Arm GPU Errata for Application Developers

Software Developer Errata Notice

Date of issue: July 04, 2025

Non-Confidential

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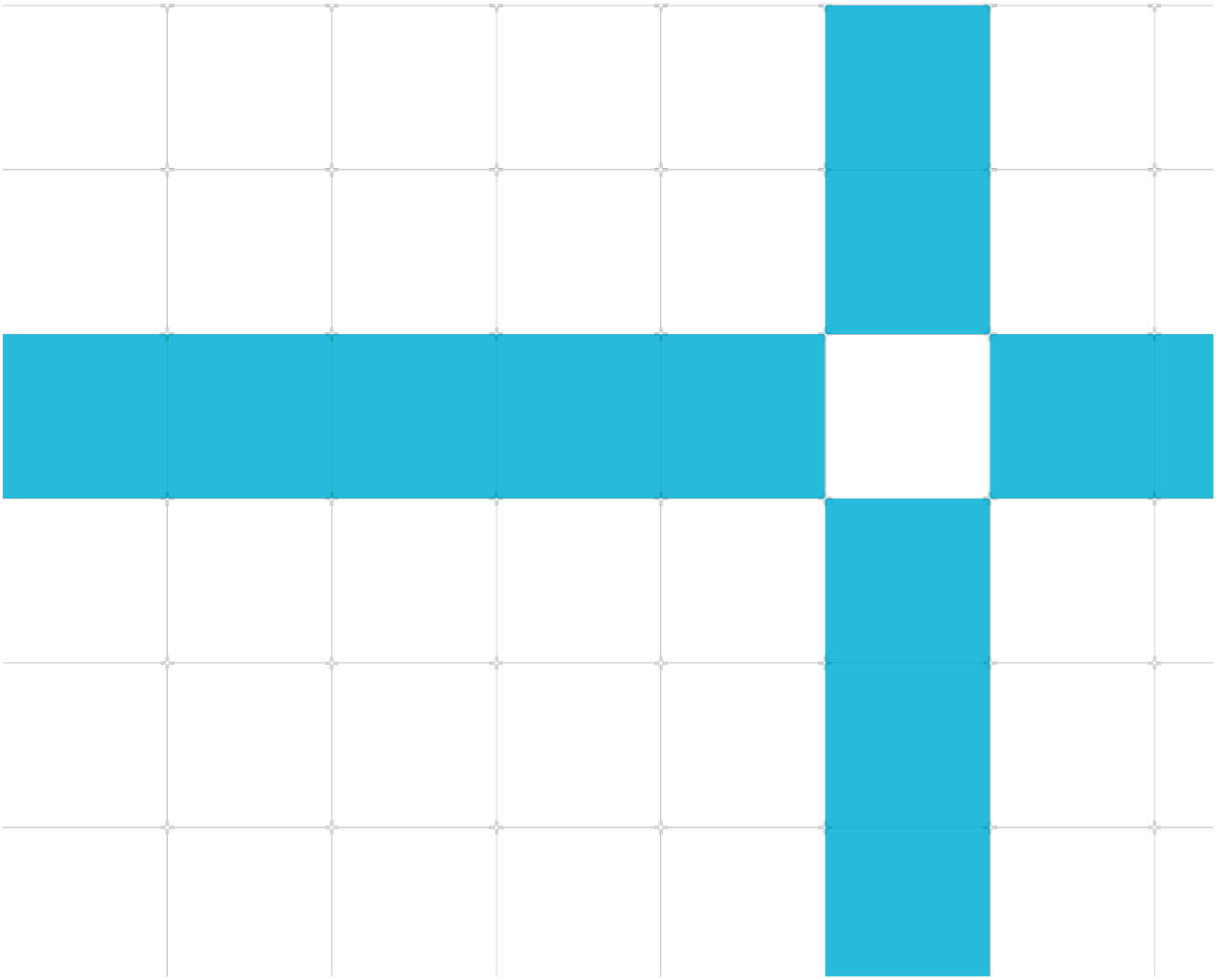
This document contains all known errata since the r38p0 release of the product.



This document (SDEN_3735689_4.0_en) was issued on July 04, 2025.

There might be a later issue at **http://developer.arm.com/documentation/SDEN-3735689**

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To provide feedback on the document, fill the following survey:
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Contents

Product version scope

This document covers Arm GPU and driver errata that have API-visible impact on application software.

To be included in this document an erratum must meet the following criteria:

- Must impact Arm GPU hardware from the Mali-G710 series onwards.
- Must impact Arm GPU drivers from the r38p0 release onwards.
- Must have been encountered by an application developer on a shipping device.

Driver version information

The latest Arm DDK driver release version at the time this document was generated was r54p1.

The impacted driver versions listed for each erratum are based on the version of the original Arm DDK release made by Arm. Older drivers released in OEM devices may include backported fixes from a later Arm DDK release, and therefore not be impacted by an issue listed here.

Application-visible errata caused by hardware issues that are independent of driver version will not document an impacted driver version.

Hardware version information

Arm GPUs are released as sets of products based on the same microarchitecture. Errata will list the GPU series, instead of individual products, if the whole series is impacted.

Product series	Products
Mali-G710 series	Mali-G710, Mali-G610, Mali-G510, Mali-G310
Immortalis-G715 series	Immortalis-G715, Mali-G715, Mali-G615
Immortalis-G720 series	Immortalis-G720, Mali-G720, Mali-G620
Immortalis-G925 series	Immortalis-G925, Mali-G725, Mali-G625

Application-visible errata that are independent of the hardware product will not document an impacted hardware version.

Introduction

Scope

This document describes errata categorized by level of severity. Each description includes:

- The current status of the erratum.
- Where the implementation deviates from the specification and the conditions required for erroneous behavior to occur.
- The implications of the erratum with respect to typical applications.
- The application and limitations of a workaround where possible.

Categorization of errata

Errata are split into three levels of severity and further qualified as common or rare:

Category A	A critical error. No workaround is available or workarounds are impactful. The error is likely to be common for many systems and applications.
Category A (Rare)	A critical error. No workaround is available or workarounds are impactful. The error is likely to be rare for most systems and applications. Rare is determined by analysis, verification and usage.
Category B	A significant error or a critical error with an acceptable workaround. The error is likely to be common for many systems and applications.
Category B (Rare)	A significant error or a critical error with an acceptable workaround. The error is likely to be rare for most systems and applications. Rare is determined by analysis, verification and usage.
Category C	A minor error.

Change Control

Errata are listed in this section if they are new to the document, or marked as "updated" if there has been any change to the erratum text. Fixed errata are not shown as updated unless the erratum text has changed. The **errata summary table** identifies errata that have been fixed in each product revision.

July 04, 2025: Changes in document version v4.0

ID	Status	Area	Category	Summary
3893908	Updated	Programmer	Category B	Declaring NxM matrices as row_major reports incorrect buffer size
3895259	New	Programmer	Category B	Enabling inherited occlusion queries with no active query in the primary command buffer causes DEVICE_LOST
4021056	New	Programmer	Category B	Incorrect rendering when using a separate stencil layout for a depth-stencil attachment
4021113	New	Programmer	Category B	Shader compiler reassociation ignores wrapping behavior of integer types
4065742	New	Programmer	Category C	GPU Active performance counter may overcount

March 06, 2025: Changes in document version v3.0

ID	Status	Area	Category	Summary
3922301	New	Programmer	Category B	ASTC decompression incorrectly rounds linear color endpoints when using unorm8 decode mode

February 07, 2025: Changes in document version v2.0

ID	Status	Area	Category	Summary
3786926	Updated	Programmer	Category B	vkCmdBeginRendering() causes rendering artifacts or DEVICE_LOST
3809538	New	Programmer	Category B	Dynamic render state incorrectly inherited on pipeline change
3809543	New	Programmer	Category B	Vulkan pipeline caches incorrectly accessed when created with external synchronization
3809544	New	Programmer	Category B	OpenGL ES shaders incorrectly use buffer instance name to define bind location
3809560	New	Programmer	Category B	OpenGL ES surface reads have missing dependency on earlier MSAA surface writes
3809773	New	Programmer	Category B	OpenGL ES deadlocks when deleting resources when many compute dispatches are outstanding
3809774	New	Programmer	Category B	Incorrect rendering when dynamic state disables depth/stencil write if shader reads depth/stencil
3817626	New	Programmer	Category B	Shader constant folding treats unsigned integer values as signed
3843108	New	Programmer	Category B	Atomic access coordinates for images and texture buffers always truncated to 16-bits
3843237	New	Programmer	Category B	Vector bitwise of swizzle/combine returns incorrect result
3893903	New	Programmer	Category B	Dynamic render state incorrectly used when modified between two binds of a static pipeline
3893905	New	Programmer	Category B	Dynamic render state incorrectly inherited on pipeline change (2)
3893908	New	Programmer	Category B	Declaring NxM matrices as row_major reports incorrect buffer size
3893910	New	Programmer	Category B	Declaring matrices in struct or array as row_major reports incorrect buffer size
3893911	New	Programmer	Category B	vkQueuePresentKHR() can hang if no vkQueueSubmit() calls were made
3785718	Updated	Programmer	Category B	Pipeline barriers are not transitive when intermediate stage is HOST
3786517	Updated	Programmer	Category B	vkCmdSetCullMode() incorrectly culls non-triangle topologies
3817843	New	Programmer	Category C	Vulkan VK_ARM_scheduling_controls feature query always reports false

November 14, 2024: Changes in document version v1.0

ID	Status	Area	Category	Summary
3787671	New	Programmer	Category A (rare)	Shader scalar integer right shifts return an incorrect result
3734951	New	Programmer	Category B	Freeing command buffers without explicit release causes memory leaks
3786926	New	Programmer	Category B	vkCmdBeginRendering() causes rendering artifacts or DEVICE_LOST
3787459	New	Programmer	Category B	Incorrect rendering when input gl_Position is declared outside of an input block
3787677	New	Programmer	Category B	Render pass loadOp will return black for 3D images that are 32x32x1 or smaller
3779191	New	Programmer	Category B	Read-only storage buffer accesses in inactive control flow are speculatively executed
3779215	New	Programmer	Category B	Shader clamp of conditional values with a zero limit produces incorrect code
3781413	New	Programmer	Category B	Rendering large amounts of geometry causes rendering artifacts or DEVICE_LOST
3781554	New	Programmer	Category B	Unreferenced vertex indices are speculatively shaded
3785718	New	Programmer	Category B	Pipeline barriers are not transitive when intermediate stage is HOST
3786496	New	Programmer	Category B	vkCmdBindVertexBuffers2() updates dynamic strides for an incorrect binding
3786517	New	Programmer	Category B	vkCmdSetCullMode() incorrectly culls non-triangle topologies
3786532	New	Programmer	Category B	Freeing simultaneous use command buffers causes memory corruption

Errata summary table

The errata associated with this product affect the product versions described in the following table.

ID	Area	Category	Summary	Found in versions	Fixed in version
3787671	Programmer	Category A (rare)	Shader scalar integer right shifts return an incorrect result	r42p0 - r47p0	r48p0
3734951	Programmer	Category B	Freeing command buffers without explicit release causes memory leaks	r48p0, r49p0	r49p1, r50p0
3779191	Programmer	Category B	Read-only storage buffer accesses in inactive control flow are speculatively executed	r29p0 - ...	Open
3779215	Programmer	Category B	Shader clamp of conditional values with a zero limit produces incorrect code	r38p1 - r49p0, r50p0 - r51p0	r49p1, r52p0
3781413	Programmer	Category B	Rendering large amounts of geometry causes rendering artifacts or DEVICE_LOST	r0p0 - ...	Open
3781554	Programmer	Category B	Unreferenced vertex indices are speculatively shaded	r0p0 - ...	Open
3785718	Programmer	Category B	Pipeline barriers are not transitive when intermediate stage is HOST	r41p0 - r49p0, r50p0 - r51p0	r49p1, r52p0
3786496	Programmer	Category B	vkCmdBindVertexBuffers2() updates dynamic strides for an incorrect binding	r42p0 - r47p0	r48p0
3786517	Programmer	Category B	vkCmdSetCullMode() incorrectly culls non-triangle topologies	r41p0 - r49p2, r50p0 - r51p0	r49p3, r52p0
3786532	Programmer	Category B	Freeing simultaneous use command buffers causes memory corruption	r46p0 - r49p0, r50p0	r49p1, r51p0
3786926	Programmer	Category B	vkCmdBeginRendering() causes rendering artifacts or DEVICE_LOST	r49p1 - r49p2, r50p0 - r51p0	r49p3, r52p0
3787459	Programmer	Category B	Incorrect rendering when input gl_Position is declared outside of an input block	r19p0 - r46p0	r47p0
3787677	Programmer	Category B	Render pass loadOp will return black for 3D images that are 32x32x1 or smaller	r29p0 - r38p1	r39p0
3809538	Programmer	Category B	Dynamic render state incorrectly inherited on pipeline change	r38p0 - r44p0	r44p1
3809543	Programmer	Category B	Vulkan pipeline caches incorrectly accessed when created with external synchronization	r43p0 - r45p0	r46p0

ID	Area	Category	Summary	Found in versions	Fixed in version
3809544	Programmer	Category B	OpenGL ES shaders incorrectly use buffer instance name to define bind location	r43p0 - r46p0	r47p0
3809560	Programmer	Category B	OpenGL ES surface reads have missing dependency on earlier MSAA surface writes	r44p0 - r45p0	r46p0
3809773	Programmer	Category B	OpenGL ES deadlocks when deleting resources when many compute dispatches are outstanding	r42p0 - r47p0	r48p0
3809774	Programmer	Category B	Incorrect rendering when dynamic state disables depth/stencil write if shader reads depth/stencil	r37p0 - r44p0	r44p1
3817626	Programmer	Category B	Shader constant folding treats unsigned integer values as signed	r0p0 - ...	Open
3843108	Programmer	Category B	Atomic access coordinates for images and texture buffers always truncated to 16-bits	r18p0 - r53p0	r54p0
3843237	Programmer	Category B	Vector bitwise of swizzle/combine returns incorrect result	r18p0 - r53p0	r54p0
3893903	Programmer	Category B	Dynamic render state incorrectly used when modified between two binds of a static pipeline	r48p0 - r53p0	r54p0
3893905	Programmer	Category B	Dynamic render state incorrectly inherited on pipeline change (2)	r48p0 - r53p0	r54p0
3893908	Programmer	Category B	Declaring NxM matrices as row_major reports incorrect buffer size	r18 - ...	Open
3893910	Programmer	Category B	Declaring matrices in struct or array as row_major reports incorrect buffer size	r18p0 - r54p0	r54p1
3893911	Programmer	Category B	vkQueuePresentKHR() can hang if no vkQueueSubmit() calls were made	r37p0 - r42p0, r44p0 - r49p0	r43p0, r49p1
3895259	Programmer	Category B	Enabling inherited occlusion queries with no active query in the primary command buffer causes DEVICE_LOST	r50p0 - ...	Open
3922301	Programmer	Category B	ASTC decompression incorrectly rounds linear color endpoints when using unorm8 decode mode	r0p0 - ...	Open
4021056	Programmer	Category B	Incorrect rendering when using a separate stencil layout for a depth-stencil attachment	r41p0 - r54p0	Open

ID	Area	Category	Summary	Found in versions	Fixed in version
4021113	Programmer	Category B	Shader compiler reassociation ignores wrapping behavior of integer types	r19p0 - r54p0	Open
3817843	Programmer	Category C	Vulkan VK_ARM_scheduling_controls feature query always reports false	r47p0 - r49p2, r50p0 - r52p0	r49p3, r53p0
4065742	Programmer	Category C	GPU Active performance counter may overcount	r0p0 - ...	Open

Errata descriptions

Category A

There are no errata in this category.

Category A (rare)

3787671
Shader scalar integer right shifts return an incorrect result

Status

APIs Affected: OpenGL ES, Vulkan
Impacted driver versions: r42p0 - r47p0
Fixed driver version: r48p0

Description

A shader compiler optimization can result in integer right shifts by a constant returning the wrong value if all of the following conditions are true:

- The shifted value is a scalar, and not a vec2 16-bit pair.
- The right shifted value was multiplied by a literal constant immediately prior to the right shift, including multiplies that are generated to implement a left shift operation.
- The literal constants must be equivalent to the pair of shifts show in the expression below where *const1* shifts more bits than *const0*.

```
(X << const0) >> const1
```

This erratum affects right shifts created explicitly, using the right shift operator, and implicitly, for instance as part of a compiler address generation.

Implications

The result of the right shift operation will be incorrect. If this causes an incorrect address to be calculated, this might result in a Vulkan *DEVICE_LOST* if it causes a memory fault.

Workaround

There is no workaround for this erratum for compiler-generated shifts in addressing logic.

You can avoid the issue for user-generated shifts by sourcing either of the shift constants from a uniform rather than a literal constant.

Using OpenGL ES *GL_EXT_robustness* or Vulkan *robustBufferAccess* can be be used to reduce the number of instances of *DEVICE_LOST* caused by memory faults. However, in these circumstances rendering will still be incorrect as the address accessed inside the buffer will be incorrect.

Category B

3734951
Freeing command buffers without explicit release causes memory leaks

Status

APIs affected: Vulkan
Impacted driver versions: r48p0 - r49p0
Fixed driver versions: r49p1, r50p0

Description

The GPU driver might leak memory when freeing a command buffer after it has been individually reset. The issue is triggered when using the following API usage sequence:

1. Create a command pool using *vkCreateCommandPool()*, with *VK_COMMAND_POOL_CREATE_RESET_COMMAND_BUFFER_BIT* set.
2. Allocate a command buffer from the command pool using *vkAllocateCommandBuffers()*.
3. Record some commands using the command buffer to trigger memory allocation.
4. Reset the command buffer without releasing resources, either by using an implicit reset when calling *vkBeginCommandBuffer()*, or by using *vkResetCommandBuffer()* without *VK_COMMAND_BUFFER_RESET_RELEASE_RESOURCES_BIT* set.
5. Free the command buffer using *vkFreeCommandBuffers()*.

In this scenario, the memory used for command buffer recording will not be freed or reused until the command pool has been reset using *vkResetCommandPool()* with *VK_COMMAND_POOL_RESET_RELEASE_RESOURCES_BIT* set, or destroyed using *vkDestroyCommandPool()*.

Implications

An application will run out of memory when enough memory is leaked.

Workaround

You can explicitly reset all command buffers using *vkResetCommandBuffer()* with *VK_COMMAND_BUFFER_RESET_RELEASE_RESOURCES_BIT* set before freeing them.

Alternatively, you can regularly reset the command pool using *vkResetCommandPool()* with *VK_COMMAND_POOL_RESET_RELEASE_RESOURCES_BIT* set.

3779191
Read-only storage buffer accesses in inactive control flow are speculatively executed

Status

APIs Affected: OpenGL ES, Vulkan
Impacted driver versions: r29p0 onwards
Fixed driver version: No shipping fix

Description

Read-only storage buffer accesses might be speculatively executed, even when located in a code path which is dynamically not taken. For example, in the code below, the *values* array may be accessed even when *index* is greater than *maxIndex*.

```
layout(set = 0, binding = 0) buffer B {
  vec4 values[16];
};

void main()
{
  uint index = ...; // Calculation of accessed index
  uint maxIndex = ...; // Calculation of dynamically last backed index
  if (index <= maxIndex)
  {
    vec4 readValue = values[index];
  }
}
```

Implications

An application might encounter incorrect rendering or Vulkan *DEVICE_LOST* if the speculative access results in a memory fault.

Workaround

You can ensure that the buffer is valid for the full range of potentially speculatively accessed indices. This requires that the buffer descriptor is valid and that it is backed by sufficient memory.

Alternatively, you can use OpenGL ES *GL_EXT_robustness* or Vulkan *robustBufferAccess* to clamp the memory range accessed. However, note that this can reduce shader performance.

3779215
Shader clamp of conditional values with a zero limit produces incorrect code

Status

APIs affected: OpenGL ES, Vulkan, OpenCL
Impacted driver versions: r38p1 - r49p0, r50p0 - r51p0
Fixed driver versions: r49p1, r52p0

Description

When clamping values between two constants the compiler might generate incorrect code if all of the following conditions are true:

- The value being clamped is conditionally chosen from values known at compile-time.
- The value being clamped can be positive or negative depending on the conditional selection.
- The value of one of the clamp limits is known at compile time to be zero.

On impacted drivers the clamp is replaced by a *min()* or *max()*, limiting to only one end of the range, instead of clamping to both ends of the range.

Clamp behavior implemented manually, for example using separate *min()* and *max()* calls, is also impacted by this errata.

The following example can trigger the errata on impacted driver versions:

```
vec2 data[4] = vec2[](vec2(-1.0, -1.0), vec2(-1.0, 3.0), vec2(3.0, -1.0), vec2(3.0, -1.0));
vec2 pos_xy = data[min(gl_VertexIndex, 3)];
vec2 pos_xy_clamp = clamp(pos_xy, vec2(0.0, 0.0), vec2(1.0, 1.0));
```

Implications

The miscalculated data value can cause undefined behavior in the impacted shader program.

Workaround

You can use a uniform buffer to provide the constant inputs, so that they are no longer compile-time known constants. For example:

```
uniform vec2 data[4];
vec2 pos_xy = data[min(gl_VertexIndex, 3)];
vec2 pos_xy_clamp = clamp(pos_xy, vec2(0.0, 0.0), vec2(1.0, 1.0));
```

Alternatively, you can add a uniform-sourced zero to each constant before using it, so that the input in to the clamp is no longer a compile-time known constants. This can have more performance overhead than directly sourcing the data from a uniform buffer.

3781413
Rendering large amounts of geometry causes rendering artifacts or DEVICE_LOST

Status

APIs Affected: OpenGL ES, Vulkan
Impacted hardware: All Arm GPUs
Fixed hardware: No shipping fix, but less likely on recent products

Description

Arm GPUs store intermediate outputs from vertex, tessellation, and geometry pipeline stages to an implementation-owned memory pool in system memory. When the intermediate memory pool is exhausted the application might experience missing geometry or a Vulkan *DEVICE_LOST* error.

The memory allocation strategy and storage requirements have been improved in recent generations of Arm hardware, making it much harder to hit the out-of-memory condition. The sections below describe the behavior in each generation. In these sections, "Advanced geometry" includes draw calls using transform feedback, tessellation shaders, and geometry shaders.

Arm GPUs implementing the Midgard or Bifrost architectures

This generation of hardware defaults to a 180MB memory pool per render pass that is used for intermediate memory allocations.

For all draw calls, memory is allocated to store the output data of all pipeline stages, for all vertices in the min-to-max range of spanned indices. This includes storage for indices between the min and max that are not referenced, and storage for indices that contribute only to culled primitives.

Note: The 180MB limit is the Arm default, but we are aware of some entry-level devices where the limit has been lowered by device manufacturers.

Arm GPUs implementing the Valhall architecture

This generation of hardware defaults to a 180MB memory pool per render pass that is used for intermediate memory allocations.

For draw calls that are not using Advanced geometry, memory is allocated to store output data of the vertex shader for all vertices that are used by visible primitives.

For all draw calls that are using Advanced geometry, memory is still allocated to store the output data of all pipeline stages, for all vertices in the min-to-max range of spanned indices.

Note: The 180MB limit is the Arm default, but we are aware of some entry-level devices where the limit has been lowered by device manufacturers.

Arm GPUs implementing the 5th Generation architecture

This generation of hardware uses a larger memory pool that can be dynamically shared by multiple render passes, so there is no longer a clearly defined limit.

For draw calls that are not using Advanced geometry, this generation of hardware uses Deferred Vertex Shading (DVS). When using DVS, the upfront processing only stores primitive binning metadata information to the intermediate pool. Vertex shader data outputs are no longer stored, and are recomputed during the main phase that runs the full vertex shader and fragment shading per tile.

For all draw calls that are using Advanced geometry, memory is still allocated to store the output data of all pipeline stages, for all vertices in the min-to-max range of spanned indices.

Implications

Exhausting the intermediate memory pool can result in rendering corruption or Vulkan *DEVICE_LOST* errors.

Workaround

There is no complete workaround, but limits are very hard to hit if you follow the Arm best practice advice:

- You should ensure that all indices between a draw call's min and max index are actually used in the index buffer.
- You should avoid encoding metadata in the index value high bits, even if masking the value when loading data from buffers, because it can increase the spanned index range.
- You should avoid using shader pipelines that require the Advanced geometry path in the implementation.
- You should avoid using very dense geometry meshes.
- You should minimize the per-vertex storage requirements by reducing the number and data precision of vertex attributes.

3781554
Unreferenced vertex indices are speculatively shaded

Status

APIs Affected: OpenGL ES, Vulkan
Impacted hardware: All Arm GPUs
Fixed hardware: Partial fix in Immortalis-G925 series

Description

Most Arm GPUs process vertices in groups of 4 sequential index locations, naturally aligned on multiple of four index boundary. Vertex indices which are not referenced by an index buffer may be speculatively shaded if they are located in a group of 4 indices where at least one of the other indices is referenced.

For example, a draw call using the index buffer [1, 2, 3, 2, 9, 3] will shade 8 vertices in two groups of 4, group 0-3 and group 8-11.

Starting from the Immortalis-G925 series, Arm GPUs will no longer speculatively shade vertices when performing a standard draw call. Pipelines using the advanced geometry implementation may still make speculative accesses. Advanced geometry includes draw calls using transform feedback, tessellation shaders, and geometry shaders.

Implications

An application might encounter incorrect rendering or Vulkan *DEVICE_LOST* if the speculative execution results in a memory fault on an indirect data load. Direct vertex attribute loads will not generate faults.

Workaround

You can avoid speculative accesses causing data faults by ensuring that buffer data is valid for all vertices in each referenced group of four indices, padding the start and end of the buffer if required.

Alternatively, you can use OpenGL ES *GL_EXT_robustness* or Vulkan *robustBufferAccess* to clamp the memory access to valid buffer extents. However, note that this can reduce shader performance.

3785718
Pipeline barriers are not transitive when intermediate stage is HOST

Status

APIs Affected: Vulkan
Impacted driver versions: r41p0 - r49p0, r50p0 - r51p0
Fixed driver version: r49p1, r52p0

Description

Vulkan pipeline barriers define an execution dependency chain. A pipeline barrier can depend on source stages inferred by a transitive dependency on an earlier pipeline barrier, even if it does not explicitly list those stages in its own *srcStageMask*.

For example, in the code sequence below the second dispatch has a dependency on first due to the two pipeline barriers having a transitive dependency caused by the use of the *HOST* stage. The second *vkCmdDispatch()* must wait for the first to complete before it can start processing.

```
vkCmdDispatch(1)
vkCmdPipelineBarrier(srcStageMask=COMPUTE, dstStageMask=HOST)
vkCmdPipelineBarrier(srcStageMask=HOST, dstStageMask=COMPUTE)
vkCmdDispatch(2)
```

For the impacted driver versions, hardware stage dependencies inferred by a transitive dependency on the HOST stage are ignored. In the example above, this means that there is no enforced wait between the two compute dispatches, and they could incorrectly run out of order.

Implications

Loss of synchronization can cause incorrect rendering or Vulkan *DEVICE_LOST* if a memory access results in a memory fault.

Workaround

Avoid transitive *HOST* dependencies by using a *srcStageMask* that explicitly lists the hardware stages that you depend on, copying the *srcStageMask* of the first pipeline barrier into the *srcStageMask* of the second.

3786496
vkCmdBindVertexBuffers2() updates stride for an incorrect binding

Status

APIs Affected: Vulkan
Impacted driver versions: r42p0 - r47p0
Fixed driver version: r48p0

Description

When using *vkCmdBindVertexBuffers2()*, a dynamic stride is applied to the incorrect binding when the index of the binding in the *VkPipelineVertexInputStateCreateInfo::pVertexBindingDescriptions* array does not match the value of the binding location in the corresponding *VkVertexInputBindingDescription*.

For example:

```
VkVertexInputBindingDescription binding_desc[2] = {};
binding_desc[0].binding = 0;
binding_desc[1].binding = 2;
...

VkDeviceSize strides[3] = { stride0, stride1, stride2 };
vkCmdBindVertexBuffers2EXT(cmd_buf, 0, 3, buffers, offsets, nullptr, strides);
```

In this example, the erratum will mean that *stride1* is used for the binding with index 2, instead of the expected *stride2*.

This erratum also impacts *vkCmdBindVertexBuffers2EXT()*.

Implications

When an incorrect stride is used, an incorrect image may be rendered, or a *DEVICE_LOST* might occur if incorrect data causes a memory access fault.

Workaround

You can add dummy entries to the *VkPipelineVertexInputStateCreateInfo pVertexBindingDescriptions* array to ensure that the array index matches the binding index.

Alternatively, you can use static vertex buffer strides.

3786517
vkCmdSetCullMode() incorrectly culls non-triangle topologies

Status

APIs Affected: Vulkan
Impacted driver versions: r41p0 - r49p2, r50p0 - r51p0
Fixed driver versions: r49p3, r52p0

Description

When using *vkCmdSetCullMode()*, the dynamic cull mode will be incorrectly applied to non-triangle topologies. This can result in primitives being incorrectly culled when they should be visible.

This erratum also impacts *vkCmdSetCullModeEXT()*.

Implications

An incorrect image that is missing geometry may be rendered.

Workaround

You can use a static cull mode for pipelines rendering non-triangle topologies.

3786532
Freeing simultaneous use command buffers causes memory corruption

Status

APIs Affected: Vulkan
Impacted driver versions: r46p0 - r49p0, r50p0
Fixed driver versions: r49p1, r51p0

Description

Freeing backing memory for command buffers allocated with the *VK_COMMAND_BUFFER_USAGE_SIMULTANEOUS_USE_BIT* might cause memory corruption.

Memory is freed when using any of the following API calls:

- *vkResetCommandBuffer()* with *VK_COMMAND_BUFFER_RESET_RELEASE_RESOURCES_BIT* set.
- *vkFreeCommandBuffers()*.
- *vkResetCommandPool()* with *VK_COMMAND_POOL_RESET_RELEASE_RESOURCES_BIT* set.
- *vkDestroyCommandPool()*.

Implications

The graphics driver may crash or behave unpredictably.

Workaround

You can switch to single-use command buffers, allocating command buffers without the *VK_COMMAND_BUFFER_USAGE_SIMULTANEOUS_USE_BIT* set.

3786926
vkCmdBeginRendering() causes rendering artifacts or DEVICE_LOST

Status

APIs Affected: Vulkan
Impacted driver versions: r49p1 - r49p2, r50p0 - r51p0
Fixed driver versions: r49p3, r52p0

Description

When using *vkCmdBeginRendering()* the driver will reuse internal resources based on the state values passed via the *VkRenderingInfo* structure. Incorrect state hashing can cause the driver to use stale internal data.

This erratum also impacts *vkCmdBeginRenderingKHR()*.

Implications

This erratum may cause rendering artifacts or *DEVICE_LOST* during execution of the render pass.

Workaround

You can avoid this issue by using static render passes started with *vkCmdBeginRenderPass()*.

Alternatively, you can avoid state hash collisions by not deleting any *VkImageView* handle that is referred to by a *VkRenderingInfo* structure or its children.

3787459
Incorrect rendering when input gl_Position is declared outside of an input block

Status

APIs Affected: Vulkan
Impacted driver versions: r19p0 - r46p0
Fixed driver version: r47p0

Description

Vulkan allows input built-in variables to be specified either as a variable, or as a member of a built-in block. This built-in block is known as the *gl_PerVertex* block in GLSL. When an incoming *gl_Position* is declared as a normal variable, outside of the *gl_PerVertex* block, the position value used might be incorrect.

Vertex position inputs impact tessellation control, tessellation evaluation and geometry shaders. It is known that HLSL shaders compiled with DXC can trigger this pattern.

Implications

This erratum may cause rendering artifacts due to incorrect vertex positions being used.

Workaround

You can change the affected SPIR-V program to declare *gl_Position* inside of a built-in block.

Alternatively, it is possible that a different high-level language to SPIR-V compiler does not emit *gl_Position* as a variable outside of a built-in block.

3787677
Render pass loadOp will return black for 3D images that are 32x32x1 or smaller

Status

APIs Affected: Vulkan
Impacted driver versions: r29p0 - r38p1
Fixed driver version: r39p0

Description

Vulkan render pass attachment *loadOp* will fail to load attached image slices from a 3D image if the image is less than or equal to 32x32x1 in all three dimensions. When this erratum is encountered, the *loadOp* will return black values for the impacted attachments.

Implications

The failing *loadOp* might result in incorrect rendering.

Workaround

You can workaround this issue by adding an dummy Z plane to the impacted images, increasing the Z dimension to 2.

Alternatively, you can insert a manual readback at the start of the render pass using a draw call containing a textured quad to write the data into the framebuffer.

3809538
Dynamic render state incorrectly inherited on pipeline change

Status

APIs Affected: Vulkan
Impacted driver versions: r38p0 - r44p0
Fixed driver version: r44p1

Description

Draw calls using Vulkan pipelines with dynamic render states will not use the correct dynamic value when changing pipeline if the draw immediately before the pipeline change also used the same state dynamically. For example, in the following scenario:

1. Bind Pipeline1
2. Set dynamic state
3. Draw
4. Bind Pipeline2
5. Draw

... where *Pipeline1* and *Pipeline2* are both pipelines using one of the impacted dynamic states, the second draw will not use the dynamically set render state value.

This erratum impacts the following dynamic states:

- *VK_DYNAMIC_STATE_DEPTH_TEST_ENABLE*
- *VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE*
- *VK_DYNAMIC_STATE_DEPTH_COMPARE_OP*
- *VK_DYNAMIC_STATE_STENCIL_TEST_ENABLE*
- *VK_DYNAMIC_STATE_STENCIL_OP*
- *VK_DYNAMIC_STATE_STENCIL_WRITE_MASK*
- *VK_DYNAMIC_STATE_CULL_MODE*
- *VK_DYNAMIC_STATE_VERTEX_INPUT_BINDING_STRIDE*

Implications

The application might encounter incorrect rendering.

Workaround

You can reset the value of all impacted dynamic states after binding a new pipeline.

Alternatively, you can use static pipeline render state.

3809543
Vulkan pipeline caches incorrectly accessed when created with external synchronization

Status

APIs Affected: Vulkan
Impacted driver versions: r43p0 - r45p0
Fixed driver version: r46p0

Description

When creating a Vulkan pipeline cache using the *VK_PIPELINE_CACHE_CREATE_EXTERNALLY_SYNCHRONIZED_BIT*, memory corruption or a driver crash may be encountered due to the driver failing to synchronize a concurrent access made by driver-owned threads.

This erratum also impacts *VK_PIPELINE_CACHE_CREATE_EXTERNALLY_SYNCHRONIZED_BIT_EXT*.

Implications

An application might encounter incorrect rendering due to memory corruption, or software instability.

Workaround

You can create Vulkan pipeline caches without setting *VK_PIPELINE_CACHE_CREATE_EXTERNALLY_SYNCHRONIZED_BIT*.

3809544
OpenGL ES shaders incorrectly use buffer instance name to define bind location

Status

APIs Affected: OpenGL ES
Impacted driver versions: r43p0 - r46p0
Fixed driver version: r47p0

Description

For a buffer interface block defined as:

```
storage_qualifier block_name
{
    ....
} instance_name;
```

... the compiler buffer address binding logic incorrectly uses the interface *instance_name*, instead of the *block_name*, to define the internal binding location used. This might cause an incorrect binding to be accessed if the same buffer is used in multiple shader stages in a program and these stages use more than one *instance_name* to refer to it.

Implications

An application might encounter incorrect rendering or a context lost error.

Workaround

You can use the same *instance_name* for buffers that are shared across multiple shader stages.

Alternatively, you can avoid specifying an *instance_name* and use only the *block_name* in your shaders.

3809560
OpenGL ES surface reads have missing dependency on earlier MSAA surface writes

Status

APIs Affected: OpenGL ES
Impacted driver versions: r44p0 - r45p0
Fixed driver version: r46p0

Description

Multisampled OpenGL ES framebuffer attachments can be implicitly resolved to a single sample at the end of a render pass when the framebuffer is written to memory, avoiding the need to resolve manually using a separate *glBlitFramebuffer()* call. This is the default behavior for multisampled EGL window surfaces, and can be enabled for offscreen rendering by using the *GL_EXT_multisampled_render_to_texture* extension.

During multisampled rendering with an implicit resolve, the GPU will use two logical surfaces for each attachment point:

- a multisampled surface that stores all samples per pixel,
- and a resolve surface that stores a single sample per pixel.

When the multisampled surface is implicitly invalidated at the end of a render pass, in situations where it does not need to be persisted, the driver incorrectly also clears scheduling dependencies on its sibling resolve surface. This can result in later readers of the resolve surface reading from it before it has been written, causing incorrect values to be read by the GPU or the system display controller.

Implications

An application might encounter incorrect rendering or screen corruption.

Workaround

To avoid screen corruption, you can render to single-sampled EGL window surface configurations.

To avoid off-screen rendering synchronization issues, you can render to single-sampled OpenGL ES textures or render buffers.

3809773
OpenGL ES deadlocks when deleting resources when many compute dispatches are outstanding

Status

APIs Affected: OpenGL ES
Impacted driver versions: r42p0 - r47p0
Fixed driver version: r48p0

Description

The OpenGL ES driver might deadlock when the application calls *glDeleteBuffers()* or *glDeleteTextures()* while the driver's internal compute dispatch task queue is full.

Implications

The application will hang.

Workaround

You can avoid the deadlock by ensuring that all compute workloads are complete before deleting a texture or a buffer.

3809774
Incorrect rendering when dynamic state disables depth/stencil write if shader reads depth/stencil

Status

APIs Affected: Vulkan
Impacted driver versions: r37p0 - r44p0
Fixed driver version: r44p1

Description

The driver will not correctly use dynamically set states that disable depth or stencil writes if the fragment shader reads depth or stencil values from the input attachment.

This erratum impacts the following dynamic states:

- *VK_DYNAMIC_STATE_DEPTH_WRITE_ENABLE*
- *VK_DYNAMIC_STATE_STENCIL_WRITE_MASK*

Implications

The application might encounter incorrect rendering.

Workaround

You can use static pipeline state to control depth and stencil writes.

3817626
Shader constant folding treats unsigned integer values as signed

Status

APIs Affected: OpenGL ES
Impacted driver versions: r0p0 - ...
Fixed driver version: No shipping fix.

Description

A shader compiler optimization that evaluates constants for constant folding can treat unsigned integer values as signed values, which changes the semantics of the operation and can result in an incorrectly optimized value being used. This erratum impacts literal constant values, and literal constants assigned to a *const* local variable.

Implications

The result of unsigned integer constant folding might be incorrect. If this causes an incorrect address to be calculated, this might result in context loss if it causes a memory fault.

Workaround

You can avoid this erratum by assigning impacted constants values to a non-const local variable, and using this variable in any subsequent computations in place of the literal value.

Using OpenGL ES *GL_EXT_robustness* can be be used to reduce the number of instances of context loss caused by memory faults. However, in these circumstances rendering will still be incorrect as the address accessed inside the buffer will be incorrect.

3843108
Atomic access coordinates for images and texture buffers always truncated to 16-bits

Status

APIs Affected: OpenGL ES, Vulkan
Impacted driver versions: r18p0 - r53p0
Fixed driver version: r54p0

Description

The compiler incorrectly truncates 32-bit coordinates used to make atomic accesses to images and texture buffers to 16 bits.

Implications

Atomics access coordinates will wrap and only use the bottom 16 bits of each coordinate, so incorrect data values will be returned for texel indices above 65535.

Workaround

You can avoid the issue by manually wrapping texel coordinates at 16-bit boundaries.

For image access, you can often implement wrapping in a single axis by making use of the 2D coordinate space available. For example, an image using 1M x 1 resolution can be converted into a 2D image using 64K x 16 resolution.

For texel buffers, which are fixed to use a single coordinate, the resource must be either split across multiple texel buffer bindings or converted to a 2D image.

3843237
Vector bitwise of swizzle/combine returns incorrect result

Status

APIs Affected: OpenGL ES, Vulkan
Impacted driver versions: r18p0 - r53p0
Fixed driver version: r54p0

Description

During compilation the shader compiler can apply an incorrect code transform to vector operations that combine an integer bitwise operator with an implicit or explicit lane swizzle.

Implications

Integer bitwise operators on vector variables can give an incorrect result.

Workaround

You can avoid the issue by manually scalarizing the impacted operations. For example, rewrite this:

```
uvec2 a = uvec2(input1, 2u) | 1u;
```

... as ...

```
uvec2 a = uvec2(input1, 2u);
a.y |= 1u;
```

3893903
Dynamic render state incorrectly used when modified between two binds of a static pipeline

Status

APIs Affected: Vulkan
Impacted driver versions: r48p0 - r53p0
Fixed driver version: r54p0

Description

Draw calls using a Vulkan pipeline with a static render state may incorrectly use a dynamically set state value when the dynamic state is modified between two binds of the same pipeline. For example, in the following scenario:

1. Bind pipeline1 using a static state
2. Set the equivalent dynamic state
3. Rebind pipeline1
4. Draw

This erratum impacts the following dynamic states:

- *VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT*
- *VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT*
- *VK_DYNAMIC_STATE_SAMPLE_MASK_EXT*

Implications

The application might encounter incorrect rendering.

Workaround

You can set the value of the impacted dynamic states to match the required static state in the bound pipeline.

Alternatively, you can avoid using these dynamic render states.

3893905
Dynamic render state incorrectly inherited on pipeline change (2)

Status

APIs Affected: Vulkan
Impacted driver versions: r48p0 - r53p0
Fixed driver version: r54p0

Description

Draw calls using Vulkan pipelines with dynamic render states will not use the correct dynamic value when changing pipeline if the draw immediately before the pipeline change also used the same state dynamically. For example, in the following scenario:

1. Bind Pipeline1
2. Set dynamic state
3. Draw
4. Bind Pipeline2
5. Draw

... where *Pipeline1* and *Pipeline2* are both pipelines using one of the impacted dynamic states, the second draw will not use the correct dynamically set render state value.

This erratum impacts the following dynamic states:

- *VK_DYNAMIC_STATE_CONSERVATIVE_RASTERIZATION_MODE_EXT*
- *VK_DYNAMIC_STATE_LINE_RASTERIZATION_MODE_EXT*

Implications

The application might encounter incorrect rendering.

Workaround

You can reset the value of all impacted dynamic states after binding a new pipeline.

Alternatively, you can use static pipeline render state.

3893908
Declaring NxM matrices as row_major reports incorrect buffer size

Status

APIs Affected: OpenGL ES
Impacted driver versions: r18p0 - ...
Fixed driver version: No shipping fix.

Description

Buffer sizes will be reported incorrectly when specifying *layout(row_major)* on a non-square matrix variable in a buffer.

For example, in the code below, the *GL_UNIFORM_BLOCK_DATA_SIZE* will be reported as 32 bytes when it should be 48.

```
layout(std140) uniform Block {
    layout(row_major) mediump mat2x3 var;
};
```

Implications

The application might encounter incorrect rendering if the application uses the buffer size returned by the query to size the allocated buffer. The actual buffer layout used by the shader compiler is correct, and the shader will function correctly if the allocated buffer size matches the specification requirements.

Workaround

You can specify the layout qualifier on the interface block instead of the member variables. For example:

```
layout(std140, row_major) uniform Block {
    mediump mat2x3 var;
};
```

Alternatively, you can use *layout(column_major)* matrices.

3893910
Declaring matrices in struct or array as row_major reports incorrect buffer size

Status

APIs Affected: OpenGL ES
Impacted driver versions: r18p0 - r54p0
Fixed driver version: r54p1

Description

Buffer sizes will be reported incorrectly when specifying *layout(row_major)* on a variable in a buffer when the member is an array of matrices, or the member is nested inside a structure.

For example, in the code below, the *GL_UNIFORM_BLOCK_DATA_SIZE* will be reported as 96 bytes when it should be 144.

```
layout(std140) uniform Block {
    layout(row_major) highp mat2x3 var[3];
};
```

Implications

The application might encounter incorrect rendering if the application uses the buffer size returned by the query to size the allocated buffer. The actual buffer layout used by the shader compiler is correct, and the shader will function correctly if the allocated buffer size matches the specification requirements.

Workaround

You can specify the layout qualifier on the interface block instead of the member variables. For example:

```
layout(std140, row_major) uniform Block {
    highp mat2x3 var[3];
};
```

Alternatively, you can use *layout(column_major)* matrices.

3893911
vkQueuePresentKHR() can hang if no vkQueueSubmit() calls were made

Status

APIs Affected: Vulkan
Impacted driver versions: r37p0 - r42p0, r44 - r49p0
Fixed driver version: r43p0, r49p1

Description

If an application repeatedly calls *vkQueuePresentKHR()* on a queue without any *vkQueueSubmit()* calls on the same queue, the the application will hang.

Implications

The call to *vkQueuePresentKHR()* will hang.

Workaround

You can change the call to *vkQueuePresentKHR()* to use the queue that is used for rendering workloads and therefore also uses *vkQueueSubmit()* as part of normal operation.

Alternatively, if you have a dedicated present queue, you can add an empty *vkQueueSubmit()* to the queue before calling *vkQueuePresentKHR()*.

3895259
Enabling inherited occlusion queries with no active query in the primary command buffer causes DEVICE_LOST

Status

APIs Affected: Vulkan
Impacted driver versions: r50p0 - ...
Fixed driver version: No shipping fix.

Description

Enabling support for inherited occlusion queries in a secondary command buffer, by setting *VkCommandBufferInheritanceInfo.occlusionQueryEnable* to *VK_TRUE*, can result in a *DEVICE_LOST* error if no occlusion query is active in the primary command buffer when the secondary is executed.

Implications

Enabling inherited queries without an active query in the primary can result in a *DEVICE_LOST* error.

Workaround

You can avoid this erratum by only setting *occlusionQueryEnable* to *VK_TRUE* if there is an active query in the primary command buffer when the secondary is executed. If there is no active query ensure this setting is *VK_FALSE*.

3922301
ASTC decompression incorrectly rounds linear color endpoints when using unorm8 decode mode

Status

APIs Affected: OpenGL ES, Vulkan
Impacted hardware versions: All Arm GPUs.
Fixed hardware version: No shipping fix.

Description

The Khronos Data Format Specification states that non-sRGB color endpoints are expanded to 16-bit values using bit replication.

```
C0 = (C0 << 8) | C0;
C1 = (C1 << 8) | C1;
```

When decompressing a linear texture using the unorm8 decode mode, the impacted hardware incorrectly expands the color endpoint to 16-bits using the sRGB style of endpoint expansion:

```
C0 = (C0 << 8) | 0x80;
C1 = (C1 << 8) | 0x80;
```

Implications

The incorrect endpoint expansion style causes rounding changes during decompression. This results in least-significant bit differences in the decompressed result for some input values.

Workaround

There is no workaround for textures that are compressed offline.

Textures that are compressed at runtime can use a compressor that corrects for the rounding differences caused by the erratum present in the specific platform in use.

4021056
Incorrect rendering when using a separate stencil layout for a depth-stencil attachment

Status

APIs Affected: Vulkan
Impacted driver versions: r41p0 - r54p0
Fixed driver version: r54p1

Description

When using a depth-stencil attachment, the driver will not correctly apply a separate stencil aspect layout set using *VkAttachmentDescriptionStencilLayoutKHR* or *VkAttachmentReferenceStencilLayoutKHR*, and will always use the layout set for the combined depth-stencil image.

This can result in the stencil aspect of a depth-stencil attachment being incorrectly discarded at the end of a render pass if the combined depth-stencil image layout is a *READ_ONLY* layout.

Implications

The application might encounter incorrect rendering.

Workaround

You can set an appropriate combined image layout on the packed depth-stencil image, instead of using the extension functionality to set a separate layout for the stencil aspect of the image.

4021113
Shader compiler reassociation ignores wrapping behavior of integer types

Status

APIs Affected: OpenGL ES, Vulkan
Impacted driver versions: r19p0 - r54p0
Fixed driver version: r54p1

Description

The GLSL and SPIR-V specifications define integer arithmetic as wrapping when a variable overflows, so it is legal for an application to rely on wrapping behavior when performing calculations in a shader program. A shader compiler optimization pass can incorrectly reassociate integer arithmetic operations in a manner which changes the precision of the computation and therefore changes if, and where, wrapping overflow occurs.

The invalid reassociation can be performed if an addition that can wrap has at least one argument that is a value multiplied by a constant. For example:

```
mediump uint y = /* e.g. value of uint(-1) */;
mediump uint z = 5;
int res = (y + z) * 6;  /* Reassociates to (y * 6) + (z * 6) */
```

The invalid reassociation can also be performed for address calculations when an array is accessed with an addition that can wrap and where one argument is a constant. For example:

```
uint x = /* e.g. value of uint(-1) */;
int res = Array[x + 2];
```

The invalid reassociation can also can also be performed when an array is accessed using an index computed using an addition that can wrap and where one argument is an induction variable which becomes constant due to loop unrolling. For example:

```
uint x = /* e.g. value of uint(-1) */;
for (uint i = 1; i < 5; ++i) {
  int res = Array[x + i];
  ...
}
```

The invalid reassociation can also be performed for address calculations when a uniform array is accessed with a 16-bit addition where one argument is a constant. For example:

```
mediump uint y = /* e.g. value of uint(-1) */;
mediump uint z = 5;
int res = UniformArray[y + z];
```

Implications

If the invalid reassociation triggers on numerical calculation, the overflow is removed and incorrect values are used by later calculations.

If the invalid reassociation triggers on an array access without bounds checking, the overflow is removed and the shader can access an incorrect array index. This may return an incorrect in-bounds access, or make an out-of-bounds access triggering a DEVICE_LOST.

If the invalid reassociation triggers on an array access with robust access bounds checking, the overflow is removed and the shader can access an incorrect array index. This may return an incorrect in-bounds access, or make an out-of-bounds access that returns zeros.

Workaround

You can avoid this erratum by not using overflowing integer arithmetic in your shader calculations.

If you must use overflowing arithmetic, you can avoid the issue by using 32-bit data types, removing use of *mediump* or *RelaxedPrecision* integer variables, and using uniform values for integer values instead of literal constants. This workaround is likely to reduce shader performance, especially if use of a uniform loop limit prevents loop unrolling.

Category B (rare)

There are no errata in this category.

Category C

3817843
Vulkan VK_ARM_scheduling_controls feature query always reports false

Status

APIs Affected: Vulkan
Impacted driver versions: r47p0 - r49p2, r50p0 - r52p0
Fixed driver versions: r49p3, r53p0

Description

The *VK_ARM_scheduling_controls* extension feature availability check is incorrectly implemented in *vkGetPhysicalDeviceProperties2()* instead of *vkGetPhysicalDeviceFeatures2()*. When applications use *vkGetPhysicalDeviceFeatures2()* the extension availability is always reported as *VK_FALSE*.

Implications

The application feature query will incorrectly indicate that *VK_ARM_scheduling_controls* is not available. This loss of functionality should have no impact on production applications.

Workaround

If the extension is supported in the list of available extensions you can assume that the feature is available, and attempt to use it. If it is disabled you may not see the shader core scheduling configuration take impact.

Alternatively, on impacted driver versions, you can use the *vkGetPhysicalDeviceProperties2()* function to query extension availability.

4065742
GPU Active performance counter may overcount

Status

APIs Affected: OpenGL ES, Vulkan
Impacted hardware: Immortalis-G715 series
Fixed hardware: Immortalis-G720 series

Description

The *GPU Active* (GPU_ACTIVE) performance counter is intended to increment every cycle that the GPU has at least one hardware command stream queued for processing. In the impacted products, cycles that are handling GPU internal low power state operations are also counted, even if no hardware command stream is queued. This results in the *GPU Active* performance counter significantly overcounting compared to the same counter in other Arm GPU products.

Implications

The *GPU Active* performance counter can be misleading for profiling application workloads, because it appears that the GPU is busy processing work when it is actually idle.

Workaround

The *GPU Active* performance counter can be substituted for the *GPU Queue Active* (GPU_ITER_ACTIVE) performance counter. The *GPU Queue Active* counter increments every cycle that at least one of the hardware queues that dispatches tasks to shader cores has work queued. This instrumentation point counts later in the hardware pipeline than the *GPU Active* counter, and will exclude cycles spent processing the command stream when no work is queued on the shader cores. It therefore tends to count slightly lower than a functionally correct *GPU Active* counter.

This workaround has been applied in all Arm-provided tools and open source libraries. If you attempt to access the *GPU Active* counter using Arm Streamline, RenderDoc for Arm GPUs, or the libGPUCounters library, the *GPU Queue Active* counter will be transparently substituted in its place.

Proprietary notice

(PRE-1121-V1.0)

Product and document information

Read the information in these sections to understand the release status of the product and documentation, and the conventions used in the Arm documents.

Product status

All products and Services provided by Arm require deliverables to be prepared and made available at different levels of completeness. The information in this document indicates the appropriate level of completeness for the associated deliverables.

Product completeness status

The information in this document is Final, that is for a developed product.

Product revision status

The rxpy identifier indicates the revision status of the product described in this manual, where:

rx

Identifies the major revision of the product.

py

Identifies the minor revision or modification status of the product.