The Witness on Android Post Mortem

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3 March, 2017

Starting Point

- The Witness is in active development by Thekla
- Designed for PC and PS4/Xbox One
- Custom game engine
- Small codebase:

  about 1500 C++ source files and 200 DX11 shader source files

- OpenGL renderer is implemented but not perfect
- Extraordinary gameplay

Visual component is important for gameplay

Goals of the Port

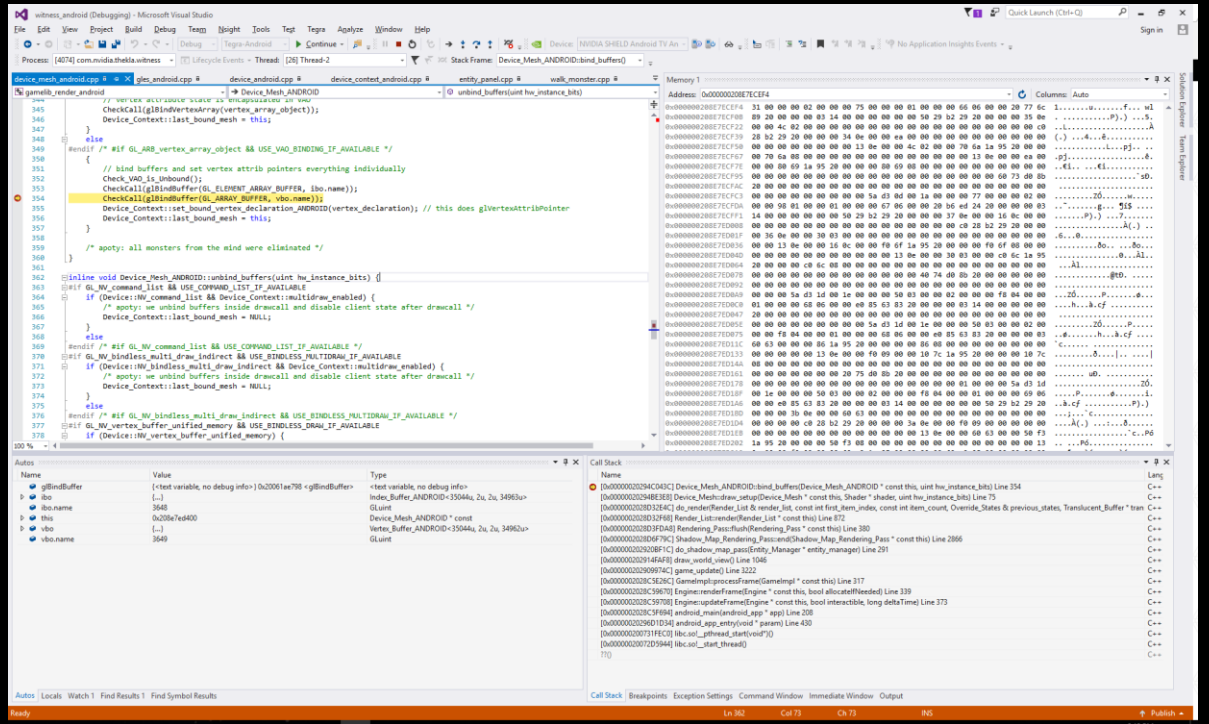
- PC quality shaders and effects
- Mobile quality textures, geometry and audio
- Input support for most controllers
- Cloud saves
- A mix of PC and console code/data
- Targeting AArch64

Porting Workflow

- Nsight Tegra
- Tegra System Profiler
- Tegra Graphics Debugger

Nsight Tegra, Visual Studio Edition

- Same projects as PC development environment
- Relatively fast because of small code base
- Java/Native debug



Middleware integration

- Straightforward port:
  - freetype
  - harfbuzz
  - ogg
  - vorbis

Bink – not very straightforward port

SSE to NEON

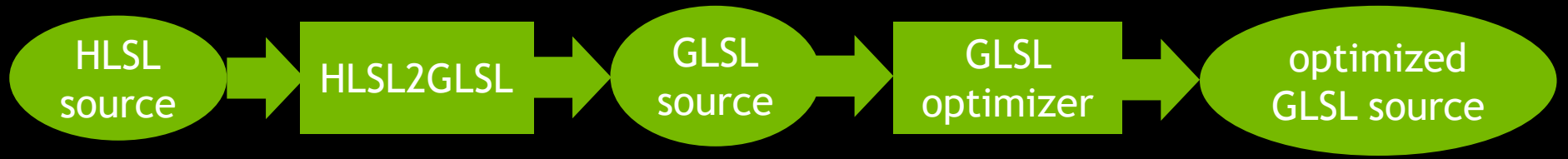
API translation layer:

```
FORCE_INLINE float _mm_cvtss_f32(__m128 a)
{
    return vgetq_lane_f32(a, 0);
}

FORCE_INLINE __m128i _mm_set_epi32(int i3, int i2, int i1, int i0)
{
     int32_t __attribute__((aligned(16))) data[4] = { i0, i1, i2, i3 };
     return vld1q_s32(data);
}

FORCE_INLINE int _mm_movemask_ps(__m128 a)
{
     static const uint32x4_t movemask = { 1, 2, 4, 8 };
     static const uint32x4_t highbit = { 0x80000000, 0x80000000, 0x80000000, 0x80000000 };
     uint32x4_t t0 = vreinterpretq_u32_f32(a);
     uint32x4_t t1 = vtstq_u32(t0, highbit);
     uint32x4_t t2 = vandq_u32(t1, movemask);
     uint32x2_t t3 = vorr_u32(vget_low_u32(t2), vget_high_u32(t2));
     return vget_lane_u32(t3, 0) | vget_lane_u32(t3, 1);
}
```

HLSL to GLSL

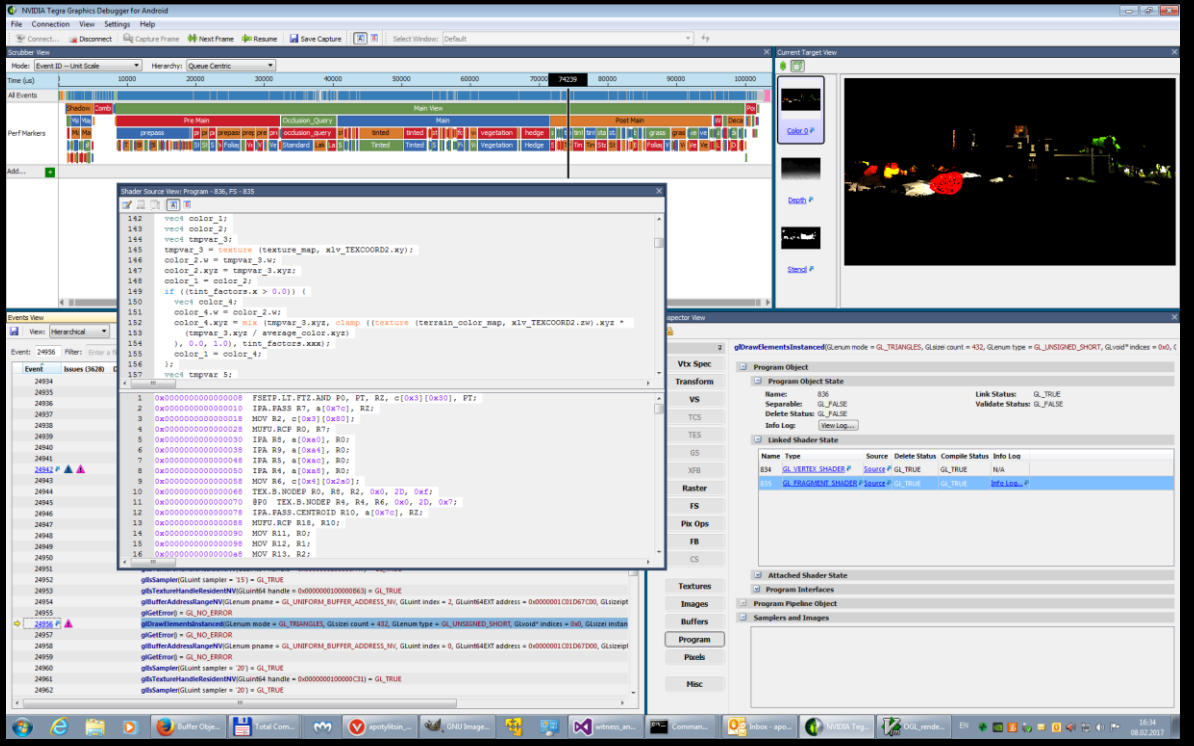

HLSL source
HLSL2GLSL
GLSL source
GLSL optimizer
optimized GLSL source

Shaders

- Shader compilation is slow
- Each android app has shader cache
- Pre warm: compile and release all shaders at every startup
- Only first startup is slow
- Now every shader is “compiled” immediately
- Whitelist: The Witness has about 2000 shader permutations (including debug/developer etc), only 300 are used

Tegra Graphics Debugger

- Deep dive via links into resource, event, texture, buffer views
- Dynamic editing and experiments
- Frame scrubber
- Frame profiler



GLSL Optimizer is not perfect:

```
int j = 0;
for ( ; (j < sy); (j++)) {
      int i = 0;
      for ( ; (i < sx); (i++)) {
```

became

```
for (int j_3; j_3 < sy_5; j_3++) {
   for (int i_7; i_7 < sx_6; i_7++) {
```

good enough to be compiled without errors and warnings

GLSL Optimizer output:

```
tmpvar_200.w = 0.0;
tmpvar_200.xy = uv_198;
tmpvar_200.z = tmpvar_164.z;
average_166 = (average_166 + ((tmpvar_170 * tmpvar_176) * texture (sun_shadow_texture, tmpvar_200.xyz)));
vec2 uv_201;
vec2 tmpvar_202;
tmpvar_202.x = tmpvar_173;
tmpvar_202.y = tmpvar_179;
uv_201 = (base_uv_165 + (tmpvar_202 * uv_inv_scale.zw));
uv_201.y = (1.0 - uv_201.y);
vec4 tmpvar_203;
tmpvar_203.w = 0.0;
tmpvar_203.xy = uv_201;
tmpvar_203.z = tmpvar_164.z;
average_166 = (average_166 + ((7.0 * tmpvar_176) * texture (sun_shadow_texture, tmpvar_203.xyz)));
vec2 uv_204;
vec2 tmpvar_205;
tmpvar_205.x = tmpvar_174;
tmpvar_205.y = tmpvar_179;
uv_204 = (base_uv_165 + (tmpvar_205 * uv_inv_scale.zw));
uv_204.y = (1.0 - uv_204.y);
vec4 tmpvar_206;
tmpvar_206.w = 0.0;
tmpvar_206.xy = uv_204;
tmpvar_206.z = tmpvar_164.z;
average_166 = (average_166 + ((tmpvar_171 * tmpvar_176) * texture (sun_shadow_texture, tmpvar_206.xyz)));
average_166 = (average_166 * 0.00694444);
```

Float packing

- Packing: converting floating point values to bytes in range [0, 255]

```
void * writePackedByte3(void * dst, const Bounding_Box &bbox, const float x, const float y, const float z) {
    uint8 * ptr = (uint8 *)dst;
    const Vector3 unpack_mesh_offs = bbox.min;
    const Vector3 unpack_mesh_scale = max((bbox.max - bbox.min), Vector3(0.1f);
    *ptr++ = nv::clamp(nv::iround(((x - unpack_mesh_offs.x) / unpack_mesh_scale.x) * 255.f), 0, 255);
    *ptr++ = nv::clamp(nv::iround(((y - unpack_mesh_offs.y) / unpack_mesh_scale.y) * 255.f), 0, 255);
    *ptr++ = nv::clamp(nv::iround(((z - unpack_mesh_offs.z) / unpack_mesh_scale.z) * 255.f), 0, 255);
    return ptr;
}
```

- Considering small/flat meshes to avoid divide by zero
- Sending bytes to shader program as GL_BYTE array
- Values are scaled to [0, 1] when vertex shader gets them

Floats packing

- Increasing scale when rendering to avoid some gaps in meshes

```
const Vector3 unpack_mesh_scale = max((bbox.max - bbox.min), Vector3(0.1f) * (256.f / 255.f);
```

- Unpacking: rescaling to original size

```
in vec4 attr_position;

float3 unpack_position(float3 position) {
    return ((position * unpack_mesh_scale.xyz) + unpack_mesh_offs.xyz);
}
```

- Same method is used to pack values in 2-byte integers

Float packing

How to pack sign into vector’s coordinates?

- Normalize vector
- Divide negative vector by two
- Unpack sign:

```
float4 unpack_tangent(float4 tangent) {
      tangent.w = sign(dot(tangent.xyz, tangent.xyz) - 0.255f);
      tangent.xyz = normalize(tangent.xyz);
      return tangent;
}
```

Float packing

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      return tangent;
}
```

- Realize what would happen when you normalize zero vector

Float packing

Fixed version:

```
float4 unpack_tangent(float4 tangent) {
    float d = dot(tangent.xyz, tangent.xyz);
    float s = sign(d - 0.56f);
    tangent.w = s * sign(d);
    tangent.xyz = tangent.xyz * (1.5f - 0.5f * s);
    return tangent;
}
```

Low Latency Audio

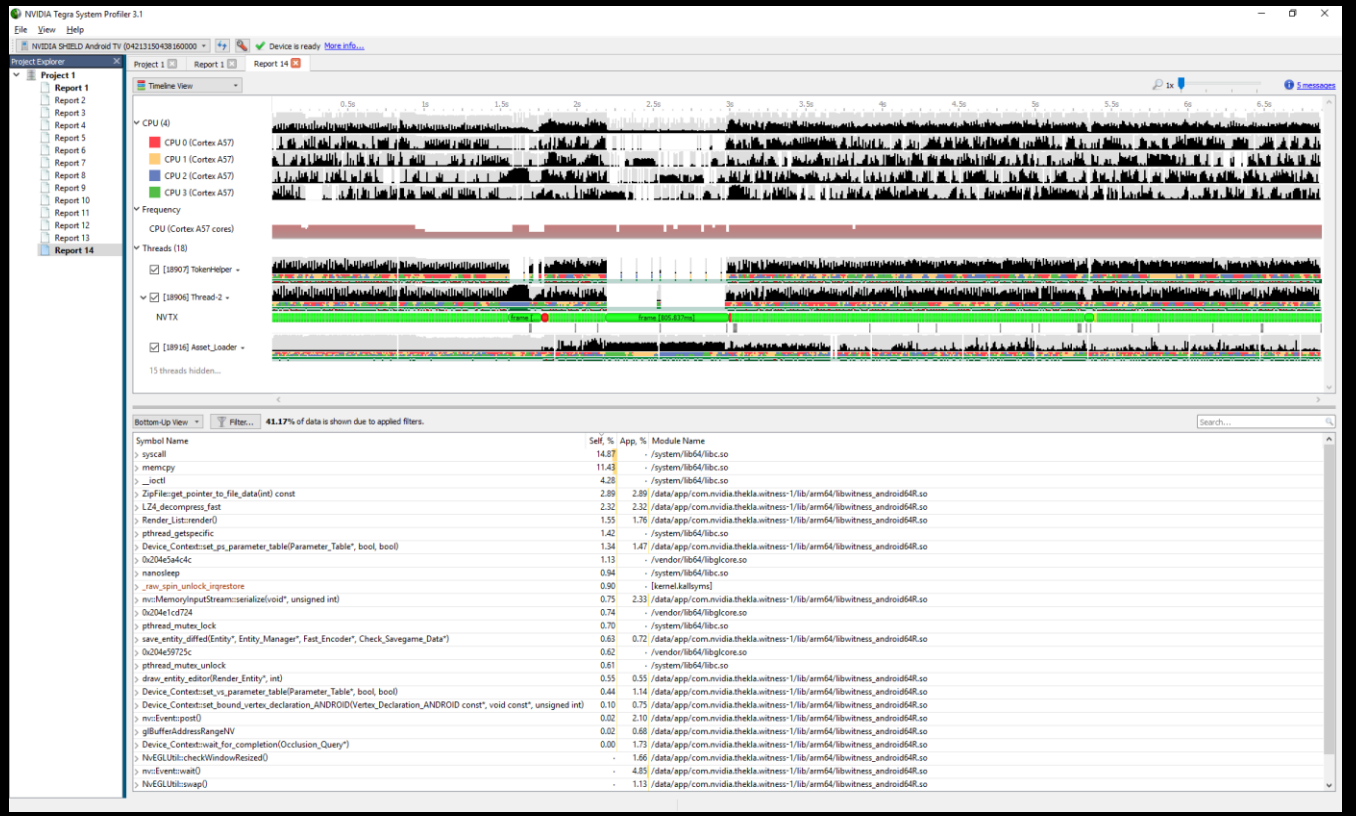
Usually, latency of normal audio mixer is about 200-300ms

But AudioFlinger can use fast mixer (10-20ms):

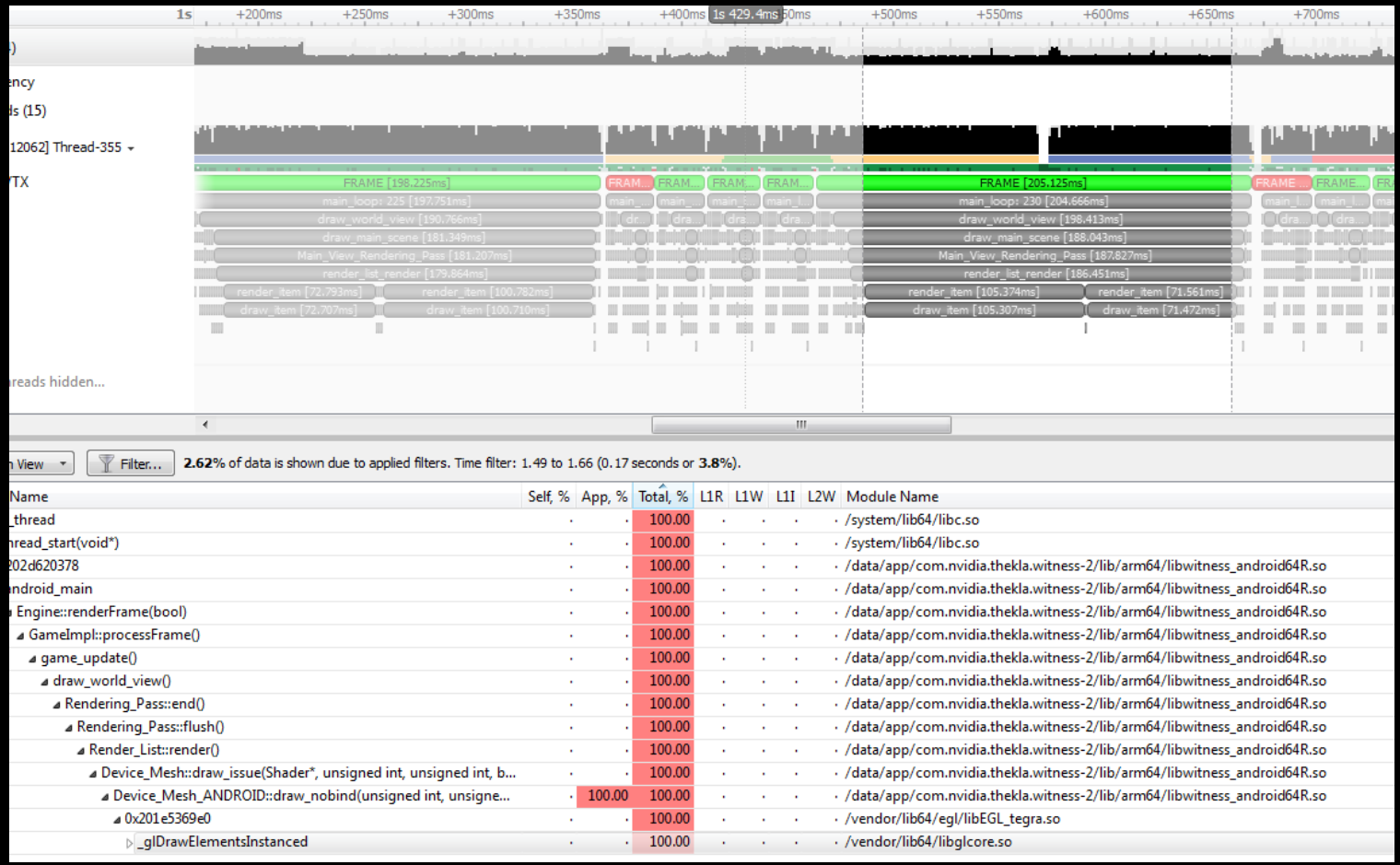
- Accessed only through OpenSL ES
- OpenSL AudioPlayer must match format of low level audio. Must be the same:
  - number of channels
  - sample rate
  - buffer size

Tegra System Profiler

- Sampling profiler, configurable rate and counters
- Top down/bottom up/flat
- Core migration
- Filter by thread



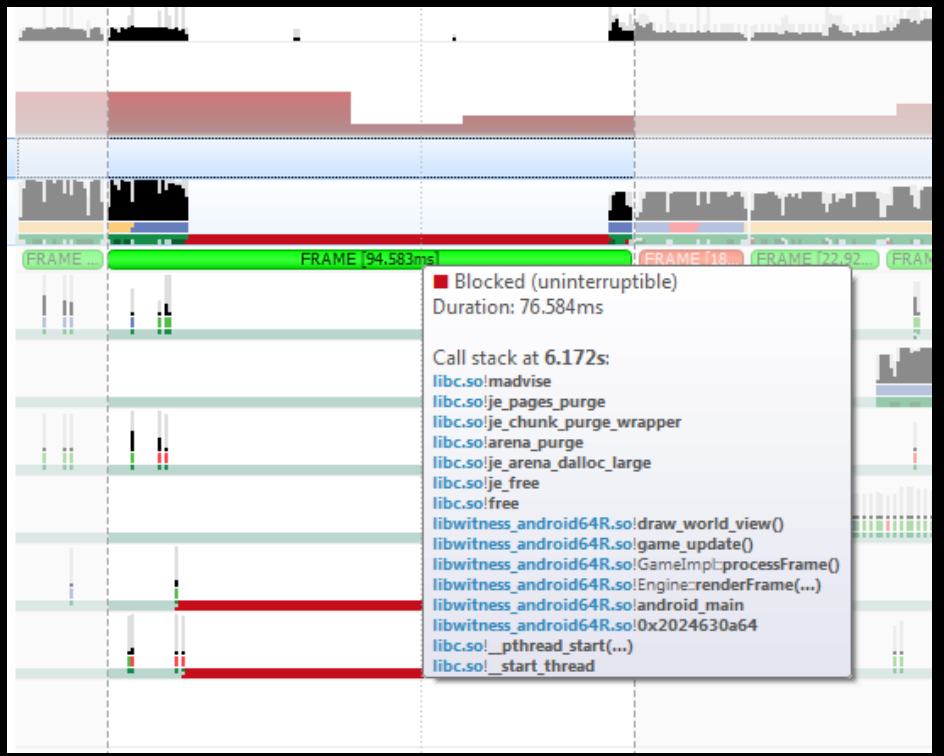
Sometimes shader can be compiled by driver during draw call



Memory issues

Extensive memory allocation causes:

- Blocks from memory management functions
- CPU downclocking
- Crash due to lack of virtual memory



Memory issues

What we fixed:

- Reduced memory allocations
  - Per frame allocations are very critical
  - Third party libraries and drivers should be considered too
  - Use stack when it’s possible
- Fixed memory leaks
- Used memory mapped files

OpenGL - Zero driver overhead

- Per-mesh vertex array object (ARB_vertex_array_object extension)
- Uniform buffer objects for shader parameters (ARB_uniform_buffer_object extension)
- Single parameter block was split in two parts: per_shader and per_item
- Direct state access (ARB_direct_state_access extension)
- True hardware instanced rendering
- Uploading textures via pixel buffer objects
- Bindless textures (NV_bindless_texture extension)

OpenGL - Zero driver overhead

- Unified memory for vertex buffer objects (NV_vertex_buffer_unified_memory extension)
- Unified memory for uniform buffer objects (NV_uniform_buffer_unified_memory extension)
- Multi-Draw Indirect (NV_bindless_multi_draw_indirect extension)
- Persistent mapped buffers (ARB_buffer_storage extension)

Tools summary

NVIDIA's in-house porting tools can help you push game to the limits

Nsight Tegra

- Visual Studio efficiency, with cross-platform Android development
- C/C++ multi-platform projects, builds, and debugging

Tegra System Profiler

- Get the big picture! How are your algorithms, APIs, and system interacting?
- Find hotspots, thread, and hardware sync issues you never even expected

Tegra Graphics Debugger

- Debug complex graphics issues
- Analyze and tune shader performance

How to get it

Codeworks

https://developer.nvidia.com/codeworks-android

Simple single installer Android development environment

SDK, NDK, ANT, Gradle, NVIDIA tools, samples, drivers …

Questions? Thank you

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