OpenGL® ES 3.0 and Beyond
How To Deliver Desktop Graphics on Mobile Platforms

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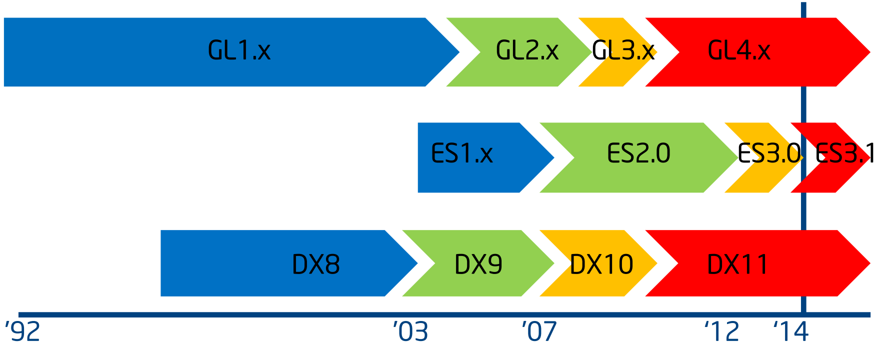
Legal

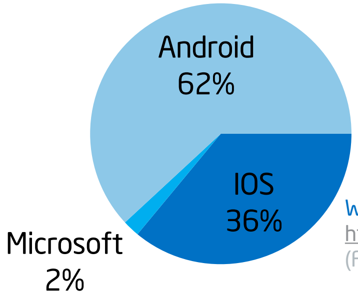
Why is OpenGL ES 3.0 and Beyond Important?

OpenGL ES 3.1 specification is released at GDC 2014.
http://www.khronos.org/registry/gles/

OpenGL ES 3.1 is reaching parity with desktop

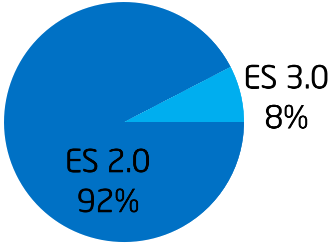


Android is dominant in the market



Worldwide Tablet Sales to End Users 2013
http://www.gartner.com/newsroom/id/2674215
(Feb 2014)

OpenGL ES 3.0 is gaining market share



Android OpenGL ES Version Support Distribution
https://developer.android.com/about/dashboards/index.html
(Feb 2014)

New Features for OpenGL ES 3.0

Main new features

- Multiple Render Targets
- Occlusion Queries
- Instanced rendering
- Uniform Buffer Objects (UBO) and Uniform Blocks
- Transform feedback
- Primitive restart
- Program Binary

Enhanced texturing functionality

- Swizzles, 3D textures, 2D array textures, LOD/MIP level clamps, seamless cube maps, immutable textures, NPOT textures, sampler objects

New renderbuffer and texture formats

- Floating point formats
- Shared exponent RGB formats
- ETC/EAC texture compression
- Depth and depth/stencil formats
- Single and dual channel texture
  - (R and RG)

ES Shading Language Version 3.00

- Full support for 32 bit integer/floating point data types (IEEE754)
- In/out storage qualifier
  - value copied to/from subsequent/previous pipeline stage
- Array constructors and operations
- New built-in functions

OpenGL ES 3.0 - Multi-Render Targets

What is it?

- Enables writing to multiple framebuffer color buffer attachment points with a single pass

Why is it useful?

- Techniques requiring multiple passes can be condensed into a single pass to save redundant execution of the vertex shader
- Useful for Deferred Shading and Screen Space Ambient Occlusion

OpenGL ES 3.0 - Multi-Render Targets

Enabled by attaching framebuffer-attachable images to GL_COLOR_ATTACHMENTi of a created FBO

- Support for at least 4 attachment points
  - Intel supports 8
- Maximum specified by GL_MAX_COLOR_ATTACHMENTS

Most often used in deferred shading i.e.

- 1 colour buffer for the surface colours
- 1 colour buffer for the surface normals
- 1 colour buffer for the depth values
- 1 colour buffer for extra lighting information, such as specular or ambient occlusion

OpenGL ES 3.0 - Multi-Render Targets Sample

GL ES API Code Snippet

```
// Create FBO and bind it
glGenFramebuffers(1, &fbo);
glBindFramebuffer(GL_FRAMEBUFFER, fbo);

// Create 2 textures, allocate storage and attach to FBO
glGenTextures(2, texBuf);
…
glFramebufferTexture2D(GL_FRAMEBUFFER, GL_COLOR_ATTACHMENT0, texBuf[0], 0);
glFramebufferTexture2D(GL_FRAMEBUFFER, GL_COLOR_ATTACHMENT1, texBuf[1], 0);

// Set the list of draw buffers.
Glenum drawBuffers[2] = {GL_COLOR_ATTACHMENT0, GL_COLOR_ATTACHMENT1};
glDrawBuffers(2, drawBuffers);
```

GLSL Fragment Shader Snippet

```
out vec4 my_FragData[2];

void main(void)
{
    my_FragData[0] = vec4(1.0, 0.0, 0.0, 1.0);
    my_FragData[1] = vec4(0.0, 1.0, 0.0, 1.0);
}
```

OpenGL ES 3.0 - Occlusion Queries

What is it?

- A hardware method for detecting whether an object is visible
  - Works by testing if samples pass the depth test
- Queries are asynchronous, but blocking call available if required

Why is it useful?

- Remove complex scene geometry by culling large batches of geometry via bounding box tests
  - Best on large scenes with large nearby occluders

OpenGL ES 3.0 - Occlusion Queries Sample

GL ES API Code Snippet

```
glGenQueries(1,  &query);
glBeginQuery(GL_ANY_SAMPLES_PASSED, query);
// Draw some primitives
…
glEndQuery(query);

// Check if the result is available
glGetQueryObjectuiv(query, GL_QUERY_RESULT_AVAILABLE, &result);
if (result == GL_TRUE)
{
    // This is a blocking call
    glGetQueryObjectuiv(query, GL_QUERY_RESULT, &anyPassed);
}
```

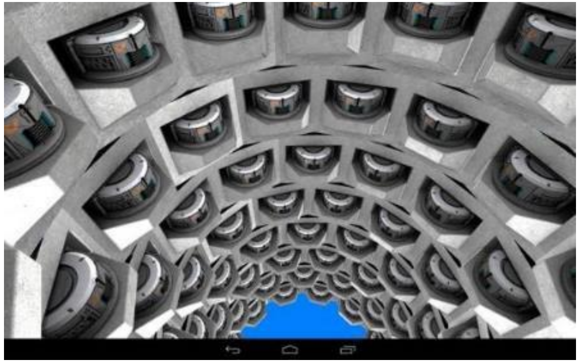
OpenGL ES 3.0 - Instanced Rendering

What is it?

- Enables rendering multiple geometry instances with a single draw call
- Instances may be provided with unique attributes (transformation, bones, etc.)

Why is it useful?

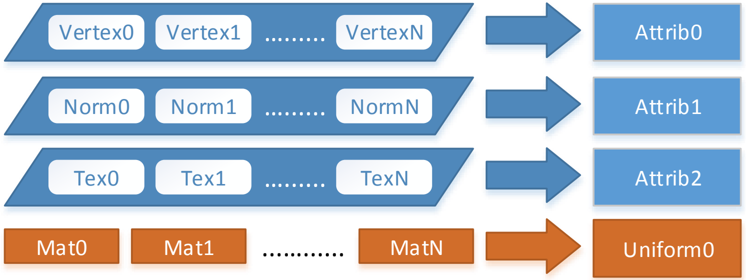
- Reduces API call overhead when rendering duplicate meshes



OpenGL ES 3.0 - Instanced Rendering

Non-instanced

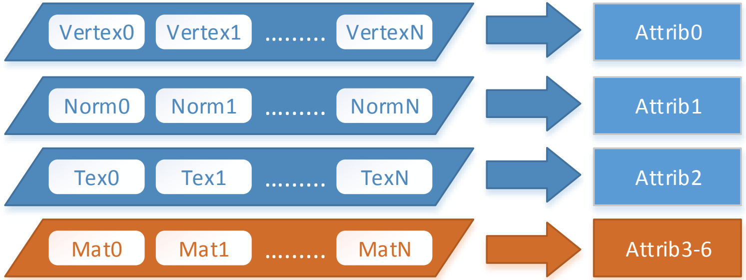
- BO's store Vertex, Normal, Tex data
- Transformations stored as uniform data
  - Set per-instance with glUniformMatrix*




```
for (int i = 0; i < NumInstances; ++i) {
    …
    glUniformMatrix4fv(…);
    ….
    glDrawElements(…);
}
```

Instanced

- BO's store Vertex, Normal, Tex data
- Transformations stored in a BO
  - glVertexAttribDivisor handles the creation of "instanced attributes"




```
glVertexAttribDivisor(3, 1);
…
glDrawElementsInstanced(…, NumInstances);
```

OpenGL ES 3.0 - Instanced Rendering Sample

GL ES API Code Snippet

```
// Attrib 0 (vertex information) changes per vertex
glVertexAttribDivisor(0,0)

// Attrib 1 (matrix data) changes per instance
glVertexAttribDivisor(1,1)
…

// When rendering
glDrawArraysInstanced(Mode, First, Count,
                      NumberOfInstances);
// or
glDrawElementsInstanced(Mode, Count, IndType, Indicies,
                        NumOfInstances);
```

GLES Vertex Shader Code Snippet

```
// By default attributes have a divisor of zero—advancing per vertex
// Attributes with a positive divisor will advance every divisor instances

// The built-in variable gl_InstanceID holds the current instance
// Default value is zero; safe to reference when not using instanced draw
// calls
in vec3 Position;

// Takes attribute positions 1,2,3,4
in mat4 WorldPosition;

// Pass the instance id on to the pixel shader
flat out int InstanceID;

void main()
{
   gl_Position = vec4(WorldPosition + Position, 1.0);
   InstanceID = gl_InstanceID;
};
```

OpenGL® ES 3.1

OpenGL ES 3.1

Intel announced support for the OpenGL ES 3.1 specification on the Bay Trail platform for Android.

http://blogs.intel.com/technology/2014/03/open-gl-es-gdc-2104-sweet-spot-mobile-graphics-evolution/

"Product is based on a published Khronos Specification, and is expected to pass the Khronos Conformance Testing Process when available. Current conformance status can be found at www.khronos.org/conformance."

Intel has extended support beyond the core specification to include Geometry Shaders, Tesselation and Intel Pixel Sync Technology.

OpenGL ES 3.1 Specification and header files can be found here :

http://www.khronos.org/registry/gles/

OpenGL ES 3.1 on Intel's Bay Trail Platform

Shader Stages
- Compute Shaders
- EXT: Tesselation
- EXT: Geometry Shaders

Shader I/O
- Shader Image Load Store
- Shader Storage Buffer Objects

Shader Synchronisation
- Atomic Counters
- OES: Shader Image Atomics
- INTEL: Fragment Shader Ordering

API Helpers
- Indirect Draw Commands
- Framebuffer No Attachments
- Program Interface Query
- Separate Shader Objects
- Vertex Attribute Binding

Textures
- Texture Storage Multisample
- OES: Texture Stencil 8

Blending
- KHR: Blend Equation Advanced

GLSL
- Array of Arrays
- Explicit Uniform Locations
- Shader Bitfield Operation
- Shader Layout Binding
- Texture Gather
- Stencil Texturing

GLSL Extensions
- OES: Shader Multisample Interpolation
- OES: Sample Shading
- OES: Sample Variables

Core

Extension

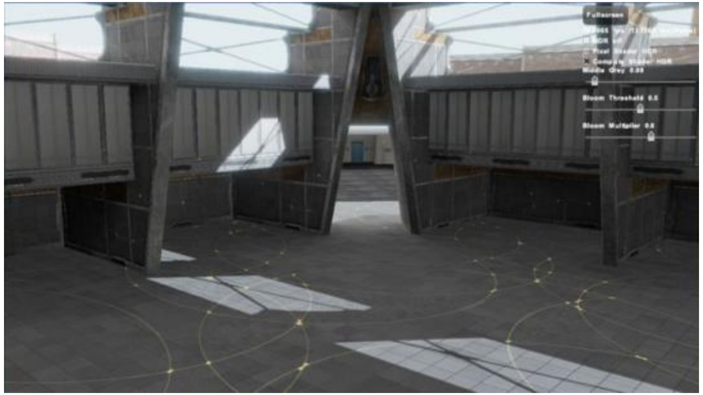
OpenGL ES 3.1 - Compute Shaders

What are they?

- A compute shader is used for general compute on shader defined inputs with shader defined outputs.
- Run logically independent of the 3D pipeline.
  - Although well pipelined with 3D primitives.
- Run at a user defined frequency.
- Similar to OpenCL® Kernels.
  - Allow better integration into 3D applications.
  - Can directly access OpenGL ES textures, images and buffer objects.
  - Can be efficiently pipelined with 3D primitives.
  - Lightweight.

Why are they useful?

- Compute shaders are frequently used on the desktop for image post-processing, deferred rendering, visibility culling, computer vision, particle physics, etc...



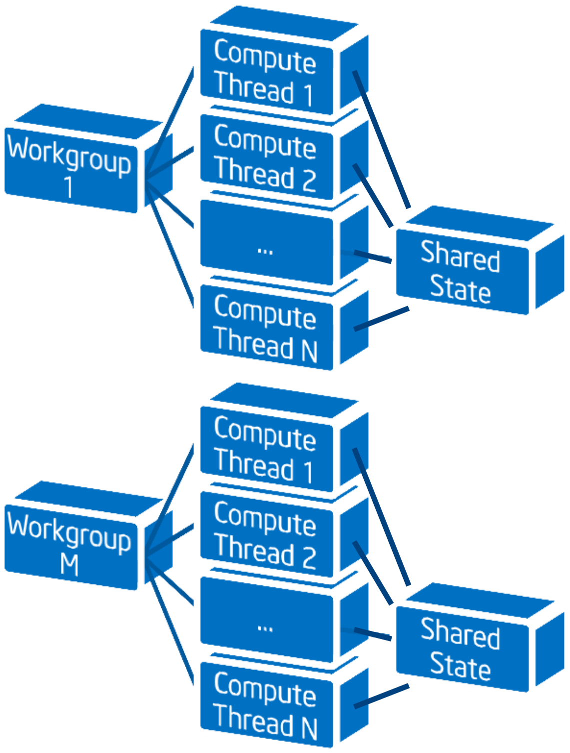
HDR using compute shaders

Cloth using compute shaders

OpenGL ES 3.1 - Compute Shaders

Compute shaders work on:

- Workgroups
  - Each workgroups consists of a number of compute shader threads,
  - The user defines the workgroup size and number of workgroups. Both parameters are in 3 dimensions.
    - The workgroup size is fixed at compilation time,
    - The number of workgroups is specified at dispatch time.
- Compute Shader Threads
  - Each thread can share data with other members of the workgroup via special shared variables,
  - Each thread can issue memory and control barriers to synchronise with other members of the workgroup,
  - Data can **not** be effectively shared between workgroups, unless via images, buffer objects or atomic counters,
  - Each thread can uniquely identify itself within a workgroup and globally with builtin variables. This is the only method for a thread to determine where to get its input and where to write its output.



OpenGL ES 3.1 - Compute Shaders

Compute shaders also bring:

- Shader Image Load Store
  - Random read/write access to a single level of a texture map
  - Atomic operations
- Shader Storage Buffer Objects
  - Random read/write access to variables stored within a buffer object
  - Atomic operations
- Shader Atomic Counters
  - Backed by buffer object memory
  - They allow the proper sequencing of memory accesses between workgroups

These are also available to other shader stages.

GL ES API Code Snippet

```
glGenTextures(1, &texHandle);
glBindTexture(GL_TEXTURE_2D, texHandle);
glTexImage2D(GL_TEXTURE_2D, 0, GL_R32F, 512, 512, 0, GL_RED, GL_FLOAT, NULL);

// Bind the texture to an image so it can be written to
glBindImageTexture(0, texHandle, 0, GL_FALSE, 0, GL_WRITE_ONLY, GL_R32F);

glUseProgram(computeHandle);
GLuint loc = glGetUniformLocation(computeHandle, "roll");
glUniform1f(loc, frame*0.01f);
// 512^2 threads in blocks of 16^2
glDispatchCompute(512/16, 512/16, 1);
```

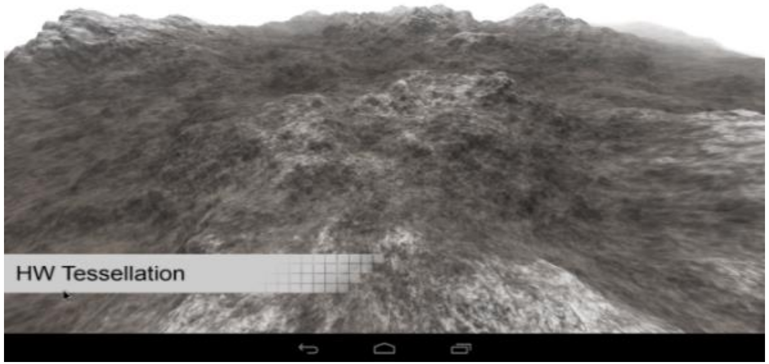
GLSL Compute Shader Code Snippet

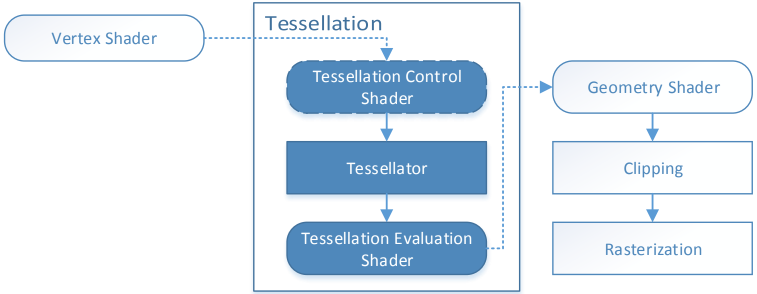
```
uniform float roll;
uniform image2D destTex;
layout (local_size_x = 16, local_size_y = 16) in; // 16x16 threads per workgroup
void main()
{
    ivec2 storePos = ivec2(gl_GlobalInvocationID.xy);
    float localCoef = length(vec2(ivec2(gl_LocalInvocationID.xy)-8)/8.0);
    float globalCoef = sin(float(gl_WorkGroupID.x+gl_WorkGroupID.y)*0.1 + roll)*0.5;
    imageStore(destTex, storePos, vec4(1.0-globalCoef*localCoef, 0.0, 0.0, 0.0));
}
```

OpenGL ES 3.1 EXT Extensions –Tessellation Shaders

What is it?

- An optional stage in the rendering pipeline that is capable of generating additional geometry
    - More efficient than geometry shaders for high levels of geometry expansion; tessellation can not be used for culling patches.
- The **control shader** operates on control points and is responsible for specifying tessellation levels, per-control point position and per patch varyings for the evaluation shader.
- The **evaluation shader** outputs the positions/normal/etc. using abstract coordinates from the tesselator
    - Each invocation operates on a single vertex within the tessellated patch





Why do you want it?

- Reduces memory bandwidth/footprint

What can you do with it?

- Progressive LOD, Displacement mapping, Sub-D surfaces, Complex hair modelling

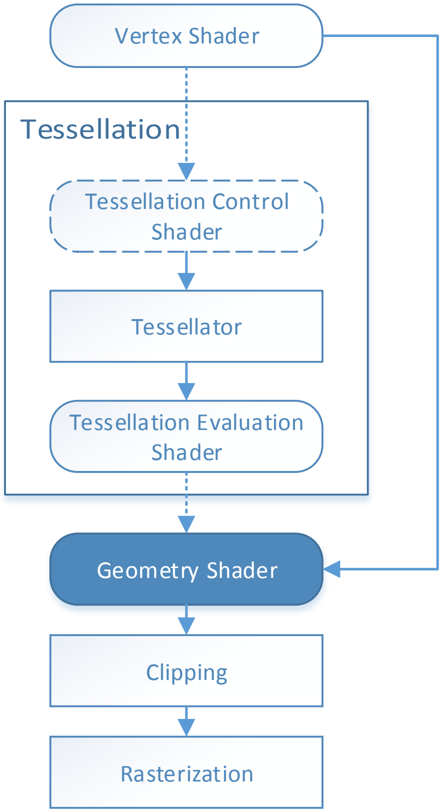
OpenGL ES 3.1 EXT Extensions - Geometry Shaders

What are they?

- A shader which processes the output of the primitive assembler (or the tessellation evaluation shader)
  - Full access to the assembled primitive (points, lines, lines with adjacency, triangles, triangles with adjacency)
  - Output new geometry (points, line strips, triangle strips)—does not have to match the input stage

Why are they useful?

- Impostors, Wireframe rendering, NPR, Procedural Geometry, Shadow Volume Extrusion, Geometry Culling
- Layered rendering(with the appropriate extensions)—rendering a single primitive to multiple images without changing render targets



OpenGL ES 3.1 Intel Extensions – Pixel Sync

What is it?

- An Intel OpenGL|ES Extension:
  `GL_INTEL_fragment_shader_ordering`
- Allows synchronisation to unordered memory accesses from within a shader
- Add a single builtin to your shader at the point of synchronization

```
beginFragmentShaderOrderingINTEL();
```

Why do you want it?

- Fragments mapping to the same pixel using unordered memory accesses can cause data races
- Fragments can be shaded out-of-order

What can you do with it?

- Order independent transparency
- Programmable blending
- Adaptive volumetric shadow maps
- Etc

Adaptive Volumetric Shadow Maps (AVSM)

No AVSM

With AVSM

Codemasters Grid 2 in-game screenshots

http://software.intel.com/en-us/articles/pixel-synchronization-solving-old-graphics-problems-with-new-data-structures

OpenGL ES 3.1 – More Information

- More demos can be seen at the Intel Booth (#1016) in the South Hall.
- You can hear more about OpenGL ES 3.1 and its use in real games by visiting further Intel talks entitled:
  - “SSX: Bringing a PS3 game to Android”
    – Thursday 10-11AM
  - “Adding High-end Graphical Effects to GT Racing 2 on Android x86”
    – Thursday 2:30-3:30
  - “Rendering in Codemasters’ GRID2 and beyond: Achieving the ultimate graphics on both PC and tablet”
    – Thursday 4-5PM

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- Intel University Games Showcase
  Marriott Marquis Salon 7, Thursday 5:30pm
  RSVP at **bit.ly/intelgame**
- Intel Developer Forum, San Francisco
  September 9-11, 2014
  intel.com/idf14
- Intel Software Adrenaline
  @inteladrenaline
- Intel Developer Zone
  software.intel.com
  @intelsoftware

Up Next…

3:30 – 4:30

Multi-player, multi-touch game development: Developing games for the fastest growing segment in desktop!

Presented by:

Alex Guo - Symbio Games & Faisal Habib - Intel