Profiling and Debugging Games on Mobile Platforms

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The Architecture for the Digital World® ARM®

Agenda

- Introduction to Performance Analysis with ARM® DS-5™ and Streamline™
- Debugging with Mali™ Graphics Debugger
  - Architecture
  - Features
- Working out Limiting Factor
  - CPU bound
  - Fragment Bound
  - Vertex Bound
  - Bandwidth Bound
- Identify the problem and find out how to fix it
- Vertex Buffer Objects
- Q & A

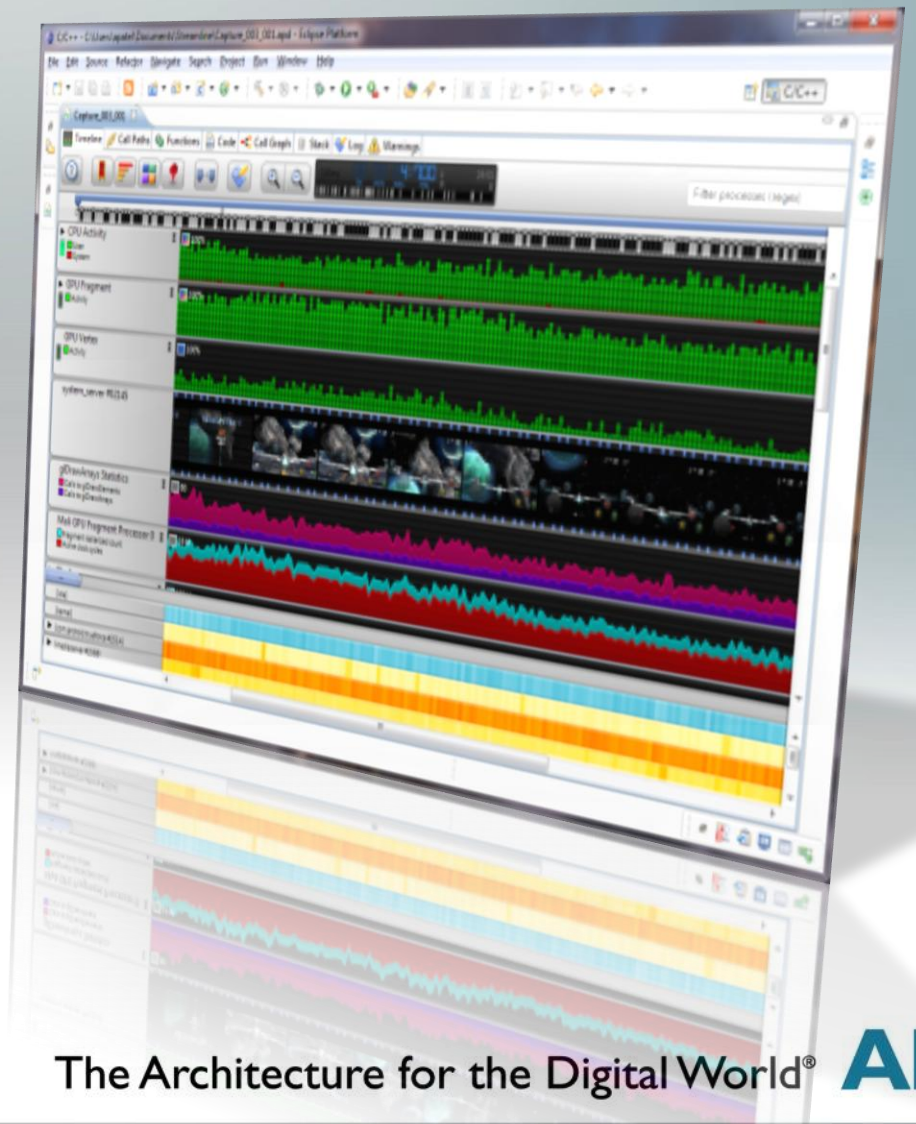
ARM Mali Developer Center

- One-stop-shop for developers developing on ARM Mali GPUs
- Rich set of development tools
  - Tools to enable system level approach for performance analysis and debug
  - Tools to enable pre-silicon software development
  - Tools to enable asset and content creation
- Direct access to ARM Mali experts
- Potential route to become an ARM partner and have demos showcased across ARMs channels into OEMs, Silicon companies and the market

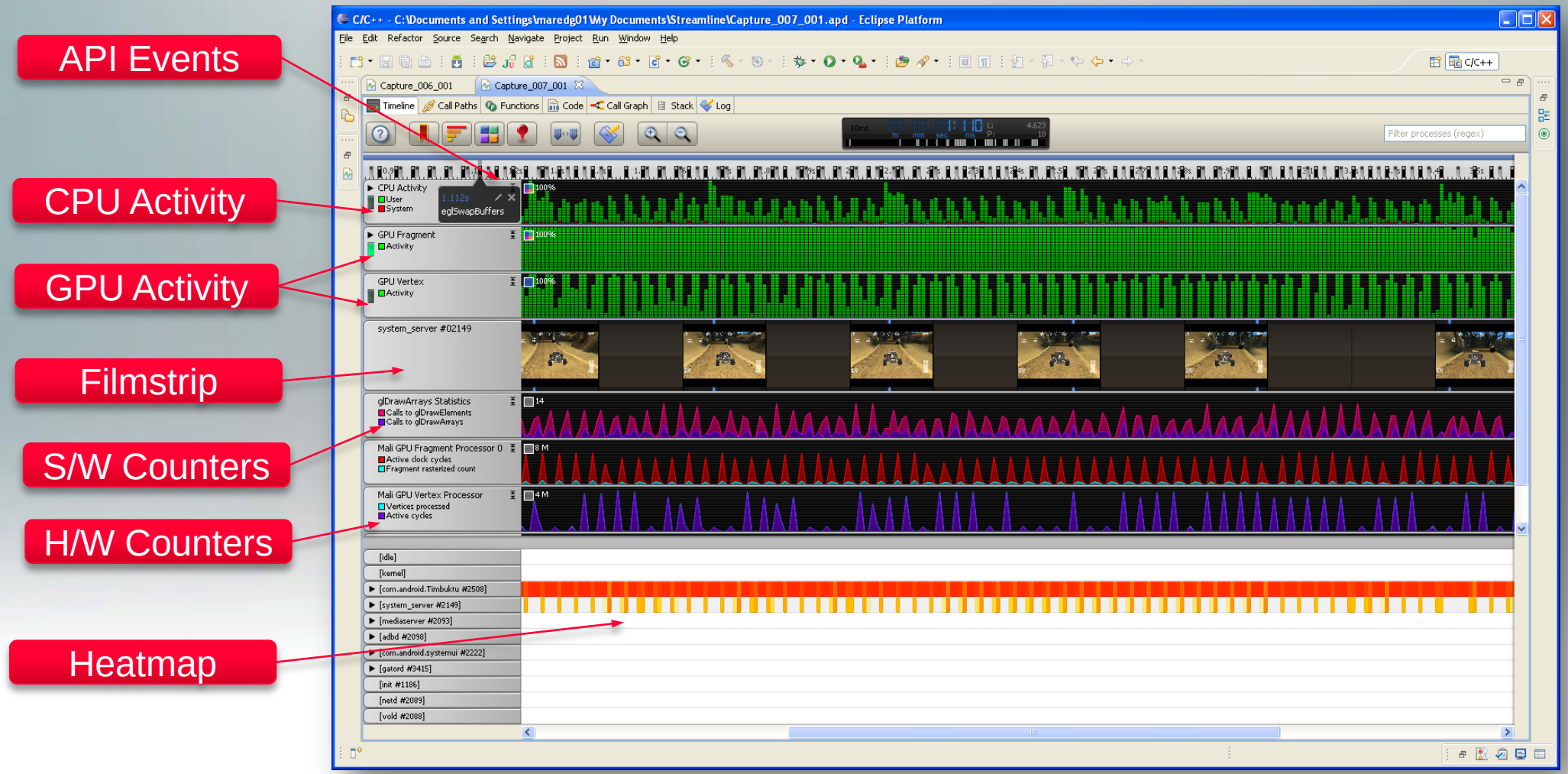
malideveloper.arm.com

Performance Analysis

- **ARM DS-5 toolchain** with support for ARM Mali GPUs
- **System wide performance analysis** Simultaneous visibility across ARM Cortex® processors & Mali GPUs
- **Optimize performance and power efficiency** of gaming applications across the system



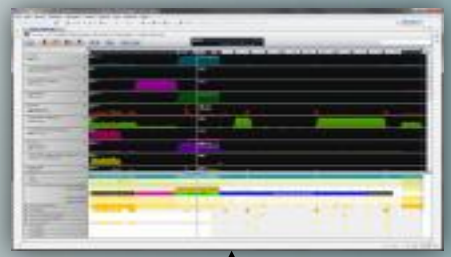
Streamline Performance Analyzer

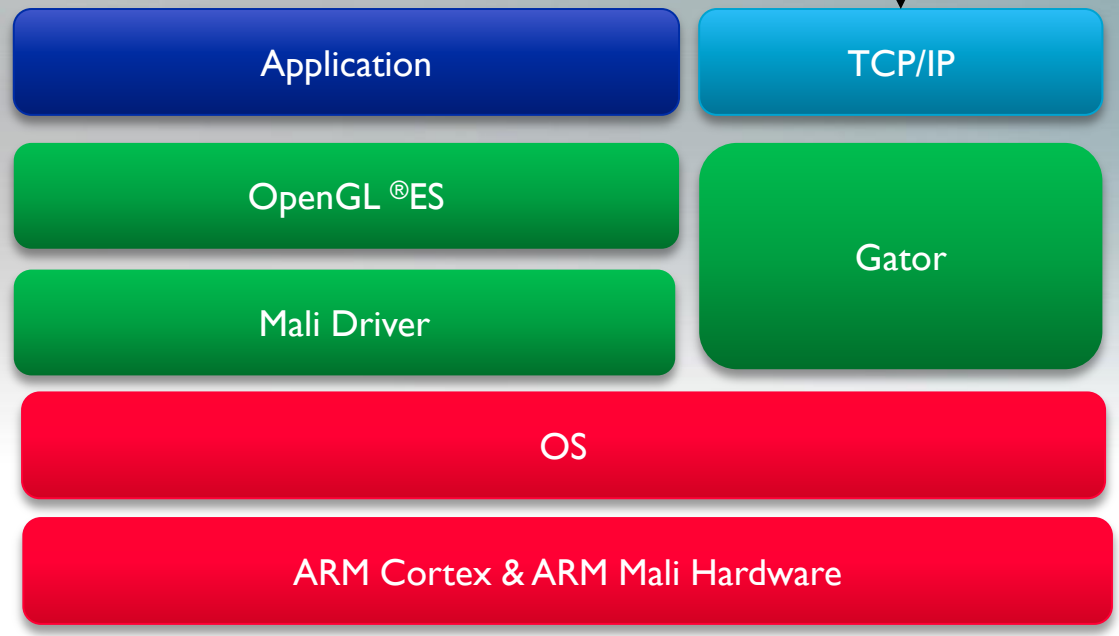


Streamline Setup

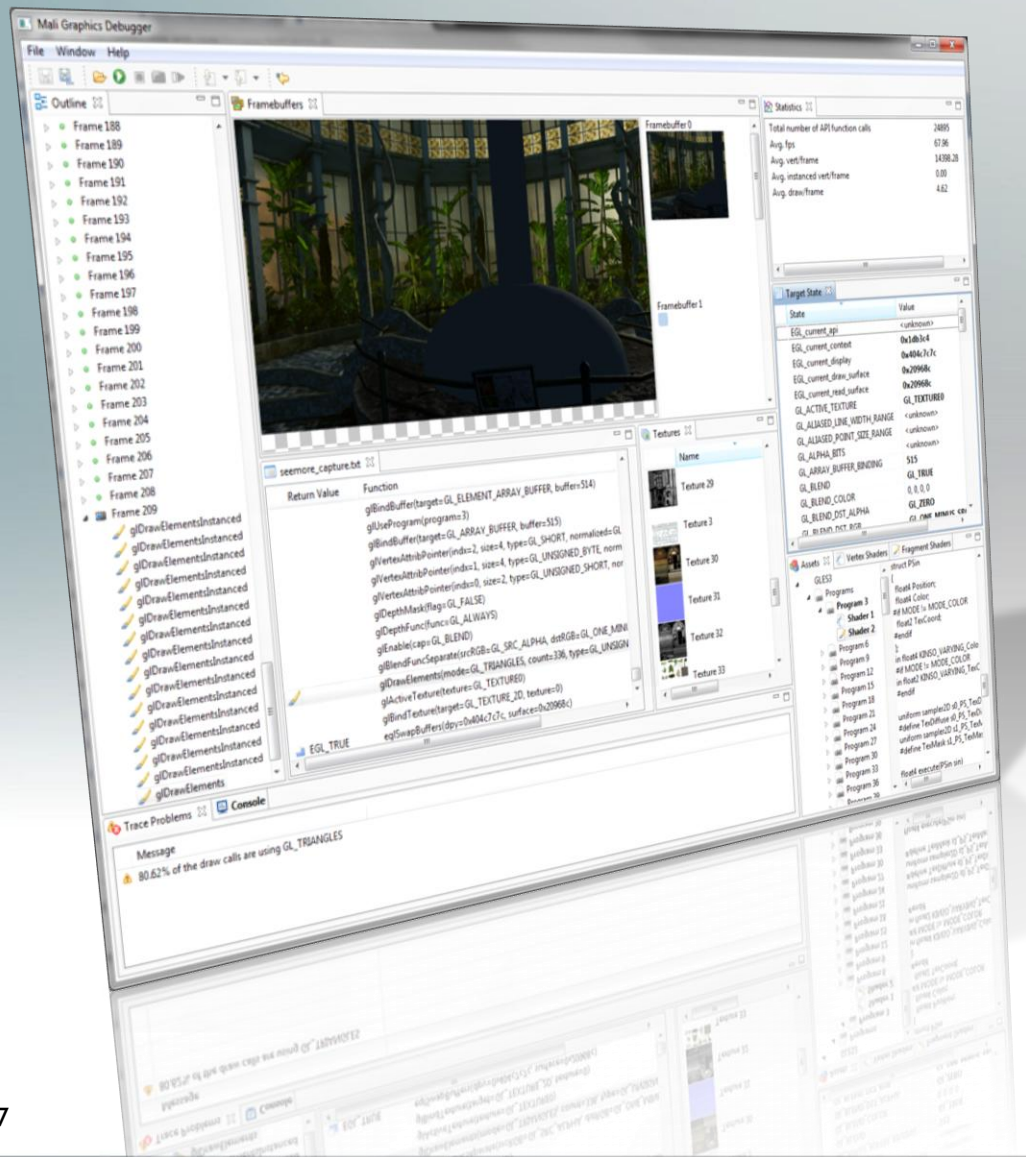
- Gator interfaces with Kernel & Mali Drivers
  - Extracts H/W & S/W counters
  - Extract frame buffer
  - Passes through events & annotations
  - Transmit data over TCP/IP to DS-5 tools
- Transparent to user application
  - Option to add annotations to user application for more advanced debugging
- Negligible performance impact
  - Zero impact when profiling disabled
  - Minimal impact in performance when enabled

ARM DS-5 toolchain with Streamline





Debug



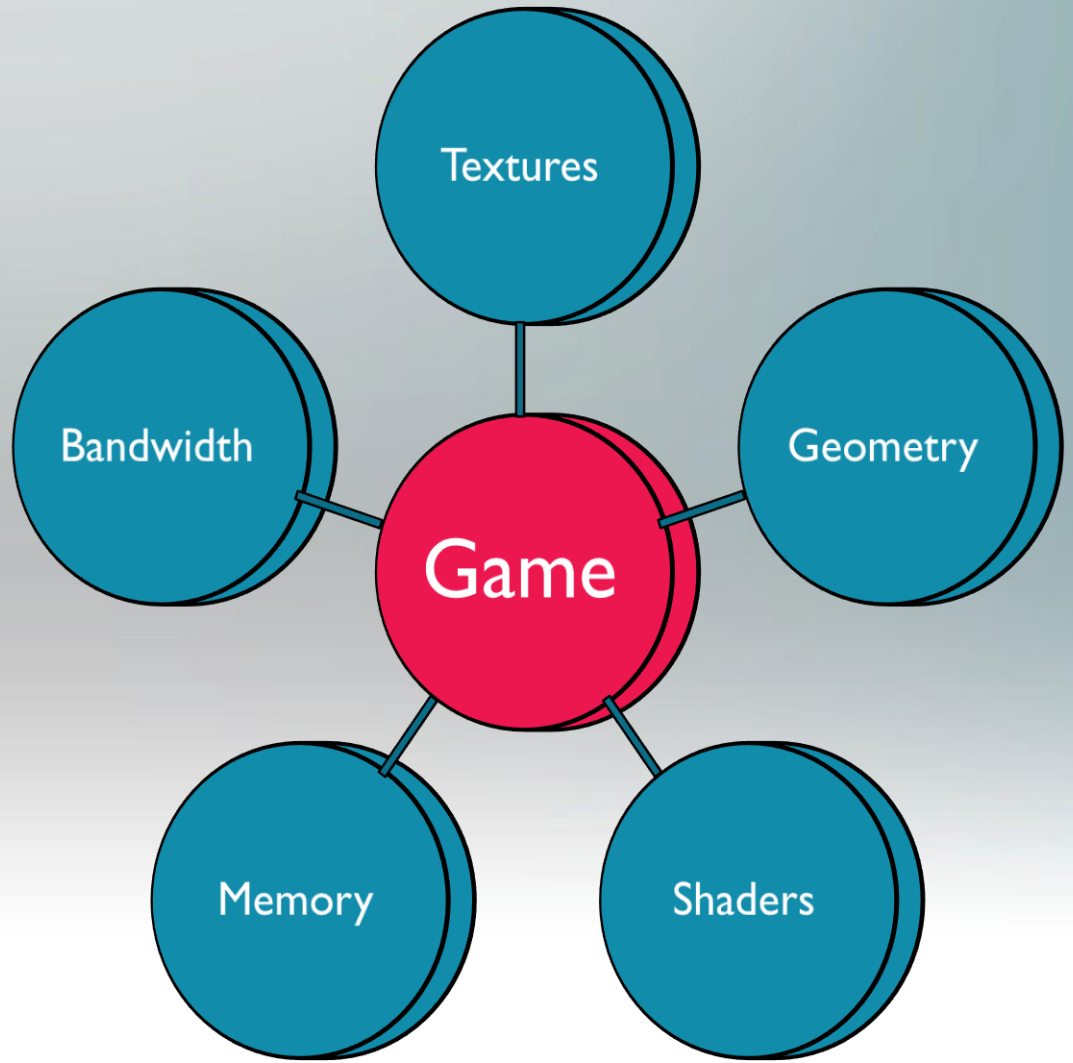
Mali Graphics Debugger

- Graphics debugging for content developers
- API level tracing
- Understand issues and causes at frame level
- Support for OpenGL® ES 2.0, 3.0, EGL & OpenCL™ 1.1
- Complimentary to DS-5 Streamline

API Level Analysis

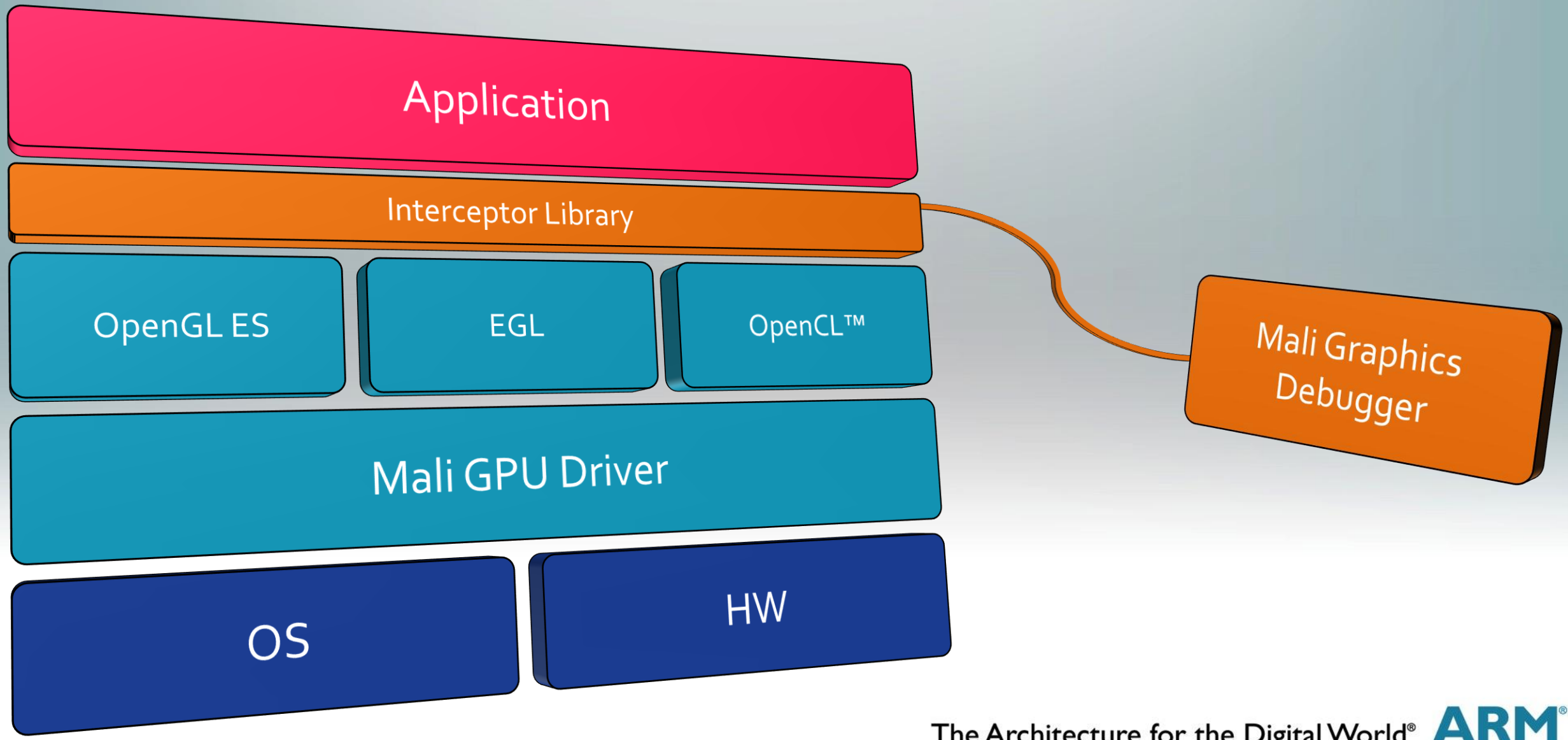
- **GOAL: increase the performance of the application (frames per second)**
  - Analyse a 3D application running on a Mali GPU device
  - Find issues
  - Present potential solutions

- Improve the understanding of the graphics pipeline
  - Draw call stepping & profiling
  - State viewing



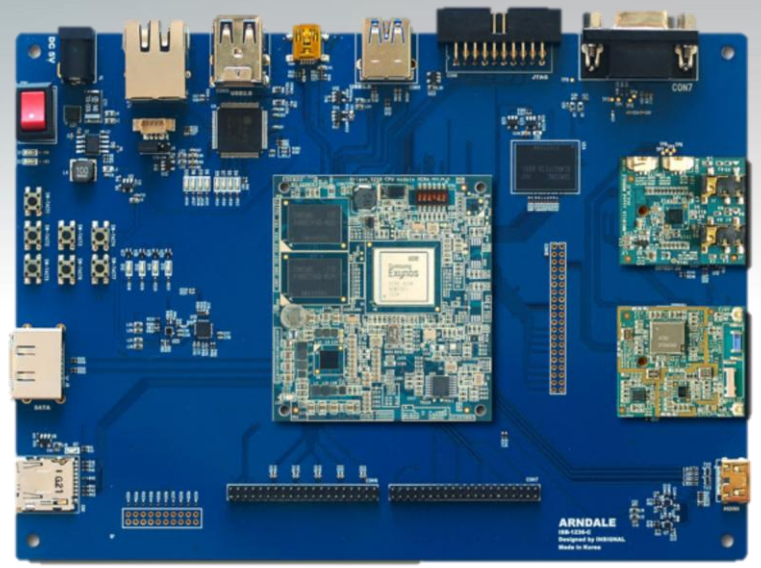
Analyzing and Debugging on Device

Architecture of the Mali Graphics Debugger



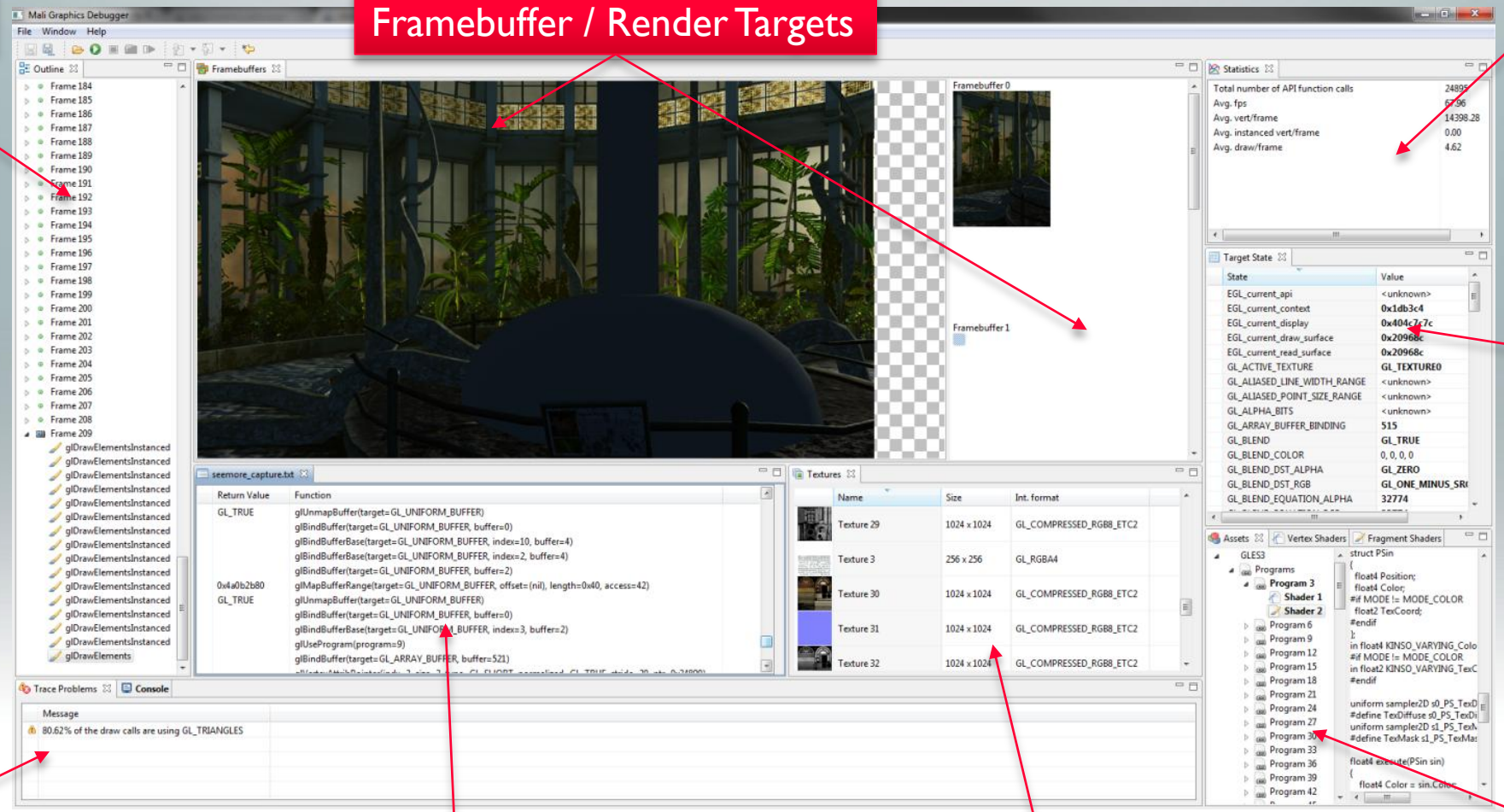
Out of the Box

- Nexus™ 10
  - Dual-core Cortex-A15 processor @1.7GHz
  - Mali-T604 @533MHz
  - 4 MP resolution (2560×1600)
  - Stock Android™ 4.2.1 with DS-5 support



- Arndale
  - First Samsung Exynos 5 development board
  - Targets both Linux and Android
  - Low cost development at around $250

Mali Graphics Debugger



The Architecture for the Digital World® ARM®

API Calls Affect the State

Application

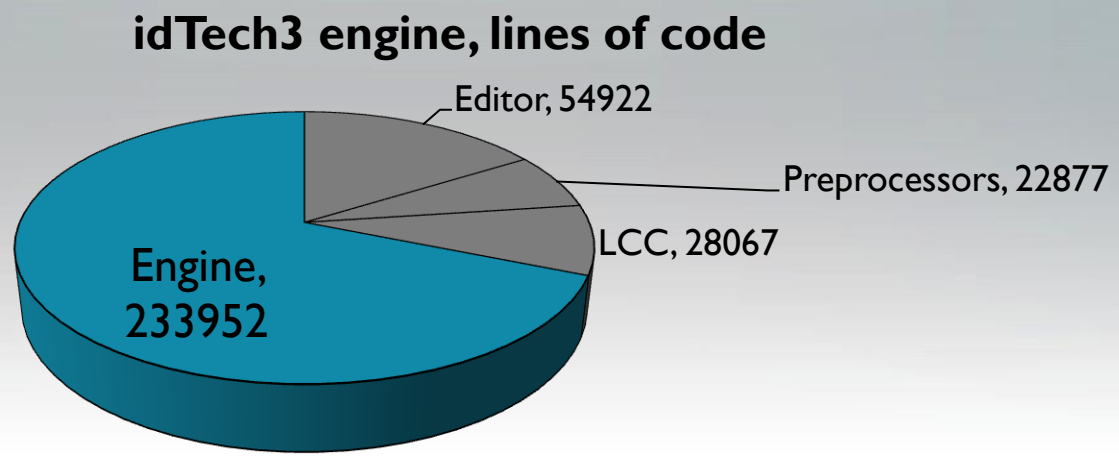
```
while(true)
{
    angleX += 3;
    if(angleX >= 360) angleX -= 360;
    if(angleX < 0) angleX += 360;
    modelView = Matrix::createRotationX(angleX);
    modelView[8] -= 2.5;

    glUniformMatrix4fv(iLocMVP, 1, GL_FALSE,
      modelViewPerspective.getAsArray());

    glClear(GL_COLOR_BUFFER_BIT);
    glDrawArrays(GL_TRIANGLES, 0, 36);
}
...
```

Driver

```
glUniformMatrix4fv(5, 1, 0, [.36 .48 .8...]);
glClear(16384);
glDrawArrays(4, 0, 36);
glUniformMatrix4fv(5, 1, 0, [.31 .42 .5...]);
glClear(16384);
glDrawArrays(4, 0, 36);
glUniformMatrix4fv(5, 1, 0, [.26 .37 .2...]);
glClear(16384);
glDrawArrays(4, 0, 36);
glUniformMatrix4fv(5, 1, 0, [.21 .35 -.1...]);
glClear(16384);
glDrawArrays(4, 0, 36);
...
```

Analyzing 3D Applications

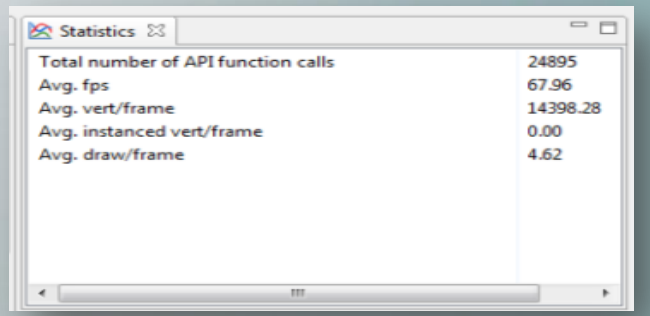
- Games tend to have quite large code bases
  - Quake III engine (1999), ~ 300k lines of C code
  - Ogre3D (2012), ~1M lines of C++ code

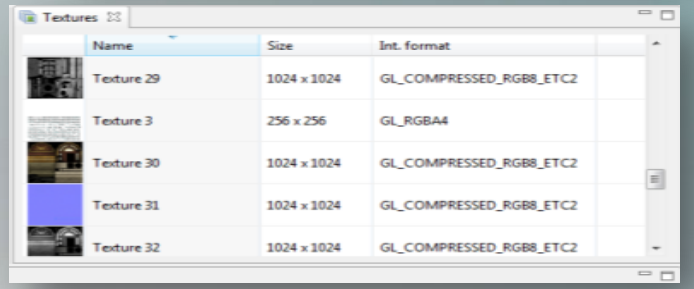


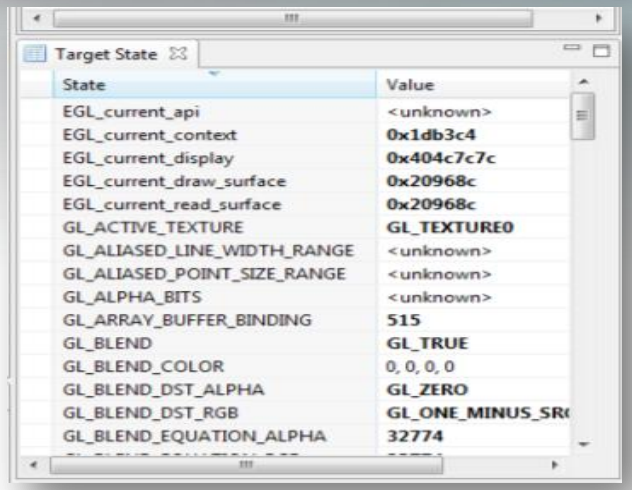
* http://fabiensanglard.net/quake3 Updated: Feb, 02, 2013.

Identify Issues

- **Statistics View to identify :**
  - High vertex count,
  - Large number of draw calls per frame
- **Texture View to identify :**
  - Frames where compression is not being used
  - Unnecessarily large texture dimensions
  - Unnecessary pixel format being used
- **Target State View to identify :**
  - Surprise changes to state
  - Unnecessary changes

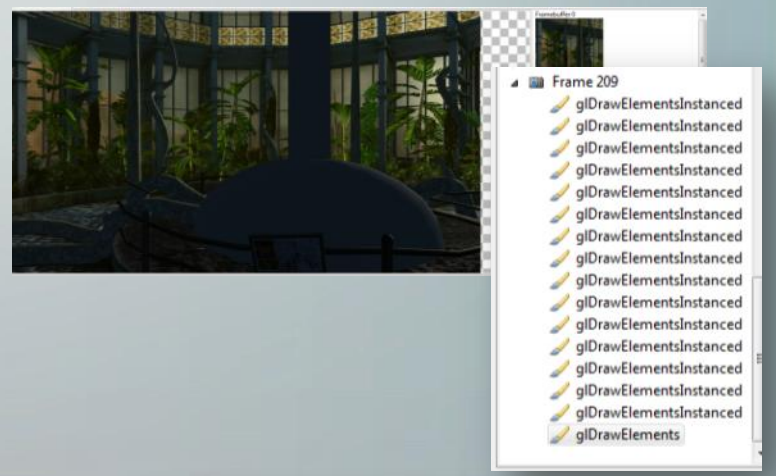




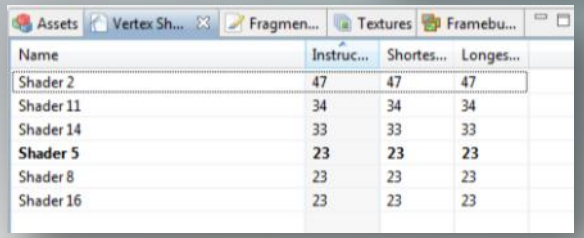


Identify Issues

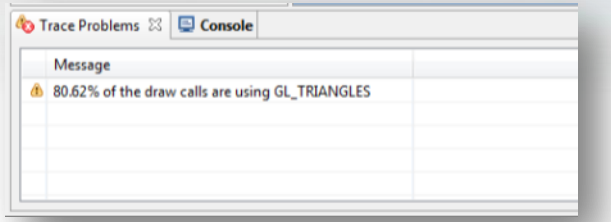
- **Draw-Call stepping to identify** :
  - Redundant draw-calls
  - Potential opportunity for batching



- **Shader Statistic View to identify :**
  - Expensive shaders by cycle count

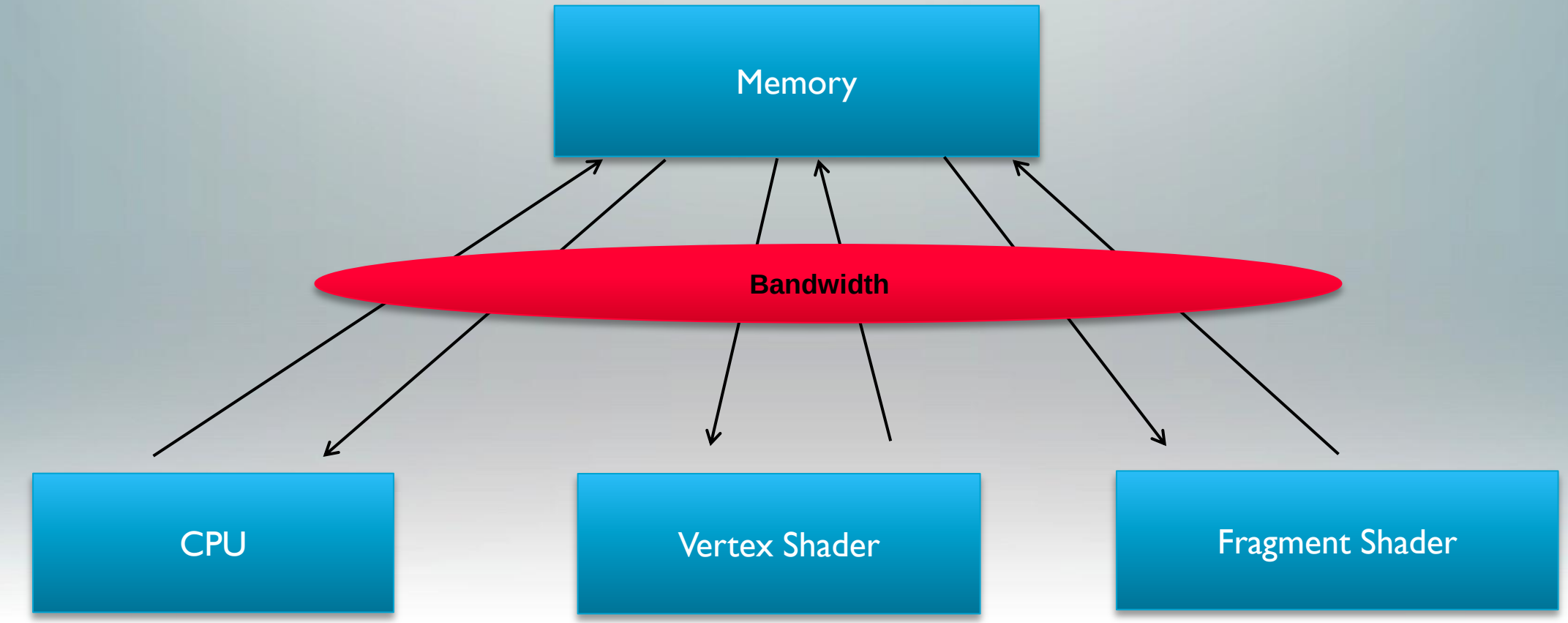


- **Dynamic Help to highlight optimization opportunity**



Timbuktu Demo

Bandwidth Vertex Fragment CPU



CPU doing too much and stalling GPU?

Vertex shader operating on too many vertices stalls fragment shader and CPU?

Fragment shader trying to do a lot of fancy effects stalling CPU and vertex shader?

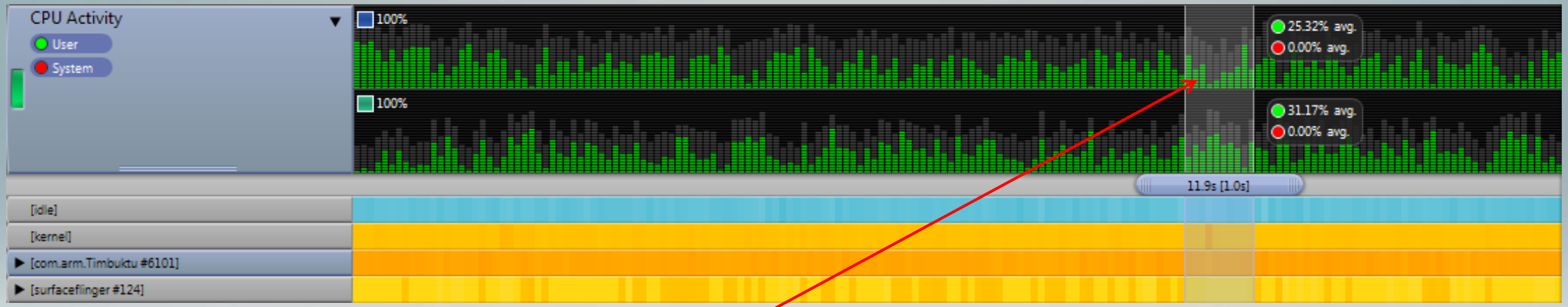
CPU Bound

- Sometimes a slow frame rate can actually be a CPU issue and not a GPU one
  - In this case optimizing your graphics won't achieve anything
- Most mobile devices have more than one core these days Are you threading your application as much as possible?

- Mali GPU is a deferred architecture
  - Reduce the amount of draw calls you make
  - Try to combine your draw calls together
- Offload some of the work to the GPU
  - Even easier with Mali-T604 supporting OpenCL Full Profile

CPU Bound Streamline

- Easy just look at the CPU Activity
  - Remember to look at all the cores.



Some of the area is greyed out due to Streamline's ability to present per App CPU activity

Fragment Bound

- Overdraw
  - This is when you draw to each pixel on the screen more than once
  - Drawing your objects front to back instead of back to front reduces overdraw
  - Also limiting the amount of transparency in the scene can help
- Resolution too high or too many effects or cycles in shader
  - Every light and effect that you add will add to the number of cycles your shader will take
  - If you decide to run your app at native resolution be careful

DS-5 Streamline: Fragment Bound

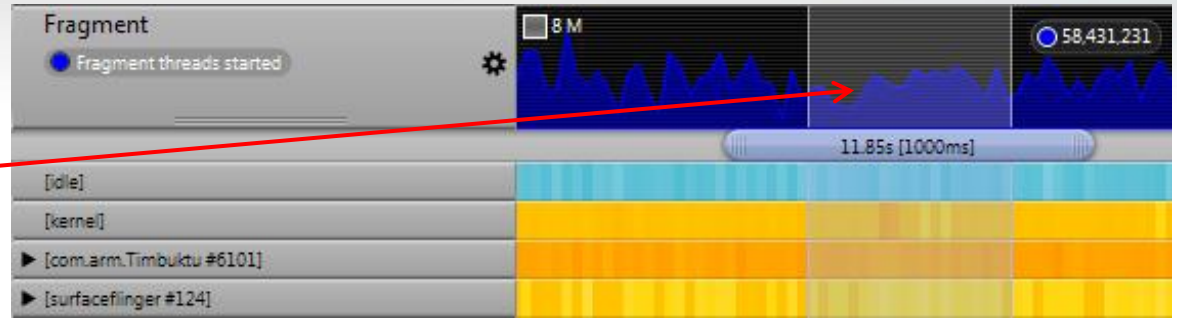
- Involves just 1 counter and the frequency of the GPU
  - Job Slot 0 Active

Fragment Percentage = (Job Slot 0 active / Frequency) *100

Fragment Percentage = 84%

Overdraw = Fragment Threads Started * Number of Cores / Resolution * FPS

Overdraw = 3.9



Mali Graphics Debugger: Shaders Statistics

- Find the top heavyweigh
- Run the Mali Offline Sha
- Calculate statistics abou they were compiled for
  - Number of instruction
  - Shortest and longest pa

ve Resolution
) = 4,096,000 pixels
PU 533Mhz
per pixel Approx.
PS
your shader

ogre_trace.txt | Shader 2 (GL_VERTEX_SHADER)

```
uniform mat4    worldviewproj_matrix;
uniform mat4    texture_matrix;
uniform mat4    texture_matrix1;



attribute   vec4    vertex;
attribute   vec4    uv0;
varying vec2    oTexcoord2_0;
varying vec2    oTexcoord2_1;
void main() {
    vec4 outputPosition;
    vec4    lLocalParam_0;
    vec4    lLocalParam_1;

    FFP_Transform(worldviewproj_matrix, vertex, outputPosition);

    FFP_Construct(1.0, 1.0, 1.0, 1.0, lLocalParam_0);

    FFP_Construct(0.0, 0.0, 0.0, 0.0, lLocalParam_1);

    FFP_TransformTexCoord(texture_matrix, uv0.xy, oTexcoord2_0);

    FFP_TransformTexCoord(texture_matrix1, uv0.xy, oTexcoord2_1);

    gl_Position = outputPosition;
}
```

Instructions ▲	Shortest path	Longest path
47	47	47
34	34	34
33	33	33
23	23	23
23	23	23
23	23	23
3	3	3
3	3	3
2	2	2
2	2	2
1	1	1
1	1	1

Example Shader Optimization

```
11  uniform sampler2D noiseMap;
12  uniform samp
13  uniform samp
14
15  varying vec3
16  varying vec4
17  varying vec3
18  varying vec3
19
20  void main()
21  {
22      vec2 fin
23
24      vec3 noi
25      final +=
26
27      float fr
28
29      vec4 ref
30      vec4 ref
31
32      gl_FragC
33  }
34
```

Assets | Vertex Shad... | Fragment Sh... | Textures | Framebuffers

Name	Instructions	Shortest path	Longest path
Shader 135	6	6	6
Shader 174	4	4	4
Shader 192	4	4	4
Shader 21	3	3	3
Shader 129	3	3	3
Shader 165	3	3	3
Shader 204	3	3	3
Shader 3	2	2	2
Shader 12	2	2	2
Shader 18	2	2	2
Shader 147	2	2	2
Shader 159	2	2	2

```
g * noiseScale;
, fresnelPower);
```

Debug the draw calls

Outline

- Frame 16 : 36 draws
- Frame 17 : 63 draws
- Frame 18 : 63 draws
- Frame 19 : 63 draws
  - 0 glDrawElements : 10629 vert.
  - 1 glDrawElements : 3912 vert.
  - 2 glDrawElements : 10629 vert.
  - 3 glDrawElements : 3912 vert.
  - 4 glDrawElements : 3168 vert.
  - 5 glDrawElements : 1320 vert.
  - 6 glDrawElements : 804 vert.
  - 7 glDrawElements : 3036 vert.
  - 8 glDrawElements : 2220 vert.
  - 9 glDrawElements : 1338 vert.
  - 10 glDrawElements : 1080 vert.
  - 11 glDrawElements : 2718 vert.
  - 12 glDrawElements : 2133 vert.
  - 13 glDrawElements : 21483 vert.
  - 14 glDrawElements : 2352 vert.
  - 15 glDrawElements : 898 vert.
  - 16 glDrawElements : 2626 vert.

Debug the draw calls

Outline

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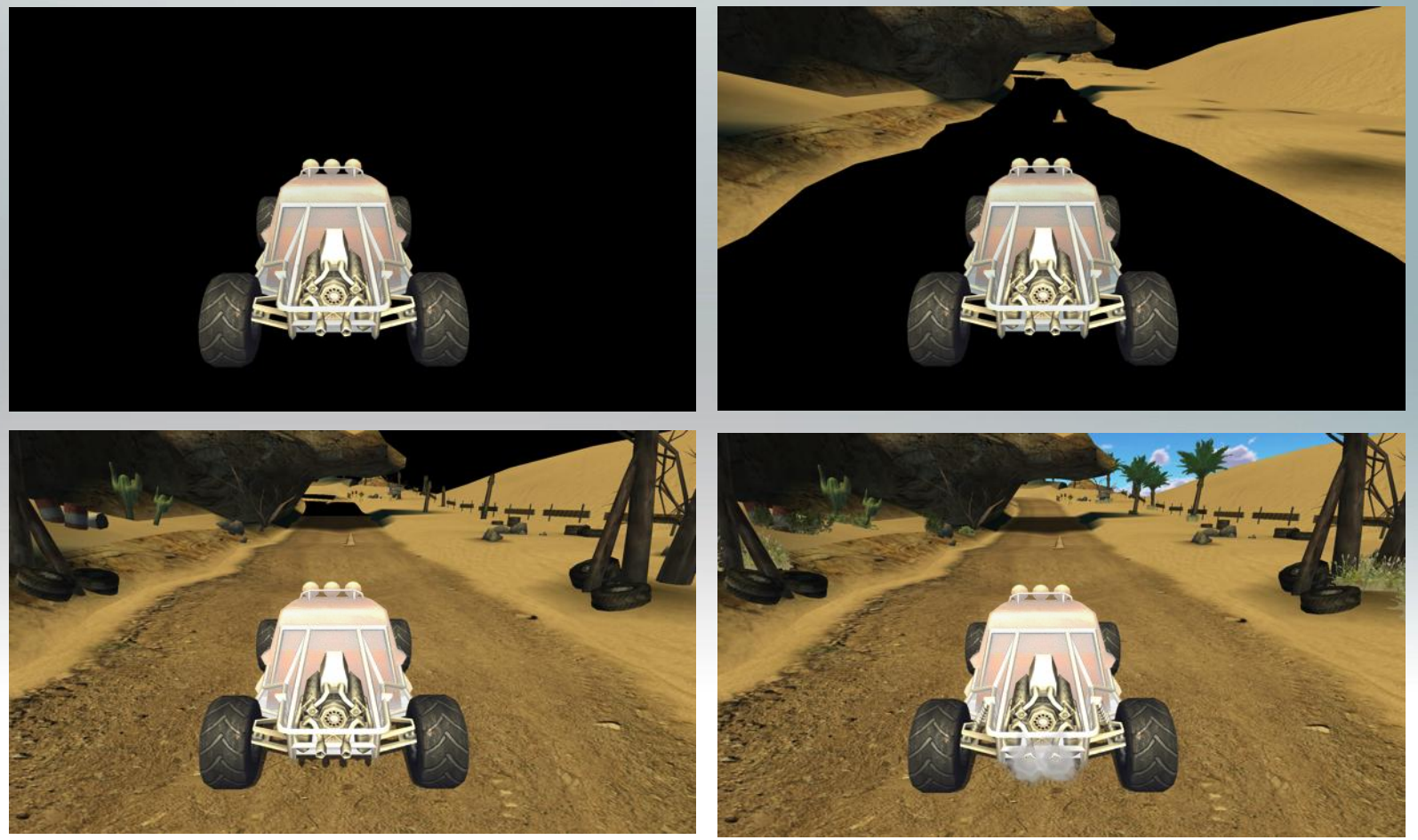
  - 12 glDrawElements : 2133 vert.
  - 13 glDrawElements : 21483 vert.
  - 14 glDrawElements : 2352 vert.
  - 15 glDrawElements : 898 vert.
  - 16 glDrawElements : 2626 vert.



Vertex Bound

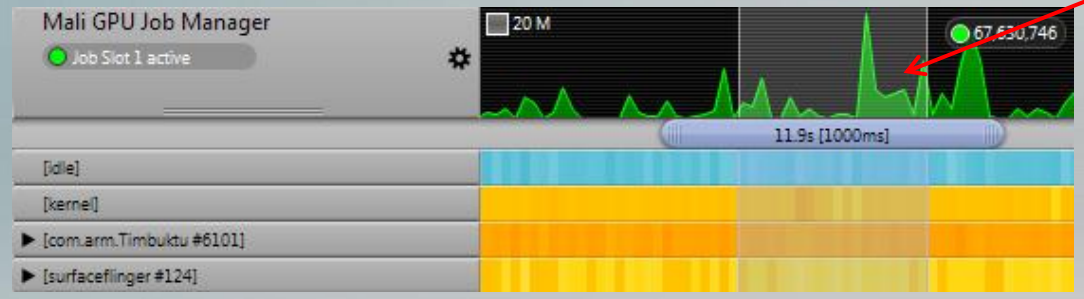
- Too many vertices in geometry
  - Get your artist to remove unnecessary vertices
    - A lot of artists still generate content for high end desktop content
    - Impose some budgeting and limits
  - LOD Switching
    - Only objects near the camera need to be in high detail
    - Objects that are further away don't need the same level of detail
  - Use culling

- Too many cycles in the vertex shader
  - You only have a limited amount of cycles to do your vertex shading
  - The amount of cycles you can afford to spend on vertex shading is directly dependent on the number of vertices

DS-5 Streamline: Vertex Bound

- Involves just 1 counter and the frequency of the GPU
  - Job Slot 1 Active

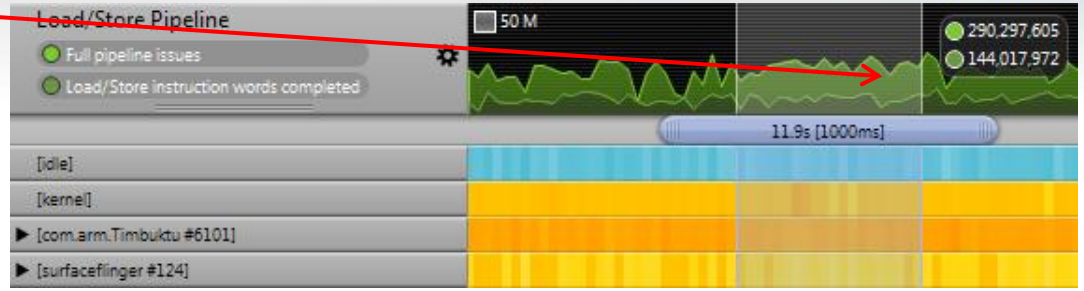
Vertex Percentage = (Job Slot 1 active / Frequency) *100



Vertex Percentage = 13%

Load Store CPI = Full Pipeline issues / Load Store Instruction Words Completed

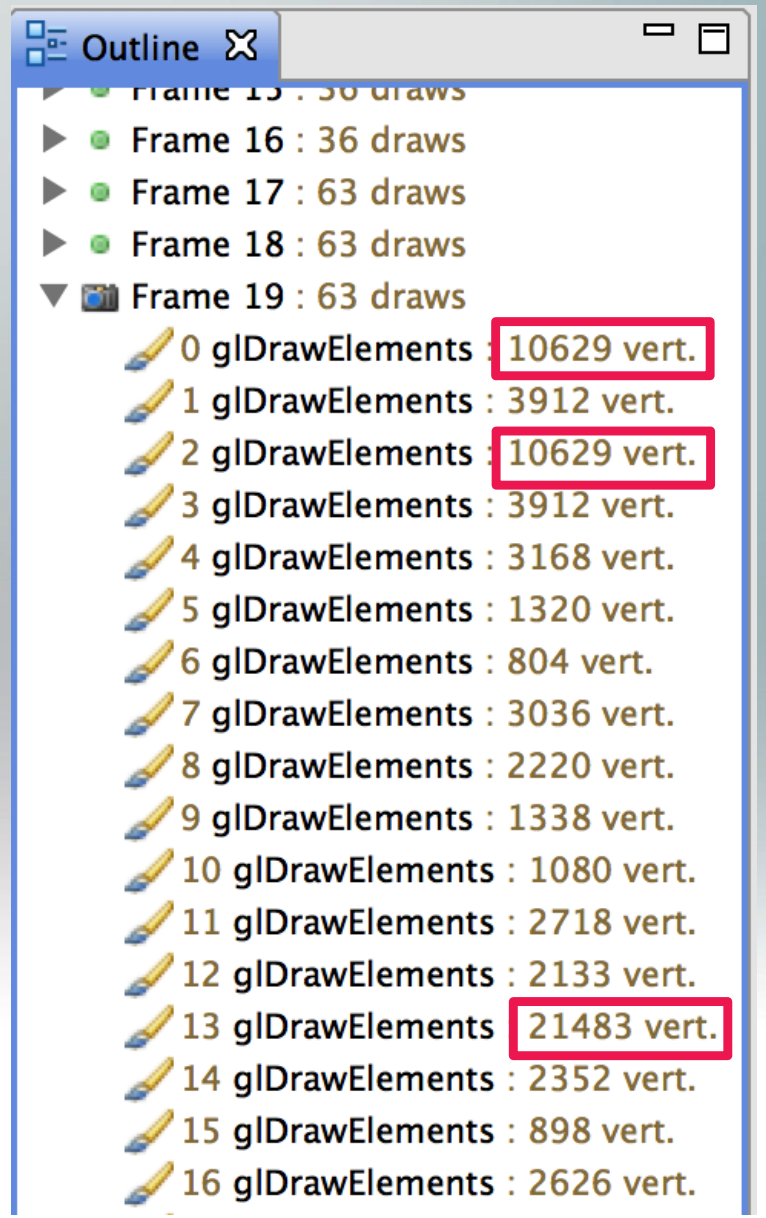
Load Store CPI = 2.02



Vertices Count

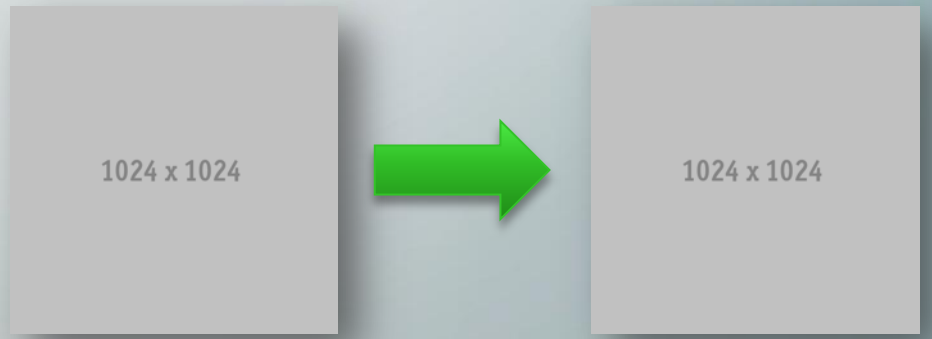
- Analyze the trace in Mali Graphics Debugger
- Find the draw calls with a high number of vertices

- Shader Statistics
  - Find the vertex shaders with a high number of instructions



Bandwidth Bound

- When creating embedded graphics applications bandwidth is a scarce resource
  - A typical embedded device can handle ≈ 5.0 Gigabytes a second of bandwidth
  - A typical desktop GPU can do in excess of 100 Gigabytes a second
- Use texture compression
  - The main popular format is ETC Texture Compression
  - ASTC (Adaptive Scalable Texture Compression) < 1 bit per pixel



~ 4 MB
(32 bit per pixel)

~ 0.5 MB
(4 bits per pixel)

http://blogs.arm.com/multimedia/643-astc-texture-compression-arm-pushes-the-envelope-in-graphics-technology/

DS-5 Streamline: Bandwidth Counters

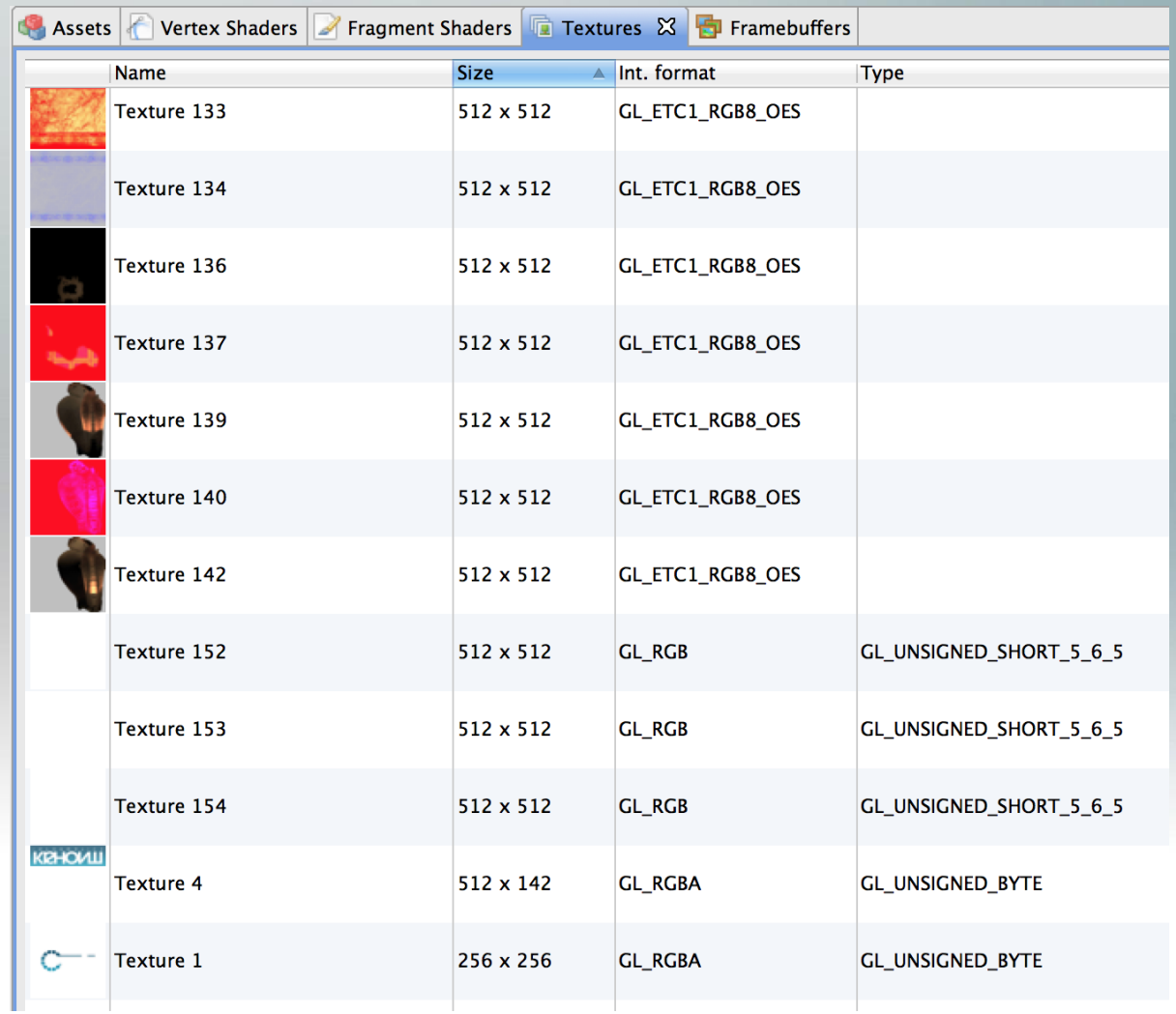
- Involves just 2 Streamline Counters
  - External Bus Read Beats
  - External Bus Write Beats

Bandwidth = 967 MB/S

Bandwidth in Bytes = (External Bus Read Beats + External Bus Write Beats) * Bus Width

Mali Graphics Debugger: Textures

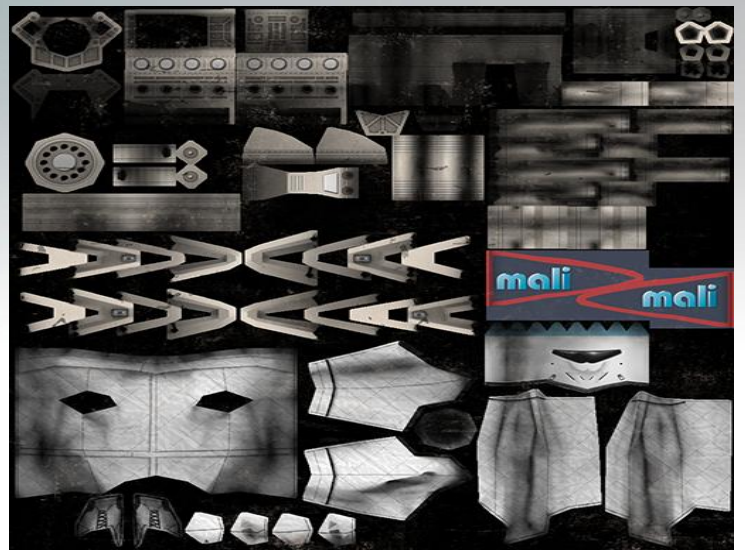
- Show preview of the textures
- RGB, RGBA, Luminance Textures
  - Uncompressed
  - ETC1
  - ETC2
  - ASTC
- Sort by size, format, type
- Display full size



Name	Size	Int. format	Type
Texture 133	512 x 512	GL_ETC1_RGB8_OES	
Texture 134	512 x 512	GL_ETC1_RGB8_OES	
Texture 136	512 x 512	GL_ETC1_RGB8_OES	
Texture 137	512 x 512	GL_ETC1_RGB8_OES	
Texture 139	512 x 512	GL_ETC1_RGB8_OES	
Texture 140	512 x 512	GL_ETC1_RGB8_OES	
Texture 142	512 x 512	GL_ETC1_RGB8_OES	
Texture 152	512 x 512	GL_RGB	GL_UNSIGNED_SHORT_5_6_5
Texture 153	512 x 512	GL_RGB	GL_UNSIGNED_SHORT_5_6_5
Texture 154	512 x 512	GL_RGB	GL_UNSIGNED_SHORT_5_6_5
Texture 4	512 x 142	GL_RGBA	GL_UNSIGNED_BYTE
Texture 1	256 x 256	GL_RGBA	GL_UNSIGNED_BYTE

Batching

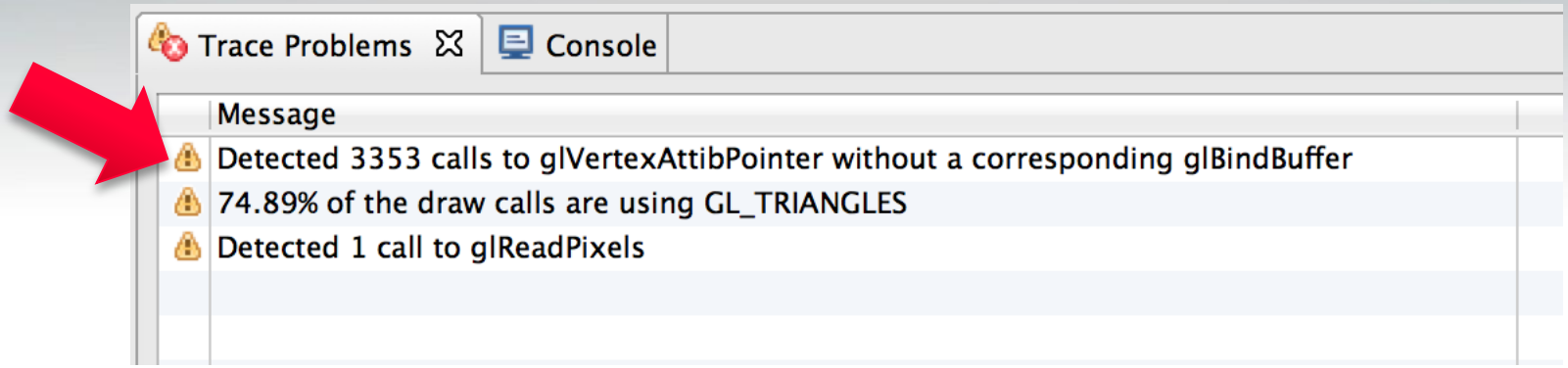
- Try to combine as many of your drawcalls together as possible
- If objects use different textures try to combine the textures together in a texture atlas
  - This can be done automatically but often best done by artists
  - Update your texture coordinates accordingly




```
glBindTexture(<texture1>);
GlDrawElements(<someVertices>);
glBindTexture(<texture2>);
glDrawElements(<someVertices2>);
glBindTexture(<texture3>);
glDrawElements(<someVertices3>);
glBindTexture(<texture4>);
Etc....
```

Vertex Buffer Objects

- Vertex Buffer Objects
  - Using Vertex Buffer Objects (VBO's) can save you a lot of time in overhead
  - Every frame in your application all of your vertices and colour information will get sent to the GPU
  - A lot of the time these won't change. So there is no need to keep sending them
  - Would be a much better idea to cache the data in graphics memory
  - This is where VBO's can be useful



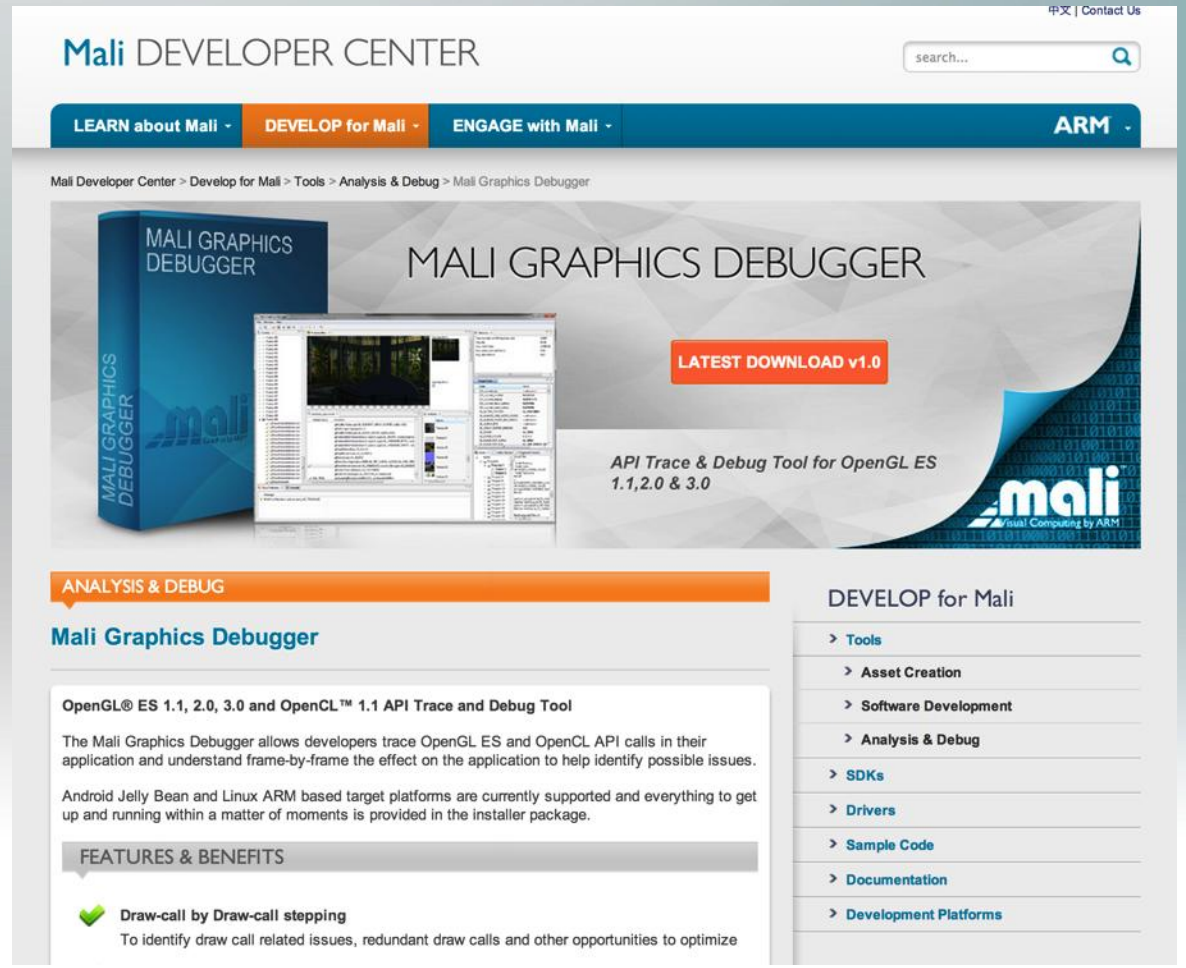
Mali Graphics Debugger v1.0.1

- Available on Mali Developer Center:

http://malideveloper.arm.com

- Being used by our vendors and partners
- Available free of charge

Stay in touch for the next release with vertex attributes, uniforms and VBOs.



Thank you

malideveloper.arm.com