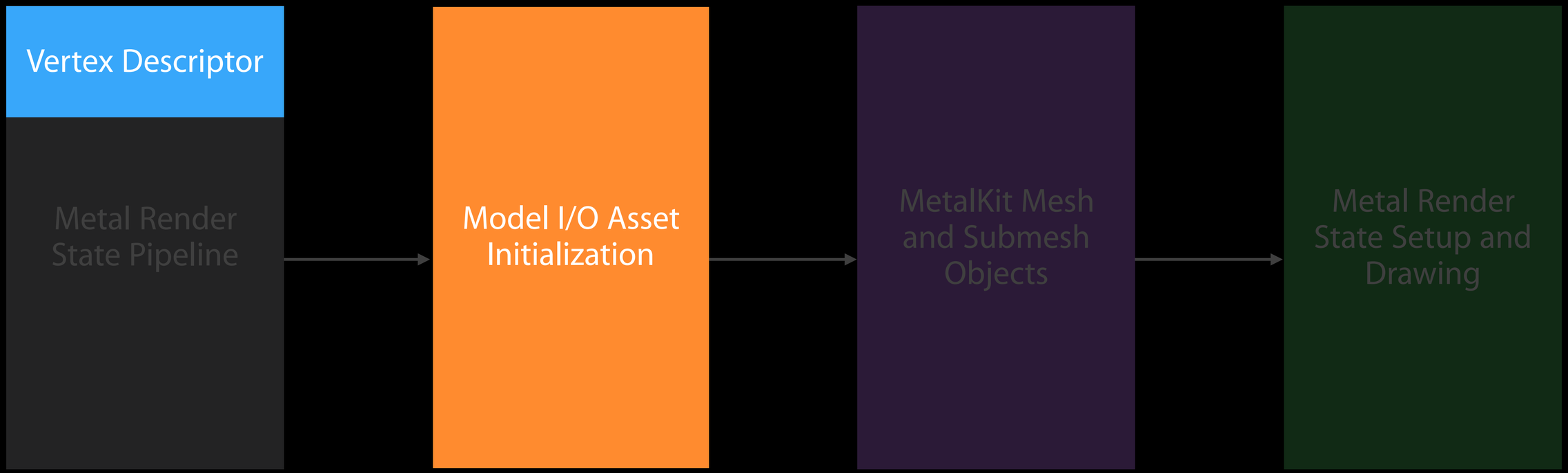
Setup for Model Rendering

Asset initialization



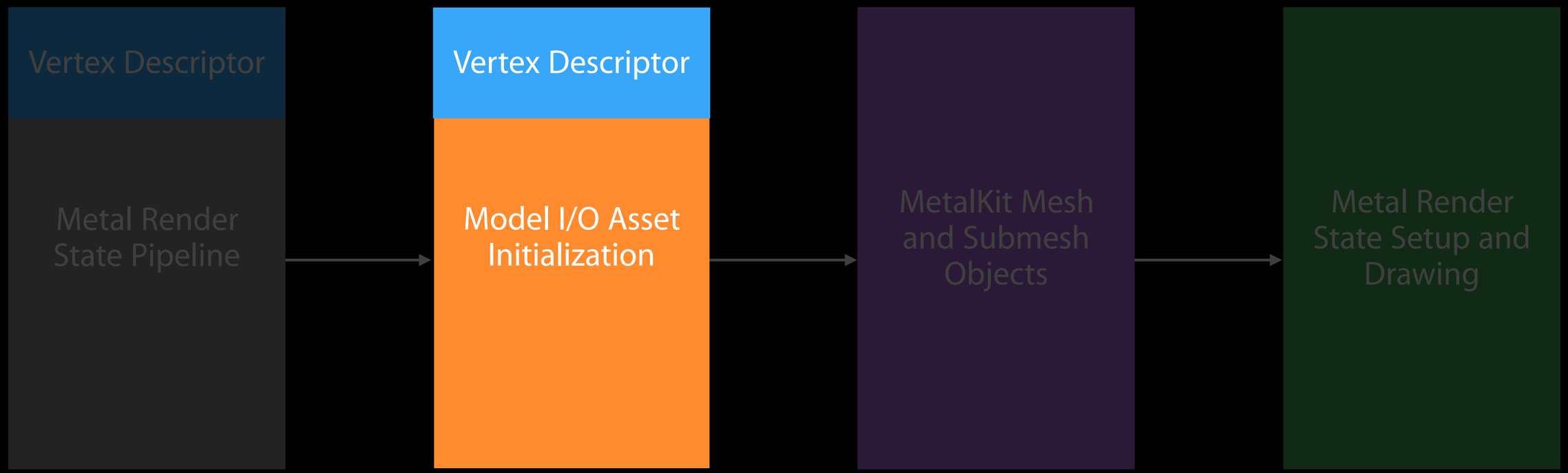
Setup for Model Rendering

Asset initialization



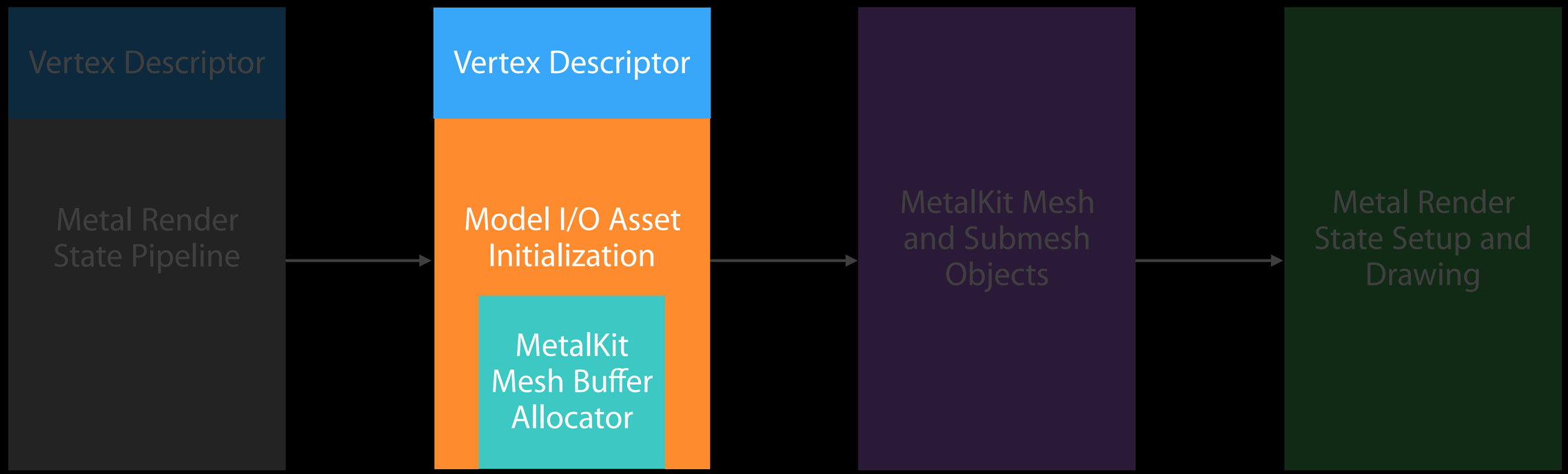
Setup for Model Rendering

Asset initialization



Setup for Model Rendering

Asset initialization



Asset Initialization

Model I/O Vertex Descriptor vs. Metal Vertex Descriptor

Asset Initialization

Model I/O Vertex Descriptor vs. Metal Vertex Descriptor

Model I/O Vertex Descriptor

- Describes the layout of vertex attributes in a mesh

Asset Initialization

Model I/O Vertex Descriptor vs. Metal Vertex Descriptor

Model I/O Vertex Descriptor

- Describes the layout of vertex attributes in a mesh

Metal Vertex Descriptor

- Describes the layout of vertex attribute inputs to a render state pipeline

Asset Initialization

Model I/O Vertex Descriptor vs. Metal Vertex Descriptor

Model I/O Vertex Descriptor

- Describes the layout of vertex attributes in a mesh

Metal Vertex Descriptor

- Describes the layout of vertex attribute inputs to a render state pipeline

Intentionally designed to look similar

- Both contain an array of attribute and buffer layout objects
- Simplifies translation from one type to other

Asset Initialization

Defaults and layout efficiency

Each attribute in a Model I/O Vertex Descriptor has an identifying string-based name

- Model I/O assigns a default name if one does not exist in the model file
  - Names include `@“position”`, `@“normal”`, `@“textureCoordinate”`, and `@“color”`
  - Model I/O defines these with the string-based `MDLVertexAttribute` name constants

Asset Initialization

Defaults and layout efficiency

Each attribute in a Model I/O Vertex Descriptor has an identifying string-based name

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  - Names include `@“position”`, `@“normal”`, `@“textureCoordinate”`, and `@“color”`
  - Model I/O defines these with the string-based `MDLVertexAttribute` name constants

Custom `MDLVertexDescriptor` recommended

- By default, Model I/O loads vertices as high-precision floating point types
- Feed pipelines with the smallest type that meets your precision requirements
- Improves vertex bandwidth efficiency

Asset Initialization

Asset Initialization


```
MDLVertexDescriptor *modelIOVertexDesc =
    MTKModelIOVertexFormatFromMetal(metalVertexDesc);

modelIOVertexDesc.attributes[0].name = MDLVertexAttributePosition;
modelIOVertexDesc.attributes[1].name = MDLVertexAttributeColor;
modelIOVertexDesc.attributes[2].name = MDLVertexAttributeTextureCoordinate;
```

Asset Initialization


```
MDLVertexDescriptor *modelIOVertexDesc =
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modelIOVertexDesc.attributes[0].name = MDLVertexAttributePosition;
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Asset Initialization


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MDLVertexDescriptor *modelIOVertexDesc =
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MDLVertexDescriptor *modelIOVertexDesc =
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modelIOVertexDesc.attributes[2].name = MDLVertexAttributeTextureCoordinate;
```

Asset Initialization

MetalKit Mesh Buffer Allocator

```
MTKMeshBufferAllocator *mtkBufferAllocator =
    [[MTKMeshBufferAllocator alloc] initWithDevice:metalDevice];
```

Asset Initialization

Creating the Asset Object

```
MDLAsset *asset = [[MDLAsset alloc] initWithURL:fileURL
                                vertexDescriptor:modelioVertexDesc
                                 bufferAllocator:mtkBufferAllocator];
```

Asset Initialization

Creating the Asset Object

```
MDLAsset *asset = [[MDLAsset alloc] initWithURL:fileURL
                                vertexDescriptor:modelioVertexDesc
                                 bufferAllocator:mtkBufferAllocator];
```

Asset Initialization

Creating the Asset Object

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                                vertexDescriptor:modelioVertexDesc
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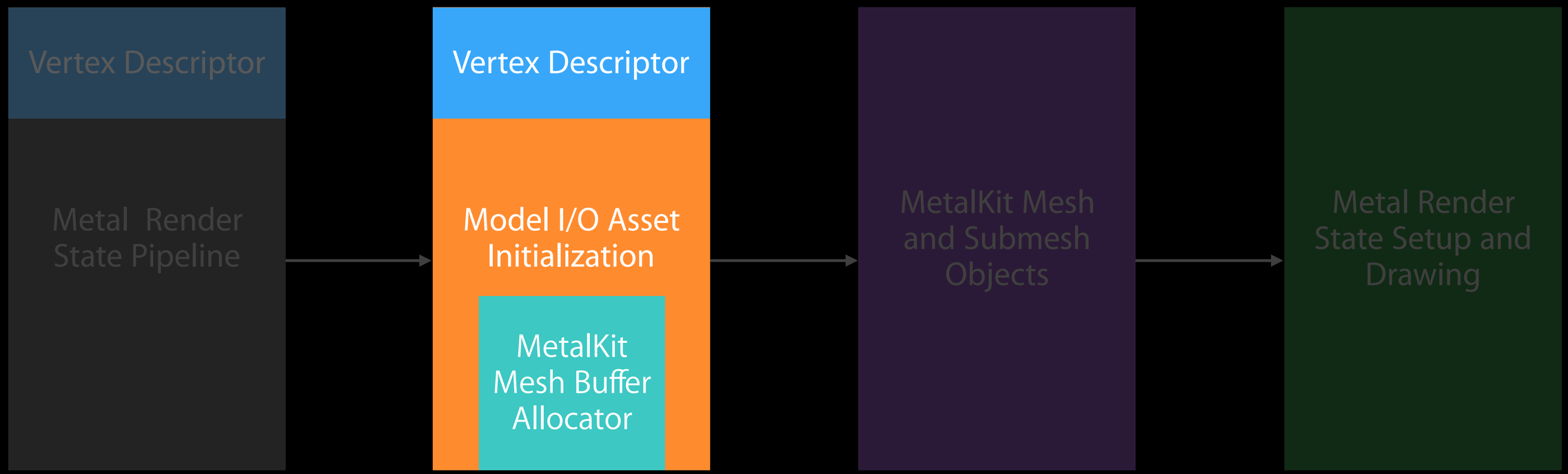
Asset Initialization

Creating the Asset Object

```
MDLAsset *asset = [[MDLAsset alloc] initWithURL:fileURL
                                vertexDescriptor:modelioVertexDesc
                                 bufferAllocator:mtkBufferAllocator];
```

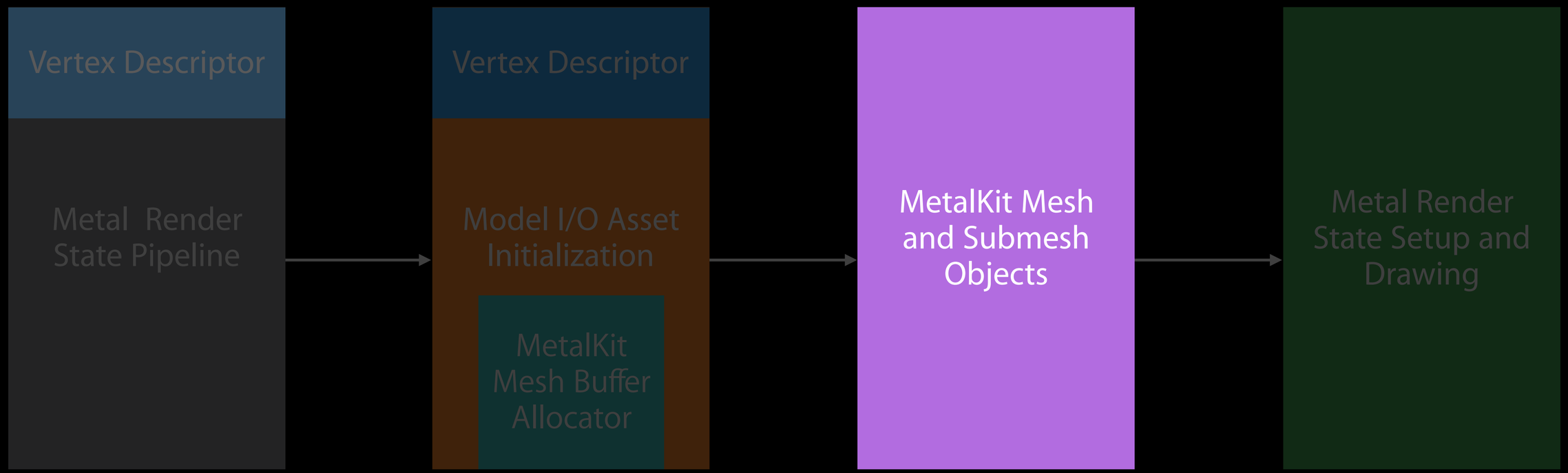
MetalKit Meshes Initialization

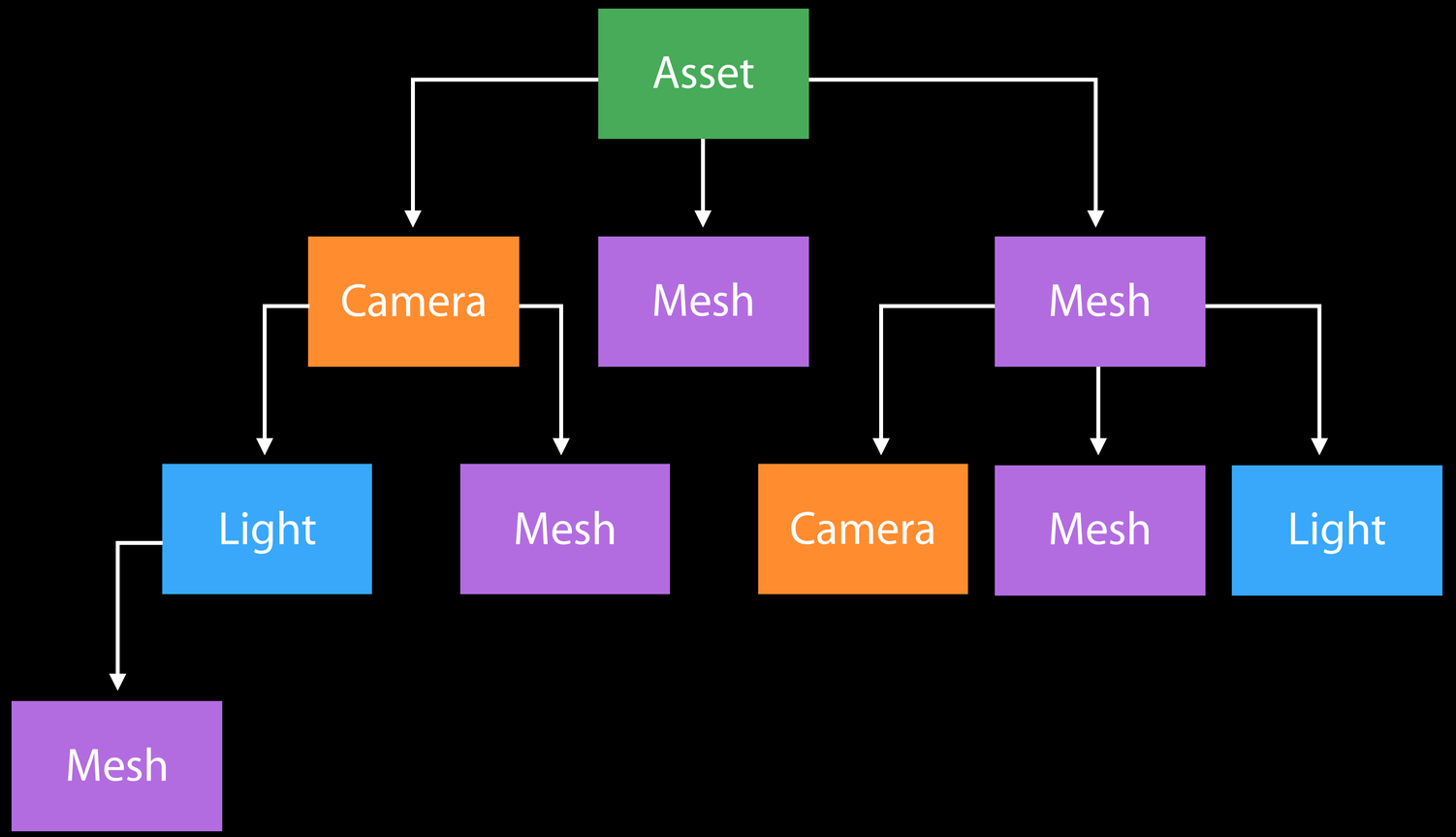
Setup for model rendering

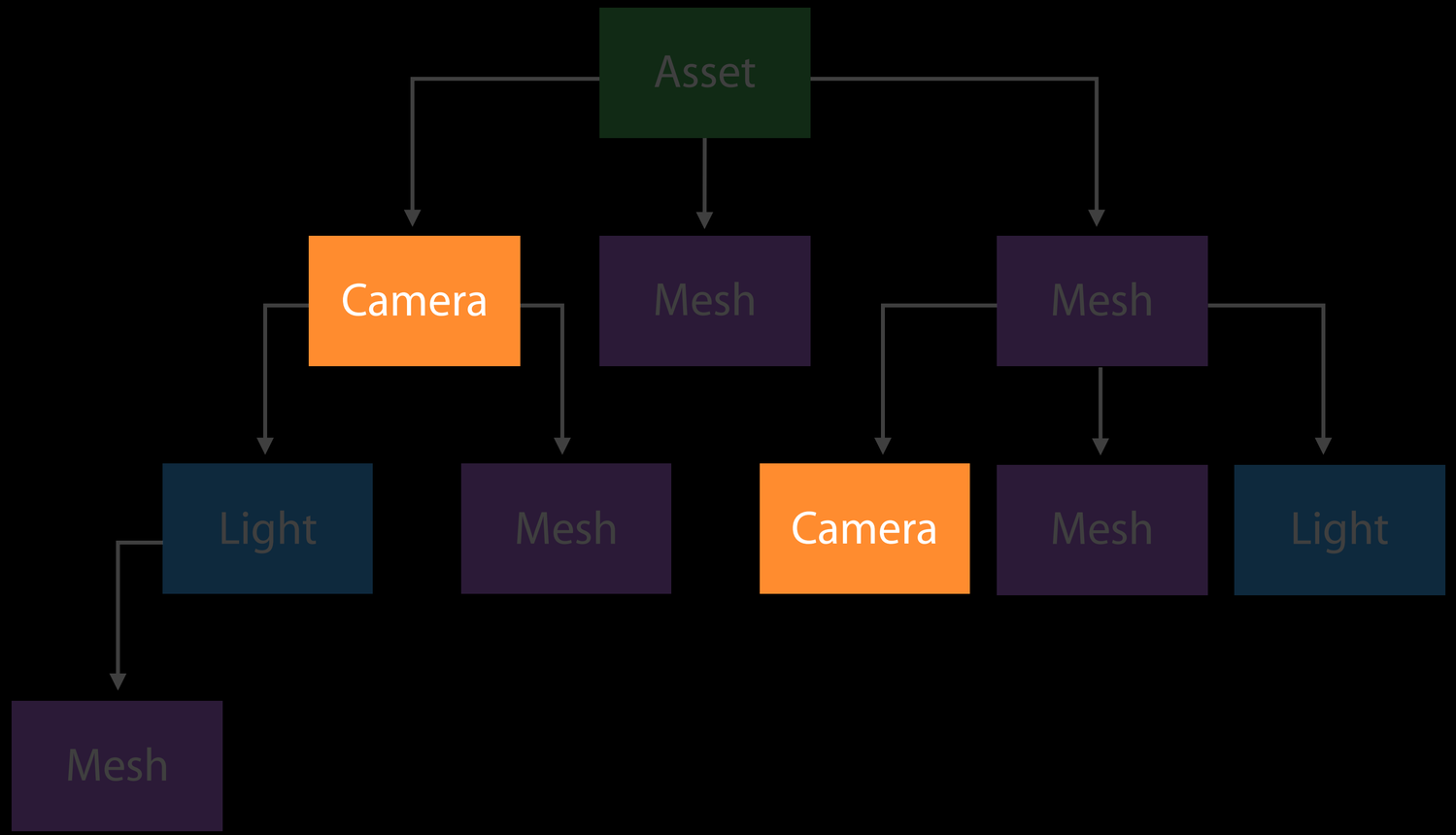


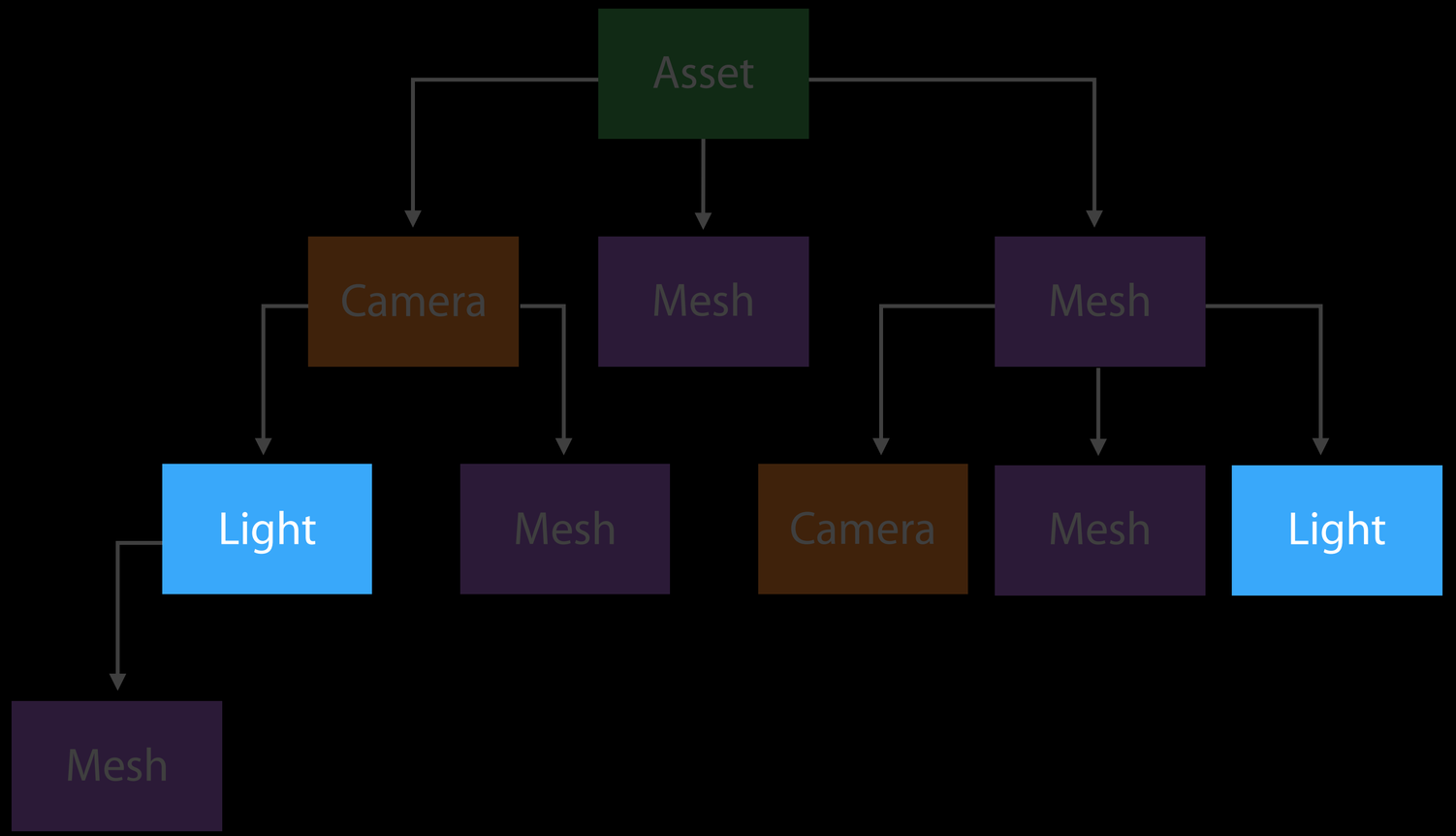
MetalKit Meshes Initialization

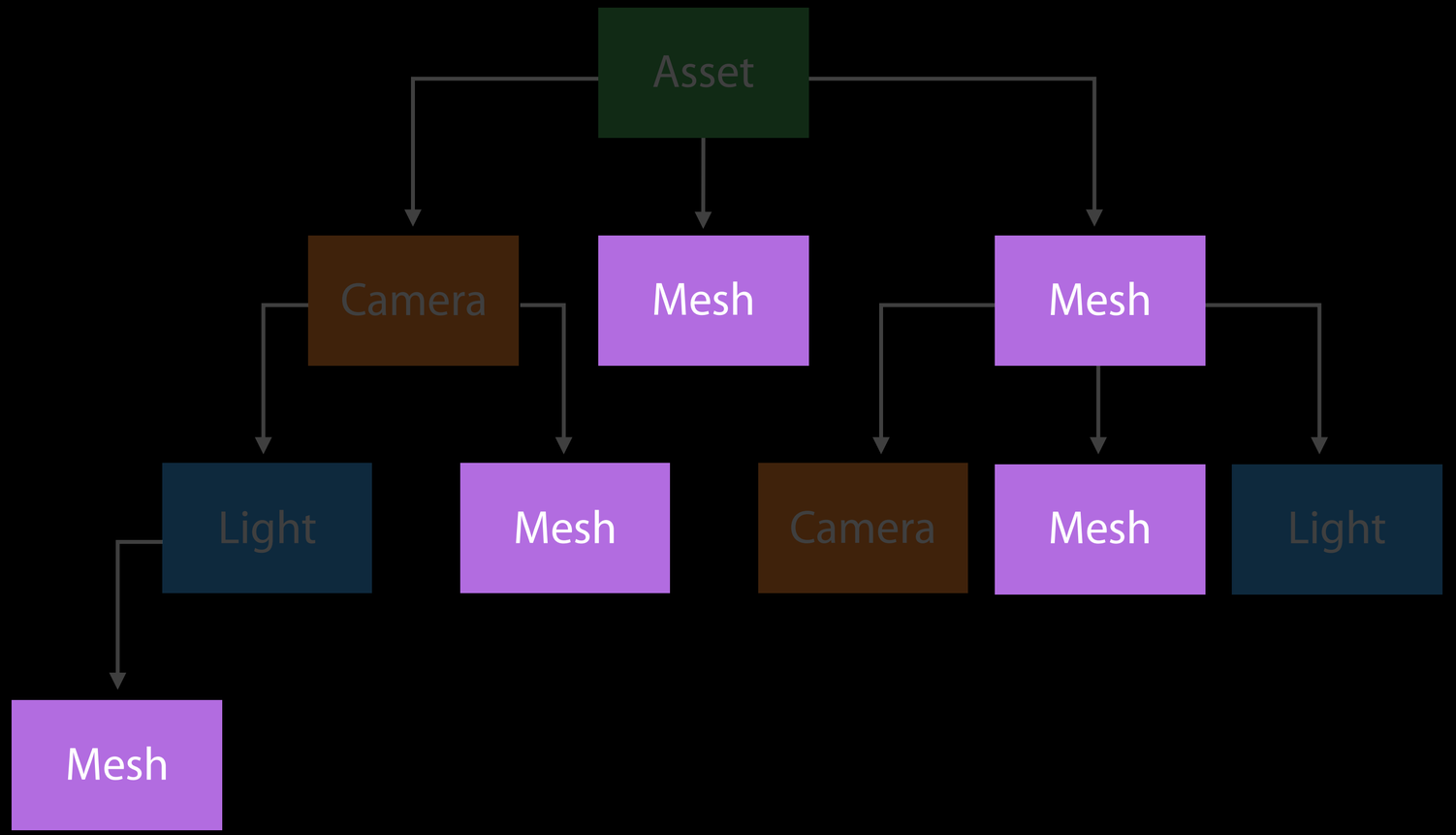
Setup for model rendering



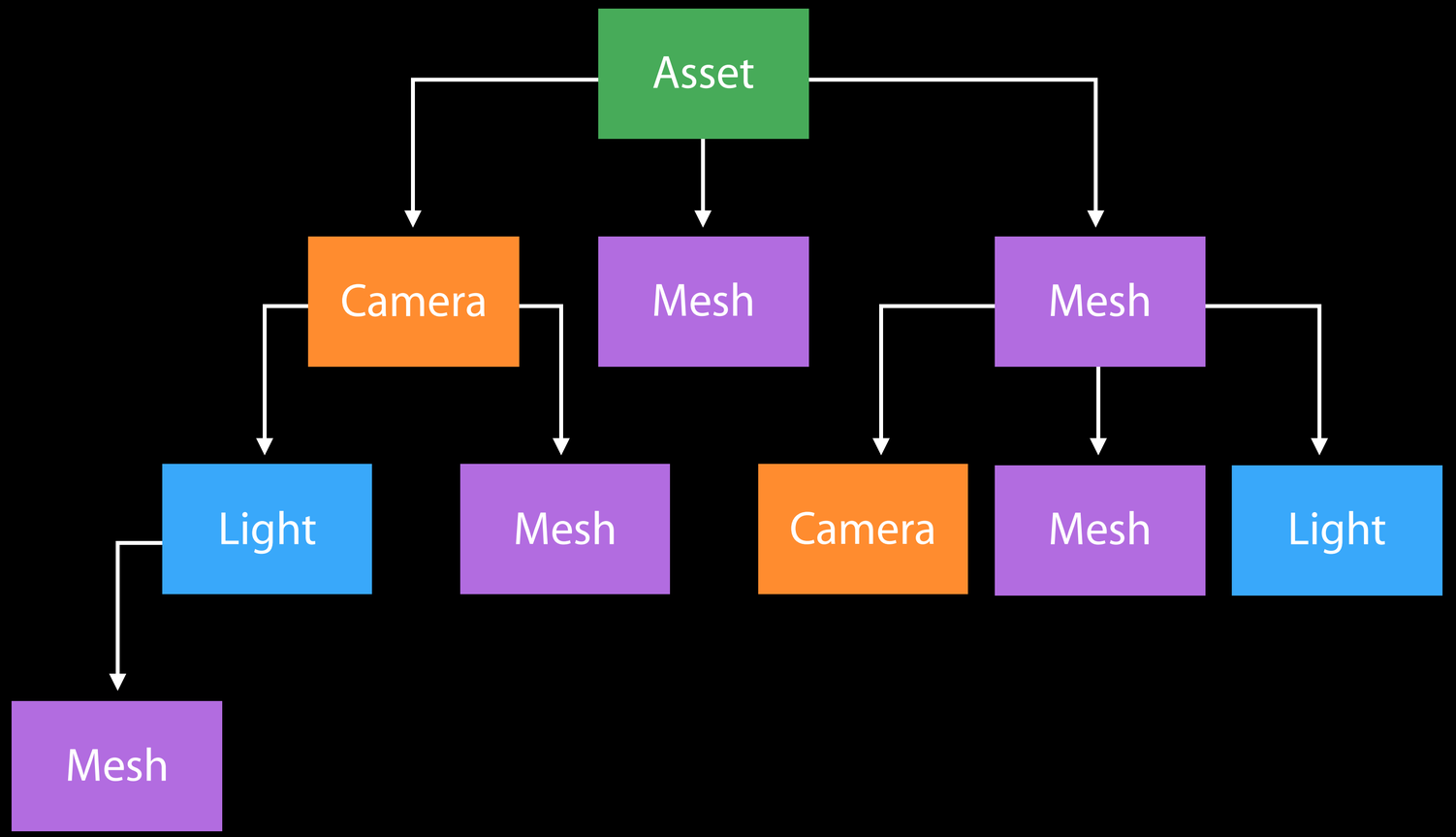

Asset
Camera
Mesh
Mesh
Light
Mesh
Camera
Mesh
Light
Mesh


Asset
Camera
Mesh
Mesh
Light
Mesh
Camera
Mesh
Light
Mesh


Asset
Camera
Mesh
Mesh
Light
Mesh
Mesh
Camera
Mesh
Light
Mesh


Asset
Camera
Mesh
Mesh
Light
Mesh
Camera
Mesh
Light
Mesh

```
NSArray<MTKMesh *> *meshes = [MTKMesh meshesFromAsset:asset device:device];
```



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NSArray<MTKMesh *> *meshes = [MTKMesh meshesFromAsset:asset device:device];
```

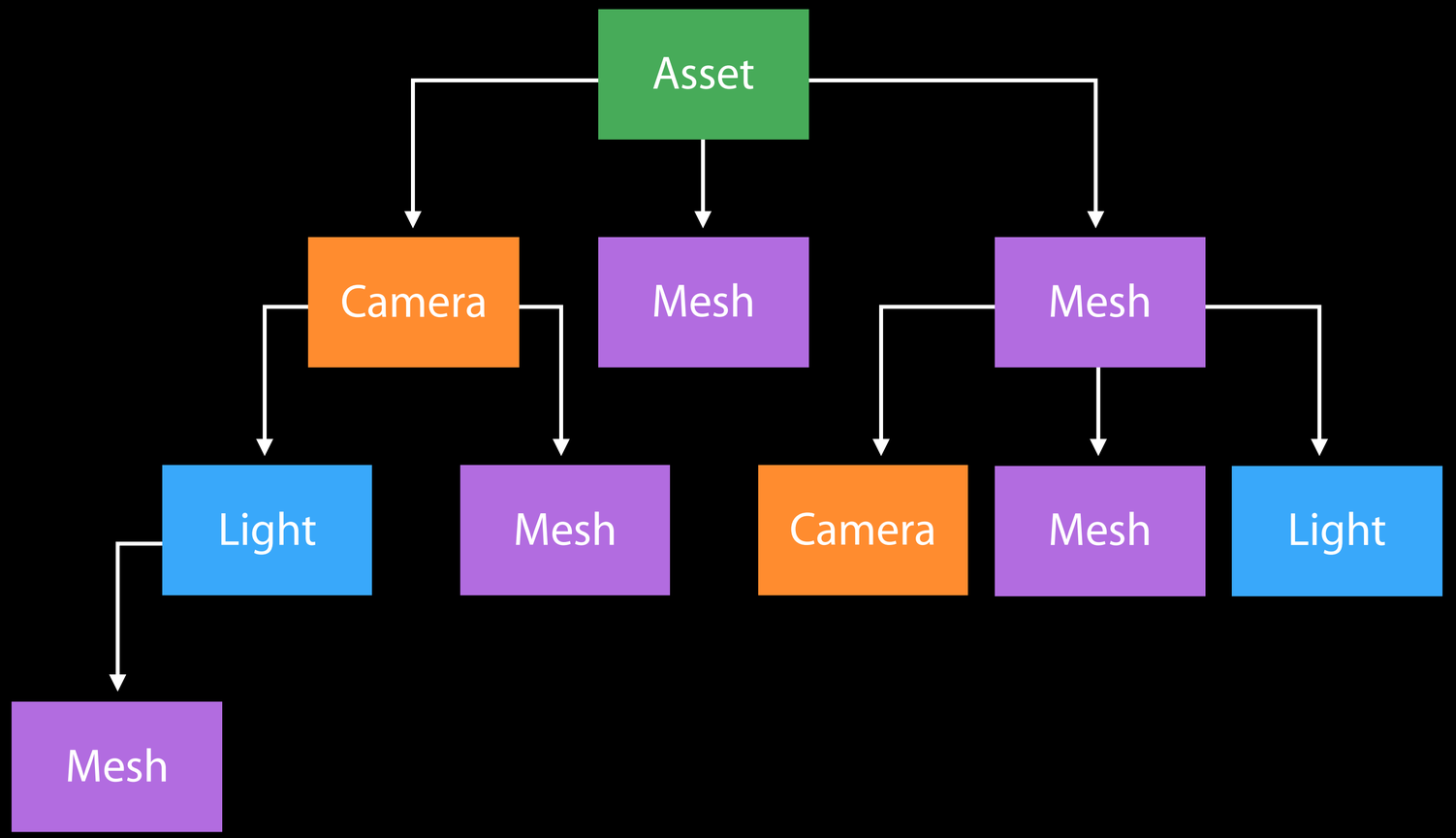

```
NSArray<MTKMesh *> *meshes = [MTKMesh meshesFromAsset:asset device:device];
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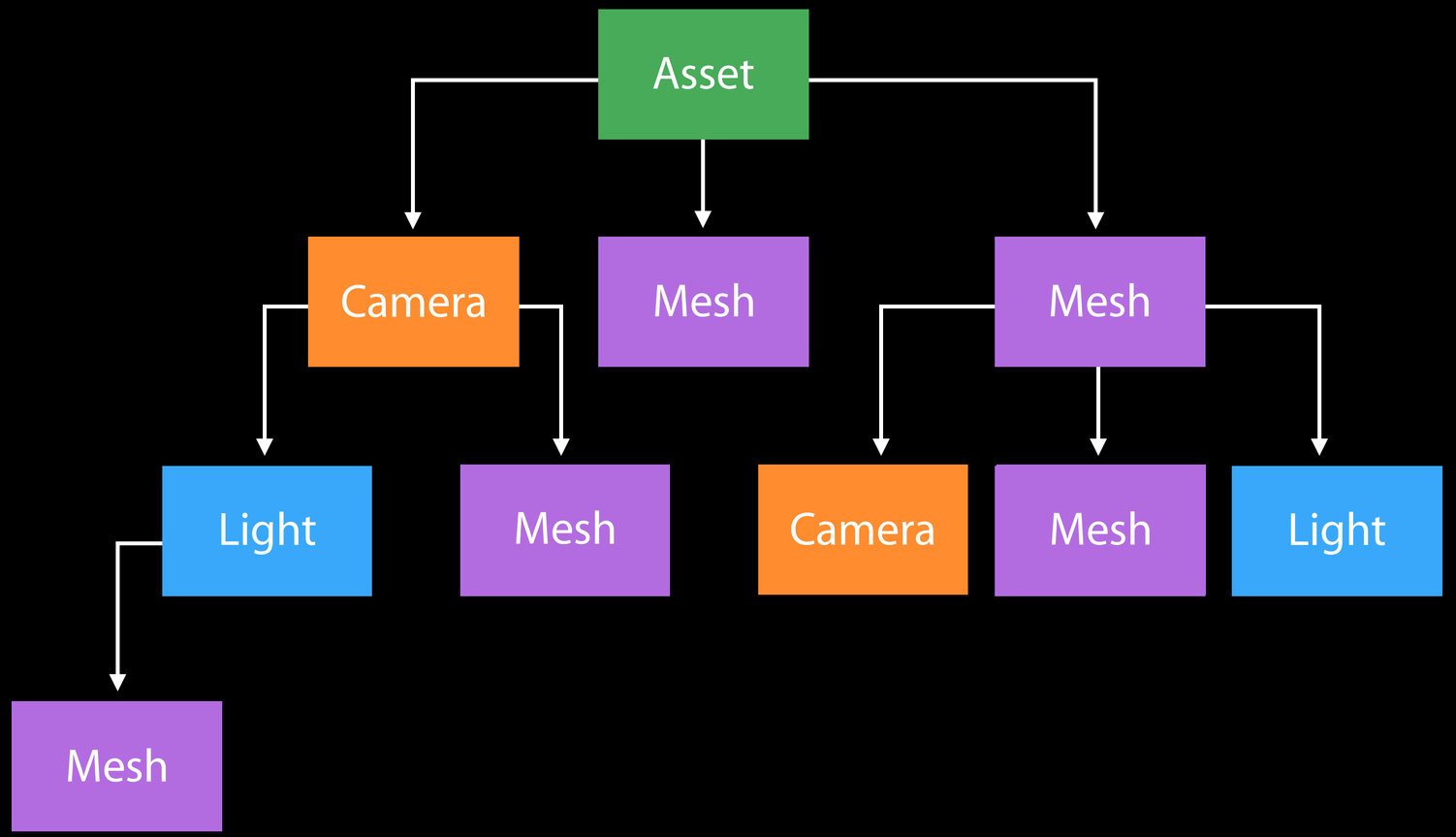
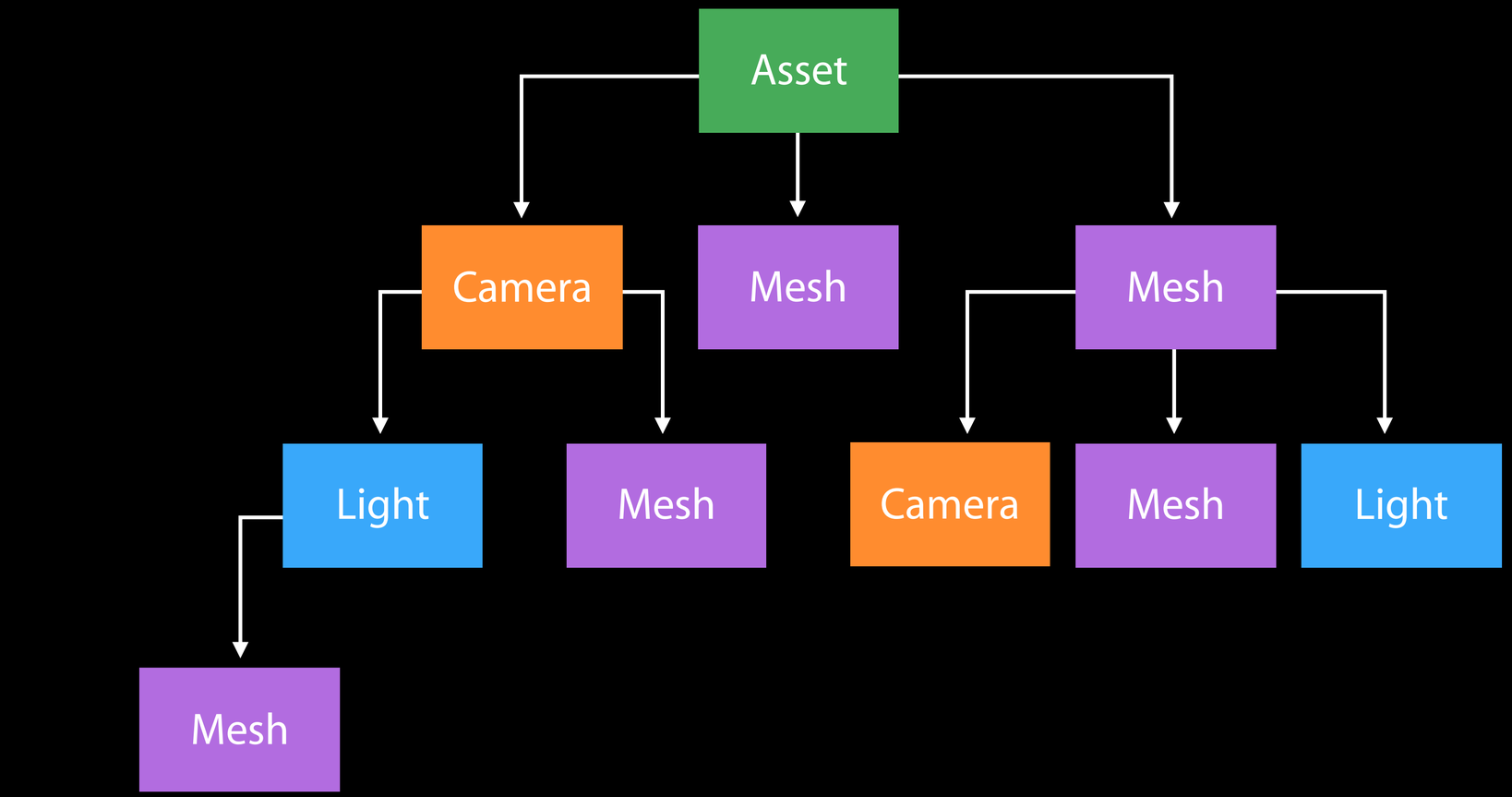


```
NSArray<MTKMesh *> *meshes = [MTKMesh meshesFromAsset:asset device:device];
```



```
NSArray<MTKMesh *> *meshes = [MTKMesh meshesFromAsset:asset device:device];
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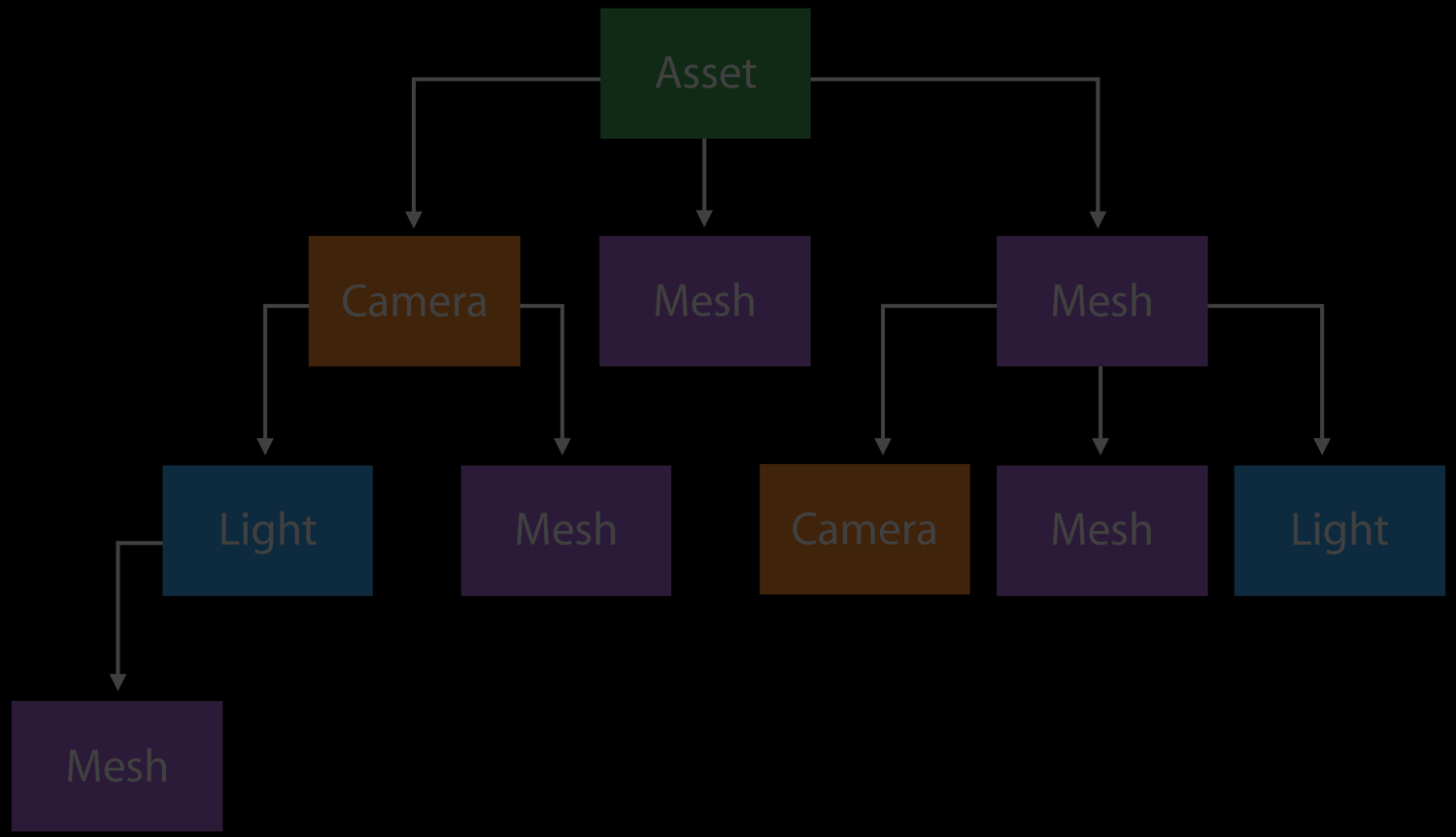
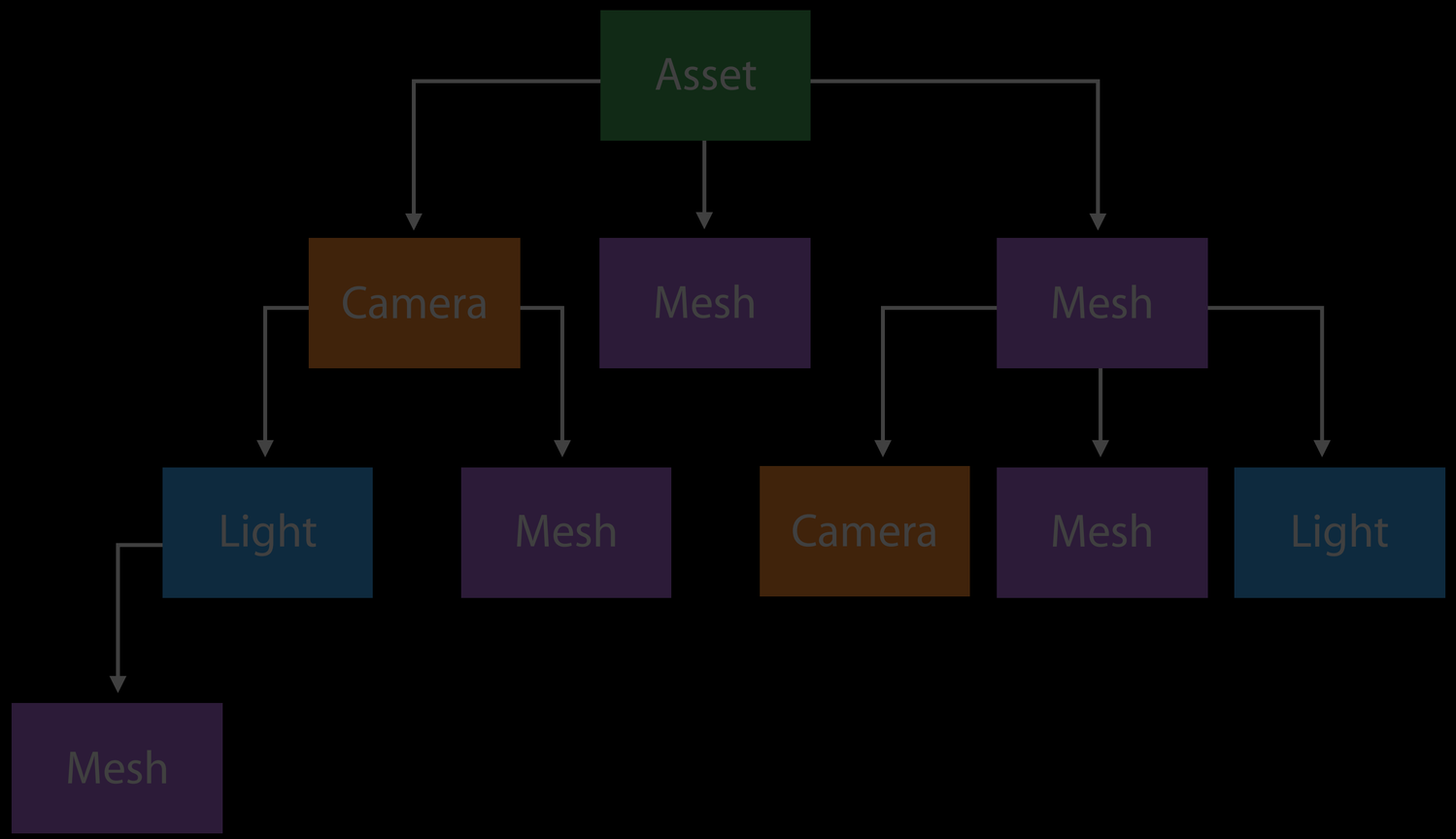
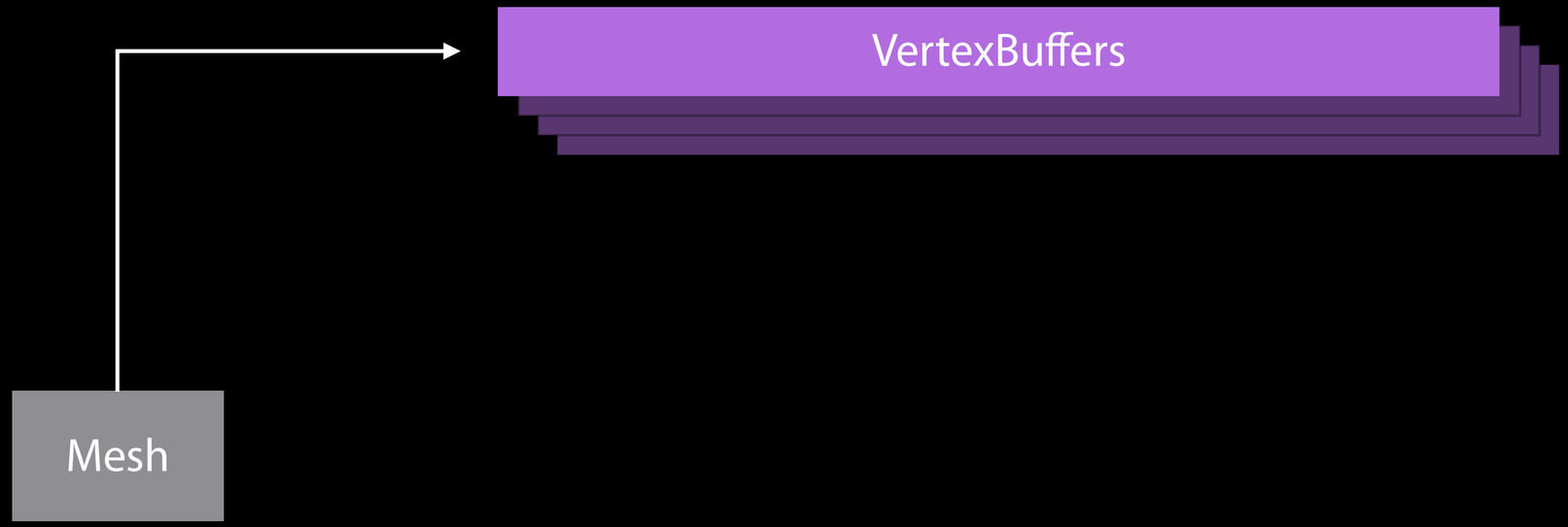


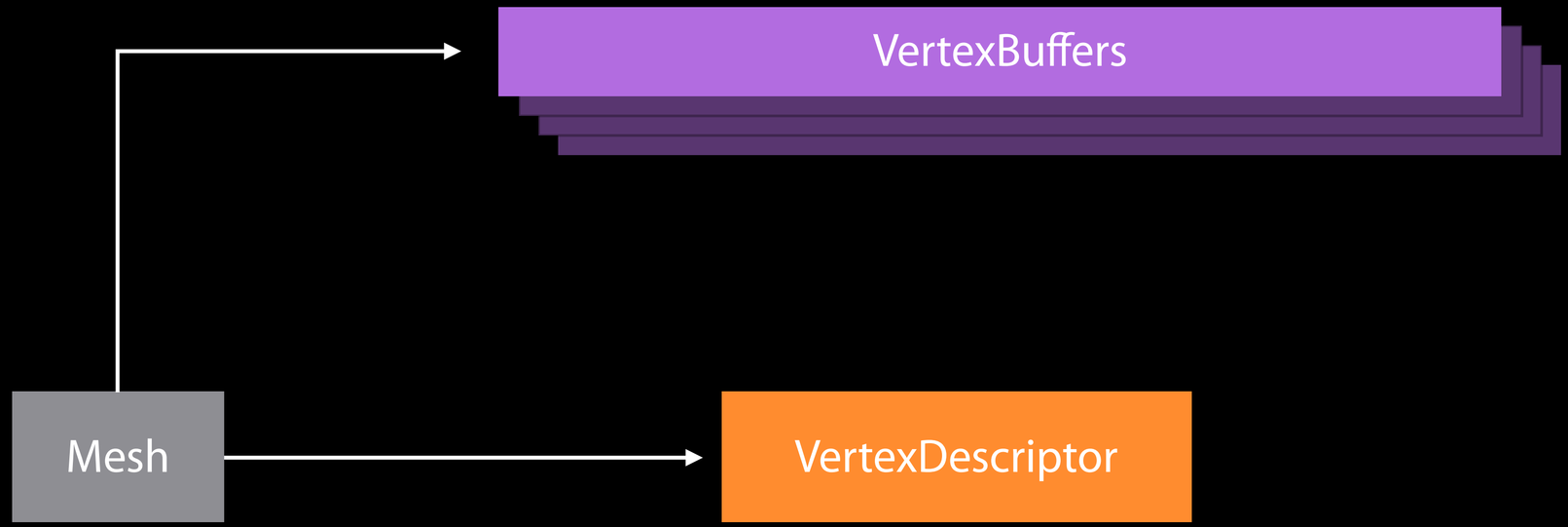
```
NSArray<MTKMesh *> *meshes = [MTKMesh meshesFromAsset:asset device:device];
```

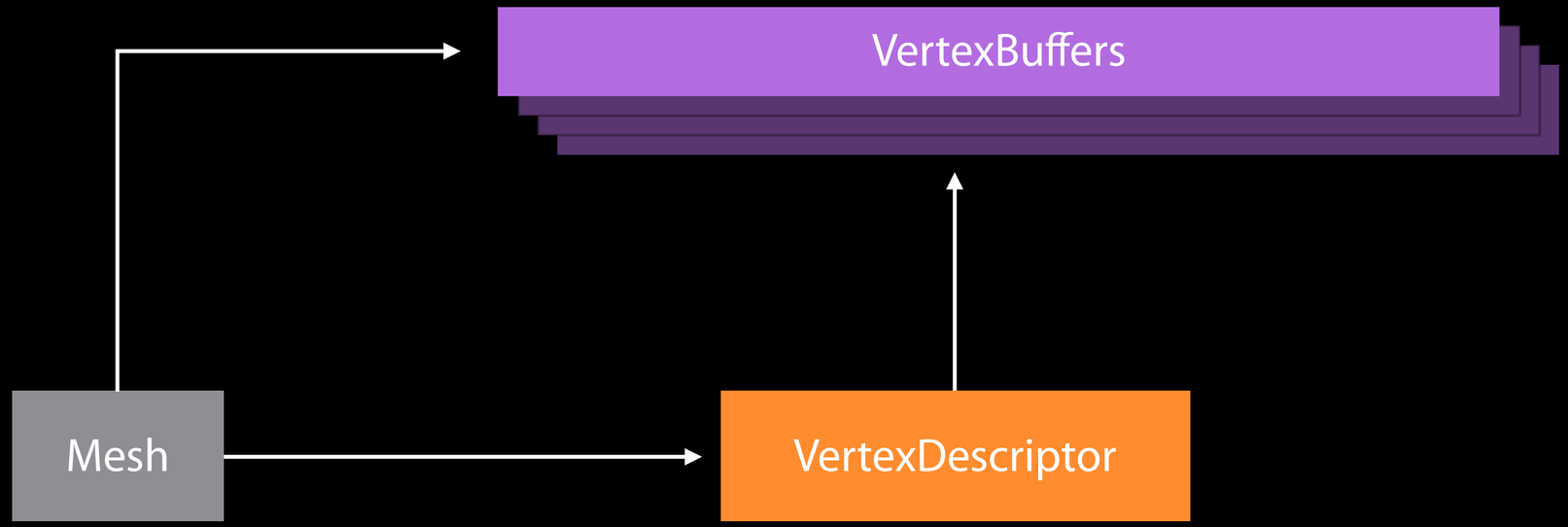


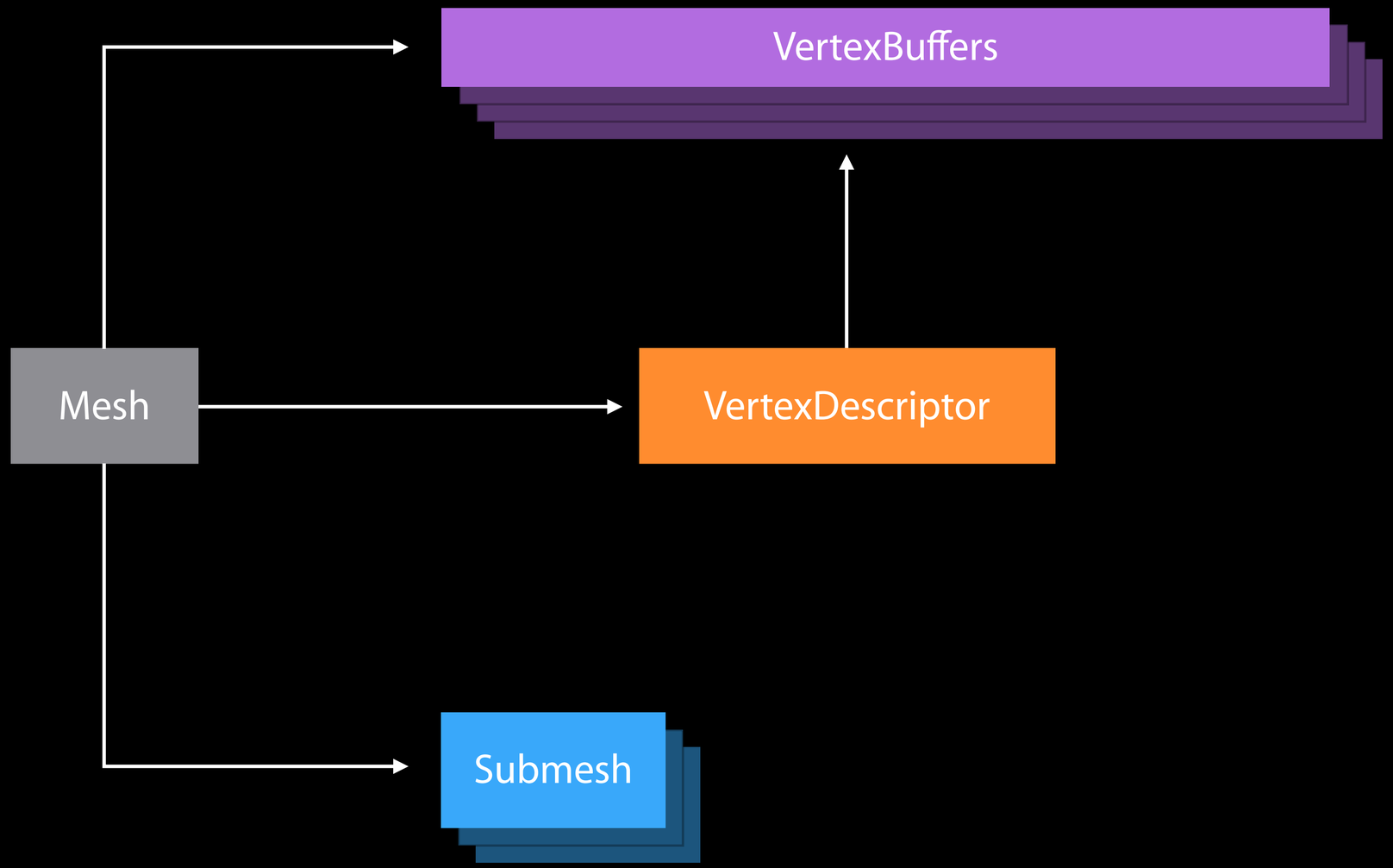
Mesh

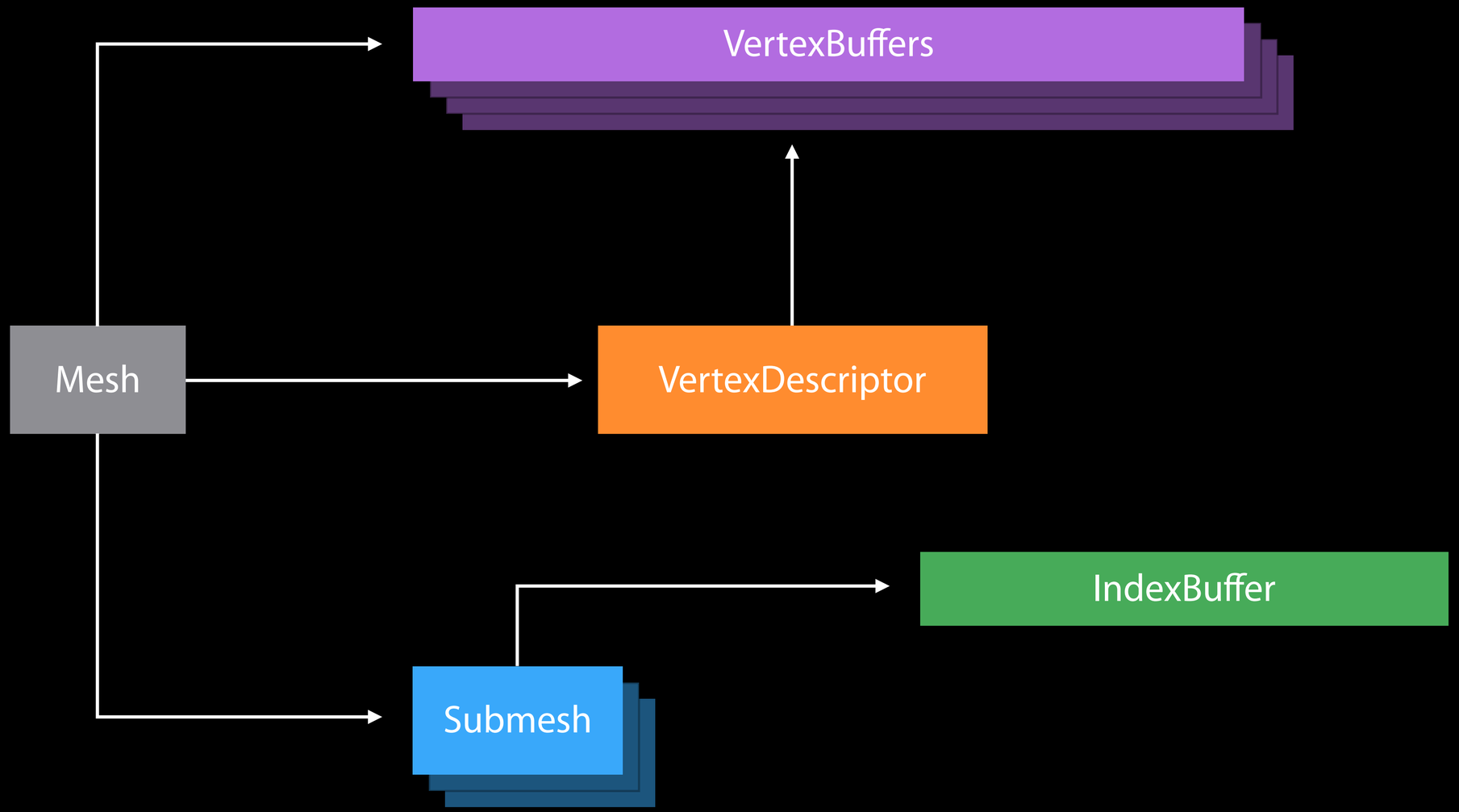
Mesh

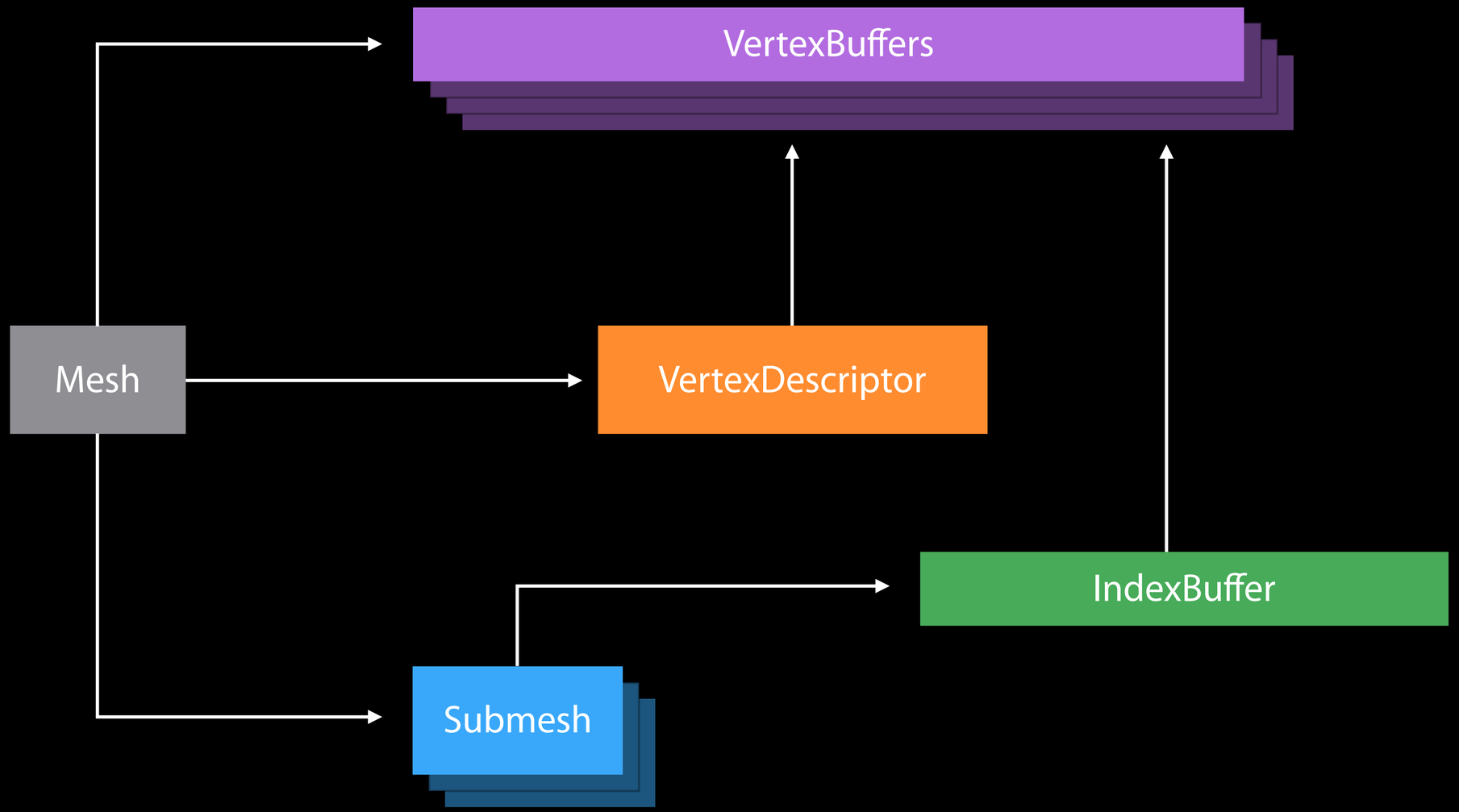

VertexBuffers
Mesh

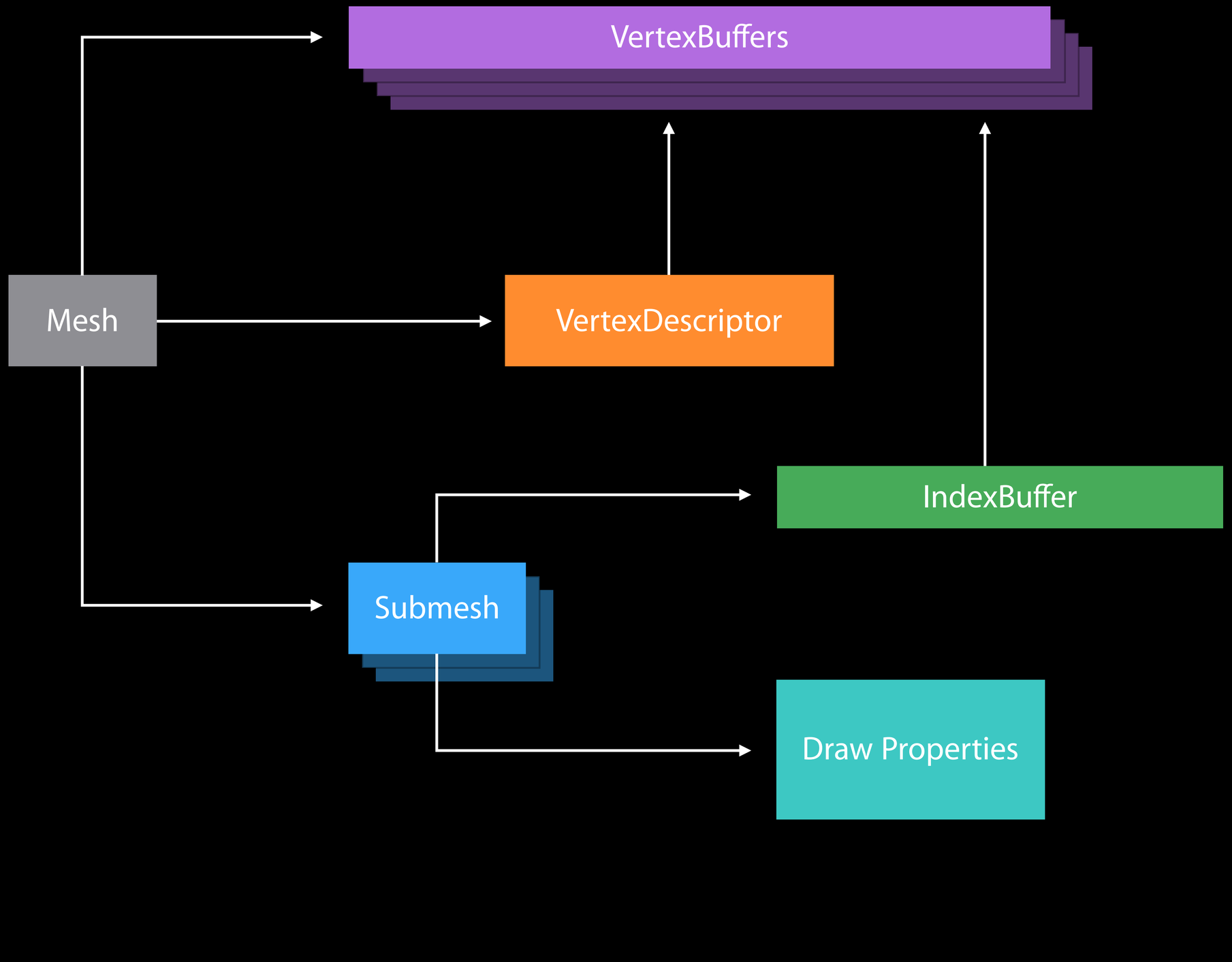

VertexBuffers
Mesh
VertexDescriptor

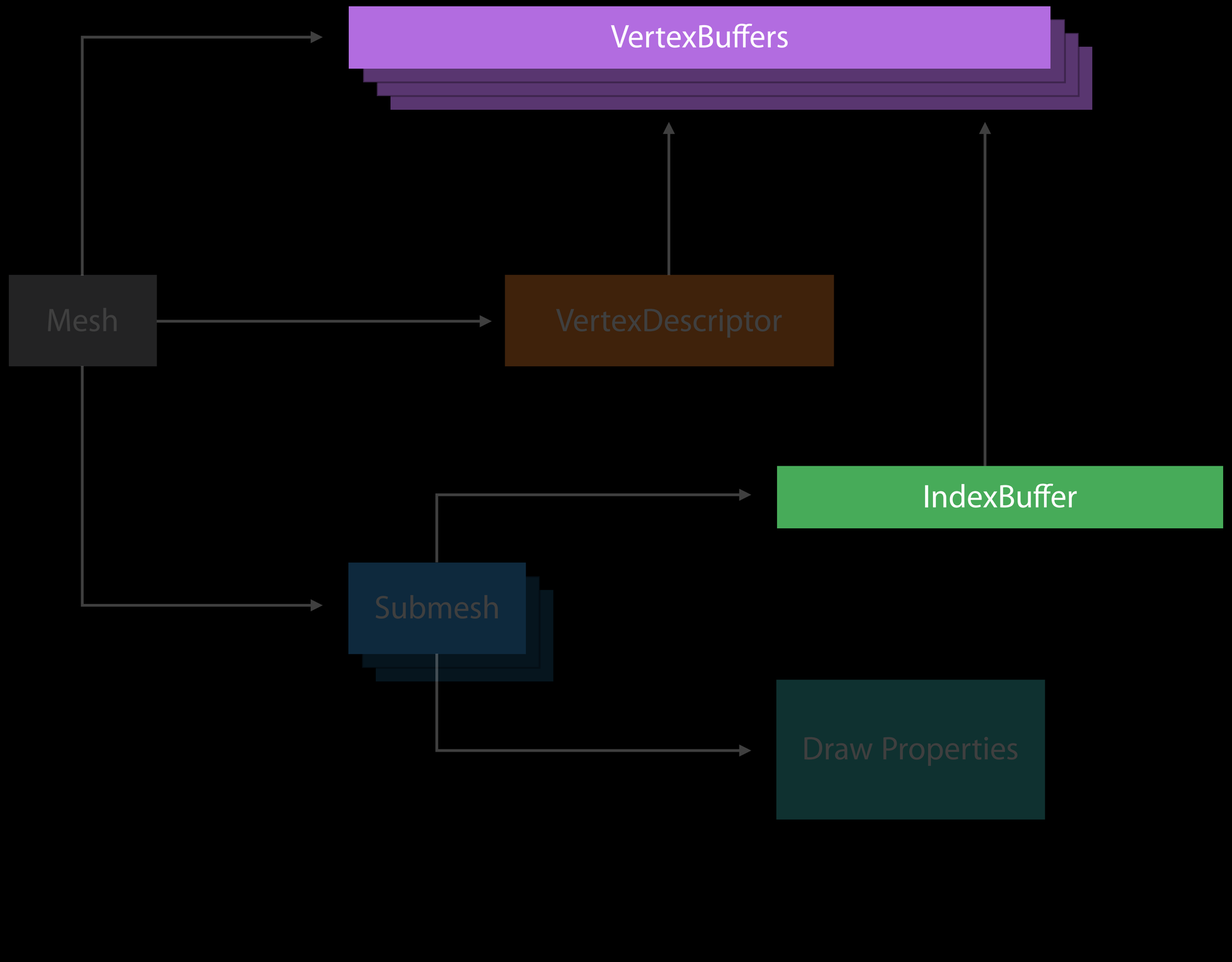

VertexBuffers
Mesh
VertexDescriptor


VertexBuffers
Mesh
VertexDescriptor
Submesh


VertexBuffers
Mesh
VertexDescriptor
IndexBuffer
Submesh

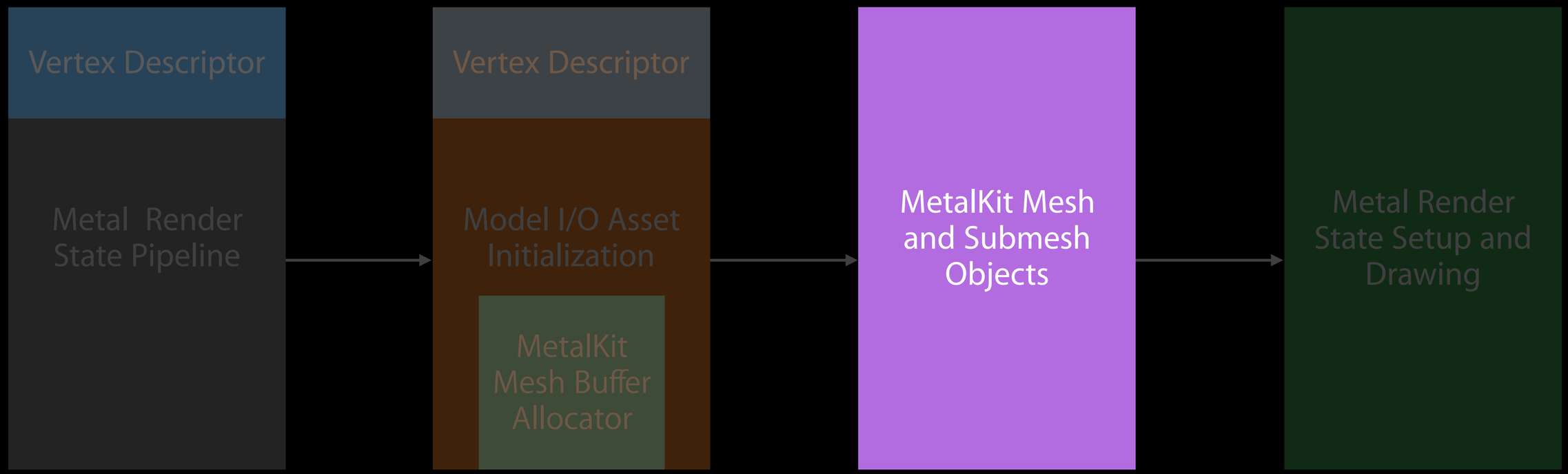

VertexBuffers
Mesh
VertexDescriptor
IndexBuffer
Submesh


VertexBuffers
Mesh
VertexDescriptor
IndexBuffer
Submesh
Draw Properties


VertexBuffers
Mesh
VertexDescriptor
IndexBuffer
Submesh
Draw Properties

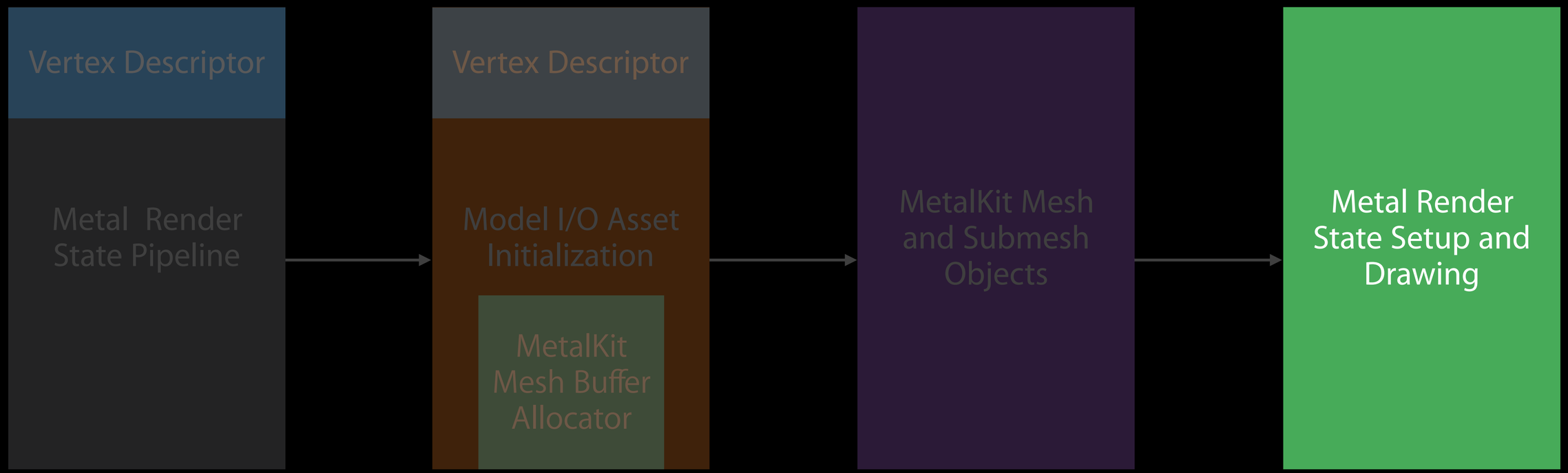
Mesh Rendering with Metal

Setup for model rendering



Mesh Rendering with Metal

Setup for model rendering



Setting Mesh State

```
NSUInteger bufferIndex = 0;
for(MTKMeshBuffer *vertexBuffer in mesh.vertexBuffers) {
    if(vertexBuffer.buffer != nil) {
        [renderEncoder setVertexBuffer:vertexBuffer.buffer
                                offset:vertexBuffer.offset
                               atIndex:bufferIndex];
    }
    bufferIndex++;
}
```

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Rendering the Mesh

```
for(MTKSubmesh *submesh in mesh.submeshes)
{
    [renderEncoder drawIndexedPrimitives:submesh.primitiveType
                              indexCount:submesh.indexCount
                               indexType:submesh.indexType
                             indexBuffer:submesh.indexBuffer.buffer
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}
```

Rendering the Mesh

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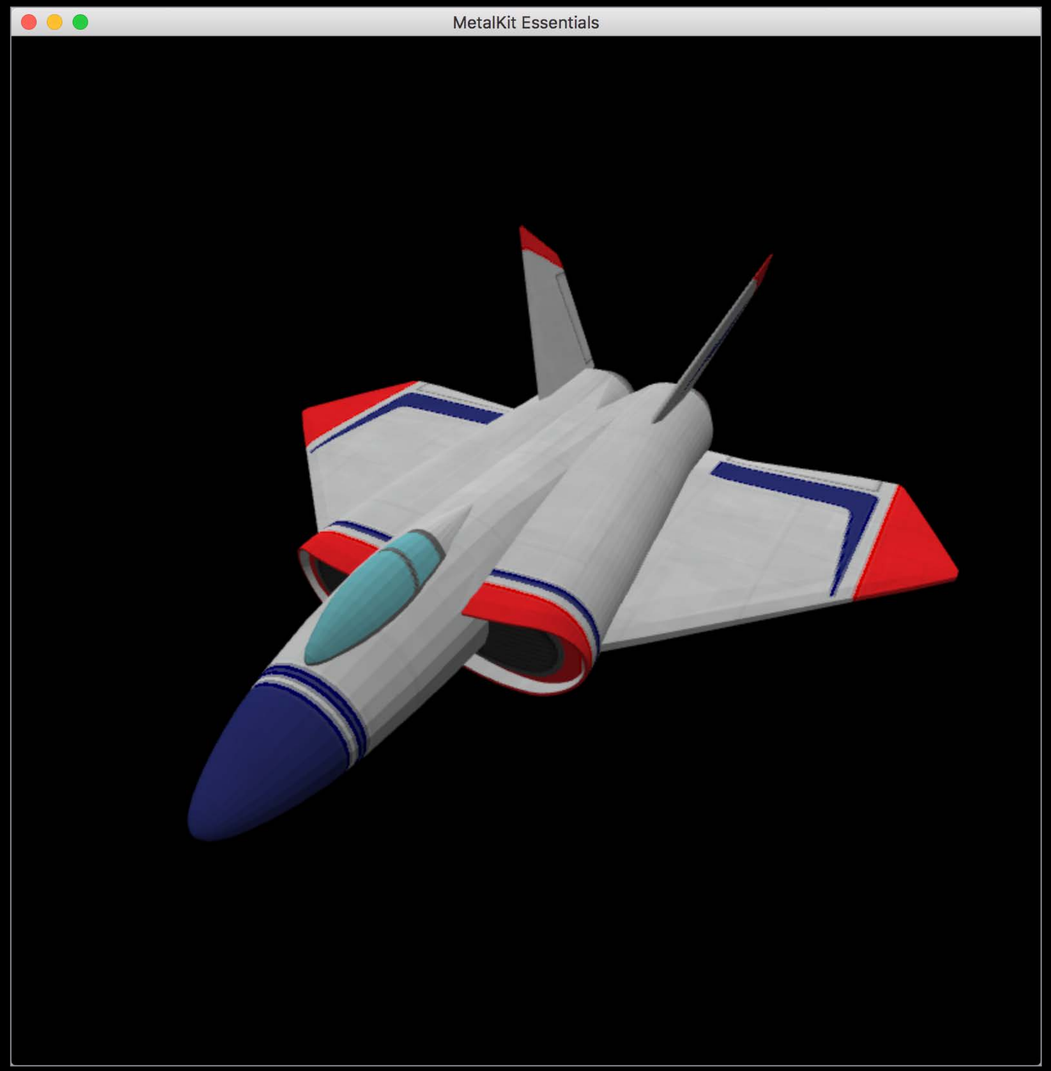
MetalKit Essentials



Metal Performance Shaders

Anna Tikhonova GPU Software Frameworks Engineer

Metal Performance Shaders

Introduction

NEW

A framework of data-parallel algorithms for the GPU

CPU-style library for the GPU

Metal Performance Shaders

Introduction

NEW

Optimized for iOS

Available in iOS 9 for the A8 processor

iPad Air 2 iPhone 6 Plus iPhone 6

Metal Performance Shaders

Introduction

NEW

Designed to integrate easily into your Metal applications

As simple as calling a library function

Metal Performance Shaders

NEW

Supported image operators

Histogram, Equalization, and Specification

Morphology—Min, Max, Dilate, and Erode

Lanczos Resampling

Median

Thresholding

Integral

Convolution—General, Gaussian Blur, Box, Tent, and Sobel

Metal Performance Shaders

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Gaussian Blur

Gaussian Blur

Using Metal Performance Shaders

Use a 'blur' filter

```
// Create a filter object
MPSImageGaussianBlur *blurFilter =
    [[MPSImageGaussianBlur alloc]
    initWithDevice: device sigma: 3];

// Encode filter to the command buffer
[blurFilter encodeToCommandBuffer: commandBuffer
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Using Metal Performance Shaders

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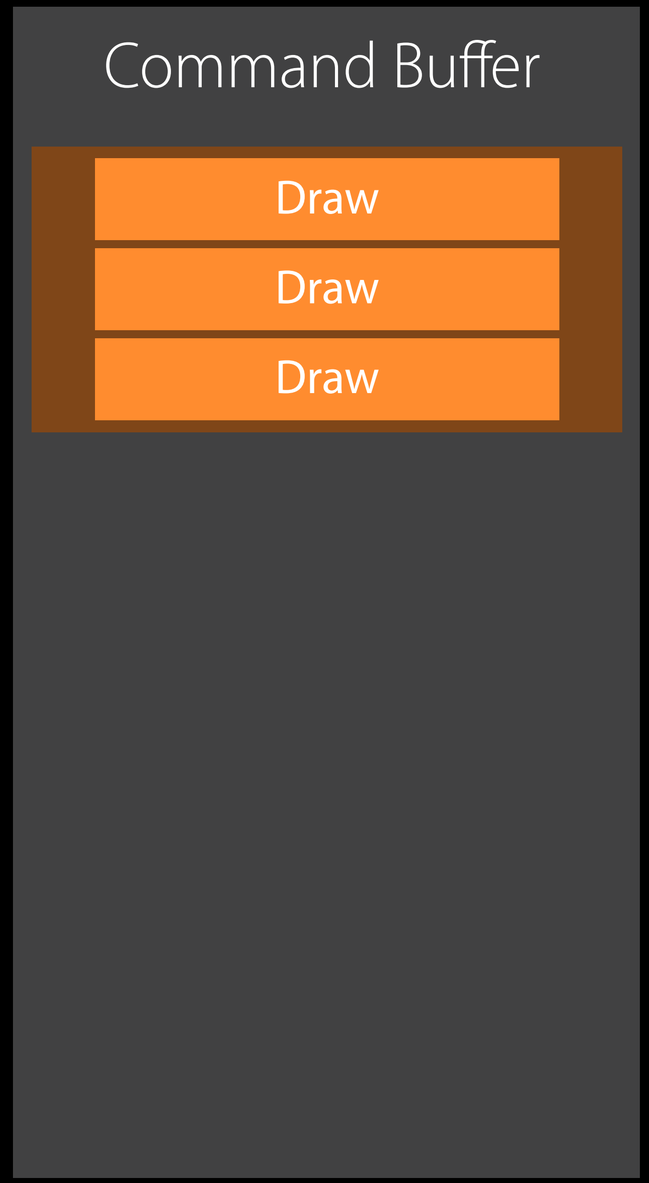

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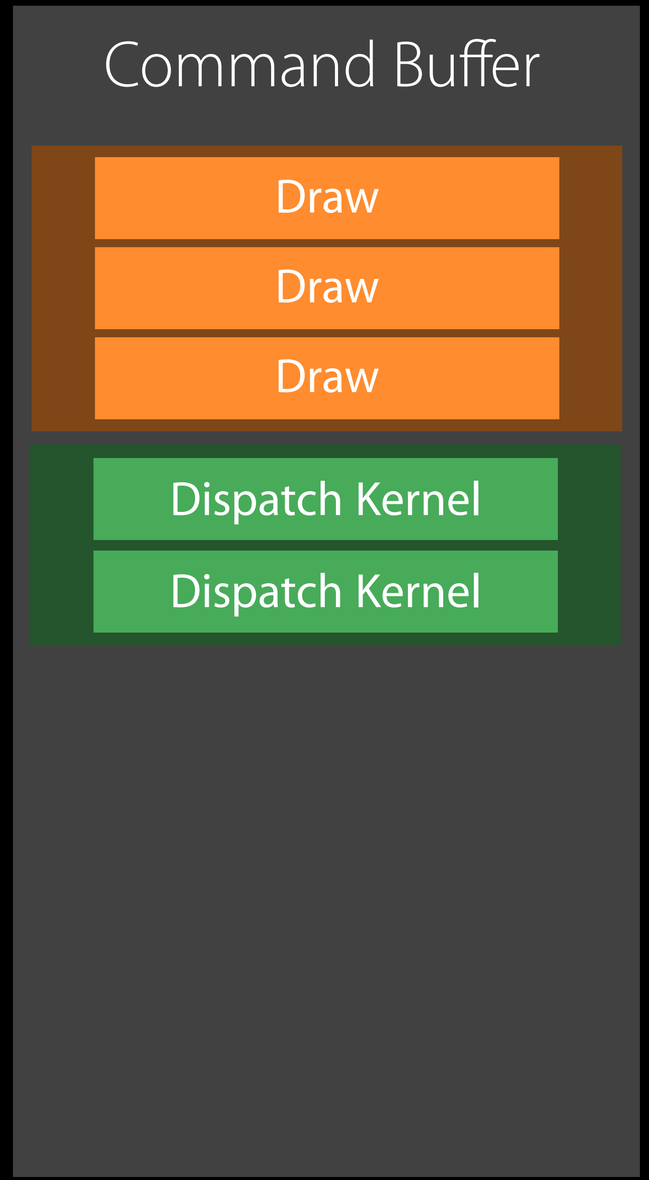

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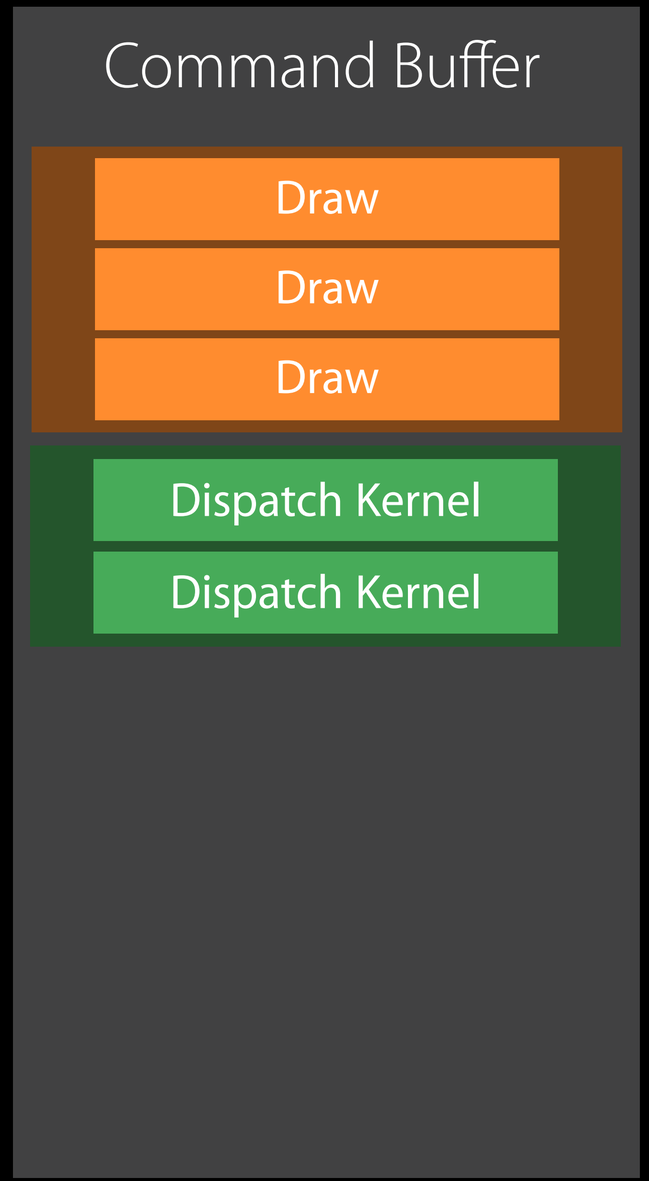
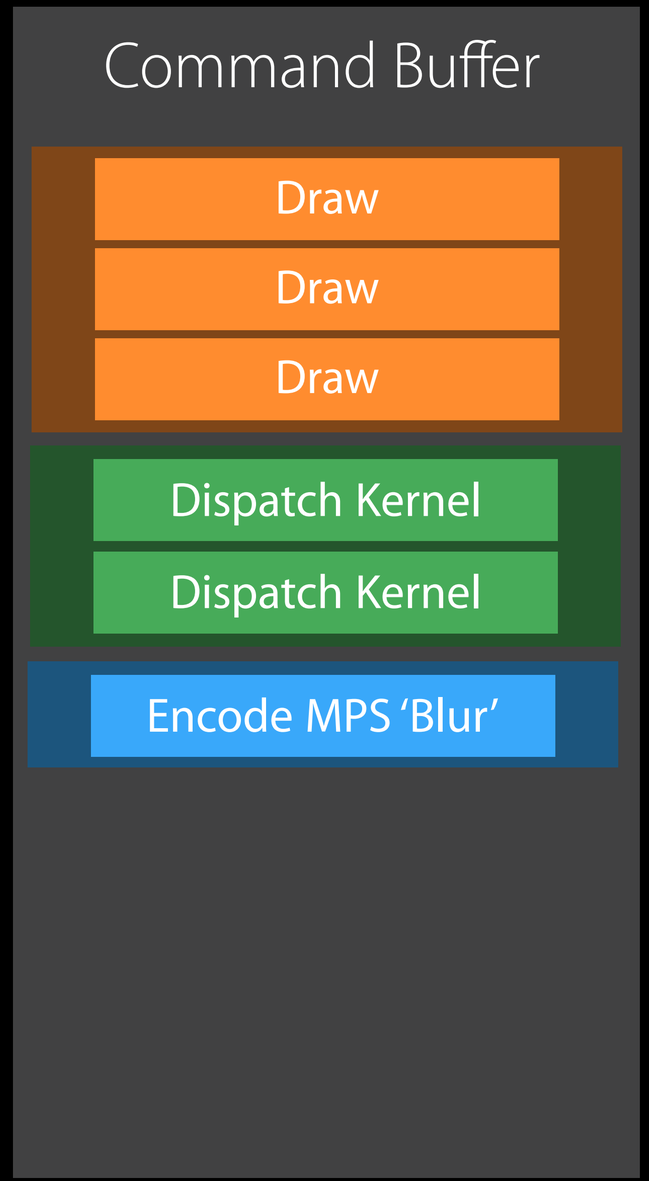


Using Metal Performance Shaders

Use a ‘blur’ filter



Using Metal Performance Shaders

Use a ‘blur’ filter

Download Sample Code

https://developer.apple.com/library/prerelease/ios/samplecode/MetalPerformanceShadersHelloWorld

Performance

Behind the scenes

Choose the right algorithm

Tune for

- Kernel radius
- Pixel format
- Memory hierarchy
- Number of pixels per thread
- Threadgroup dimensions

CPU optimizations

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CPU optimizations

Optimized Gaussian Blur

Statistics

Optimized Gaussian Blur

Statistics

49 Metal kernels

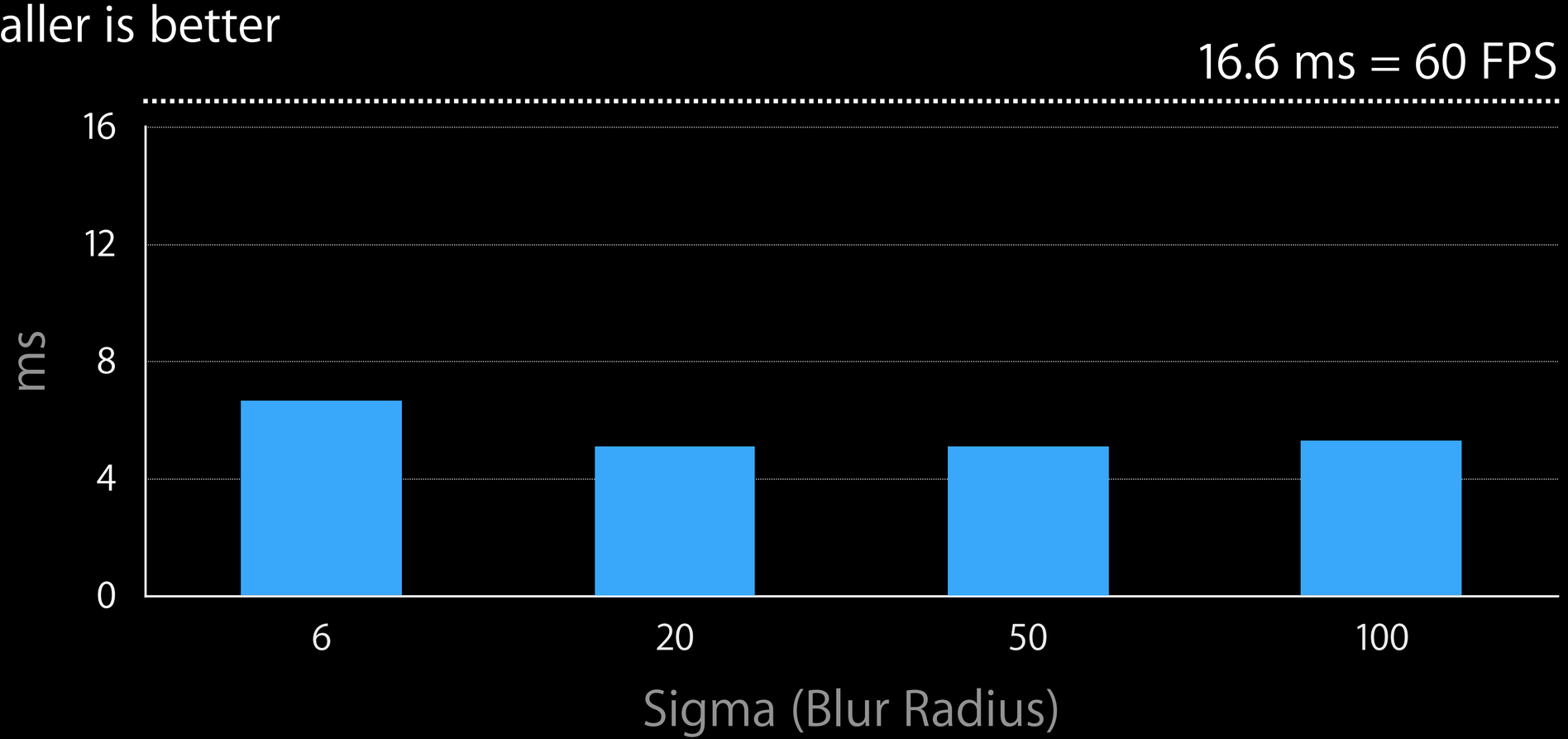
2000 Lines of kernel code

821 Different Gaussian filter implementations

Demo

Filter Performance

Not capped by screen refresh rate



A Few More Details

Source ‘offset’ and Destination ‘clipRect’

Filter properties

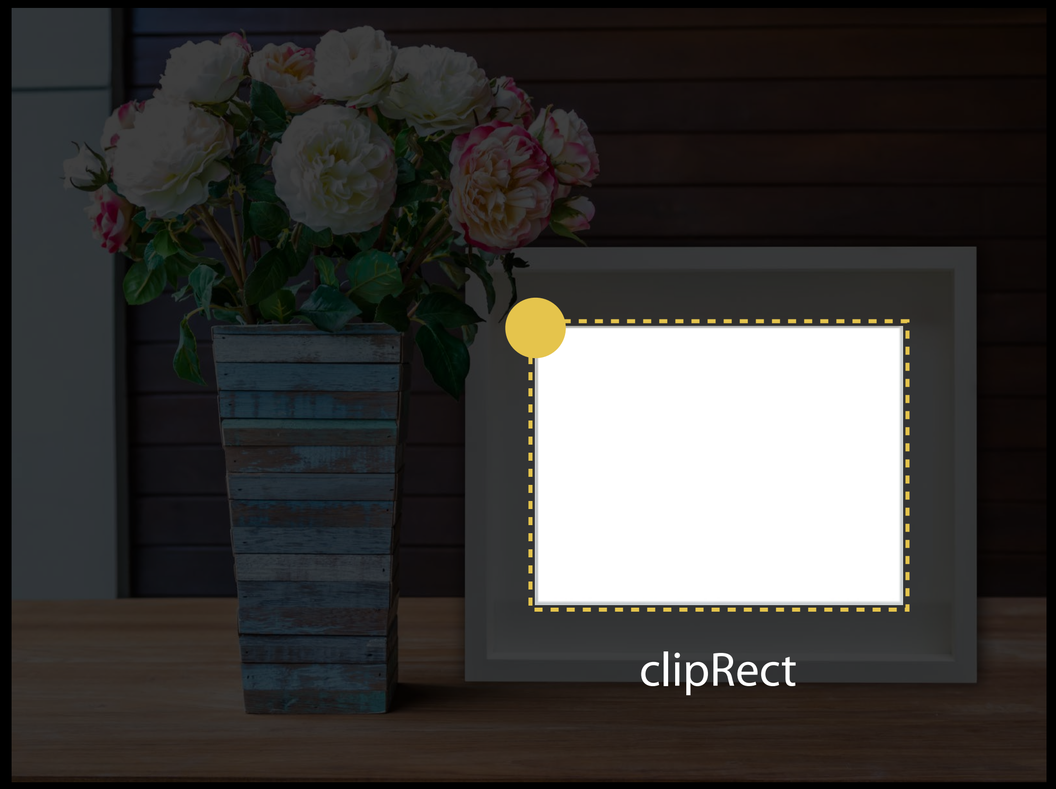
Source

Destination

Source ‘offset’ and Destination ‘clipRect’

Filter properties

Source



Destination

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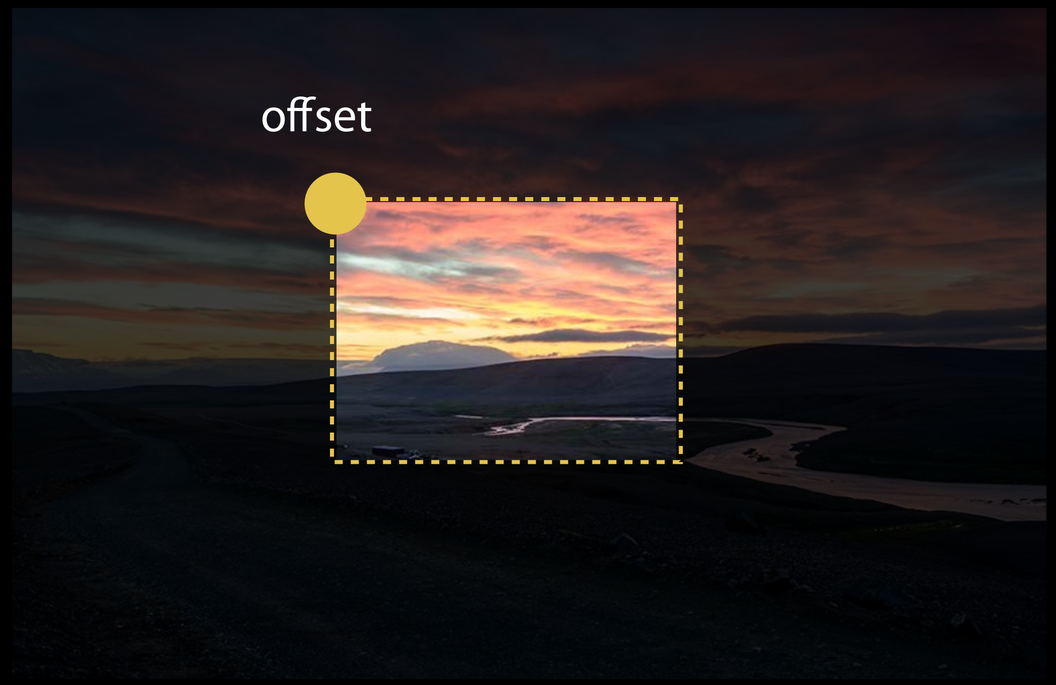
Filter properties



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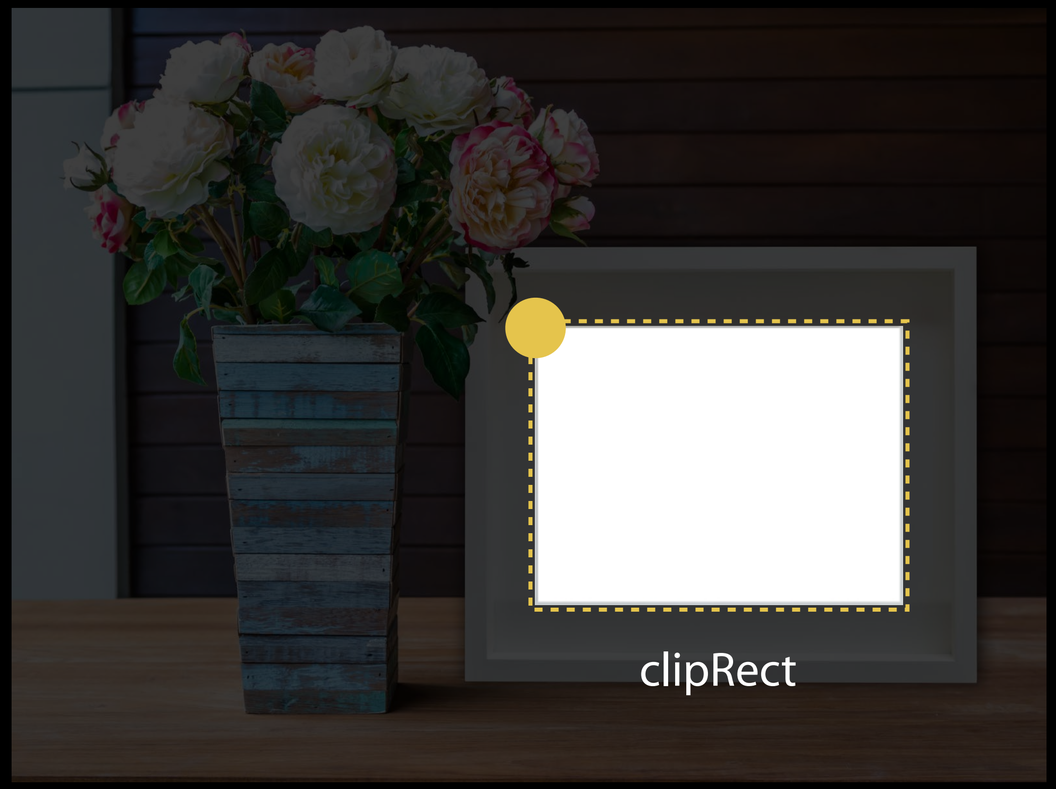
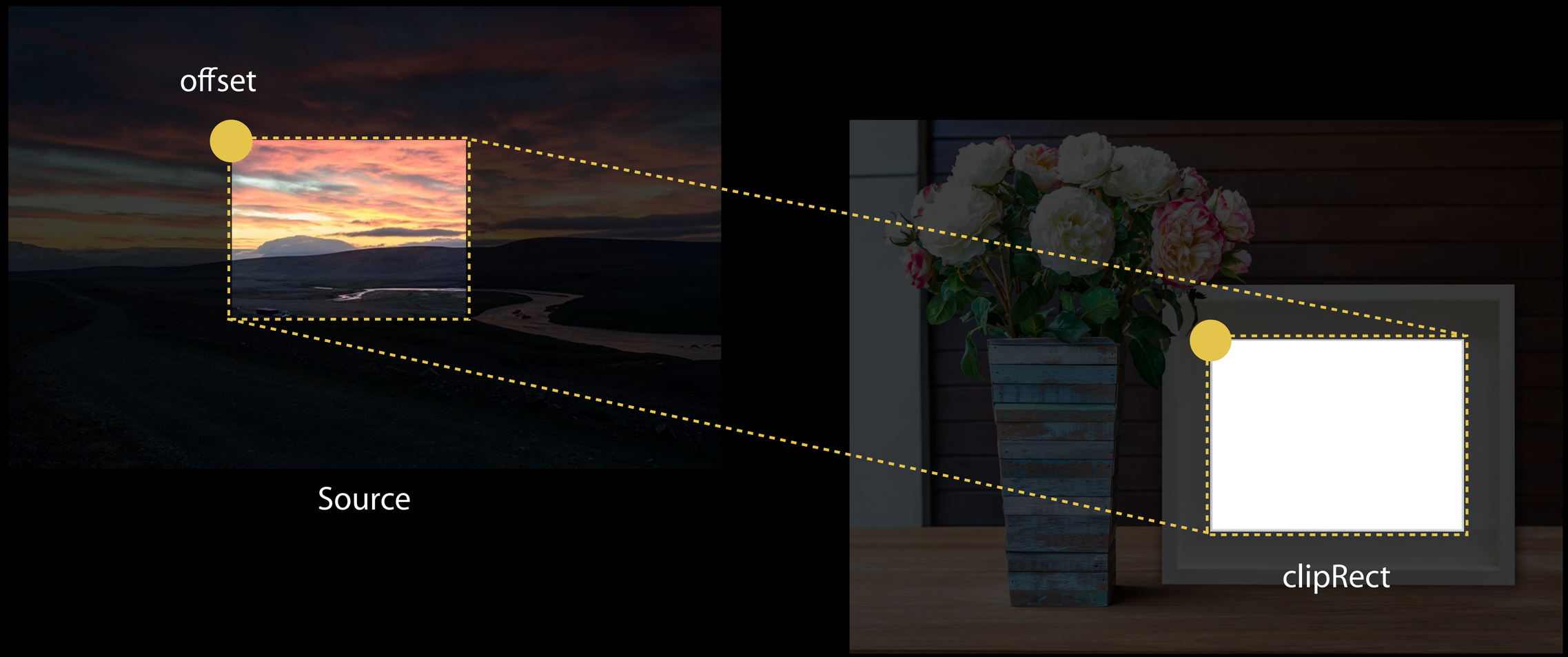


Destination

Source ‘offset’ and Destination ‘clipRect’

Filter properties



Source

Destination

Source ‘offset’ and Destination ‘clipRect’

Filter properties

Source

Destination

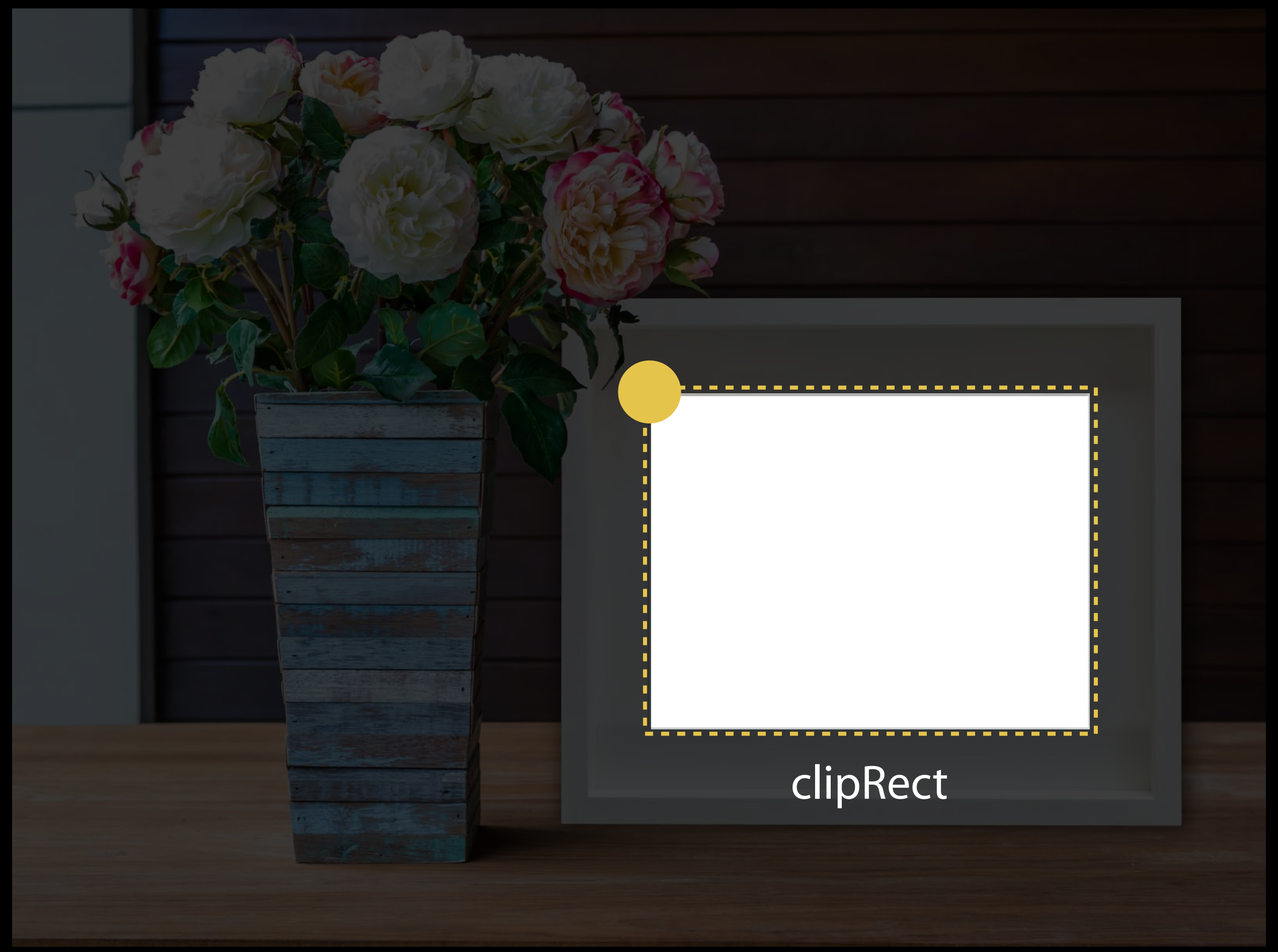
In-place Operation

Save memory

Source == Destination

In-place Operation

Save memory



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In-place Operation

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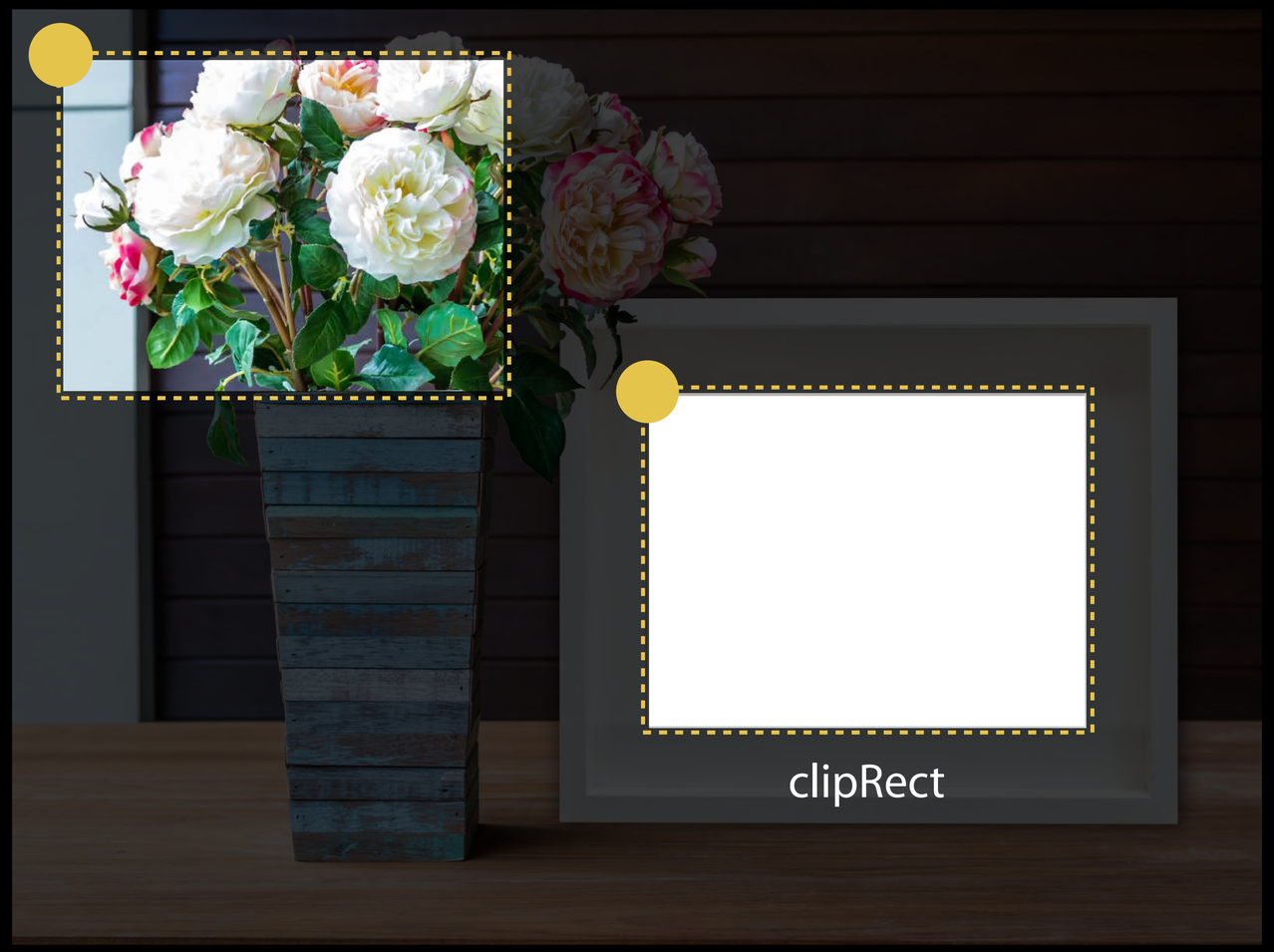

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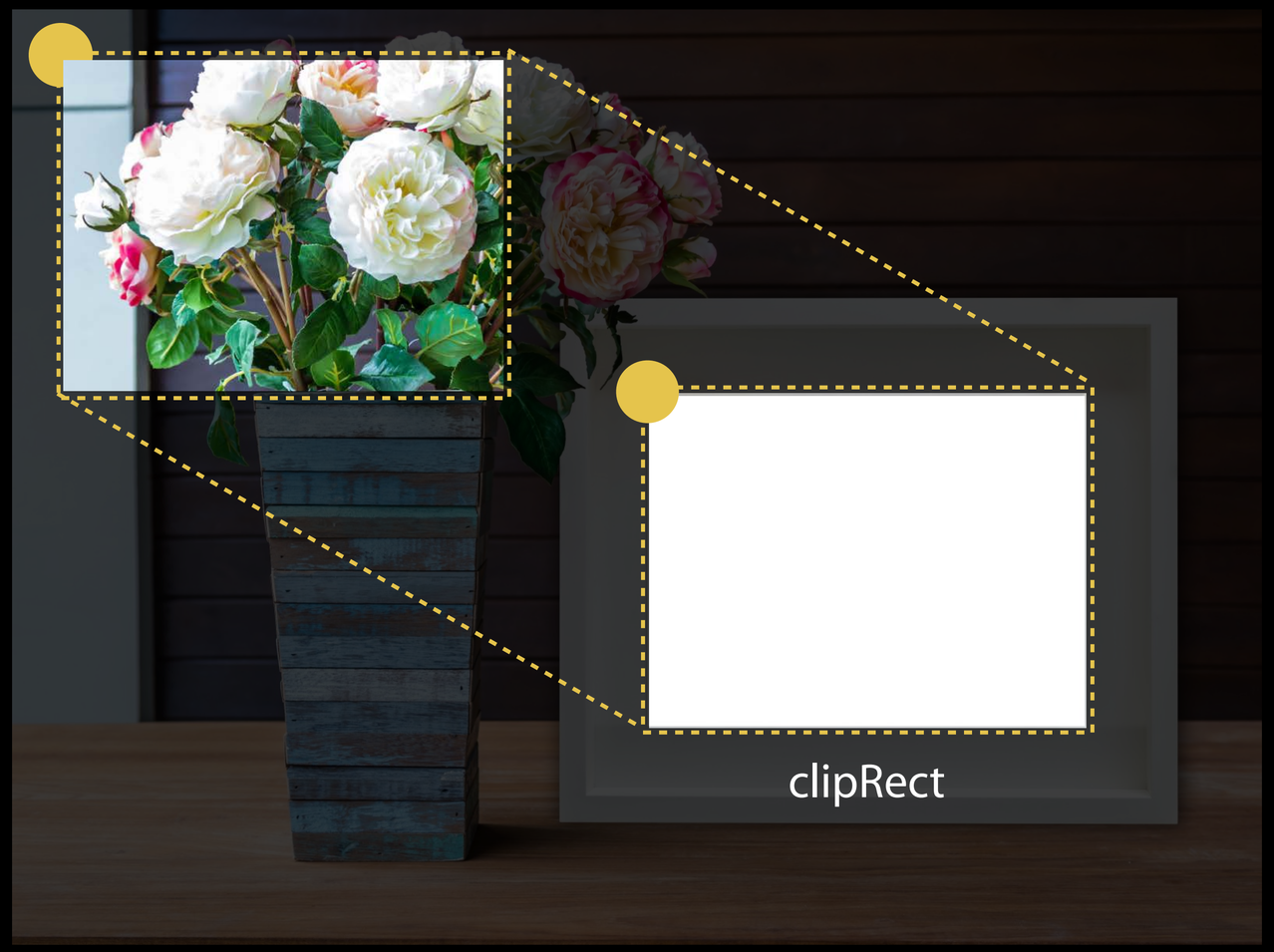

Source == Destination

In-place Operation

Save memory

Source == Destination

In-place Operation

How?

```
// Encode filter in-place in a Metal command buffer
[blurFilter encodeToCommandBuffer: commandBuffer
    inPlaceTexture: sourceTexture
    fallbackCopyAllocator: myAllocator];
```

In-place Operation

How?

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[blurFilter encodeToCommandBuffer: commandBuffer
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```

It’s not always possible for Metal Performance Shaders filters to run in-place

Depends on filter, filter parameters and properties

Copy allocator will create a destination texture, so operation can proceed out-of-place

Fallback Copy Allocator

Example

```
MPSCopyAllocator myAllocator = ^id <MTLTexture>(
    MPSKernel * filter,
    id <MTLCommandBuffer> commandBuffer,
    id <MTLTexture> sourceTexture)
{
    MTLTextureDescriptor * desc = descriptorFromTexture(sourceTexture);
    id <MTLTexture> destinationTexture = [commandBuffer.device
        newTextureWithDescriptor: desc];

    return destinationTexture;
};
```

Fallback Copy Allocator

Example

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    // Use Metal encoder to initialize the destinationTexture from
    // sourceTexture, if necessary

    return destinationTexture;
};
```

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};
```

Summary

Make use of the new Metal support frameworks

- Robust, optimized, easy to integrate
- Faster bring-up of your application
- Less code to write and maintain

Give us your feedback!

More Information

Metal Documentation and Videos
http://developer.apple.com/metal

Apple Developer Forums
http://developer.apple.com/forums

Developer Technical Support
http://developer.apple.com/support/technical

General Inquiries
Allan Schaffer, Game Technologies Evangelist
aschaffer@apple.com

Related Sessions

Managing 3D Assets with Model I/O	Mission	Tuesday 2:30PM
What's New in Metal, Part 1	Presidio	Tuesday 3:30PM
Metal Performance Optimization Techniques	Pacific Heights	Friday 11:00AM

Related Labs

Metal Lab	Graphics D	Friday 12:00PM

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