

# Introduction to Computer Graphics

186.832, 2021W, 3.0 ECTS



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## *Vulkan Lecture Series, Episode 5:* **Pipelines and Stages**

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TU Wien, Austria



# Different Types of Commands

## Graphics Pipeline

### Commands:

vkCmdDraw  
 vkCmdDrawIndexed  
 vkCmdDrawIndirect  
 vkCmdDrawIndirectCount  
 vkCmdDrawIndexedIndirect  
 vkCmdDrawIndexedIndirectCount  
  
 vkCmdDrawMeshTasksNV  
 vkCmdDrawMeshTasksIndirectNV  
 vkCmdDrawMeshTasksIndirectCountNV  
  
 vkCmdClearAttachments

## Ray-Tracing Acceleration Structure

### Build Commands:

vkCmdBuildAccelerationStructuresKHR  
 vkCmdBuildAccelerationStructuresIndirectKHR

## Compute Pipeline

### Commands:

vkCmdDispatch  
 vkCmdDispatchBase  
 vkCmdDispatchIndirect

## Ray Tracing Pipeline

### Commands:

vkCmdTraceRaysKHR  
 vkCmdTraceRaysIndirectKHR

## Transfer Commands:

vkCmdCopyBuffer  
 vkCmdCopyImage  
 vkCmdCopyBufferToImage  
 vkCmdCopyImageToBuffer  
 vkCmdCopyAccelerationStructureKHR  
 vkCmdCopyAccelerationStructureToMemoryKHR  
 vkCmdCopyMemoryToAccelerationStructureKHR  
 vkCmdFillBuffer  
  
 vkCmdBlitImage  
  
 vkCmdResolveImage  
  
 vkCmdClearColorImage  
 vkCmdClearDepthStencilImage

## Bind Commands:

vkCmdBindDescriptorSets  
 vkCmdBindPipeline  
 vkCmdBindVertexBuffers  
 vkCmdBindIndexBuffer

## Other Commands:

vkCmdPushConstants  
 vkCmdPushDescriptorSetKHR  
 vkCmdSetScissor  
 vkCmdSetViewport  
 vkCmdSetDepthBias

...



# Different Types of Commands

## Graphics Pipeline

### Commands:

vkCmdDraw  
 vkCmdDrawIndexed  
 vkCmdDrawIndirect  
 vkCmdDrawIndirectCount  
 vkCmdDrawIndexedIndirect  
 vkCmdDrawIndexedIndirectCount  
  
 vkCmdDrawMeshTasksNV  
 vkCmdDrawMeshTasksIndirectNV  
 vkCmdDrawMeshTasksIndirectCountNV  
  
 vkCmdClearAttachments

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## Transfer Commands:

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 vkCmdCopyMemoryToAccelerationStructureKHR  
 vkCmdFillBuffer  
  
 vkCmdBlitImage  
  
 vkCmdResolveImage  
  
 vkCmdClearColorImage  
 vkCmdClearDepthStencilImage

## STATE-Type

### Bind Commands:

vkCmdBindDescriptorSets  
 vkCmdBindPipeline  
 vkCmdBindVertexBuffers  
 vkCmdBindIndexBuffer

### Other Commands:

vkCmdPushConstants  
 vkCmdPushDescriptorSetKHR  
 vkCmdSetScissor  
 vkCmdSetViewport  
 vkCmdSetDepthBias  
  
 ...



## Graphics Pipeline

### Commands:

- vkCmdDraw
- vkCmdDrawIndexed
- vkCmdDrawIndirect
- vkCmdDrawIndirectCount
- vkCmdDrawIndexedIndirect
- vkCmdDrawIndexedIndirectCount
- vkCmdDrawMeshTasksNV
- vkCmdDrawMeshTasksIndirectNV
- vkCmdDrawMeshTasksIndirectCountNV
- vkCmdClearAttachments

## Ray-Tracing Acceleration Structure

### Build Commands:

- vkCmdBuildAccelerationStructuresKHR
- vkCmdBuildAccelerationStructuresIndirectKHR

## Compute Pipeline

### Commands:

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- vkCmdDispatchBase
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- vkCmdCopyBuffer
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- vkCmdCopyMemoryToAccelerationStructureKHR
- vkCmdFillBuffer
- vkCmdBlitImage
- vkCmdResolveImage
- vkCmdClearColorImage
- vkCmdClearDepthStencilImage

## ACTION-Type

### Bind Commands:

- vkCmdBindDescriptorSets
- vkCmdBindPipeline
- vkCmdBindVertexBuffers
- vkCmdBindIndexBuffer

### Other Commands:

- vkCmdPushConstants
- vkCmdPushDescriptorSetKHR
- vkCmdSetScissor
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- vkCmdSetDepthBias

...



# Different Types of Commands

## Graphics Pipeline Commands:

1

- vkCmdDraw
- vkCmdDrawIndexed
- vkCmdDrawIndirect
- vkCmdDrawIndirectCount
- vkCmdDrawIndexedIndirect
- vkCmdDrawIndexedIndirectCount
- vkCmdDrawMeshTasksNV
- vkCmdDrawMeshTasksIndirectNV
- vkCmdDrawMeshTasksIndirectCountNV
- vkCmdClearAttachments

## Compute Pipeline Commands:

2

- vkCmdDispatch
- vkCmdDispatchBase
- vkCmdDispatchIndirect

## Ray Tracing Pipeline Commands:

3

- vkCmdTraceRaysKHR
- vkCmdTraceRaysIndirectKHR

## Transfer Commands:

- vkCmdCopyBuffer
- vkCmdCopyImage
- vkCmdCopyBufferToImage
- vkCmdCopyImageToBuffer
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- vkCmdCopyMemoryToAccelerationStructureKHR
- vkCmdFillBuffer
- vkCmdBlitImage
- vkCmdResolveImage
- vkCmdClearColorImage
- vkCmdClearDepthStencilImage

## ACTION-Type

## Ray-Tracing Acceleration Structure Build Commands:

- vkCmdBuildAccelerationStructuresKHR
- vkCmdBuildAccelerationStructuresIndirectKHR

## Bind Commands:

- vkCmdBindDescriptorSets
- vkCmdBindPipeline
- vkCmdBindVertexBuffers
- vkCmdBindIndexBuffer

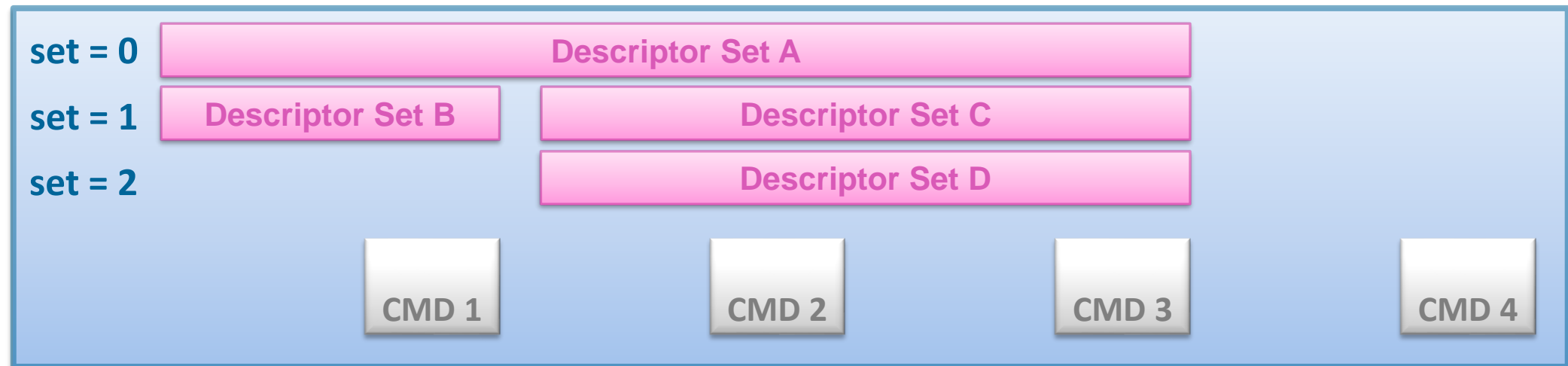
## Other Commands:

- vkCmdPushConstants
- vkCmdPushDescriptorSetKHR
- vkCmdSetScissor
- vkCmdSetViewport
- vkCmdSetDepthBias

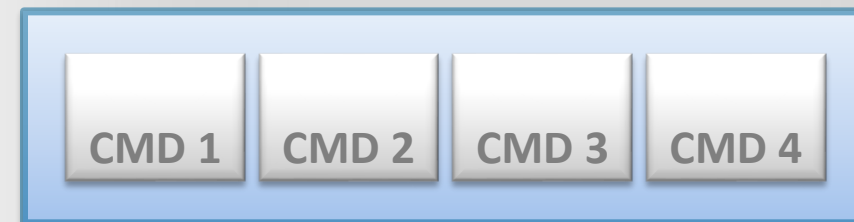
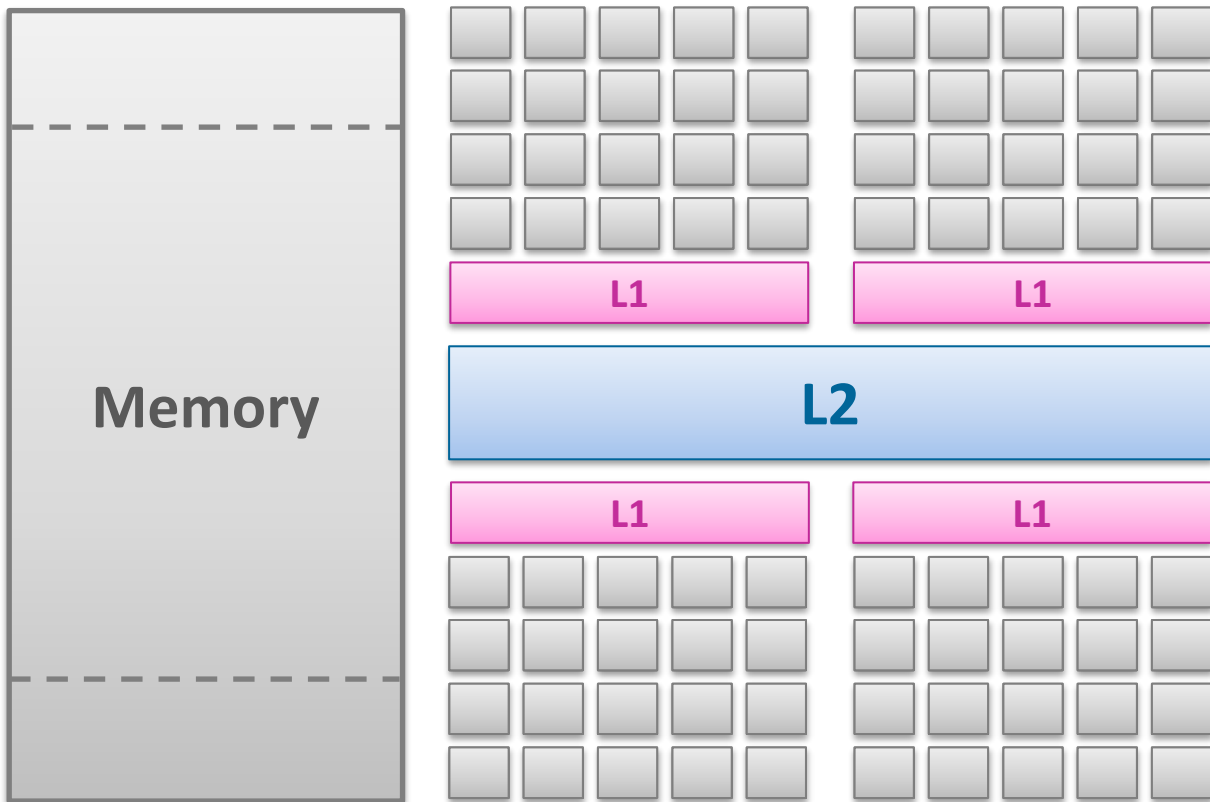
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## COMMAND BUFFER

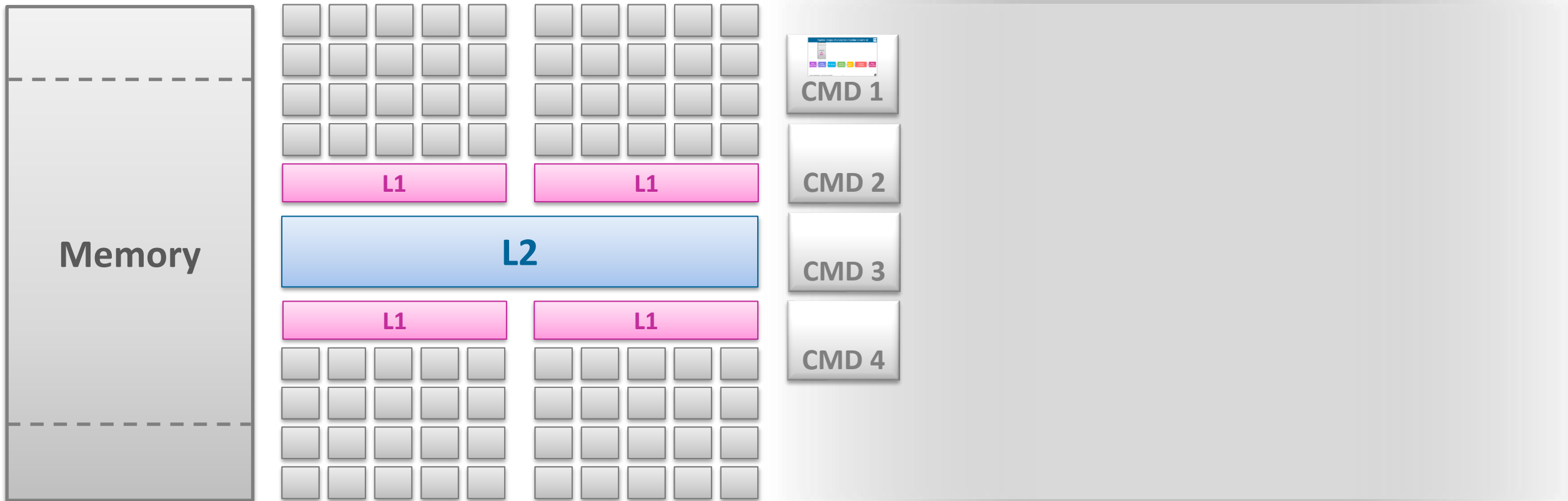


## QUEUE



# Command Recording and Queue Submission

## QUEUE





# Pipeline Stages of a Graphics Pipeline Command



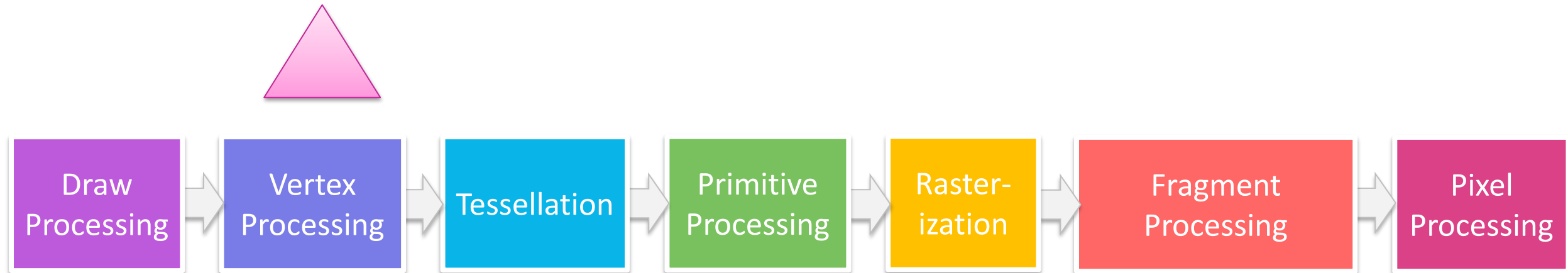
# Pipeline Stages of a Graphics Pipeline Command



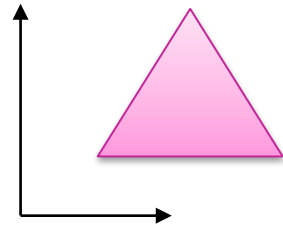
# Pipeline Stages of a Graphics Pipeline Command



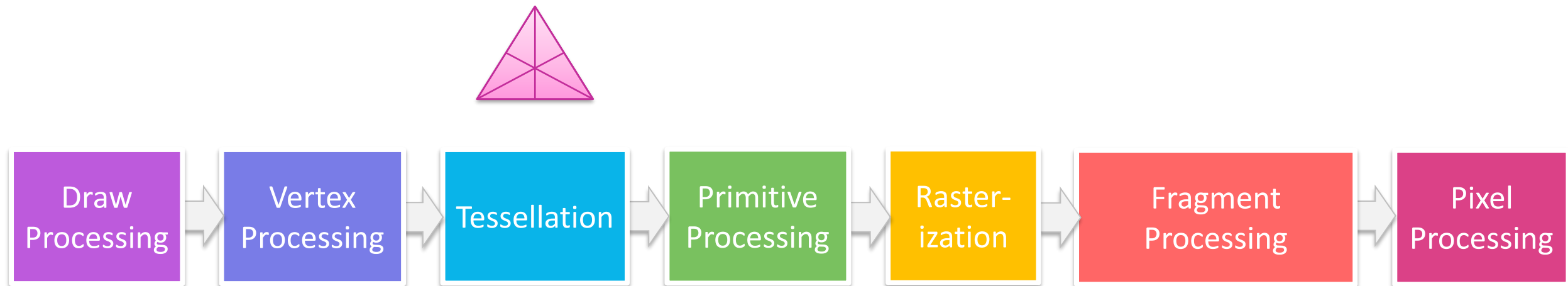
# Pipeline Stages of a Graphics Pipeline Command



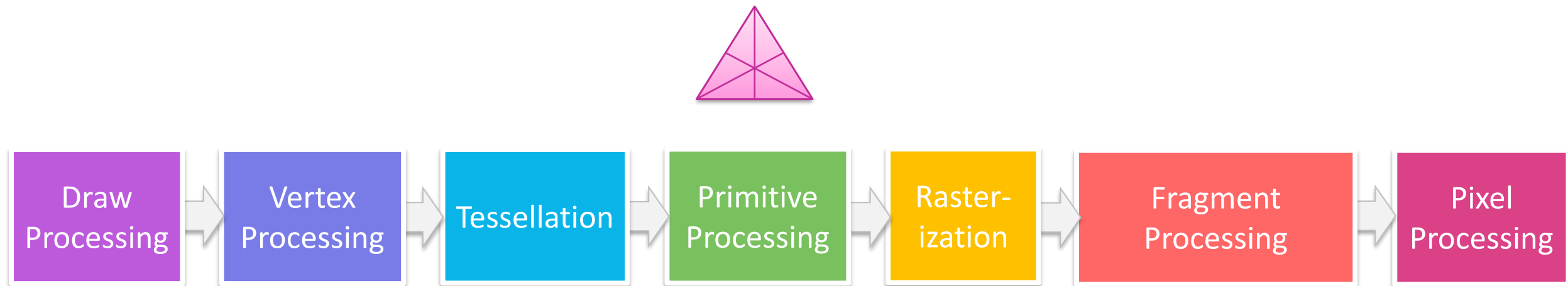
# Pipeline Stages of a Graphics Pipeline Command



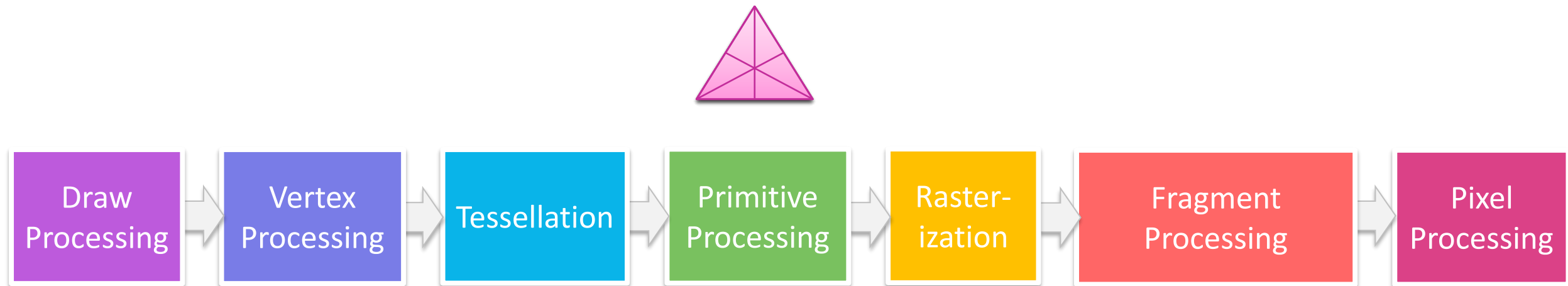
# Pipeline Stages of a Graphics Pipeline Command



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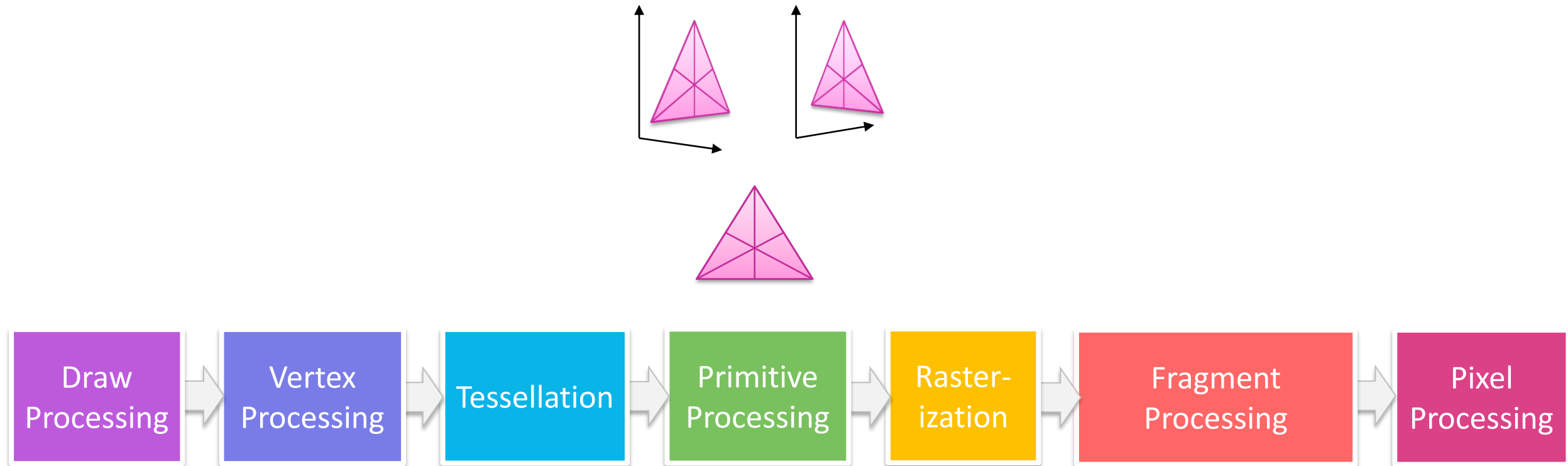


# Pipeline Stages of a Graphics Pipeline Command

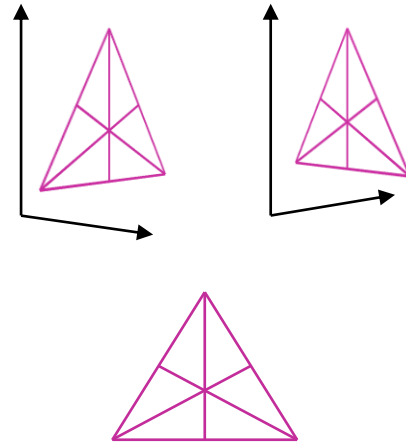




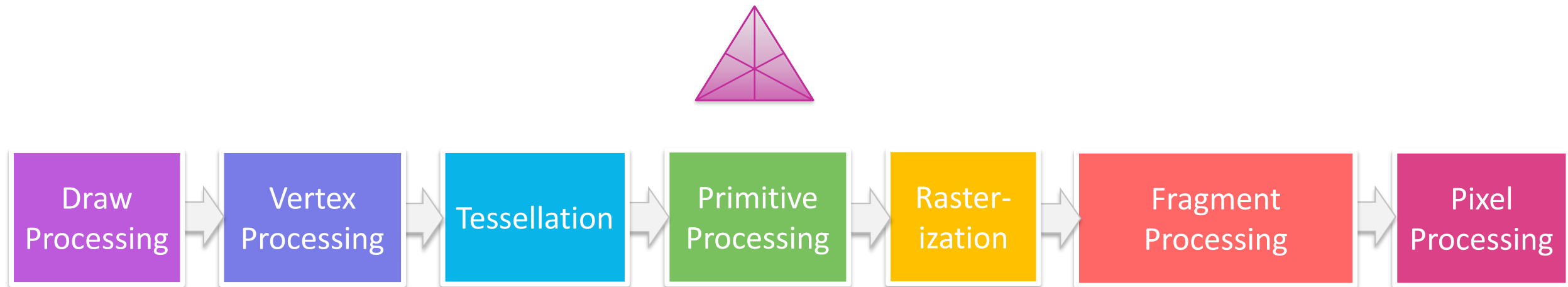
# Pipeline Stages of a Graphics Pipeline Command



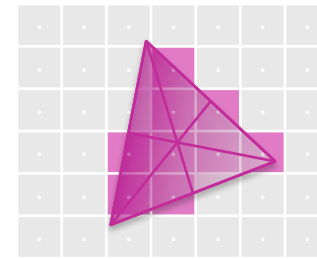
# Pipeline Stages of a Graphics Pipeline Command



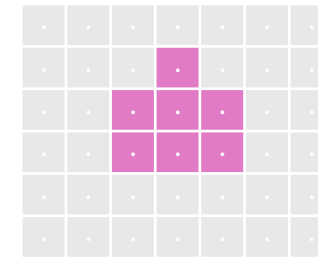
# Pipeline Stages of a Graphics Pipeline Command



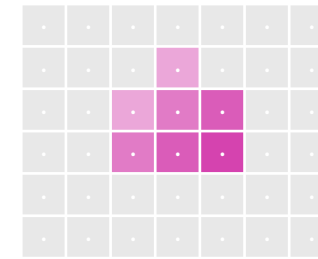
# Pipeline Stages of a Graphics Pipeline Command



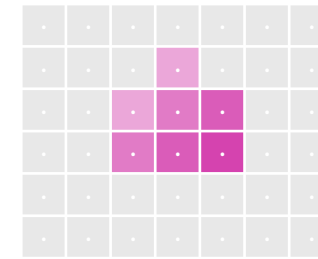
# Pipeline Stages of a Graphics Pipeline Command



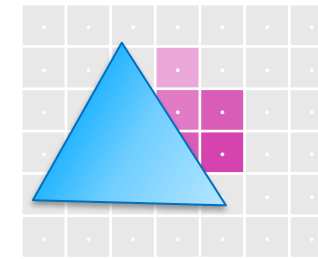
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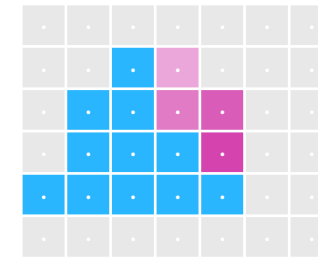


# Pipeline Stages of a Graphics Pipeline Command

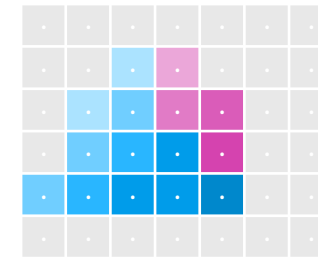




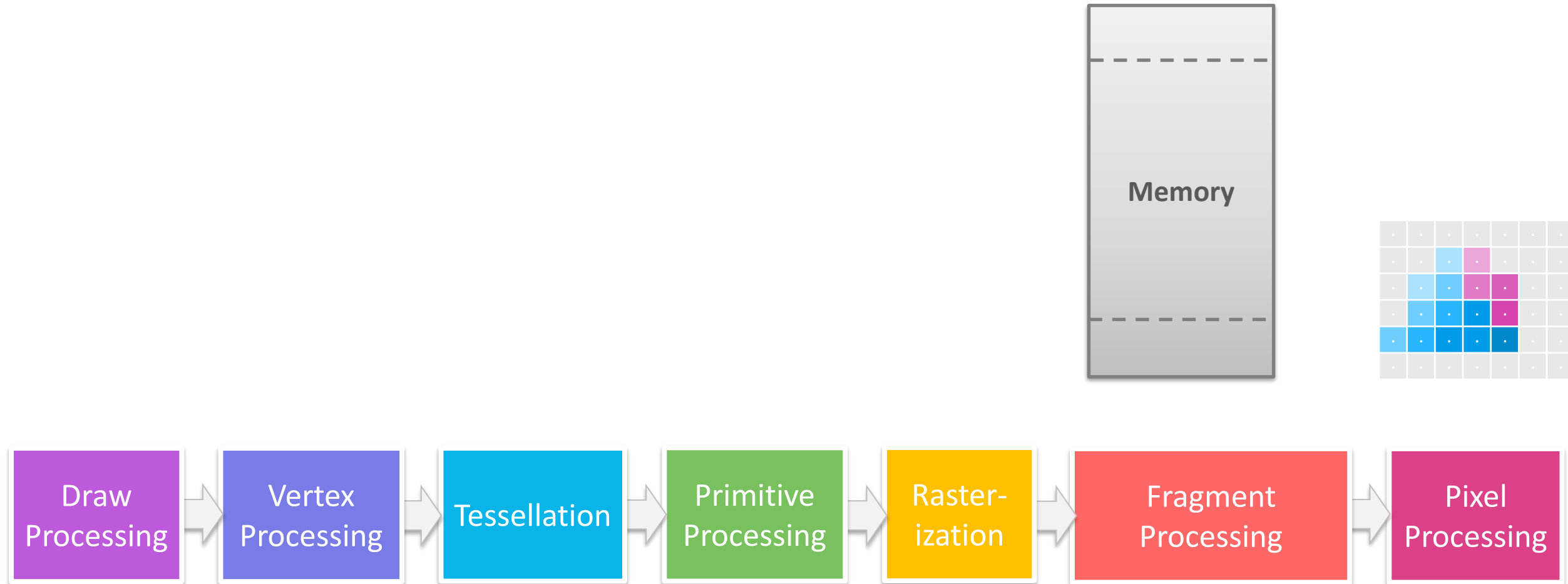
# Pipeline Stages of a Graphics Pipeline Command



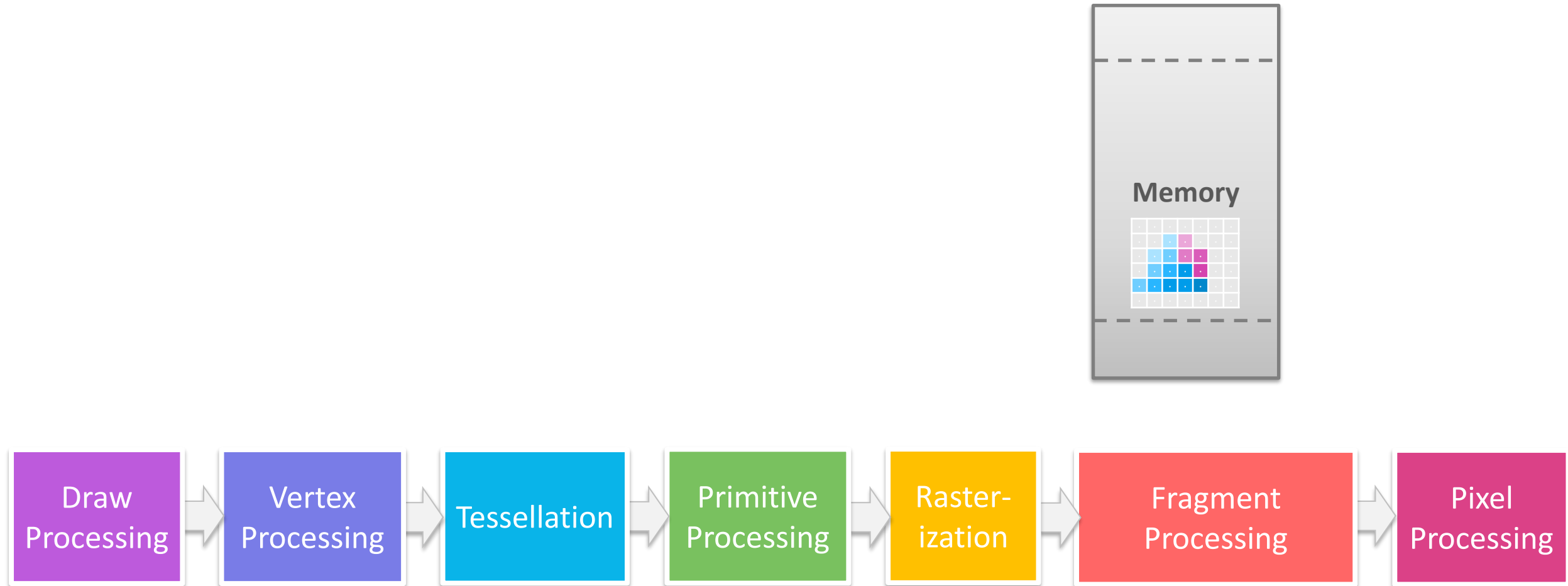
# Pipeline Stages of a Graphics Pipeline Command



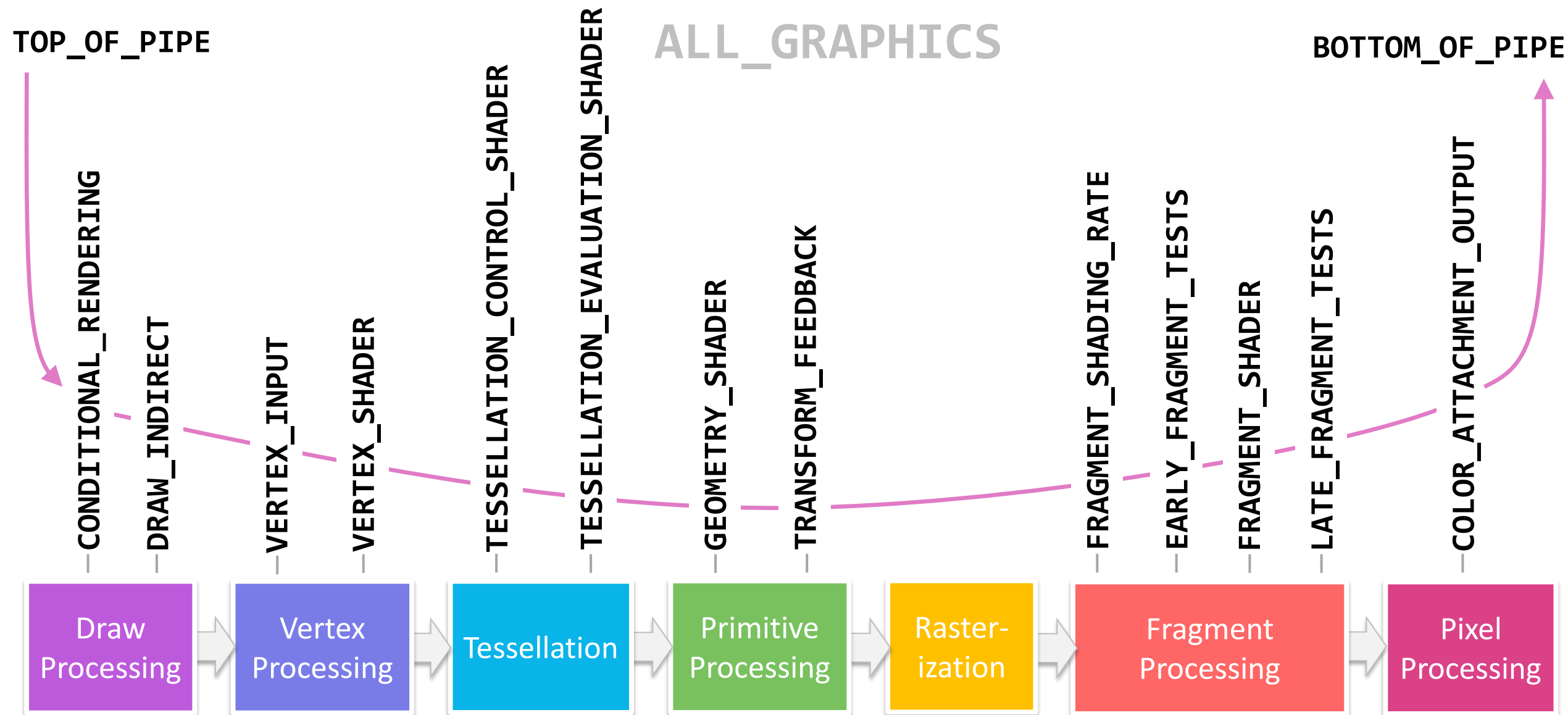
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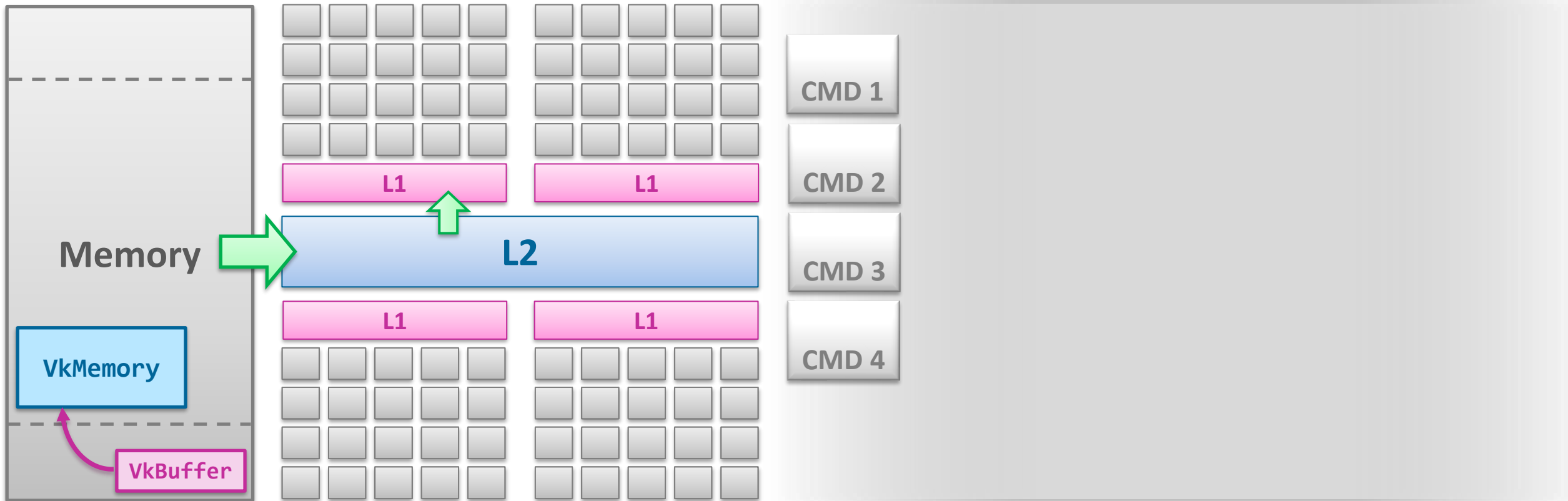


# Pipeline Stages of a Graphics Pipeline Command



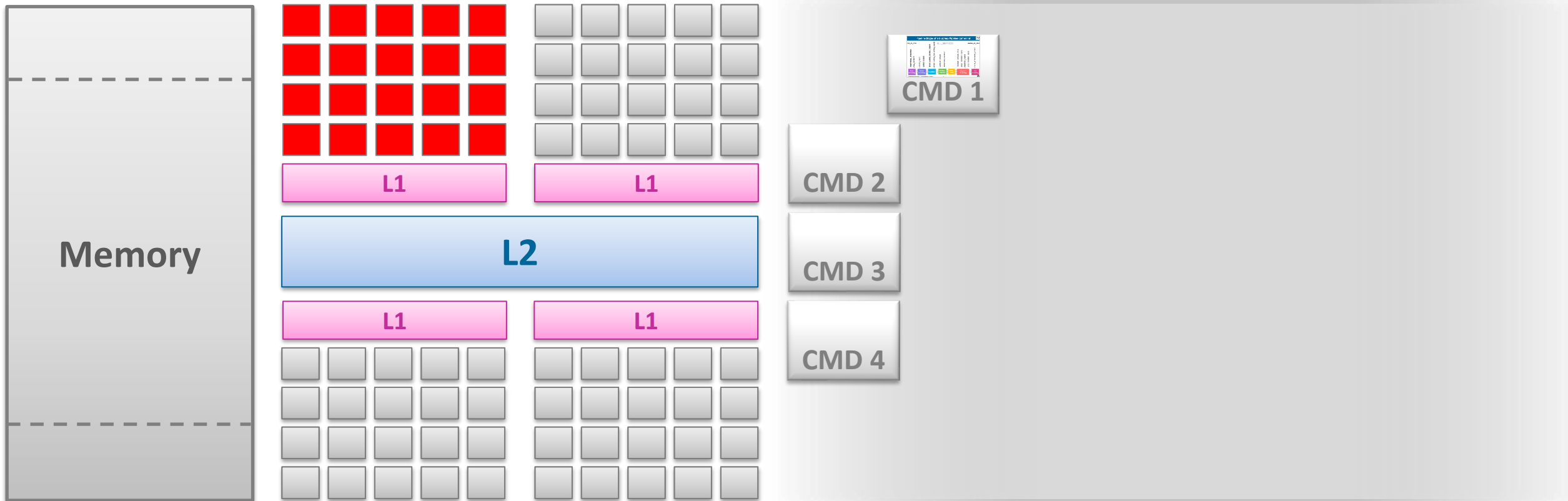
# Pipeline Stages of a Graphics Pipeline Command

QUEUE

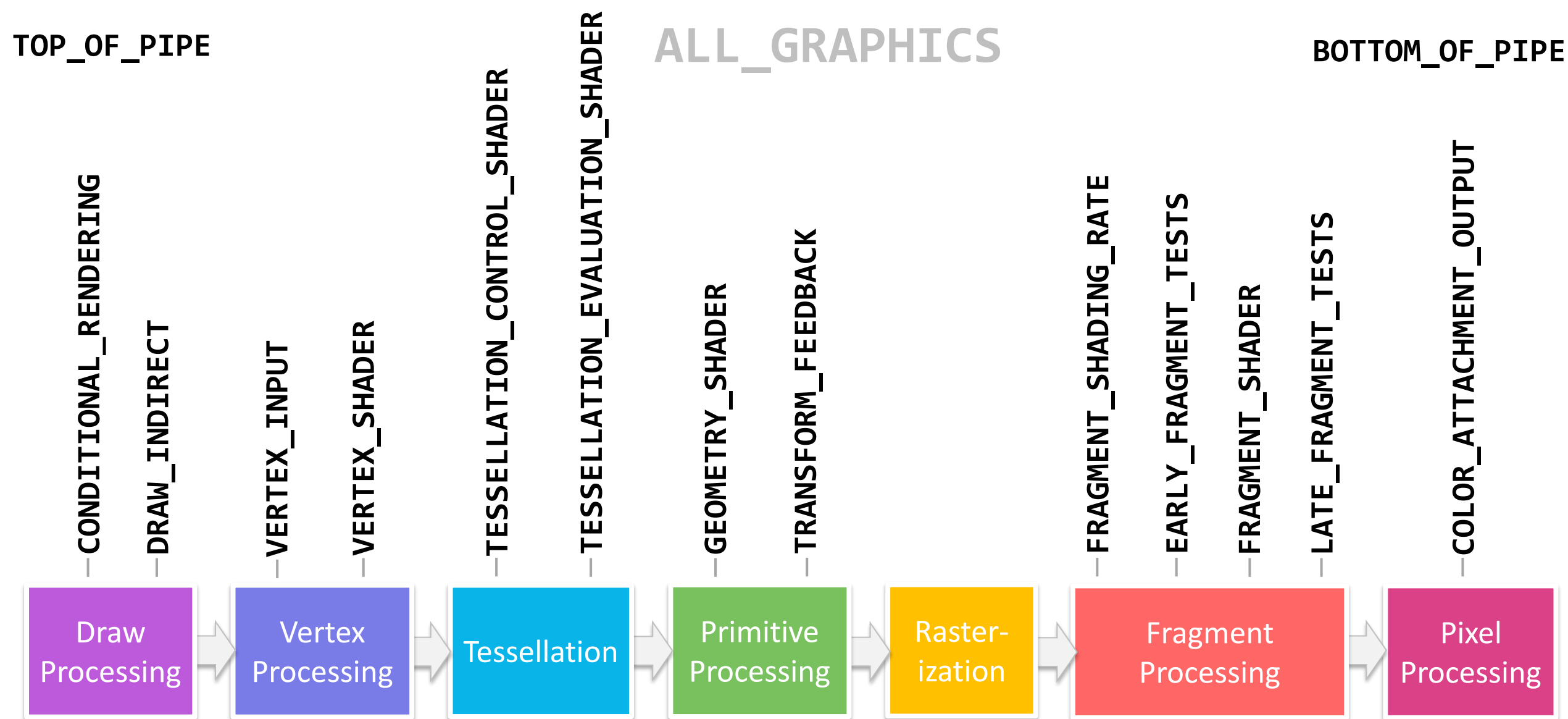


# Pipeline Stages of a Graphics Pipeline Command

QUEUE



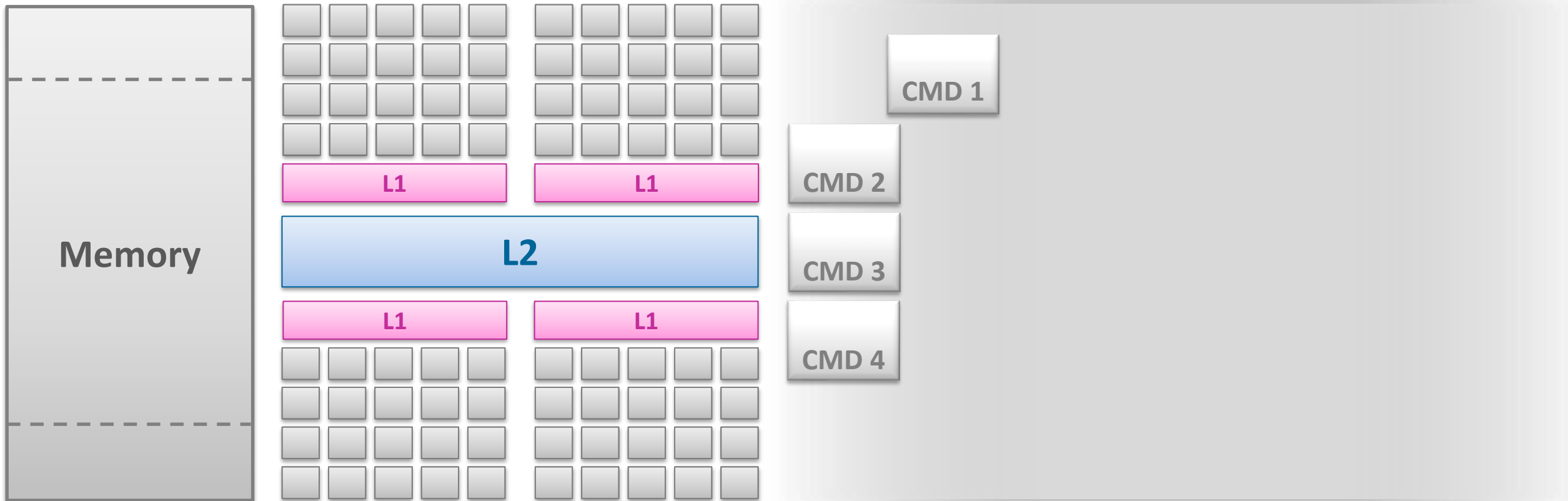
# Pipeline Stages of a Graphics Pipeline Command





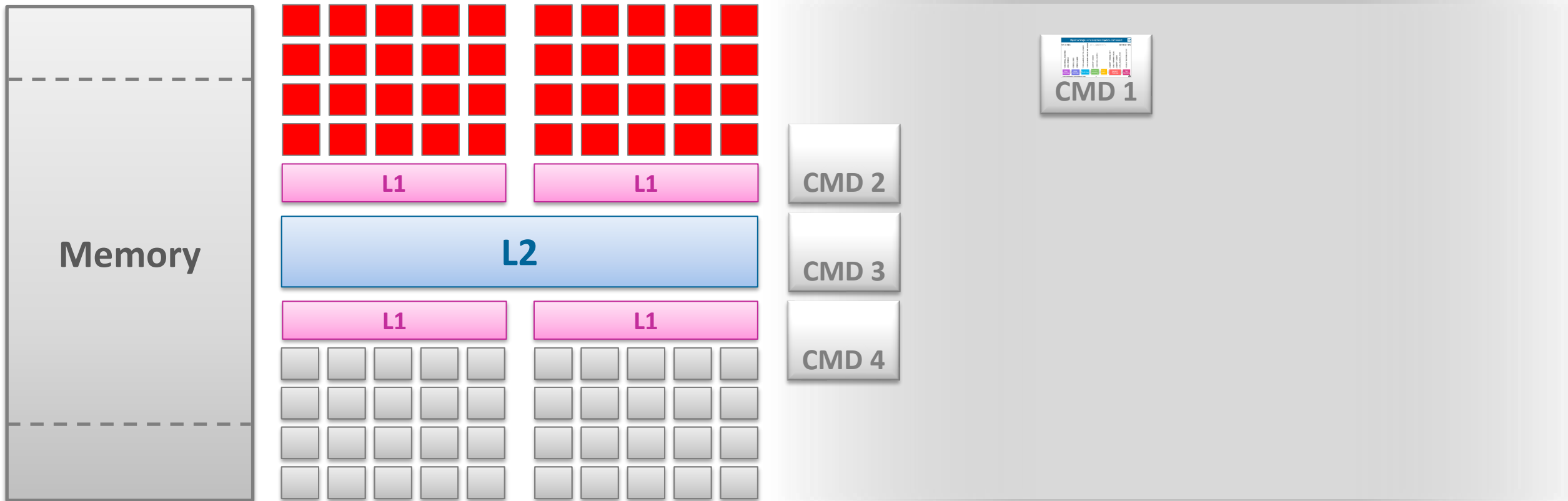
# Pipeline Stages of a Graphics Pipeline Command

QUEUE

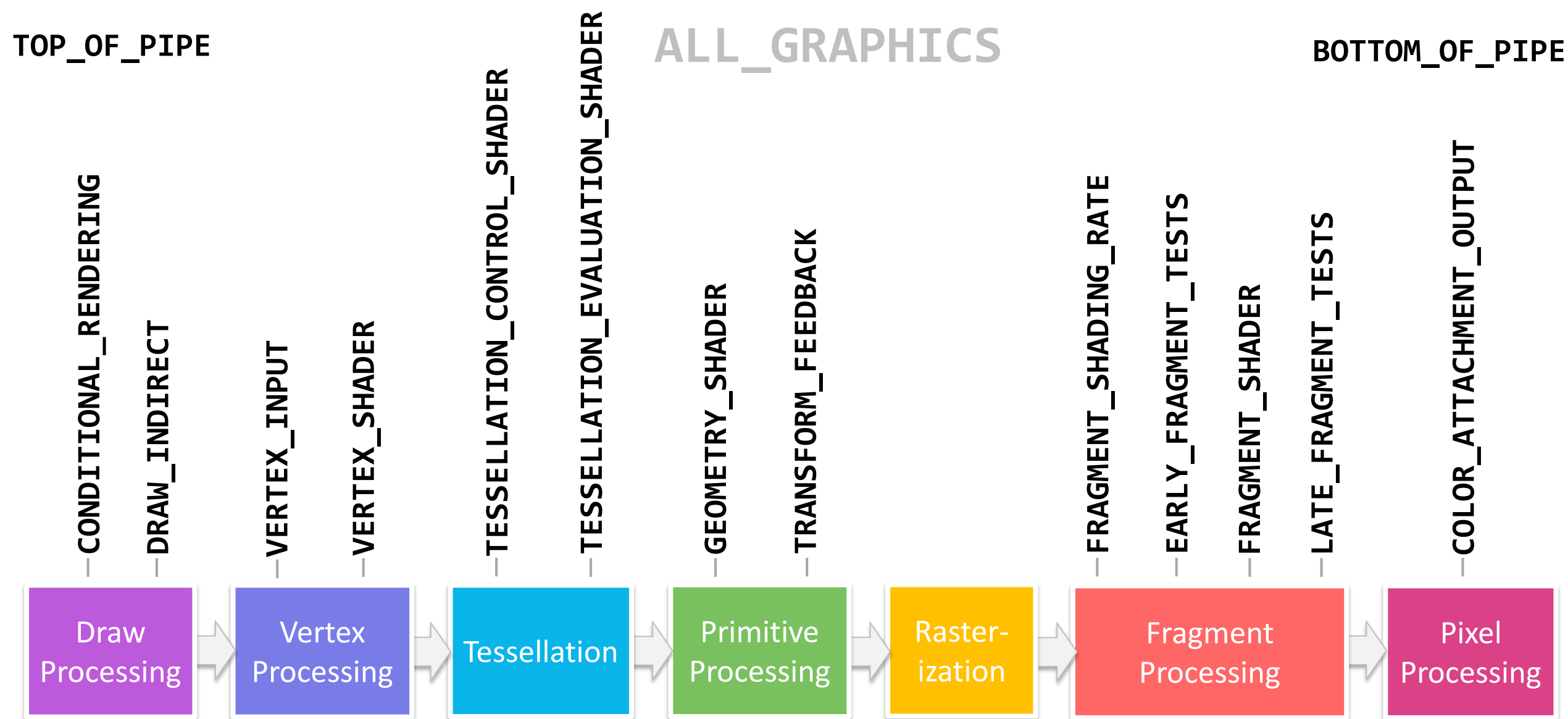


# Pipeline Stages of a Graphics Pipeline Command

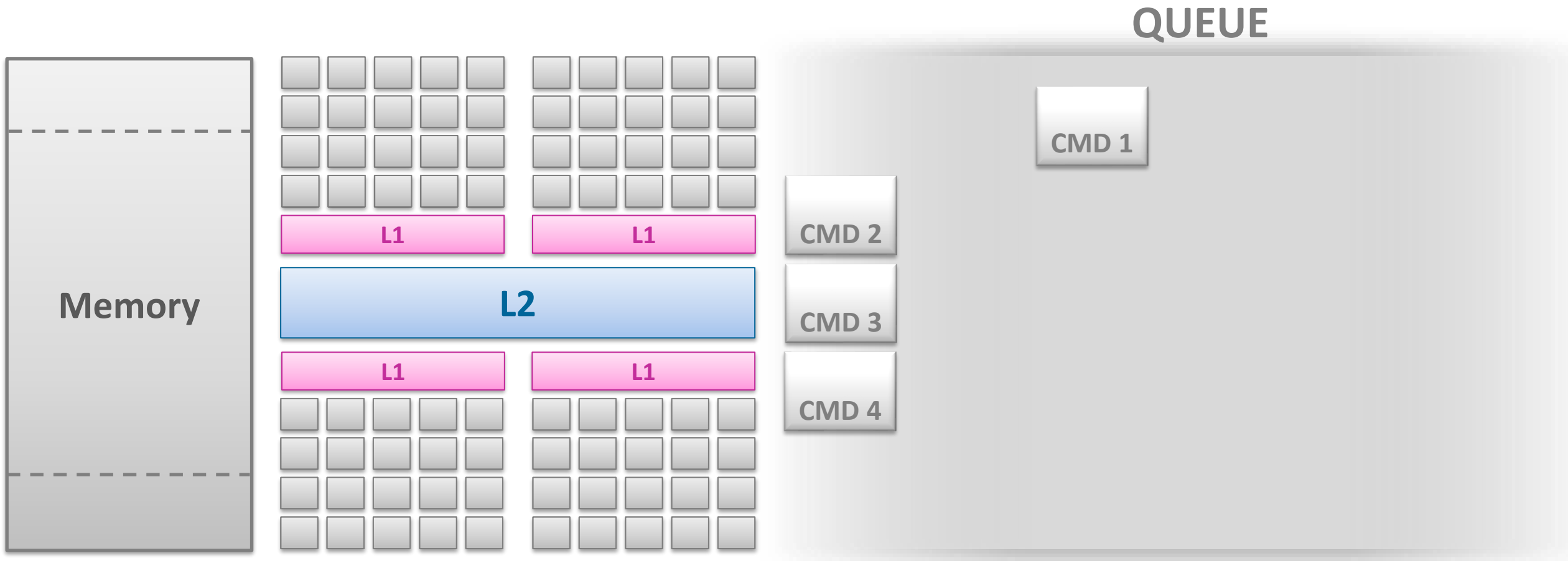
QUEUE



# Pipeline Stages of a Graphics Pipeline Command

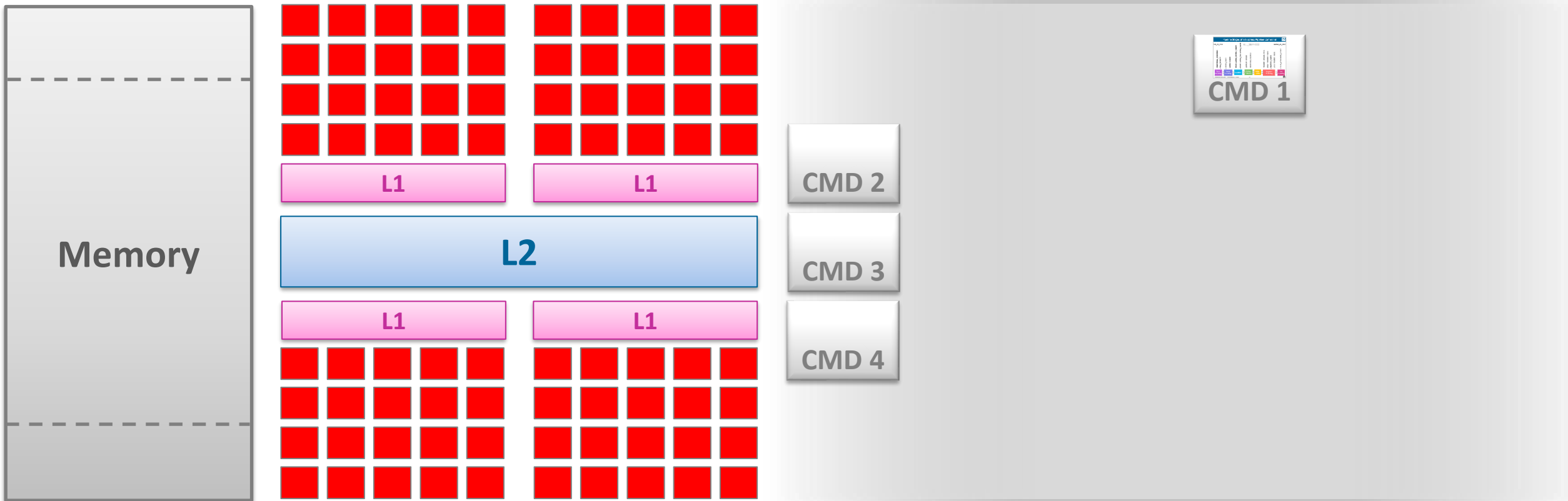


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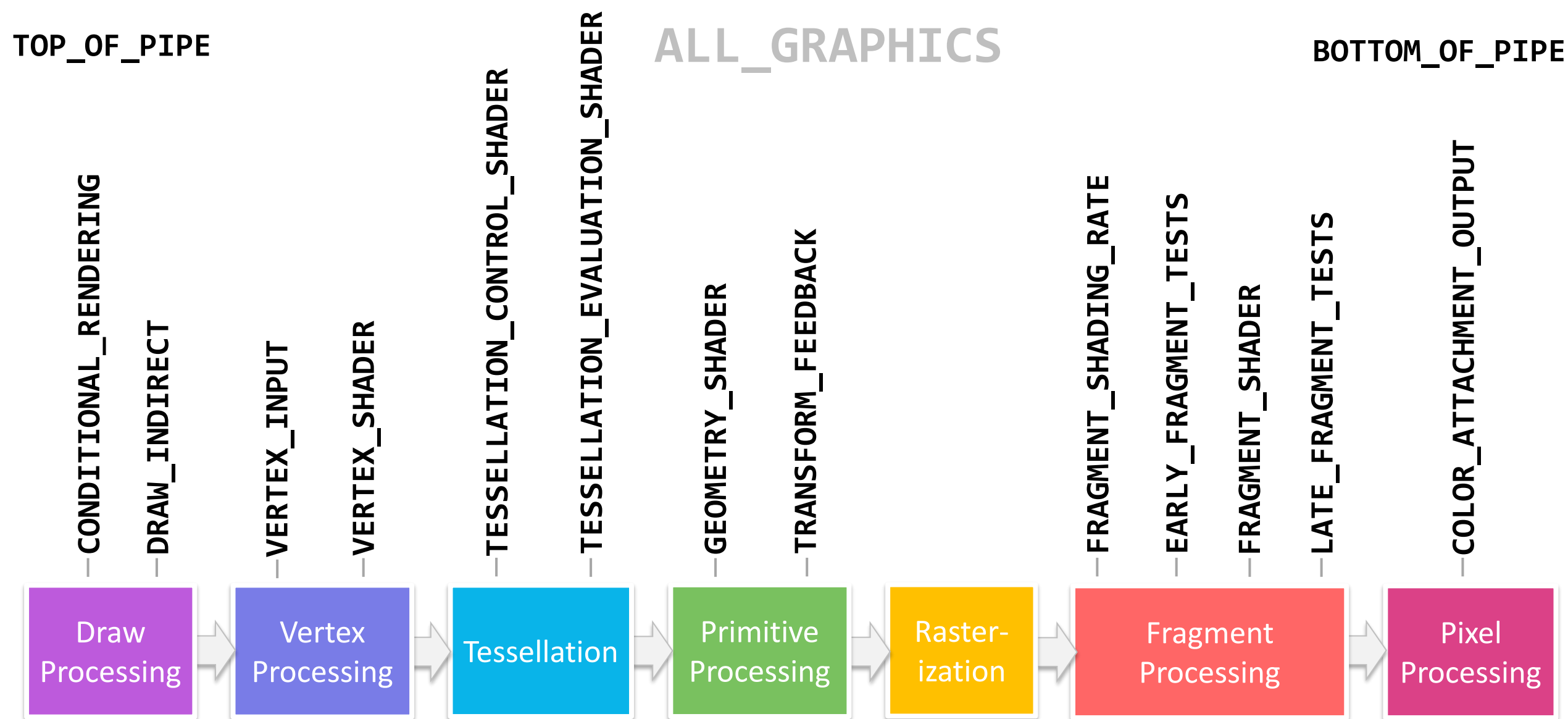


# Pipeline Stages of a Graphics Pipeline Command

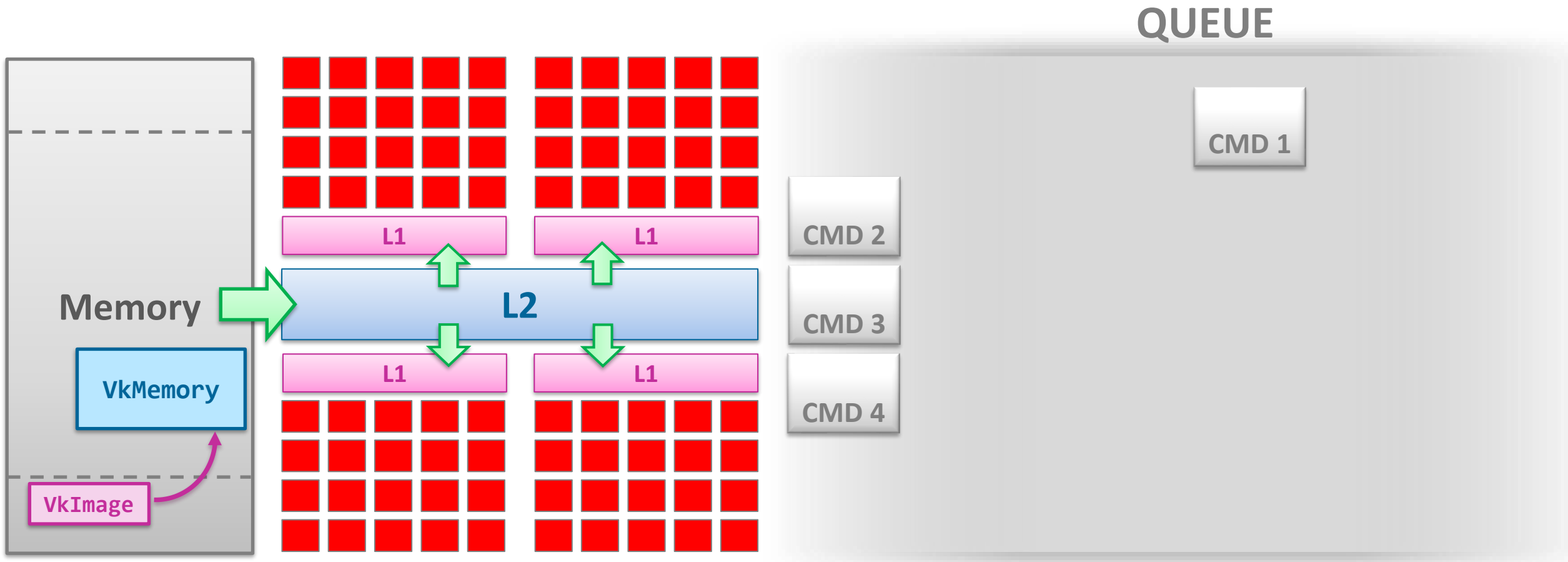
QUEUE



# Pipeline Stages of a Graphics Pipeline Command

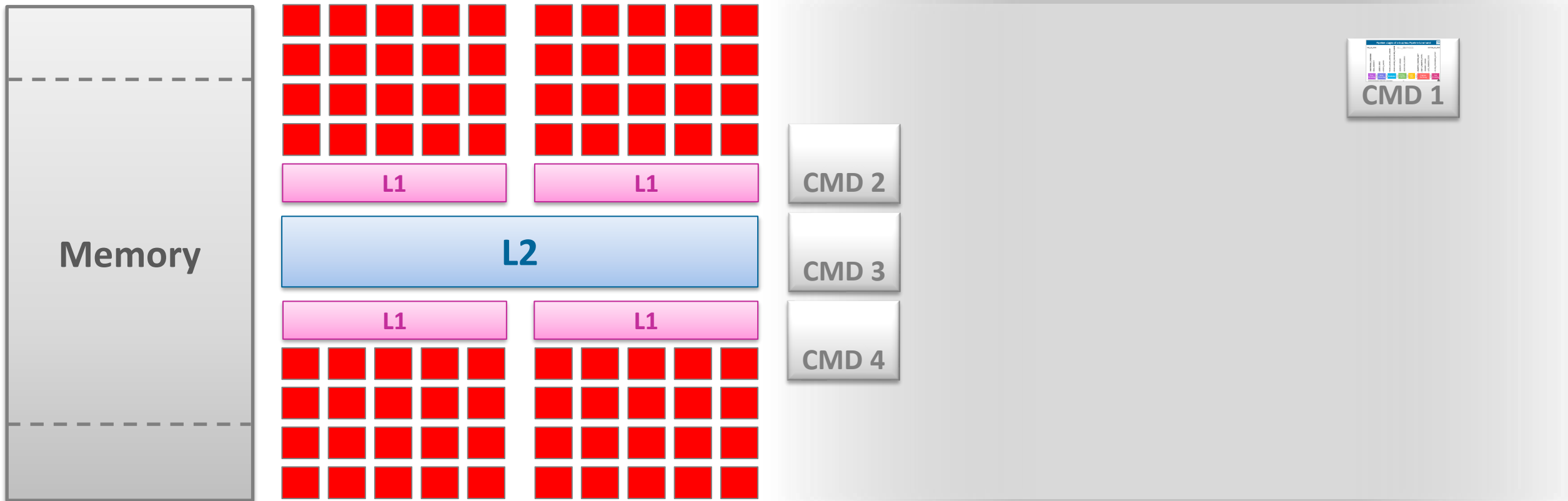


# Pipeline Stages of a Graphics Pipeline Command



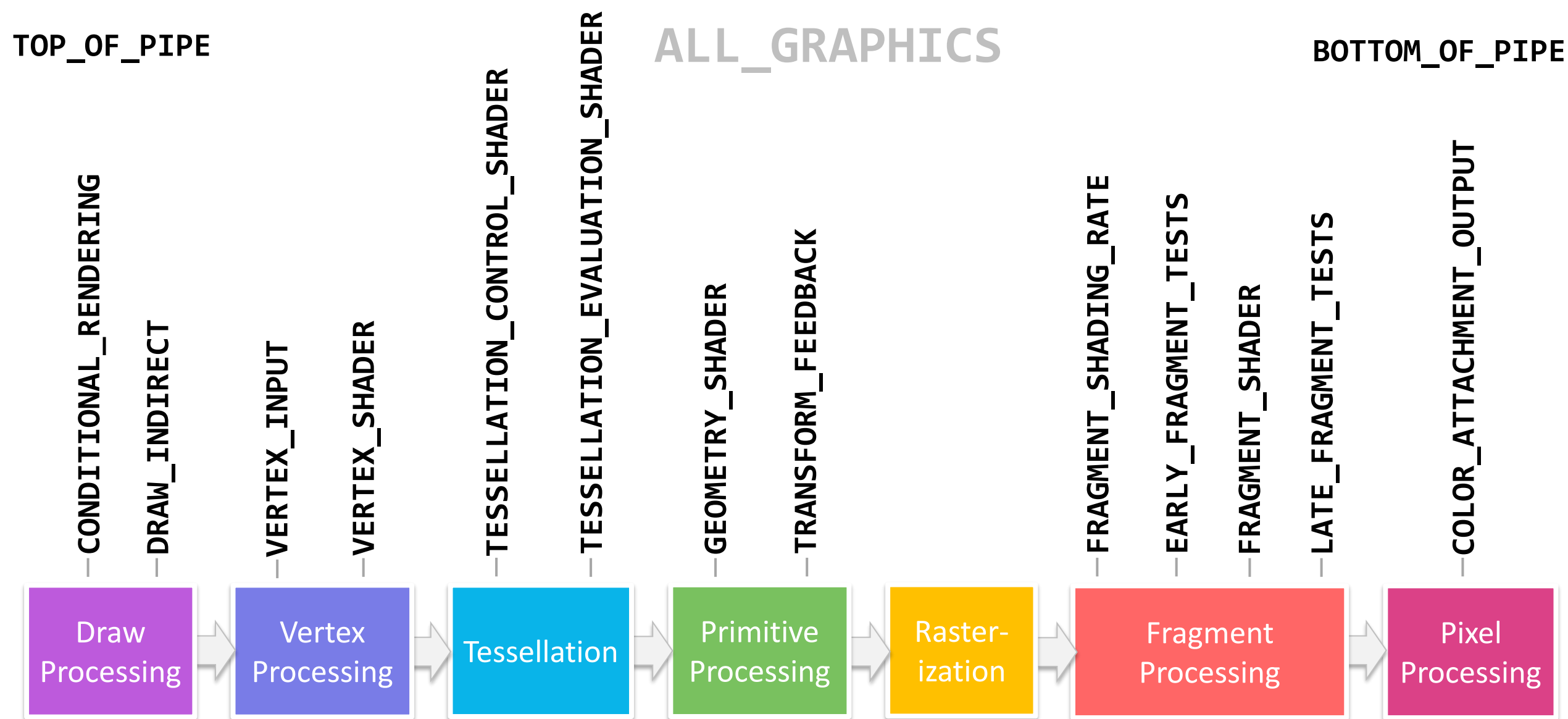
# Pipeline Stages of a Graphics Pipeline Command

QUEUE



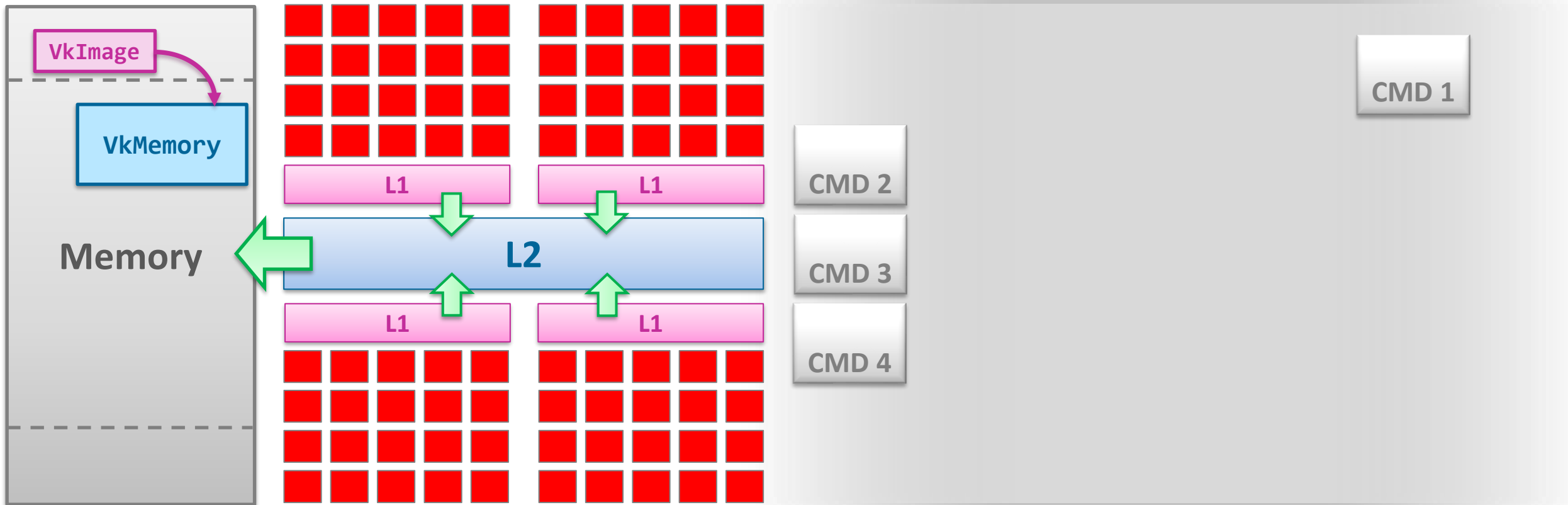


# Pipeline Stages of a Graphics Pipeline Command



# Pipeline Stages of a Graphics Pipeline Command

QUEUE



# Pipeline Stages of a Graphics Pipeline Command

QUEUE

CMD 1

CMD 2

CMD 3

CMD 4

Memory

L1

L1

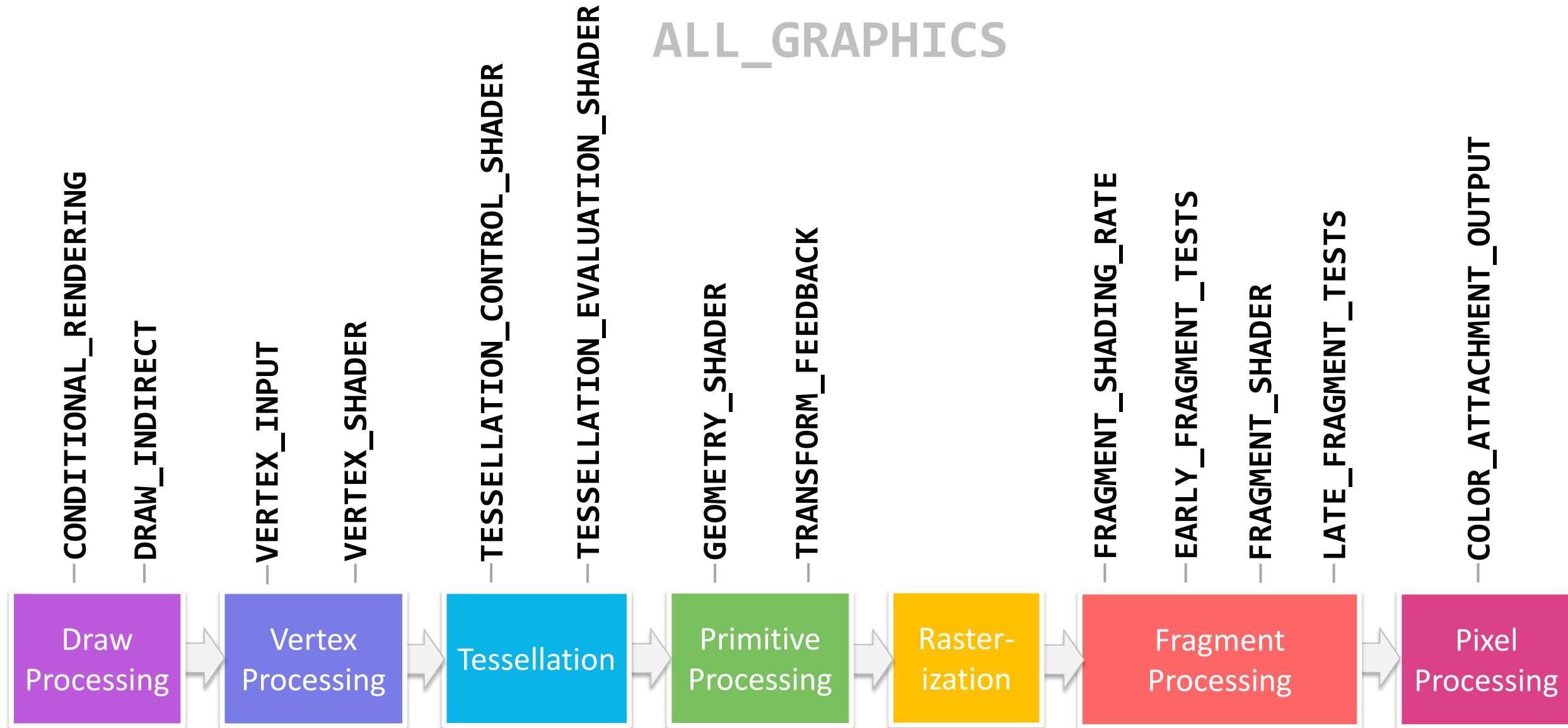
L2

L1

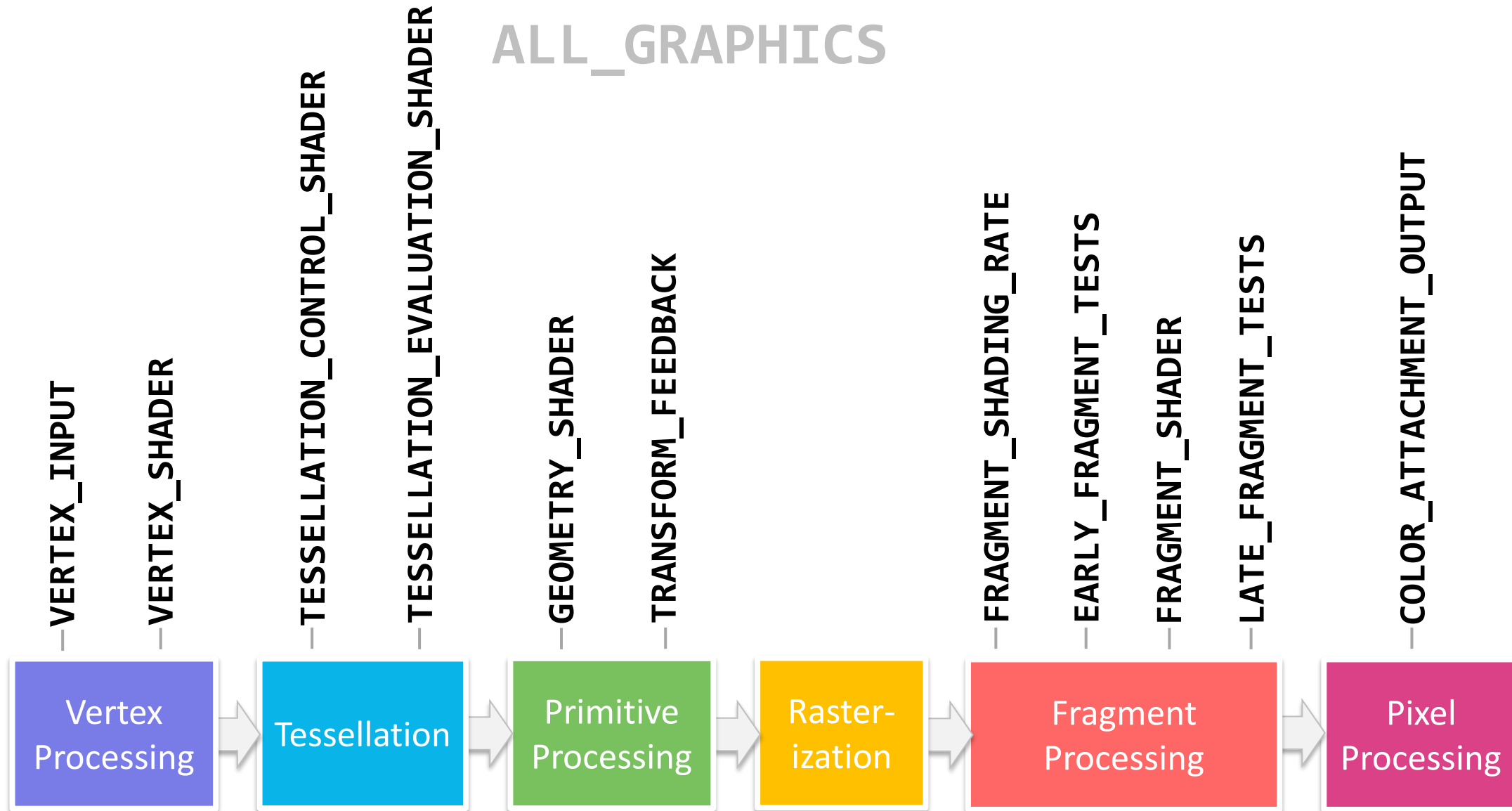
L1



# Pipeline Stages of a Graphics Pipeline Command

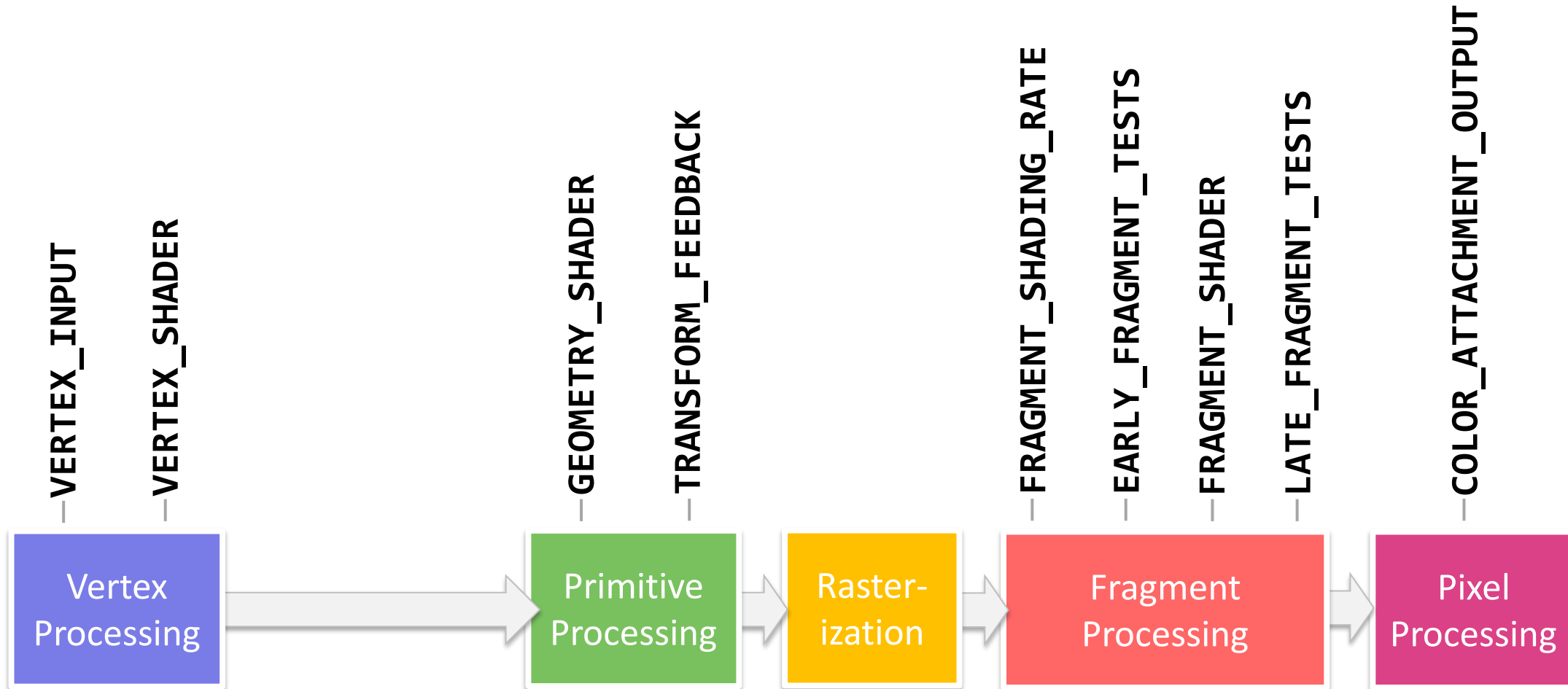


# Pipeline Stages of a Graphics Pipeline Command



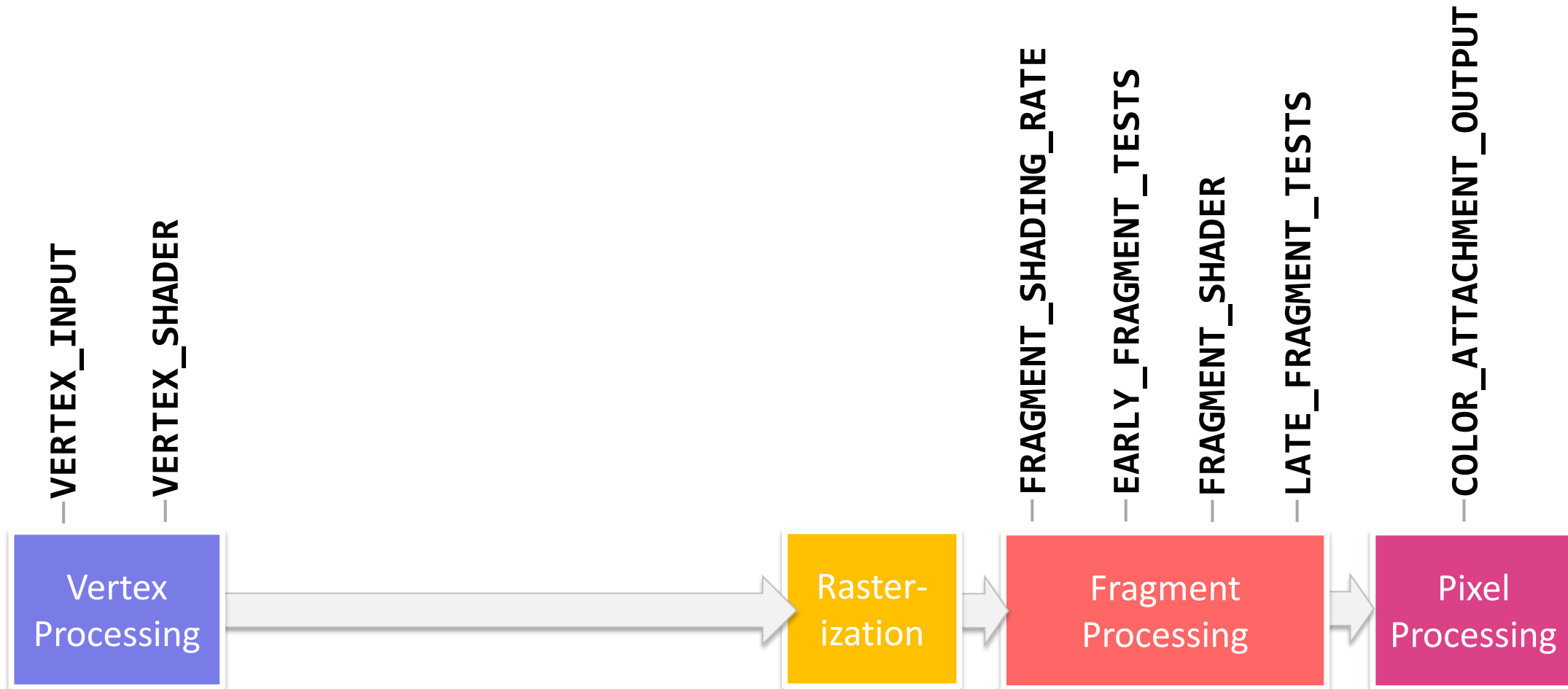
# Pipeline Stages of a Graphics Pipeline Command

ALL\_GRAPHICS



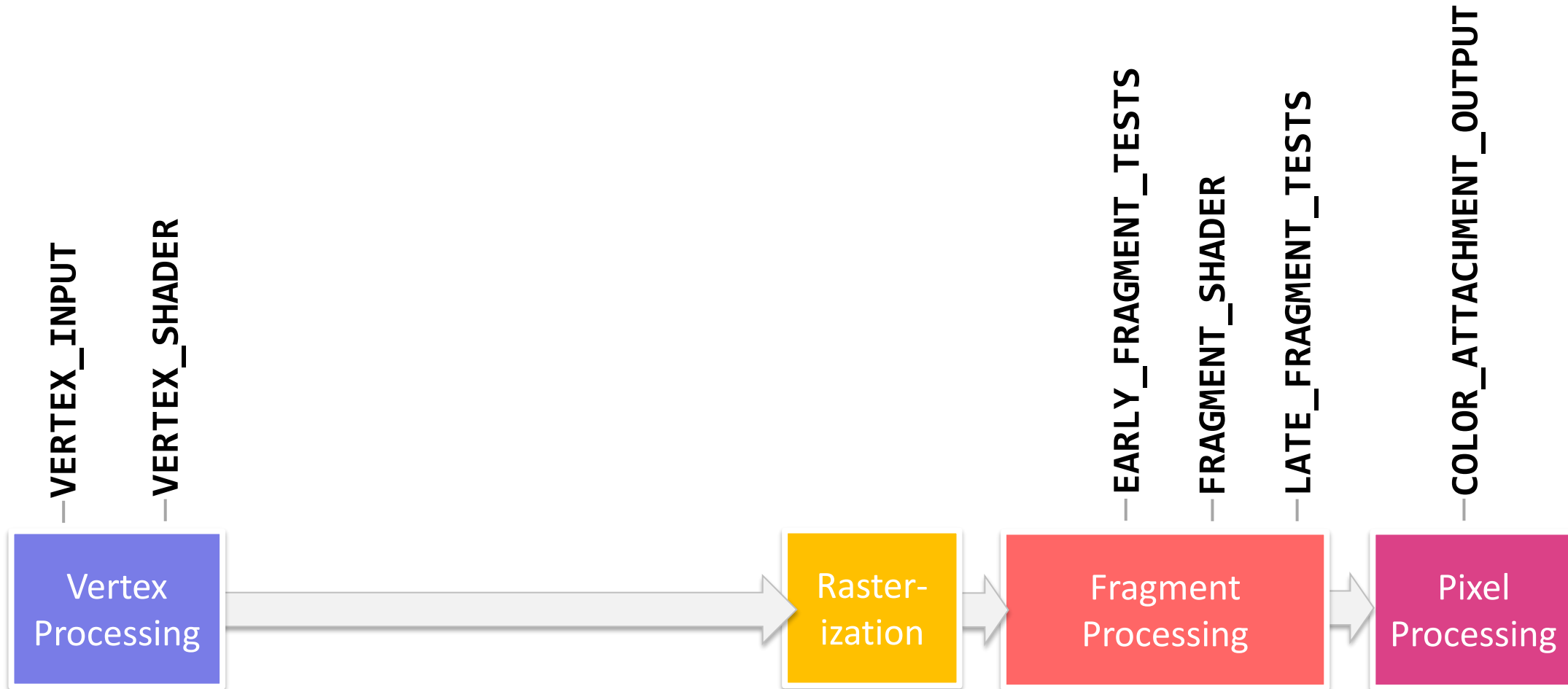
# Pipeline Stages of a Graphics Pipeline Command

ALL\_GRAPHICS



# Pipeline Stages of a Graphics Pipeline Command

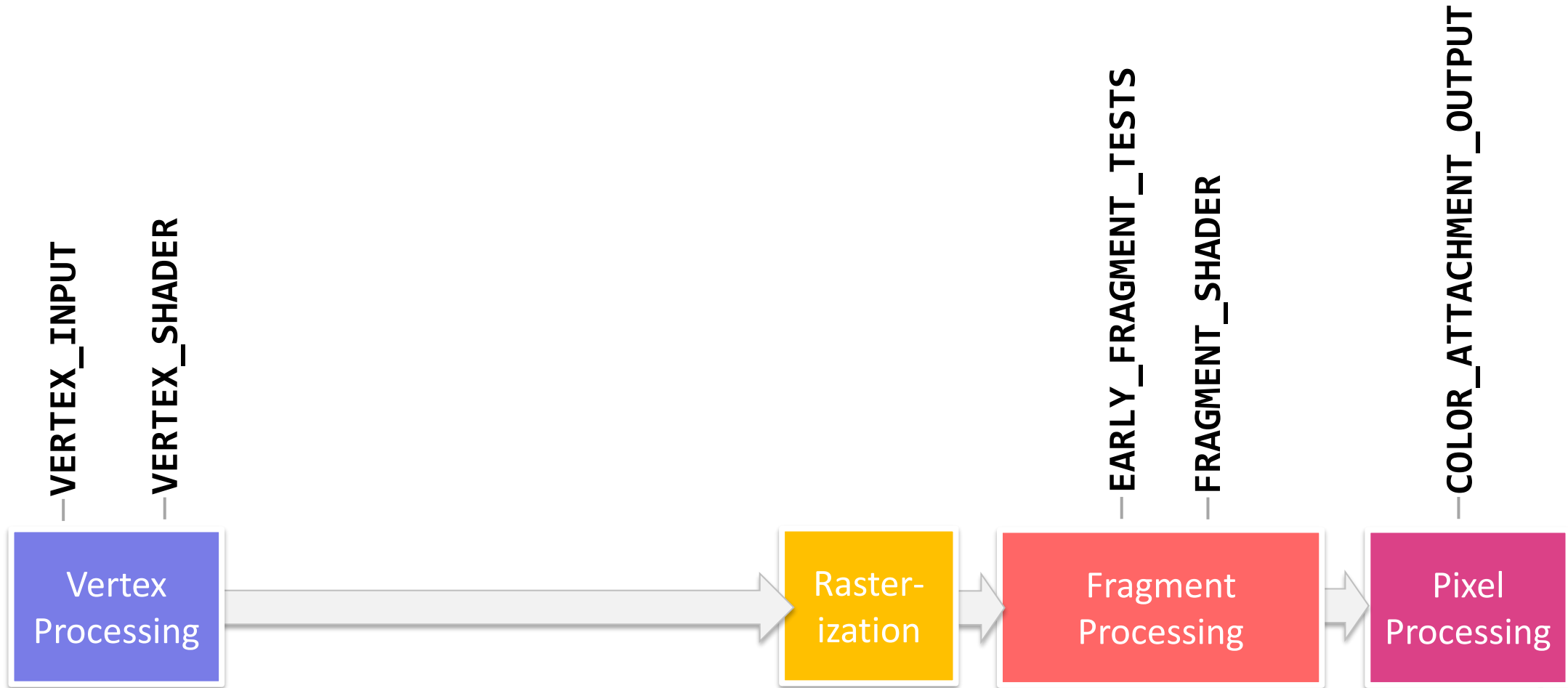
ALL\_GRAPHICS





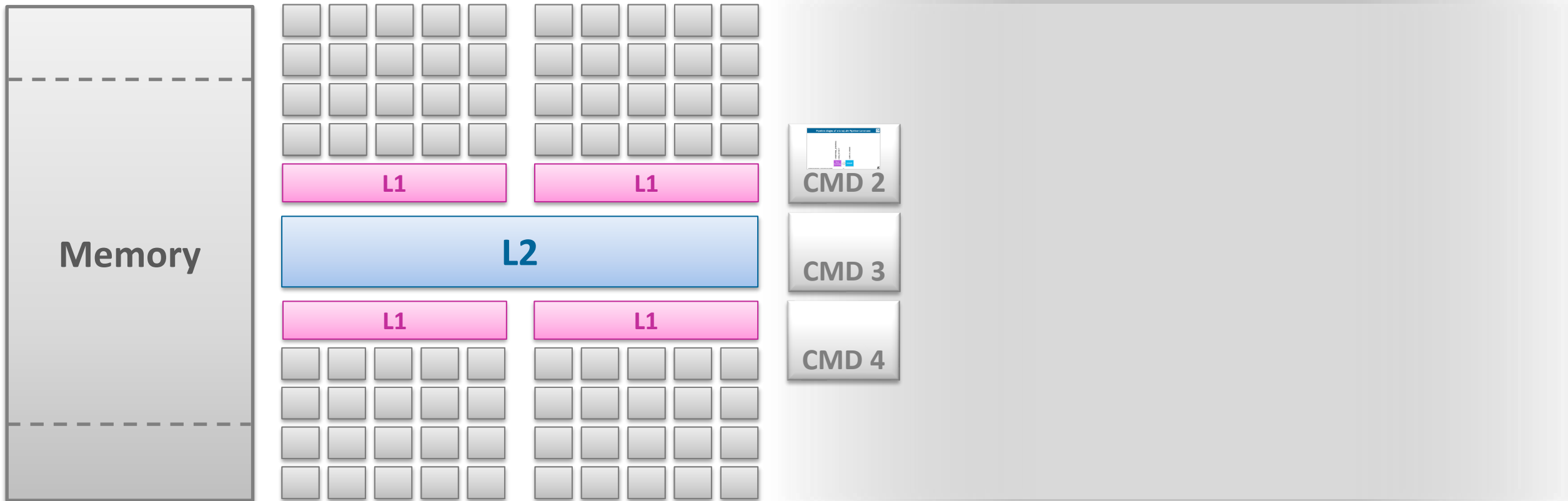
# Pipeline Stages of a Graphics Pipeline Command

ALL\_GRAPHICS

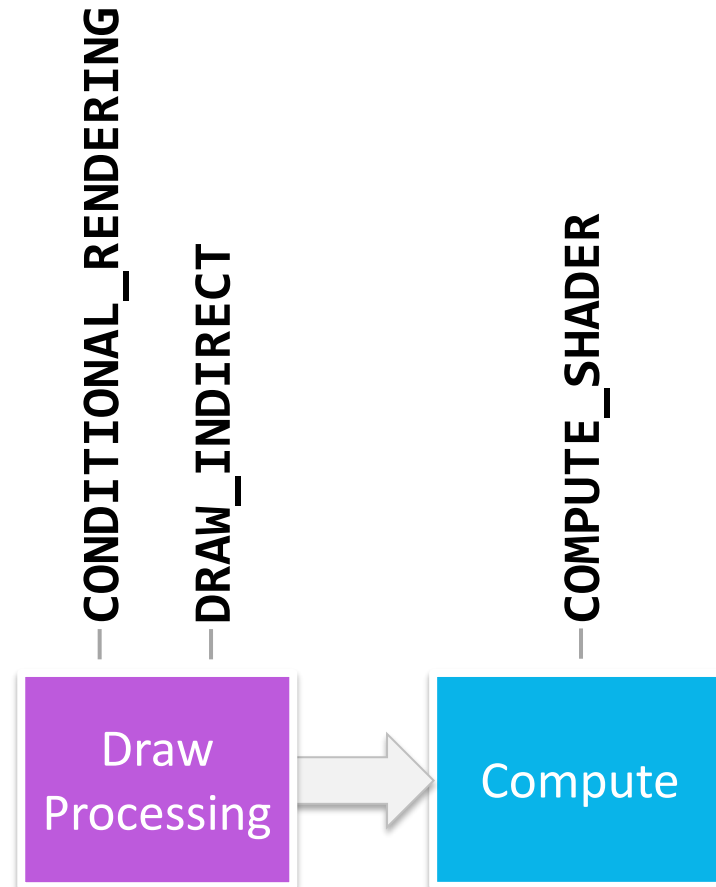


# Pipeline Stages of a Compute Pipeline Command

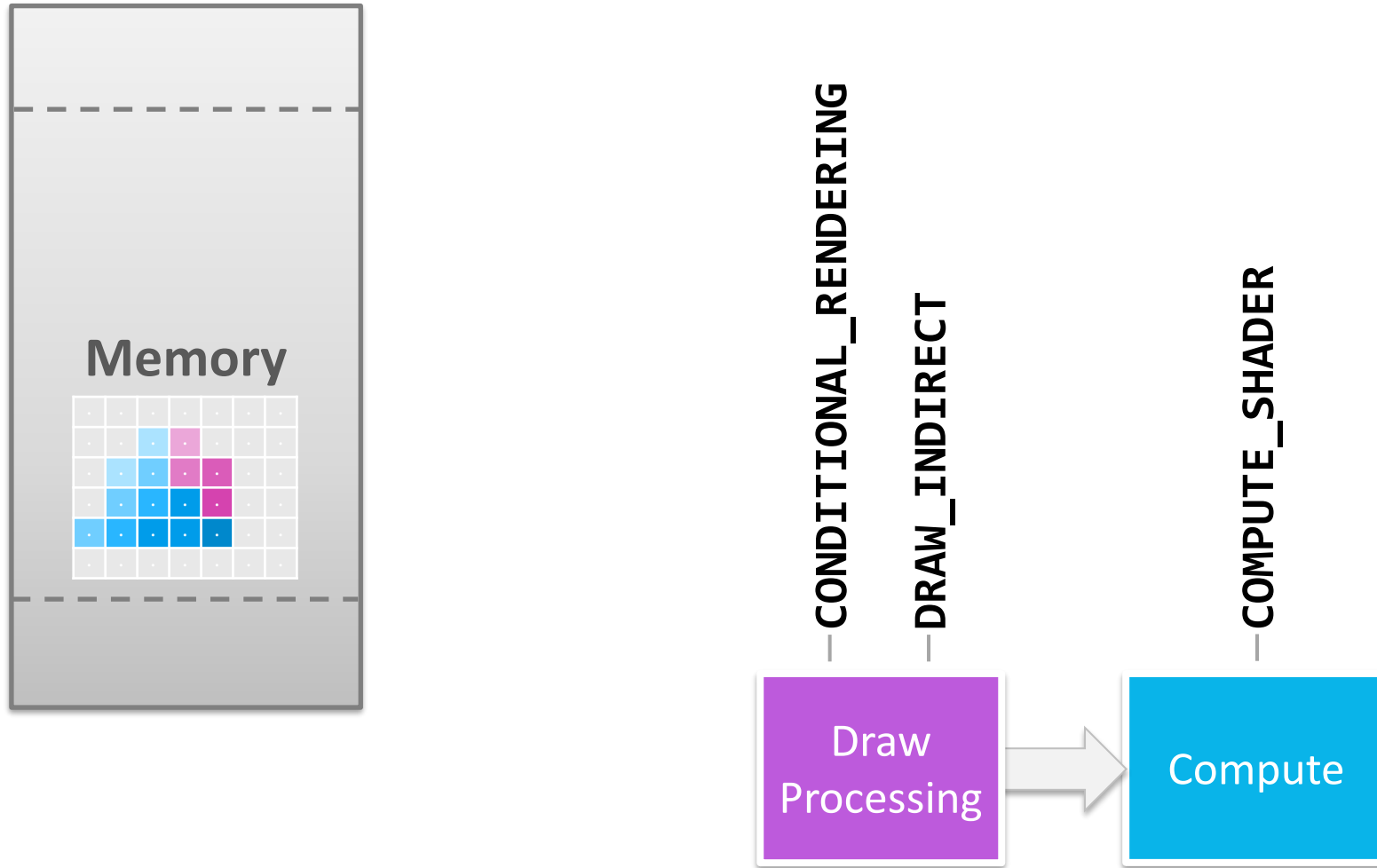
QUEUE



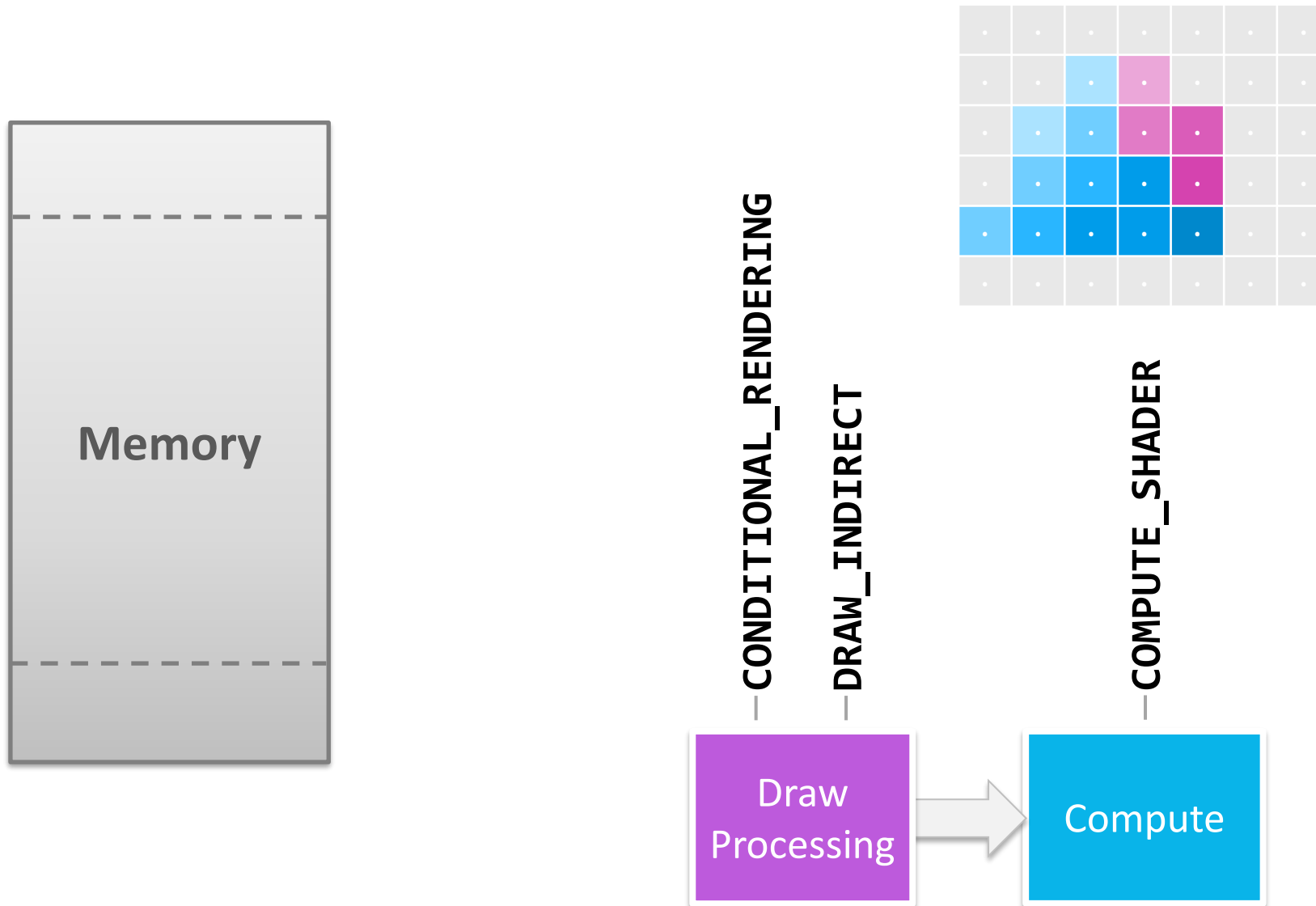
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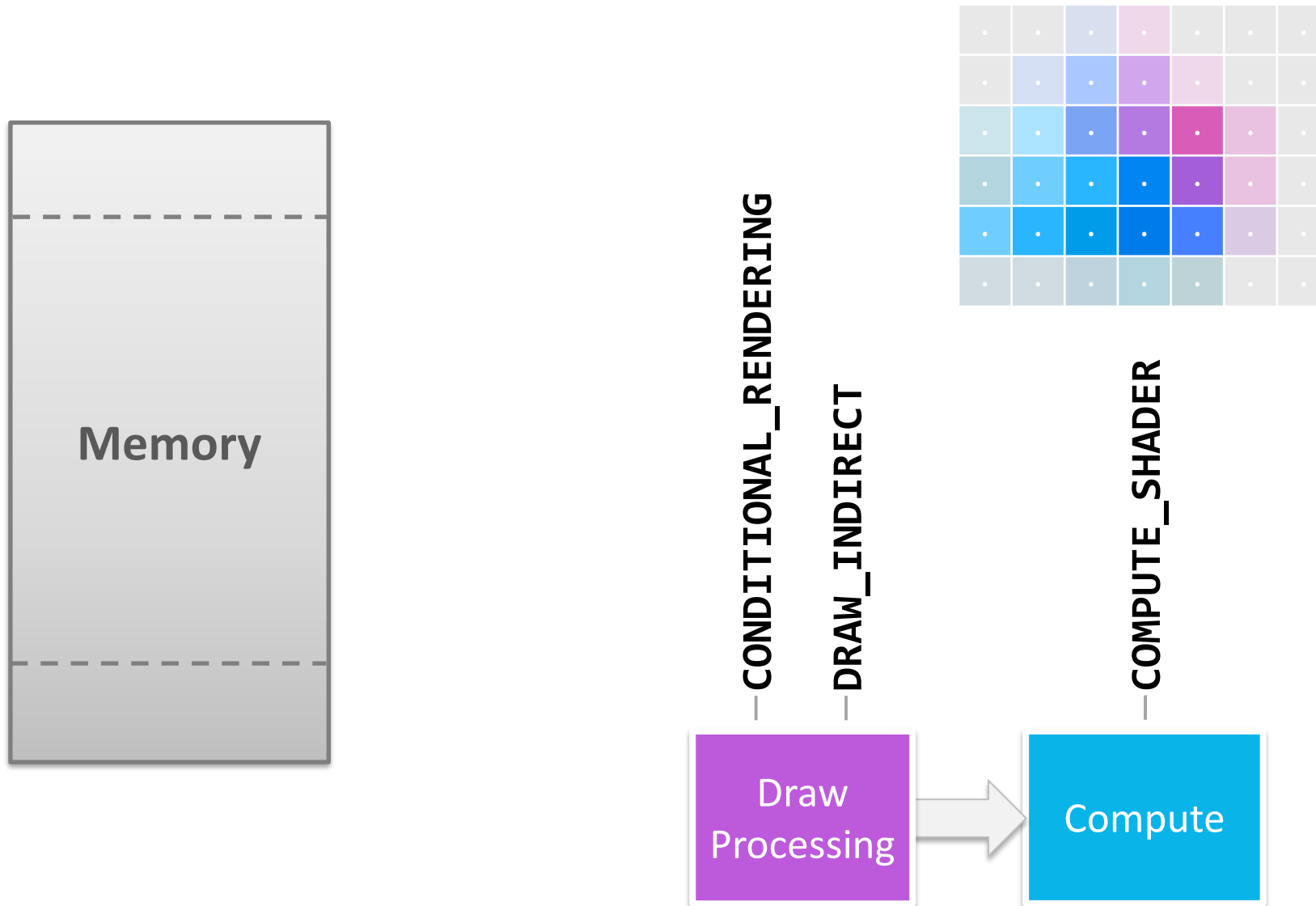
# Pipeline Stages of a Compute Pipeline Command



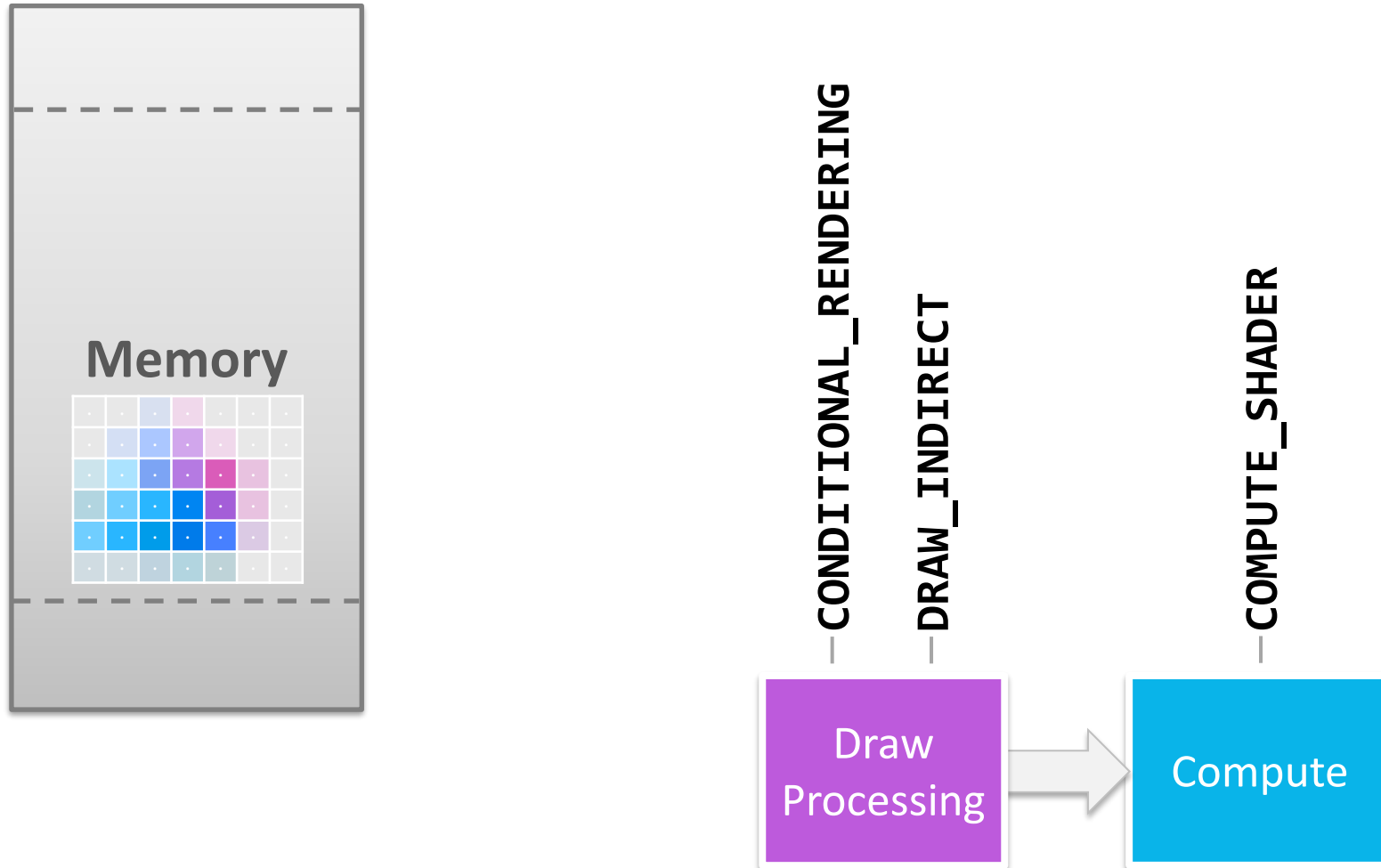
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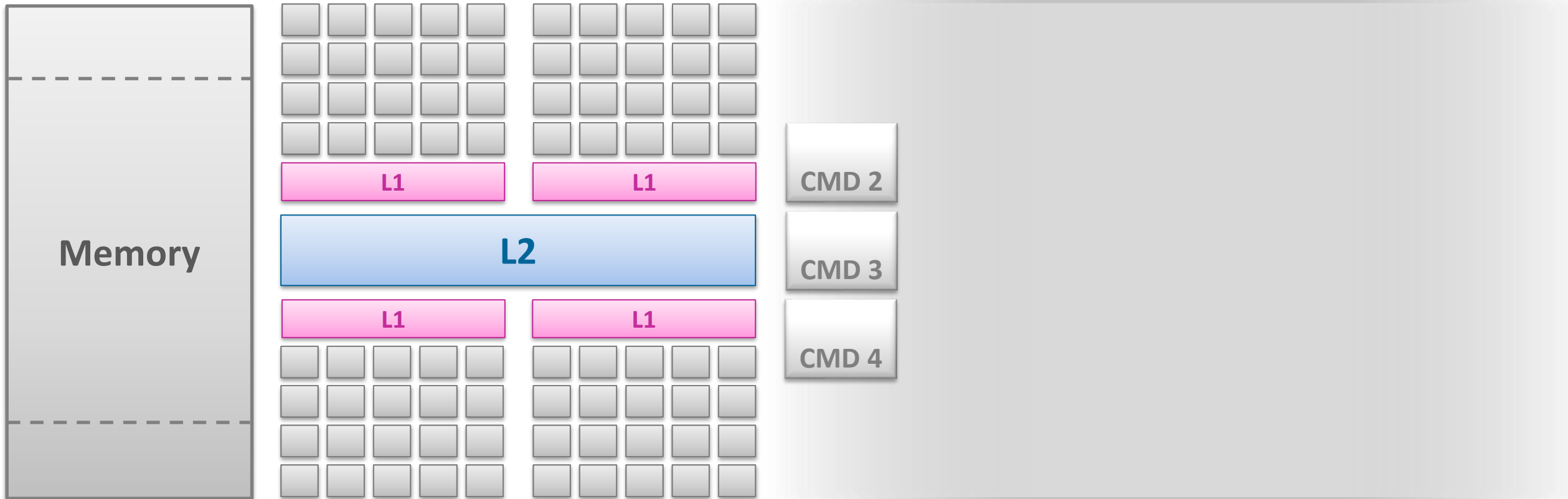


# Pipeline Stages of a Compute Pipeline Command



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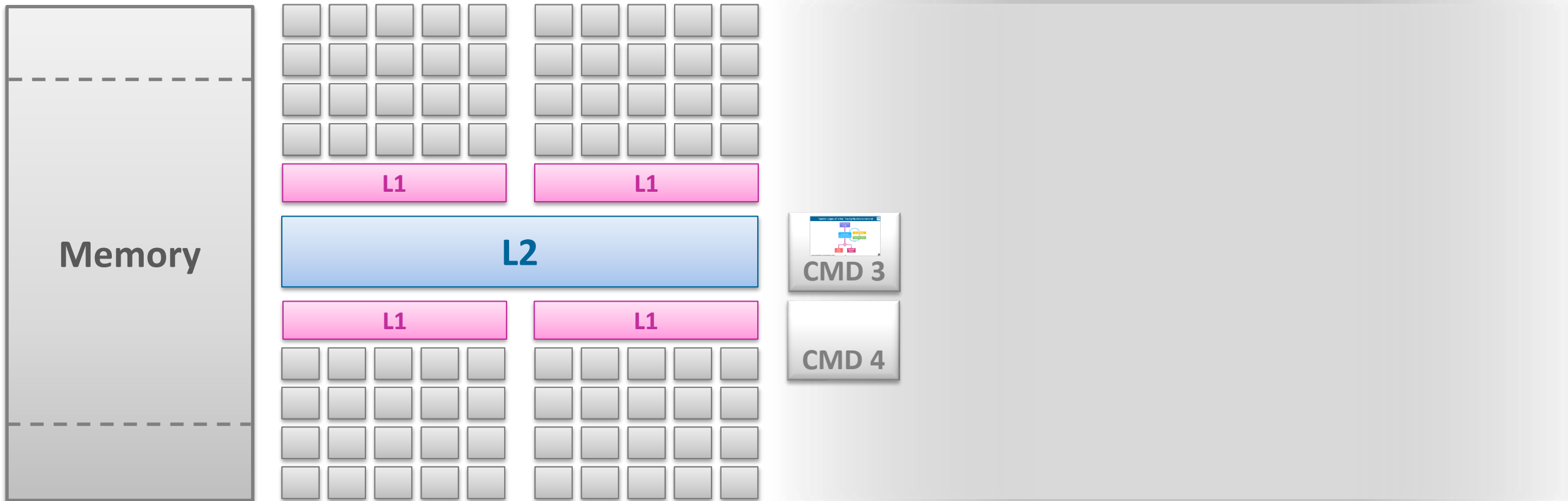
QUEUE



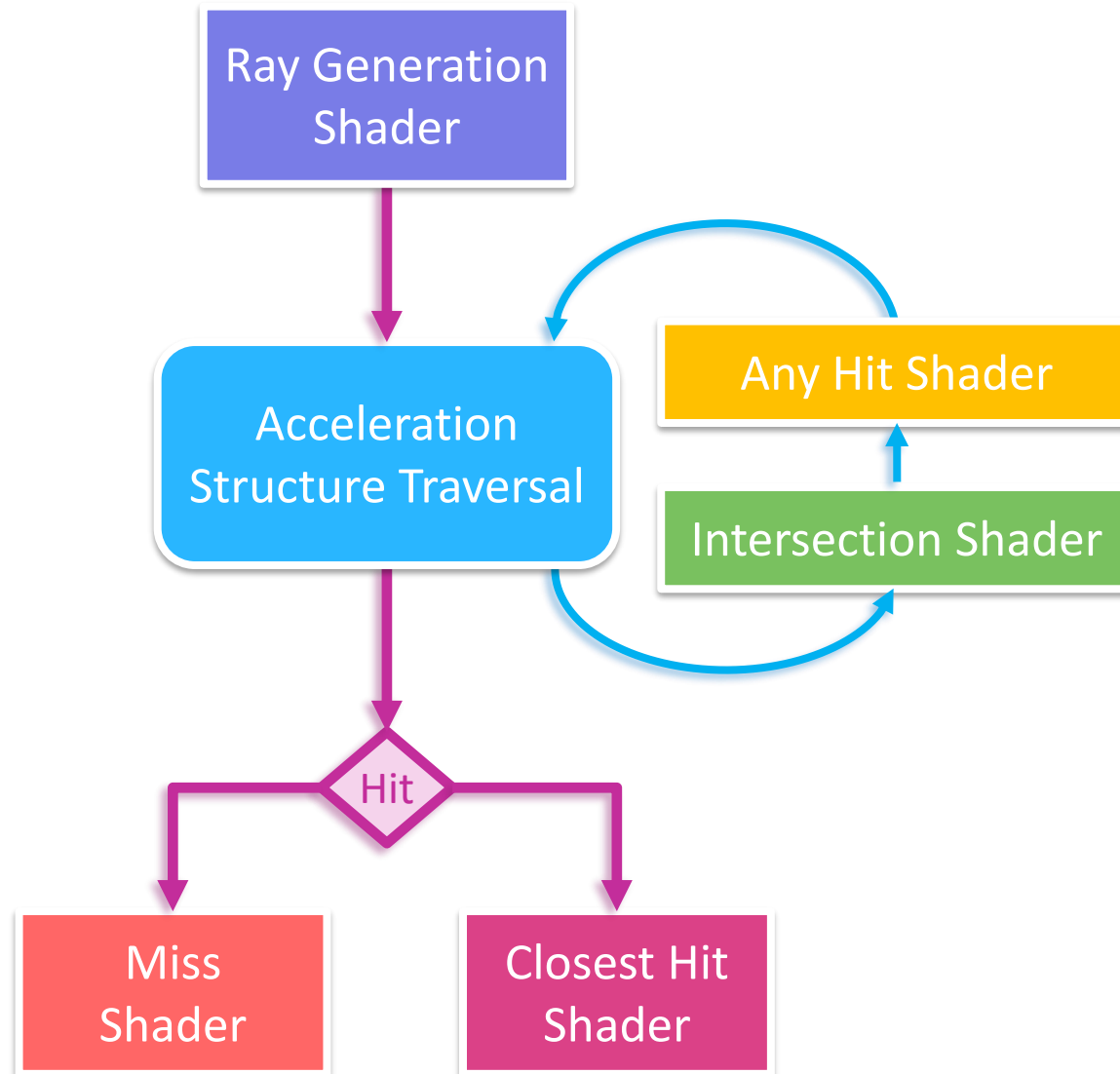


# Pipeline Stages of a Ray Tracing Pipeline Command

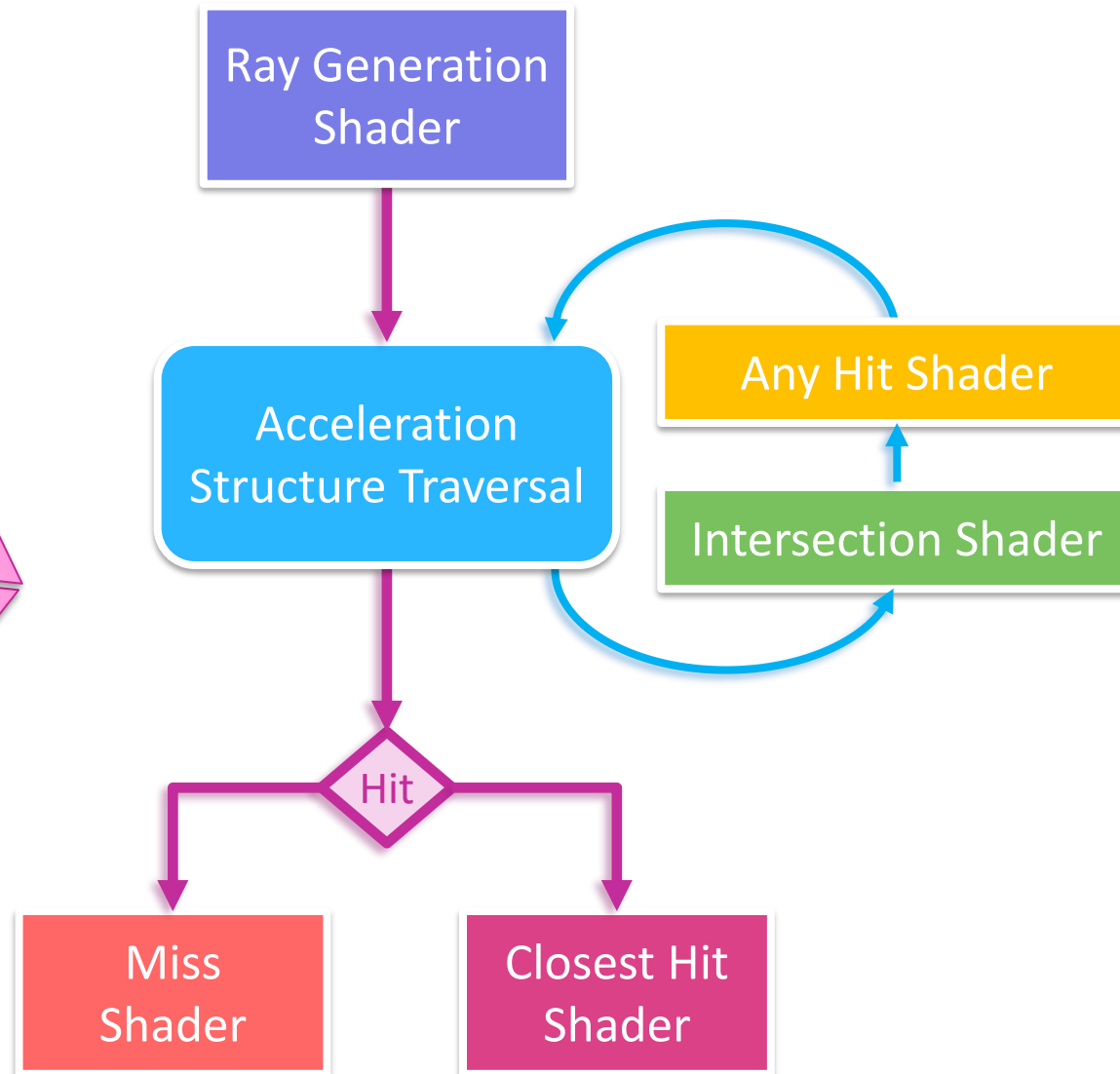
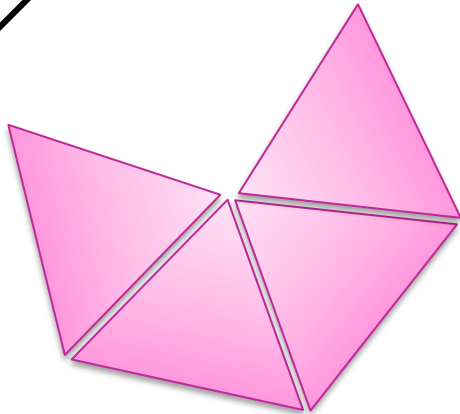
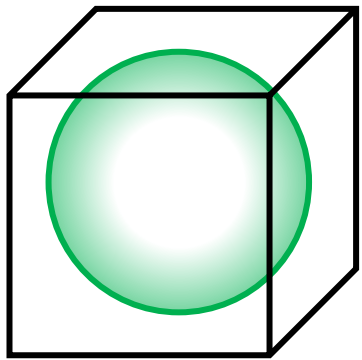
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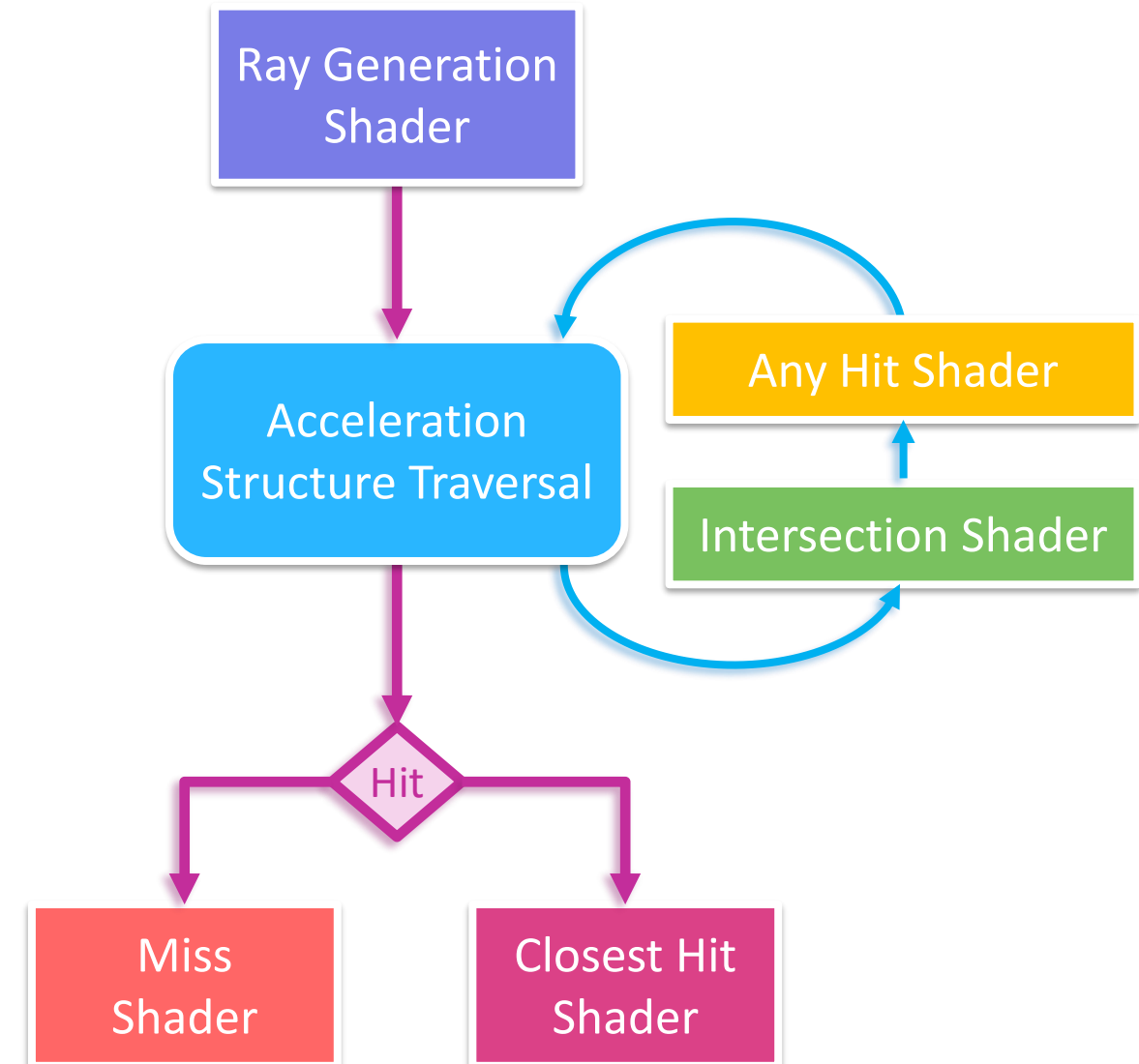
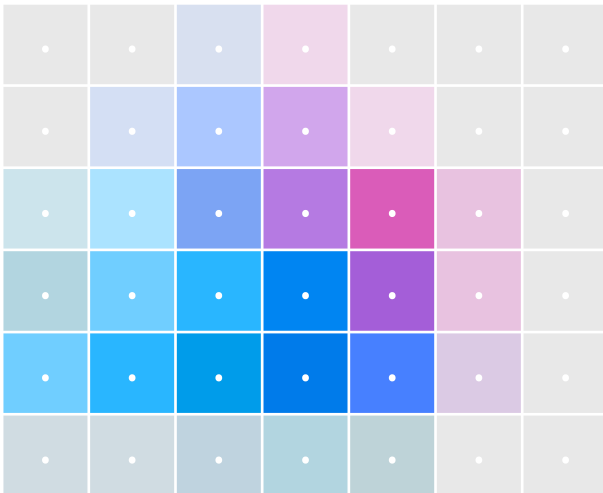
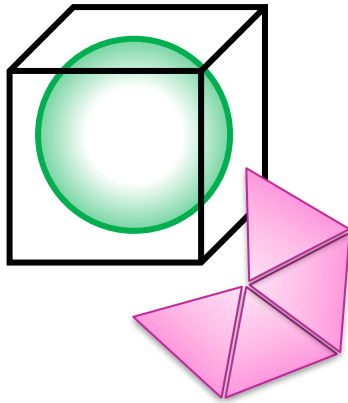
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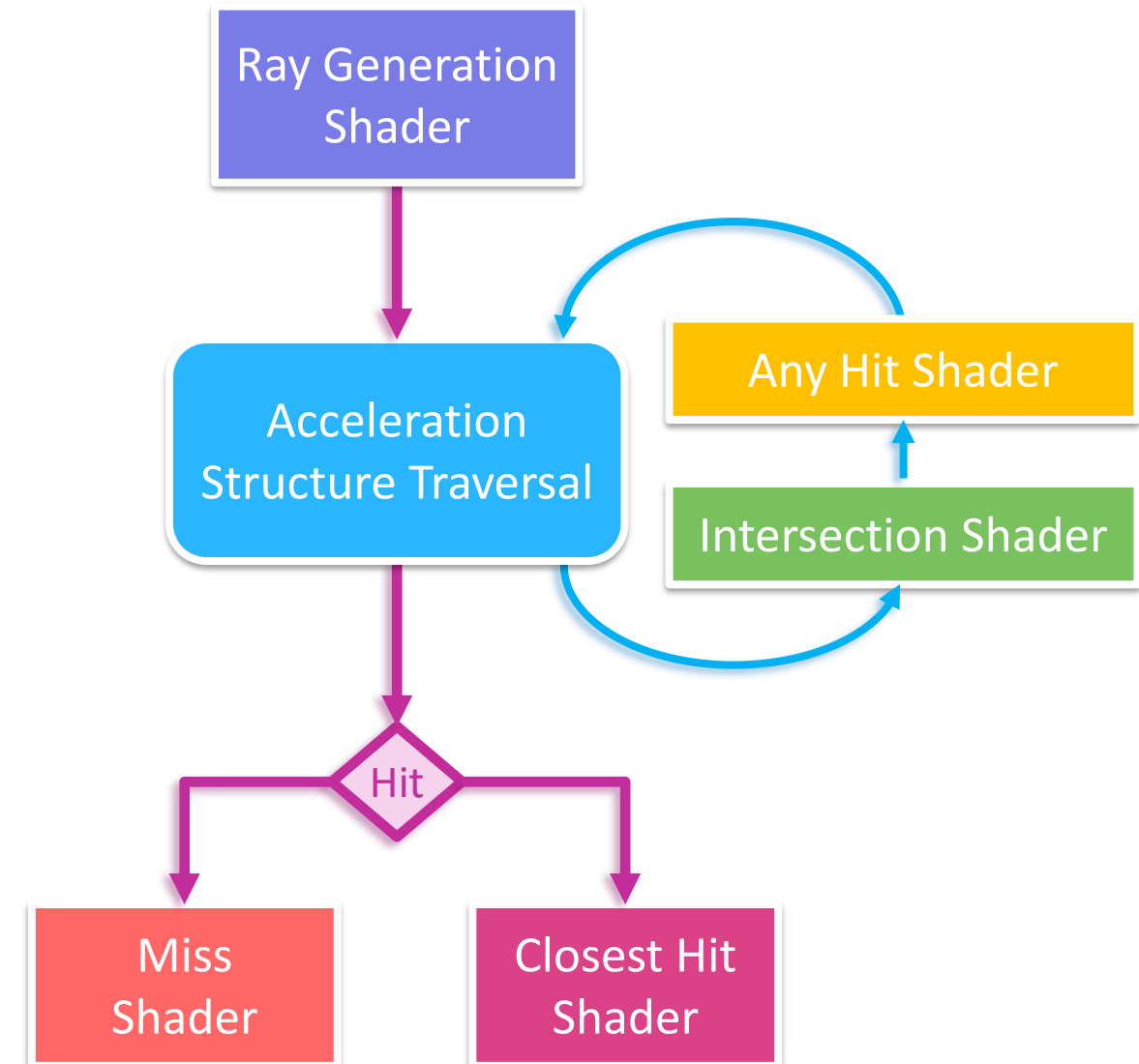
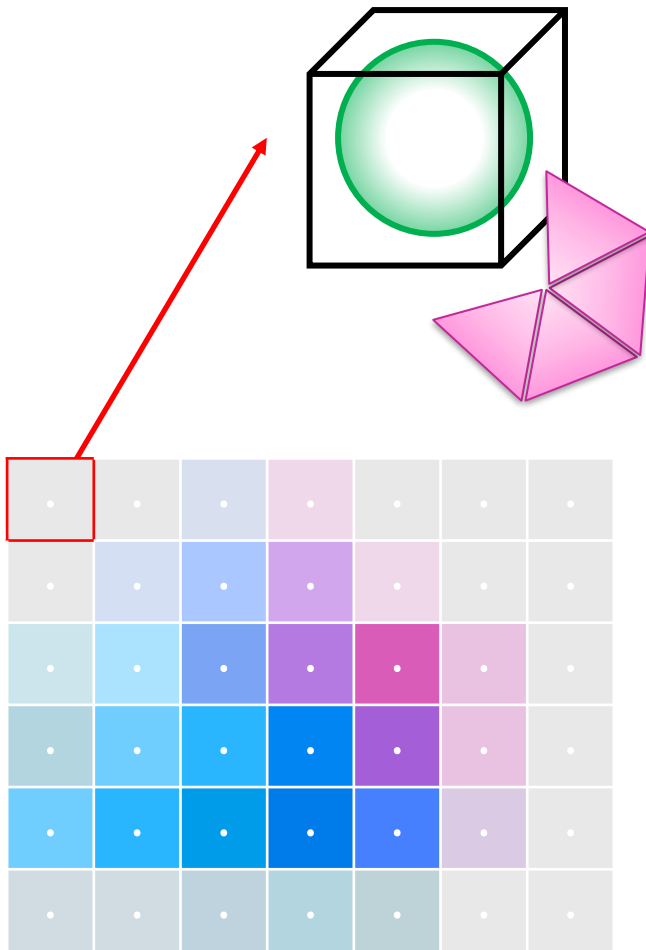
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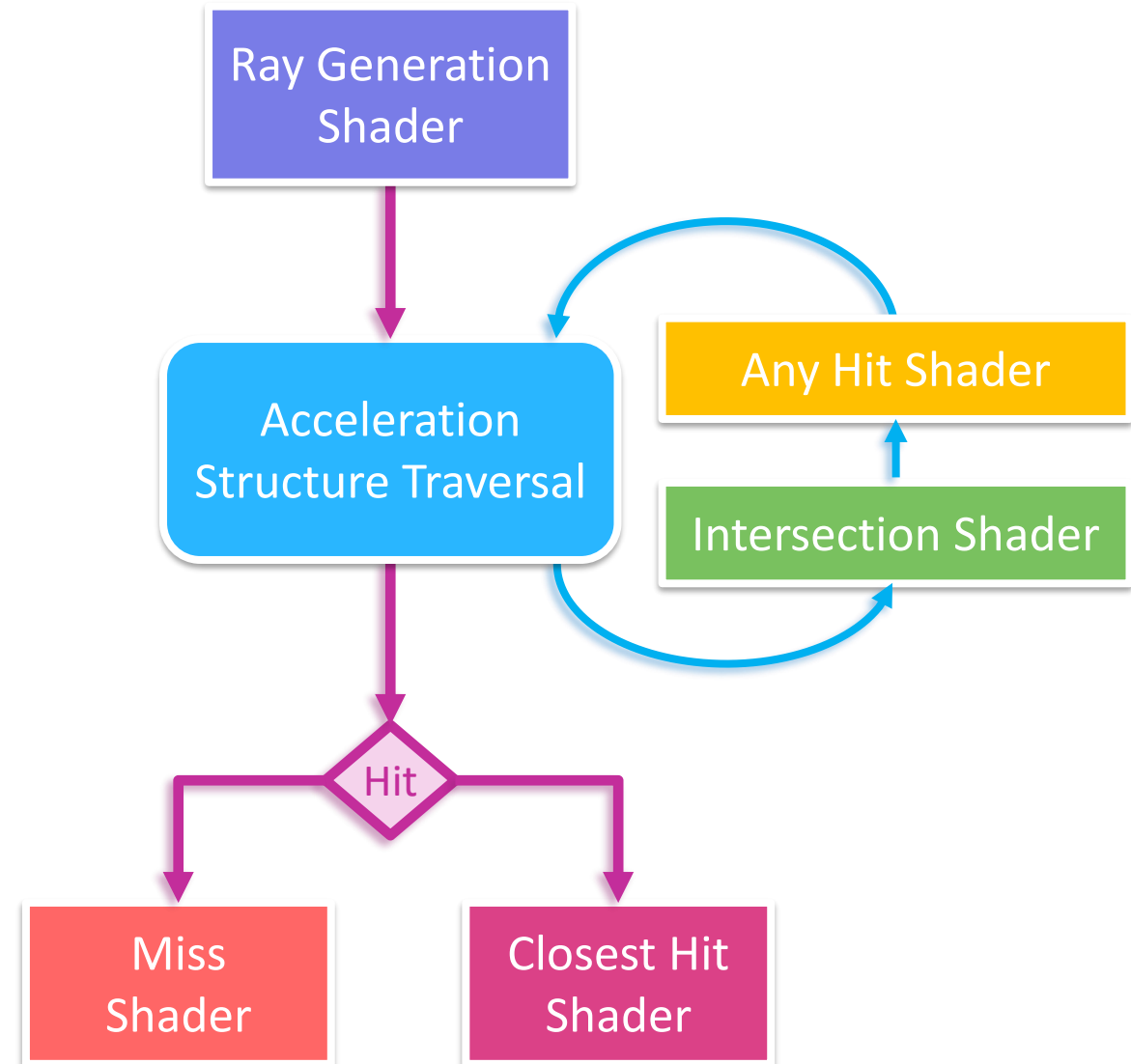
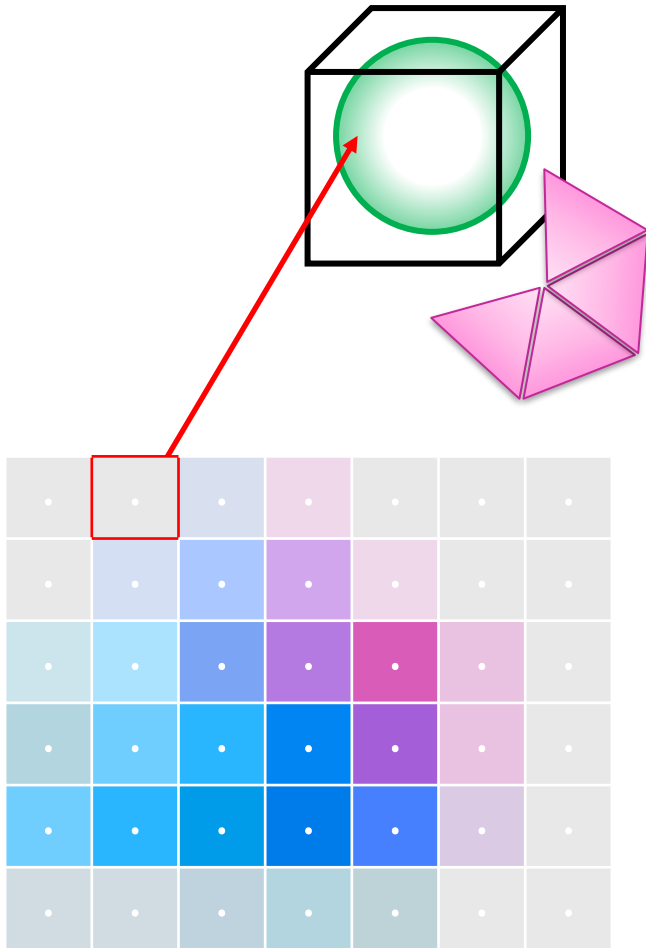
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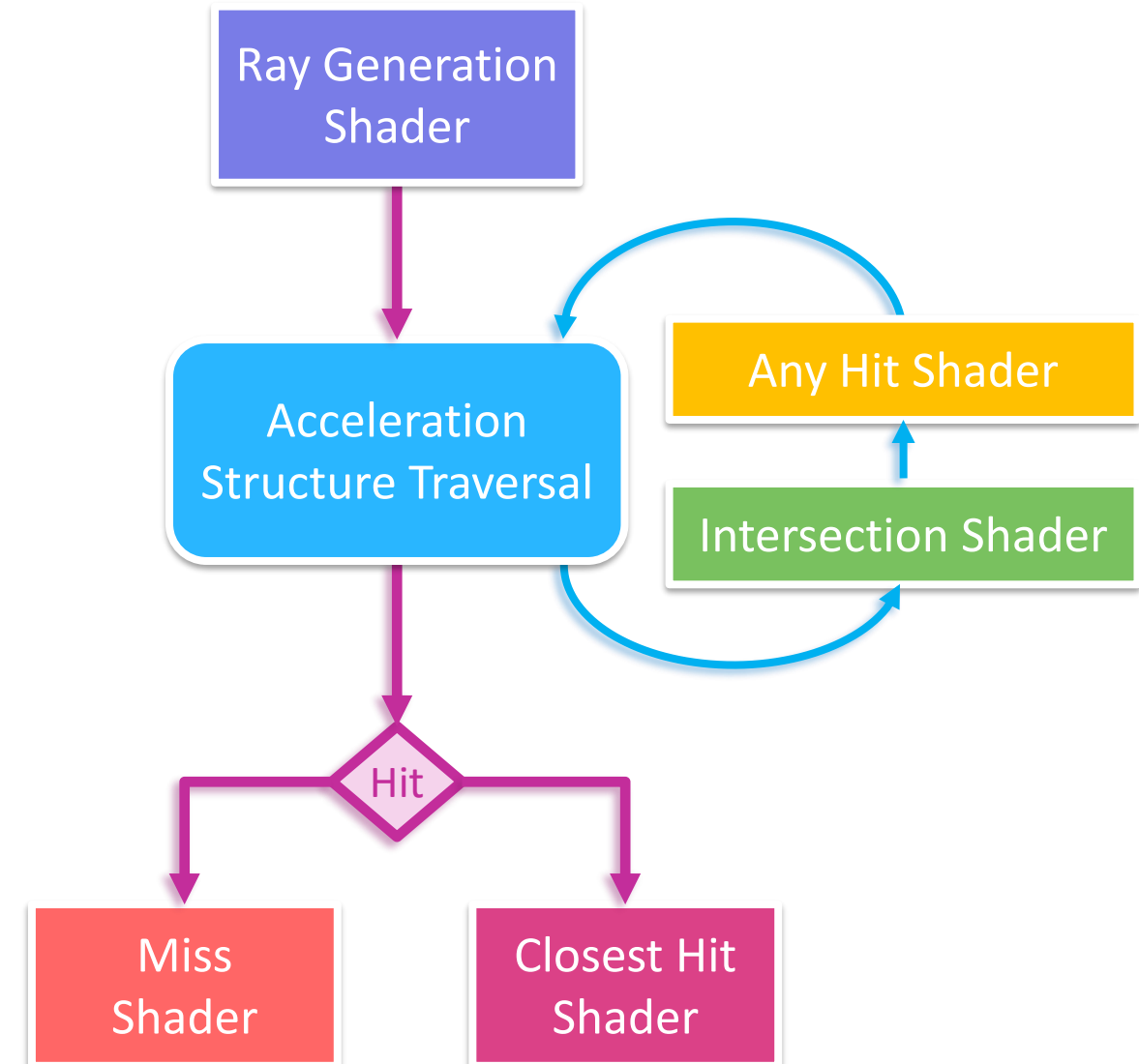
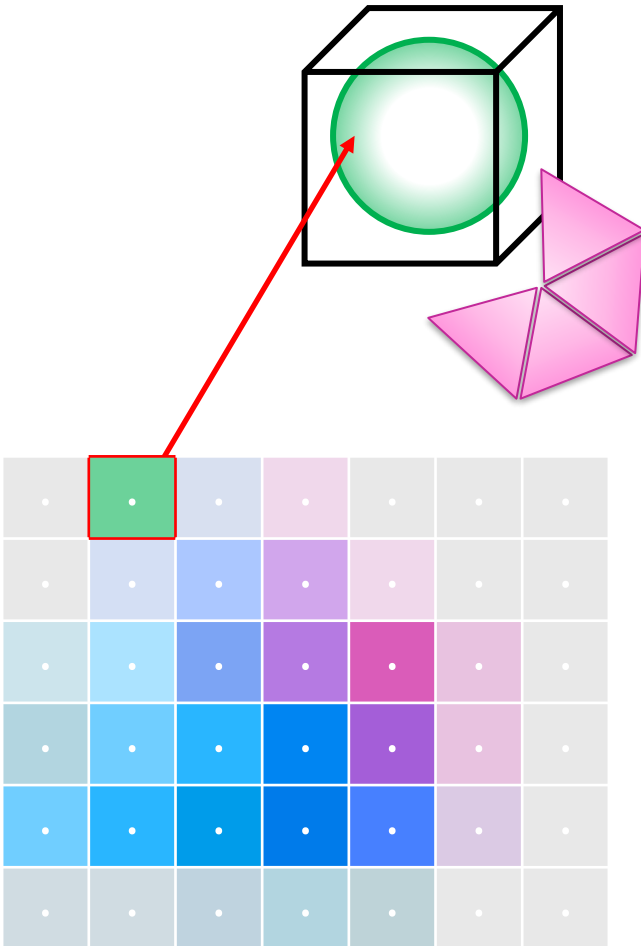
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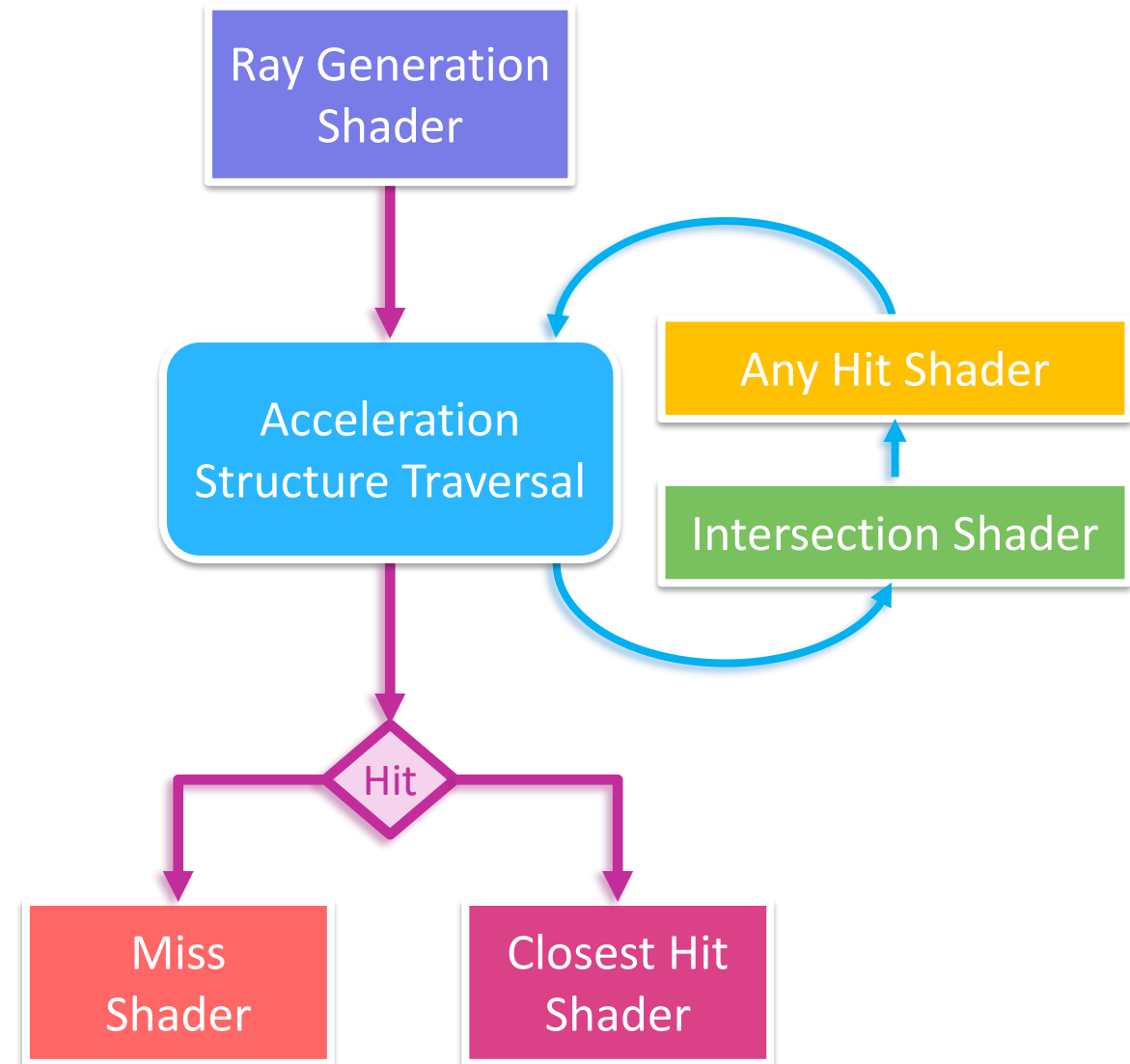
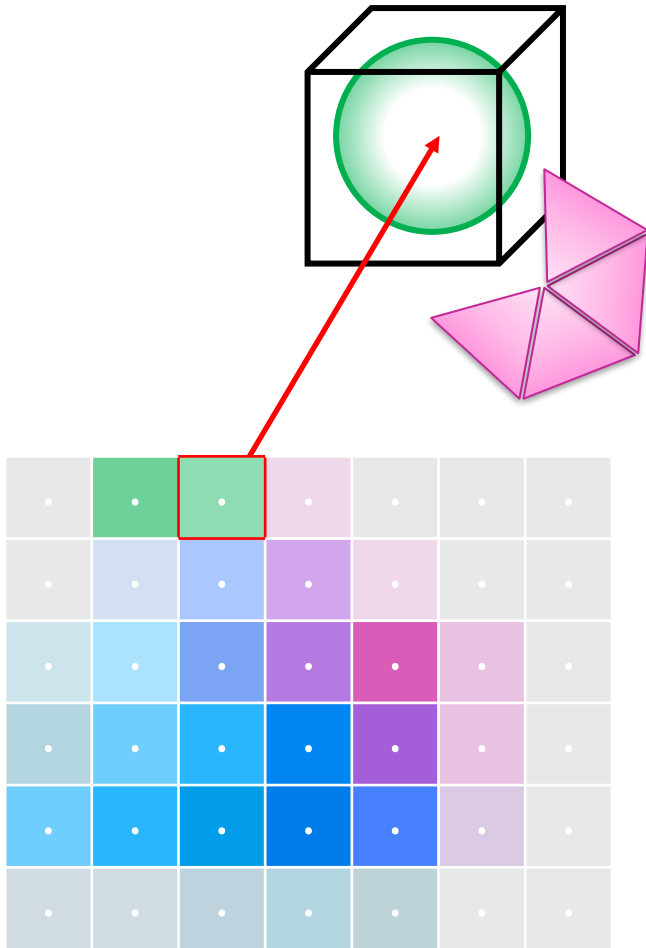
# Pipeline Stages of a Ray Tracing Pipeline Command



# Pipeline Stages of a Ray Tracing Pipeline Command

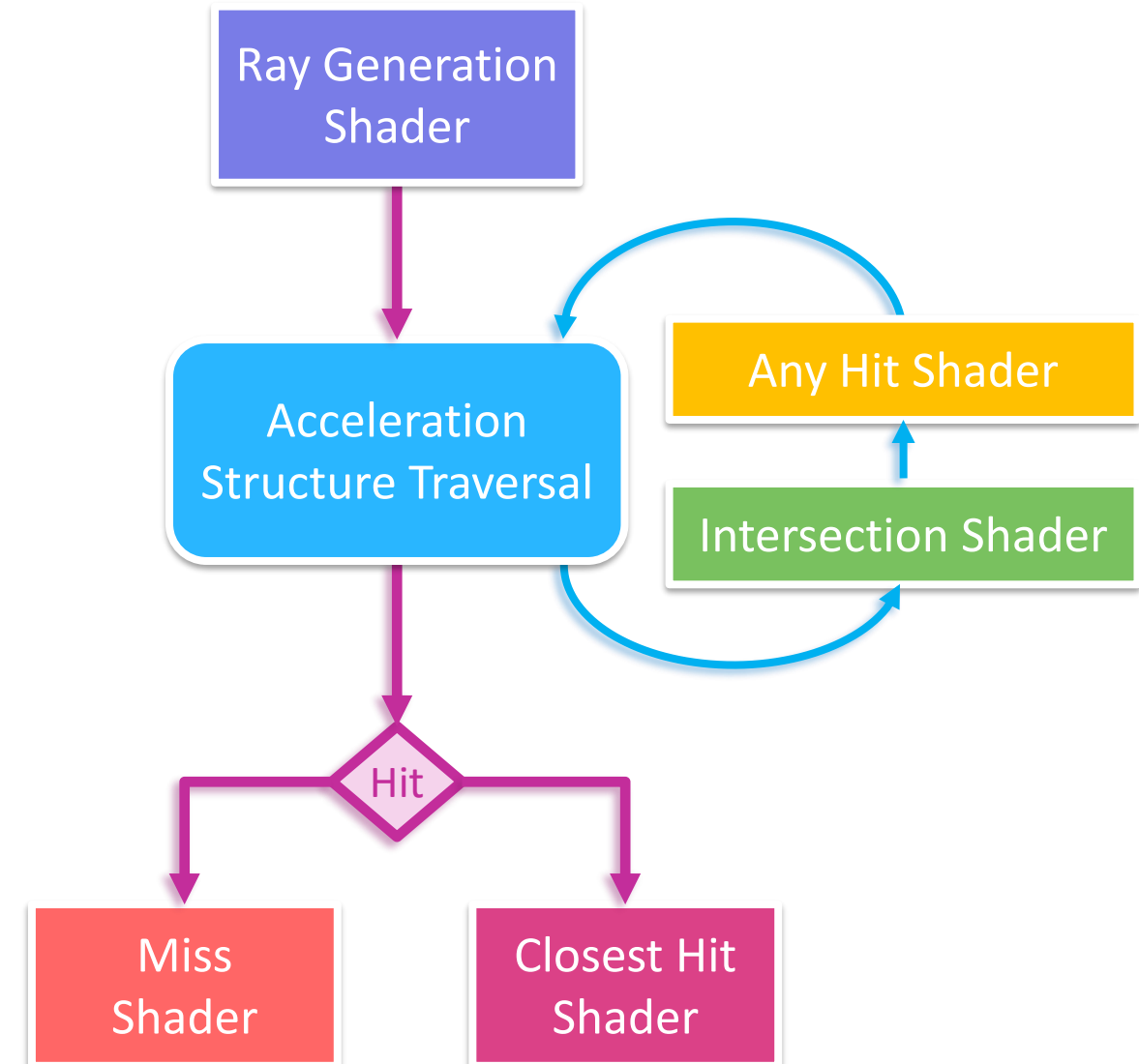
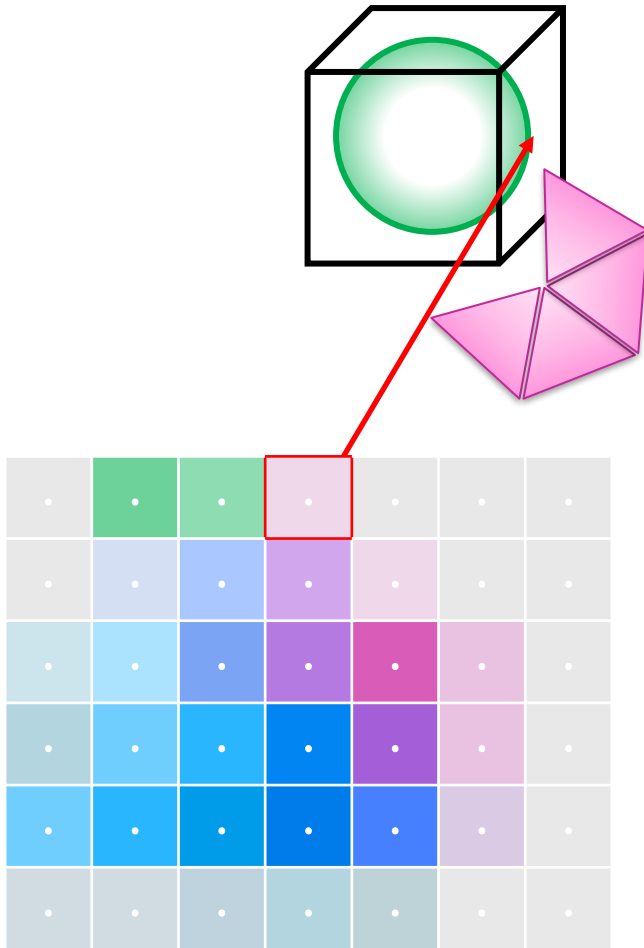


# Pipeline Stages of a Ray Tracing Pipeline Command

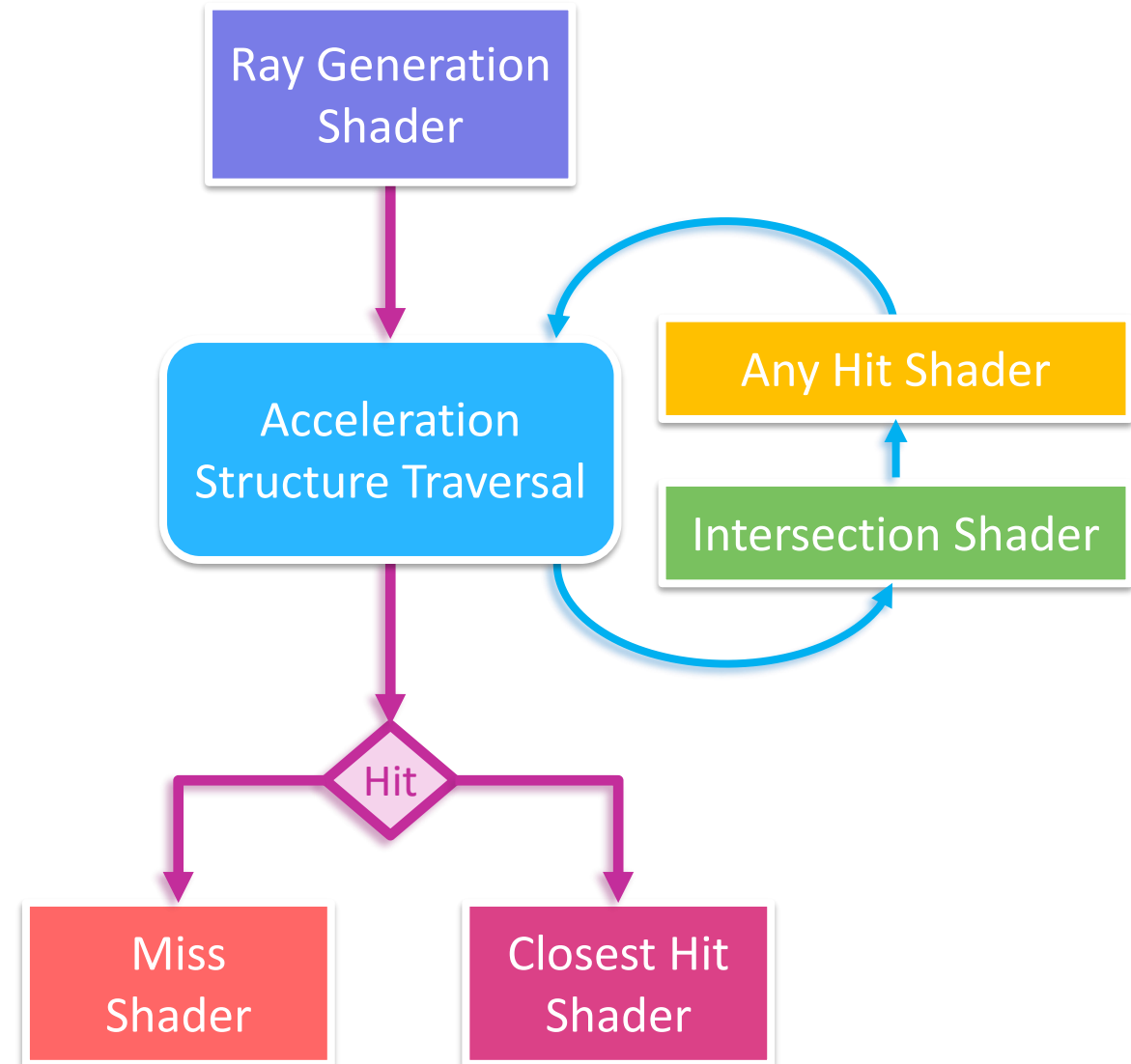
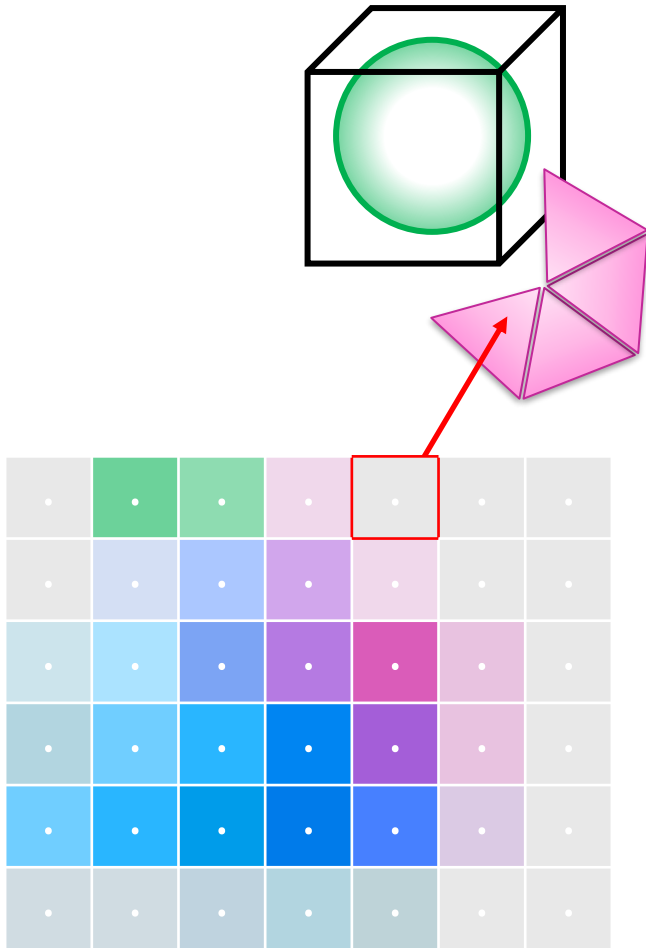




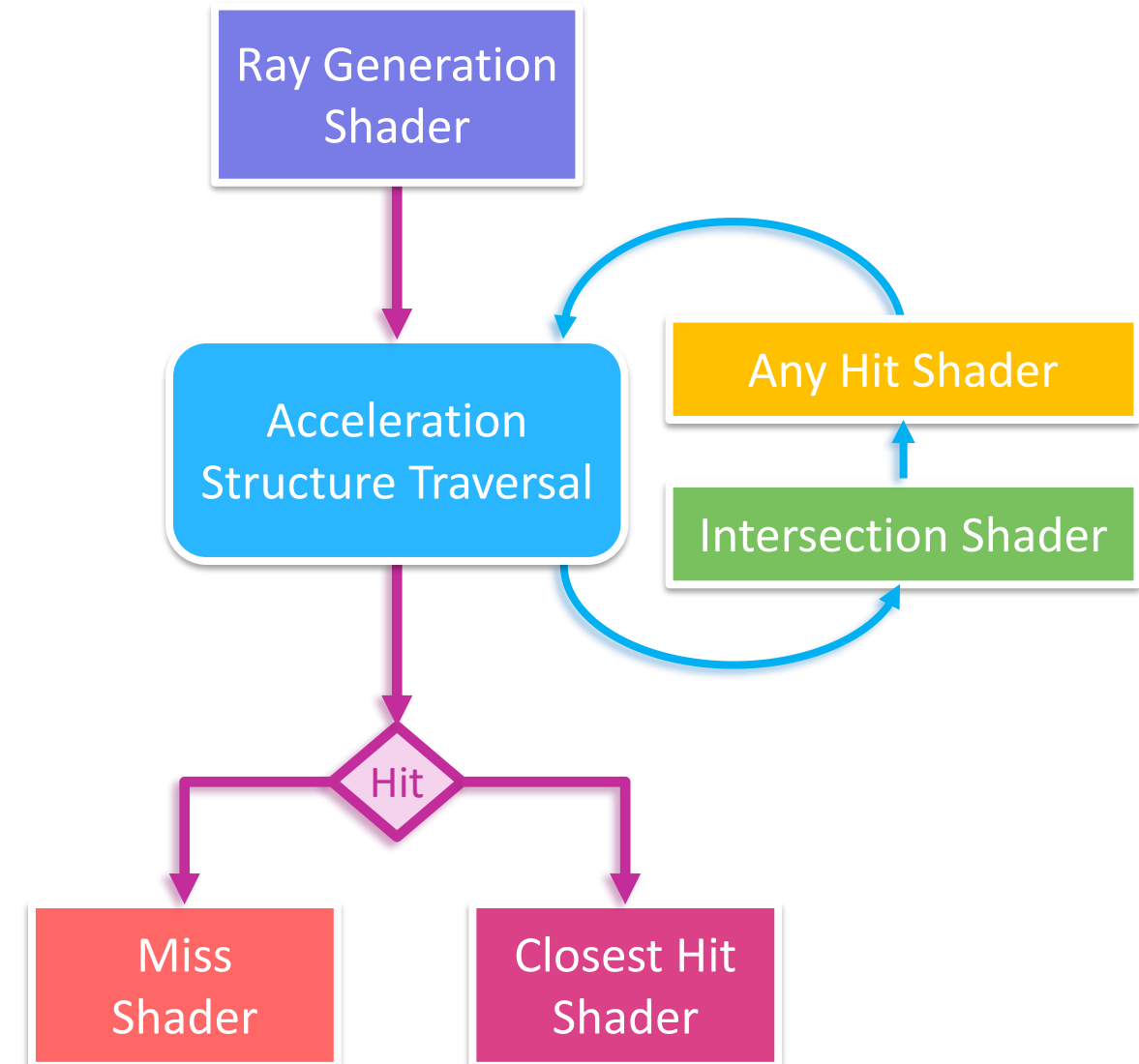
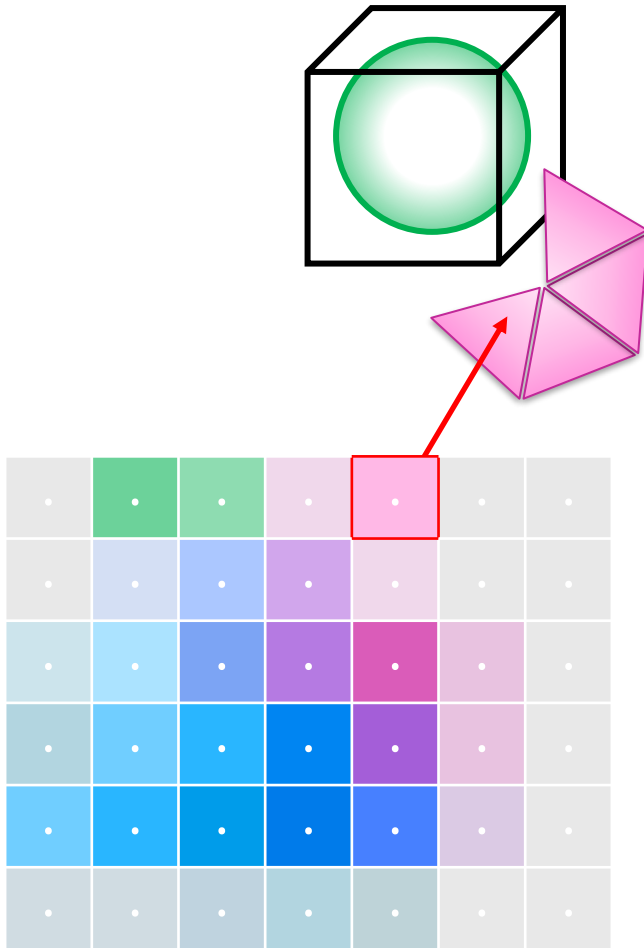
# Pipeline Stages of a Ray Tracing Pipeline Command



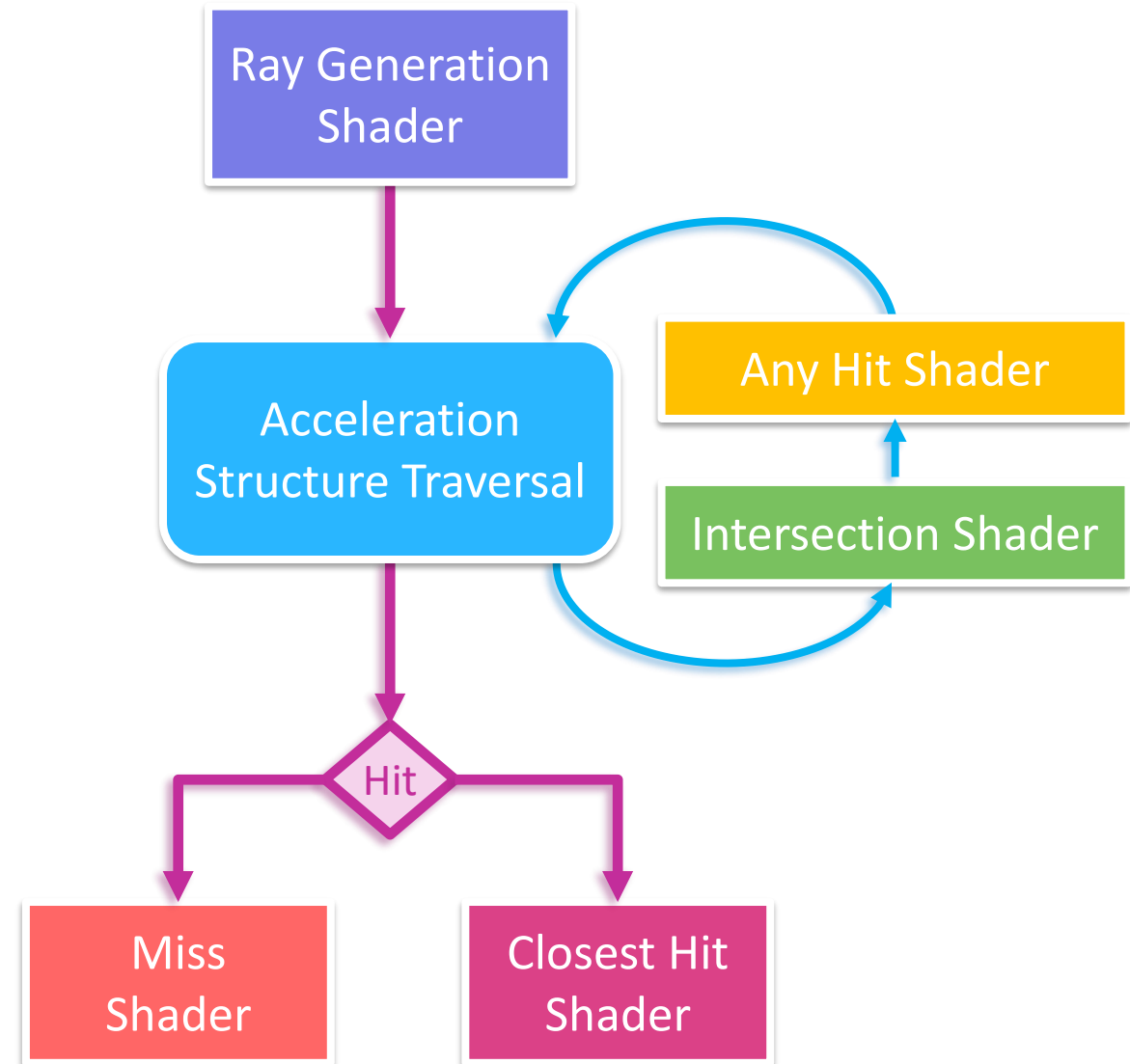
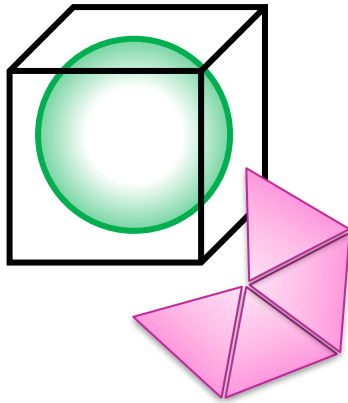
# Pipeline Stages of a Ray Tracing Pipeline Command



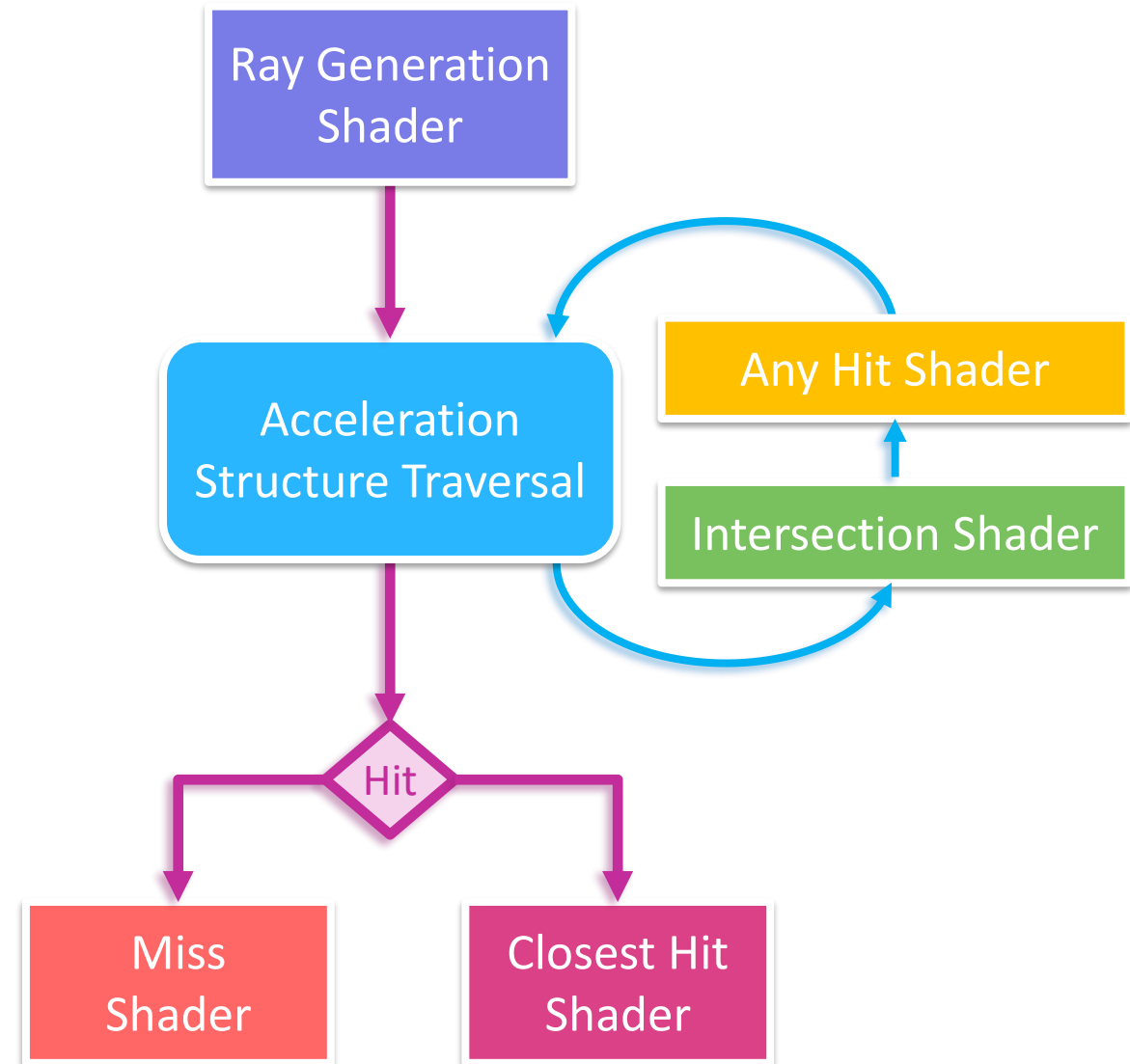
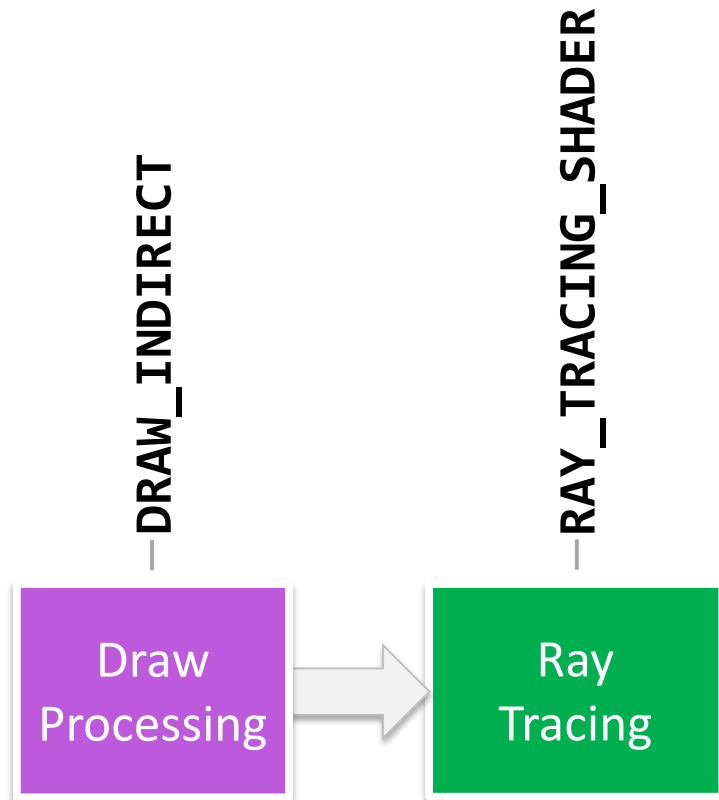
# Pipeline Stages of a Ray Tracing Pipeline Command



# Pipeline Stages of a Ray Tracing Pipeline Command

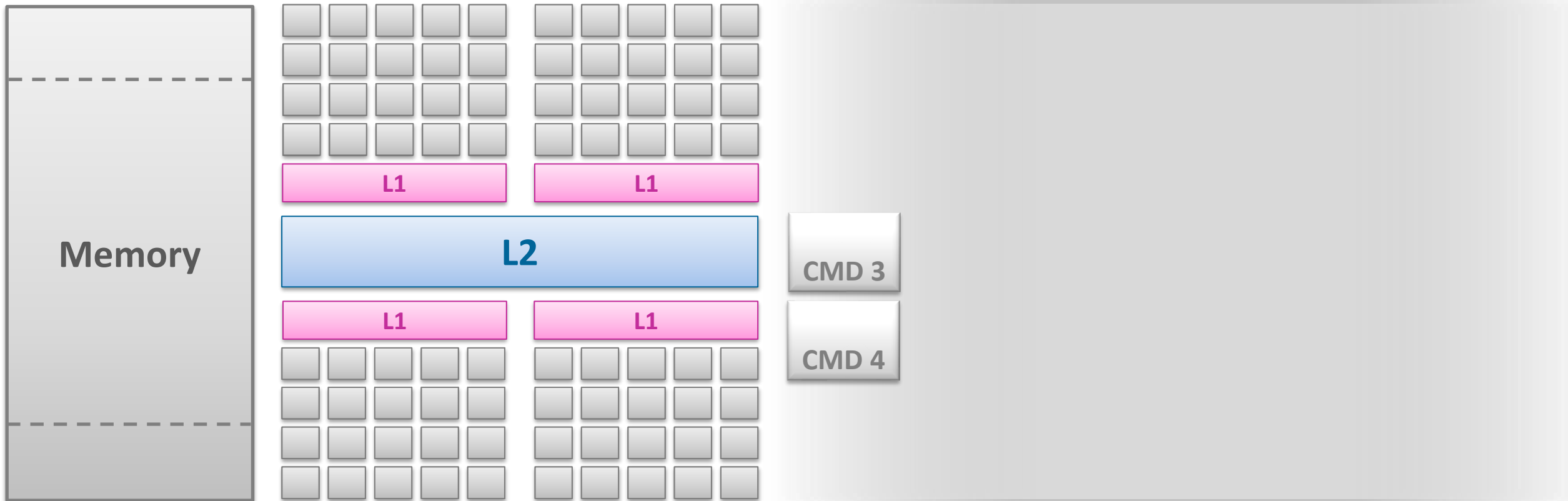


# Pipeline Stages of a Ray Tracing Pipeline Command



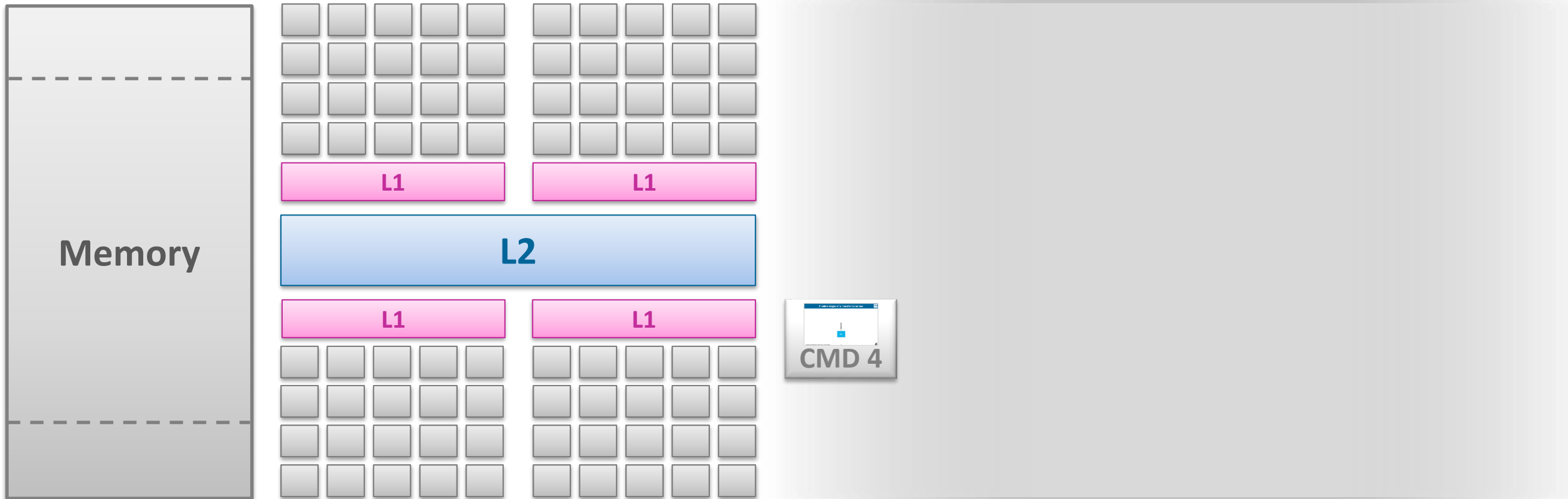
# Pipeline Stages of a Ray Tracing Pipeline Command

QUEUE

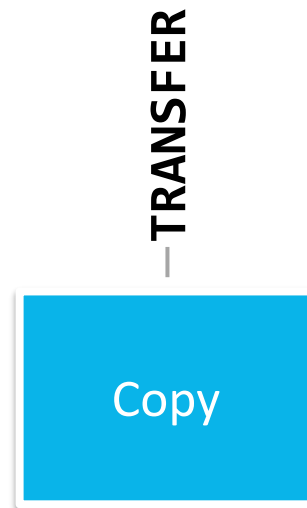


# Pipeline Stages of a Transfer Command

QUEUE

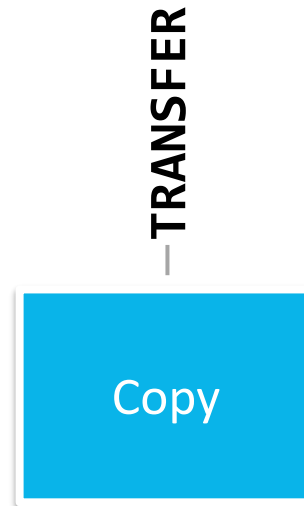
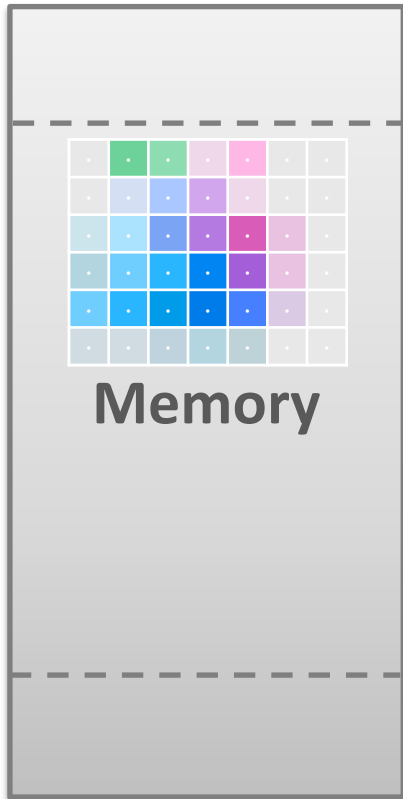


# Pipeline Stages of a Transfer Command

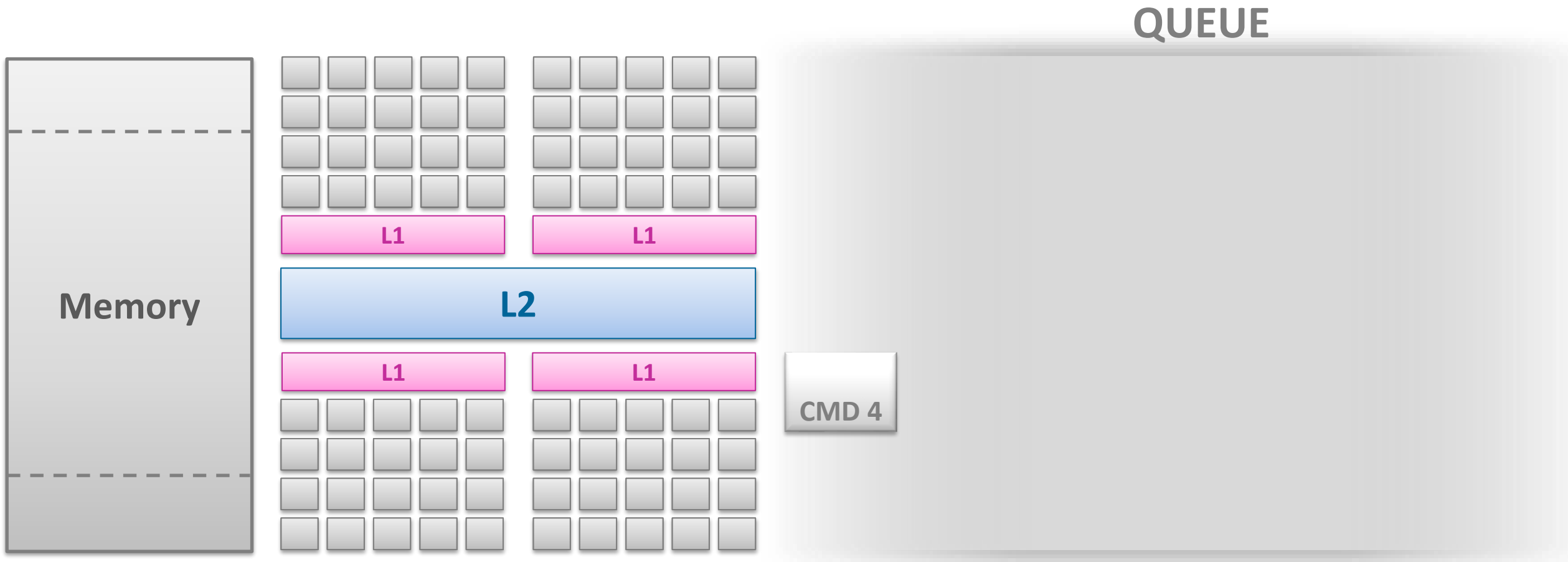




# Pipeline Stages of a Transfer Command



# Pipeline Stages of a Transfer Command



## The Stages of...

### Graphics Pipelines:

TOP\_OF\_PIPE  
CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
VERTEX\_INPUT  
VERTEX\_SHADER  
TESSELLATION\_CONTROL\_SHADER  
TESSELLATION\_EVALUATION\_SHADER  
GEOMETRY\_SHADER  
TRANSFORM\_FEEDBACK(EXT)  
FRAGMENT\_SHADING\_RATE(KHR)  
EARLY\_FRAGMENT\_TESTS  
FRAGMENT\_SHADER  
LATE\_FRAGMENT\_TESTS  
COLOR\_ATTACHMENT\_OUTPUT  
BOTTOM\_OF\_PIPE

### Compute Pipelines:

TOP\_OF\_PIPE  
CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
COMPUTE\_SHADER  
BOTTOM\_OF\_PIPE

### Transfer Commands:

TOP\_OF\_PIPE  
TRANSFER  
BOTTOM\_OF\_PIPE

### Ray Tracing Pipelines:

TOP\_OF\_PIPE  
DRAW\_INDIRECT  
RAY\_TRACING\_SHADER(KHR)  
BOTTOM\_OF\_PIPE

### Ray-Tracing Acceleration Structure Build Commands:

TOP\_OF\_PIPE  
ACCELERATION\_STRUCTURE\_BUILD(KHR)  
BOTTOM\_OF\_PIPE

### Aggregate Stages:

ALL\_GRAPHICS  
ALL\_COMMANDS

Full List of Pipeline Stages:

[VkPipelineStageFlagBits](#)

*The Khronos Group. Vulkan 1.2.199 Specification*



## The Stages of...

### Graphics Pipelines:

TOP\_OF\_PIPE  
CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
VERTEX\_INPUT  
VERTEX\_SHADER  
TESSELLATION\_CONTROL\_SHADER  
TESSELLATION\_EVALUATION\_SHADER  
GEOMETRY\_SHADER  
TRANSFORM\_FEEDBACK(EXT)  
FRAGMENT\_SHADING\_RATE(KHR)  
EARLY\_FRAGMENT\_TESTS  
FRAGMENT\_SHADER  
LATE\_FRAGMENT\_TESTS  
COLOR\_ATTACHMENT\_OUTPUT  
BOTTOM\_OF\_PIPE

### Compute Pipelines:

TOP\_OF\_PIPE  
CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
COMPUTE\_SHADER  
BOTTOM\_OF\_PIPE

### Ray Tracing Pipelines:

TOP\_OF\_PIPE  
DRAW\_INDIRECT  
RAY\_TRACING\_SHADER(KHR)  
BOTTOM\_OF\_PIPE

### Full List of Pipeline Stages:

[VkPipelineStageFlagBits](#)

*The Khronos Group. Vulkan 1.2.199 Specification*

### Transfer Commands:

TOP\_OF\_PIPE  
TRANSFER  
BOTTOM\_OF\_PIPE

### Ray-Tracing Acceleration Structure Build Commands:

TOP\_OF\_PIPE  
ACCELERATION\_STRUCTURE\_BUILD(KHR)  
BOTTOM\_OF\_PIPE

### Aggregate Stages:

ALL\_GRAPHICS  
ALL\_COMMANDS



# Command-Specific Pipeline Stages

## The Stages of...

### Graphics Pipelines:

TOP\_OF\_PIPE  
 CONDITIONAL\_RENDERING(EXT)  
 DRAW\_INDIRECT  
 VERTEX\_INPUT  
 VERTEX\_SHADER  
 TESSELLATION\_CONTROL\_SHADER  
 TESSELLATION\_EVALUATION\_SHADER  
 GEOMETRY\_SHADER  
 TRANSFORM\_FEEDBACK(EXT)  
 FRAGMENT\_SHADING\_RATE(KHR)  
 EARLY\_FRAGMENT\_TESTS  
 FRAGMENT\_SHADER  
 LATE\_FRAGMENT\_TESTS  
 COLOR\_ATTACHMENT\_OUTPUT  
 BOTTOM\_OF\_PIPE

### Compute Pipelines:

TOP\_OF\_PIPE  
 CONDITIONAL\_RENDERING(EXT)  
 DRAW\_INDIRECT  
 COMPUTE\_SHADER  
 BOTTOM\_OF\_PIPE

### Transfer Commands:

TOP\_OF\_PIPE  
 TRANSFER  
 BOTTOM\_OF\_PIPE

### Ray Tracing Pipelines:

TOP\_OF\_PIPE  
 DRAW\_INDIRECT  
 RAY\_TRACING\_SHADER(KHR)  
 BOTTOM\_OF\_PIPE

### Ray-Tracing Acceleration Structure Build Commands:

TOP\_OF\_PIPE  
 ACCELERATION\_STRUCTURE\_BUILD(KHR)  
 BOTTOM\_OF\_PIPE

### Aggregate Stages:

ALL\_GRAPHICS  
 ALL\_COMMANDS

### Full List of Pipeline Stages:

[VkPipelineStageFlagBits](#)

*The Khronos Group. Vulkan 1.2.199 Specification*



## The Stages of...

### Graphics Pipelines:

TOP\_OF\_PIPE  
CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
VERTEX\_INPUT  
VERTEX\_SHADER  
TESSELLATION\_CONTROL\_SHADER  
TESSELLATION\_EVALUATION\_SHADER  
GEOMETRY\_SHADER  
TRANSFORM\_FEEDBACK(EXT)  
FRAGMENT\_SHADING\_RATE(KHR)  
EARLY\_FRAGMENT\_TESTS  
FRAGMENT\_SHADER  
LATE\_FRAGMENT\_TESTS  
COLOR\_ATTACHMENT\_OUTPUT  
BOTTOM\_OF\_PIPE

### Compute Pipelines:

TOP\_OF\_PIPE  
CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
COMPUTE\_SHADER  
BOTTOM\_OF\_PIPE

### Ray Tracing Pipelines:

TOP\_OF\_PIPE  
DRAW\_INDIRECT  
RAY\_TRACING\_SHADER(KHR)  
BOTTOM\_OF\_PIPE

### Full List of Pipeline Stages:

[VkPipelineStageFlagBits](#)

*The Khronos Group. Vulkan 1.2.199 Specification*

### Transfer Commands:

TOP\_OF\_PIPE  
TRANSFER  
BOTTOM\_OF\_PIPE

### Ray-Tracing Acceleration Structure Build Commands:

TOP\_OF\_PIPE  
ACCELERATION\_STRUCTURE\_BUILD(KHR)  
BOTTOM\_OF\_PIPE

### Aggregate Stages:

ALL\_GRAPHICS  
ALL\_COMMANDS



# Command-Specific Pipeline Stages

## The Stages of...

### Graphics Pipelines:

TOP\_OF\_PIPE  
 CONDITIONAL\_RENDERING(EXT)  
 DRAW\_INDIRECT  
 VERTEX\_INPUT  
 VERTEX\_SHADER  
 TESSELLATION\_CONTROL\_SHADER  
 TESSELLATION\_EVALUATION\_SHADER  
 GEOMETRY\_SHADER  
 TRANSFORM\_FEEDBACK(EXT)  
 FRAGMENT\_SHADING\_RATE(KHR)  
 EARLY\_FRAGMENT\_TESTS  
 FRAGMENT\_SHADER  
 LATE\_FRAGMENT\_TESTS  
 COLOR\_ATTACHMENT\_OUTPUT  
 BOTTOM\_OF\_PIPE

### Compute Pipelines:

TOP\_OF\_PIPE  
 CONDITIONAL\_RENDERING(EXT)  
 DRAW\_INDIRECT  
 COMPUTE\_SHADER  
 BOTTOM\_OF\_PIPE

### Transfer Commands:

TOP\_OF\_PIPE  
 TRANSFER  
 BOTTOM\_OF\_PIPE

### Ray Tracing Pipelines:

TOP\_OF\_PIPE  
 DRAW\_INDIRECT  
 RAY\_TRACING\_SHADER(KHR)  
 BOTTOM\_OF\_PIPE

### Ray-Tracing Acceleration Structure Build Commands:

TOP\_OF\_PIPE  
 ACCELERATION\_STRUCTURE\_BUILD(KHR)  
 BOTTOM\_OF\_PIPE

### Full List of Pipeline Stages:

[VkPipelineStageFlagBits](#)

*The Khronos Group. Vulkan 1.2.199 Specification*

### Aggregate Stages:

ALL\_GRAPHICS  
 ALL\_COMMANDS



## The Stages of...

### Graphics Pipelines:

TOP\_OF\_PIPE  
CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
VERTEX\_INPUT  
VERTEX\_SHADER  
TESSELLATION\_CONTROL\_SHADER  
TESSELLATION\_EVALUATION\_SHADER  
GEOMETRY\_SHADER  
TRANSFORM\_FEEDBACK(EXT)  
FRAGMENT\_SHADING\_RATE(KHR)  
EARLY\_FRAGMENT\_TESTS  
FRAGMENT\_SHADER  
LATE\_FRAGMENT\_TESTS  
COLOR\_ATTACHMENT\_OUTPUT  
BOTTOM\_OF\_PIPE

### Compute Pipelines:

TOP\_OF\_PIPE  
CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
COMPUTE\_SHADER  
BOTTOM\_OF\_PIPE

### Ray Tracing Pipelines:

TOP\_OF\_PIPE  
DRAW\_INDIRECT  
RAY\_TRACING\_SHADER(KHR)  
BOTTOM\_OF\_PIPE

### Transfer Commands:

TOP\_OF\_PIPE  
TRANSFER  
BOTTOM\_OF\_PIPE

### Ray-Tracing Acceleration Structure Build Commands:

TOP\_OF\_PIPE  
ACCELERATION\_STRUCTURE\_BUILD(KHR)  
BOTTOM\_OF\_PIPE

### Aggregate Stages:

ALL\_GRAPHICS  
ALL\_COMMANDS

### Full List of Pipeline Stages:

[VkPipelineStageFlagBits](#)

*The Khronos Group. Vulkan 1.2.199 Specification*





# Aggregate Stages

## The Stages of...

### Graphics Pipelines:

TOP\_OF\_PIPE  
 CONDITIONAL\_RENDERING(EXT)  
 DRAW\_INDIRECT  
 VERTEX\_INPUT  
 VERTEX\_SHADER  
 TESSELLATION\_CONTROL\_SHADER  
 TESSELLATION\_EVALUATION\_SHADER  
 GEOMETRY\_SHADER  
 TRANSFORM\_FEEDBACK(EXT)  
 FRAGMENT\_SHADING\_RATE(KHR)  
 EARLY\_FRAGMENT\_TESTS  
 FRAGMENT\_SHADER  
 LATE\_FRAGMENT\_TESTS  
 COLOR\_ATTACHMENT\_OUTPUT  
 BOTTOM\_OF\_PIPE

### Compute Pipelines:

TOP\_OF\_PIPE  
 CONDITIONAL\_RENDERING(EXT)  
 DRAW\_INDIRECT  
 COMPUTE\_SHADER  
 BOTTOM\_OF\_PIPE

### Transfer Commands:

TOP\_OF\_PIPE  
 TRANSFER  
 BOTTOM\_OF\_PIPE

### Ray Tracing Pipelines:

TOP\_OF\_PIPE  
 DRAW\_INDIRECT  
 RAY\_TRACING\_SHADER(KHR)  
 BOTTOM\_OF\_PIPE

### Ray-Tracing Acceleration Structure Build Commands:

TOP\_OF\_PIPE  
 ACCELERATION\_STRUCTURE\_BUILD(KHR)  
 BOTTOM\_OF\_PIPE

#### Full List of Pipeline Stages:

[VkPipelineStageFlagBits](#)

*The Khronos Group. Vulkan 1.2.199 Specification*

#### Aggregate Stages:

ALL\_GRAPHICS  
 ALL\_COMMANDS



# Aggregate Stages

## The Stages of...

### Graphics Pipelines:

TOP\_OF\_PIPE  
 CONDITIONAL\_RENDERING(EXT)  
 DRAW\_INDIRECT  
 VERTEX\_INPUT  
 VERTEX\_SHADER  
 TESSELLATION\_CONTROL\_SHADER  
 TESSELLATION\_EVALUATION\_SHADER  
 GEOMETRY\_SHADER  
 TRANSFORM\_FEEDBACK(EXT)  
 FRAGMENT\_SHADING\_RATE(KHR)  
 EARLY\_FRAGMENT\_TESTS  
 FRAGMENT\_SHADER  
 LATE\_FRAGMENT\_TESTS  
 COLOR\_ATTACHMENT\_OUTPUT  
 BOTTOM\_OF\_PIPE

### Compute Pipelines:

TOP\_OF\_PIPE  
 CONDITIONAL\_RENDERING(EXT)  
 DRAW\_INDIRECT  
 COMPUTE\_SHADER  
 BOTTOM\_OF\_PIPE

### Ray Tracing Pipelines:

TOP\_OF\_PIPE  
 DRAW\_INDIRECT  
 RAY\_TRACING\_SHADER(KHR)  
 BOTTOM\_OF\_PIPE

### Full List of Pipeline Stages:

[VkPipelineStageFlagBits](#)

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### Transfer Commands:

TOP\_OF\_PIPE  
 TRANSFER  
 BOTTOM\_OF\_PIPE

### Ray-Tracing Acceleration Structure Build Commands:

TOP\_OF\_PIPE  
 ACCELERATION\_STRUCTURE\_BUILD(KHR)  
 BOTTOM\_OF\_PIPE

### Aggregate Stages:

ALL\_GRAPHICS  
 ALL\_COMMANDS



# Aggregate Stages

## The Stages of...

### Graphics Pipelines:

TOP\_OF\_PIPE  
 CONDITIONAL\_RENDERING(EXT)  
 DRAW\_INDIRECT  
 VERTEX\_INPUT  
 VERTEX\_SHADER  
 TESSELLATION\_CONTROL\_SHADER  
 TESSELLATION\_EVALUATION\_SHADER  
 GEOMETRY\_SHADER  
 TRANSFORM\_FEEDBACK(EXT)  
 FRAGMENT\_SHADING\_RATE(KHR)  
 EARLY\_FRAGMENT\_TESTS  
 FRAGMENT\_SHADER  
 LATE\_FRAGMENT\_TESTS  
 COLOR\_ATTACHMENT\_OUTPUT  
 BOTTOM\_OF\_PIPE

### Compute Pipelines:

TOP\_OF\_PIPE  
 CONDITIONAL\_RENDERING(EXT)  
 DRAW\_INDIRECT  
 COMPUTE\_SHADER  
 BOTTOM\_OF\_PIPE

### Transfer Commands:

TOP\_OF\_PIPE  
 TRANSFER  
 BOTTOM\_OF\_PIPE

### Ray Tracing Pipelines:

TOP\_OF\_PIPE  
 DRAW\_INDIRECT  
 RAY\_TRACING\_SHADER(KHR)  
 BOTTOM\_OF\_PIPE

### Ray-Tracing Acceleration Structure Build Commands:

TOP\_OF\_PIPE  
 ACCELERATION\_STRUCTURE\_BUILD(KHR)  
 BOTTOM\_OF\_PIPE

### Full List of Pipeline Stages:

[VkPipelineStageFlagBits](#)

*The Khronos Group. Vulkan 1.2.199 Specification*

### Aggregate Stages:

ALL\_GRAPHICS  
 ALL\_COMMANDS



## Enter Synchronization2

enabled via [VK\\_KHR\\_synchronization2](#)



**This is the way**

since December 2020



## The Stages of...

### Graphics Pipelines:

TOP\_OF\_PIPE  
CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
VERTEX\_INPUT  
VERTEX\_SHADER  
TESSELLATION\_CONTROL\_SHADER  
TESSELLATION\_EVALUATION\_SHADER  
GEOMETRY\_SHADER  
TRANSFORM\_FEEDBACK(EXT)  
FRAGMENT\_SHADING\_RATE(KHR)  
EARLY\_FRAGMENT\_TESTS  
FRAGMENT\_SHADER  
LATE\_FRAGMENT\_TESTS  
COLOR\_ATTACHMENT\_OUTPUT  
BOTTOM\_OF\_PIPE

### Compute Pipelines:

TOP\_OF\_PIPE  
CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
COMPUTE\_SHADER  
BOTTOM\_OF\_PIPE

### Transfer Commands:

TOP\_OF\_PIPE  
TRANSFER  
BOTTOM\_OF\_PIPE

The TOP and BOTTOM pipeline stages are deprecated, and applications should prefer `VK_PIPELINE_STAGE_2_ALL_COMMANDS_BIT_KHR` and `VK_PIPELINE_STAGE_2_NONE_KHR`.

*The Khronos Group. Vulkan 1.2.199 Specification*

### Ray Tracing Acceleration

### Acceleration Structure Build Commands:

TOP\_OF\_PIPE  
ACCELERATION\_STRUCTURE\_BUILD(KHR)  
BOTTOM\_OF\_PIPE

### None/Aggregate Stages:

NONE  
ALL\_GRAPHICS  
ALL\_COMMANDS

### Full List of Pipeline Stages:

[VkPipelineStageFlagBits2KHR](#)

*The Khronos Group. Vulkan 1.2.199 Specification*



# Pipeline Stages with Synchronization2

## The Stages of...

### Graphics Pipelines:

TOP\_OF\_PIPE

CONDITIONAL\_RENDERING(EXT)

DRAW\_INDIRECT

VERTEX\_INPUT

VERTEX\_SHADER

TESSELLATION\_CONTROL\_SHADER

TESSELLATION\_EVALUATION\_SHADER

GEOMETRY\_SHADER

TRANSFORM\_FEEDBACK(EXT)

FRAGMENT\_SHADING\_RATE(KHR)

EARLY\_FRAGMENT\_TESTS

FRAGMENT\_SHADER

LATE\_FRAGMENT\_TESTS

COLOR\_ATTACHMENT\_OUTPUT

BOTTOM\_OF\_PIPE

### Compute Pipelines:

TOP\_OF\_PIPE

CONDITIONAL\_RENDERING(EXT)

DRAW\_INDIRECT

COMPUTE\_SHADER

BOTTOM\_OF\_PIPE

### Transfer Commands:

TOP\_OF\_PIPE

TRANSFER

BOTTOM\_OF\_PIPE

### Ray Tracing Pipelines:

TOP\_OF\_PIPE

DRAW\_INDIRECT

RAY\_TRACING\_SHADER(KHR)

BOTTOM\_OF\_PIPE

### Ray-Tracing Acceleration Structure Build Commands:

TOP\_OF\_PIPE

ACCELERATION\_STRUCTURE\_BUILD(KHR)

BOTTOM\_OF\_PIPE

### None/Aggregate Stages:

NONE

ALL\_GRAPHICS

ALL\_COMMANDS

Full List of Pipeline Stages:

[VkPipelineStageFlagBits2KHR](#)

*The Khronos Group. Vulkan 1.2.199 Specification*



# Pipeline Stages with Synchronization2

## The Stages of...

### Graphics Pipelines:

TOP\_OF\_PIPE

CONDITIONAL\_RENDERING(EXT)

DRAW\_INDIRECT

VERTEX\_INPUT

VERTEX\_SHADER

TESSELLATION\_CONTROL\_SHADER

TESSELLATION\_EVALUATION\_SHADER

GEOMETRY\_SHADER

TRANSFORM\_FEEDBACK(EXT)

FRAGMENT\_SHADING\_RATE(KHR)

EARLY\_FRAGMENT\_TESTS

FRAGMENT\_SHADER

LATE\_FRAGMENT\_TESTS

COLOR\_ATTACHMENT\_OUTPUT

BOTTOM\_OF\_PIPE

e.g.:

### Compute Pipelines:

TOP\_OF\_PIPE

CONDITIONAL\_RENDERING(EXT)

DRAW\_INDIRECT

COMPUTE\_SHADER

BOTTOM\_OF\_PIPE

### Transfer Commands:

TOP\_OF\_PIPE

TRANSFER

BOTTOM\_OF\_PIPE

### Ray Tracing Pipelines:

TOP\_OF\_PIPE

DRAW\_INDIRECT

RAY\_TRACING\_SHADER(KHR)

BOTTOM\_OF\_PIPE

### Ray-Tracing Acceleration Structure Build Commands:

TOP\_OF\_PIPE

ACCELERATION\_STRUCTURE\_BUILD(KHR)

BOTTOM\_OF\_PIPE

### None/Aggregate Stages:

NONE

ALL\_GRAPHICS

ALL\_COMMANDS

Full List of Pipeline Stages:

[VkPipelineStageFlagBits2KHR](#)

*The Khronos Group. Vulkan 1.2.199 Specification*



# Pipeline Stages with Synchronization2

## The Stages of...

### Graphics Pipelines:

TOP\_OF\_PIPE

CONDITIONAL\_RENDERING(EXT)

DRAW\_INDIRECT

VERTEX\_INPUT

VERTEX\_SHADER

TESSELLATION\_CONTROL\_SHADER

TESSELLATION\_EVALUATION\_SHADER

GEOMETRY\_SHADER

TRANSFORM\_FEEDBACK(EXT)

FRAGMENT\_SHADING\_RATE(KHR)

EARLY\_FRAGMENT\_TESTS

FRAGMENT\_SHADER

LATE\_FRAGMENT\_TESTS

COLOR\_ATTACHMENT\_OUTPUT

ALL\_COMMANDS

e.g.:

### Compute Pipelines:

TOP\_OF\_PIPE

CONDITIONAL\_RENDERING(EXT)

DRAW\_INDIRECT

COMPUTE\_SHADER

BOTTOM\_OF\_PIPE

### Transfer Commands:

TOP\_OF\_PIPE

TRANSFER

BOTTOM\_OF\_PIPE

### Ray Tracing Pipelines:

ALL\_COMMANDS

DRAW\_INDIRECT

RAY\_TRACING\_SHADER(KHR)

BOTTOM\_OF\_PIPE

### Ray-Tracing Acceleration Structure Build Commands:

TOP\_OF\_PIPE

ACCELERATION\_STRUCTURE\_BUILD(KHR)

BOTTOM\_OF\_PIPE

### None/Aggregate Stages:

NONE

ALL\_GRAPHICS

ALL\_COMMANDS

Full List of Pipeline Stages:

[VkPipelineStageFlagBits2KHR](#)

*The Khronos Group. Vulkan 1.2.199 Specification*





# Pipeline Stages with Synchronization2

## The Stages of...

### Graphics Pipelines:

TOP\_OF\_PIPE

CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
VERTEX\_INPUT  
VERTEX\_SHADER  
TESSELLATION\_CONTROL\_SHADER  
TESSELLATION\_EVALUATION\_SHADER  
GEOMETRY\_SHADER  
TRANSFORM\_FEEDBACK(EXT)  
FRAGMENT\_SHADING\_RATE(KHR)  
EARLY\_FRAGMENT\_TESTS  
FRAGMENT\_SHADER  
LATE\_FRAGMENT\_TESTS  
COLOR\_ATTACHMENT\_OUTPUT  
ALL\_COMMANDS

e.g.:

### Compute Pipelines:

TOP\_OF\_PIPE

CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
COMPUTE\_SHADER  
BOTTOM\_OF\_PIPE

### Transfer Commands:

TOP\_OF\_PIPE

TRANSFER  
BOTTOM\_OF\_PIPE

### Ray Tracing Pipelines:

ALL\_COMMANDS

DRAW\_INDIRECT  
RAY\_TRACING\_SHADER(KHR)  
BOTTOM\_OF\_PIPE

### Ray-Tracing Acceleration Structure Build Commands:

TOP\_OF\_PIPE

ACCELERATION\_STRUCTURE\_BUILD(KHR)  
BOTTOM\_OF\_PIPE

### None/Aggregate Stages:

NONE  
ALL\_GRAPHICS  
ALL\_COMMANDS

Full List of Pipeline Stages:

[VkPipelineStageFlagBits2KHR](#)

*The Khronos Group. Vulkan 1.2.199 Specification*



# Pipeline Stages with Synchronization2

## The Stages of...

### Graphics Pipelines:

NONE

CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
VERTEX\_INPUT  
VERTEX\_SHADER  
TESSELLATION\_CONTROL\_SHADER  
TESSELLATION\_EVALUATION\_SHADER  
GEOMETRY\_SHADER  
TRANSFORM\_FEEDBACK(EXT)  
FRAGMENT\_SHADING\_RATE(KHR)  
EARLY\_FRAGMENT\_TESTS  
FRAGMENT\_SHADER  
LATE\_FRAGMENT\_TESTS  
COLOR\_ATTACHMENT\_OUTPUT  
ALL\_COMMANDS

e.g.:

### Compute Pipelines:

TOP\_OF\_PIPE

CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
COMPUTE\_SHADER  
BOTTOM\_OF\_PIPE

### Ray Tracing Pipelines:

ALL\_COMMANDS

DRAW\_INDIRECT  
RAY\_TRACING\_SHADER(KHR)  
NONE

### Transfer Commands:

TOP\_OF\_PIPE

TRANSFER  
BOTTOM\_OF\_PIPE

### Ray-Tracing Acceleration Structure Build Commands:

TOP\_OF\_PIPE

ACCELERATION\_STRUCTURE\_BUILD(KHR)  
BOTTOM\_OF\_PIPE

### None/Aggregate Stages:

NONE  
ALL\_GRAPHICS  
ALL\_COMMANDS

Full List of Pipeline Stages:

[VkPipelineStageFlagBits2KHR](#)

*The Khronos Group. Vulkan 1.2.199 Specification*



## The Stages of...

### Graphics Pipelines:

CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
VERTEX\_INPUT  
VERTEX\_SHADER  
TESSELLATION\_CONTROL\_SHADER  
TESSELLATION\_EVALUATION\_SHADER  
GEOMETRY\_SHADER  
TRANSFORM\_FEEDBACK(EXT)  
FRAGMENT\_SHADING\_RATE(KHR)  
EARLY\_FRAGMENT\_TESTS  
FRAGMENT\_SHADER  
LATE\_FRAGMENT\_TESTS  
COLOR\_ATTACHMENT\_OUTPUT

### Compute Pipelines:

CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
COMPUTE\_SHADER

### Transfer Commands:

TRANSFER

### Ray Tracing Pipelines:

DRAW\_INDIRECT  
RAY\_TRACING\_SHADER(KHR)

### Ray-Tracing Acceleration Structure Build Commands:

ACCELERATION\_STRUCTURE\_BUILD(KHR)

### None/Aggregate Stages:

NONE

ALL\_GRAPHICS

ALL\_COMMANDS

Full List of Pipeline Stages:

[VkPipelineStageFlagBits2KHR](#)

*The Khronos Group. Vulkan 1.2.199 Specification*



## The Stages of...

### Graphics Pipelines:

CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
VERTEX\_INPUT  
VERTEX\_SHADER  
TESSELLATION\_CONTROL\_SHADER  
TESSELLATION\_EVALUATION\_SHADER  
GEOMETRY\_SHADER  
TRANSFORM\_FEEDBACK(EXT)  
FRAGMENT\_SHADING\_RATE(KHR)  
EARLY\_FRAGMENT\_TESTS  
FRAGMENT\_SHADER  
LATE\_FRAGMENT\_TESTS  
COLOR\_ATTACHMENT\_OUTPUT

### Compute Pipelines:

CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
COMPUTE\_SHADER

### Transfer Commands:

TRANSFER

### Ray Tracing Pipelines:

DRAW\_INDIRECT  
RAY\_TRACING\_SHADER(KHR)

### Ray-Tracing Acceleration Structure Build Commands:

ACCELERATION\_STRUCTURE\_BUILD(KHR)

### None/Aggregate Stages:

NONE  
ALL\_GRAPHICS  
ALL\_COMMANDS

### Full List of Pipeline Stages:

[VkPipelineStageFlagBits2KHR](#)

*The Khronos Group. Vulkan 1.2.199 Specification*



## The Stages of...

### Graphics Pipelines:

CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
VERTEX\_INPUT  
VERTEX\_SHADER  
TESSELLATION\_CONTROL\_SHADER  
TESSELLATION\_EVALUATION\_SHADER  
GEOMETRY\_SHADER  
TRANSFORM\_FEEDBACK(EXT)  
FRAGMENT\_SHADING\_RATE(KHR)  
EARLY\_FRAGMENT\_TESTS  
FRAGMENT\_SHADER  
LATE\_FRAGMENT\_TESTS  
COLOR\_ATTACHMENT\_OUTPUT

### Compute Pipelines:

CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
COMPUTE\_SHADER

### Ray Tracing Pipelines:

DRAW\_INDIRECT  
RAY\_TRACING\_SHADER(KHR)

### Transfer Commands:

TRANSFER

Ray-Tracing Acceleration  
Structure Build Commands:  
ACCELERATION\_STRUCTURE\_BUILD(KHR)

### None/Aggregate Stages:

NONE  
ALL\_GRAPHICS  
ALL\_COMMANDS

### Full List of Pipeline Stages:

[VkPipelineStageFlagBits2KHR](#)

*The Khronos Group. Vulkan 1.2.199 Specification*



# Pipeline Stages with Synchronization2

## The Stages of...

### Graphics Pipelines:

CONDITIONAL\_RENDERING(EXT)  
 DRAW\_INDIRECT  
 VERTEX\_INPUT  
 VERTEX\_SHADER  
 TESSELLATION\_CONTROL\_SHADER  
 TESSELLATION\_EVALUATION\_SHADER  
 GEOMETRY\_SHADER  
 TRANSFORM\_FEEDBACK(EXT)  
 FRAGMENT\_SHADING\_RATE(KHR)  
 EARLY\_FRAGMENT\_TESTS  
 FRAGMENT\_SHADER  
 LATE\_FRAGMENT\_TESTS  
 COLOR\_ATTACHMENT\_OUTPUT

### Compute Pipelines:

CONDITIONAL\_RENDERING(EXT)  
 DRAW\_INDIRECT  
 COMPUTE\_SHADER

### Ray Tracing Pipelines:

DRAW\_INDIRECT  
 RAY\_TRACING\_SHADER(KHR)

### Ray-Tracing Acceleration

### Structure Build Commands:

ACCELERATION\_STRUCTURE\_BUILD(KHR)

### Full List of Pipeline Stages:

[VkPipelineStageFlagBits2KHR](#)

*The Khronos Group. Vulkan 1.2.199 Specification*

### Transfer Commands:

TRANSFER

### None/Aggregate Stages:

NONE  
 ALL\_GRAPHICS  
 ALL\_COMMANDS



# Pipeline Stages with Synchronization2

## The Stages of...

### Graphics Pipelines:

CONDITIONAL\_RENDERING(EXT)  
 DRAW\_INDIRECT  
 VERTEX\_INPUT  
 VERTEX\_SHADER  
 TESSELLATION\_CONTROL\_SHADER  
 TESSELLATION\_EVALUATION\_SHADER  
 GEOMETRY\_SHADER  
 TRANSFORM\_FEEDBACK(EXT)  
 FRAGMENT\_SHADING\_RATE(KHR)  
 EARLY\_FRAGMENT\_TESTS  
 FRAGMENT\_SHADER  
 LATE\_FRAGMENT\_TESTS  
 COLOR\_ATTACHMENT\_OUTPUT

### Compute Pipelines:

CONDITIONAL\_RENDERING(EXT)  
 DRAW\_INDIRECT  
 COMPUTE\_SHADER

### Ray Tracing Pipelines:

DRAW\_INDIRECT  
 RAY\_TRACING\_SHADER(KHR)

### Ray-Tracing Acceleration

### Structure Build Commands:

ACCELERATION\_STRUCTURE\_BUILD(KHR)

### Full List of Pipeline Stages:

[VkPipelineStageFlagBits2KHR](#)

*The Khronos Group. Vulkan 1.2.199 Specification*

### Copy Commands:

COPY

### Blit Commands:

BLIT

### Resolve Commands:

RESOLVE

### Clear Commands:

CLEAR

### None/Aggregate Stages:

NONE

ALL\_GRAPHICS

ALL\_COMMANDS



# Pipeline Stages with Synchronization2

## The Stages of...

### Graphics Pipelines:

CONDITIONAL\_RENDERING(EXT)  
 DRAW\_INDIRECT  
 VERTEX\_INPUT  
 VERTEX\_SHADER  
 TESSELLATION\_CONTROL\_SHADER  
 TESSELLATION\_EVALUATION\_SHADER  
 GEOMETRY\_SHADER  
 TRANSFORM\_FEEDBACK(EXT)  
 FRAGMENT\_SHADING\_RATE(KHR)  
 EARLY\_FRAGMENT\_TESTS  
 FRAGMENT\_SHADER  
 LATE\_FRAGMENT\_TESTS  
 COLOR\_ATTACHMENT\_OUTPUT

### Compute Pipelines:

CONDITIONAL\_RENDERING(EXT)  
 DRAW\_INDIRECT  
 COMPUTE\_SHADER

### Ray Tracing Pipelines:

DRAW\_INDIRECT  
 RAY\_TRACING\_SHADER(KHR)

### Ray-Tracing Acceleration

### Structure Build Commands:

ACCELERATION\_STRUCTURE\_BUILD(KHR)

### Full List of Pipeline Stages:

[VkPipelineStageFlagBits2KHR](#)

*The Khronos Group. Vulkan 1.2.199 Specification*

### Copy Commands:

COPY

### Blit Commands:

BLIT

### Resolve Commands:

RESOLVE

### Clear Commands:

CLEAR

### None/Aggregate Stages:

NONE

ALL\_GRAPHICS

ALL\_COMMANDS

ALL\_TRANSFER





# Pipeline Stages with Synchronization2

## The Stages of...

### Graphics Pipelines:

CONDITIONAL\_RENDERING(EXT)  
 DRAW\_INDIRECT  
 VERTEX\_INPUT  
 VERTEX\_SHADER  
 TESSELLATION\_CONTROL\_SHADER  
 TESSELLATION\_EVALUATION\_SHADER  
 GEOMETRY\_SHADER  
 TRANSFORM\_FEEDBACK(EXT)  
 FRAGMENT\_SHADING\_RATE(KHR)  
 EARLY\_FRAGMENT\_TESTS  
 FRAGMENT\_SHADER  
 LATE\_FRAGMENT\_TESTS  
 COLOR\_ATTACHMENT\_OUTPUT

### Compute Pipelines:

CONDITIONAL\_RENDERING(EXT)  
 DRAW\_INDIRECT  
 COMPUTE\_SHADER

### Ray Tracing Pipelines:

DRAW\_INDIRECT  
 RAY\_TRACING\_SHADER(KHR)

### Ray-Tracing Acceleration

### Structure Build Commands:

ACCELERATION\_STRUCTURE\_BUILD(KHR)

### Full List of Pipeline Stages:

[VkPipelineStageFlagBits2KHR](#)

*The Khronos Group. Vulkan 1.2.199 Specification*

### Copy Commands:

COPY

### Blit Commands:

BLIT

### Resolve Commands:

RESOLVE

### Clear Commands:

CLEAR

### None/Aggregate Stages:

NONE  
 ALL\_GRAPHICS  
 ALL\_COMMANDS  
 ALL\_TRANSFER



# Pipeline Stages with Synchronization2

## The Stages of...

### Graphics Pipelines:

CONDITIONAL\_RENDERING(EXT)  
 DRAW\_INDIRECT  
 INDEX\_INPUT(KHR)  
 VERTEX\_ATTRIBUTE\_INPUT(KHR)  
 VERTEX\_SHADER  
 TESSELLATION\_CONTROL\_SHADER  
 TESSELLATION\_EVALUATION\_SHADER  
 GEOMETRY\_SHADER  
 TRANSFORM\_FEEDBACK(EXT)  
 FRAGMENT\_SHADING\_RATE(KHR)  
 EARLY\_FRAGMENT\_TESTS  
 FRAGMENT\_SHADER  
 LATE\_FRAGMENT\_TESTS  
 COLOR\_ATTACHMENT\_OUTPUT

### Compute Pipelines:

CONDITIONAL\_RENDERING(EXT)  
 DRAW\_INDIRECT  
 COMPUTE\_SHADER

### Ray Tracing Pipelines:

DRAW\_INDIRECT  
 RAY\_TRACING\_SHADER(KHR)

### Ray-Tracing Acceleration

### Structure Build Commands:

ACCELERATION\_STRUCTURE\_BUILD(KHR)

### Full List of Pipeline Stages:

[VkPipelineStageFlagBits2KHR](#)

*The Khronos Group. Vulkan 1.2.199 Specification*

### Copy Commands:

COPY

### Blit Commands:

BLIT

### Resolve Commands:

RESOLVE

### Clear Commands:

CLEAR

### None/Aggregate Stages:

NONE  
 ALL\_GRAPHICS  
 ALL\_COMMANDS  
 ALL\_TRANSFER



- VK\_KHR\_synchronization2 extension
  - Device-level extension
  - Simplifies the interface
  - Improves usability
  - Increases efficiency in some cases (e.g., Events)
  - Requires only Vulkan 1.0
  - Introduces new commands (e.g., [vkCmdPipelineBarrier2KHR](#))
  - Introduces new structures (e.g., [VkBufferMemoryBarrier2KHR](#))
  - Introduces new bitmasks and enums (e.g., [VkPipelineStageFlags2KHR](#) and [VkPipelineStageFlagBits2KHR](#))



# Draw Indirect

## The Stages of...

### Graphics Pipelines:

CONDITIONAL\_RENDERING(EXT)  
 DRAW\_INDIRECT  
 INDEX\_INPUT(KHR)  
 VERTEX\_ATTRIBUTE\_INPUT(KHR)  
 VERTEX\_SHADER  
 TESSELLATION\_CONTROL\_SHADER  
 TESSELLATION\_EVALUATION\_SHADER  
 GEOMETRY\_SHADER  
 TRANSFORM\_FEEDBACK(EXT)  
 FRAGMENT\_SHADING\_RATE(KHR)  
 EARLY\_FRAGMENT\_TESTS  
 FRAGMENT\_SHADER  
 LATE\_FRAGMENT\_TESTS  
 COLOR\_ATTACHMENT\_OUTPUT

### Compute Pipelines:

CONDITIONAL\_RENDERING(EXT)  
 DRAW\_INDIRECT  
 COMPUTE\_SHADER

### Ray Tracing Pipelines:

DRAW\_INDIRECT  
 RAY\_TRACING\_SHADER(KHR)

### Ray-Tracing Acceleration

### Structure Build Commands:

ACCELERATION\_STRUCTURE\_BUILD(KHR)

### Full List of Pipeline Stages:

[VkPipelineStageFlagBits2KHR](#)

*The Khronos Group. Vulkan 1.2.199 Specification*

### Copy Commands:

COPY

### Blit Commands:

BLIT

### Resolve Commands:

RESOLVE

### Clear Commands:

CLEAR

### None/Aggregate Stages:

NONE

ALL\_GRAPHICS

ALL\_COMMANDS

ALL\_TRANSFER



# Draw Indirect

## The Stages of...

### Graphics Pipelines:

CONDITIONAL\_RENDERING(EXT)  
**DRAW\_INDIRECT**  
 INDEX\_INPUT(KHR)  
 VERTEX\_ATTRIBUTE\_INPUT(KHR)  
 VERTEX\_SHADER  
 TESSELLATION\_CONTROL\_SHADER  
 TESSELLATION\_EVALUATION\_SHADER  
 GEOMETRY\_SHADER  
 TRANSFORM\_FEEDBACK(EXT)  
 FRAGMENT\_SHADING\_RATE(KHR)  
 EARLY\_FRAGMENT\_TESTS  
 FRAGMENT\_SHADER  
 LATE\_FRAGMENT\_TESTS  
 COLOR\_ATTACHMENT\_OUTPUT

### Compute Pipelines:

CONDITIONAL\_RENDERING(EXT)  
**DRAW\_INDIRECT**  
 COMPUTE\_SHADER

### Ray Tracing Pipelines:

**DRAW\_INDIRECT**  
 RAY\_TRACING\_SHADER(KHR)

### Ray-Tracing Acceleration Structure Build Commands:

ACCELERATION\_STRUCTURE\_BUILD(KHR)



### Full List of Pipeline Stages:

[VkPipelineStageFlagBits2KHR](#)

*The Khronos Group. Vulkan 1.2.199 Specification*

### Copy Commands:

COPY

### Blit Commands:

BLIT

### Resolve Commands:

RESOLVE

### Clear Commands:

CLEAR

### None/Aggregate Stages:

NONE  
 ALL\_GRAPHICS  
 ALL\_COMMANDS  
 ALL\_TRANSFER



# Draw Indirect

## The Stages

### Graphics

**VK\_PIPELINE\_STAGE\_ACCELERATION\_STRUCTURE\_BUILD\_BIT\_KHR** specifies the execution of `vkCmdBuildAccelerationStructureNV`, `vkCmdCopyAccelerationStructureNV`, `vkCmdWriteAccelerationStructuresPropertiesNV`, `vkCmdBuildAccelerationStructuresKHR`, **`vkCmdBuildAccelerationStructuresIndirectKHR`**, `vkCmdCopyAccelerationStructureKHR`, `vkCmdCopyAccelerationStructureToMemoryKHR`, `vkCmdCopyMemoryToAccelerationStructureKHR`, and `vkCmdWriteAccelerationStructuresPropertiesKHR`.

*The Khronos Group. Vulkan 1.2.199 Specification*

**ACCELERATION\_STRUCTURE\_BUILD(KHR)**

Full List of Pipeline Stages:

[`VkPipelineStageFlagBits2KHR`](#)

*The Khronos Group. Vulkan 1.2.199 Specification*

## None/Aggregate Stages:

NONE

ALL\_GRAPHICS

ALL\_COMMANDS

ALL\_TRANSFER



# Conditional Rendering

## The Stages of...

### Graphics Pipelines:

CONDITIONAL\_RENDERING(EXT)

DRAW\_INDIRECT

INDEX\_INPUT(KHR)

VERTEX\_ATTRIBUTE\_INPUT

VERTEX\_SHADER

TESSELLATION\_CONTROL\_SHADER

TESSELLATION\_EVALUATION\_SHADER

GEOMETRY\_SHADER

TRANSFORM\_FEEDBACK\_SHADER

FRAGMENT\_SHADING\_RATE\_SHADER

EARLY\_FRAGMENT\_TESTS

FRAGMENT\_SHADER

LATE\_FRAGMENT\_TESTS

COLOR\_ATTACHMENT\_OUTPUT

### Compute Pipelines:

CONDITIONAL\_RENDERING(EXT)

DRAW\_INDIRECT

COMPUTE\_SHADER

### Copy Commands:

COPY

### Blit Commands:

BLIT

### Resolve Commands:

RESOLVE

### Clear Commands:

CLEAR

### None/Aggregate Stages:

NONE

ALL\_GRAPHICS

ALL\_COMMANDS

ALL\_TRANSFER

### Ray Tracing Pipelines:

The conditional rendering stage is formally part of both the graphics, and the compute pipeline.

The pipeline stage where the predicate read happens has unspecified order relative to other stages of these pipelines.

*The Khronos Group. Vulkan 1.2.199 Specification*

### Full List of Pipeline Stages:

[VkPipelineStageFlagBits2KHR](#)

*The Khronos Group. Vulkan 1.2.199 Specification*



## The Stages of...

### Graphics Pipelines:

CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
INDEX\_INPUT(KHR)  
VERTEX\_ATTRIBUTE\_INPUT(KHR)  
VERTEX\_SHADER  
TESSELLATION\_CONTROL\_SHADER  
TESSELLATION\_EVALUATION\_SHADER  
GEOMETRY\_SHADER  
TRANSFORM\_FEEDBACK(EXT)  
FRAGMENT\_SHADING\_RATE(KHR)  
EARLY\_FRAGMENT\_TESTS  
FRAGMENT\_SHADER  
LATE\_FRAGMENT\_TESTS  
COLOR\_ATTACHMENT\_OUTPUT

### Compute Pipelines:

CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
COMPUTE\_SHADER

### Ray Tracing Pipelines:

DRAW\_INDIRECT  
RAY\_TRACING\_SHADER(KHR)

### Ray-Tracing Acceleration

### Structure Build Commands:

ACCELERATION\_STRUCTURE\_BUILD(KHR)

### Full List of Pipeline Stages:

[VkPipelineStageFlagBits2KHR](#)

*The Khronos Group. Vulkan 1.2.199 Specification*

### Copy Commands:

COPY

### Blit Commands:

BLIT

### Resolve Commands:

RESOLVE

### Clear Commands:

CLEAR

### None/Aggregate Stages:

NONE

ALL\_GRAPHICS

ALL\_COMMANDS

ALL\_TRANSFER





## The Stages of...

### Graphics Pipelines:

CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT

INDEX\_INPUT(KHR)

VERTEX\_ATTRIBUTE\_INPUT(KHR)

VERTEX\_SHADER

TESSELLATION\_CONTROL\_SHADER

TESSELLATION\_EVALUATION\_SHADER

GEOMETRY\_SHADER

TRANSFORM\_FEEDBACK(EXT)

FRAGMENT\_SHADING\_RATE(KHR)

EARLY\_FRAGMENT\_TESTS

FRAGMENT\_SHADER

LATE\_FRAGMENT\_TESTS

COLOR\_ATTACHMENT\_OUTPUT

### Compute Pipelines:

CONDITIONAL\_RENDERING(EXT)

DRAW\_INDIRECT

COMPUTE\_SHADER

### Ray Tracing Pipelines:

DRAW\_INDIRECT

RAY\_TRACING\_SHADER(KHR)

### Ray-Tracing Acceleration

### Structure Build Commands:

ACCELERATION\_STRUCTURE\_BUILD(KHR)

### Full List of Pipeline Stages:

[VkPipelineStageFlagBits2KHR](#)

*The Khronos Group. Vulkan 1.2.199 Specification*

### Copy Commands:

COPY

### Blit Commands:

BLIT

### Resolve Commands:

RESOLVE

### Clear Commands:

CLEAR

### None/Aggregate Stages:

NONE

ALL\_GRAPHICS

ALL\_COMMANDS

ALL\_TRANSFER



# Graphics Mesh Pipelines

## The Stages of...

### Graphics Mesh Pipelines:

CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT

TASK\_SHADER

MESH\_SHADER

FRAGMENT\_SHADING\_RATE(KHR)  
EARLY\_FRAGMENT\_TESTS  
FRAGMENT\_SHADER  
LATE\_FRAGMENT\_TESTS  
COLOR\_ATTACHMENT\_OUTPUT

### Compute Pipelines:

CONDITIONAL\_RENDERING(EXT)  
DRAW\_INDIRECT  
COMPUTE\_SHADER

### Ray Tracing Pipelines:

DRAW\_INDIRECT  
RAY\_TRACING\_SHADER(KHR)

### Ray-Tracing Acceleration Structure Build Commands:

ACCELERATION\_STRUCTURE\_BUILD(KHR)

### Full List of Pipeline Stages:

[VkPipelineStageFlagBits2KHR](#)

*The Khronos Group. Vulkan 1.2.199 Specification*

### Copy Commands:

COPY

### Blit Commands:

BLIT

### Resolve Commands:

RESOLVE

### Clear Commands:

CLEAR

### None/Aggregate Stages:

NONE  
ALL\_GRAPHICS  
ALL\_COMMANDS  
ALL\_TRANSFER





# Introduction to Computer Graphics

186.832, 2021W, 3.0 ECTS

**Thank you for your attention!**

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