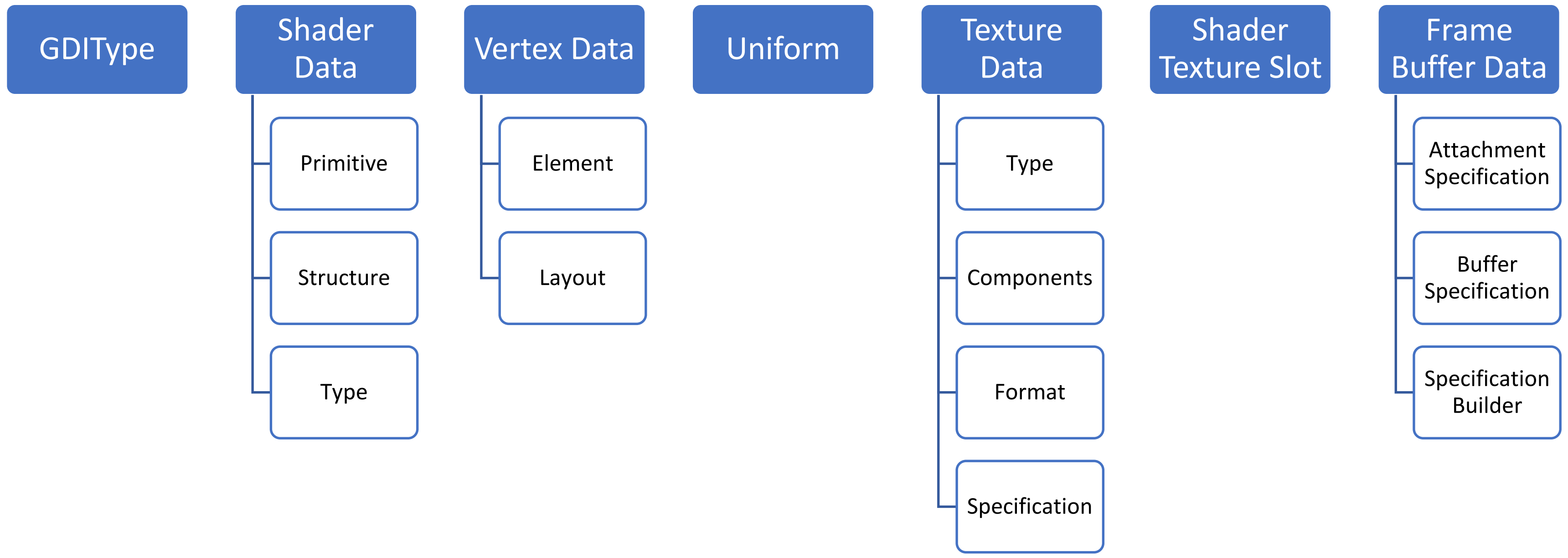
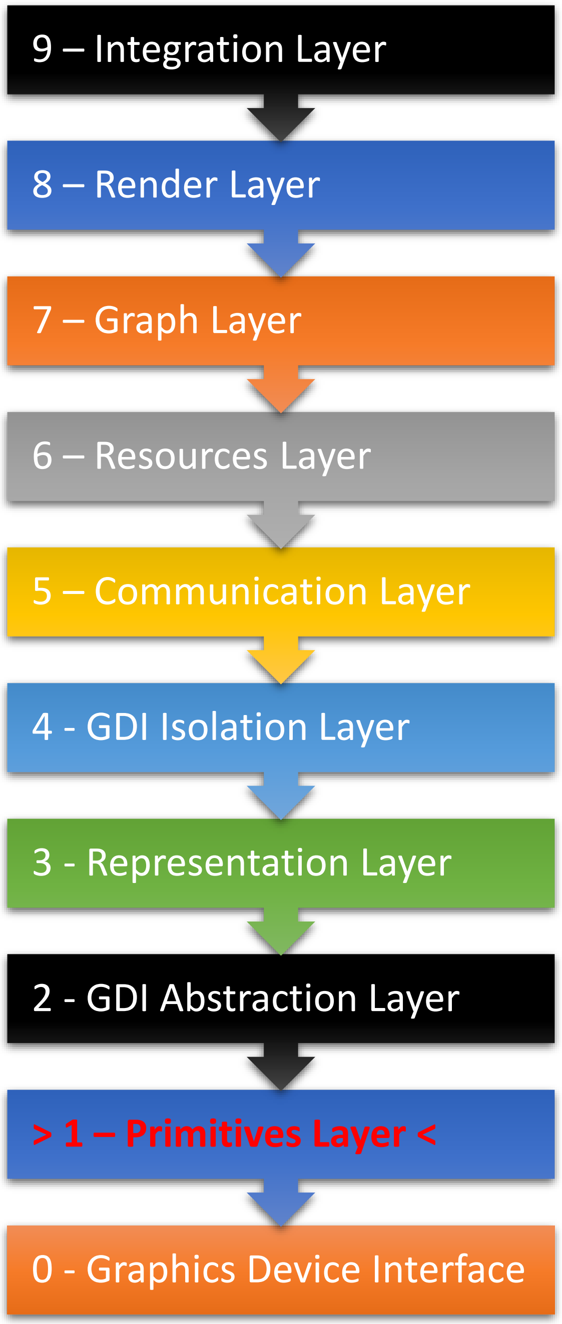
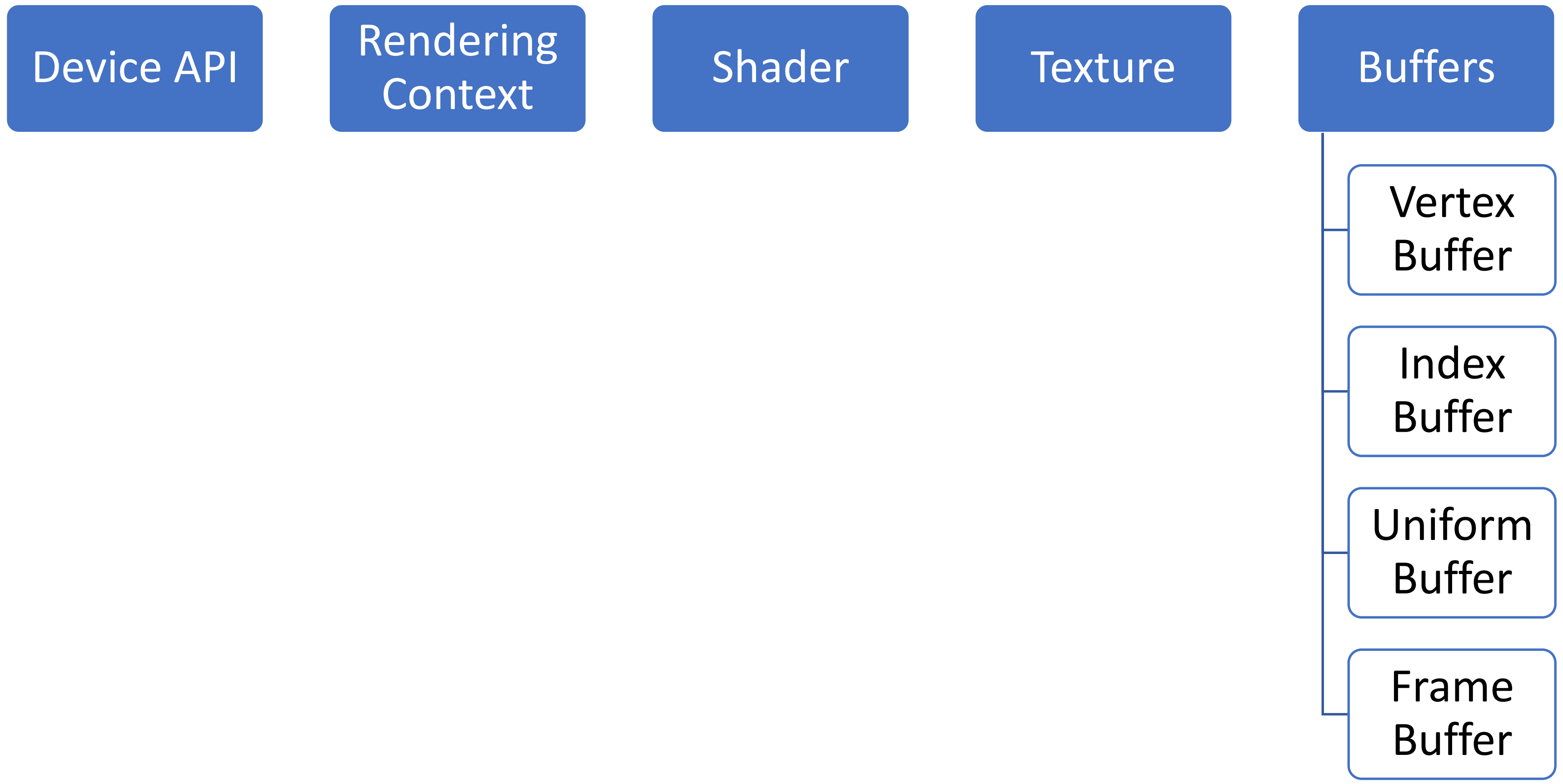
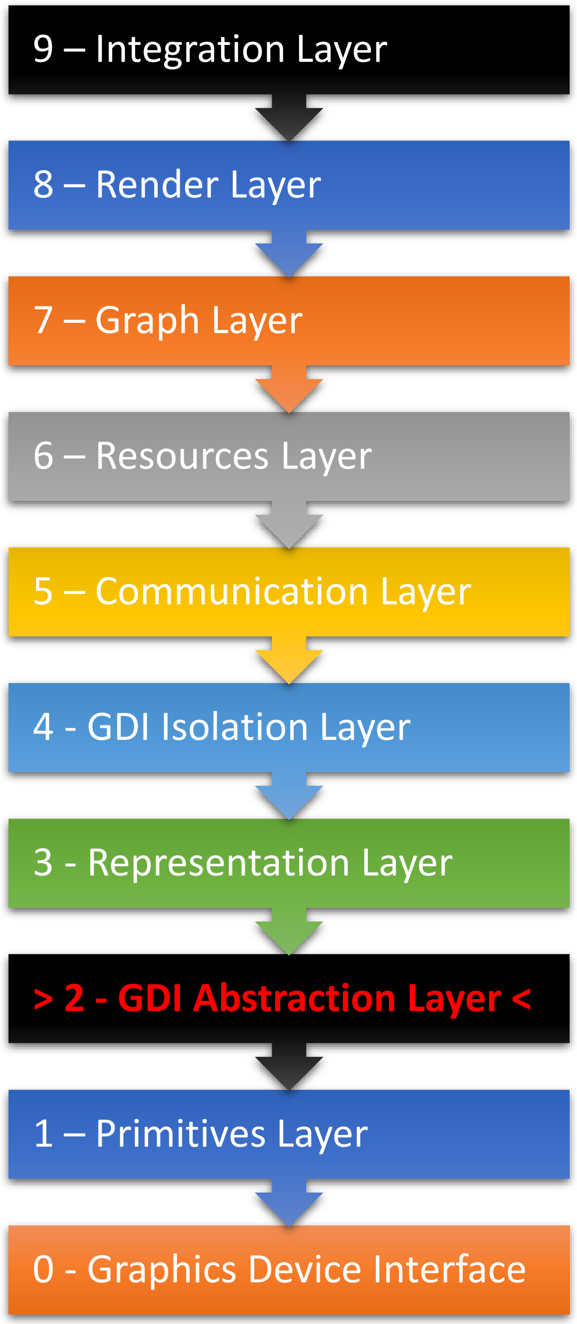
Rendering Architecture of Fools Engine

Work in progress


GDIType
Shader Data
Primitive
Structure
Type
Vertex Data
Element
Layout
Uniform
Texture Data
Type
Components
Format
Specification
Shader Texture Slot
Frame Buffer Data
Attachment Specification
Buffer Specification
Specification Builder


9 – Integration Layer
8 – Render Layer
7 – Graph Layer
6 – Resources Layer
5 – Communication Layer
4 - GDI Isolation Layer
3 - Representation Layer
2 - GDI Abstraction Layer
> 1 – Primitives Layer <
0 - Graphics Device Interface


Device API
Rendering Context
Shader
Texture
Buffers
Vertex Buffer
Index Buffer
Uniform Buffer
Frame Buffer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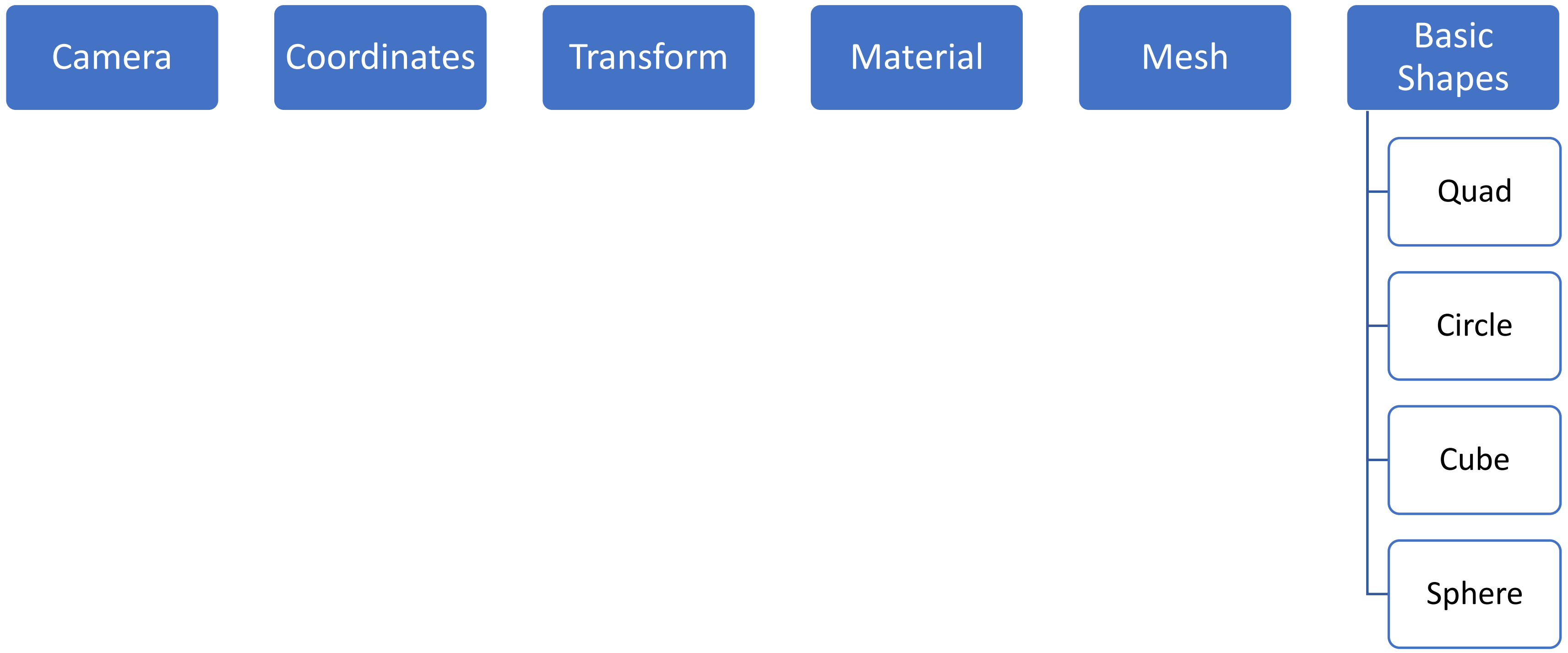
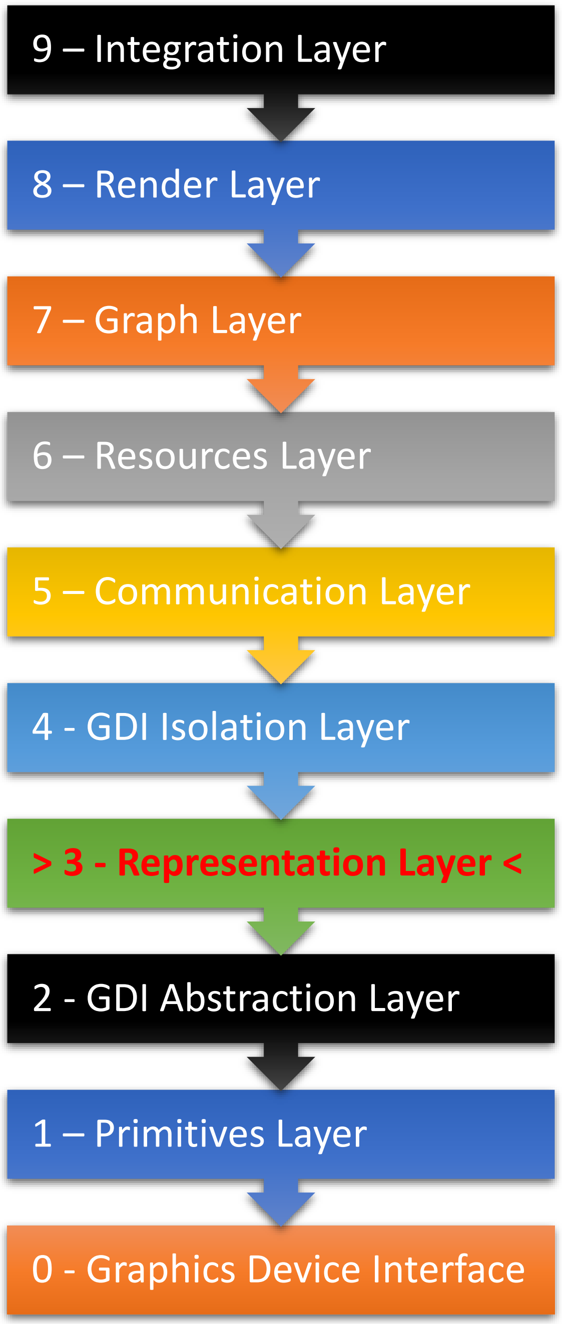

Camera
Coordinates
Transform
Material
Mesh
Basic Shapes
Quad
Circle
Cube
Sphere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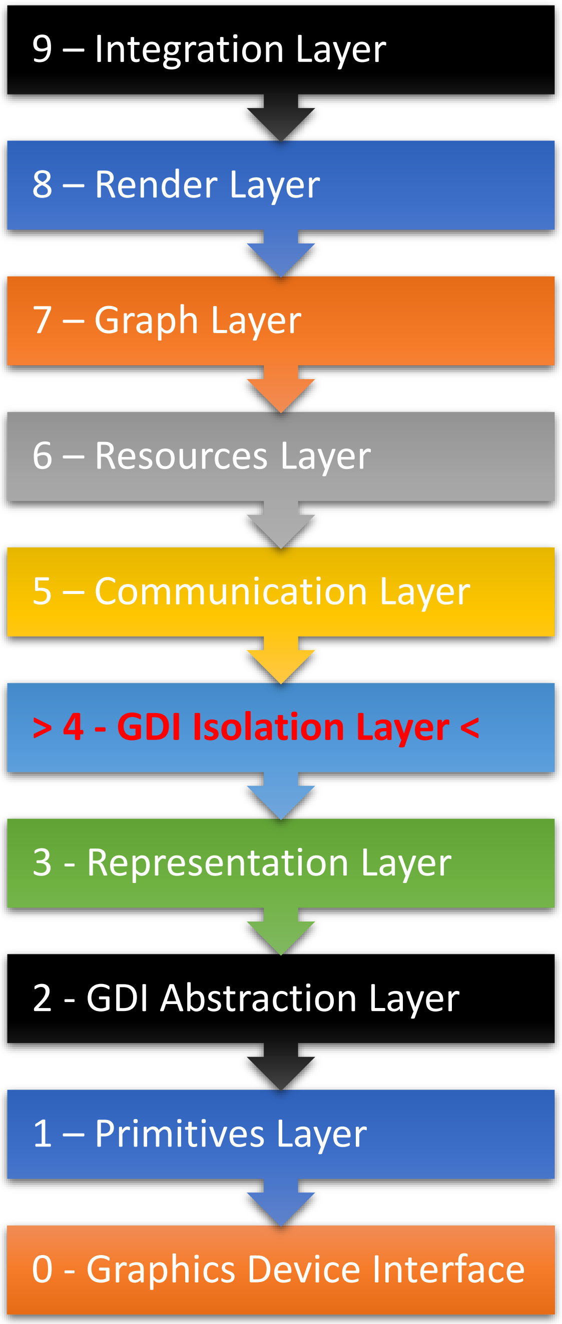
Render Device

- asd
- asd

Render Commands

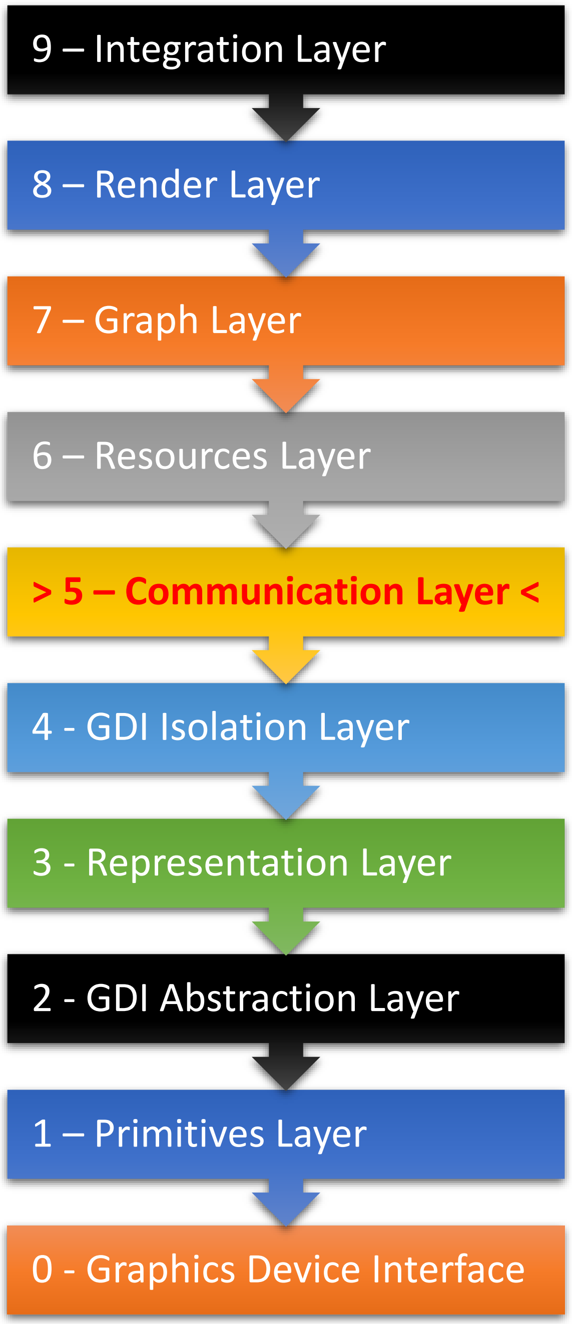
- Asd
- ads



Asset Loader

Command Queue

Swap Chain



Render Asset Manager

Material Library

Texture Library

Shader Library

Mesh Library

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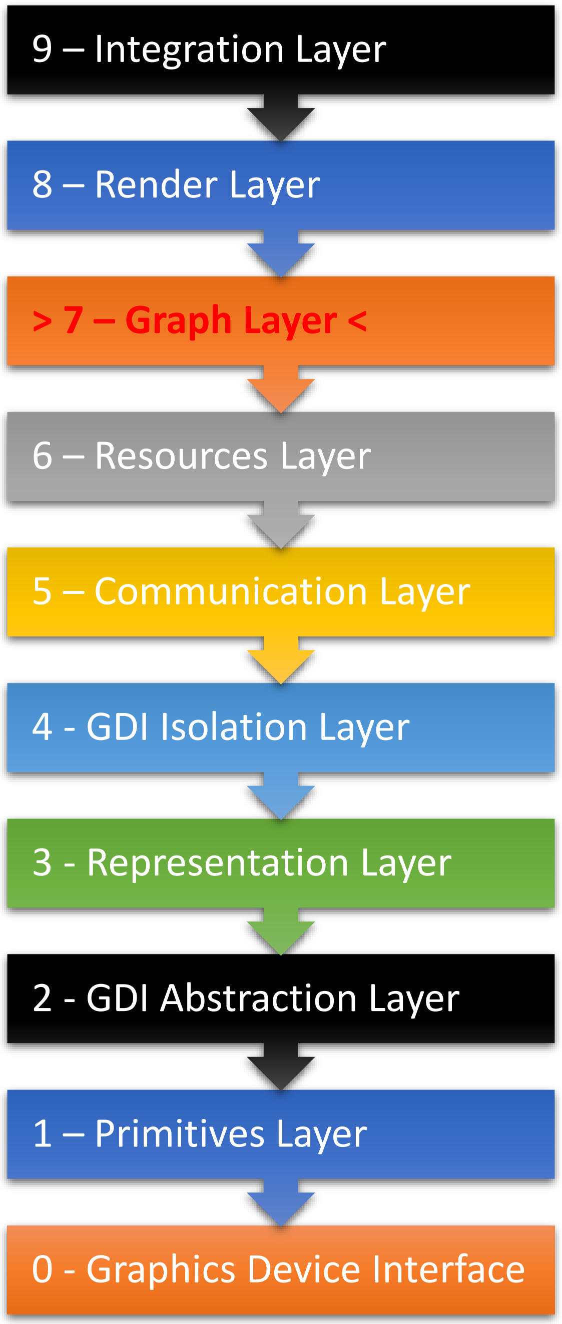
Render Pipeline

Render Pass



Geometry Renderer

Deferred Renderer

Forward Renderer

VFX Renderer

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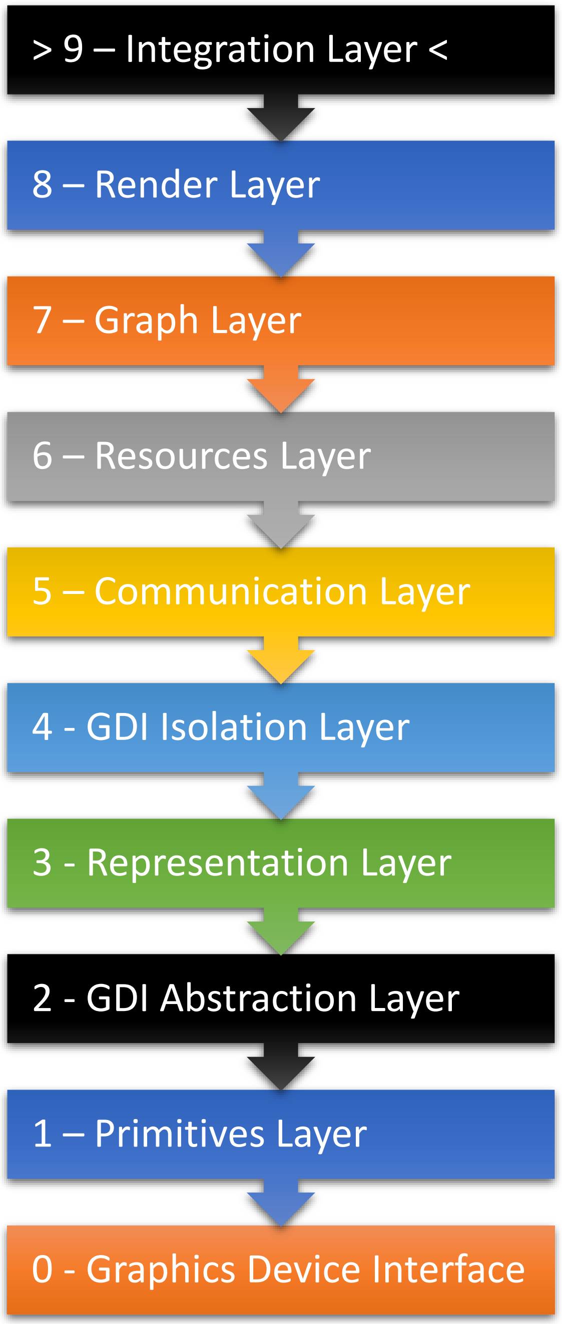
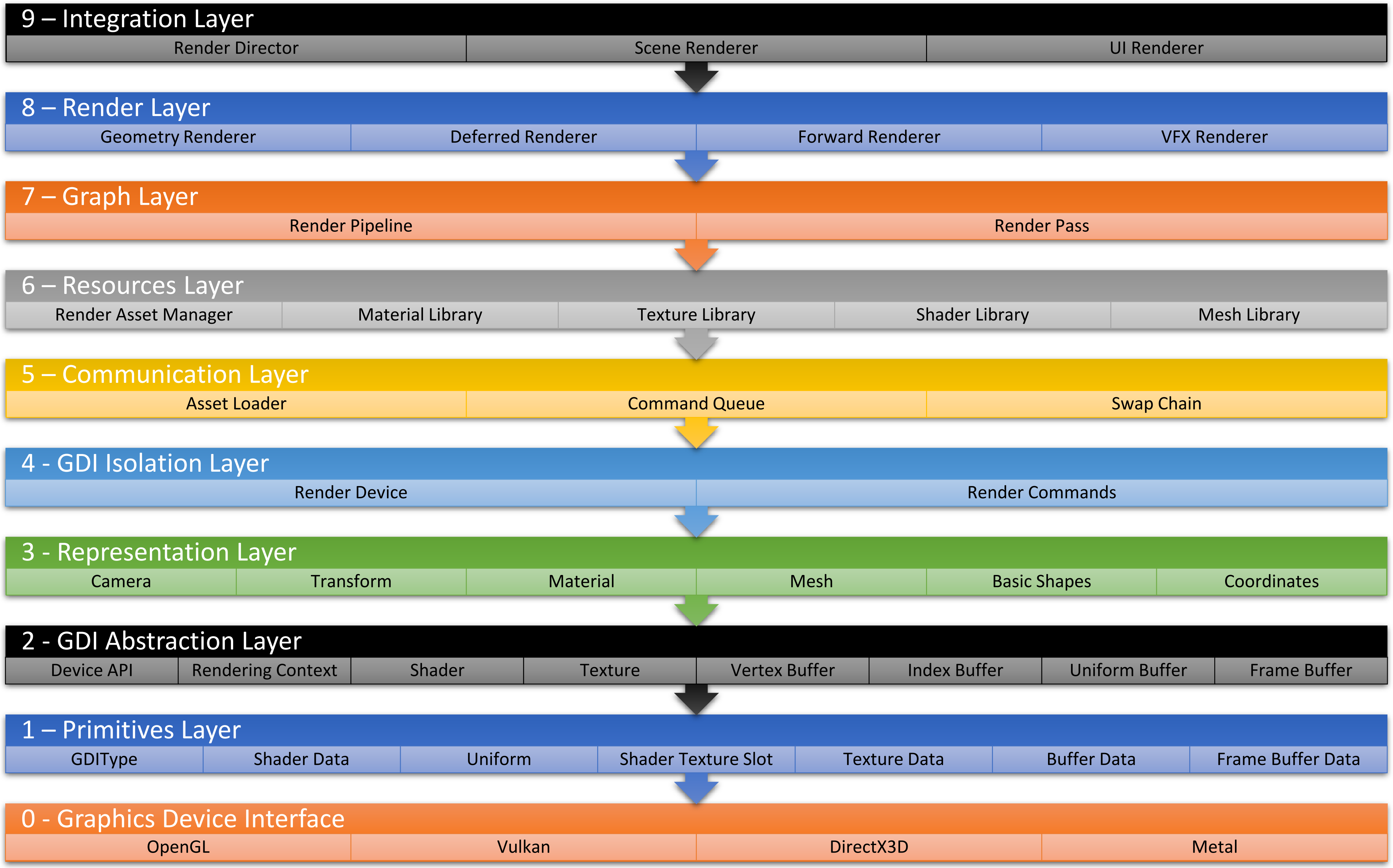
Render Director

Scene Renderer

UI Renderer




9 – Integration Layer
Render Director
Scene Renderer
UI Renderer
8 – Render Layer
Geometry Renderer
Deferred Renderer
Forward Renderer
VFX Renderer
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OpenGL
Vulkan
DirectX3D
Metal

Redeferred rendering – Experimental concept

Let's split diffused and specular contributions of the rendering equation

$$\mathrm{L}_o(\mathrm{p}, \omega_o) =$$
$$= \sum_i \left(k_d \frac{c}{\pi} + \frac{DFG}{4(\omega_o \cdot n)(\omega_i \cdot n)} \right) L_i\,(n \cdot \omega_i) =$$
$$= \sum_i \left(k_d \frac{c}{\pi} L_i\,(n \cdot \omega_i) + \frac{DFG}{4(\omega_o \cdot n)(\omega_i \cdot n)} L_i\,(n \cdot \omega_i) \right) =$$
$$= \sum_i \left(k_d \frac{c}{\pi} L_i\,(n \cdot \omega_i) + \frac{DFG}{4(\omega_o \cdot n)} L_i \right) =$$
$$= \sum_i k_d \frac{c}{\pi} L_i\,(n \cdot \omega_i) + \sum_i \frac{DFG}{4(\omega_o \cdot n)} L_i$$
$$\mathrm{L}_d(\mathrm{p}, \omega_o) = \sum_i k_d \frac{c}{\pi} L_i\,(n \cdot \omega_i)$$
$$\mathrm{L}_s(\mathrm{p}, \omega_o) = \sum_i \frac{DFG}{4(\omega_o \cdot n)} L_i$$
$$\mathrm{L}_o(\mathrm{p}, \omega_o) = L_d(\mathrm{p}, \omega_o) + L_s(\mathrm{p}, \omega_o)$$

We're going to store them in dedicated variables while calculating them in a per light loop.

Then we are going to add them back together outside the loop.

Diffused

$$\mathrm{L}_d(\mathrm{p},\omega_o) = \sum_i k_d \frac{c}{\pi} L_i\,(n\cdot\omega_i) = \frac{c}{\pi}\sum_i k_d L_i(n\cdot\omega_i) =$$

$$= \frac{c}{\pi}\sum_i (1-k_s)(1-m)L_i(n\cdot\omega_i) =$$

$$= (1-m)\frac{c}{\pi}\sum_i (1-k_s)L_i(n\cdot\omega_i) \approx$$

$$\approx (1-m)\frac{c}{\pi}\sum_i \big(1-(F_0+(1-F_0)P_i)\big)L_i(n\cdot\omega_i) =$$

$$= (1-m)\frac{c}{\pi}\sum_i (1-F_0-(1-F_0)P_i)L_i(n\cdot\omega_i) =$$

$$= (1-m)\frac{c}{\pi}\sum_i \big((1-F_0)-(1-F_0)P_i\big)L_i(n\cdot\omega_i) =$$

$$= (1-m)\frac{c}{\pi}\sum_i \big((1-F_0)(1-P_i)\big)L_i(n\cdot\omega_i) =$$

$$= (1-m)\frac{c}{\pi}(1-F_0)\sum_i (1-P_i)L_i(n\cdot\omega_i)$$

$$\mathrm{L}_{d_1} = \sum_i (1-P_i)L_i(n\cdot\omega_i)$$

$$\mathrm{L}_d(\mathrm{p},\omega_o) \approx (1-m)\frac{c}{\pi}(1-F_0)\mathrm{L}_{d_1}$$

Specular

$$\mathrm{L}_s(\mathrm{p},\omega_o) = \sum_i \frac{FDG}{4(\omega_o\cdot n)}L_i = \frac{1}{4(\omega_o\cdot n)}\sum_i DGL_iF \approx$$

$$\approx \frac{1}{4(\omega_o\cdot n)}\sum_i DGL_i(F_0+(1-F_0)P_i) =$$

$$= \frac{1}{4(\omega_o\cdot n)}\sum_i (DGL_iF_0 + DGL_iP_i(1-F_0)) =$$

$$= \frac{1}{4(\omega_o\cdot n)}\left(\sum_i DGL_iF_0 + \sum_i DGL_iP_i(1-F_0)\right) =$$

$$= \frac{1}{4(\omega_o\cdot n)}\left(F_0\sum_i DGL_i + (1-F_0)\sum_i DGL_iP_i\right)$$

$$\mathrm{L}_{s_1} = \sum_i DGL_i$$

$$\mathrm{L}_{s_2} = \sum_i DGL_iP_i$$

$$\mathrm{L}_s(\mathrm{p},\omega_o) \approx \frac{1}{4(\omega_o\cdot n)}\big(F_0\mathrm{L}_{s_1} + (1-F_0)\mathrm{L}_{s_2}\big)$$

Fresnel-Schlick approximation:

$$k_s = F = F_0 + (1-F_0)\big(1-(h_i\cdot v)\big)^5$$

$$P_i = \big(1-(h_i\cdot v)\big)^5$$

$$k_s = F = F_0 + (1-F_0)P_i$$

Recombination

$$\mathrm{L}_{d_1} = \sum_i (1 - P_i) L_i (n \cdot \omega_i)$$

$$\mathrm{L}_{s_1} = \sum_i DGL_i \qquad\qquad P_i = \left(1 - (h_i \cdot v)\right)^5$$

$$\mathrm{L}_{s_2} = \sum_i DGL_i P_i$$

$$\mathrm{L}_d(\mathrm{p}, \omega_o) \approx (1 - m)\frac{c}{\pi}(1 - F_0)\mathrm{L}_{d_1}$$

$$\mathrm{L}_s(\mathrm{p}, \omega_o) \approx \frac{1}{4(\omega_o \cdot n)}\left(F_0 \mathrm{L}_{s_1} + (1 - F_0)\mathrm{L}_{s_2}\right)$$

$$\mathrm{L}_o(\mathrm{p}, \omega_o) = L_d(\mathrm{p}, \omega_o) + L_s(\mathrm{p}, \omega_o)$$

We are going to calculate $\mathrm{L}_{s_1}, \mathrm{L}_{s_2}, \mathrm{L}_{d_1}$ inside the lights loop
We are going to calculate L_s, L_d and finally L_o outside the loop

A portion of calculations is now pushed out of the loop and performed only once, instead of on a per light basis.

Metalness and albedo are now not accessed inside the loop at all, what reduces memory congestion.

Depending on chosen approximations of normal distribution function and geometry function additional elements could be pulled out of the loop (e.g. $\frac{\alpha^2}{\pi}$ can be pulled out of Trowbridge-Reitz GGX approximation of NDF) although not fully.

Redeffered rendering

$$P_i = \left(1 - (h_i \cdot v)\right)^5$$
$$\mathrm{L}_{d_1} = \sum_i (1 - P_i) L_i (n \cdot \omega_i)$$
$$\mathrm{L}_{s_1} = \sum_i DGL_i$$
$$\mathrm{L}_{s_2} = \sum_i DGL_i P_i$$

$$\mathrm{L}_d(\mathrm{p}, \omega_o) \approx (1 - m) \frac{c}{\pi} (1 - F_0) \mathrm{L}_{d_1}$$
$$\mathrm{L}_s(\mathrm{p}, \omega_o) \approx \frac{1}{4(\omega_o \cdot n)} \left(F_0 \mathrm{L}_{s_1} + (1 - F_0) \mathrm{L}_{s_2}\right)$$
$$\mathrm{L}_o(\mathrm{p}, \omega_o) = L_d(\mathrm{p}, \omega_o) + L_s(\mathrm{p}, \omega_o)$$

Lets split shading into two stages.

First stage will produce L_{d_1}, L_{s_1}, L_{s_2} values and store them in a dedicated buffer – I-buffer.
Second stage will use those values to calculate L_o.

I-buffer retains fundamental characteristic of light to be cumulative. This allows first step to be split into multiple passes using specialized shaders for different types of lights and shadows. Redeferred rendering can be used analogously with most of the indirect illumination techniques too and their results can be accumulated to the same I-buffer with a common second stage to be applied.

First stage depends only on lights and geometry (from PBR point of view roughness is a simplified representation of subpixel geometry, not a property of a substance). The variability of output buffer is expected to be low (imagine white world with colorful lights). That makes this stage a good candidate for shading rate reducing technique (lower overall resolution of the buffer / VRS / Deferred Adaptive Compute Shading / etc.). We can safely apply reduced shading rate everywhere unless there is an illumination discontinuity (hard shadow / geometry edge) from a particular illumination source – this will require visual confirmation about quality.

Second stage does not have to iterate over illumination sources, so it will be used to refine results by integrating them with materials at full resolution. It will fully cover artifacts of reduced shading rate from first pass, making them completely imperceptible. If roughness is pulled out of Trowbridge-Reitz GGX approximation of NDF, then we have all parameters of a given pixel from G-buffer taken into consideration during refining second pass.

Redeffered rendering - considerations

$$P_i = \left(1 - (h_i \cdot v)\right)^5$$
$$\mathrm{L}_{d_1} = \sum_i (1 - P_i) L_i (n \cdot \omega_i)$$
$$\mathrm{L}_{s_1} = \sum_i DGL_i$$
$$\mathrm{L}_{s_2} = \sum_i DGL_i P_i$$

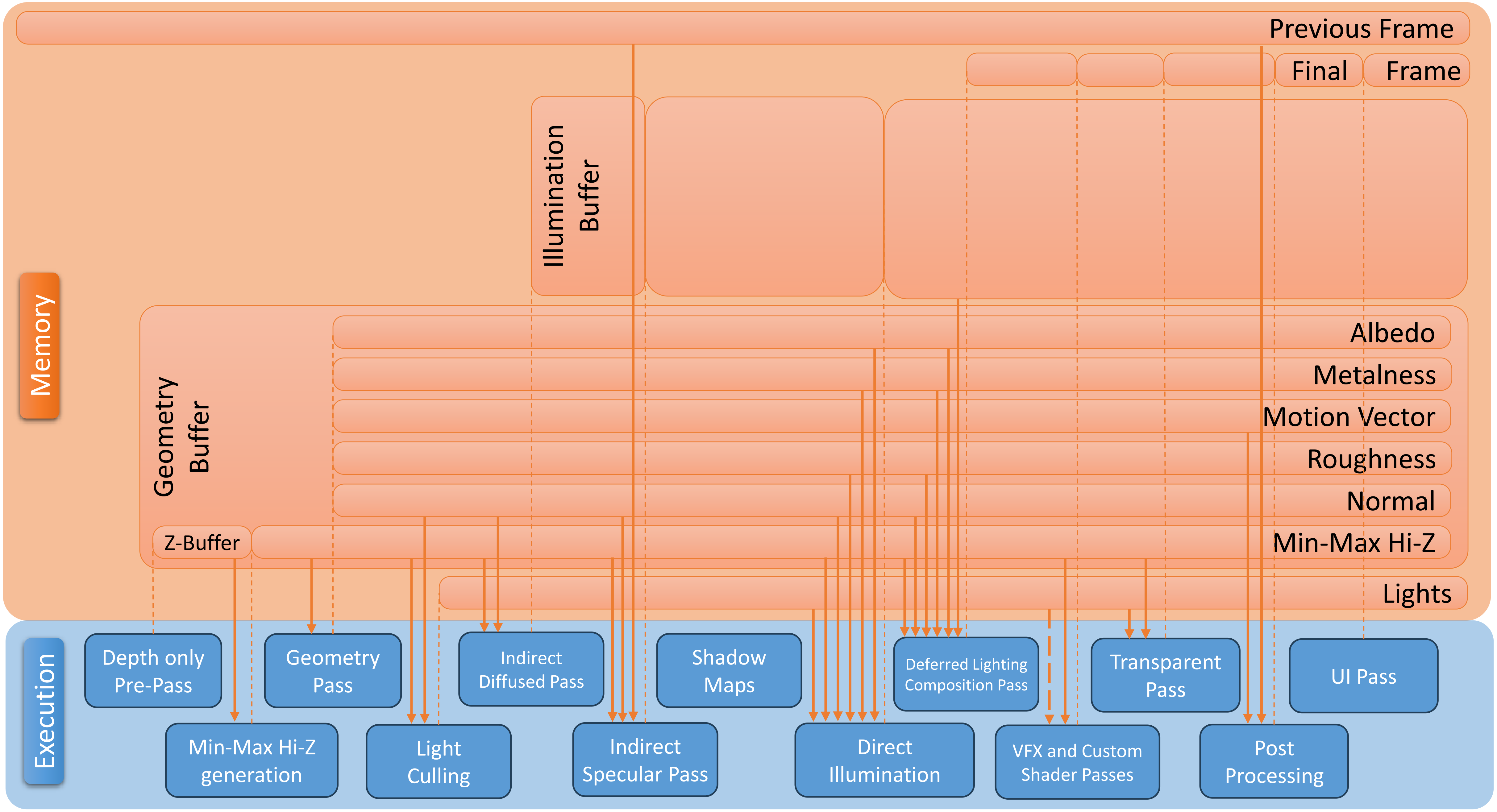
$$\mathrm{L}_d(\mathrm{p}, \omega_o) \approx (1 - m)\frac{c}{\pi}(1 - F_0)\mathrm{L}_{d_1}$$
$$\mathrm{L}_s(\mathrm{p}, \omega_o) \approx \frac{1}{4(\omega_o \cdot n)}\left(F_0 \mathrm{L}_{s_1} + (1 - F_0)\mathrm{L}_{s_2}\right)$$
$$\mathrm{L}_o(\mathrm{p}, \omega_o) = L_d(\mathrm{p}, \omega_o) + L_s(\mathrm{p}, \omega_o)$$

In case memory throughput becomes significant bottleneck:

A. Calculating $\frac{1}{F_0}\left(F_0 \mathrm{L}_{s_1} + (1 - F_0)\mathrm{L}_{s_2}\right)$ in first pass, storing results as a 1 color instead of 2 and multiplying back by F_0 in second pass (F_0 is different now, because is taken from a different sampling point – full resolution second pass vs reduced shading rate in first pass).
B. Precalculating $(\omega_o \cdot n)$ in geometry pass – no need for normal and depth in second pass
C. Smart combined packing of I-Buffer and G-Buffer

In case of light bleeding over edges and aliased shadow edges due to greater aliasing in I-Buffer then in G-Buffer:

A. Using VRS with dedicated shading rate attachments per illumination aspect (direct, shadows, reflections, indirect, etc.)
B. Using different shading rates per illumination aspect


Previous Frame
Final
Frame
Illumination Buffer
Memory
Geometry Buffer
Albedo
Metalness
Motion Vector
Roughness
Normal
Z-Buffer
Min-Max Hi-Z
Lights
Execution
Depth only Pre-Pass
Geometry Pass
Indirect Diffused Pass
Shadow Maps
Deferred Lighting Composition Pass
Transparent Pass
UI Pass
Min-Max Hi-Z generation
Light Culling
Indirect Specular Pass
Direct Illumination
VFX and Custom Shader Passes
Post Processing