World War Z - Using Vulkan® to tame the zombie swarm

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Jordan Logan, AMD
World War Z

- Cooperative 3rd person shooter, up to 4 players
- Large zombie crowds onto the screen
- PC rendering
  - Vulkan/DX11 backends
- Consoles support (Xbox One/PS4)
  - 30 fps
  - 4k rendering (dynamic resolution)
Pipeline overview

- Full depth prepass
- Deferred shadowmask (4 lights)
- Forward+ shading
- GPU-driven visibility system
  - 2 frames latency
Depth + Vertex Normals
Shadowmask: 4 lights, filtered
SSAO + Capsule shadows[Iwanicki13]
After shading & postproc
Short review

- Check presentations from the GDC 2019 for more details
  - Zombie rendering tech
    - “High zombie throughput in modern graphics”
  - Lightmap technology
    - “Enabling light baking workflows”
Why Vulkan?

- Designed to make CPU/GPU frame time lower
  - Multithreading
  - Async Compute
- Explicitly manage memory
  - Implement dynamic resolution
  - Alias memory resources
- Runs on different operating systems
CPU performance

- Zombie crowds
- Large number of drawcalls (up to 3k)
  - Chance to be CPU-bound
CPU performance

- Wait GPU occlusion query (OQ) results
  - Reduce colorpass DIPs number by 30%
CPU performance

- Possible GPU idle
  - GPU has done its job, but CPU is not ready to submit new commands
CPU performance

- Direct3D 11
  - Dedicated driver thread
  - Explicitly flush command buffer queue
    - Extra CPU time cost
- Vulkan
  - Manually control submission
  - Split work across several threads
CPU performance

- Record command buffers in parallel
  - Check # of physical cores
    - If >= 4, use 1 main + 2 extra threads scheme
- Split the most largest passes
  - Z Prepass
  - Shadowmap
  - Colorpass
CPU performance

- World War Z
  - 24 command buffers per frame
    - Double buffering to avoid synchronization
    - Wait for GPU before the main shading pass
  - Only 5 queue submissions
    - Each vkQueueSubmit has limited CPU overhead
Multithreading benefits

- Separate recording from submission
  - Allows for much higher throughput
- In critical cases may save more than 40% of CPU time
  - From 18-20 ms down to 12-16 ms (AMD Ryzen 7 2700X)
GPU performance

- Improve GPU utilization
- Share resources with ROP-bound passes
  - Shadowmaps, occlusion testing...
- Use another hw queue
  - Run compute shaders simultaneously
GPU async workflow

- Z-Pass
- SSAO
- Capsule AO
- Shadows
- Forward+Shading
- Postproc
- Present
- Z-Pass
- SSR
- Light Froxel Mask
- Visibility
- Raster
- Compute
- CPU Readback
GPU occupancy

• VGPR pressure
  • Material fetching
  • Reflection & lighting calculation loops
• Try to keep your registers amount as low as possible
  • Helps to hide memory latency

<table>
<thead>
<tr>
<th>VGPR</th>
<th>&lt;=24</th>
<th>28</th>
<th>32</th>
<th>36</th>
<th>40</th>
<th>48</th>
<th>64</th>
<th>84</th>
<th>&lt;=128</th>
<th>&gt; 128</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waves</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
GPU occupancy

- Pack divergent data tightly
  - 2xfp32 to 1xfp16
    - packHalf2x16 / unpackHalf2x16
  - GL_ARB_gpu_shader_int64
    - 64-bit bitwise operations
- Apply cross-lane wave intrinsics
GPU occupancy

vec4 albedoCol = GetAlbedoColor (texUV.xy);
uint2 packedAlbedo =
uint2(packHalf2x16(albedoCol.xy),
packHalf2x16(albedoCol.zw));
....
vec4 unpackedAlbedo =
float4(unpackHalf2x16(packedAlbedo.x),
unpackHalf2x16(packedAlbedo.y));

image_sample v[0:3], v[0:2], s[8:15],
s[16:19] dmask:0xf
v_cvt_pkrtz_f16_f32 v0, v0, v1
v_cvt_pkrtz_f16_f32 v1, v2, v3
....
v_cvt_f32_f16 v2, v0
v_cvt_f32_f16 v0, v0 src0_sel: WORD_1
v_cvt_f32_f16 v4, v1
v_cvt_f32_f16 v1, v1 src0_sel: WORD_1
GPU performance

- Run compute shaders in parallel
  - Can save up to 1.5 ms (10 %) in some cases (AMD Radeon RX480)
- Can greatly reduce VGPRs num from intrinsics & packing
  - Best case: from 113 up to 64
  - Decrease GPU frame time by 33%
Memory management

• Vulkan® Memory Allocator from AMD
  • https://gpuopen.com/gaming-product/vulkan-memory-allocator/
  • Designed to:
    • Better manage memory
    • Optimize for specific platforms
    • Alias transient resources
Alias transient resources

- Fixate render target amount beforehand
- Analyze lifetime dependencies
  - Store sharenmasks for each RT
- Want to achieve lower upper memory bound
Alias transient resources

- For each target get aliased resources
- Calculate memory pool block layout
  - Share space with most similar placed RT
  - respect mask bits
- Allocate device memory block to cover all laid out targets
Alias transient resources

- Allocate first target #0 (sharemask: 0111b)
Alias transient resources

- Process target #1 (0011b)
  - It’s size is lower and (mask0 & mask1) != 0
  - Use same address as previous rt
Alias transient resources

- Target #2 (sharemask 0101b)
  - Skip resource #1 block (no common bits)
  - Use remaining space within resource #0 space
Alias transient resources

- Target #3 (1000b)
  - No target to share with, place to the end of the pool

Memory allocation
Alias transient resources

- Take into account alignment requirements
  - Calculate appropriate offsets
- Utilize produced alignment holes
  - Try to overlap them with next blocks
Alias transient resources

• Can be used to save video memory
  • More than 50% (351 vs 198 Mb)
• Carefully share compressed RT with UAVs
  • Use explicit barrier to switch between 2 images
    • Old layout = UNDEFINED
Dynamic resolution

- For each render target
  - Create alternate size versions
  - Map them to the mem address of original target

![Diagram showing different resolutions]
Dynamic resolution

- Set the FPS goal target
- Measure frame statistics:
  - CPU/GPU timings
- Use exponential smooth average
  - 2 frames history
  - Faster response to frameload changes
Dynamic resolution

- GPU bound
  - Average fps < target fps
    - Drop resolution by 1 step (5 %)
  - Average GPU time higher than desired
    - Use more aggressive scheme (2 steps) (10 %)
- Otherwise (GPU usage < 90%)
  - Increase res by 1 step (5%)
Dynamic resolution

- Apply downscale immediately
  - Near constant framerate
- Upscale resolution after specified delay (20 frames)
  - Don’t want to switch resolution too often
  - Can makes the final image sharper
Dynamic resolution

- 3840x2160 resolution
- Horizontal
  - Frame number
- Vertical:
  - Render target percentage
  - Average GPU time
- Low GPU time is better
PSO management

- `vkCreateGraphicsPipelines` works rather slow
  - Especially for the first time calls
- Want to decrease level loading time
- Want to eliminate potential spikes during gameplay sessions
PSO management

Shaders

Full cache
- Particles
- Dynamic decals
- Post-process
  (all combination accessible)

Scene only
- Objects materials
- Static SFXes
  (combinations used in scene)
PSO management

- Serialize scene PSO creation data during export
  - Shader defines, renderstates, rendertarget formats,...
- Create shaders during the level start
  - But what we should do with the full cache ones?
PSO management

- Simple solution :)
- Ask QA to play a couple of sessions for each level
  - Record data about used full cache PSO
- Use this information on export stage
- Just works in our case
PSO management

- Can reduce shader creation time significantly
  - Level loading: from 10 min up to 1.5
- Delete unused PSOs
  - Sometimes migrate to system ram
- Always enable pipeline objects cache
  - Could help when run game not for the first time
Jordan Logan
AMD DevTech

- We provide direct support with developers.
- Help with optimizations and profiling.
- Work with the driver teams to make sure that consumers have better experience.
- Deal with GPU specific issues.
Transfer queue

- Vulkan exposes using the hardware DMA engine though the use of transfer queues.
  - The transfer queue is helpful on all platforms except APUs.
  - This piece of hardware can run completely async to the graphics and compute queues.
  - It is a faster way to transfer data across the PCI-e® bus.
- Must be explicitly used.
  - If you don’t use the transfer queue, then uploads will be going down the slow path.
  - Best used asynchronously. Uploads and downloads should not block the rendering loop.
  - The graphics queue should not wait for the transfer queue.
Texture Streaming

- Transfer queue is designed for texture uploads and streaming.
- In the streaming case the old texture can be used while the texture is streaming.
- Once the texture is uploaded all that has to be done is to update the next frames descriptors.
  - With persistent descriptors you will want 2 copies of every descriptor
  - This can allow updating without doing a full GPU/CPU sync.
Texture Streaming

New texture request

CPU streaming thread

Read texture → Submit commands → Wait for complete → Update descriptor

Transfer queue

Transfer → Barrier → Signal fence
Transfer queue gotchas

- Transfer queue can have a different granularity then other queues.
  - The copy must be either a full sub-resource copy or be divisible by the queue granularity.
  - Undefined behavior can happen if you don’t follow the rules.
    - Common seen behavior is that the transfer queue will hang.
- Missing barrier on queue could cause corruption.
  - Stale data in cache, etc.
Stencil optimizations

- A stencil mask is created with a checkerboard like pattern.
  - This is done with 4 draws.
  - Each draw has a different stencil ref and rejects pixels based on the position.

Pixel Quad

<table>
<thead>
<tr>
<th>Draw 1 Stencil</th>
<th>Draw 2 Stencil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draw 3 Stencil</td>
<td>Draw 4 Stencil</td>
</tr>
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</table>
Stencil optimizations

- Radeon GPU Profiler shows very low occupancy.
- Why is the occupancy low?
  - Shader is very small and does not do much.
  - Shader waves are finishing faster than they can be launched.
Stencil optimizations

- Enter VK_EXT_shader_stencil_export
  - VK_EXT_shader_stencil_export is an extension supported by multiple vendors that allows the pixel shader to set the stencil ref value per pixel.
  - With this we can combine the 4 draws into 1.

- GLSL
  - `gl_FragStencilRefARB = int(lut[y * DITHER_PATTERN_SIZE + x]);`

- HLSL
  - `int main() : SV_StencilRef`
Stencil optimizations

- Saw ~75% savings for the pass.
Subgroup ops

- Subgroup ops introduced in Vulkan 1.1, supported by most desktop hardware, including AMD
  - Enable bringing over optimizations from other gaming platforms.
  - Allow lots of new potential optimizations.
  - Query the driver to see what ops are supported.
Subgroup ops

- Reduced divergence in the wave and scalarized some resources by using `subgroupOr` to unify the lighting bitmask.
  - Before the shader would loop though every light in the bitmask.
  - Changed it so every lane goes though the same lights. This allows some resources to be converted to scalars.

Lane 1

Lane 2

Lane 3

Lane 4
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Lane 1
Lane 2
Lane 3
Lane 4

OR
Scalar promotion
Subgroup ops

- Scalarized cubemask look ups by using `subgroupBroadcastFirst` to convert cubemask index to a scaler.
- `subgroupBroadcastFirst` used a lot for scalarization of shader code.
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Thanks

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  - Timur Popov
Q & A
Addendum

Testing done by Jordan Logan and Nikolai Petrov.

Testing by Jordan done on AMD Ryzen™ 7 1800x Processor, 2x16GB DDR4-2666, Vega64 (driver 19.10.2), ASUS Prime X370-PRO Socket AM4 motherboard, WD Blue 250GB M.2 SSD, Windows 10 x64 Pro (RS4).

Testing by Nikolai done on AMD Ryzen™ 7 2700x, 32GB, RX 580 (driver 19.10.2), Windows 10 x64.
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