What’s New in OpenGL ES

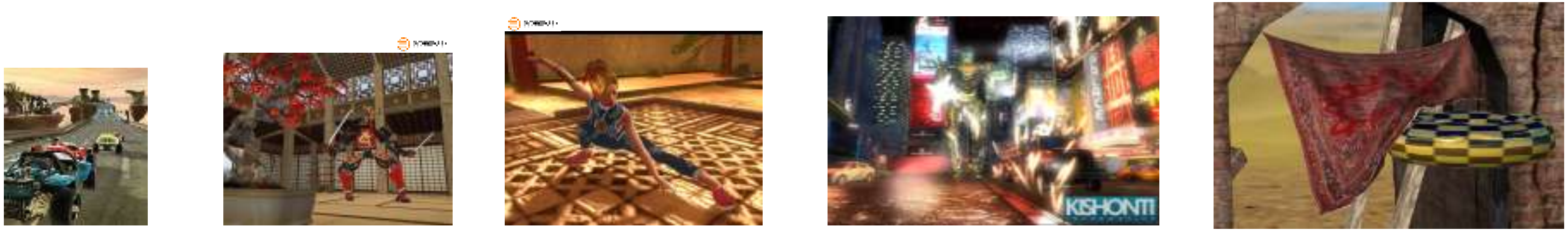
Tom Olson
Director of Graphics Research, ARM
Chair, OpenGL ES Working Group

Introducing OpenGL ES 3.1

- **Designed for rapid adoption**
  - Should run on most OpenGL ES 3.0 hardware
  - Backward compatible with ES 2.0/3.0 for easy software porting

- **Brings the most requested features of OpenGL 4.x to mobile**
  - Significant, even game-changing upgrade in functionality

- **Continued improvement in portability - tighter specs, less undefined behavior**



Driver Update | Silicon Update | Silicon Update | Driver Update

2002	2003	2004	2007	2012	2014
Working Group Formed	1.0	1.1	2.0	3.0	3.1

Key Working Group Participants

Apple

- GPU Designers
- SoC Vendors
- Platform Owners
- End Equipment Makers
- Middleware ISVs
- Tool and Game Engine Developers

Outline

- Introduction and Goals
  - Tom Olson, ARM / ES WG Chair
- OpenGL ES 3.1 Compute Features
  - Daniel Koch, NVIDIA
- OpenGL ES 3.1 API Features
  - Slawek Grajewski, Intel
- GLSL ES 3.1 Shading Language
  - Bill Licea-Kane, Qualcomm
- EGL 1.5 Features
  - Jon Leech, Khronos / EGL 1.5 and OpenGL ES 3.1 Specification Editor
- Wrap-up / Questions / Demos

OpenGL ES 3.1 Compute Features

Daniel Koch, NVIDIA

dkoch@nvidia.com

Compute Shader Motivation

- **A new way of accessing the computation power in the GPU**
  - Execute general purpose algorithms
  - New single-stage pipeline, separate from the graphics pipeline
- **Uses concepts familiar to graphics programs**
  - Written in same GLSL ES language as other shaders
- **Standard part of all OpenGL ES 3.1 implementations**
  - Similar to OpenGL 4.3 and DirectX 11 functionality

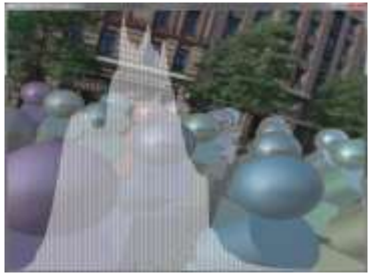
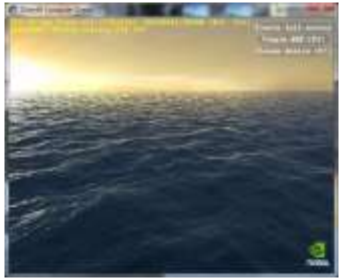


Image processing

AI Simulation

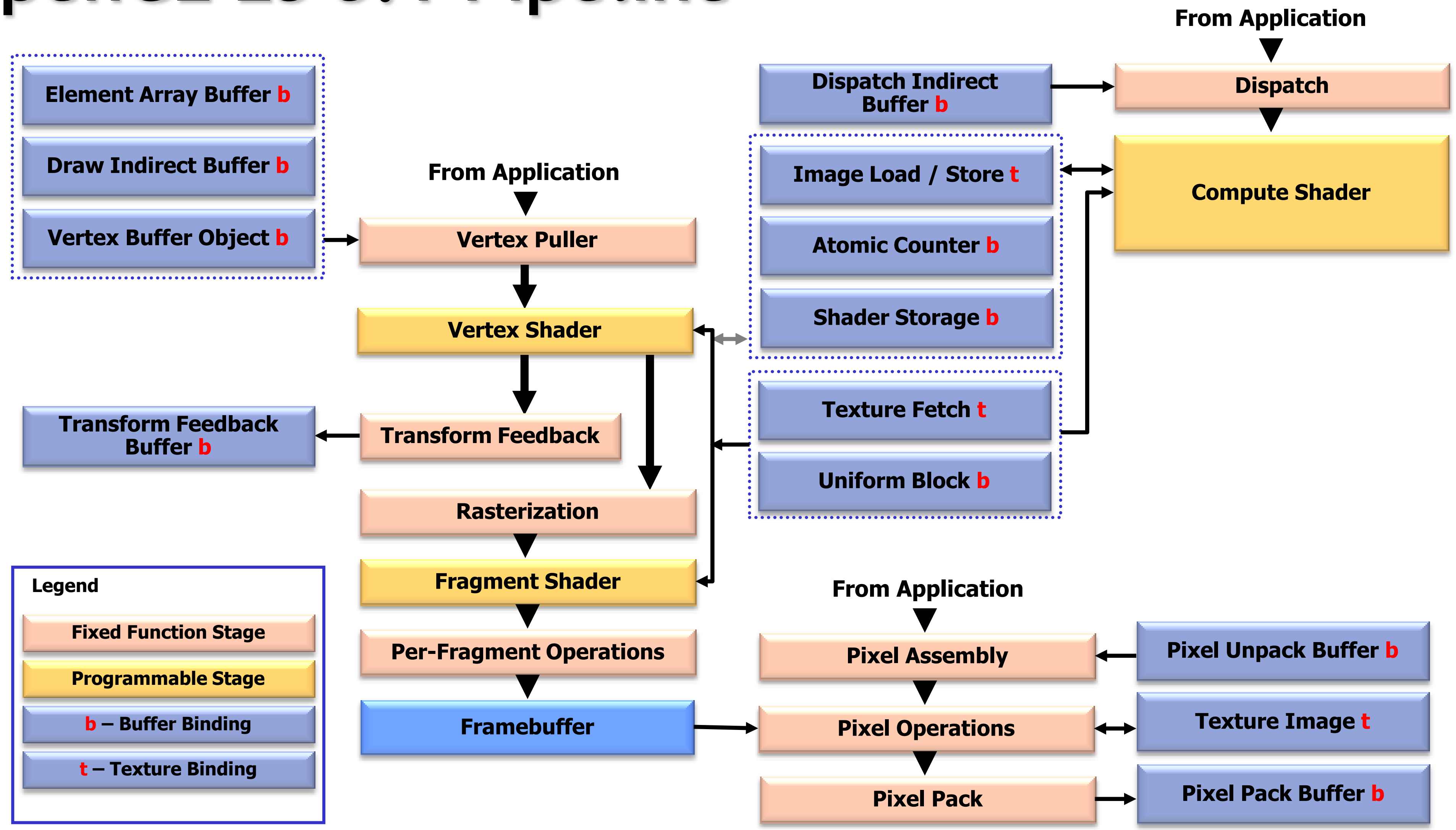
Ray Tracing



Wave Simulation

Global Illumination

OpenGL ES 3.1 Pipeline

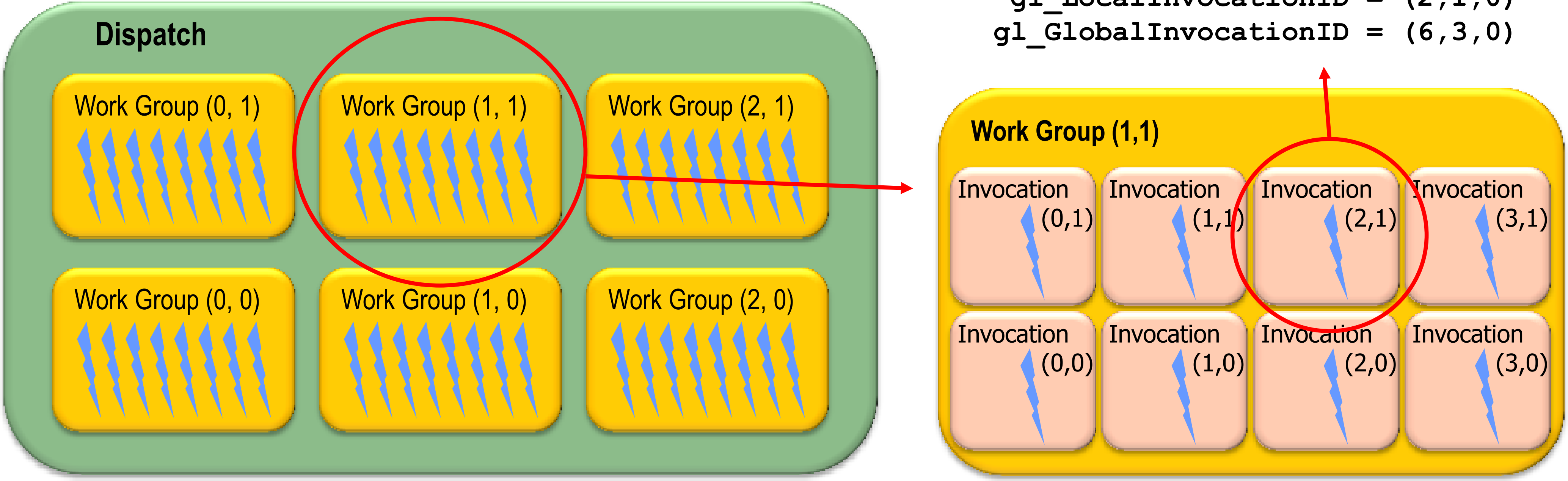


Compute Shaders

- New shader type: GL_COMPUTE_SHADER
- Behaves as other shader types you know and love (or hate…)
  - glShaderSource, glCompileShader, glAttachShader, and glLinkProgram
  - Or `glCreateShaderProgram`()
- Operates on the same resources as the graphics pipeline
  - buffers, textures
- No predefined inputs or outputs; only side effects are on memory
- New types of memory-backed resources
  - images, buffers, atomic counters (more about these later)
- Conceptually a grid of work items
  - Communicate with each other via shared memory
- To launch work: glDispatchCompute*()

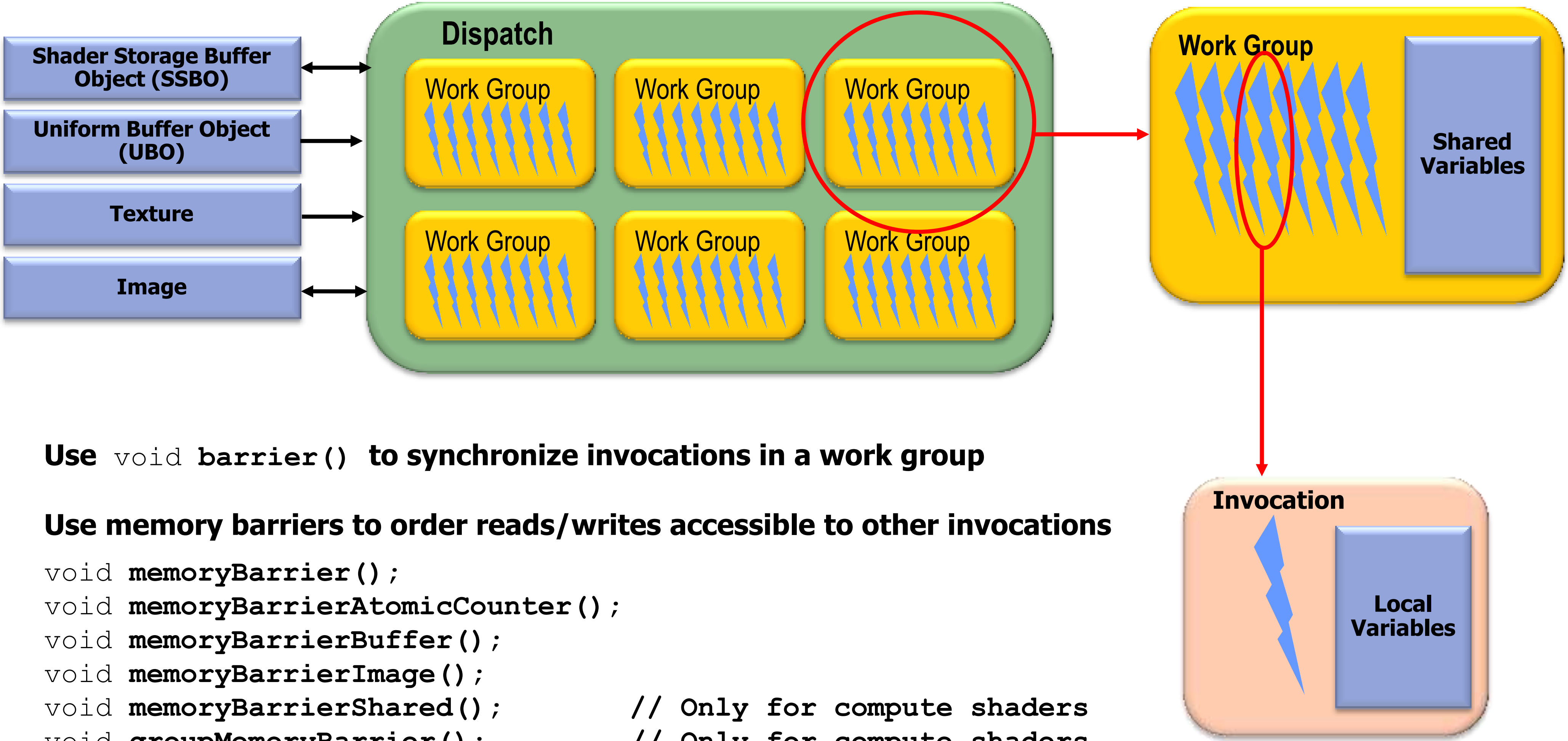
Compute Programming Model

```
gl_WorkGroupSize = (4,2,1)
gl_WorkGroupID = (1,1,0)
gl_LocalInvocationID = (2,1,0)
gl_GlobalInvocationID = (6,3,0)
```




```
   in uvec3 gl_NumWorkGroups;       // Number of workgroups dispatched
const uvec3 gl_WorkGroupSize;       // Size of each work group for current shader
   in uvec3 gl_WorkGroupID;         // Index of current work group being executed
   in uvec3 gl_LocalInvocationID;   // index of current invocation in a work group
   in uvec3 gl_GlobalInvocationID;  // Unique ID across all work groups and invocations
```

Compute Memory Hierarchy



Use `void barrier()` **to synchronize invocations in a work group**

Use memory barriers to order reads/writes accessible to other invocations

```
void memoryBarrier();
void memoryBarrierAtomicCounter();
void memoryBarrierBuffer();
void memoryBarrierImage();
void memoryBarrierShared();        // Only for compute shaders
void groupMemoryBarrier();         // Only for compute shaders
```

Compute Shader Example

```
#version 310 es
layout (local_size_x = 4, local_size_y = 2) in; // z defaults to 1
float varA;    // per invocation variable
// per workgroup shared memory [4][2]
shared float shmem[gl_WorkGroupSize.x][gl_WorkGroupSize.y];
layout(std430, binding = 0) buffer b {
  float result;
};
void main(void) {
  varA = ....;
  shmem[gl_LocalInvocationID.x][gl_LocalInvocationID.y] = varA;
  barrier();
  b.result = ....;  // calculation on any/all locations in shmem
}
```

Shader Storage Buffer Objects (SSBO)

- Read/write and atomic operations on the variables stored in a buffer object
  - Essentially writeable UBOs
- Support for very large buffers
  - Required minimum is 128 MB
- New buffer binding point `SHADER_STORAGE_BUFFER`
  - Limited number available per shader type: `MAX_<STAGE>_STORAGE_BLOCKS`
  - Required for compute (min 4), optional in vertex and fragment
- New `std430` memory layout
  - More efficient packing of vector and scalar arrays, structures
  - `std140` is also supported
- Can use C-style code in a shader to read and write the buffer
- Ideal for getting data in/out of a compute shader

SSBO Example

```
glGenBuffers(1, &posSSBO);
glBindBuffer(GL_SHADER_STORAGE_BUFFER, posSSBO);
glBufferData(GL_SHADER_STORAGE_BUFFER, .... );
glUseProgram(MyShaderProgram);
glBindBufferBase(GL_SHADER_STORAGE_BUFFER, 2, posSSBO);

 struct MyVertex {
   vec2 tex[2]; // tightly packed array in std430
   vec3 pos;
   int  materialIdx;
 }
 layout(std430, binding = 2) buffer b {
    MyVertex vertices[ ]; // unsized array allowed at end of buffer
 };

 ... // compute data to store in Vertices[]
 b.vertices[i].materialIdx = idx; // directly write to buffer content
```

Shader Image Load Store

- **Read/Write and atomic operations on the data in an image**
  - Essentially writeable textures
- **Adds *image units* where a single texture level is bound, similar to texture units**
- **New GLSL `image*` uniform data types, similar to samplers**
  - Limited number available per shader type: `MAX_<STAGE>_IMAGE_UNIFORMS`
  - Required for compute (min 4), optional for vertex and fragment
- **Built-in `imageLoad()`, `imageStore()`, `imageSize()` functions**
  - Integer coordinates used to identify texels accessed
- **Optional ability to perform atomic read-modify-write operations**
  - `imageAtomic*()` functions on subset of formats: `r32i`, `r32ui`, `r32f`
  - OES_shader_image_atomic
- **Ability to explicitly enable "early" per-fragment tests**
  - Depth and stencil operations can occur before fragment shader execution
  - Must be opted in when fragment shaders can have side effects

Image Load Store Example

```
glGenTexture(1, &imgTex);
glBindTexture(GL_TEXTURE_2D, imgTex);
glTexStorage(GL_TEXTURE_2D, 1, GL_RGBA32F, 32, 32);
glTexSubImage2D(GL_TEXTURE_2D, 0, 0, 0, 32, 32, ...);

glBindImageTexture(3, imgTex, 0, GL_FALSE, GL_READ_ONLY, GL_RGBA32F);

layout(rgba32f, binding = 3) readonly highp uniform image2D myImage;

ivec2 size = imageSize(myImage); // get image dimensions
int i,j;
for (i = 0; i < size.x; i++) {
  for (j = 0; j < size.y; j++) {
    vec4 color = imageLoad(myImage, ivec2(i, j));
    // do something with color
  }
}
```

Shader Atomic Counters

- **Provides a set of buffer-backed atomic counters**
  - The contents of the atomic counters are stored in the buffer object
- **Can be set and queried with normal buffer access functions**
  - `glBufferSubData()`, `glMapBufferRange()`, etc
- **Enables a shader to read or write from unique offsets**
  - Append and consume buffers
- **New buffer binding point `ATOMIC_COUNTER_BUFFER`**
  - Limited number per shader type: `MAX_<SHADER>_ATOMIC_COUNTER_BUFFERS`
  - Required for compute (8), optional for vertex and fragment
- **New GLSL `atomic_counter` opaque uniform data type**
  - Limited number available per shader type: `MAX_<STAGE>_ATOMIC_COUNTERS`
  - Required for compute (8), optional for vertex and fragment
- **Builtin GLSL functions to atomically query/increment/decrement the counters**
  - `atomicCounter()`, `atomicCounterIncrement()`, `atomicCounterDecrement()`

Shader Memory Access

- Updates to buffer or texture data
  - API commands: the GL implementation takes care of synchronization
  - Written by shaders: the app is responsible for synchronization
- Order of shader memory accesses is largely undefined
  - Order (and even number!) of shader types and invocations may vary
- Use `MemoryBarrier()` API
  - Memory operations issued by rendering command before the MB
  - Are ordered relative to commands coming after the MB
- `barriers` parameter: specify how the data will be used after the MB
- Eg. DispatchCompute - launch compute shader which updates a buffer
  - `glMemoryBarrier(GL_BUFFER_UPDATE_BARRIER_BIT)`
    - buffer can be read/updated using glMapBufferRange(), etc.
  - `glMemoryBarrier(GL_VERTEX_ATTRIB_ARRAY_BARRIER_BIT)`
    - Buffer can be used as vertex data source for subsequent Draw* command

Shader Memory Control Functions

- Multiple invocations can simultaneously access the same memory
- Memory access qualifiers (for image and buffer variables)
  - `coherent`, `volatile`, `restrict`, `readonly` and `writeonly`
- Atomic memory functions (for buffer and shared variables)
  - Atomic read/modify/write operations that return the original value
  - `Atomic`{`Add`, `Min`, `Max`, `And`, `Or`, `Xor`, `Exchange`, `CompSwap`}
- Order accesses to selected types of resources shared between invocations
  - `memoryBarrier`{`AtomicCounter`, `Buffer`, `Image`, `Shared`}
- Order access to all types of memory resources between invocations
  - `memoryBarrier()` // for all invocations
  - `groupMemoryBarrier()` // for all invocations in the same work group
- Used with coherent variables

Differences from GL

- Coherence guarantees altered (no inter-stage coherence within a draw call)
- Lower minimum maxima (4 vs 8) [buffers, images]
- Support is optional in fragment shaders [buffers, images, atomic counters]
- Compile-time constant expressions to index into arrays of buffers, images
  - GL allows dynamically uniform expressions
- Binding points can only be set in the shader
  - no glShaderStorageBlockBinding API to change bind point after linking [buffers]
  - glUniform1i() cannot be used to change location after linking [images]
- Compute Shaders
  - Added precision qualifiers, same default precisions as vertex shaders in ES 3.0
    - Precision of new types and resources must be specified
  - Reduced workgroup size (x, y) dimensions and invocations (128 vs 1024)
- Minimum SSBO size is 128MB instead of 16MB

Differences from GL

- **Images**
  - Only supported for immutable textures (use TexStorage* API!)
  - Format **must** be specified in shader for all image declarations
  - Image variables must be readonly or writeonly except r32f, r32i, and r32ui
  - Image formats supported have been subset (check your formats!)
    - Different default format as well (R32UI vs R8)
  - Support for imageAtomic* functions is optional (OES_shader_image_atomic)
  - No support for multisample images
- **Didn't add queries that would be duplicated by program interface query**
  - GetActiveAtomicCounterBufferiv
  - UNIFORM_BLOCK_REFERENCED_BY_COMPUTE_SHADER
  - ATOMIC_COUNTER_BUFFER_REFERENCED_BY_COMPUTE_SHADER

OpenGL ES3.1 API Features

Slawomir (Slawek) Grajewski, Intel

slawomir.grajewski@intel.com

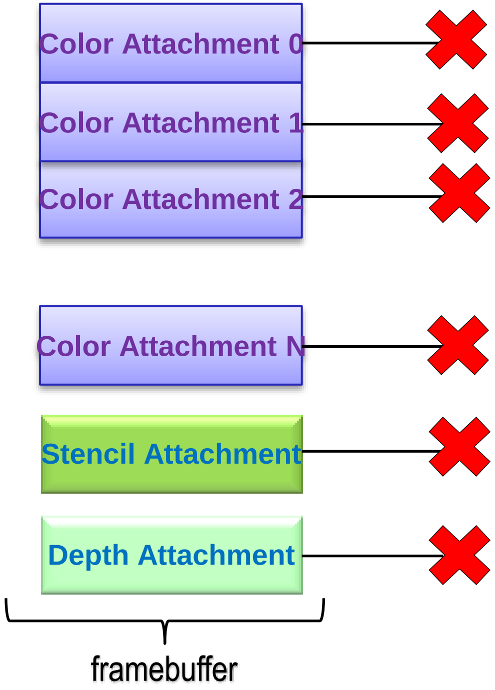
Agenda

New ES3.1 features

- Framebuffer no attachments
- New draw indirect commands
- Separate Shader Objects (aka SSO)
- Program Interface Query
- Vertex Attrib Binding
- Texture gather
- Texture multisample
- Stencil texturing
- OES_texture_stencil8

Framebuffer No Attachments

- Shaders can operate on
  - Images
  - Shader storage buffer objects
  - Atomic counter buffers
- Sometimes framebuffer attachments not needed at all
- Specify default frambuffer parameters and don't waste memory
  - FRAMEBUFFER_DEFAULT_WIDTH
  - FRAMEBUFFER_DEFAULT_HEIGHT
  - FRAMEBUFFER_DEFAULT_SAMPLES
  - FRAMEBUFFER_DEFAULT_FIXED_SAMPLE_LOCATIONS

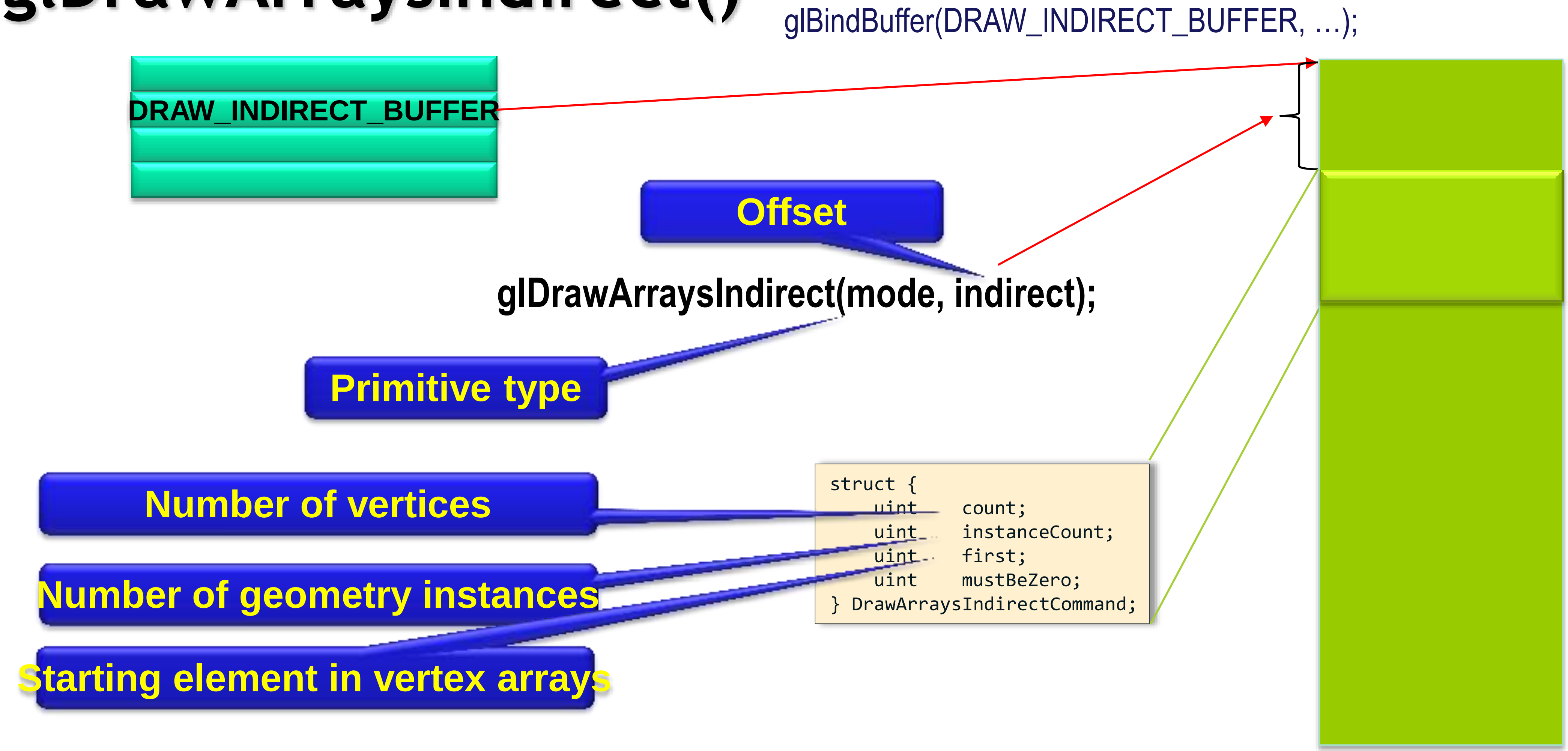


~~FRAMEBUFFER_INCOMPLETE_MISSING_ATTACHMENT~~

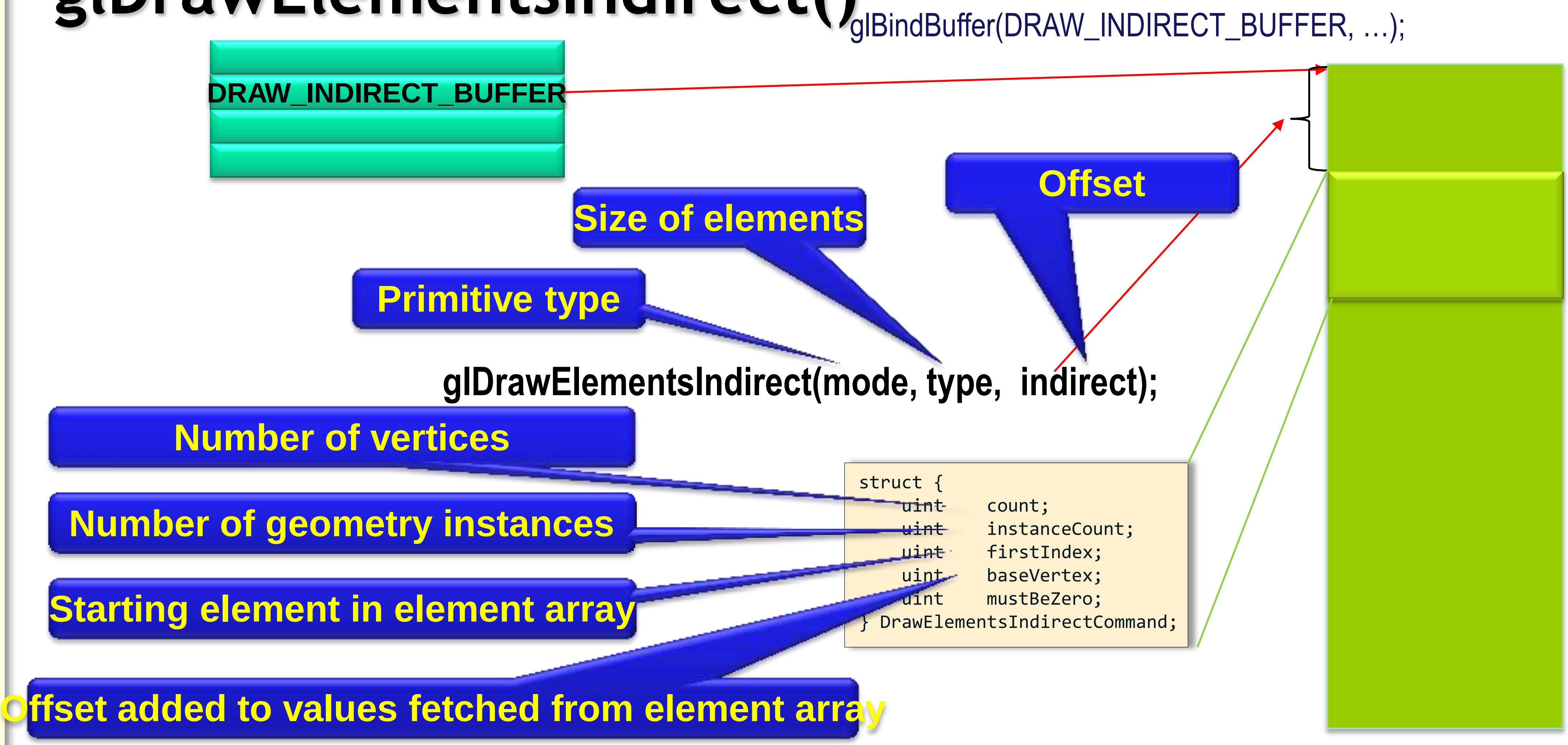
New Draw Indirect Commands

- **ES3.1 Introduces two new DrawIndirect commands**
  - glDrawArraysIndirect()
  - glDrawElementsIndirect()
- **And one for dispatching indirectly Compute Shaders**
  - glDispatchComputeIndirect()
- **Useful for draw parameters established by GPU**
  - Compute Shader for example
  - Eliminate GPU/CPU round trip
- **Important differences from GL**
  - Cannot be used with transform feedback active
  - Cannot be used with default VAO
  - Parameters cannot be fetched from client memory

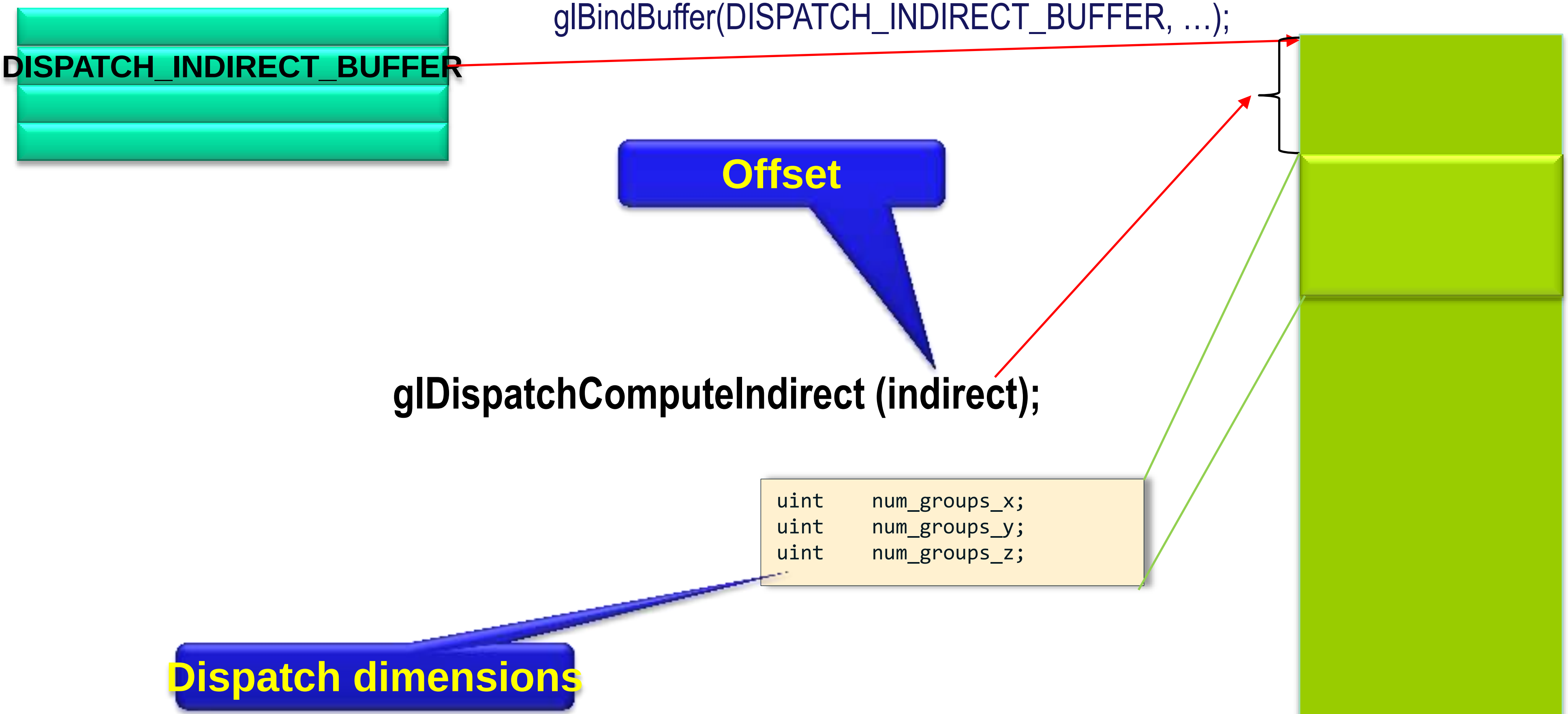
glDrawArraysIndirect()



glDrawElementsIndirect()

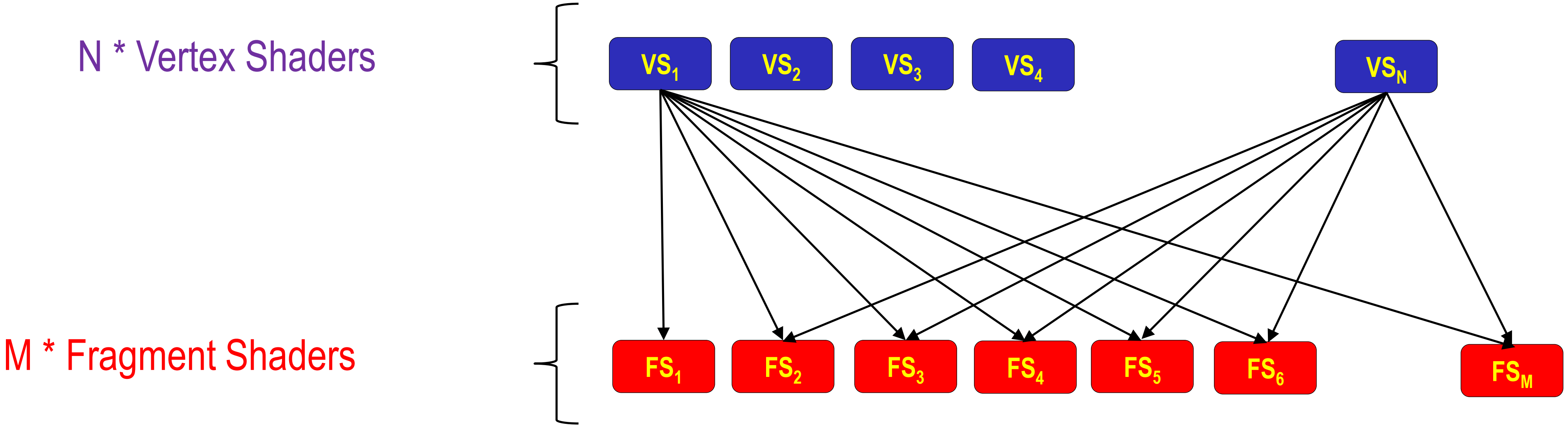


glDispatchComputeIndirect()



Separate Shader Objects

- **Separate Shaders**
  - Eliminate (expensive) program linking operations (glLinkProgram())
    - Needed for every VS/FS pair; in extreme case N x M
  - Replaces with mix-and-match approach
    - Compiled shaders can be mixed-and-matched at "zero" cost.



Monolithic Programs

For every Vertex Shader

glCreateShader()
glShaderSource()
glCompileShader()

glCreateShader()
glShaderSource()
glCompileShader()

glCreateShader()
glShaderSource()
glCompileShader()

For every VS/FS pair (program)

glCreateProgram()
glAttachShader()
glAttachShader()
glLinkProgram()

Can be expensive

For every Fragment Shader

glCreateShader()
glShaderSource()
glCompileShader()

glCreateShader()
glShaderSource()
glCompileShader()

glCreateShader()
glShaderSource()
glCompileShader()

Pipeline Objects

- "Replacement" for monolithic programs

glGenProgramPipelines()

- A container for collection of separate shaders

glUseProgramStages()
glUseProgramStages()

- Where to get separate shaders from?
  - Stand-alone shader programs containing single shader

glCreateShaderProgram()

  - Monolithic programs linked with SEPARABLE_PROGRAM parameter

glProgramParameter(…,
PROGRAM_SEPARABLE);
glLinkProgram();

glUseProgram(0);
glBindProgramPipeline();

- Pipeline objects can be used instead of programs

Mix-and-match

Separate Shaders

For every Vertex Shader

```
glCreateShaderProgram()
```

```
glCreateShaderProgram()
```

```
glCreateShaderProgram()
```

For every VS/FS pair (pipeline)

```
glGenProgramPipelines()
glUseProgramStages(pipeline, VERTEX_SHADER_BIT, program)
glUseProgramStages(pipeline, FRAGMENT_SHADER_BIT, program)
```

Lite operations

For every Fragment Shader

```
glCreateShaderProgram()
```

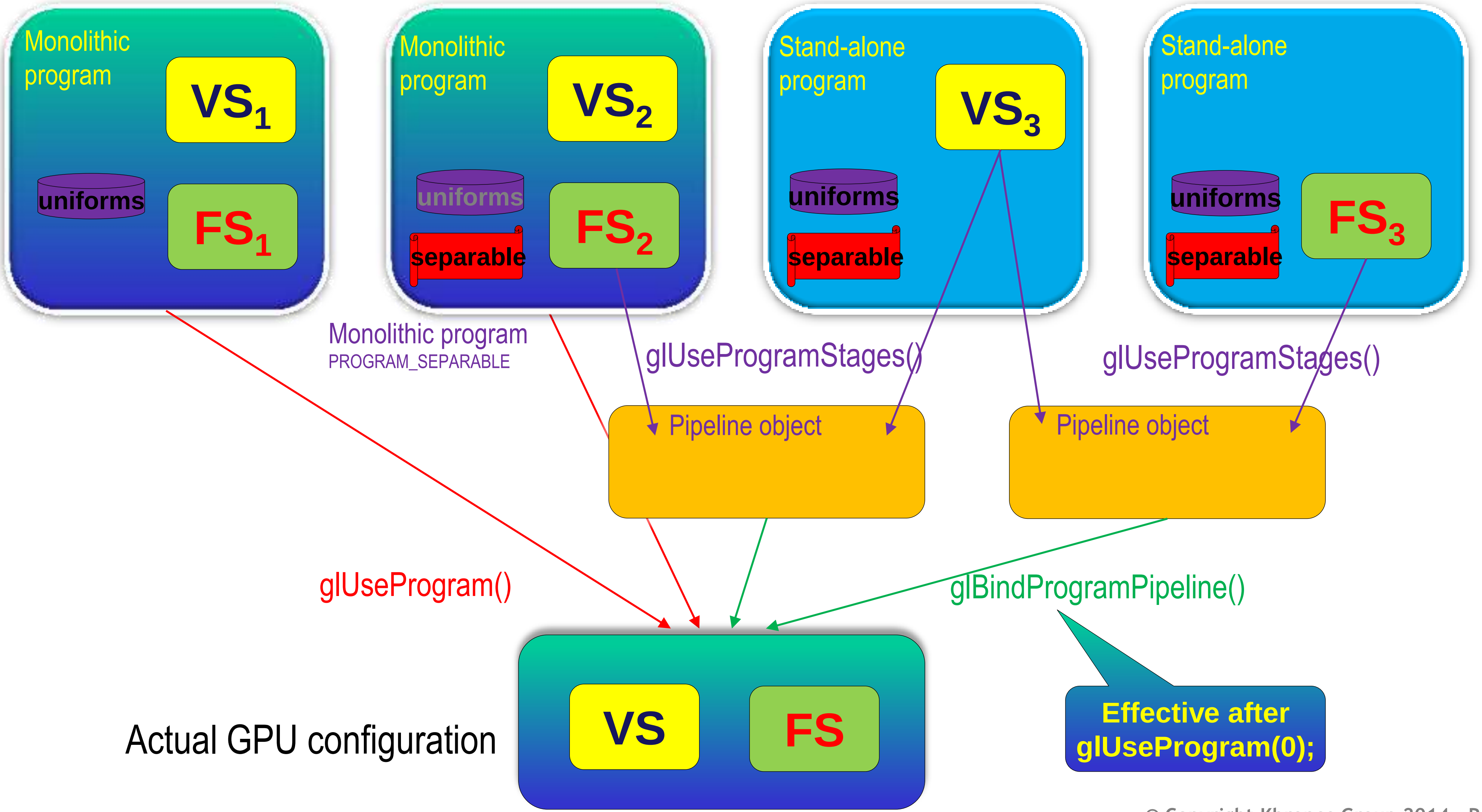
```
glCreateShaderProgram()
```

```
glCreateShaderProgram()
```

Or at draw time

```
// for bound pipeline object
glUseProgramStages(); // VS
glUseProgramStages(); // FS
```

Putting This All Together



Uniforms

- Constant data per program
- *If VS* and FS come from pipeline object each come from different program
- glActiveShaderProgram() selects where glUniform*() calls are directed
  - Redirects only if pipeline object defines VS/FS
- To make things easier DSA versions of glUniform*() entry points are introduced
  - glProgramUniform*()(program, location, value);

```
glUseprogram(0);
glBindProgramPipeline();
```

```
glActiveShaderProgram();
glUniform*();     // VS
glActiveShaderProgram();
glUniform*(); // FS
```

```
glProgramUniform(program, ...);

glProgramUniform(program, ...);
```


Matching Rules

- **Each vertex shader output has matching fragment shader input and vice versa**
  - No dangling outputs/inputs
- **Input matches output if:**
  - Both are declared with the same location qualifiers OR with the same name
  - Have the same type
  - Variables defined as structures have to match
  - Variables defined as arrays have to match
  - Precision has to match!
- **Some things can differ**
  - Obvious: storage qualifier (in/out)
  - Interpolation qualification (flat/smooth)
  - Auxiliary qualification (centroid)
  - Qualifier *sample*
- **Draw time error in case of mismatch**

Pros/Cons

- Separate shaders eliminate expensive linking of vertex and fragment shaders
- Vertex and fragment shaders can be mixed-and-matched at "zero" cost
- "Legacy" GLSL monolithic approach allows for more advanced optimizations
  - The extend of such optimizations is IHV dependent

Program Interface Query

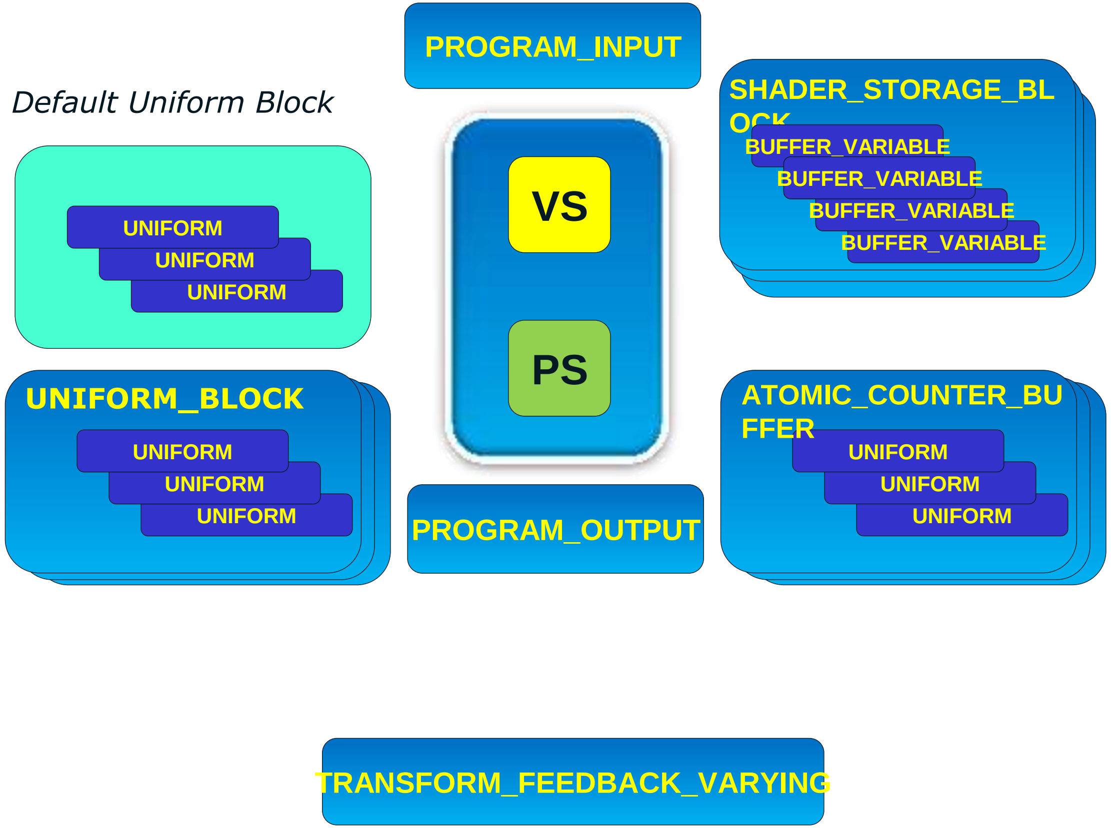
- **Why do we need Program Interface Query?**
  - New queries required for new features
    - Shader storage buffer objects
    - Atomic counter buffers

- **ES3.0 has separate set of query commands for different program interfaces and resources**
  - Some existing ES queries have limited capabilities
    - Fragment shader outputs cannot be queried

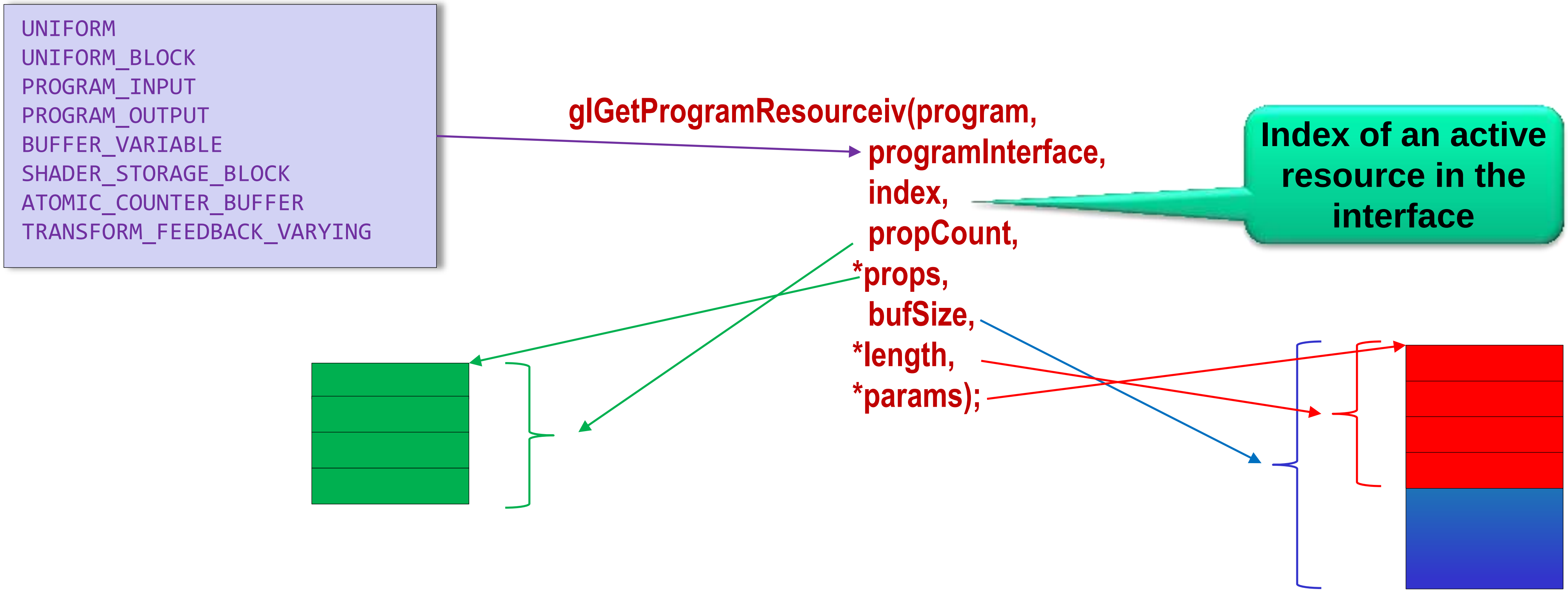
- **Design decision for ES3.1**
  - New program interface query that
    - Addresses the new functionality
    - Covers missing gaps
    - Allows for easy expansion

Program Interface Query

- All program interfaces can be queried
- Only ACTIVE resources within these interfaces are reported
  - That have observable effect
- What are resources?
  - Variables
  - Interface blocks
  - Atomic counter binding points



Program Interface Query API



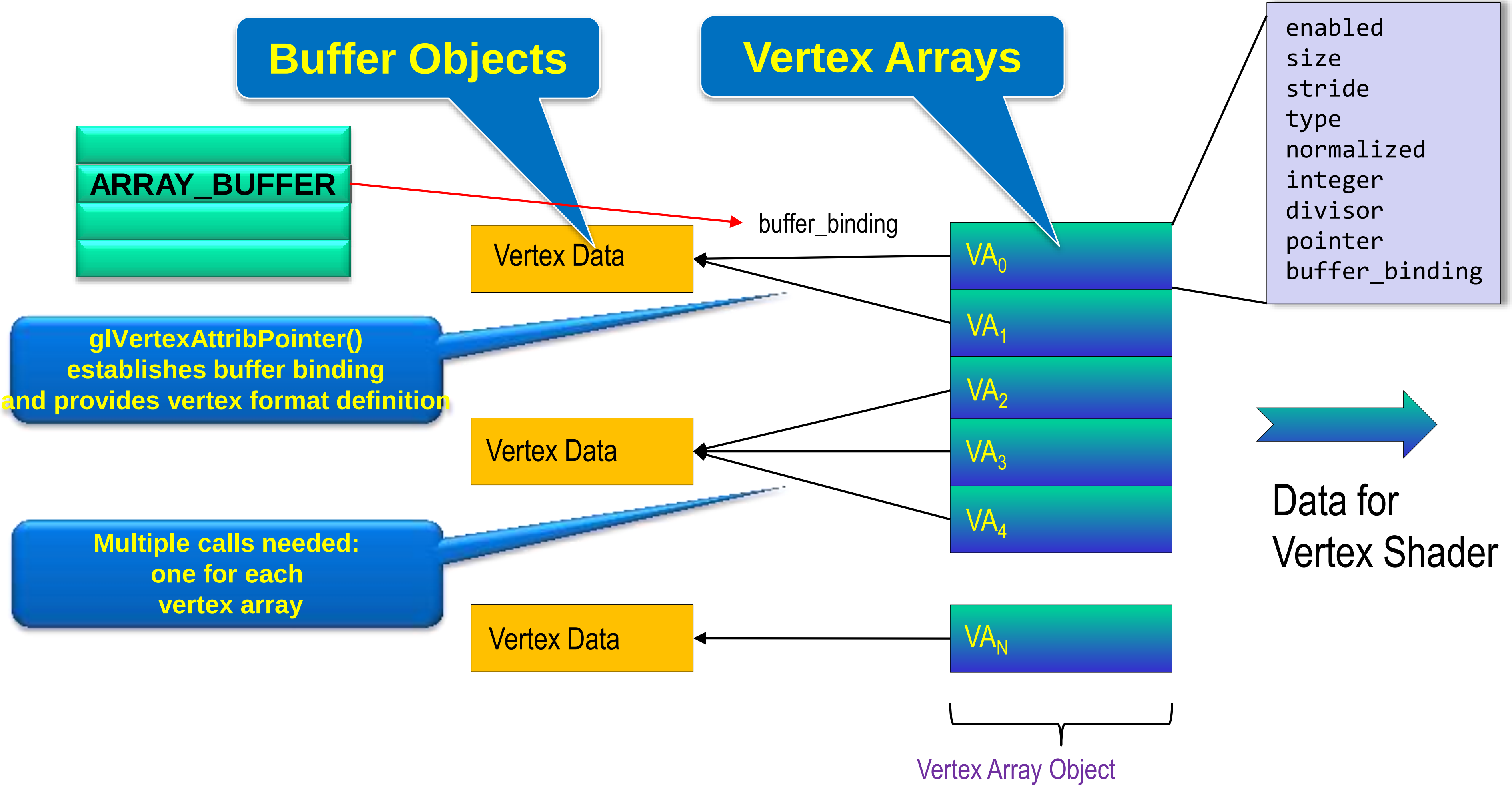
Program Interface Query API

Property	Supported Interfaces	Property	Supported Interfaces
LOCATION	UNIFORM, PROGRAM_INPUT, PROGRAM_OUTPUT	TYPE	UNIFORM, PROGRAM_INPUT, PROGRAM_OUTPUT, TRANSFORM_FEEDBACK_VARYING, BUFFER_VARIABLE
OFFSET	UNIFORM, BUFFER_VARIABLE	ATOMIC_COUNTER_BUFFER_ INDEX	UNIFORM
REFERENCED_BY_VERTEX_ SHADER REFERENCED_BY_FRAGMENT_ SHADER REFERENCED_BY_COMPUTE_ SHADER	UNIFORM, UNIFORM_BLOCK, ATOMIC_COUNTER_ BUFFER, SHADER_STORAGE_BLOCK, BUFFER_VARIABLE, PROGRAM_INPUT, PROGRAM_OUTPUT	BLOCK_INDEX	UNIFORM, BUFFER_VARIABLE
		NAME_LENGTH	all but ATOMIC_COUNTER_BUFFER
		ARRAY_STRIDE	UNIFORM, BUFFER_VARIABLE
		MATRIX_STRIDE	UNIFORM, BUFFER_VARIABLE
BUFFER_BINDING	UNIFORM_BLOCK, ATOMIC_COUNTER_BUFFER, SHADER_STORAGE_BLOCK	BUFFER_DATA_SIZE	UNIFORM_BLOCK, ATOMIC_COUNTER_BUFFER, SHADER_STORAGE_BLOCK
NUM_ACTIVE_VARIABLES	UNIFORM_BLOCK, ATOMIC_COUNTER_BUFFER, SHADER_STORAGE_BLOCK	ACTIVE_VARIABLES	UNIFORM_BLOCK, ATOMIC_COUNTER_BUFFER, SHADER_STORAGE_BLOCK
ARRAY_SIZE	UNIFORM, BUFFER_VARIABLE, PROGRAM_INPUT, PROGRAM_OUTPUT, TRANSFORM_FEEDBACK_VARYING	IS_ROW_MAJOR	UNIFORM, BUFFER_VARIABLE

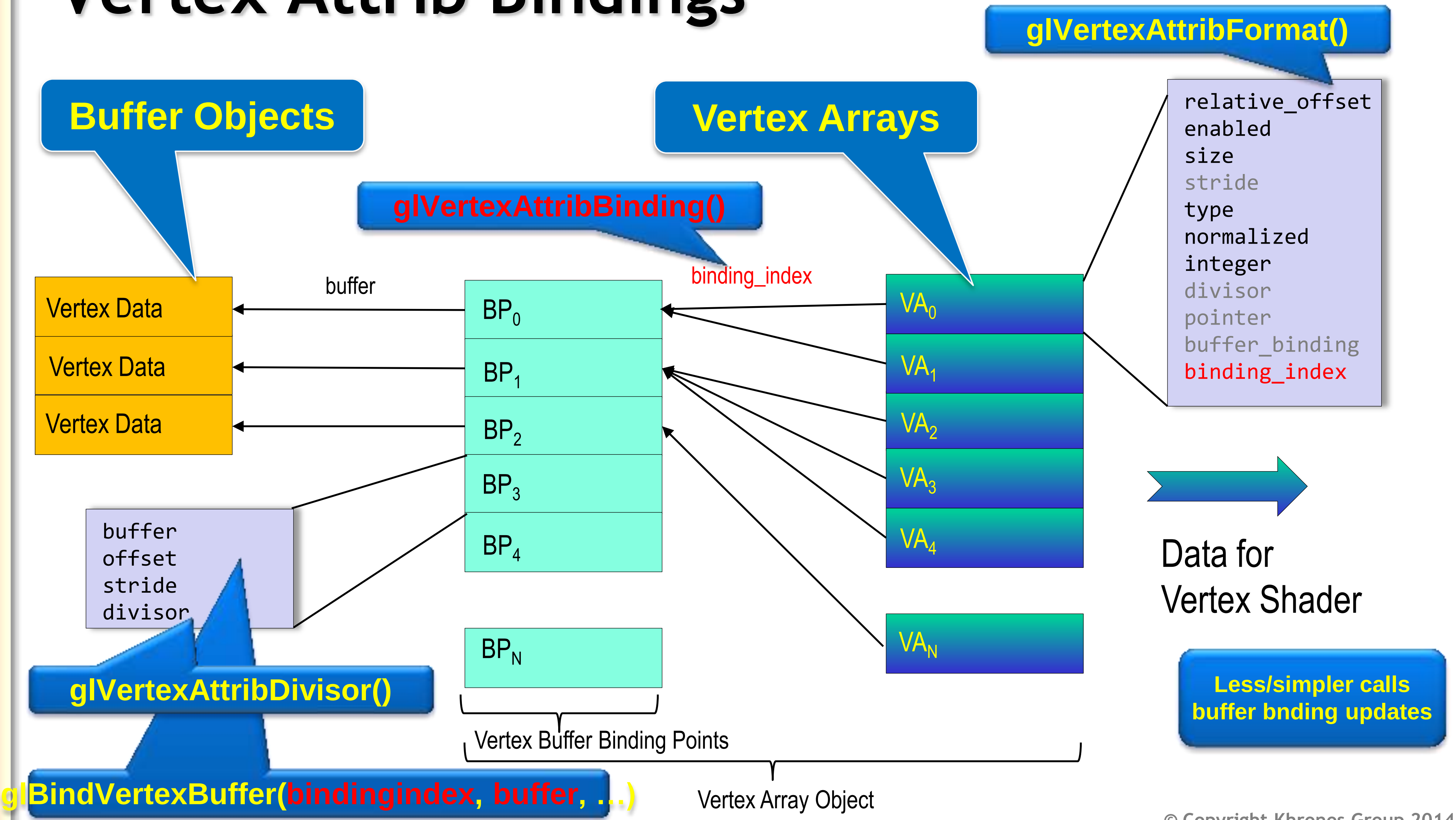
Vertex Attrib Binding

- **Why do we need new vertex attrib API?**
  - To be efficient for interleaved vertex buffers
  - To make independent updates of
    - Vertex buffer
    - Vertex format

"Legacy" Vertex Arrays

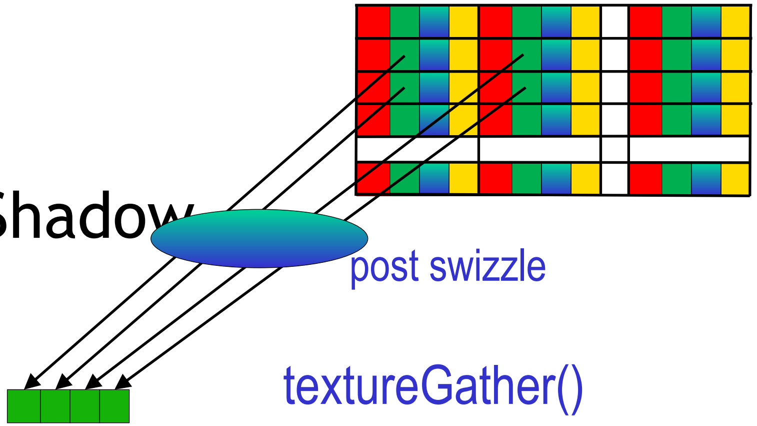


Vertex Attrib Bindings



textureGather

- **Fetch 2x2 footprint used in linear filtering**
- **Selected component is returned**
- **Supported on samplers**
  - 2D, 2DArray, Cube, 2DShadow, 2DArrayShadow, CubeShadow
- **textureGatherOffset()**
  - Run-time offsets (x,y) common for all channels
- **Differences from GL**
  - Offset must be a constant expression
  - No textureGatherOffsets()



Multisample Textures

- New type of immutable textures
  - TEXTURE_2D_MULITISAMPLE and TEXTURE_2D_MULTISAMPLE_ARRAY
  - No LOD
  - Can be attached to framebuffer
  - New GLSL sampler types
    - {i|u}sampler2DMS
    - {i|u}sampler2DMSArray
  - New texelFetch function
    - Returns requested sample for given coordinates

```
void glTexStorage2DMultisample (enum target,
                   sizei samples,
                   enum sizedinternalformat,
                   sizei width,
                   sizei height,
                   boolean fixedsamplelocations);

void glTexStorage3DMultisample (enum target,
                   sizei samples,
                   enum sizedinternalformat,
                   sizei width,
                   sizei height,
                   sizei depth,
                   boolean fixedsamplelocations);
```

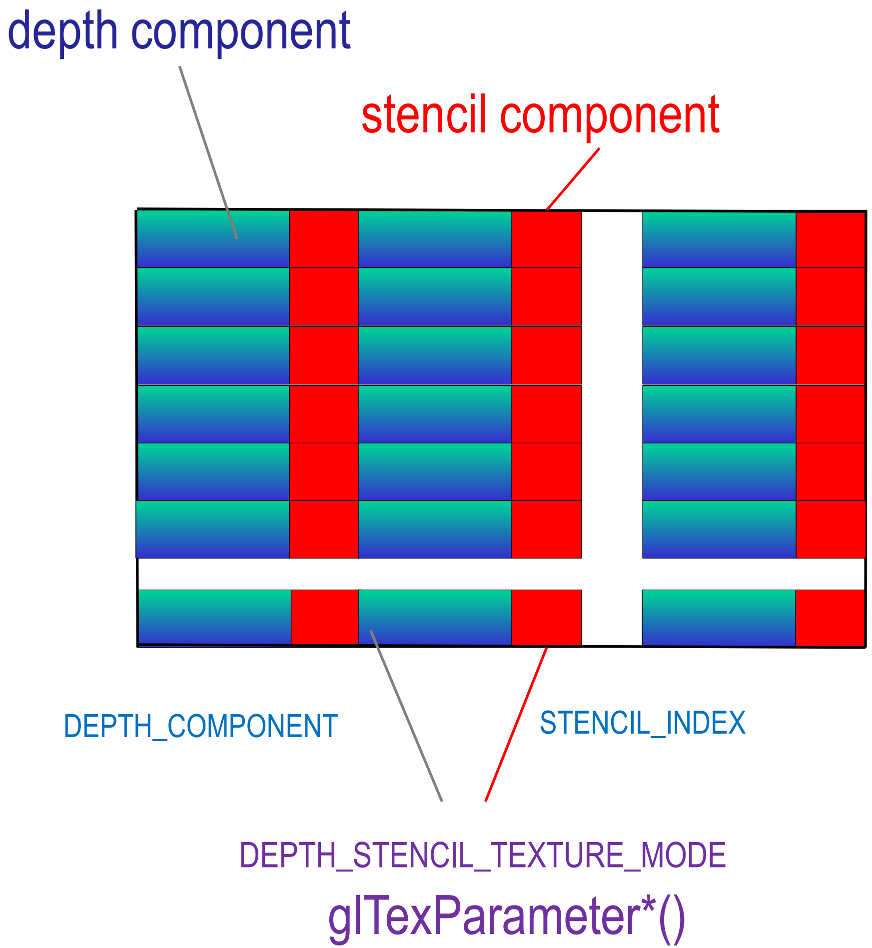
```
gvec4 texelFetch(gsampler2DMS sampler, ivec2 P, int sample)
gvec4 texelFetch(gsampler2DMSArray sampler, ivec3 P, int sample)
```

OES_texture_storage_multisample_2d_array

```
ivec2 textureSize(gsampler2DMS sampler)
ivec3 textureSize(gsampler2DMSArray sampler)
```

Stencil Texturing

- Enables sampling stencil component from packed depth stencil texture
  - As a unsigned integer
- Per texture switch
- Either
  - DEPTH_COMPONENT or
  - STENCIL_INDEX



OES_texture_stencil8

- STENCIL_INDEX8 accepted as <internalformat> by glTexImage{2|3}D, glTexStorage{2|3}D, glTexStorage{2|3}Dmulitisample for TEXTURE_2D, TEXTURE_2D_ARRAY, TEXUTRE_CUBE_MAP, TEXTURE_2D_MULITSAMPLE, TEXTURE_2D_MULITSAMPLE_ARRAY.

- STENCIL_INDEX accepted as <format> by glTexImage{2|3}D, glTexSubImage{2|3}D specifying image for TEXTURE_2D, TEXTURE_2D_ARRAY, TEXTURE_CUBE_MAP.

- Render buffers no longer needed if stencil-only format is required

OpenGL ES Version 3.1 Shading Language

Bill Licea-Kane
Qualcomm Technologies, Inc
GDC, San Francisco, March 2014

Overview

- explicit_uniform_location
- shader_helper_invocation
- shader_bitfield_operations
- arrays_of_arrays
- shader_integer_mix

explicit_uniform_location

- Shader writer may specify default-block uniform location table
- Similar to shader input, shader output location tables
- Goal - portable compile time locations, bindings, offsets

explicit_uniform_location

```
// vertex shader example
layout(location=0) in vec4 position;
layout(location=1) in vec3 normal;
layout(location=0,binding=1) uniform sampler2D lookupTable;
layout(std140,binding=0) uniform xformBlock {
    mat4 mvpMatrix;
    mat3 normalMatrix;
};

// fragment shader example
layout(location=0) out vec4 color;
layout(location=0,binding=0) uniform sampler2D baseMap;
layout(location=1,binding=2) uniform samplerCubeMap cubeMap;
```

shader_helper_invocation

- New! Why?
- dFdx(p), dFdy(p)
  fWidth(p)
  implicit derivatives

Forward differencing:

$$F(x+dx)-F(x) \sim dFdx(x)\cdot dx \qquad \text{1a}$$

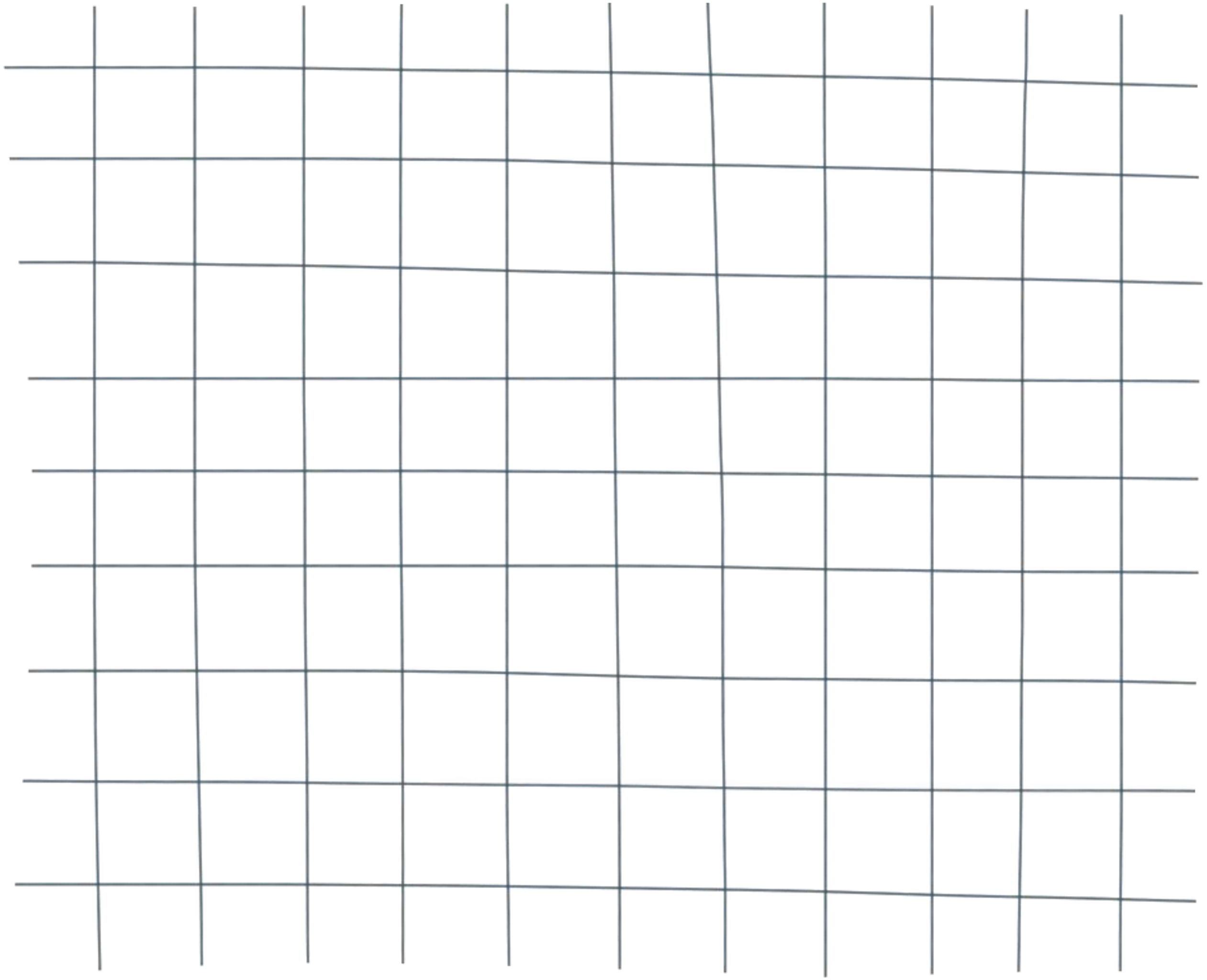
$$dFdx(x) \sim \frac{F(x+dx)-F(x)}{dx} \qquad \text{1b}$$

Backward differencing:

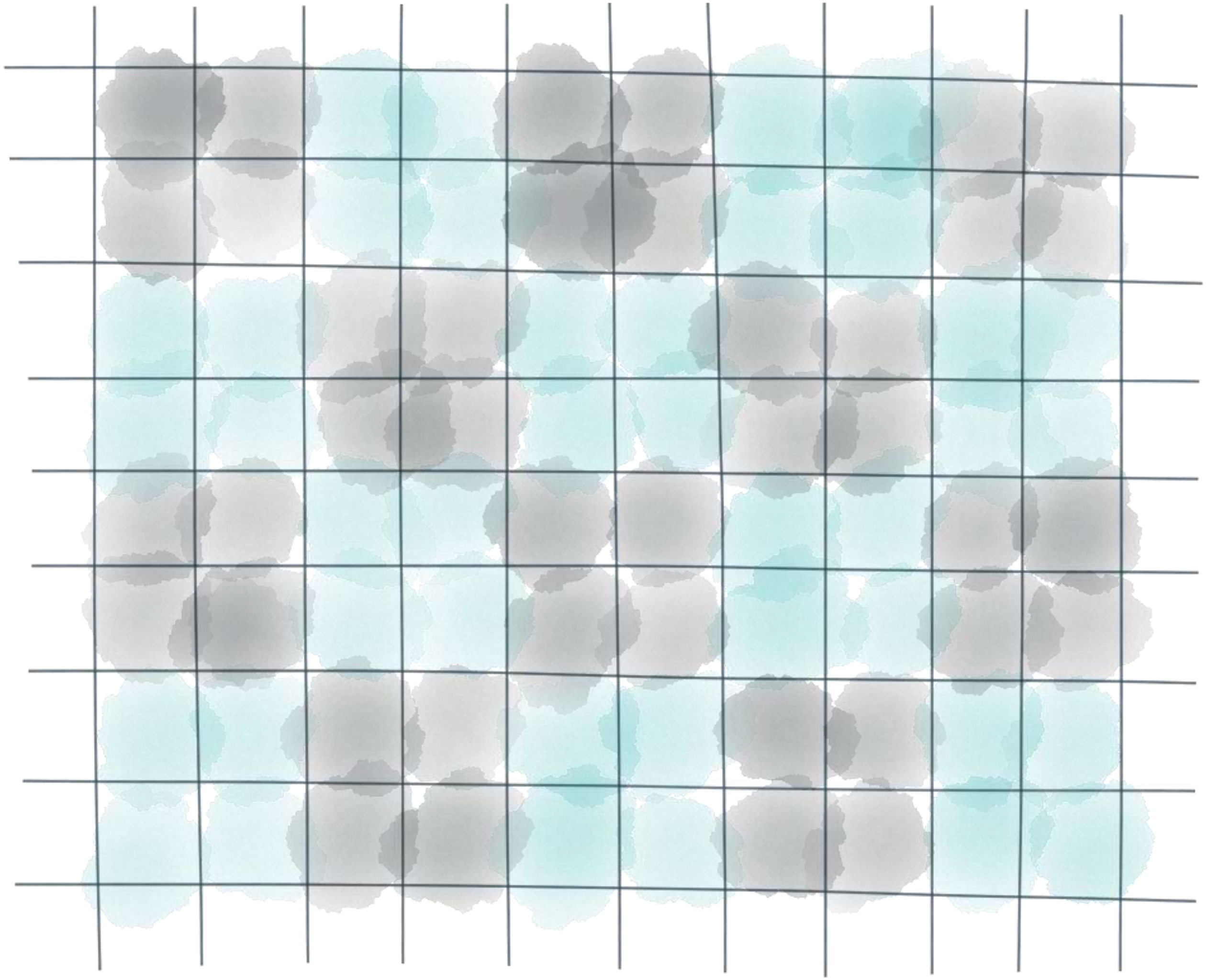
$$F(x-dx)-F(x) \sim -dFdx(x)\cdot dx \qquad \text{2a}$$

$$dFdx(x) \sim \frac{F(x)-F(x-dx)}{dx} \qquad \text{2b}$$

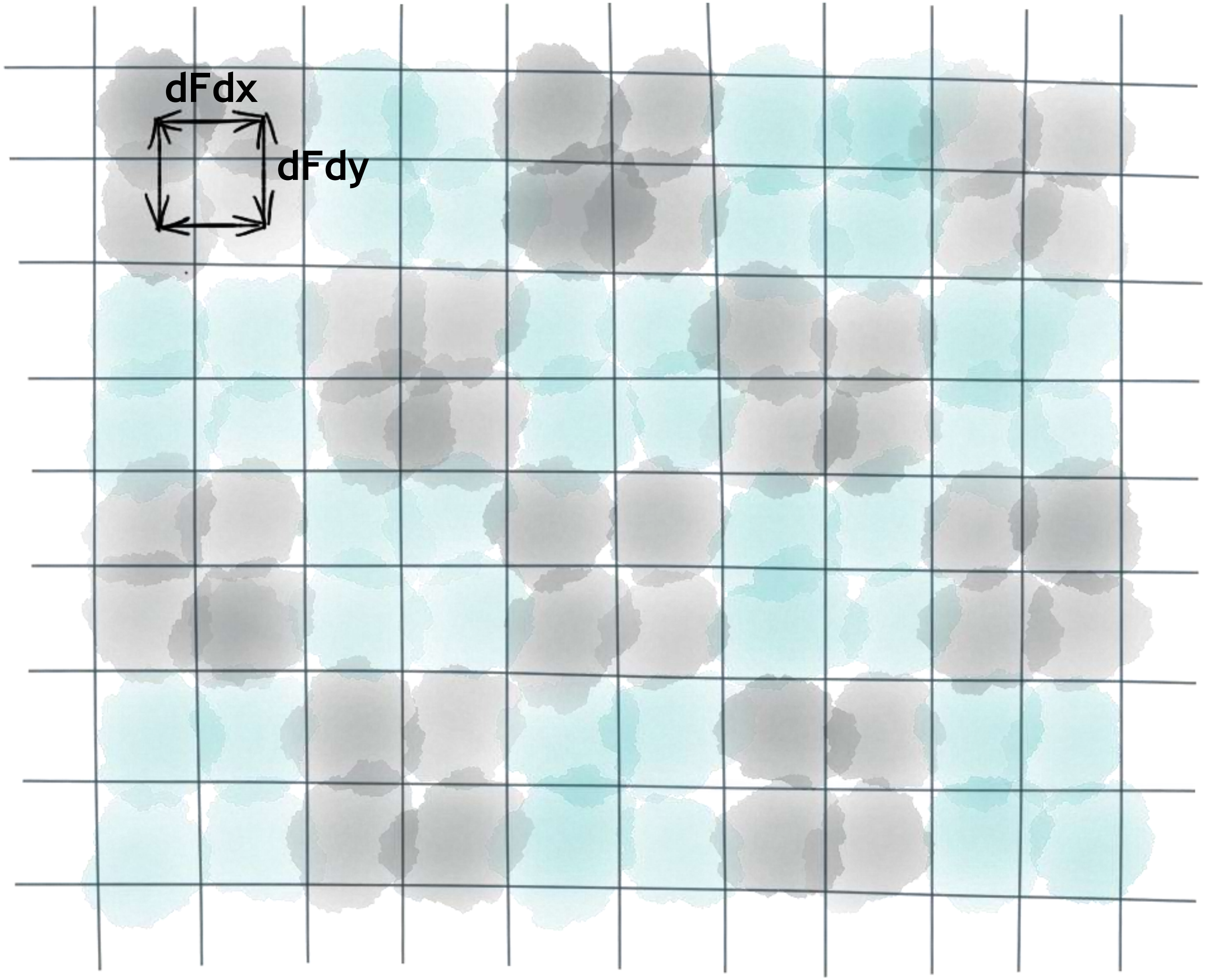
shader_helper_invocation



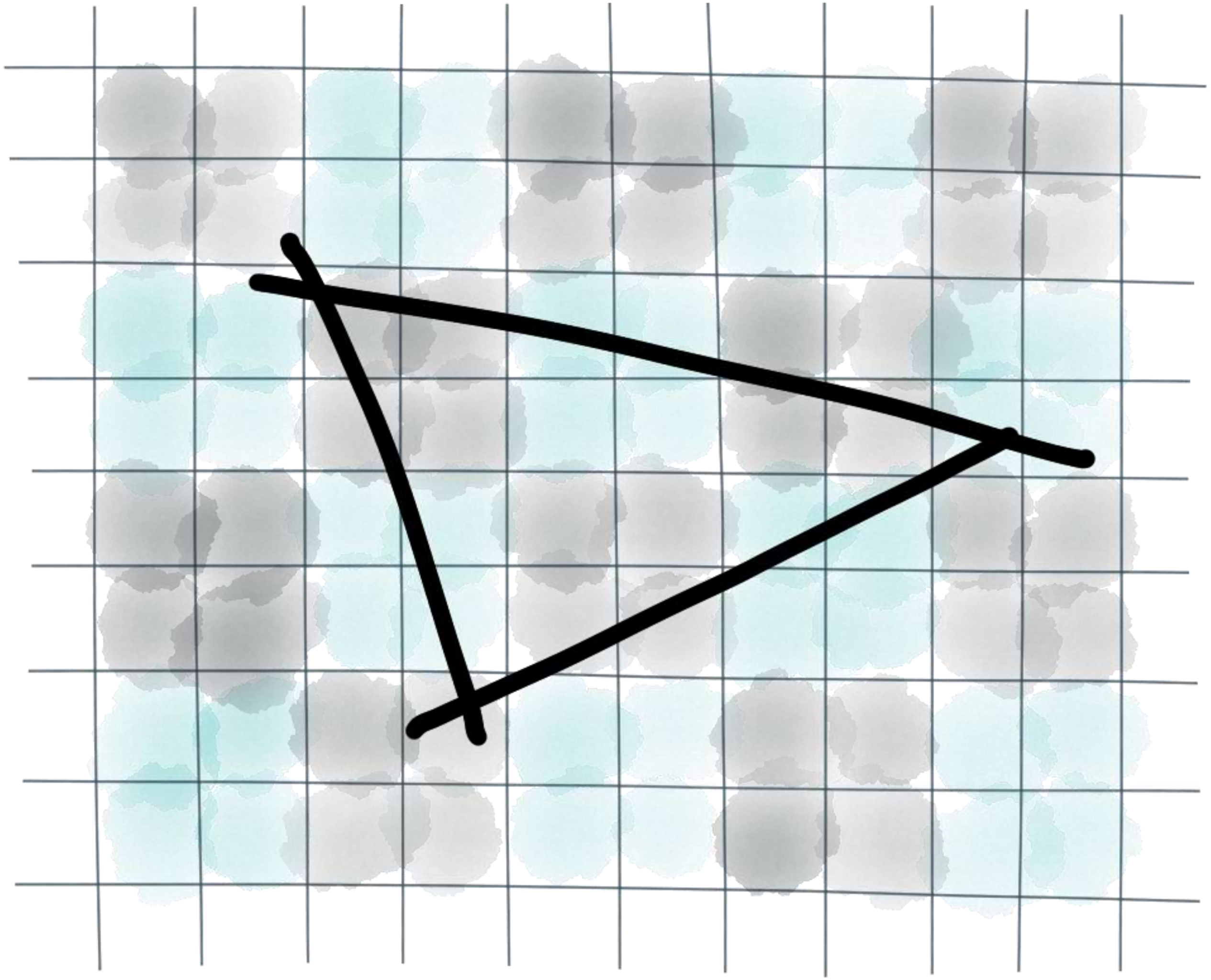
shader_helper_invocation



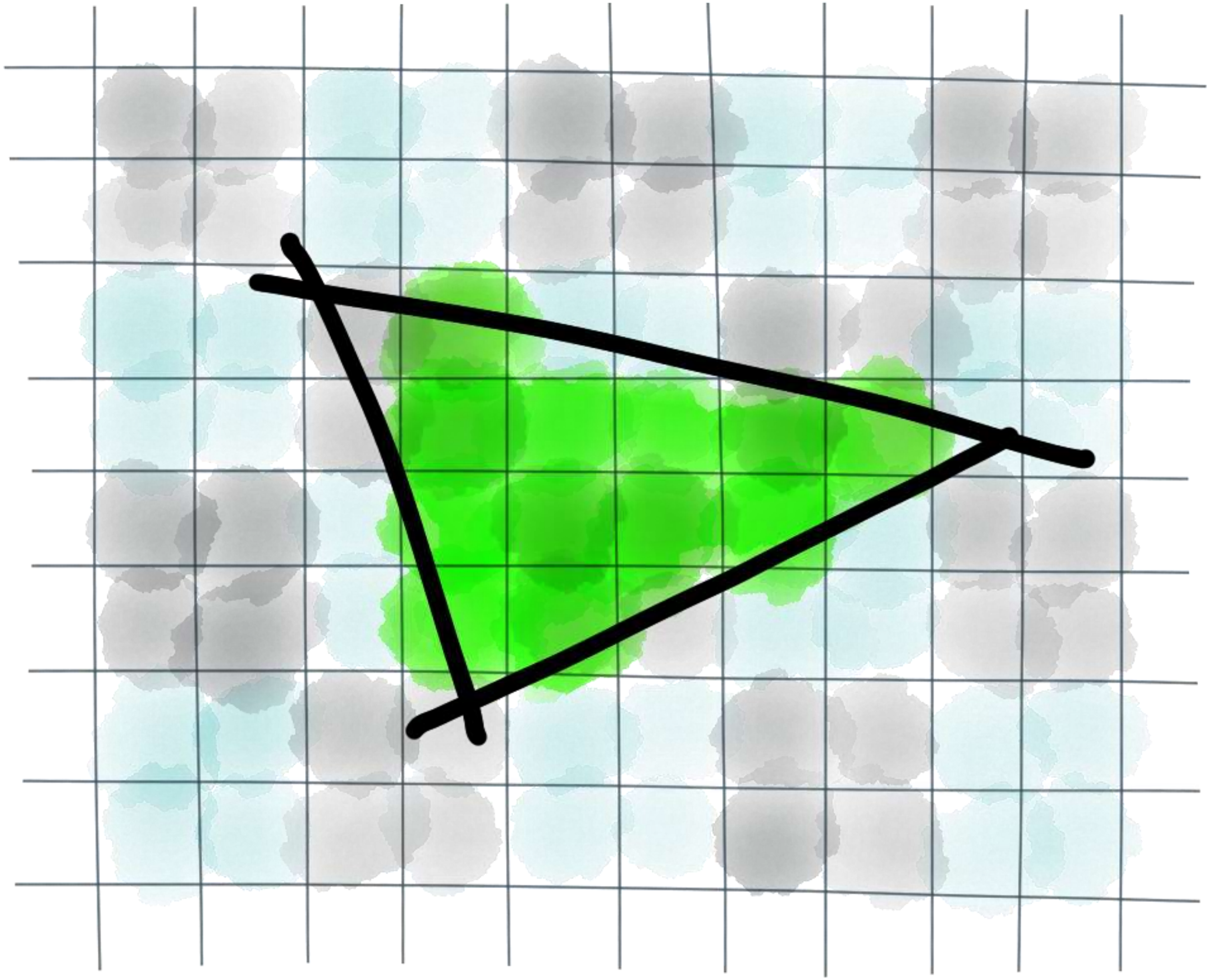
shader_helper_invocation



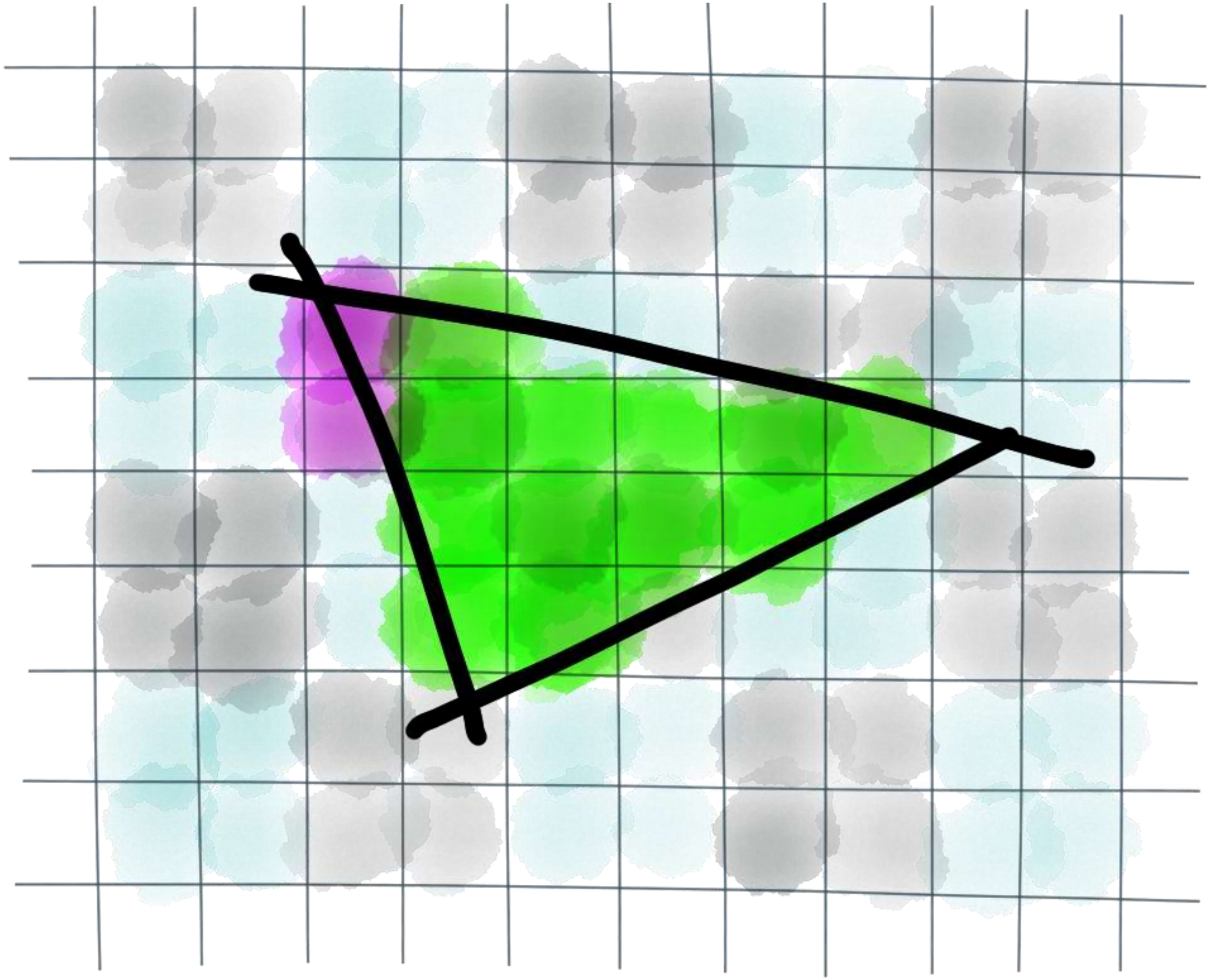
shader_helper_invocation



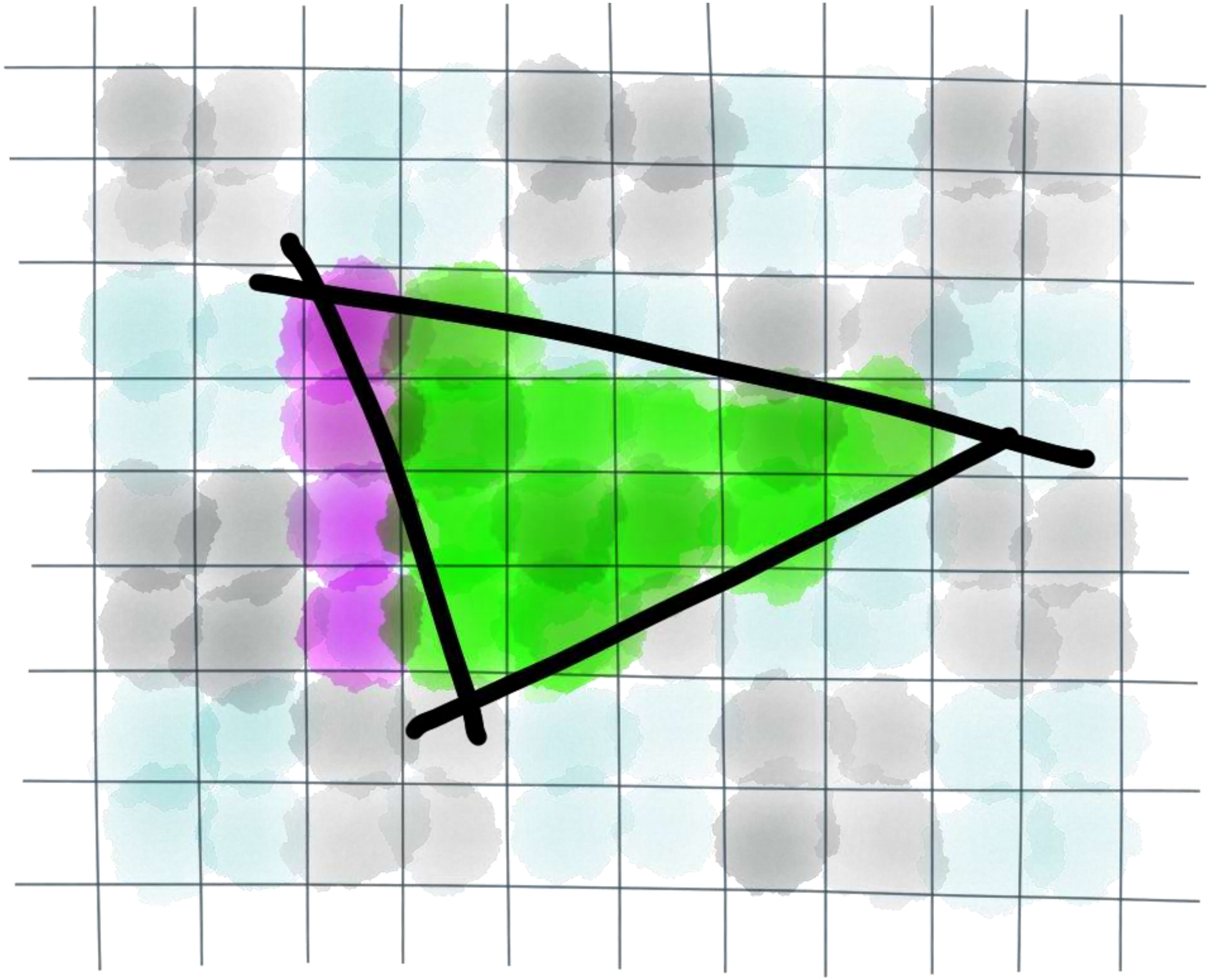
shader_helper_invocation



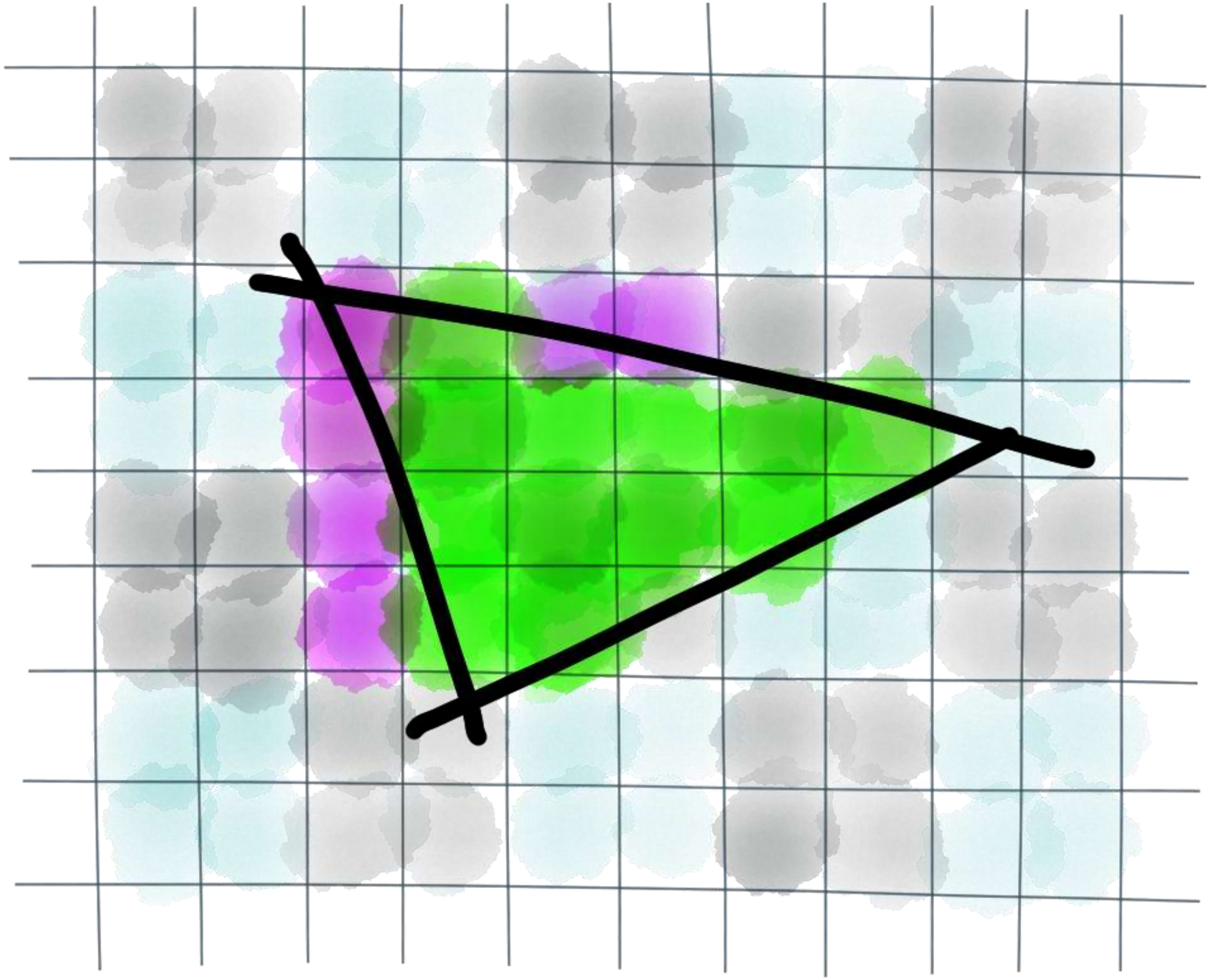
shader_helper_invocation



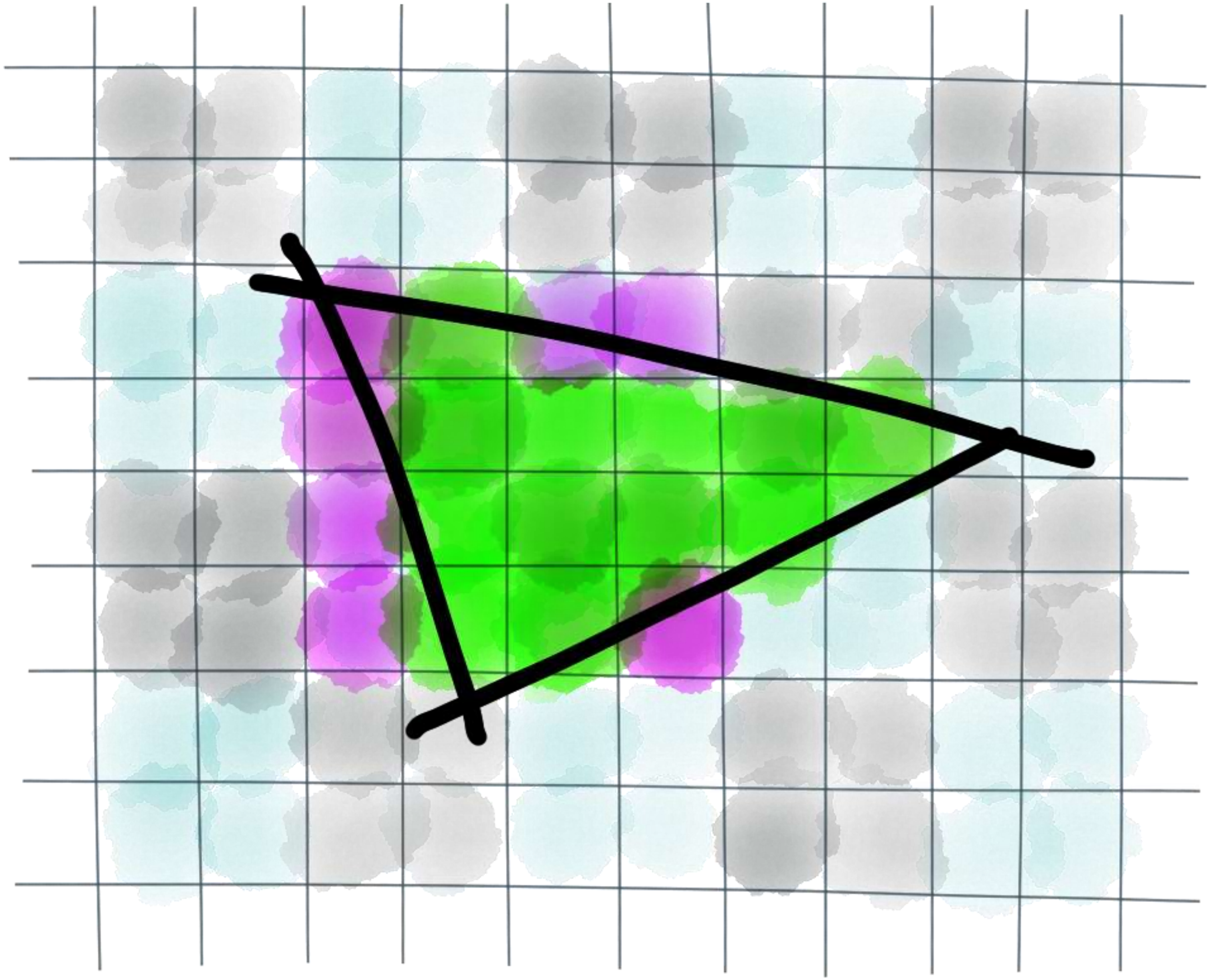
shader_helper_invocation



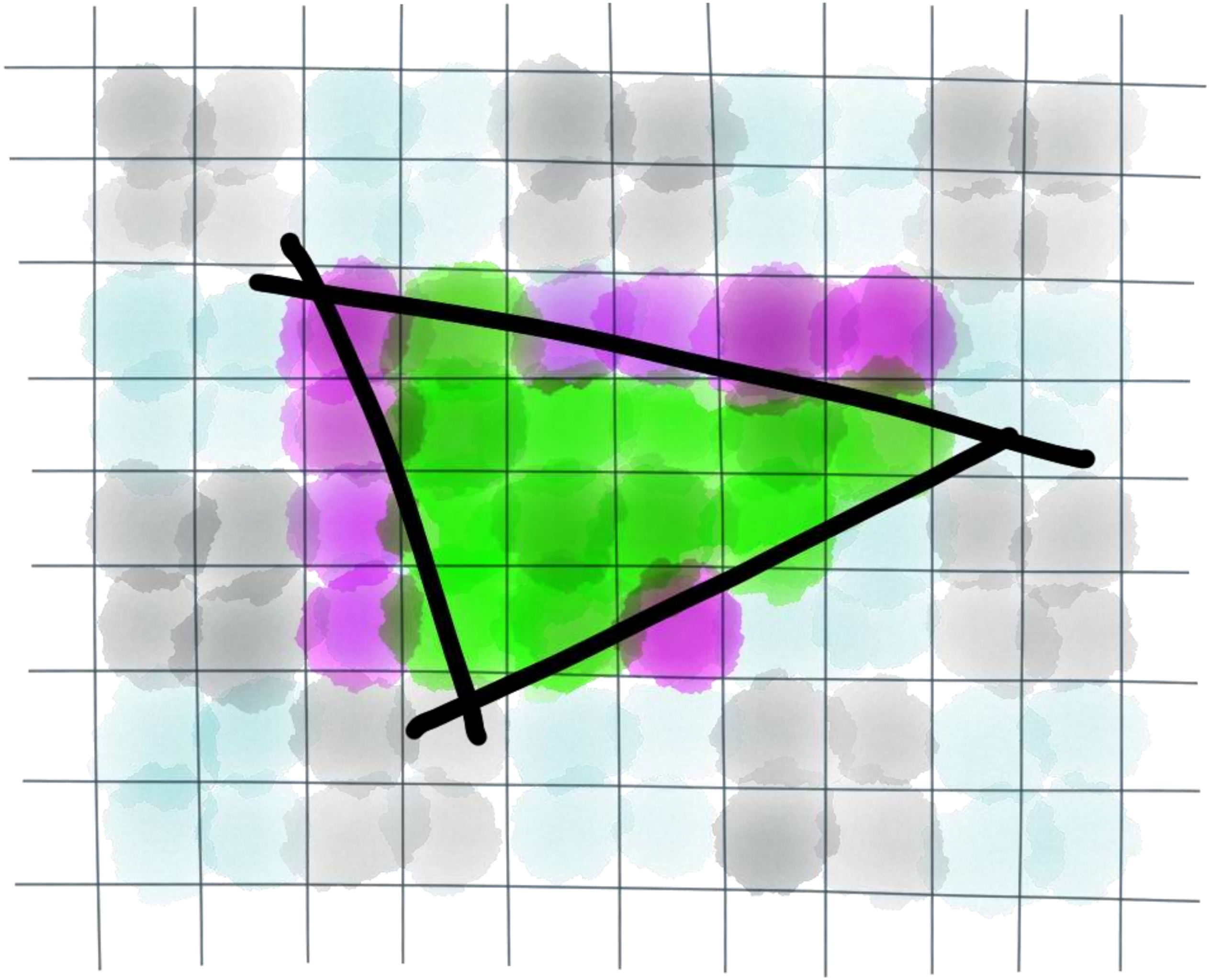
shader_helper_invocation



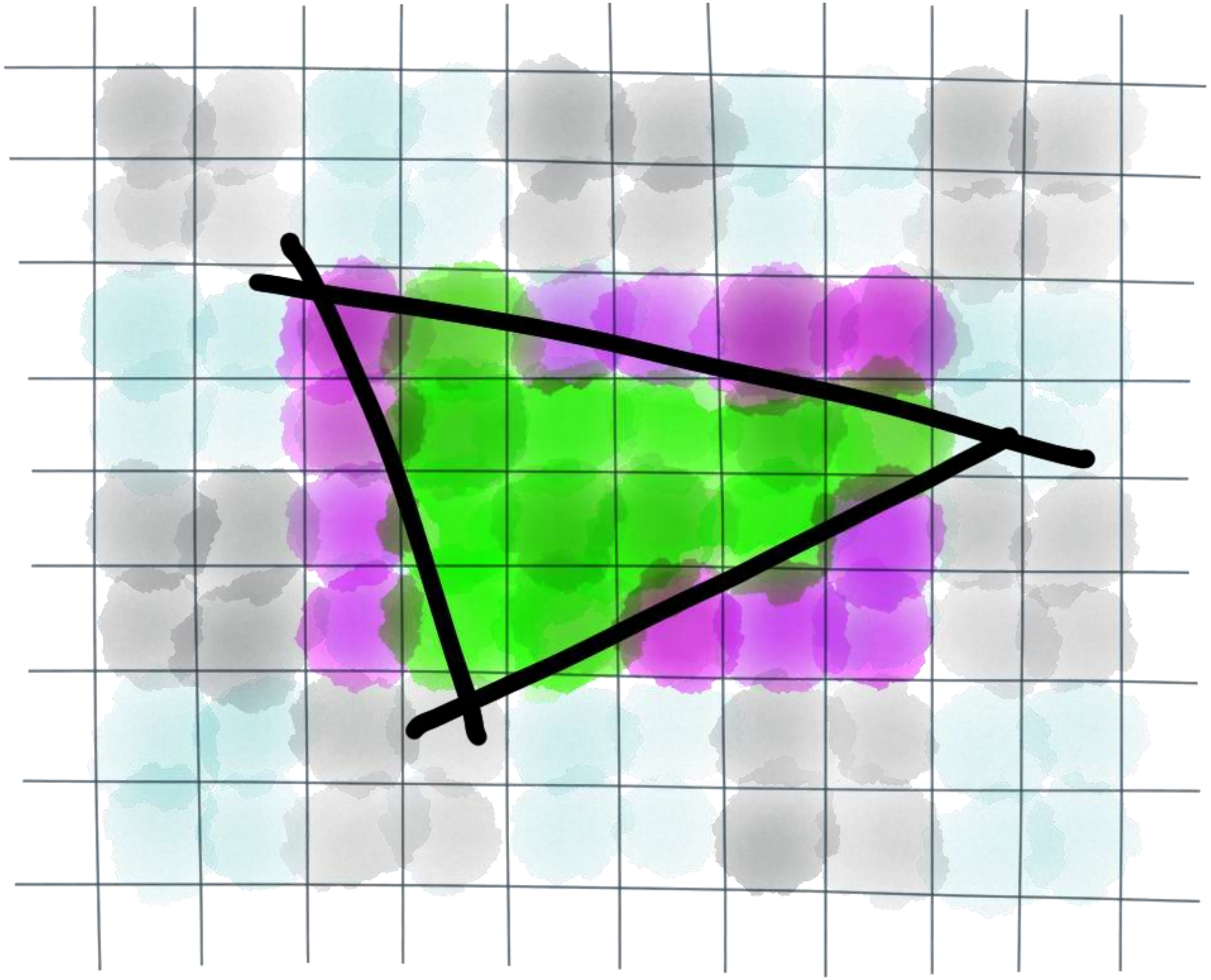
shader_helper_invocation



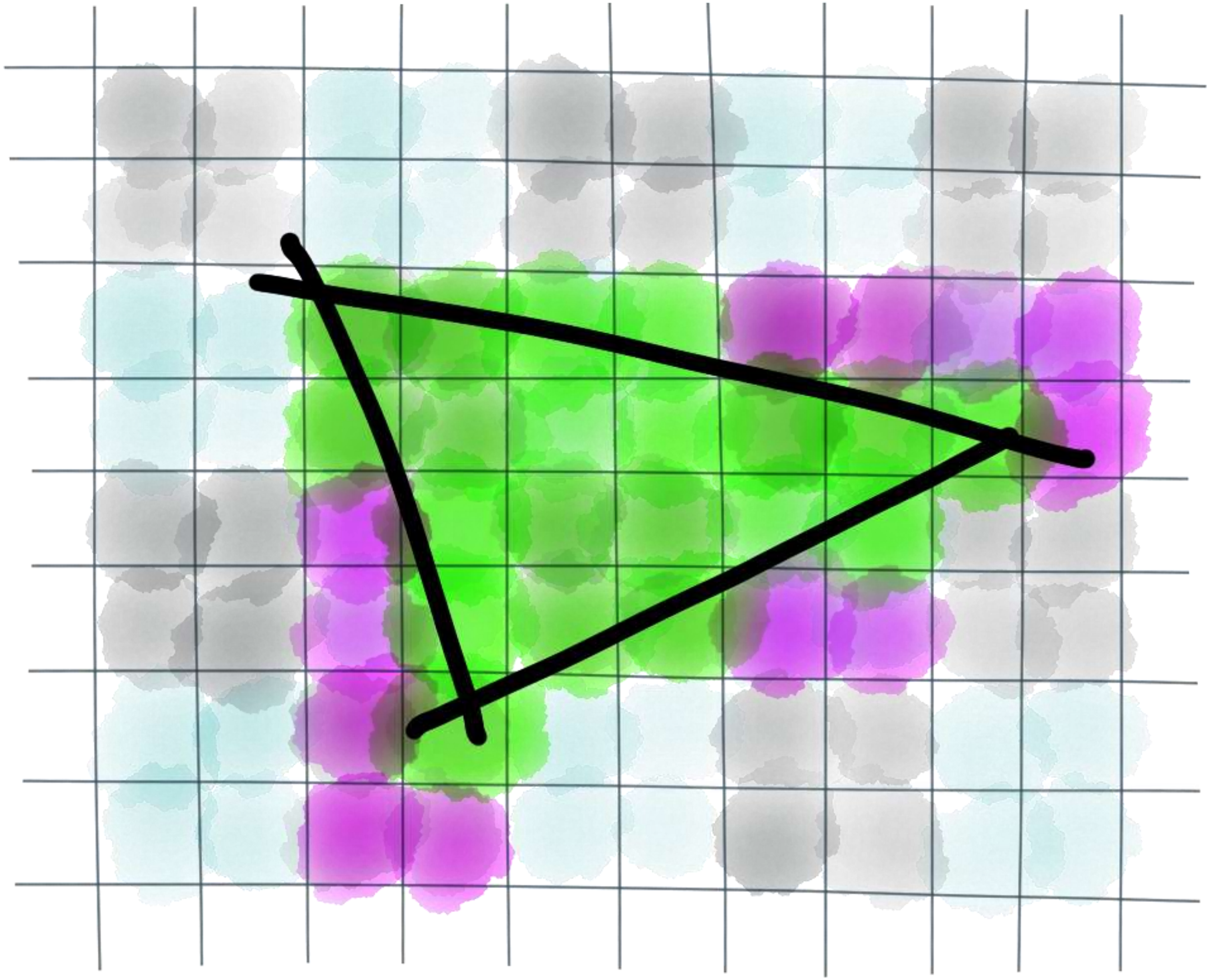
shader_helper_invocation



shader_helper_invocation



shader_helper_invocation



shader_helper_invocation

- **Two types of shader_helper_invocations:**
  - derivatives and extrapolation
  - derivatives and early fragment tests

shader_helper_invocation

- Why now?
- Side effects!
  - atomic_counters
  - shader_image_load_store
  - shader_storage_buffer_objects
- "Atomic operations to… atomic counter variables performed by helper invocations have no effect on the underlying… buffer memory. The values returned by such atomic operations are undefined."

shader_helper_invocation

```
layout(location=0) out uint data;
layout(binding=0,offset=0) uniform atomic_uint counter;
void main()
{


        uint limit = atomicDecrement( counter );
        uint count=0;
        for ( int i=0; i<limit; i++ )
        {
           count++;
        }
        data = count;

}
```

shader_helper_invocation

```
layout(location=0) out uint data;
layout(binding=0,offset=0) uniform atomic_uint counter;
void main()
{


        uint limit = atomicDecrement( counter );
        uint count=0;
        for ( int i=0; i<limit; i++ )
        {
           count++;
        }
        data = count;

}
```

shader_helper_invocation

```
layout(location=0) out uint data;
layout(binding=0,offset=0) uniform atomic_uint counter;
void main()
{
    if (!gl_HelperInvocation)
    {
        uint limit = atomicDecrement( counter );
        uint count=0;
        for ( int i=0; i<limit; i++ )
        {
            count++;
        }
        data = count;
    }
}
```

shader_bitfield_operations

- Bitfield operations from GPU_shader5
- added precision qualifiers

shader_bitfield_operations

```
highp genType frexp(highp genType x, out highp genIType exp);
highp genType ldexp(highp genType x, in highp genIType exp);
```

shader_bitfield_operations

```
highp uint   packUnorm4x8(mediump vec4 v);
highp uint   packSnorm4x8(mediump vec4 v);

mediump vec4 unpackUnorm4x8(highp uint v);
mediump vec4 unpackSnorm4x8(highp uint v);
```

shader_bitfield_operations

```
genIType bitfieldExtract(genIType value,
                            int offset, int bits);
genUType bitfieldExtract(genUType value,
                            int offset, int bits);

genIType bitfieldInsert(genIType base, genIType insert,
                           int offset, int bits);
genUType bitfieldInsert(genUType base, genUType insert,
                           int offset, int bits);
```

shader_bitfield_operations

```
highp genIType bitfieldReverse(highp genIType value);
highp genUType bitfieldReverse(highp genUType value);
```

shader_bitfield_operations

```
lowp genIType bitCount(genIType value);
lowp genIType bitCount(genUType value);

lowp genIType findLSB(genIType value);
lowp genIType findLSB(genUType value);

lowp genIType findMSB(highp genIType value);
lowp genIType findMSB(highp genUType value);
```

shader_bitfield_operations

```
highp genUType uaddCarry(highp genUType x,
                         highp genUType y,
                         out lowp genUType carry);
highp genUType usubBorrow(highp genUType x,
                          highp genUType y,
                          out lowp genUType borrow);
```

shader_bitfield_operations

```
void umulExtended(highp genUType x, highp genUType y,
                  out highp genUType msb,
                  out highp genUType lsb);
void imulExtended(highp genIType x, highp genIType y,
                  out highp genIType msb,
                  out highp genIType lsb);
```

arrays_of_arrays

- You can have arrays of arrays
- Subset
  - Can not use arrays of arrays for inputs and outputs
  - Can not use c-style initializers, {}, use constructors
  - Can not use all the declaration styles

arrays_of_arrays

```
int a[2][3][4][5];                                        // ok
```

arrays_of_arrays

```
int a[2][3][4][5];                // ok
int[2][3][4][5] b;                // error
```

arrays_of_arrays

```
int a[2][3][4][5];          // ok
int[2][3][4][5] b;          // error
int[3][4][5] c[2];          // error
int[4][5] d[2][3];          // error
```

arrays_of_arrays

```
int a[2][3][4][5];                    // ok
int[2][3][4][5] b;                    // error
int[3][4][5] c[2];                    // error
int[4][5] d[2][3];                    // error
int[5] e[2][3][4];                    // ok
```

arrays_of_arrays

```
int a[2][3][4][5];                                     // ok
int[2][3][4][5] b;                                     // error
int[3][4][5] c[2];                                     // error
int[4][5] d[2][3];                                     // error
int[5] e[2][3][4];                                     // ok
int f[2][2] = int[2][2](int[2](1,2),int[2](3,4)); // error
```

arrays_of_arrays

```
int a[2][3][4][5];                                   // ok
int[2][3][4][5] b;                                   // error
int[3][4][5] c[2];                                   // error
int[4][5] d[2][3];                                   // error
int[5] e[2][3][4];                                   // ok
int f[2][2] = int[2][2](int[2](1,2),int[2](3,4)); // error
int g[2][2] = int[][](int[2](1,2),int[2](3,4));   // ok
int h[2][2] = int[][](int[](1,2),int[](3,4));     // ok
```

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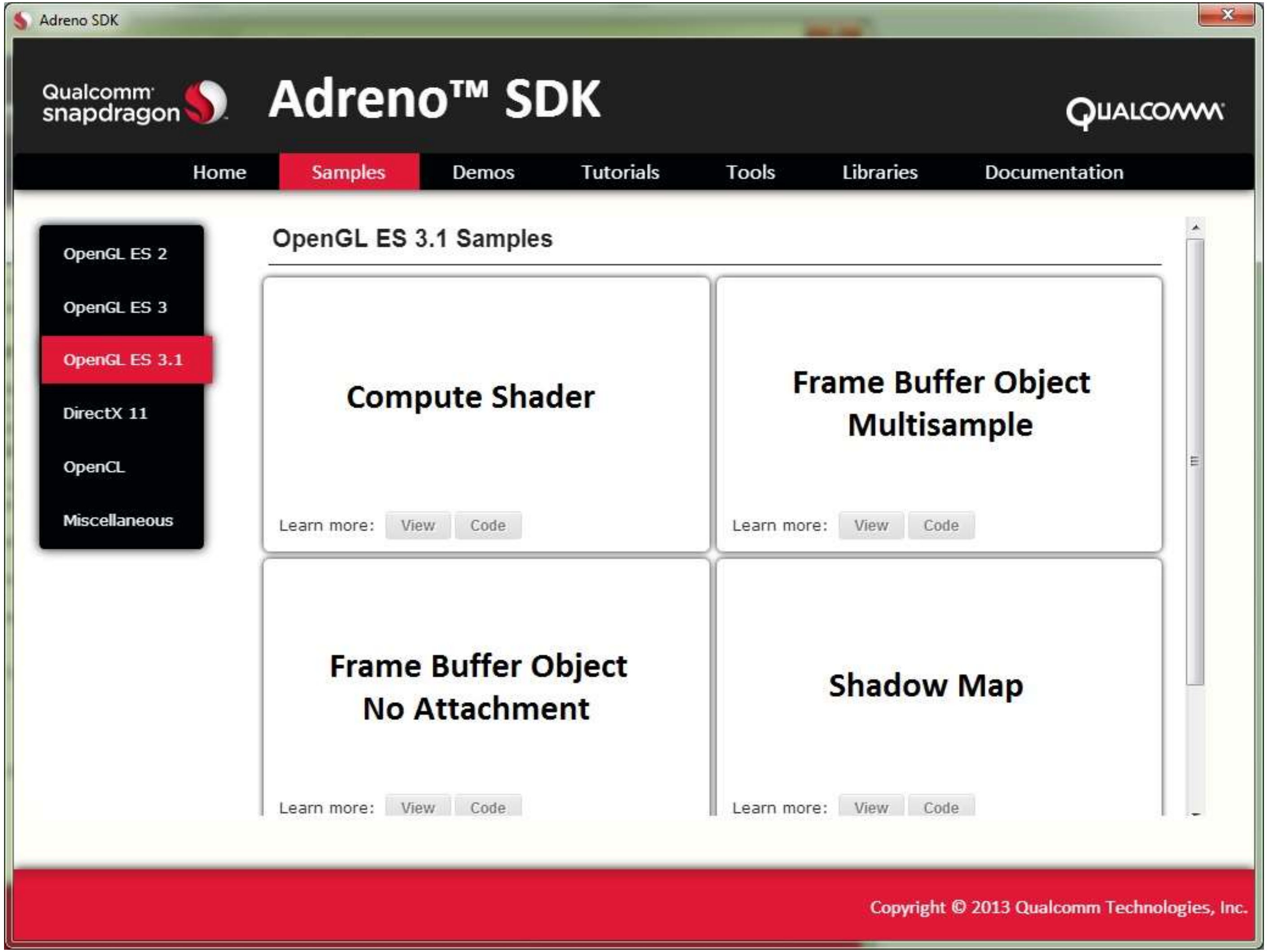
shader_integer_mix

```
genIType mix(genIType x,
             genIType y,
             genBType a)
genUType mix(genUType x,
             genUType y,
             genBType a)
genBType mix(genBType x,
             genBType y,
             genBType a)
```

developer.qualcomm.com - Thank You!



EGL 1.5 Features

Jon Leech
EGL and OpenGL ES 3.1 Spec Editor

First update since 2008

- **Lots of EGL functionality was developed in extensions**
- **Traditional EGL**
  - Interface to underlying platform (aka window system)
  - Graphics context and surface management
- **Current EGL - API “hub”**
  - Client API interop – sharing with GL ES, GL, CL, VG
  - EGLImage – share images (textures, video, etc.)
  - EGLSync – cross-API GPU-level fences

Platform Interfaces

- **EGL can now support multiple platforms in one runtime**
  - Traditional window systems or full-screen or headless
  - Android, GBM, Wayland, X11 defined today, more coming
  - Different ways to create EGLDisplays
  - Additional control possible, such as specifying an X11 Screen
  - Distinguish platform extensions from client extensions
- **Cleaned up 64-bit support**
  - EGLint was supposed to contain all possible attribute values but this didn’t always happen in practice
  - New EGLAttrib type explicitly large enough to contain pointers and handles
  - All commands taking attribute lists will henceforth be defined to use EGLAttrib

Contexts and Surfaces

- **Make context current without a surface**
  - Offscreen render-to-texture and compute
  - Graphics on compute servers without displays
- **Robust context creation**
  - Important for WebGL in particular
  - Restricts contexts to guard against malicious attacks on GPU, by enabling extensions like GL_EXT_robustness
  - Provides guarantees against buffer overruns
  - Control of and detection of graphics reset notification so single context / app failure won't cause wider takedown of the graphics stack
- **Create EGLSurfaces which GL / GL ES will render to in sRGB color space**

Image and Event Sharing

- **EGLImage allows sharing textures / renderbuffers / image objects between client APIs**
  - Promote a client API resource to an EGLImage
  - Bind an EGLImage to a client image
  - Explicit handoff between APIs (Acquire/Release)
  - Supported as KHR extensions for years, now EGL core
- **EGLSync allows finer-grained synchronization between client APIs**
  - Like GL fence sync objects, but the resulting EGLSync object can be converted to other forms (e.g. link EGLSync to OpenCL event)
  - Server-side waiting allows implementations to perform cross-API synchronization inside the GPU with no round trips to the CPU

Potential EGL Future Directions

- **These are interesting possibilities, not commitments**
- **EGLImageStream extensions are very powerful today**
  - But need wider implementation in drivers
  - Would like to stream other types of data – unformatted buffers for metadata and more
  - GPU-to-GPU streaming and invoking client API activities directly from other client APIs without CPU intervention
- **Separation of traditional context/surface functionality from “hub” functionality**
- **Support for new Khronos APIs where appropriate**
  - Streaming video + image processing + display use case

Wrap-up

OpenGL ES 3.1 Status

- Specifications and manual pages published
  - http://www.khronos.org/registry/gles/

- Conformance test is code complete and undergoing test
  - Expecting to start certifying implementations by mid-June
  - Note: major upgrade to ES 3.0 test released in January

- Khronos reference compiler in progress
  - http://www.khronos.org/opengles/sdk/tools/Reference-Compiler/
  - ‘Oracle of correctness’ for shader programs

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Khronos wants you!

- **Specs can always be better**
  - Tell us when you find an ambiguity or a hole in the specs
- **Conformance tests can always be better**
  - Tell us when you find out-of-spec behavior in conformant implementations
- **Man pages aren't perfect**
  - Tell us if there is missing / wrong information
- **https://www.khronos.org/bugzilla/**

Have Fun!