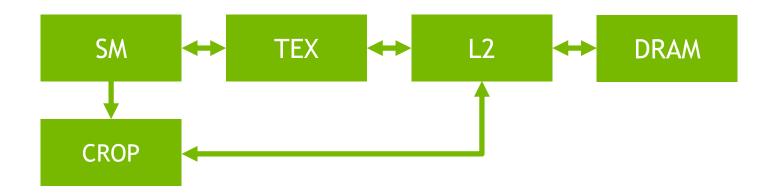
Fixing the Hyperdrive: Maximizing Rendering Performance on NVIDIA GPUs

Louis Bavoil, Principal Engineer



Booth #223 - South Hall www.nvidia.com/GDC

Full-Screen Pixel Shader



SM = Streaming Multiprocessor

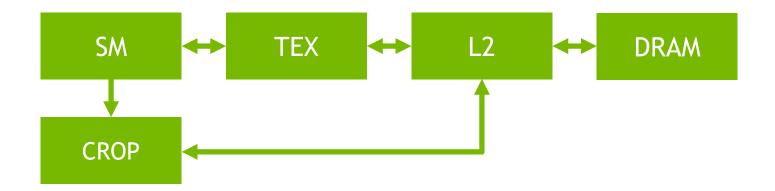
TEX = Texture unit

L2 = Level 2 cache

DRAM = physical video-memory unit

CROP = Color ROP

Speed Of Light (SOL) Metrics



"SOL%" = % of Peak Performance

Top SOL%s [SM:95% | TEX:72% | L2:72% | DRAM:34% | CROP:5%]

Capturing a Frame from a DX App Using Nsight Graphics 1.0

🟦 NVIDIA Nsight G	raphics		-	- [
File Connection To Connect Connect Dis	Connect to process				×	
	Target Platform					
	Hereit Windows	Device: localhost	•	· +		
		Launch Attach				
		Application Executable:	(required)	•		
		Working Directory:				
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		Automatically Connect:	Yes			
	Activity					
	奋 Frame Debugger 屾 Frame Profiler	This activity offers a simplified i analysis. Multiple frames may b	nterface for generating C++ Captures of your frames e collected per session.	for later		
	Benerate C++ Capture	Supported APIs: D3D11, D3D12,	. OpenGL, Vulkan			
		Additional Options				
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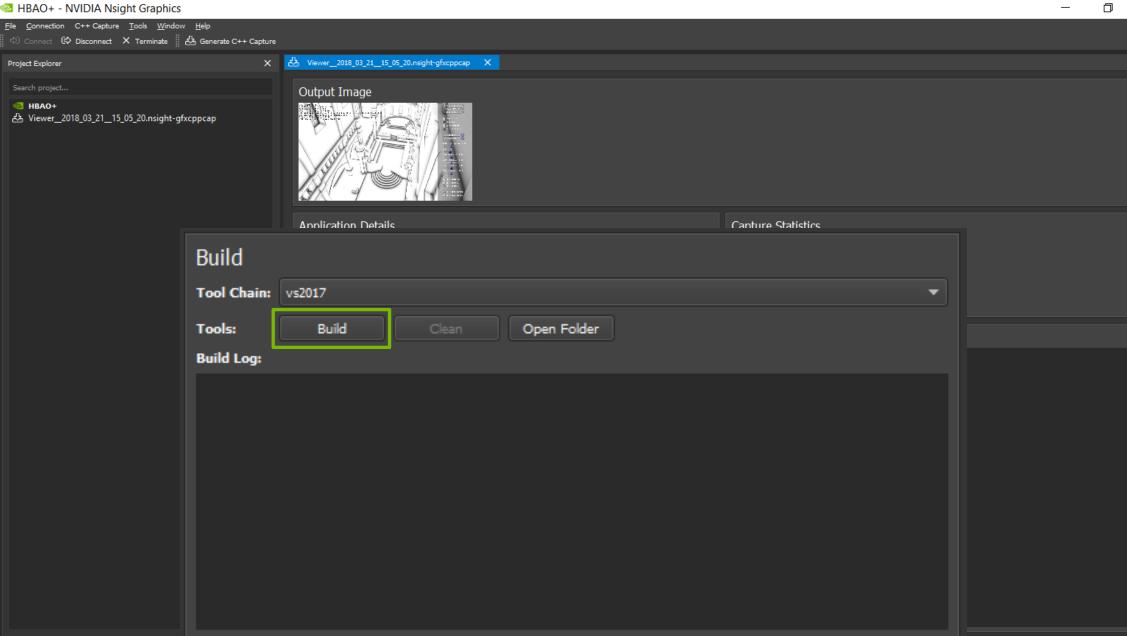


Mathematical Heat And Antipart Antip

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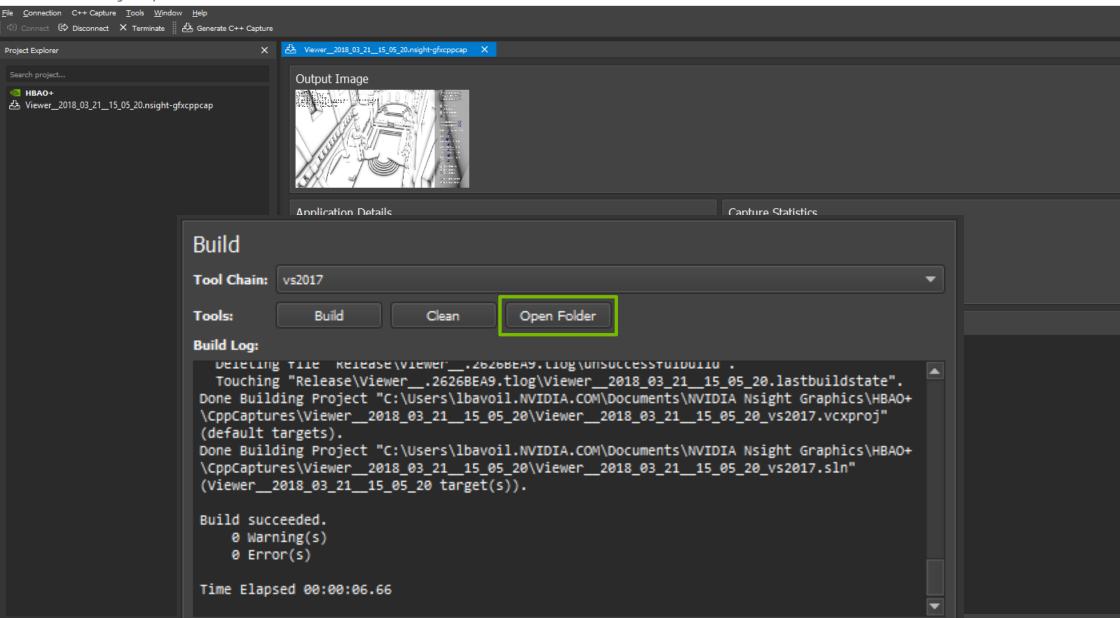
_FileConnection C++ Capture _ToolsWindow _Help		
Project Explorer X	凸 Viewer_2018_03_21_15_05_20.nsight-gfxcppcap X	
Search project	Output Image	
HBAO+		
	Application Details Application: Viewer.exe Arguments: Viewer.exe Host Name: localhost Capture Date: 3/21/2018 3:05 PM GPU(s): GeForce GTX 1080 Driver Version: 391.1	Capture Statistics API: D3D11.3 # Events: 797 # Actions: 95
	Build	Comments
	Tool Chain: vs2017 Tools: Build Clean Open Folder Build Log:	Add comments
	Run Status: Not Yet Built Options: ✓ Reset state between frames Run: Execute Connect	

HBAO+ - NVIDIA Nsight Graphics



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HBAO+ - NVIDIA Nsight Graphics



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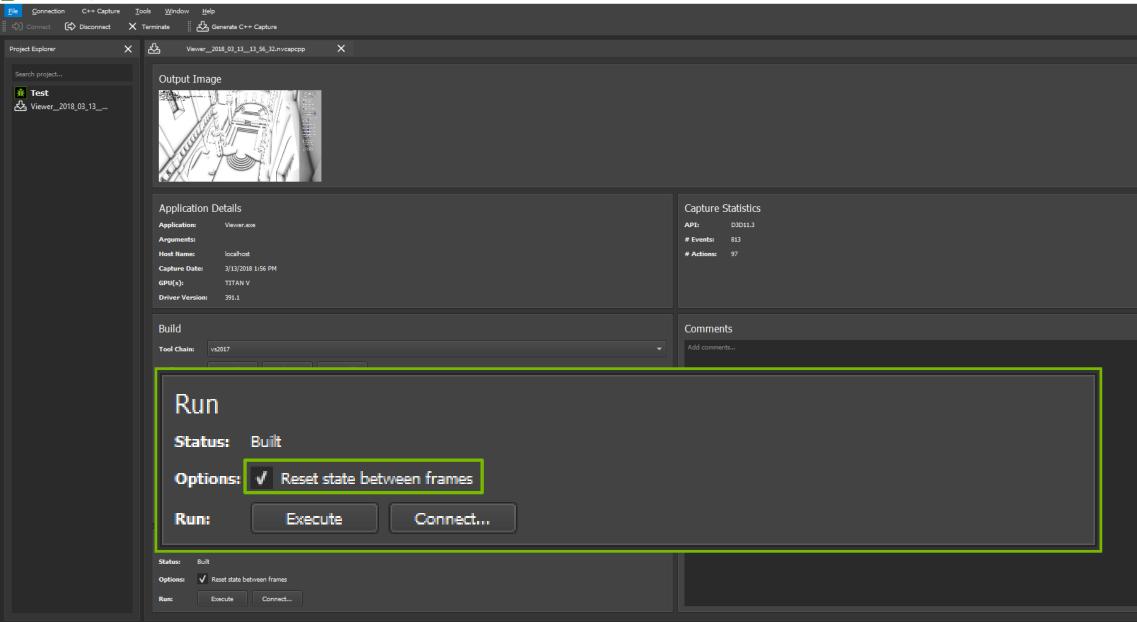
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	🔛 Resources00.cpp	3/13/2018 1:56 PM	C++ Source	89 KB
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	🔛 Threading.cpp	3/13/2018 1:56 PM	C++ Source	8 KB
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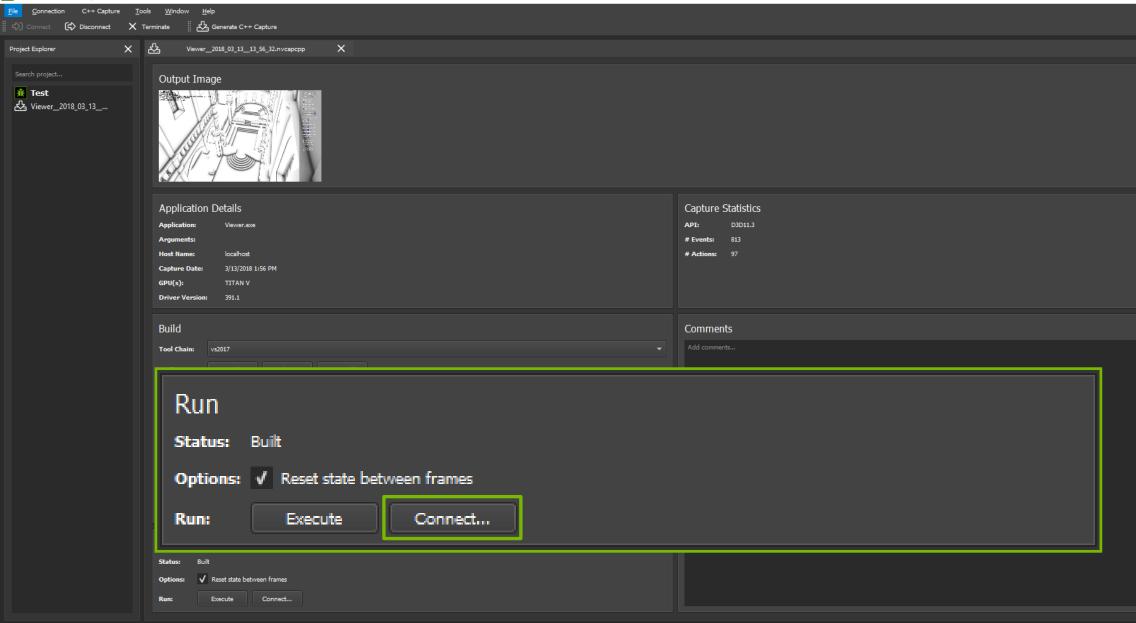
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v v v ⊡ v v -	Viewer_2018_03_13_13_57_01	Global Scope)	
Search Solution Explorer (Ctrl+;)	<pre></pre>		
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▲ Niewer_2018_03_13_13_57_01	····BEGIN_DATA_SCOPE_FUNCTION();		
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 Datascope.n ++ Frame0Part00.cpp 			
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++ FrameSetup00.cpp		oFloat(0x3F800000/*1.0f*/), HexToFloat(0x3F800000/*1.0f*/) derTargetView(pID3D11RenderTargetView_uid_550, FLOAT_temp_:	
*+ Helpers.cpp	pibblibeviceconcext_uid_55-9Clearken	dentalBeratew(htpppttvendentalBeratew_did_220, .krowl_femb_	*/;
Helpers.h	····//·Clear·#1·[01]		
▶ ++ Main.cpp	<pre>pID3D11DeviceContext_uid_53->ClearDep</pre>	thStencilView(pID3D11DepthStencilView_uid_562, 1u, 0.0f, 0));
** PerfMarkersReset.cpp		1PondonTangotViou tomo 1[2] (NULL	iou uid 552.).
 ** PerfMarkersSetup.cpp ** ReadOnlyDatabase.cpp 		1RenderTargetView_temp_1[2]·=·{·NULL,·pID3D11RenderTargetV derTargets(2u,·pID3D11RenderTargetView_temp_1,·pID3D11Dept	
ReadOnlyDatabase.h			//
A ReplayProcedures.cpp	····pID3D11DeviceContext_uid_53->OMSetDep	thStencilState(pID3D11DepthStencilState_uid_86, 1u);	
ReplayProcedures.h			
Resources.h	<pre>static FLOAT FLOAT_temp_2; pTD3D11DeviceContext_uid_53->OMSetBle</pre>	ndState(pID3D11BlendState_uid_84, NULL, @xFFFFFFFFu);	
A the Resources00.cpp	prostructed intext_ord_ss-vonsetble		
the second seco	····pID3D11DeviceContext_uid_53->RSSetSta		
 Inreading.h ** WinResourcesReset.cpp 		<pre>der(pID3D11VertexShader_uid_90, ·NULL, ·0u);</pre>	
 Winkesourceskeset.cpp ** WinkesourcesSetup.cpp 	····pID3D11DeviceContext_uid_53->PSSetSha		
		stantBuffers(0u, 1u, &pID3D11Buffer_uid_83); stantBuffers(0u, 1u, &pID3D11Buffer_uid_83);	
		bresource(((ID3D11Resource*)pID3D11Buffer_uid_83), 0u, NUL	L, NV_GET_RESOURCE(void*, 0), 0u, 0u);
	<pre>static.UINT.UINT_temp_1[1].e.{.32u.};</pre>		
	<pre>static.UINT_UINT_temp_2[1].=.{.0u.};</pre>		
	piD3D11DeviceContext_uid_53->1ASetVer	texBuffers(0u, 1u, &pID3D11Buffer_uid_93, UINT_temp_1, UIN	1_temp_2);
	····pID3D11DeviceContext_uid_53->IASetInd	exBuffer(pID3D11Buffer_uid_94, DXGI_FORMAT_R32_UINT, 0u);	
	····pID3D11DeviceContext_uid_53->IASetInp	utLayout(pID3D11InputLayout_uid_80);	
	····pID3D11DeviceContext_uid_53->IASetPri	<pre>mitiveTopology(D3D_PRIMITIVE_TOPOLOGY_TRIANGLELIST);</pre>	
	····//·Draw·#0·[089]		
	····pID3D11DeviceContext_uid_53->DrawInde	xed(234891u, 0u, 0);	
		<pre>ID3D11Asynchronous*)pID3D11Query_uid_142));</pre>	
	100 % - 4	1 *) *) *) *) *) *) *) *) *) *) *) *) *)	
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۰ · · · · · · · · · · · · · · · · · · ·	C# Interactive Call Hierarchy, Error List Find Results 1 Find Sun		

Test - NVIDIA Nsight Graphics



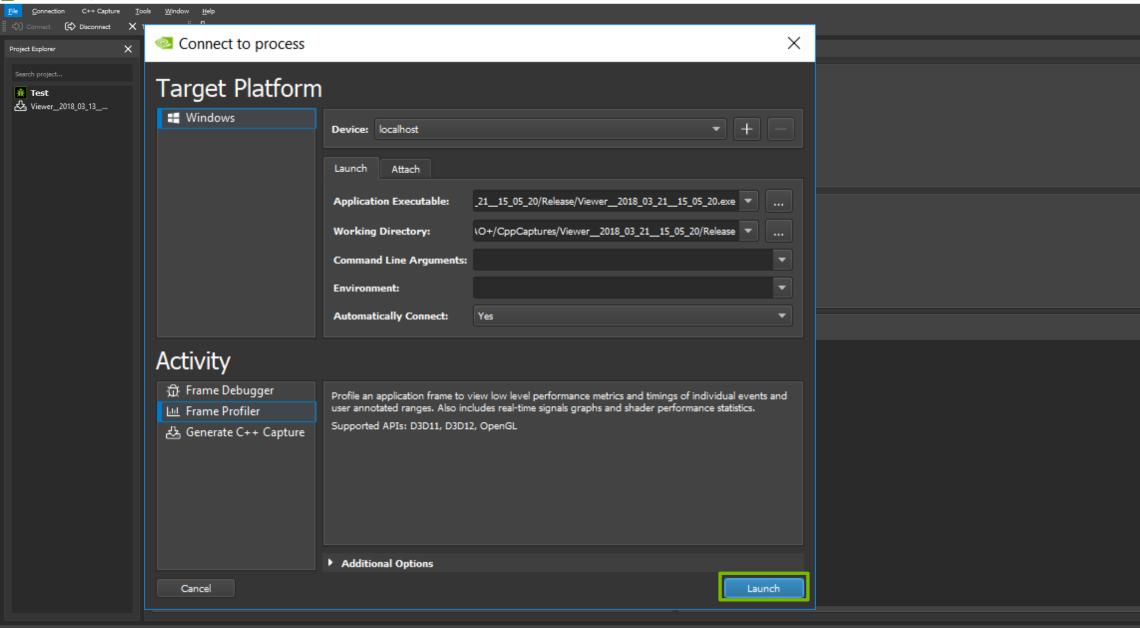
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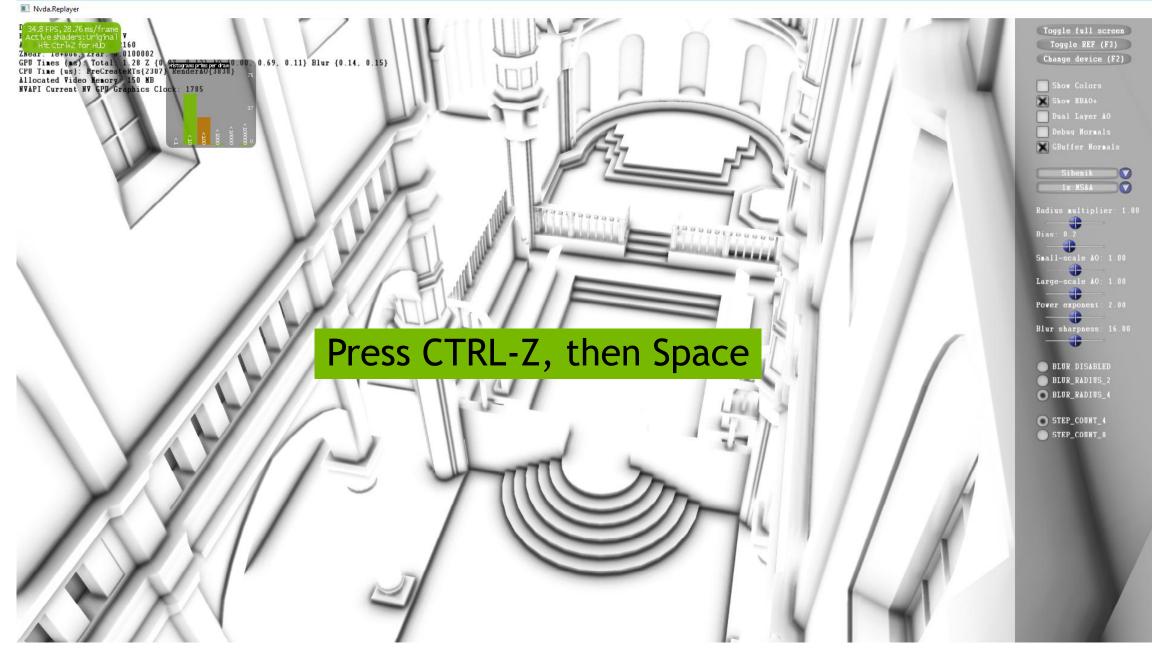
Test - NVIDIA Nsight Graphics



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Test - NVIDIA Nsight Graphics





Profiler Result for the Whole Frame

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Draws: 88 Blits: 10 Misc. Data Update: 0 Total: 713	Actions		
Dispatches: 0 Presents: 1 Non-API: 1 Clears: 2 Command List Execu 0 Other: 611	All Actions	All Actions (3.15 ms - 100.0%)	
▼ Details	Perf Markers	HBAO+ (2.55 ms - 80.9%)	
Filter: Enter a filter	C	DrawDarseAOPS (1.57 ms - 49.9%)	DrawReint DrawBlurXPS DrawBlurYPS
API Call Count ▼ Avg CP ▲	Pipelined Actions	:85 - E:94 (E:98 - E:10 E:113 - E:1 E:129 - E:1 E:145 - E:1 E:161 - E:1	
ID3D11DeviceContext3::PSSetShaderResources() 89 <		<u>E:121 - E:1</u> <u>E:137 - E:1</u> <u>E:153 - E:1</u>	<u>E:169 - E:178 (0.</u>
ID3D11DeviceContext3::Draw() 87 <			
ID3D11DeviceContext3::IASetPrimitiveTopology() 69 <			
ID3D11DeviceContext3::IASetInputLayout() 68 <	Range Info - [All Actions] All Actions (3.15 ms - 100.0)	(ov)	Summary 🔻
ID3D11DeviceContext3::IASetVertexBuffers() 66 <			
ID3D11DeviceContext3::Map() 64 < ID3D11DeviceContext3::Unmap() 64 <	GPU Frame Lin	ne: 3.15 ms ⁸⁸ Dispatch Call Count 5.7 Threads (Total/Avg)	0 0 / 0.0
			0.0 / 0.0
vents View X	Measured using D3D ti	mestamp queries	
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			Summary
Event: 712 Filter: Enter a filter or select a predefin Select a predefined filter V			
Event A Description			
0 👗 // Start of Capture		6 TEX:58.4% L2:46.5% DRAM:44.1% CROP:25.5%	
1 T ResetInitialFrameState - D3DPERF_BeginEvent(D3DCOLOR col	GPU Idle	0.0% Wait For Idle Count	7
2 ID3D11DeviceContext3::CSSetConstantBuffers(UINT StartSlot =	TSL2 Stall Cycles	0.1% Pixel Shader Barrier Count	6
3 ID3D11DeviceContext3::CSSetSamplers(UINT StartSlot = 0, UINT	SM Active	92.5% SM Active Threads Per Instruction Executed	99.4%
4 ID3D11DeviceContext3::CSSetShader(ID3D11ComputeShader* p(SM Active SM Active Min/Max Delta	92.3% SM Active Threads Per Instruction Executed 0.7% SM Warp Stall Long Scoreboard	31.0%
5 ID3D11DeviceContext3::CSSetShaderResources(UINT StartSlot =	SM Active Minimax Della SM Issue Utilization Per Active Cycle	69.6% SM Warp Stall Barrier	0.0%
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7 ID3D11DeviceContext3::IASetIndexBuffer(ID3D11Buffer* pInde:			0.077
8 ID3D11DeviceContext3::IASetInputLayout(ID3D11InputLayout*			
9 ID3D11DeviceContext3::IASetPrimitiveTopology(D3D11_PRIMIT			
10 ID3D11DeviceContext3::IASetVertexBuffers(UINT StartSlot = 0,	 Memory 		Summary 💌
11 ID3D11DeviceContext3::VSSetConstantBuffers(UINT StartSlot =			
12 ID3D11DeviceContext3::VSSetSamplers(UINT StartSlot = 0, UINT	L2 SOL	46.5% FB Read Utilization	28.8%
13 ID3D11DeviceContext3::VSSetShader(ID3D11VertexShader* pVeri	L2 Hit Rate	80.5% FB Write Utilization	15.3%
14 TD2D11DouiceContext2uVSSatSbadesRecourses/UIMT StatSlat -	Tex Hit Rate	85.2%	

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NOTE: The profiler always locks the GPU Core Clock frequency (for most deterministic results).

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Profiler Result for the Whole Frame

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	19 <				E:121 -	E:1 E:137 - E	:1 E:153 - E:	1 E:169 - E:	178 (0.2		
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Profiling a PerfMarker Range...

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Draws: 88 Blits: 10 Misc. Data Update: 0 Total: 713	Actions			
Dispatches: 0 Presents: 1 Non-API: 1	All Actions		All Actions (3.15 ms - 100.0%)	
Clears: 2 Command List Execu 0 Other: 611			HBAO+ (2.55 ms - 80.9%)	
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Filter: Enter a filter		E:63 - E:63 (0.44 ms - 13.99 E:85 - E:94 (E:98 - E:10 E		E-105 E-105 (0.40 ms -15 F//
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ID3D11DeviceContext3::IASetPrimitiveTopology() 69 < ID3D11DeviceContext3::IASetInputLayout() 68 <	Program Ranges	VertexShader 3, PixelShade Vertex: VertexSha	VertexShader 4, GeometryShader 1, PixelShader 26 (1.57 ms - 49.9%)	VertexShader · Vertex
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ID3D11DeviceContext3::Map() 64 <	Add	•		
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nts View X	 Range Info - [All Actions 	i] All Actions (3.15 ms - 100.0%)		Summary 🔻
View: Hierarchical 🔻 🕻] 🕂 Arguments: Variable + Value 🔻	»			
nt: 712 Filter: Enter a filter or select a predefin Select a predefined filter 💌 🚫	Draw Call Count		88 Dispatch Call Count	0
	API Primitives (Total/Avg)		79702 / 905.7 Threads (Total/Avg)	0/0.0
Event Description	Shaded Pixels (Total/Avg)		6.1112e+7 / 694455.0 Instructions (Avg Per Dispatch/Avg Per Thread)	0.0 / 0.0
1 Capture 1 ResetInitialFrameState - D3DPERF_BeginEvent(D3DCOLOR col				
2 ID3D11DeviceContext3::CSSetConstantBuffers(UINT StartSlot =	 Pipeline Overview 			Summary 💌
3 ID3D11DeviceContext3::CSSetSamplers(UINT StartSlot = 0, UINT				
4 ID3D11DeviceContext3::CSSetShader(ID3D11ComputeShader* p(
5 ID3D11DeviceContext3::CSSetShaderResources(UINT StartSlot =	Top SOLs	SM:64.4% TEX:58.4% L2:46.5%		
6 ID3D11DeviceContext3::CSSetUnorderedAccessViews(UINT Sta	GPU Idle		0.0% Wait For Idle Count	7
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ID3D11DeviceContext3::Draw() 87 <	 Range Info - [Perf Markers] DrawCoarseAOPS (1.57 ms - 49.9%) 		Summary 🔻
ID3D11DeviceContext3::IASetPrimitiveTopology() 69 <	Draw Call Count	16 Dispatch Call Count	0
ID3D11DeviceContext3::IASetInputLayout() 68 < ID3D11DeviceContext3::IASetVertexBuffers() 66 <	API Primitives (Total/Avg)	16 / 1.0 Threads (Total/Avg)	0/0.0
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ID3D11DeviceContext3::Unmap() 64 <			
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2 ID3D11DeviceContext3::CSSetConstantBuffers(UINT StartSlot =	SM Active Min/Max Delta	0.3% SM Warp Stall Long Scoreboard	16.4%
3 ID3D11DeviceContext3::CSSetSamplers(UINT StartSlot = 0, UINT	SM Issue Utilization Per Active Cycle	95.6% SM Warp Stall Barrier	0.0%
4 ID3D11DeviceContext3::CSSetShader(ID3D11ComputeShader* p(SM Occupancy (Active Warps Per Active Cycle)	46.4 SM Warp Stall Drain	0.0%
5 ID3D11DeviceContext3::CSSetShaderResources(UINT StartSlot =			
6 ID3D11DeviceContext3::CSSetUnorderedAccessViews(UINT Sta			
7 ID3D11DeviceContext3::IASetIndexBuffer(ID3D11Buffer* pInde:			
8 ID3D11DeviceContext3::IASetInputLayout(ID3D11InputLayout*	 Memory 		Summary 🔻
9 ID3D11DeviceContext3::IASetPrimitiveTopology(D3D11_PRIMIT	13 501	rear on the r	22.5%
10 ID3D11DeviceContext3::IASetVertexBuffers(UINT StartSlot = 0,	L2 SOL L2 Hit Rate	71.9% FB Read Utilization 81.8% FB Write Utilization	32.5% 1.8%
11 ID3D11DeviceContext3::VSSetConstantBuffers(UINT StartSlot =	L2 Hit Rate	81.8% PB Write Utilization 83.9%	1.8%
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13 ID3D11DeviceContext3::VSSetShader(ID3D11VertexShader* pVer 14 ID3D11DeviceContext3::VSSetShaderResources(UINT StartSlot =	 User Metrics 		Graphics Range Table 💌
15 ID3D11DeviceContext3::HSSetConstantBuffers(IIINT StartSlot =			
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Wiewer 2018 03 21 15 05 20.exe [18356]

The Top SOL Units

rt as C++ Capture 🛛 Refresh Event Timings 🔟 Profile Current Event 🖾 Profile Frame 🛛 🕅 🖻

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Dispatches: Clears:	0 Presents: 1 Non-API: 1 2 Command List Exect. 0 Other: 611	All Actions		All Actions (3.15 ms - 100.0%)		
▼ Details		Perf Markers		HBAO+ (2.56 ms - 61.2%)		
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2 [3 [4	SM Issue Utilization Per Active	e Cycle			32.040	.4% .0%
s 6	SM Occupancy (Active Warp	s Per Active Cycle)			46.4	
1 8	ID3D11DeviceContext3::IASetInputLayout(ID3D11InputLayout*	* Memory			Summary	
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	ID3D11DeviceContext3::VSSetShaderResources(UINT StartSlot =	▼ User Metrics				
	TD3D11DeviceContext3nHSSelConstantRoffnes(LINT StartSint =					

The Peak-Perf% Analysis Method

For each "Top SOL%" unit:

1. If SOL% > 80% \rightarrow (A) try removing work from this unit

- If SM: By opportunistically skipping instructions using branches (or early depth test)
- If SM: By moving math instructions to lookup tables
- If TEX: By moving structured-buffer loads to constant-buffer loads, etc.
- 2. If SOL% < 60% \rightarrow (B) try increasing the SOL% of this unit
 - By removing "idle cycles" (GPU unit is not doing any work for a % of the time)
 - By removing "stall cycles" (GPU unit has internal inefficiencies)
 - By avoiding "slow paths" if possible (e.g. 32-bit index buffers, and FP32x4 textures)
- 3. If SOL% in [60,80], do both (A) and (B)

Range Profiling & Async Compute

 For DX12, Nsight Frame Captures flatten all async COMPUTE queues to the main DIRECT queue

 For understanding overlaps of async compute work with graphics work, Nsight GPU Trace can be used

Example DX11 Workload:

Voxelization using UAV Atomics



CPU Limited?

API	Statistics View	,	×
	Summary		
	Draws:	270 Presents: 1 Other: 3716	
	Draws: Dispatches:		
	Clears:	19 Misc. Data Update: 0	
	Blits:	44 Non-API: 1	
Ŧ	Details		
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			**
	ent: 4097	Filter: Enter a filter or select a predefit Select a predefined filter 💌	
	Event 🔺	Description	
		IDXGISwapChain4::GetFullscreenState(BOOL* pFullscreen = 0x1c	
		ID3D11DeviceContext3::PSSetConstantBuffers(UINT StartSlot =	
		ID3D11DeviceContext3::VSSetConstantBuffers(UINT StartSlot =	
	4	ID3D11DeviceContext3::GSSetConstantBuffers(UINT StartSlot =	
		ID3D11DeviceContext3::CSSetConstantBuffers(UINT StartSlot =	
		ID3D11DeviceContext3::PSSetShaderResources(UINT StartSlot :	
		ID3D11DeviceContext3::VSSetShaderResources(UINT StartSlot :	
		ID3D11DeviceContext3::GSSetShaderResources(UINT StartSlot :	
		ID3D11DeviceContext3::CSSetShaderResources(UINT StartSlot :	
		ID3D11DeviceContext3::PSSetSamplers(UINT StartSlot = 0, UINT	
		ID3D11DeviceContext3::CSSetSamplers(UINT StartSlot = 0, UINT	
	12	ID3D11DeviceContext3::IASetVertexBuffers(UINT StartSlot = 0,	
	13		
		ID3D11DeviceContext3::CSSetUnorderedAccessViews(UINT Sta	
		ID3D11DeviceContext3::PSSetShader(ID3D11PixelShader* pPixel	
		ID3D11DeviceContext3::VSSetShader(ID3D11VertexShader* pVer	
		ID3D11DeviceContext3::GSSetShader(ID3D11GeometryShader* p	
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		ID3D11DeviceContext3::DSSetShader(ID3D11DomainShader* pD	
		ID3D11DeviceContext3::CSSetShader(ID3D11ComputeShader* p	C
		ID3D11DeviceContext3::IASetInputLayout(ID3D11InputLayout*	

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	DSV 1 (0.69 m		RTV 5 RTV 6 (1.81 ms - 71.1%)					RTV-	13 RTV 14 (0.89	
» Range Info	[Perf Markers] Combined Vo	xelization (0.68 ms - 8.0%)							Summary	
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Shaded Pixel	(Total/Avg)		1.12941e+6 / 11	294.1 Instructions (A	lvg Per Dispatch/Avg P	Per Thread)			0.0	/ 0.0
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		VPC:25.0% SM:21.1	% L2:20.6% DRAM:9.5% PD:	3.2%						
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"Top SOLs"

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1 Other: 3716

270 Presents:

Non-API:

Misc. Data Update:

API Statistics View

Summary

Clears

Blits:

Details

	Next Fram	e ▷ Resume 🕹 Export as C	C++ Capture 🖯 Re			Current Event		e Frame	ð Þ									
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ng un	Π)L						20.6% F	B Read Utiliza	tion								9.1%

95.7% FB Write Utilization

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"SM Active"

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Event: 4097 Filter: Enter a filter or select a predefi Select a predefined filter V	
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1 IDXGISwapChain4::GetFullscreenState(BOOL* pFullscreen = 0x1c4)	Shaded Pixels (To
2 ID3D11DeviceContext3::PSSetConstantBuffers(UINT StartSlot = 0	
3 ID3D11DeviceContext3::VSSetConstantBuffers(UINT StartSlot = 0	 Pipeline Overvie
4 ID3D11DeviceContext3::GSSetConstantBuffers(UINT StartSlot = 0	
5 ID3D11DeviceContext3::CSSetConstantBuffers(UINT StartSlot = 0	
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ndar Tarnat Rannae 📃	DSV 1 (0.69 ms			RTV 5 RTV 6 (1	1.81 ms - 21.19				8 (0.4					RTV-13	RTV 14 (0.89	
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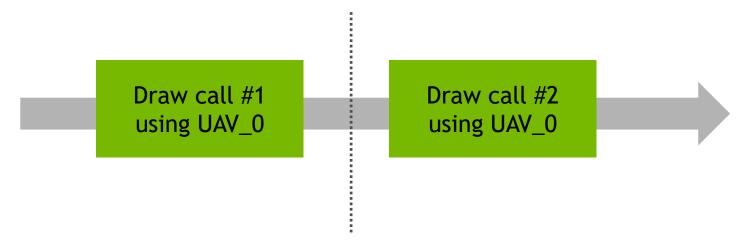
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Voxelization - NVIDIA Nsight Graphics	—	[
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Draws: 270 Presents: 1 Other: 3716		
Dispatches: 47 Command List Executes 0 Total: 4098 Clears: 19 Misc. Data Update: 0	Actions All Actions (8.57 ms - 100.0%)	
Blits: 44 Non-API: 1	Perf Markers Combined Vox Sample: G-Buffe Tracing: Area Lights (3.24 ms - 37.8%) T Tracing: Area Light Interpolation (1.86 ms - Tracin	
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1 IDXGISwapChain4::GetFullscreenState(BOOL* pFullscreen = 0x1c4	Shaded Pixels (Total/Avg) 1.12941e+6 / 11294.1 Instructions (Avg Per Dispatch/Avg Per Thread)	
2 ID3D11DeviceContext3::PSSetConstantBuffers(UINT StartSlot = 0		
3 ID3D11DeviceContext3::VSSetConstantBuffers(UINT StartSlot = 0	▼ Pipeline Overview Su	
4 ID3D11DeviceContext3::GSSetConstantBuffers(UINT StartSlot = 0		
5 ID3D11DeviceContext3::CSSetConstantBuffers(UINT StartSlot = 0	Wait For Idle (WFI) Count: 1	
6 ID3D11DeviceContext3::PSSetShaderResources(UINT StartSlot =	Top 50Ls VPC:25.0% SM:21.1% L2:20.6% DRAM:9.5% PD:3.2%	
7 ID3D11DeviceContext3::VSSetShaderResources(UINT StartSlot =	GPU Idle 0.091 Wait For Idle Count	
8 ID3D11DeviceContext3::GSSetShaderResources(UINT StartSlot =	TSL2 Stall Cycles 0.1% Pixel Shader Barrier Count	
9 ID3D11DeviceContext3::CSSetShaderResources(UINT StartSlot =		
10 ID3D11DeviceContext3::PSSetSamplers(UINT StartSlot = 0, UINT	SM Active 59.5% SM Active Threads Per Instruction Executed	
11 ID3D11DeviceContext3::CSSetSamplers(UINT StartSlot = 0, UINT	SM Active Min/Max Delta 14.3% SM Warp Stall Long Scoreboard SM Long Active Orde 25.5% CM More Stall Device	
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18 ID3D11DeviceContext3:HSSetShader(ID3D11HullShader* pHullSha		
19 ID3D11DeviceContext3::DSSetShader(ID3D11DomainShader* pDo	L2 SOL 20.6% FB Read Utilization	
20 ID3D11DeviceContext3::CSSetShader(ID3D11ComputeShader* pC	L2 Hit Rate 95.7% FB Write Utilization	
21 ID3D11DeviceContext3::IASetInputLayout(ID3D11InputLayout* p	Tex Hit Rate 76.9%	

UAVOverlap OEE.eve [10340]

DX11 Driver Behavior

By default: Serialize Draw calls with bound UAV in common

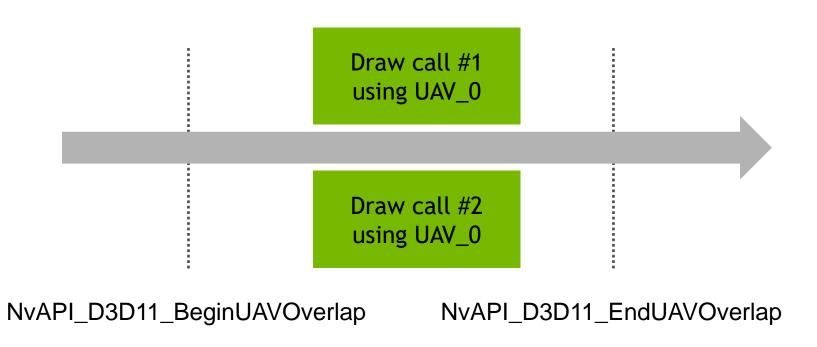


GPU Wait For Idle (WFI)



DX11 Driver Behavior

Optimized: Concurrent Draw Calls





UAV-Overlap Optimization

Add NvAPI_D3D11_{Begin,End}UAVOverlap

	BEFORE	AFTER	RATIO
WFI Count	103	3	
Top SOLs	VPC:25.0% SM:21.1% L2:20.6%	VPC:52.3% SM:44.3% L2:42.6%	VPC: 2.1x SM: 2.1x L2: 2.1x
SM Active%	59.1%	95.1%	1.6x
GPU Elapsed Time	0.69 ms	0.38 ms	1.8x Gain

The Peak-Perf% Analysis Method

BEFORE: Top SOLs: [VPC:25.0% | SM:21.1% | L2:20.6%] AFTER: Top SOLs: [VPC:52.3% | SM:44.3% | L2:42.6%]

For each "Top SOL%" unit:

- 1. If SOL% > 80% \rightarrow (A) try removing work from this unit
- 2. If SOL% < $60\% \rightarrow$ (B) try increasing the SOL% of this unit
 - By removing "idle cycles" (GPU unit is not doing any work for a % of the time)
 - By removing "stall cycles" (GPU unit has internal inefficiencies)
 - By avoiding "slow paths" if possible (e.g. avoiding 32-bit index buffers, and avoiding FP32x4 texture formats).
- 3. If SOL% in [60,80], do both (A) and (B)

Example Workload:

Drawing Tiny Triangles



Index Buffer Format = R32_UINT With all indices >= USHORT_MAX replaced with 0

🛛 🖓 Refresh Event Timings 🔟 Profile Current Event 🖆 Profile Frame 🛛 🙆 [

	088										
▼ Summary	Accumulated Event Times (ms)	20	40 60	80	100	120 14	40 160	180	200	220	240
Draws: 20498 Command List Executes 0					1 2 3						
Dispatches: 106 Misc. Data Update: 0 Clears: 22 Non-API: 1	All Actions						1%)				
Blits: 42541 Other: 231875				06 Shadows (180.79	1 ms - 71.0%)			Dir	ir 07.0 0 '.02 Draw	GBuffer (dynamic	c emissive
Presents: 1 Total: 295044				06 Shadows (180.79					07.0 07.02 Draw	vGBuffer (dynamic	c emissive
▼ Details				Shadow_AllProjectors (146.7			06.2 Directional				
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API Call	API Primitive (Count: 22.6	657.500								
		,									
	Shaded Pixels:	onal cascade 2 (5.09 ms - 2.0%									
ID3D11DeviceContext3::IASetVertexBuffers()	Draw Call Count				174 Dispatch Call	Count					
ID3D11DeviceContext3::IASetInputLayout()	API Primitives (Total/Avg)			2.26575e+7 / 130215	5.2 Threads (Tot.	tal/Avg)					
Events View X	Shaded Pixels (Total/Avg)			0 /	0.0 Instructions ((Avg Per Dispatch/Avg	, Per Thread)				
B) View: Hierarchical ▼ [] 17 * **	* Pipeline Overview	61 10/ 1 1/	C.AC T		1.26	1 /00					
Event: 295043 Filter: Enter a filter o Select a 🗸 🔊	Top SOLs [PD:	.04.1% VI	C:40. /		VI:30.	Z/0					
Event Description	Top SOLs			I:36.2% L2:18.0% SM:9.5		ilization Per Elapsed Cvc	le				9,5%
<u>0</u> [₹] // Start of Capture	GPU Idle	PD:04.1				ilization Per Elapsed Cyc					9.5%
	Wait For Idle Count					ncy (Active Warps Per A					1.6
	GPU Idle: 0.0%				0 SM Active						95.9%
	TSL2 Stall Cycles %				.0% SM Active Mir						1.3%
	✓ Memory				DRA	M Read	l Utiliza	ition:	35.9%		
	L2 SOL L2 Hit Rate			18.0							35.9%
10 ID3D11DeviceContext3::GSSel				323	.9% FB Write Utiliz						0,2%
PD = Primitive Distr	ributor unit										

PD = Primitive Distributor unit VPC = ViewPort Culling unit "DRAM Read Utilization": % of cycles that a DRAM read request is active

araphics Range Table 🔻 Transpose

Index-Buffer Format Optimization

32->16 bits per index

	BEFORE	AFTER	RATIO
Top SOLs	PD:64.1% VPC:46.7% DRAM:36.2%	PD:80.5% VPC:58.7% DRAM:28.5%	PD:1.3x VPC:1.3x DRAM: 0.8x
DRAM Read Utilization	36%	28%	0.78x
GPU Elapsed Time	5.09 ms	2.37 ms	2.1x Gain

The Peak-Perf% Analysis Method

BEFORE: Top SOLs: [PD:64.1% | VPC:46.7% | DRAM:36.2%] AFTER: Top SOLs: [PD:80.5% | VPC:58.7% | DRAM:28.5%]

For each "Top SOL%" unit:

- 1. If SOL% > 80% \rightarrow (A) try removing work from this unit
- 2. If SOL% < 60% \rightarrow (B) try increasing the SOL% of this unit
 - By removing "idle cycles" (GPU unit is not doing any work for a % of the time)
 - By removing "stall cycles" (GPU unit has internal inefficiencies)
 - By avoiding "slow paths" if possible (e.g. 32-bit index buffers, and FP32x4 textures)
- 3. If SOL% in [60,80], do both (A) and (B)

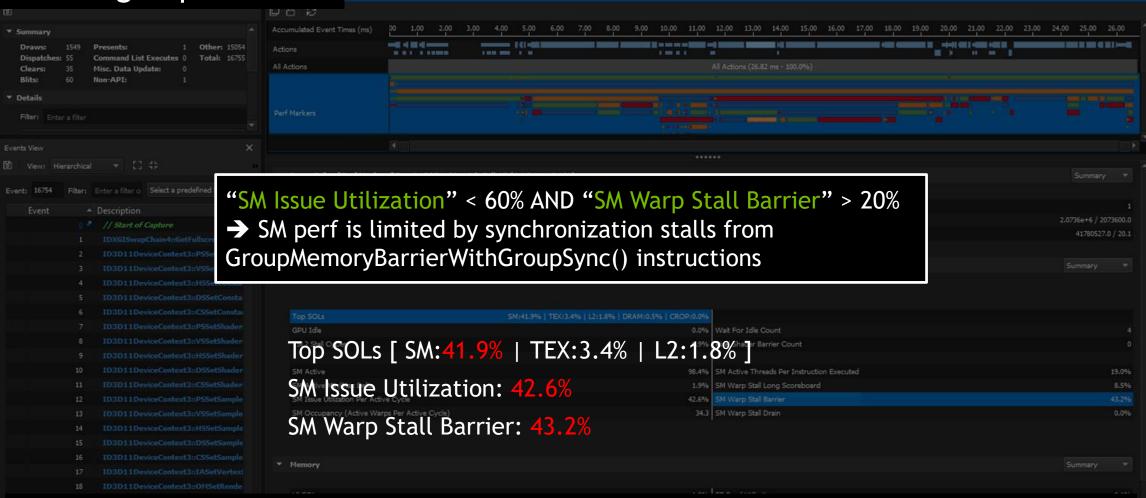
Example Workload:

Light-Tile Culling Compute Shader



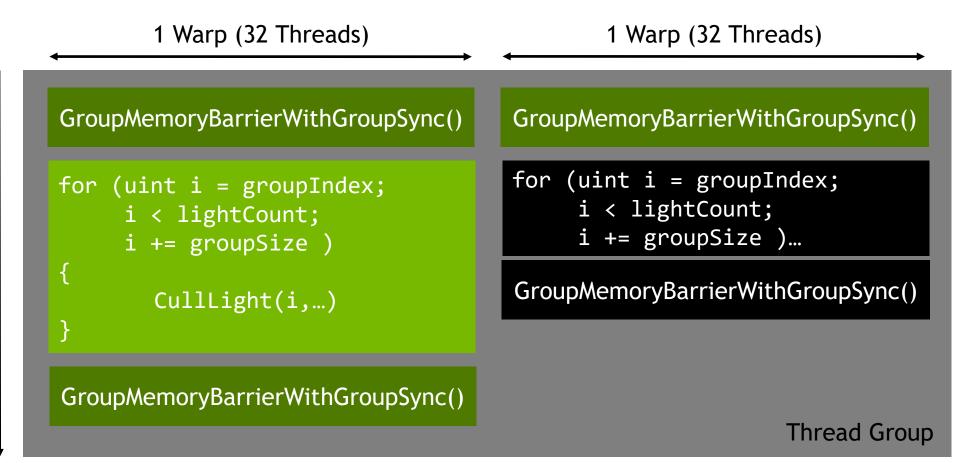
Light Tile Culling CS Thread-group size = 64

esume 🛛 🕹 Export as C++ Capture 🛱 Refresh Event Timings 🔟 Profile Current Event 🖾 Profile Frame 🛛 🗗



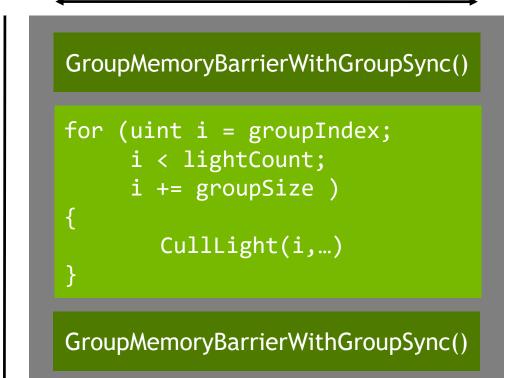
SM Issue Utilization: The % of SM active cycles a SM scheduler issued at least one instruction SM Warp Stall Barrier: % of active warps that were stalled waiting for sibling warps at a CTA barrier

BEFORE: 2-Warp Thread Groups



AFTER: 1-Warp Thread Groups

1 Warp (32 Threads)

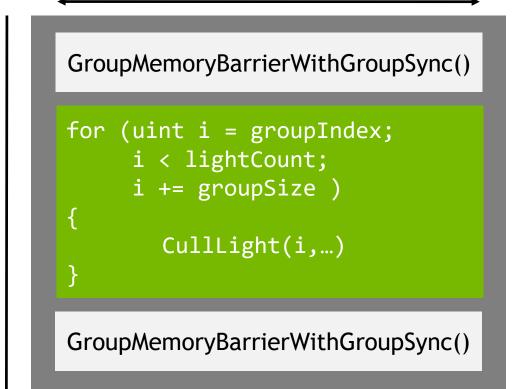


Elapsed Cycles



AFTER: 1-Warp Thread Groups

1 Warp (32 Threads)



For single-warp thread groups, barrier instructions are free on NVIDIA GPUs.

Elapsed

Cycles

Thread-Group Size Reduction:

64 threads -> 32 threads

	BEFORE	AFTER	RATIO
Top SOL	SM:41.9%	SM:73.7%	SM:1.76x
SM Issue Utilization	42.6%	76.6%	1.80x
SM Warp Stall on Barriers	43.2%	0.0%	0.0x
SM Occupancy (Active Warps)	34.3	31.2	0.91x
GPU Elapsed Time	1.10 ms	0.33 ms	3.3x Gain

The Peak-Perf% Analysis Method

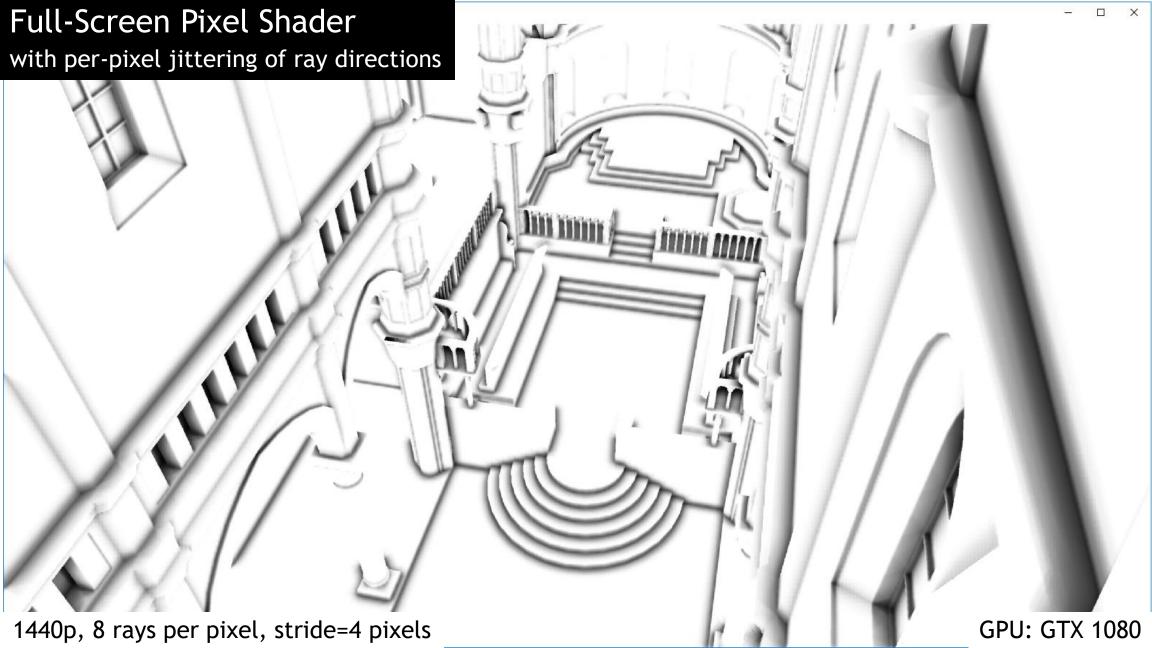
BEFORE: Top SOLs: [SM:41.9% | TEX:3.4% | L2:1.8%] AFTER: Top SOLs: [SM:73.7% | TEX:4.9% | L2:4.2%]

For each "Top SOL%" unit (from high to low SOL%):

- 1. If SOL% > 80% \rightarrow (A) try removing work from this unit
- 2. If SOL% < $60\% \rightarrow$ (B) try increasing the SOL% of this unit
 - By removing "idle cycles" (GPU unit is not doing any work for a % of the time)
 - By removing "stall cycles": SM Warp Stalls on Shared-Memory Barriers
 - By avoiding "slow paths" if possible (e.g. 32-bit index buffers, and FP32x4 textures)
- **3.** If SOL% in [60,80], do both (A) and (B)

Example Workload:

Ray-Marched SSAO



Ray-Marched SSAO Full-Screen Pixel Shader

	Summary						
	Draws: Dispatches: Clears: Blits:		Presents: Command List Exec Misc. Data Update: Non-API:		ier: 709 al: 798		
	Details						
	API Call				Count 🔻	Avg C 🔺	
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						ID3D11Dep	
	11						
	<u>12</u> ²						
	13 14)11DeviceContext3)11DeviceContext3				
						rinharga	

E:65 - E:72 (6.46 ms - 91.1%) - DSV Range Info - [Render Target Ranges] Event 72, Draw Call 2 (6.77 ms - 95.4%) Pipeline Overview Top SOLs [L2:80.3% | SM:56.0% | TEX:37.0% | DRAM:1.6% | CROP:0.5%] 0.0% Wait For Idle Count 0.0% Pixel Shader Barrier Count TEX Hit Rate: **67.0%** 99.7% SM Active Threads Per Instruction Executed \rightarrow Workload is L2 bandwidth limited due to poor TEX hit rate Memory

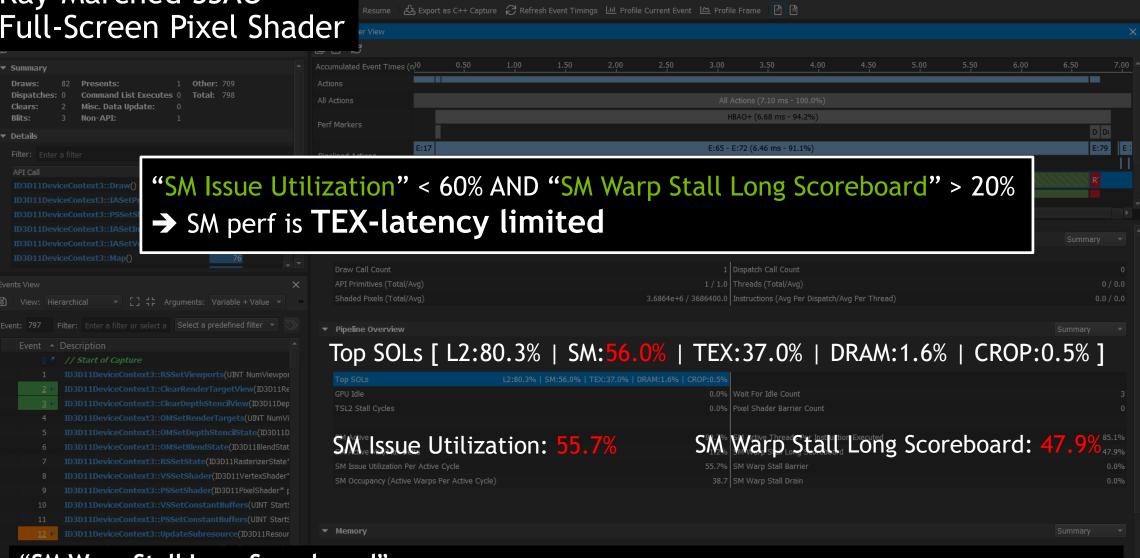
Ray-Marched SSAO Full-Screen Pixel Shader

	Summary						
0 0	Draws: Dispatches: Clears: Blits:		Presents: Command List Exe Misc. Data Updat Non-API:		er: 709 II: 798		
)eta ils						
	API Call				Count 🔻	Avg C 4	
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		Desc					
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					State(ID3D1	1BlendStat	
					ID3D11Raste		
	11						
	<u>12</u> *						
			D11DeviceContext		uffor(ID3D1)	1 Ruffer* n	

Resume 🛛 🖧 Export as C++ Capture 🛛 🤂 Refresh Event	Timings 내민 Profile Current E		me 🖪 🖻						
er View									
그) 2.00 2.50	3.00	3.50 4.0	00 4.50	5.00	5.50	6.00	6.50	7.00
ions									
Actions			s (7.10 ms - 100.0%	-					_
f Markers		HBAO+	(6.68 ms - 94.2%)					D	Di
E:17		E:65 - E:72 ((6.46 ms - 91.1%)					E:7	
der Target Ranges 📴 DSV 🚦									
Range Info - [Render Target Ranges] Event 72, Draw Call 2	(6.77 ms - 95.4%)								
Draw Call Count		1 Dispa	tch Call Count						
API Primitives (Total/Avg)			ads (Total/Avg)						
Shaded Pixels (Total/Avg)	3.686464	+6 / 3686400.0 Instru	ictions (Avg Per Dis	patch/Avg Per Thread)				0.0	0 / 0.0
Pipeline Overview									
Top SOLs [L2:80.3% 2	SM: <mark>56.0%</mark>	TEX:3	7.0 %	DRAM:	1.6%	CR	OP:0	.5%]	
GPU Idle			For Idle Count						
TSL2 Stall Cycles		0.0% Pixel	Shader Barrier Cour						
SM Issue Utilization: 5	5 7%	99.7% SM A	ctive Threads Per Ir	nstruction Executed					
	J. / /0		/arp Stall Long Scor						47.9%
SM Issue Utilization Per Active Cycle SM Occupancy (Active Warps Per Active Cycle)			/arp Stall Barrier /arp Stall Drain						0.0%
Метогу									
		80.3% FB Re	ad Utilization						

SM Issue Utilization: The % of SM active cycles a SM scheduler issued at least one instruction

Ray-Marched SSAO Full-Screen Pixel Shader

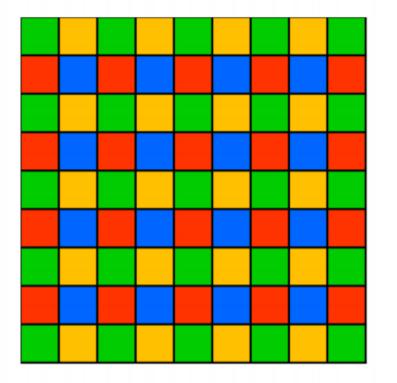


"SM Warp Stall Long Scoreboard": % of active warps that were stalled waiting for a scoreboard dependency on a TEX operation

Our Solution: "Interleaved Rendering"

Render each sampling pattern **separately**, using **downsampled** input textures

Assumption: Interleaved Sampling Patterns

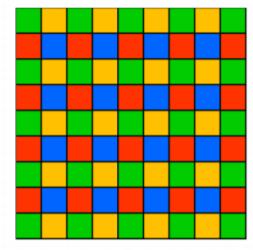


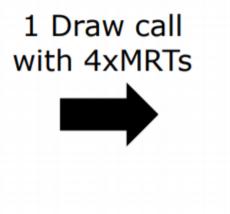
NxN sampling patterns interleaved on screen

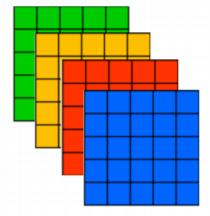
Typical sampling strategy for SSAO, SSDO, SSR, etc.

Per-pixel jitter seed fetched from a tiled "jitter texture"

STEP 1: Deinterleave Input







Full-Resolution Input Texture

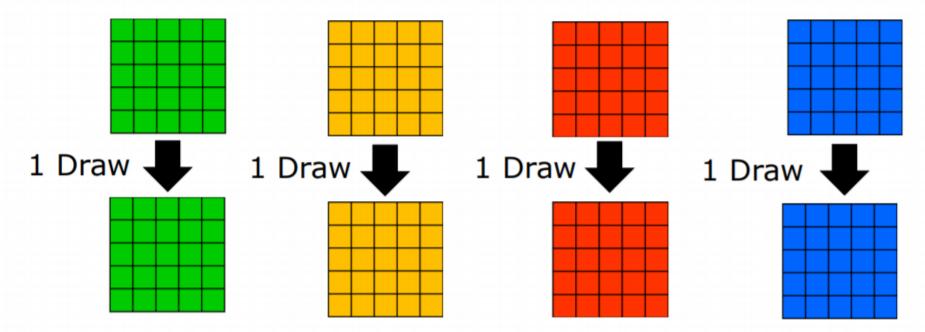
> Width = W Height = H

Half-Resolution 2D Texture Array

Width = iDivUp(W,2)Height = iDivUp(H,2)

STEP 2: Jitter-Free Sampling

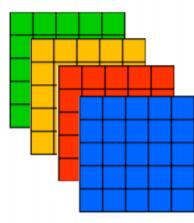
Input: Texture Array A (slices 0,1,2,3)



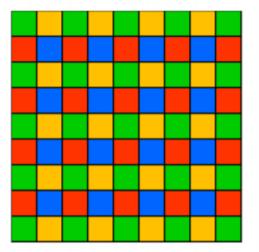
Output: Texture Array B (slices 0,1,2,3)

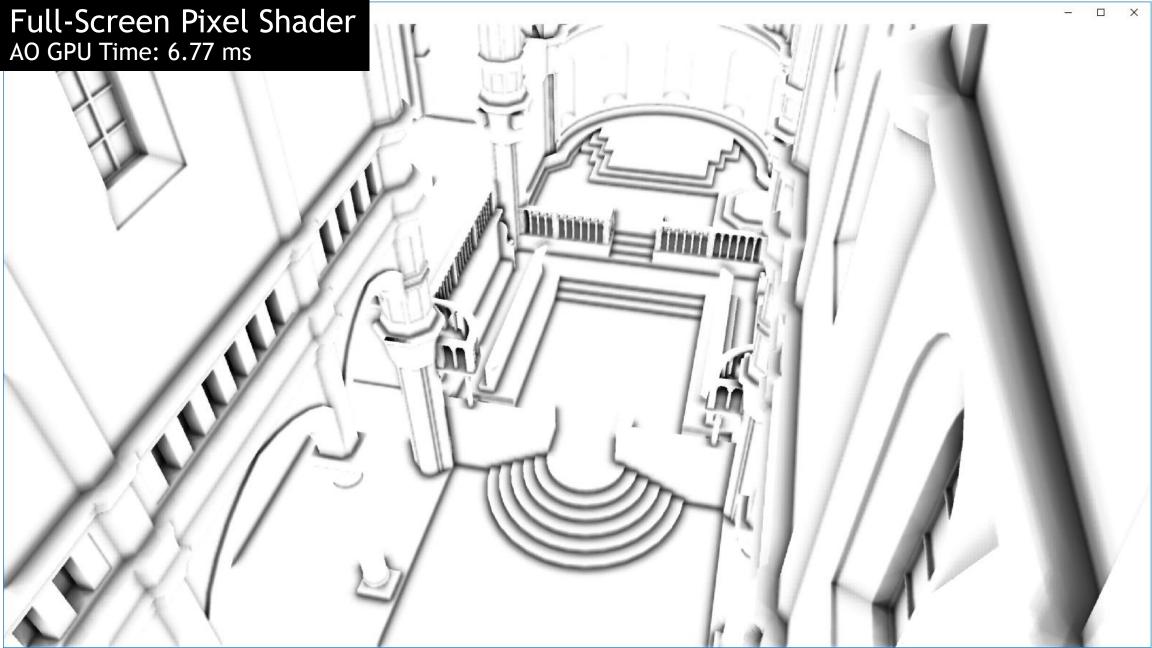
MARCH 25–29, 2013 GDCONF.COM

STEP 3: Interleave Results



1 Draw call With 1 Tex2DArray fetch per pixel



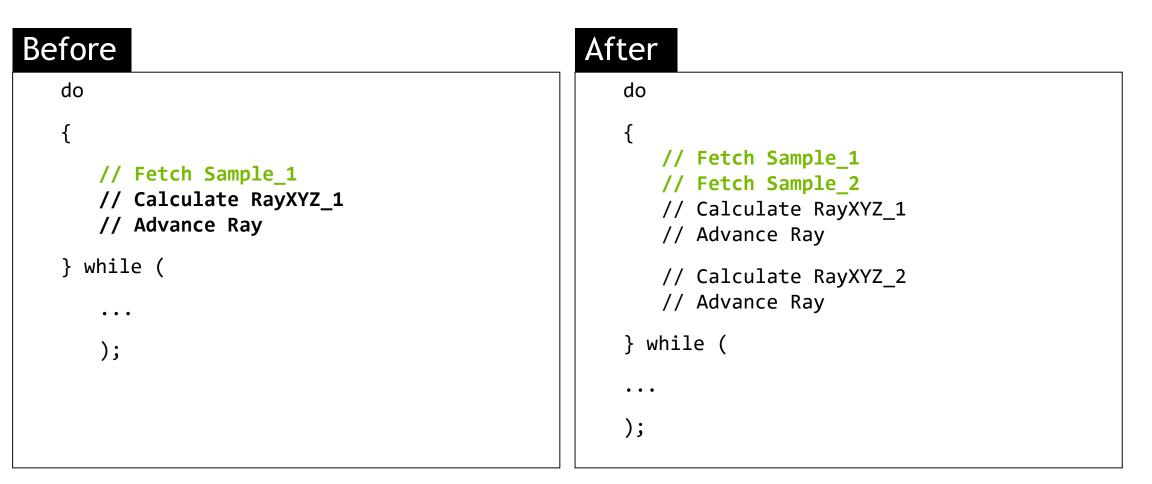




Interleaved Rendering Optimization

AO KERNEL	BEFORE	AFTER	RATIO
Top SOLs	L2:80.3% SM:56.0% TEX:37.0%	L2:11.3% SM:78.8% TEX:32.4%	L2:0.14x SM:1.4x TEX:0.9x
TEX Hit Rate	67 %	9 3%	1.4x
SM Issue Utilization	56%	73%	1.3x
SM Warp Stall Long Scoreboard	48%	28%	0.6x

2x Partial Loop Unrolling



2x Partial Loop Unrolling

	BEFORE	AFTER	RATIO
Top SOLs	SM:78.8% TEX:32.4% L2:11.3%	SM:88.6% TEX:37.4% L2:9.9%	SM:1.1x TEX:1.2x L2:0.9x
SM Issue Utilization	73%	84%	1.15x
SM Warp Stall on Long Scoreboard	28%	12%	0.43x
SM Occupancy (Active Warps)	39.0	33.8	0.87x
GPU Elapsed Time	5.04 ms	4.53 ms	11% Gain

The Peak-Perf% Analysis Method

BEFORE: Top SOLs: [L2:80.3% | SM:56.0% | TEX:37.0%] AFTER: Top SOLs: [L2:9.9% | SM:88.6% | TEX:37.4%]

For each "Top SOL%" unit:

- 1. If SOL% > 80% \rightarrow (A) try removing work from this unit
 - Reduce the number of TEX->L2 requests by improving the TEX hit rate
- 2. If SOL% < 60% \rightarrow (B) try increasing the SOL% of this unit
 - By removing "idle cycles" (GPU unit is not doing any work for a % of the time)
 - By removing "stall cycles" (GPU unit has internal inefficiencies)
 - By avoiding "slow paths" if possible (e.g. 32-bit index buffers, and FP32x4 textures)
- **3.** If SOL% in [60,80], do both (A) and (B)

The Peak-Perf% Analysis Method

BEFORE: Top SOLs: [L2:80.3% | SM:56.0% | TEX:37.0%] AFTER: Top SOLs: [L2:9.9% | SM:88.6% | TEX:37.4%]

For each "Top SOL%" unit:

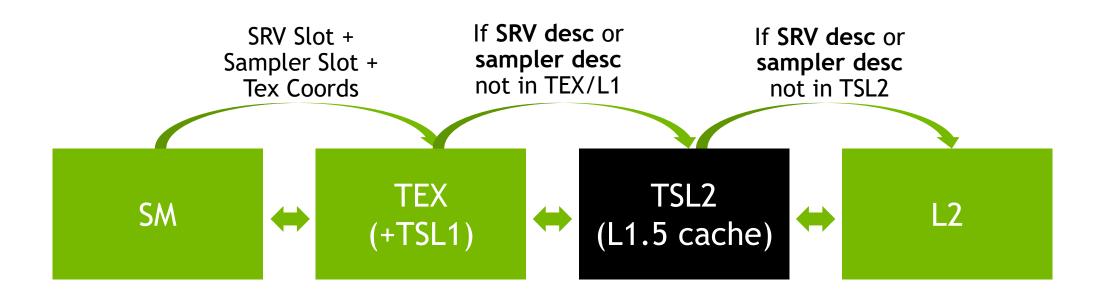
- 1. If SOL% > 80% \rightarrow (A) try removing work from this unit
- 2. If SOL% < $60\% \rightarrow$ (B) try increasing the SOL% of this unit
 - By removing "idle cycles" (GPU unit is not doing any work for a % of the time)
 - By removing "stall cycles": SM Warp Stalls on TEX dependencies
 - By avoiding "slow paths" if possible (e.g. 32-bit index buffers, and FP32x4 textures)
- 3. If SOL% in [60,80], do both (A) and (B)

DX12 Advanced Topic:

Binding SRV Descriptors



The TSL1 & TSL2 Caches



SRV descriptor contains texture metadata (type, dimensions, format, etc)

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# 50 Connect 5 Disconnect X Terminate # C Capture for Live Analysis	》 Next Frame 🖒 Resume 🖧 Export as C++ Capture 记 Refresh Event Timings Ш Profile Currer	it Event (쯔 Profile Frame] 셴 명	
API Statistics View X	Range Profiler View		×
6			
▼ Summary	Accumulated Event Times (n)0 1.00 2.00 3.00 4.00 5.00	<u>6.00 7.00 8.00 9.00 10.00 11.00 12.00 13.00</u>	14.00 15.00
Draws:1449Presents:1Other:160346Sub Draws:3Command List Exe2Total:176829Dispatches:53Signals:2033Sub Dispatches:15Waits:222Clears:47Misc.Data Updatı14591Blits:49Non-API:2133	Actions # # # # # # # # # # # # # # # # # # #	All Actions (15.45 ms - 100.0%)	
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API Call ID3D12Descri	DRAM:36.	7% SM:31.7% L2:27.6%	Summary V
ID3D12Device GPU Idle		9.6%	86 0 / 0.0
Events View TSL2 Stall Cycles		3.4%	3727605.3 / 0.0 Summary -
Event: L76828 Filter: Enter a filter or s Select a predefined filter 💌 🚫			
Event		L 7005 6 79/	
0 🎽 // Start of Capture	Top SOLs DRAM:36.7% SM:31.7% L2:27.6% TEX:25.7% GPU Idle	9.6% Wait For Idle Count	502
1 IDXGISwapChain4::GetFullscreenState(B	TSL2 Stall Cycles	3.4% Pixel Shader Barrier Count	85
2 D3DPERF_BeginEvent(D3DCOLOR col = 0xf			
3 ID3D12CommandAllocator::Reset() = 0x	SM Active	75.2% SM Active Threads Per Instruction Executed	81.3%
103D12CommandQueue::Signal(ID3D12Fe	SM Active Min/Max Delta	1.8% SM Warp Stall Long Scoreboard	48.4%
5 / ID3D12Fence1::SetEventOnCompletion(l 6 // Fence completed = 40	SM Issue Utilization Per Active Cycle	42.2% SM Warp Stall Barrier	5.0%
7 ID3D12Device4::CreateCommandAllocat	SM Occupancy (Active Warps Per Active Cycle)	37.4 SM Warp Stall Drain	1.6%
8 ID3D12CommandAllocator::Reset() = 0x			
9 ID3D12Device4::CreateCommandList(UI)			
10 Replayer added calls - ID3D12Comma	▼ Memory		Summary 🝷
11 ID3D12Device4::CreateCommandAllocat			
12 ID3D12CommandAllocator::Reset() = 0x	L2 SOL L2 Hit Rate	27.6% FB Read Utilization 73.8% FB Write Utilization	26.0% 10.7%
13 ID3D12Device4::CreateCommandList(UI) 14 ID3D12GraphicsCommandList3::Close() =	L2 HIT Rate Tex Hit Rate	81.1%	10.7%
15 ID3D12GraphicsCommandList3::Close() =			

PCR Opt ON ave [12002]

User Metrics

BindlessTex - NVIDIA Nsight Graphics

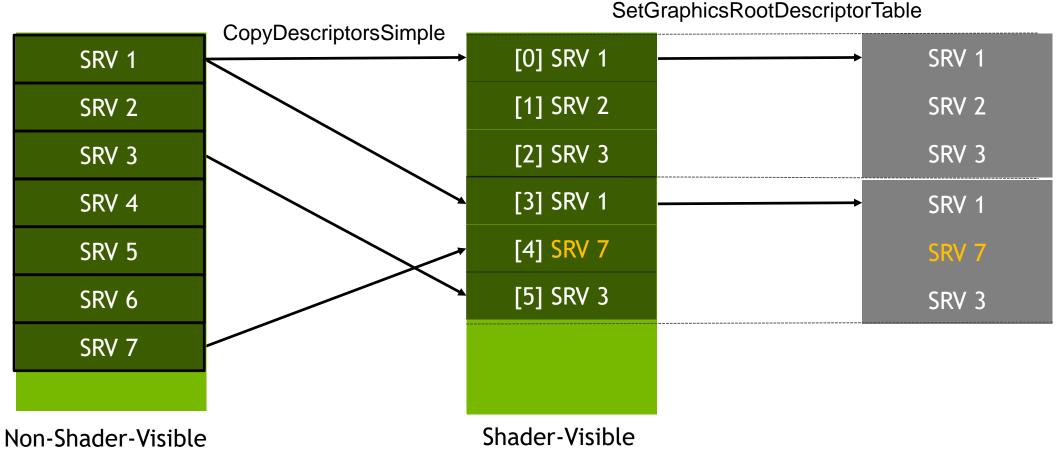
– o ×

Typical DX12 SRV Binding Pattern

	SRV 1
Draw call 1	SRV 2
	SRV 3
	SRV 1
Draw call 2	SRV 7
	SRV 3

2 Draw Calls with same Root Signature

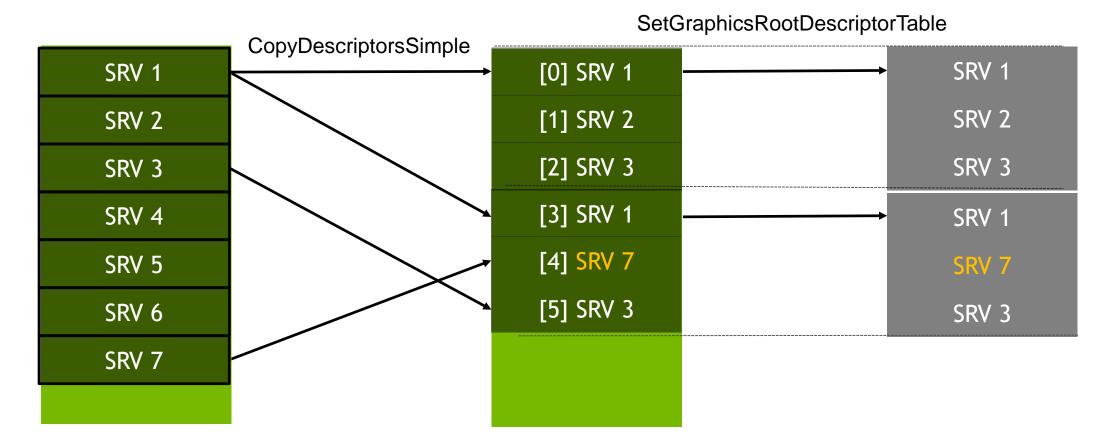
Typical DX12 SRV Binding Pattern



SRV Descriptor Heap

SRV Descriptor Heap

The Problem: Redundant Heap Entries

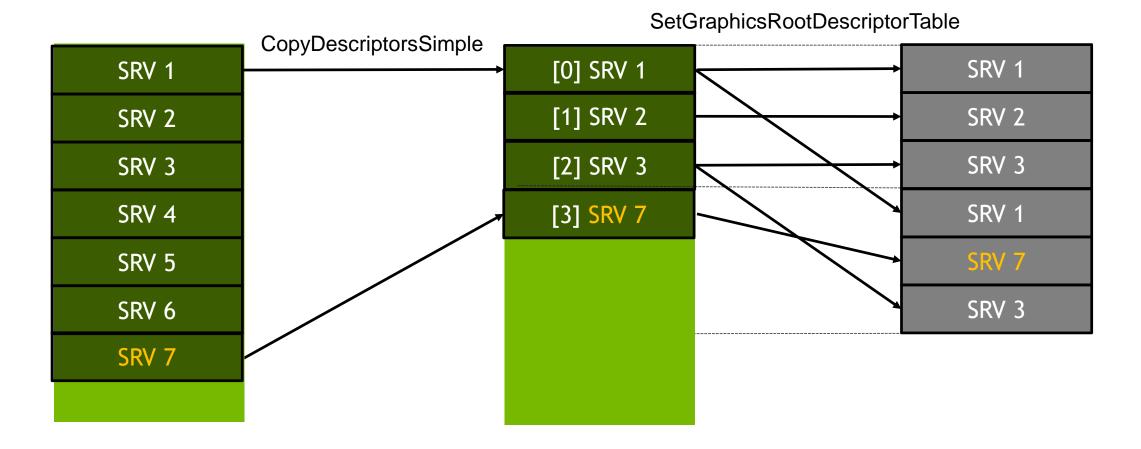


TSL1 & TSL2 caches use heap indices as tags

→ Redundant entries in the shader-visible heap → TSL1 & TSL2 cache thrashing ☺

GDC

Solution #1: Split SRV Ranges



GDC

Solution #2: Shader SRV Indexing

SRV 1 SRV 1 SRV 2 SRV 2 SRV 3 SRV 3 SRV 4 SRV 4 SRV 5 SRV 5 SRV 6 SRV 6 SRV 7 SRV 7

SetGraphicsRootDescriptorTable

Shader-Visible SRV Descriptor Heap + Dynamically index SRV descriptor in shaders using per-draw-call indices stored in a Root CBV

Split SRV Ranges vs Shader SRV Indexing

- Shader SRV Indexing
 - © Unique SRVs in shader-visible descriptor heap
 - © No CopyDescriptorsSimple calls used
 - Slight SM overhead (extra registers & instructions injected by driver)
- Split SRV Ranges
 - ⁽²⁾ CopyDescriptorsSimple CPU overhead
 - SetGraphicsRootDescriptorTable CPU & GPU overhead
 - © Can use the same shader byte code on DX12 & DX11

DX12 Advanced Topic:

Pixel Shader Barriers

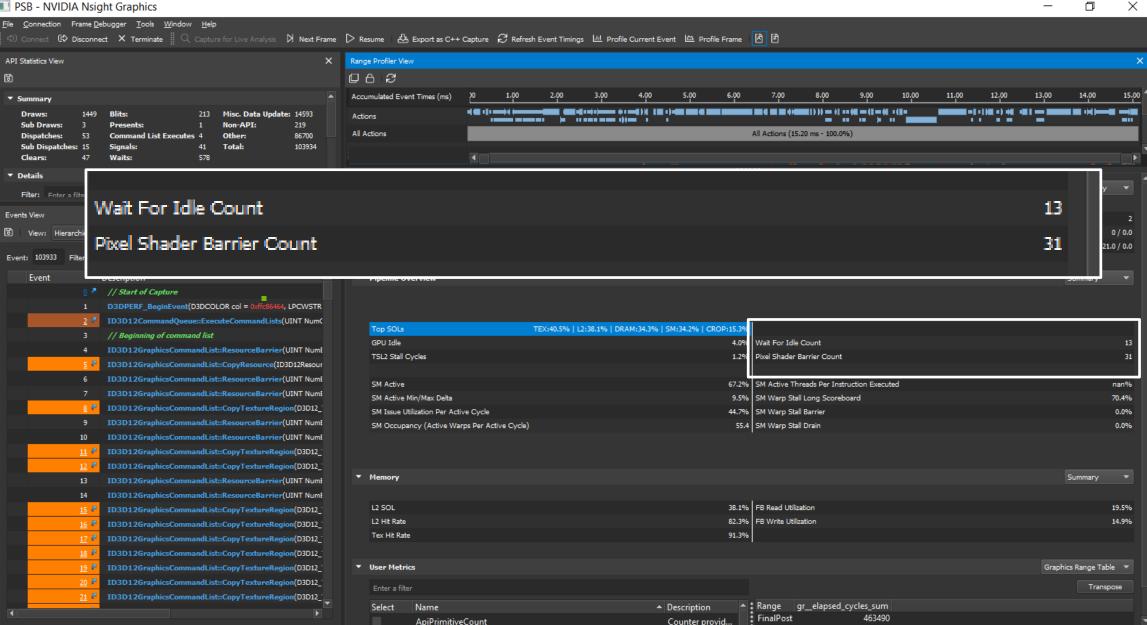


Pixel Shader Barriers (PSBs)

- PSB == lightweight WFI (Wait For Idle) for PS-to-PS dependencies.
 - Hardware command available on Maxwell and beyond.
 - Used automatically by our driver on DX11.

- On DX12, used in ResourceBarrier Transition calls with:
 - StateBefore = D3D12_RESOURCE_STATE_RENDER_TARGET
 - StateAfter = D3D12_RESOURCE_STATE_**PIXEL_SHADER_RESOURCE**
- All other transitions map to full-pipeline WFIs.

PSB - NVIDIA Nsight Graphics



ResourceBarrier Flag Optimization

POST-PROCESSING CHAIN	BEFORE	AFTER	RATIO
Top SOLs	TEX:35.4% L2:33.3% SM:29.9%	TEX:40.5% L2:38.3% DRAM:36.1%	TEX:1.1x L2:1.2x DRAM:1.2x
Wait For Idle Count	44	13	
Pixel Shader Barrier Count	0	31	
GPU Elapsed Time	0.39 ms	0.29 ms	26% Gain

Conclusion

- Nsight Graphics 1.0
 - Makes it easier to export frames to C++ and build them as EXE
 - Exposes powerful hardware metrics in the Range Profiler
- Blog post for more details:
 - o <u>"The Peak-Performance Analysis Method for Optimizing Any GPU Workload"</u>
- Demo of Nsight Graphics at NVIDIA Expo Booth

HBAO+ - NVIDIA Nsight Graphics			- 0 ×
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		~2	
▼ Summary	A COLUMNER (MS) Question	1.20 1.40 1.60 1.80 2.00 2.20	2.40 2.60 2.80 3.00
Draws: 88 Blits: 10 Misc. Data Update: 0 Total: 713	Actions		
Dispatches: 0 Presents: 1 Non-API: 1 Clears: 2 Command List Exect 0 Other: 611	All Actions	All Actions (3.15 ms - 100.0%)	
▼ Details		HBAO+ (2.56 ms - 81.2%)	
	Perf Markers DrawL DrawDein	DrawCoarseAOPS (1.58 ms - 50.2%)	awReint DrawBlurXPS DrawBlurYPS
API Call Count ▼ Avg CP ▲ ID3D11DeviceContext3::PSSetShaderResources() 89 <			
ID3D11DeviceContext3::P3setShaderKesources() 87 <	 Range Info - [Perf Markers] DrawCoarseAOPS (1.57 ms - 49.9%) 		
ID3D11DeviceContext3::IASetPrimitiveTopology() 69 <			
	Draw Call Count	16 Dispatch Call Count	
	API Primitives (Total/Avg)	16 / 1.0 Threads (Total/Avg)	
	Shaded Pixels (Total/Avg)	8.2944e+6 / 518400.0 Instructions (Avg Per Dispatch/Avg Per Thread)	
B View: Hierarchical ▼ C 1 + Arguments: Variable + Value ▼ >>>	lbavoil@nvidia.	com	
	Top SOLs SM:94.8% TEX:72.1% L2:71.9% D	RAM:34.3% CROP:5.4%	
		0.0% Wait For Idle Count	
0 V // Start of Capture	TSL2 Stall Cycles	0.1% Pixel Shader Barrier Count	
1 ResetInitialFrameState - D3DPERF_BeginEvent(D3DCOLOR col			
	SM Active SM Active Min/Max Delta	99.1% SM Active Threads Per Instruction Executed 0.3% SM Warp Stall Long Scoreboard	99.8% 16.4%
	SM Active Minimax Delta SM Issue Utilization Per Active Cycle	95.6% SM Warp Stall Eorg Scoreboard	0.0%
4 ID3D11DeviceContext3::CSSetShader(ID3D11ComputeShader* pt	SM Dissue Outzacion Per Active Cycle SM Occupancy (Active Warps Per Active Cycle)	46.4 SM Warp Stall Drain	0.0%
7 ID3D11DeviceContext3::IASetIndexBuffer(ID3D11Buffer* pInde:			
8 ID3D11DeviceContext3::IASetInputLayout(ID3D11InputLayout*	 Memory 		
	L2 SOL	71.9% FB Read Utilization	32.5%
	L2 Hit Rate	81.8% FB Write Utilization	1.8%
	Tex Hit Rate	83.9%	
14 ID3D11DeviceContext3::VSSetShaderResources(UINT StartSlot =	 User Metrics 		
15 TD3D11DeviceContext3::HSSetConstantBuffers(UINT StartSlot =			Transpose