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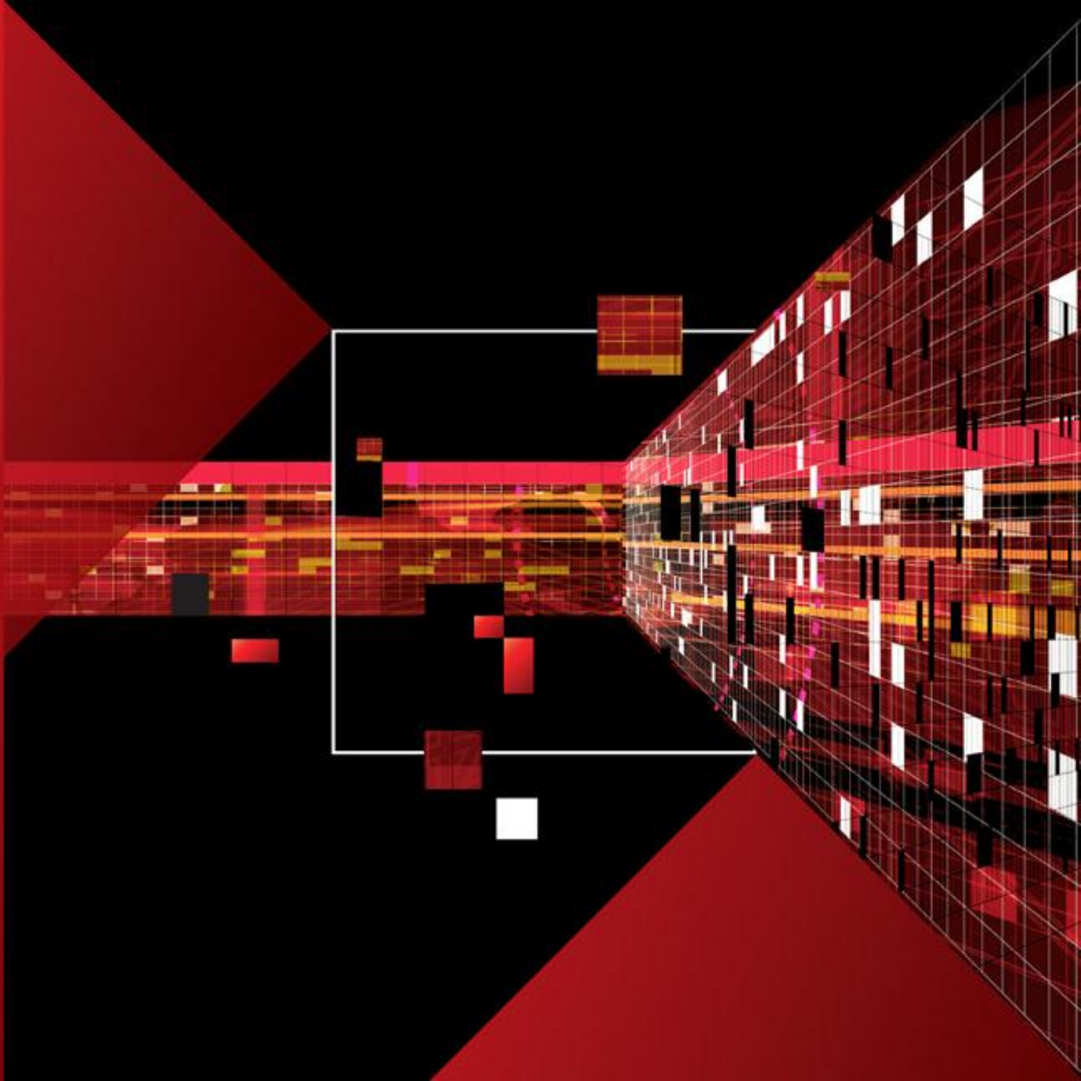

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ADVANCED OPENCL™ DEBUGGING AND PROFILING – A CASE STUDY

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ABOUT OPENCL

OpenCL is FUN!

- New programming language
- Exposes the massively multithreaded GPU
- And the CPU
- A lot of horse power, optimized for parallel computing
- Order of magnitude performance improvement!

OPENCL DEBUGGING AND PROFILING MODEL

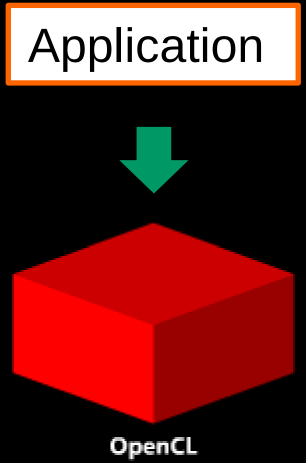
However,

- Debugging and profiling parallel processing applications is hard
- On-time delivery of robust (bug-free) OpenCL applications is challenging
- It is almost impossible to optimize an OpenCL based application to fully utilize the available parallel processing system resources

OPENCL DEBUGGING AND PROFILING MODEL

OpenCL is a “Black Box”

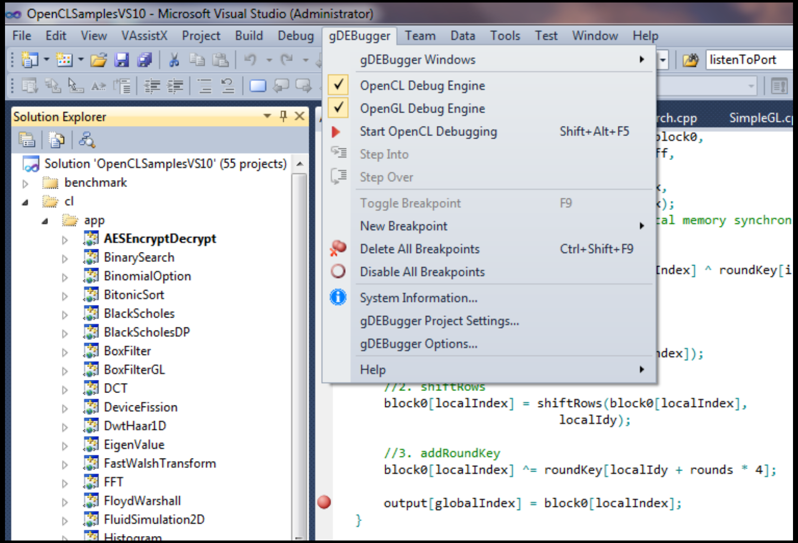
- The application enqueues OpenCL commands
- OpenCL’s runtime executes the commands
- The developer cannot
  - Debug the OpenCL kernels
  - See the execution details
  - View runtime loads



GDEBUGGER

gDEBugger™ for Microsoft Visual Studio®

- An OpenCL Debugger
  - API Level
  - Kernel Source Code
- An OpenGL API level debugger
- Integrated into Microsoft Visual Studio
- Provides the information a developer needs to find bugs and optimize the application's performance



```
                                  plock0,
                                  ff,

                                  k,
                                  k);
                                  cal memory synchron

                                  Index] ^ roundKey[i

                                  ndex]);
        //2. shiftRows
        block0[localIndex] = shiftRows(block0[localIndex],
                                       localIdy);

        //3. addRoundKey
        block0[localIndex] ^= roundKey[localIdy + rounds * 4];

        output[globalIndex] = block0[localIndex];
    }
```

DEMO

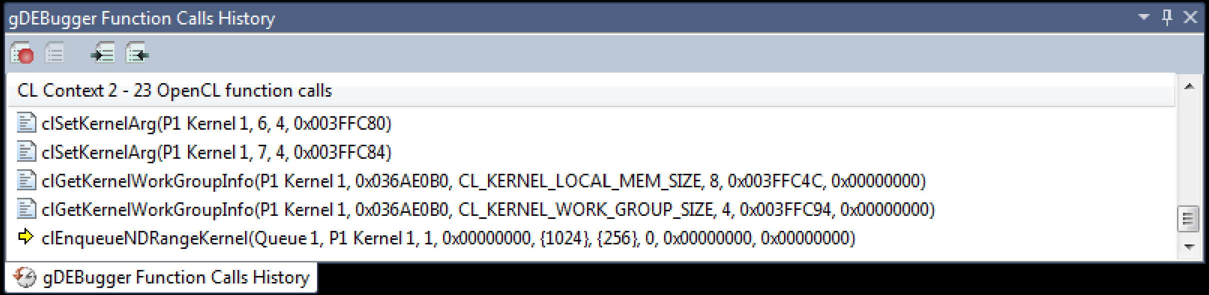
Uniform Random Noise Generator Sample

- A sample application provided with AMD APP SDK samples
- Each thread generates a uniform random deviation and applies to a pixel
- OpenCL kernel computes the deviation using a linear congruential generator proposed by Park and Miller
- The average of four neighboring pixels is used as the seed for each pixel

GDEBUGGER

API Calls History View

- Displayed a log of OpenCL and OpenGL API calls
- Call details are displayed in the Properties View



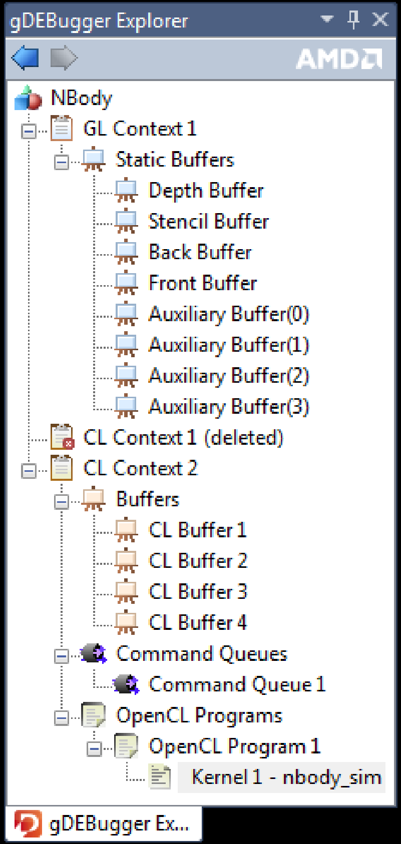
gDEBugger Function Calls History

```
CL Context 2 - 23 OpenCL function calls
clSetKernelArg(P1 Kernel 1, 6, 4, 0x003FFC80)
clSetKernelArg(P1 Kernel 1, 7, 4, 0x003FFC84)
clGetKernelWorkGroupInfo(P1 Kernel 1, 0x036AE0B0, CL_KERNEL_LOCAL_MEM_SIZE, 8, 0x003FFC4C, 0x00000000)
clGetKernelWorkGroupInfo(P1 Kernel 1, 0x036AE0B0, CL_KERNEL_WORK_GROUP_SIZE, 4, 0x003FFC94, 0x00000000)
clEnqueueNDRangeKernel(Queue 1, P1 Kernel 1, 1, 0x00000000, {1024}, {256}, 0, 0x00000000, 0x00000000)
```

GDEBUGGER

gDEBugger Explorer

- Displays OpenCL and OpenGL allocated objects
- Marks OpenGL-OpenCL shared contexts
- Focuses the GUI views on objects
- Double-click displays each object in the appropriate view



gDEBugger Explorer

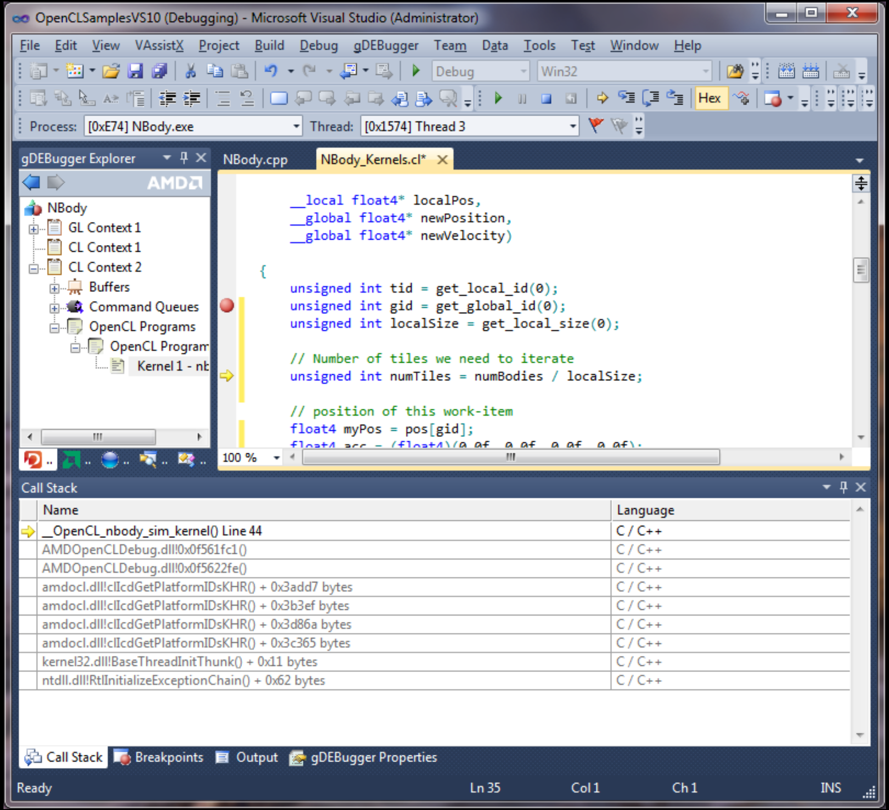
- NBody
  - GL Context 1
    - Static Buffers
      - Depth Buffer
      - Stencil Buffer
      - Back Buffer
      - Front Buffer
      - Auxiliary Buffer(0)
      - Auxiliary Buffer(1)
      - Auxiliary Buffer(2)
      - Auxiliary Buffer(3)
  - CL Context 1 (deleted)
  - CL Context 2
    - Buffers
      - CL Buffer 1
      - CL Buffer 2
      - CL Buffer 3
      - CL Buffer 4
    - Command Queues
      - Command Queue 1
    - OpenCL Programs
      - OpenCL Program 1
        - Kernel 1 - nbody_sim

gDEBugger Ex...

GDEBUGGER

Source Code and Call Stack

- Displays C, C++ and OpenCL C source code
- Enables setting source code breakpoints
- Displays a combined C, C++ and OpenCL C call stack



Process: [0xE74] NBody.exe

Thread: [0x1574] Thread 3

```
        __local float4* localPos,
        __global float4* newPosition,
        __global float4* newVelocity)

    {
        unsigned int tid = get_local_id(0);
        unsigned int gid = get_global_id(0);
        unsigned int localSize = get_local_size(0);

        // Number of tiles we need to iterate
        unsigned int numTiles = numBodies / localSize;

        // position of this work-item
        float4 myPos = pos[gid];
        float4 acc = (float4)(0.0f, 0.0f, 0.0f, 0.0f);
```

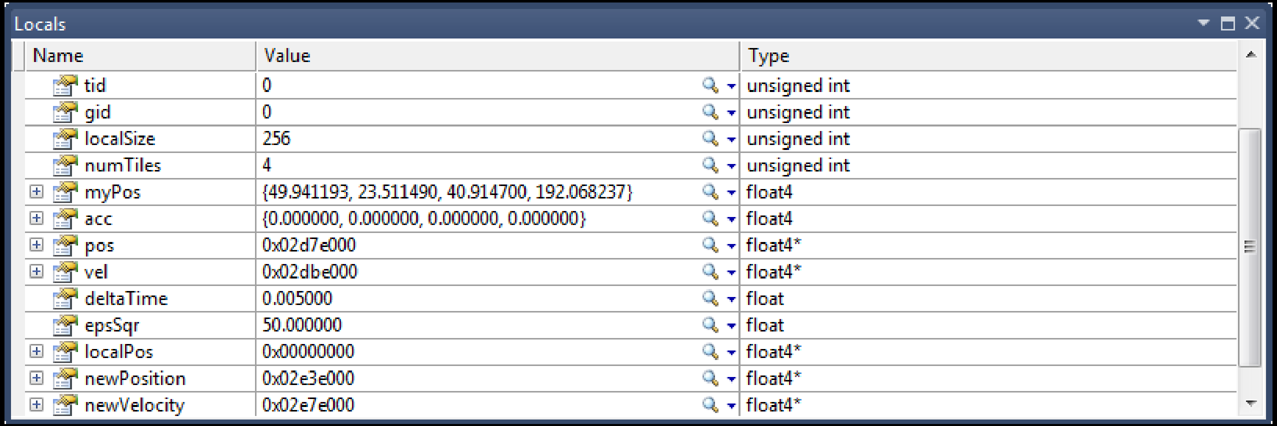
Call Stack

Name	Language
__OpenCL_nbody_sim_kernel() Line 44	C / C++
AMDOpenCLDebug.dll!0x0f561fc1()	C / C++
AMDOpenCLDebug.dll!0x0f5622fe()	C / C++
amdocl.dll!clIcdGetPlatformIDsKHR() + 0x3add7 bytes	C / C++
amdocl.dll!clIcdGetPlatformIDsKHR() + 0x3b3ef bytes	C / C++
amdocl.dll!clIcdGetPlatformIDsKHR() + 0x3d86a bytes	C / C++
amdocl.dll!clIcdGetPlatformIDsKHR() + 0x3c365 bytes	C / C++
kernel32.dll!BaseThreadInitThunk() + 0x11 bytes	C / C++
ntdll.dll!RtlInitializeExceptionChain() + 0x62 bytes	C / C++

GDEBUGGER

Watch views

- Displays OpenCL kernel’s variable values and types



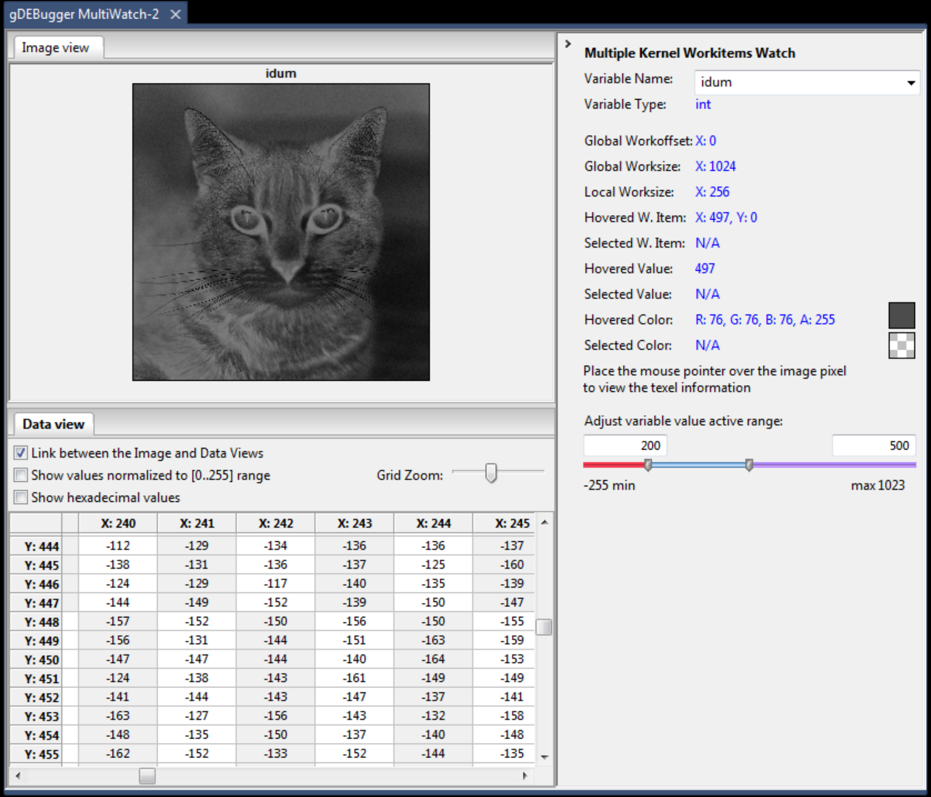
Locals

Name	Value	Type
tid	0	unsigned int
gid	0	unsigned int
localSize	256	unsigned int
numTiles	4	unsigned int
⊞ myPos	{49.941193, 23.511490, 40.914700, 192.068237}	float4
⊞ acc	{0.000000, 0.000000, 0.000000, 0.000000}	float4
⊞ pos	0x02d7e000	float4*
⊞ vel	0x02dbe000	float4*
deltaTime	0.005000	float
epsSqr	50.000000	float
⊞ localPos	0x00000000	float4*
⊞ newPosition	0x02e3e000	float4*
⊞ newVelocity	0x02e7e000	float4*

GDEBUGGER

Multi Watch View

- Displays the values of an OpenCL kernel variable across all work items and work groups
- The image view provides a graphics representation of the data (each pixel represents a single work item)



Multiple Kernel Workitems Watch

Variable Name: idum

Variable Type: int

Global Workoffset: X: 0

Global Worksize: X: 1024

Local Worksize: X: 256

Hovered W. Item: X: 497, Y: 0

Selected W. Item: N/A

Hovered Value: 497

Selected Value: N/A

Hovered Color: R: 76, G: 76, B: 76, A: 255

Selected Color: N/A

Place the mouse pointer over the image pixel
to view the texel information

Adjust variable value active range:

200 500

-255 min max 1023

☑ Link between the Image and Data Views

□ Show values normalized to [0..255] range

□ Show hexadecimal values

	X: 240	X: 241	X: 242	X: 243	X: 244	X: 245
Y: 444	-112	-129	-134	-136	-136	-137
Y: 445	-138	-131	-136	-137	-125	-160
Y: 446	-124	-129	-117	-140	-135	-139
Y: 447	-144	-149	-152	-139	-150	-147
Y: 448	-157	-152	-150	-156	-150	-155
Y: 449	-156	-131	-144	-151	-163	-159
Y: 450	-147	-147	-144	-140	-164	-153
Y: 451	-124	-138	-143	-161	-149	-149
Y: 452	-141	-144	-143	-147	-137	-141
Y: 453	-163	-127	-156	-143	-132	-158
Y: 454	-148	-135	-150	-137	-140	-148
Y: 455	-162	-152	-133	-152	-144	-135

PROFILING WITH AMD APP PROFILER

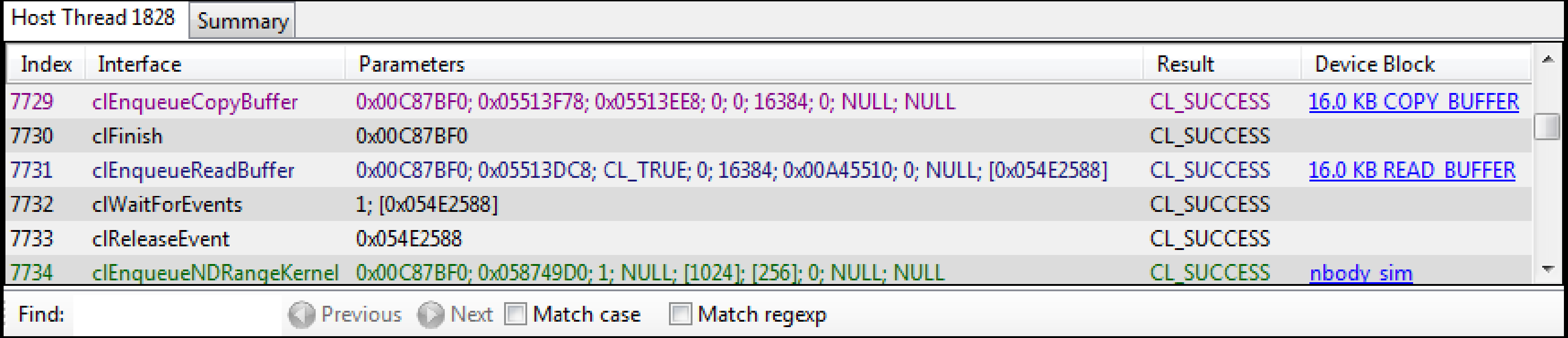
AMD APP PROFILER

- Analyzes and profiles OpenCL and DirectCompute application for AMD APUs and GPUs
- Integrates into Microsoft Visual Studio® 2008 and 2010
- Is available as a command line utility program for Windows and Linux platforms
- Does not require a custom driver
- Does not require source code or project modifications of the target application

PROFILING WITH AMD APP PROFILER

What can APP Profiler do for you?

- Analyze and Profile OpenCL applications
  - View API input arguments and output results
  - Find API hotspots
  - Determine top ten data transfer and kernel execution operations
  - Identify failed API calls, resource leaks and best practices

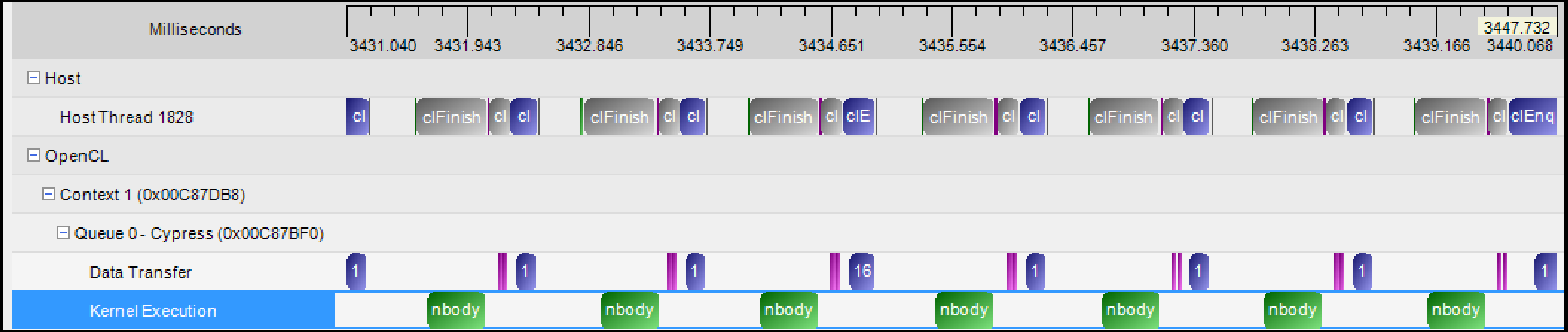


Index	Interface	Parameters	Result	Device Block
7729	clEnqueueCopyBuffer	0x00C87BF0; 0x05513F78; 0x05513EE8; 0; 0; 16384; 0; NULL; NULL	CL_SUCCESS	16.0 KB COPY_BUFFER
7730	clFinish	0x00C87BF0	CL_SUCCESS	
7731	clEnqueueReadBuffer	0x00C87BF0; 0x05513DC8; CL_TRUE; 0; 16384; 0x00A45510; 0; NULL; [0x054E2588]	CL_SUCCESS	16.0 KB READ_BUFFER
7732	clWaitForEvents	1; [0x054E2588]	CL_SUCCESS	
7733	clReleaseEvent	0x054E2588	CL_SUCCESS	
7734	clEnqueueNDRangeKernel	0x00C87BF0; 0x058749D0; 1; NULL; [1024]; [256]; 0; NULL; NULL	CL_SUCCESS	nbody_sim

PROFILING WITH AMD APP PROFILER

What can APP Profiler do for you?

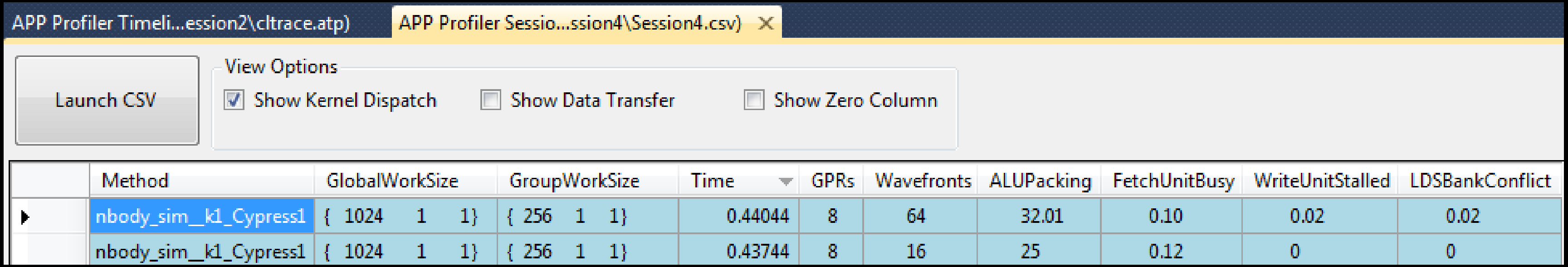
- Visualize OpenCL execution in a timeline chart
  - View number of OpenCL contexts and command queues created and the relationships between these items
  - View host and device execution operations
  - View data transfer operations
  - Determine proper synchronization and load balancing



PROFILING WITH AMD APP PROFILER

What can APP Profiler do for you?

- Analyze the OpenCL kernel execution for AMD Radeon GPUs
  - Collect GPU Performance Counters
    - The number of ALU, global and local memory instructions executed
    - GPU utilization and memory access characteristics
    - Shader Compiler VLIW packing efficiency
  - Show the kernel resource usages
  - View the AMD intermediate language (IL) and hardware disassembly (ISA)



APP Profiler Timeli...ession2\cltrace.atp)
APP Profiler Sessio...ssion4\Session4.csv) ✕
Launch CSV

View Options

☑ Show Kernel Dispatch ☐ Show Data Transfer ☐ Show Zero Column

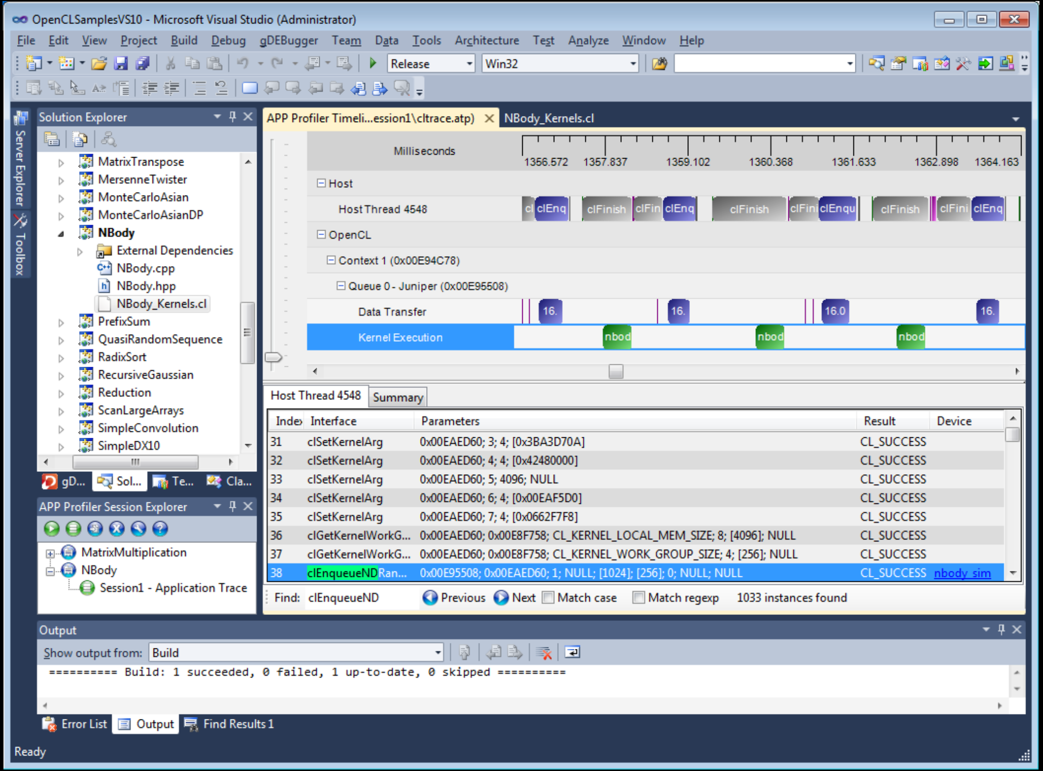
	Method	GlobalWorkSize	GroupWorkSize	Time	GPRs	Wavefronts	ALUPacking	FetchUnitBusy	WriteUnitStalled	LDSBankConflict
▸	nbody_sim__k1_Cypress1	{ 1024 1 1}	{ 256 1 1}	0.44044	8	64	32.01	0.10	0.02	0.02
	nbody_sim__k1_Cypress1	{ 1024 1 1}	{ 256 1 1}	0.43744	8	16	25	0.12	0	0

DEMO

Uniform Random Noise Generator Sample

- A sample application provided with AMD APP SDK samples
- Each thread generates a uniform random deviation and applies to a pixel
- OpenCL kernel computes the deviation using a linear congruential generator proposed by Park and Miller
- The average of four neighboring pixels is used as the seed for each pixel

PROFILING WITH AMD APP PROFILER | DEMO



Index	Interface	Parameters	Result	Device
31	clSetKernelArg	0x00EAED60; 3; 4; [0x3BA3D70A]	CL_SUCCESS	
32	clSetKernelArg	0x00EAED60; 4; 4; [0x42480000]	CL_SUCCESS	
33	clSetKernelArg	0x00EAED60; 5; 4096; NULL	CL_SUCCESS	
34	clSetKernelArg	0x00EAED60; 6; 4; [0x00EAF5D0]	CL_SUCCESS	
35	clSetKernelArg	0x00EAED60; 7; 4; [0x0662F7F8]	CL_SUCCESS	
36	clGetKernelWorkG...	0x00EAED60; 0x00E8F758; CL_KERNEL_LOCAL_MEM_SIZE; 8; [4096]; NULL	CL_SUCCESS	
37	clGetKernelWorkG...	0x00EAED60; 0x00E8F758; CL_KERNEL_WORK_GROUP_SIZE; 4; [256]; NULL	CL_SUCCESS	
38	clEnqueueNDRan...	0x00E95508; 0x00EAED60; 1; NULL; [1024]; [256]; 0; NULL; NULL	CL_SUCCESS	nbody_sim

Find: clEnqueueND Previous Next □ Match case □ Match regexp 1033 instances found

```
========== Build: 1 succeeded, 0 failed, 1 up-to-date, 0 skipped ==========
```

- Included with the AMD APP SDK v2 package
- Available as a separate download from http://developer.amd.com/AMDAPPProfiler

SUMMARY

gDEBugger for Microsoft Visual Studio

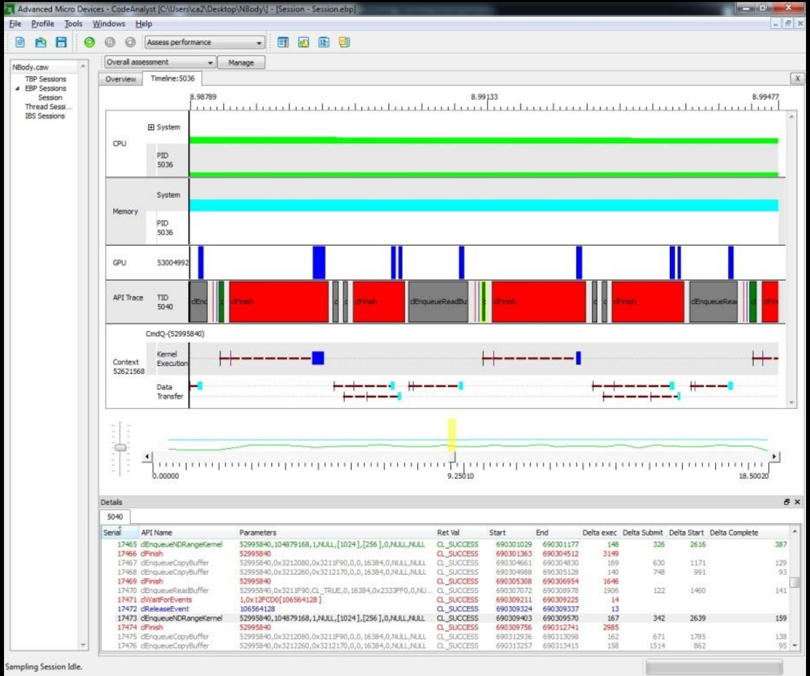
- API level debugging: view OpenCL buffers
- OpenCL kernel debugging on the GPU
  - Single step, set breakpoint and run to breakpoint
  - Inspect variables
- Call Stack and multi-watch view

AMD APP Profiler

- Trace OpenCL API calls and visualize OpenCL execution
- Determine kernel execution vs data transfer bottleneck
- Determine synchronization issues
- Identify failed API calls, resource leaks and best practices
- Collect and analyze GPU performance counters of an OpenCL kernel

OTHER AMD DEVELOPER TOOLS

- **CodeAnalyst**: a system wide profiler to analyze the performance of applications (OpenCL ,C, C++, Java, Fortran), drivers and system software on AMD CPU, GPU and APU.

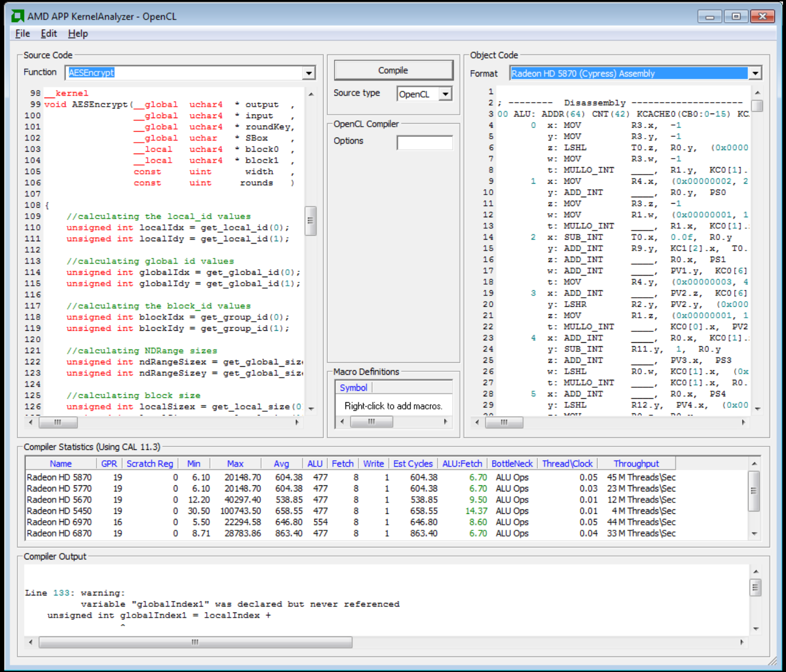


Serial	API Name	Parameters	Ret Val	Start	End	Delta exec	Delta Submit	Delta Start	Delta Complete
17465	dEnqueueNDRangeKernel	52995840,104879168,1,NULL,[1024],[256],0,NULL,NULL	CL_SUCCESS	690301029	690301177	148	326	2616	387
17466	dFinish	52995840	CL_SUCCESS	690301363	690304512	3149			
17467	dEnqueueCopyBuffer	52995840,0x3212080,0x3211F90,0,0,16384,0,NULL,NULL	CL_SUCCESS	690304661	690304830	169	630	1171	129
17468	dEnqueueCopyBuffer	52995840,0x3212260,0x3212170,0,0,16384,0,NULL,NULL	CL_SUCCESS	690304988	690305128	140	748	991	93
17469	dFinish	52995840	CL_SUCCESS	690305308	690306954	1646			
17470	dEnqueueReadBuffer	52995840,0x3211F90,CL_TRUE,0,16384,0x2333FF0,0,NU...	CL_SUCCESS	690307072	690308978	1906	122	1460	141
17471	dWaitForEvents	1,0x12FCD0[106564128]	CL_SUCCESS	690309211	690309225	14			
17472	dReleaseEvent	106564128	CL_SUCCESS	690309324	690309337	13			
17473	dEnqueueNDRangeKernel	52995840,104879168,1,NULL,[1024],[256],0,NULL,NULL	CL_SUCCESS	690309403	690309570	167	342	2639	159
17474	dFinish	52995840	CL_SUCCESS	690309756	690312741	2985			
17475	dEnqueueCopyBuffer	52995840,0x3212080,0x3211F90,0,0,16384,0,NULL,NULL	CL_SUCCESS	690312936	690313098	162	671	1785	138
17476	dEnqueueCopyBuffer	52995840,0x3212260,0x3212170,0,0,16384,0,NULL,NULL	CL_SUCCESS	690313257	690313415	158	1514	862	95

  - Optimize heterogeneous computing applications
  - Find performance hotspots and issues using AMD technology (time based profiling, event based profiling, instruction based profiling, thread profiling)
  - Tune both managed (Java) and native code (OpenCL, C/C++, Fortran)
  - Analyze programs on multi-core and NUMA platforms
  - Available as a standalone product (Windows, Linux) and a Visual Studio plug-in
  - http://developer.amd.com/CodeAnalyst/

OTHER AMD DEVELOPER TOOLS

- **AMD APP KernelAnalyzer**: a static analysis tool to compile, analyze and disassemble an OpenCL kernel for AMD GPU products



Function: AESEncrypt

Source type: OpenCL

Format: Radeon HD 5870 (Cypress) Assembly

```
__kernel
void AESEncrypt(__global  uchar4  * output  ,
                __global  uchar4  * input   ,
                __global  uchar4  * roundKey,
                __global  uchar   * SBox    ,
                __local   uchar4  * block0  ,
                __local   uchar4  * block1  ,
                const     uint      width   ,
                const     uint     rounds   )

{
    //calculating the local_id values
    unsigned int localIdx = get_local_id(0);
    unsigned int localIdy = get_local_id(1);

    //calculating global id values
    unsigned int globalIdx = get_global_id(0);
    unsigned int globalIdy = get_global_id(1);

    //calculating the block_id values
    unsigned int blockIdx = get_group_id(0);
    unsigned int blockIdy = get_group_id(1);

    //calculating NDRange sizes
    unsigned int ndRangeSizex = get_global_siz
    unsigned int ndRangeSizey = get_global_siz

    //calculating block size
    unsigned int localSizex = get_local_size(0
```

```

; --------  Disassembly --------------------
00 ALU: ADDR(64) CNT(42) KCACHE0(CB0:0-15) KC
     0  x: MOV        R3.x,  -1
        y: MOV        R3.y,  -1
        z: LSHL       T0.z,  R0.y,  (0x0000
        w: MOV        R3.w,  -1
        t: MULLO_INT  ____,  R1.y,  KC0[1].
     1  x: MOV        R4.x,  (0x00000002, 2
        y: ADD_INT    ____,  R0.y,  PS0
        z: MOV        R3.z,  -1
        w: MOV        R1.w,  (0x00000001, 1
        t: MULLO_INT  ____,  R1.x,  KC0[1].
     2  x: SUB_INT    T0.x,  0.0f,  R0.y
        y: ADD_INT    R9.y,  KC1[2].x,  T0.
        z: ADD_INT    ____,  R0.x,  PS1
        w: ADD_INT    ____,  PV1.y,  KC0[6]
        t: MOV        R4.y,  (0x00000003, 4
     3  x: ADD_INT    ____,  PV2.z,  KC0[6]
        y: LSHR       R2.y,  PV2.y,  (0x000
        z: MOV        R1.z,  (0x00000001, 1
        t: MULLO_INT  ____,  KC0[0].x,  PV2
     4  x: ADD_INT    ____,  R0.x,  KC0[1].
        y: SUB_INT    R11.y,  1,  R0.y
        z: ADD_INT    ____,  PV3.x,  PS3
        w: LSHL       R0.w,  KC0[1].x,  (0x
        t: MULLO_INT  ____,  KC0[1].x,  R0.
     5  x: ADD_INT    ____,  R0.x,  PS4
        y: LSHL       R12.y,  PV4.x,  (0x00
```

Compiler Statistics (Using CAL 11.3)

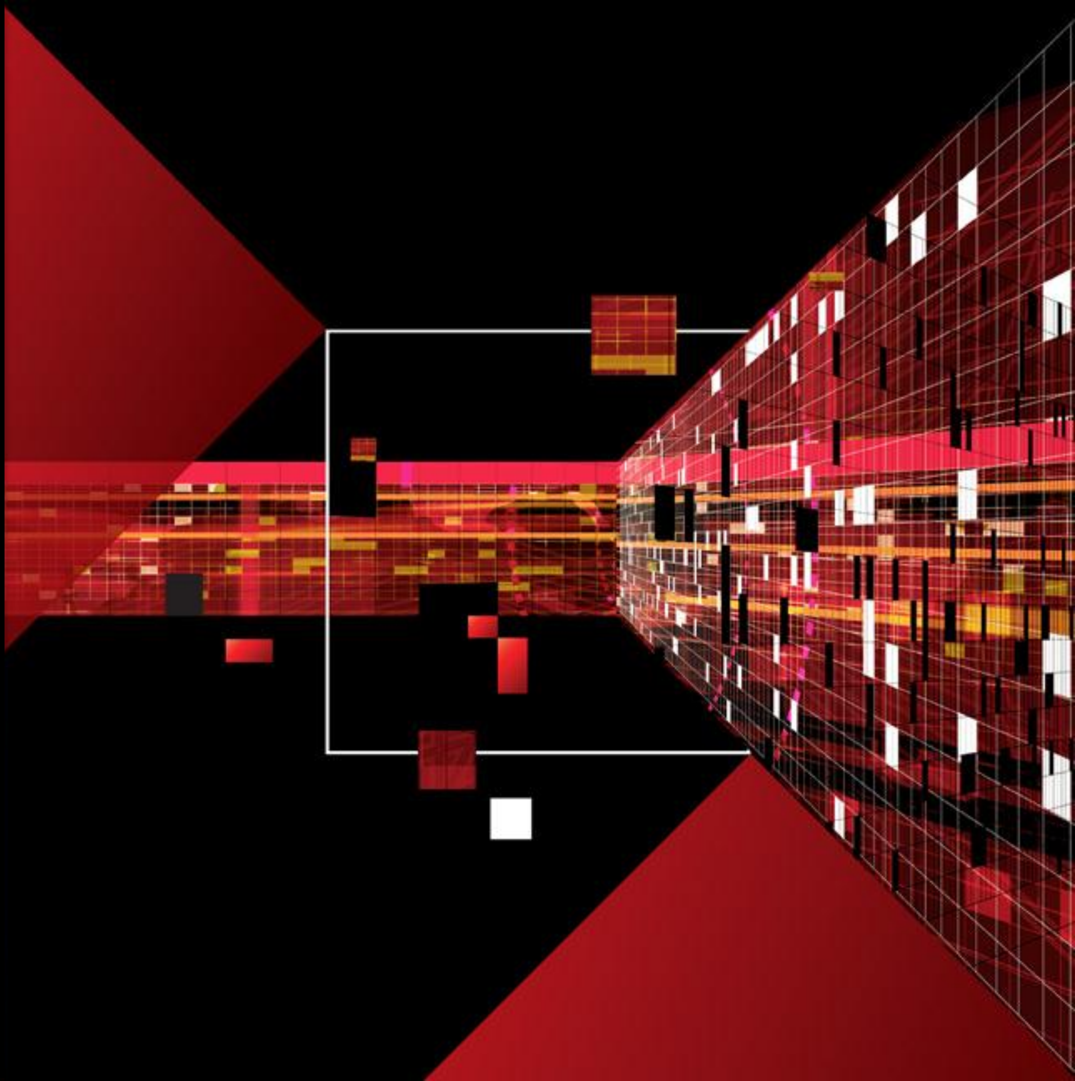
Name	GPR	Scratch Reg	Min	Max	Avg	ALU	Fetch	Write	Est Cycles	ALU:Fetch	BottleNeck	Thread\Clock	Throughput
Radeon HD 5870	19	0	6.10	20148.70	604.38	477	8	1	604.38	6.70	ALU Ops	0.05	45 M Threads\Sec
Radeon HD 5770	19	0	6.10	20148.70	604.38	477	8	1	604.38	6.70	ALU Ops	0.03	23 M Threads\Sec
Radeon HD 5670	19	0	12.20	40297.40	538.85	477	8	1	538.85	9.50	ALU Ops	0.01	12 M Threads\Sec
Radeon HD 5450	19	0	30.50	100743.50	658.55	477	8	1	658.55	14.37	ALU Ops	0.01	4 M Threads\Sec
Radeon HD 6970	16	0	5.50	22294.58	646.80	554	8	1	646.80	8.60	ALU Ops	0.05	44 M Threads\Sec
Radeon HD 6870	19	0	8.71	28783.86	863.40	477	8	1	863.40	6.70	ALU Ops	0.04	33 M Threads\Sec

Compiler Output

```
Line 133: warning:
          variable "globalIndex1" was declared but never referenced
    unsigned int globalIndex1 = localIndex +
                ^
```

- Compile and analyze for multiple Catalyst driver and GPU device targets
- View kernel compilation warning and error messages
- View AMD Intermediate Language (IL) and hardware disassembly (ISA) code
- View various statistics generated by analyzing the ISA code
- http://developer.amd.com/AMDAPPKernelAnalyzer/

QUESTIONS



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