

Profile DPC++ and GPU workload performance

Intel® VTune™ Profiler, Advisor

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Agenda

- Introduction to GPU programming model
 - Overview of GPU Analysis in Intel® VTune Profiler
 - Offload Performance Tuning
 - GPU Compute/Media Hotspots
 - A DPC++ Code Sample Analysis Demo
-
- Using Intel® Advisor to increase performance
 - Offload Advisor discrete GPUs
 - GPU Roofline for discrete GPUs

Intel GPUs and Programming Model

Gen9

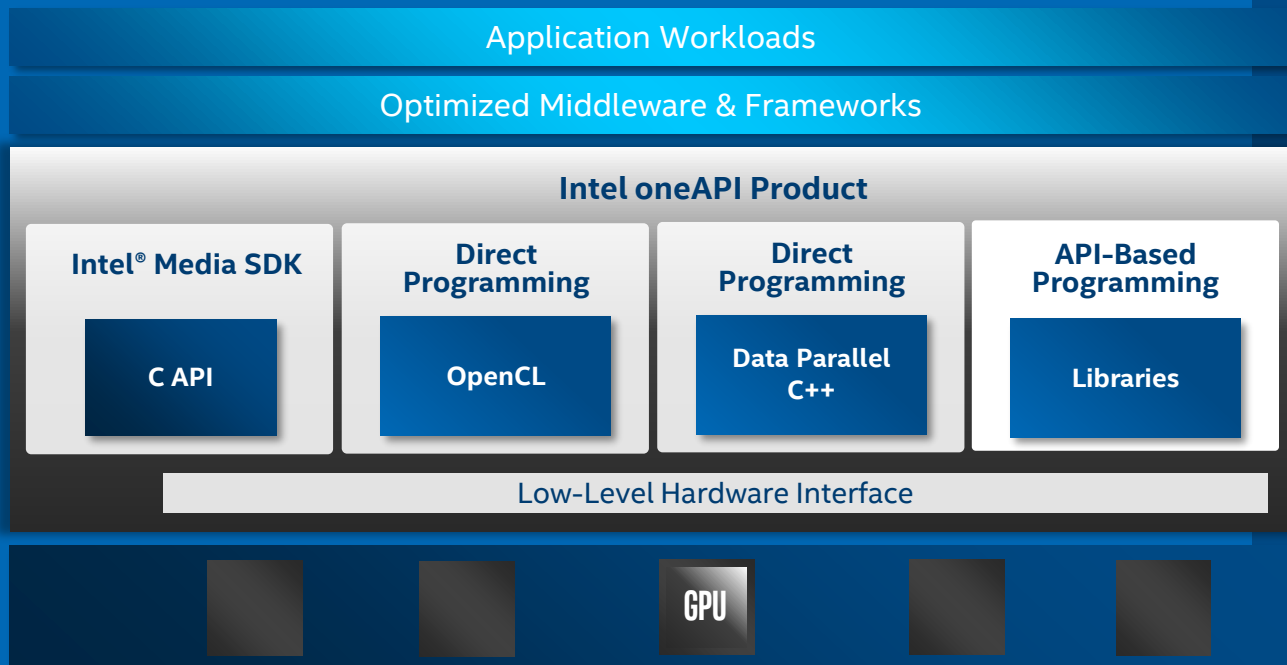
- Most common in mobile, desktop and workstations

Gen11

- Mobile platforms with Ice Lake CPU

Gen12

- Intel Xe-LP
- Tiger Lake CPU



GPU Application Analysis

GPU Compute/Media Hotspots

- Visibility into both host and GPU sides
- HW-events based performance tuning methodology
- Provides overtime and aggregated views

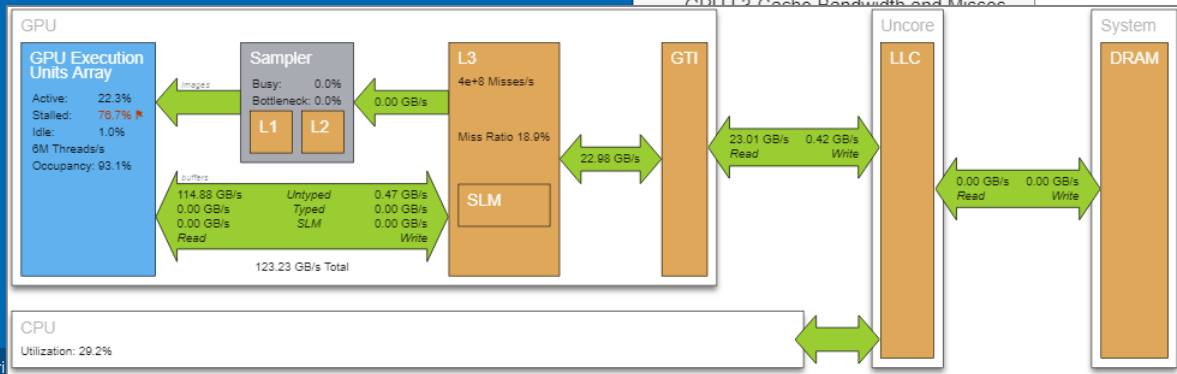
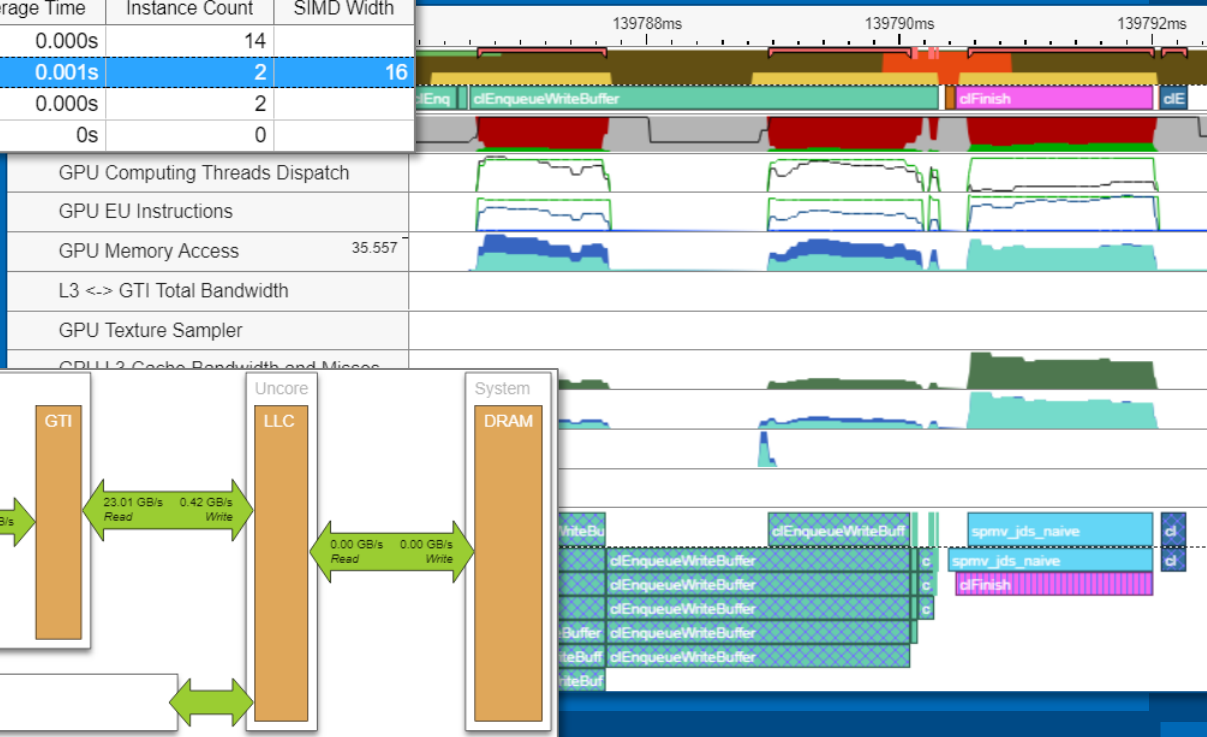
GPU In-kernel Profiling

- GPU source/instruction level profiling
- SW instrumentation
- Two modes: Basic Block latency and memory access latency

Identify GPU occupancy and which kernel to profile. Tune a kernel on a fine grain level

GPU Analysis: Aggregated and Overtime Views

Computing Task	Work Size		Computing Task			
	Global	Local	Total Time ▼	Average Time	Instance Count	SIMD Width
► cIEnqueueWriteBuffer			0.005s	0.000s	14	
► spmv_jds_naive	146944	256	0.003s	0.001s	2	16
► cIEnqueueReadBuffer			0.000s	0.000s	2	
► [Outside any task]			0s	0s	0	



GPU Analysis: In-kernel Profiling

Analyze GPU Kernel Execution

- Find memory latency or inefficient kernel algorithms
- See the hotspot on the DPC++ or OpenCL™ source & assembly code
- Analyze DMA packet execution
 - Packet Queue Depth histogram
 - Packet Duration histogram
- GPU-side call stacks

Source	Assembly	Estimated GPU Cycles
Source ▲	Source	Estimated GPU Cycles ▲
256	<code>#ifdef USE_IMAGE_STORAGE</code>	
257	<code>// Read the node information from the image</code>	
258	<code>const ushort inx = (nodeData >> 16) * 7;</code>	0.2%
259	<code>const ushort iny = (nodeData & 0xffff);</code>	
260	<code>const float4 bboxes_minX = as_float4(read_</code>	0.8%
261	<code>const float4 bboxes_maxX = as_float4(read_</code>	0.7%
262	<code>const float4 bboxes_minY = as_float4(read_</code>	0.7%
263	<code>const float4 bboxes_maxY = as_float4(read_</code>	0.7%
264	<code>const float4 bboxes_minZ = as_float4(read_</code>	0.7%
265	<code>const float4 bboxes_maxZ = as_float4(read_</code>	0.7%
266	<code>const int4 children = as_int4(read_imageui</code>	0.7%
267		
268	<code>const int4 visit = QBVHNode_BBoxIntersect(</code>	13.1%
269	<code>bboxes_minX, bboxes_maxX,</code>	
270	<code>bboxes_minY, bboxes_maxY,</code>	
271	<code>bboxes_minZ, bboxes_maxZ,</code>	

Offload Performance Tuning

GPU Offload Analysis

Heterogeneous applications

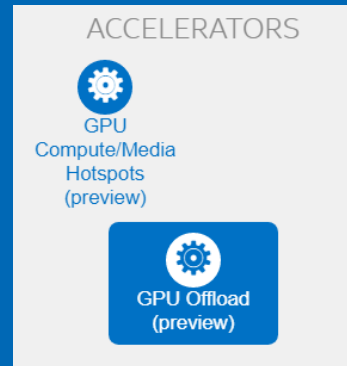
- Off-load models: OpenCL, SYCL, DPC++, OpenMP

All execution resources in focus

- Explore code execution on various CPU and GPU cores
- Correlate CPU and GPU activity
- Identify whether your application is GPU or CPU bound

Find kernels for further analysis

- Task level analysis
- Kernel efficiency
- Data transfer rates



GPU Offload (Preview) GPU Offload (Preview) ?

Analysis Configuration Collection Log Summary Graphics Platform

Grouping: Computing Task

Computing Task	EU Array			EU Threads Occupancy	Computing Threads Started	GPU Time by GPU Engine Render and GPGPU
	Active	Stalled	Idle			
workload	90.8%	7.6%	1.6%	98.4%	168	3.143s
▶ clEnqueueReadBuff	0.0%	0.0%	100.0%	0.0%	0	0.000s
▶ [Outside any task]	0.0%	0.0%	100.0%	0.0%	0	0.001s

DPC++ Sample app

DPC++ is an extension to SYCL leveraging addition features like:

- Unified shared memory (USM)
- ND-range subgroups
- Ordered queue, etc.

A bunch of sample apps can be found in the OneAPI Toolkit on Github

- We pick-up one: matrix_multiply
- Multiple kernels to select for execution the MM op
- Not fully offload example

```
void multiply1(int msize, int tid, int numt, TYPE a[][NUM], TYPE b[][NUM], TYPE c[][NUM], TYPE t[][NUM]) {
    int i, j, k;

    default_selector device;
    queue q(device, exception_handler);

    range<2> matrix_range{NUM, NUM};

    buffer<TYPE, 2> bufferA((TYPE*)a, matrix_range);
    buffer<TYPE, 2> bufferB((TYPE*)b, matrix_range);
    buffer<TYPE, 2> bufferC((TYPE*)c, matrix_range);

    q.submit([&](cl::sycl::handler& h) {
        auto accessorA = bufferA.get_access<sycl_read>(h);
        auto accessorB = bufferB.get_access<sycl_read>(h);
        auto accessorC = bufferC.get_access<sycl_read_write>(h);

        h.parallel_for<class Matrix1<TYPE> >(matrix_range, [=](cl::sycl::id<2> ind) {
            int k;
            for (k = 0; k < NUM; k++) {
                accessorC[ind[0]][ind[1]] += accessorA[ind[0]][k] * accessorB[k][ind[1]];
            }
        });
    }).wait_and_throw();
}
```

Declare a deviceQueue

Declare a 2 dimensional range

Declare 3 buffers and Initialize them

Submit our job to the queue

Declare 3 accessors to our buffers. 2RD, 1 WR

Execute matrix multiply in parallel over our matrix_range

ind is an index into this range

Perform computation ind[0] is row, ind[1] is col

Demo: GPU Offload Analysis

GPU Compute/Media Hotspots

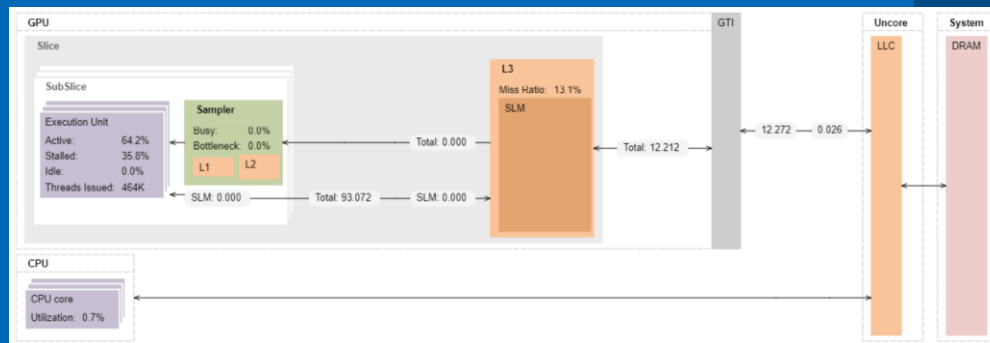
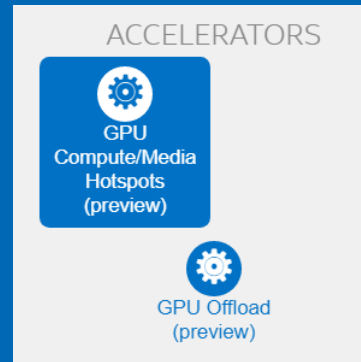
GPU Compute/Media Hotspots

A purely GPU bound analysis

- Although some metrics to SoC are measured

How to gain max performance on GPU

- In an “ideal world” you’d be using optimized IP blocks - “Performance Libraries”
- High level models like DPC++ still give ability to tweak workload layout that better match to GPU architecture
- Need to know GPU blocks as VTune is providing HW level metrics



My GPU architecture

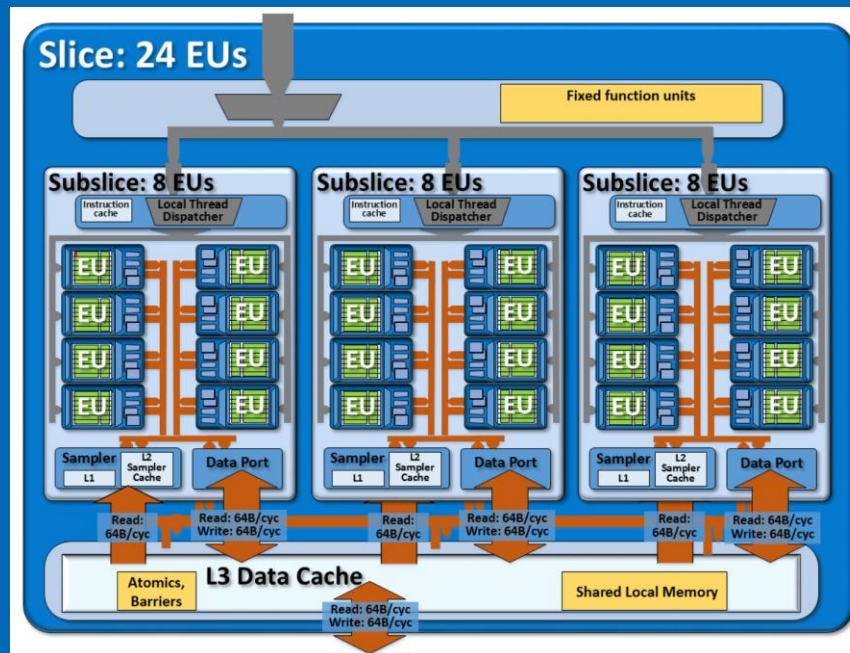
Collection and Platform Info

GPU

Name: Intel(R) UHD Graphics 620
Vendor: Intel Corporation
Driver: 27.20.100.8187
EU Count: 24
Max EU Thread Count: 7
Max Core Frequency: 1.1 GHz

GPU OpenCL Info

Version: OpenCL C 2.0
Max Compute Units: 24
Max Work Group Size: 256
Local Memory: 64 KB
SVM Capabilities: Fine-grained buffer with atomics



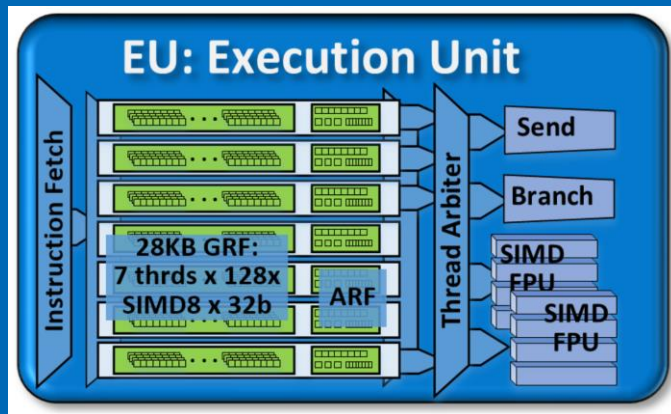
Quickly learn your GPU architecture details from VTune Profiler Summary page

Gen9 GPU EU Details

EU compute architecture includes:

- 24EU x 7thr = 168 threads to make busy
- 128 GRF of 32 Byte (accessible as vector-8 of 32-bit data), flexible
- 2 SIMD-4 FPUs of 32-bit FP or INT data
- 16 MAD/cycle (ADD + MUL) x 2 FPUs x SIMD-4)
- 2 additional units: Branch and Send

Main goal is to maximize EU utilization

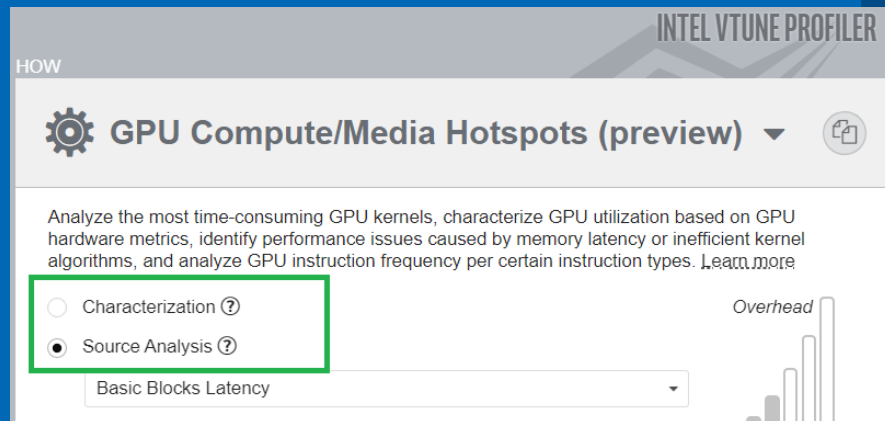


VTune Profiler Analysis

- Select either of GPU analysis configuration:
 - **Characterization** – for monitoring GPU Engine usage, effectiveness, and stalls
 - **Source Analysis** – for identifying performance-critical blocks and memory access issues in GPU kernels

Optimization strategy:

- Maximize effective EU utilization
- Maximize SIMD usage
- Minimize EU stalls due to memory issues




Analyze EU Efficiency and Memory issues


Use the **Characterization** configuration option

- EUs activity: EU Array Active, EU Array Stalled, EU Array Idle, Computing Threads Started, and Core Frequency


Select **Overview** or **Compute Basic** metric


- additional metrics: Memory Read/Write Bandwidth, GPU L3 Misses, Typed Memory Read/Write Transactions

☒ Characterization 

Compute Basic (with global/local memory accesses) 

GPU sampling interval, ms

1 

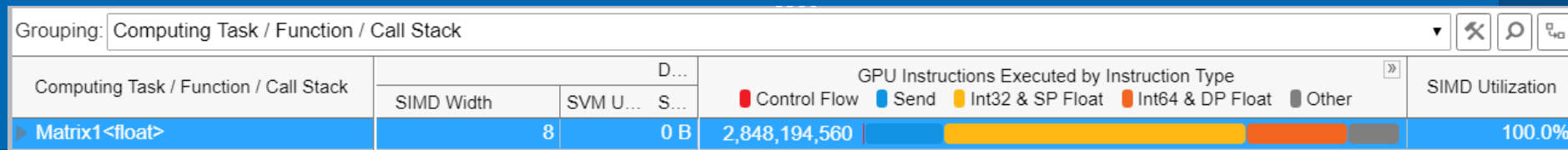
Overhead 

Grouping: Computing Task									
Computing Task	EU Array			EU Threads Occupancy	Computing Threads Started	EU Instructions			L3 Bandwidth, GB/sec
	Active	Stalled	Idle			IPC Rate	2 FPU's active	Send active	
▶ Matrix1<float>	62.6%	37.4%	0.0%	95.1%	131,040	1.583	34.9%	6.8%	89.763

Analyze GPU Instruction Execution

Use the **Dynamic Instruction Count** preset

- A breakdown of instructions executed by the kernel
- Groups of instructions
 - Control flow
 - Send
 - Synchronization
 - Int16 & HP Float | Int32 & SP Float | Int64 & DP Float
 - Other



Analyze Source Code

Use the **Source Analysis** configuration option

- Analyze a kernel of interest for basic block latency or memory latency issues
- Enable both the **Source** and **Assembly** panes to get a side-by-side view

Source		Assembly		Assembly grouping: Address			
Source		GPU Instructions Exec		Assembly		GPU... SIMD Utilization	
1 void __kernel sin_cos(__global float*		49,152		0x598 7 cmp (16 M0) (gt)f0.0 null<1>:		16,384 50.0%	
2 {				0x5a8 7 cmp (16 M16) (gt)f0.0 null<1>		16,384 50.0%	
3 size_t i = get_global_id(0);				0x5b8 7 (~f0.0) if (32 M0) bb_12 bb_2		16,384	
4				0x5c8 Block 11:			
5 if (i & 2)		655,360		0x5c8 7 mad (16 M0) r2.0<1>:f r46		313 50.0%	
6 {				0x5d0 7 mad (16 M16) r4.0<1>:f r4		313 49.8%	
7 data[i] *= sin((float)i);		7,152,845		0x5d8 7 shl (16 M0) r12.0<1>:d r2		313 50.0%	
8 }				0x5e8 7 shl (16 M16) r18.0<1>:d r		313 49.8%	
9 else				0x5f8 7 add (16 M0) r2.0<1>:f r2.		313 50.0%	
10 {				0x608 7 add (16 M16) r4.0<1>:f r4		313 49.8%	
11 data[i] *= cos((float)i);		7,057,665		0x618 7 mad (16 M0) r120.0<1>:f r		313 50.0%	
12 }				0x620 7 mad (16 M16) r6.0<1>:f r8		313 49.8%	
				0x628 7 mad (16 M0) r118.0<1>:f r		313 50.0%	

Demo: GPU Compute/Media Hotspots

Intel Advisor for dGPU



intel®

Intel® Advisor workflows



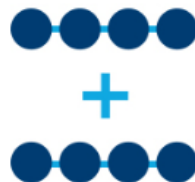
Offload Advisor

Design offload strategy and model performance on GPU.



Roofline Analysis

Optimize your application for memory and compute.



Vectorization Optimization

Enable more vector parallelism and improve its efficiency.



Thread Prototyping

Model, tune, and test multiple threading designs.

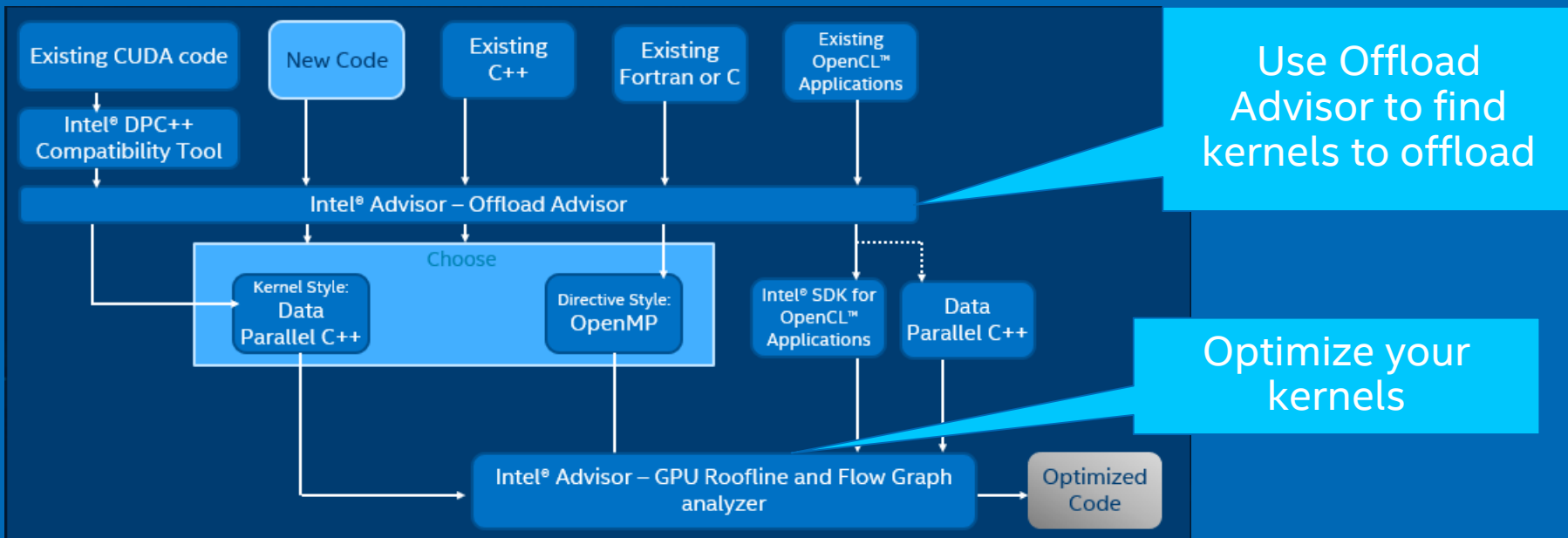


Build Heterogeneous Algorithms

Create and analyze data flow and dependency computation graphs.

Learn More: software.intel.com/advisor

Using Intel® Advisor to increase performance



Intel[®] Advisor

- Offload Advisor new UI (coming in beta10)
- Support for target GPU devices

Select offload modelling perspective

The screenshot shows the Intel Advisor Beta application window. The title bar reads "/prj/buildapm_config/tests/gen/black-scholes-omp-gen.pvc - Intel Advisor Beta". The interface is divided into several sections:

- Left Sidebar:** A vertical toolbar with various icons. The icon for perspective selection (a square with a circle and a plus sign) is highlighted with a red box.
- Main Content Area:**
 - CPU Parallelism and Memory:** Contains three tiles: "Vectorization", "CPU Roofline", and "Threading".
 - Accelerators Modeling and Roofline:** Contains two tiles: "Offload Modeling" and "GPU Roofline". The "Offload Modeling" tile is highlighted with a red box.
 - Offload Modeling Perspective:** A section at the bottom right with a "Choose" button highlighted with a red box. Below the button, there is a list of bullet points:
 - Identify high-impact opportunities to offload you code to an accelerator.
 - Determine potential benefit and key bottlenecks even before running the code on the accelerator.
 - Get reasons why certain regions are not recommended for offloading.

Three blue callout boxes with white text provide instructions:

- Open perspective selector**: Points to the perspective selection icon in the left sidebar.
- Select Offload Modelling**: Points to the "Offload Modeling" tile in the "Accelerators Modeling and Roofline" section.
- Press "Choose" button**: Points to the "Choose" button in the "Offload Modeling Perspective" section.

Offload Modelling Workflow

The screenshot displays the 'Analysis Workflow' window in Intel Advisor, specifically the 'Offload Modelling' tab. The interface is divided into several sections. On the left, there is a sidebar with icons for various analysis tasks. The main area contains a 'Run' button (a play icon) and a 'Stop' button (a square icon). Below these, there are sections for 'Accuracy' and 'Overhead', each with a dropdown menu and a slider. The 'Target Platform Model' section shows a list of device models, with 'Xe' currently selected. A red box highlights the 'Run', 'Stop', and 'Target Platform Model' sections. Three blue callout boxes point to these sections with the following text:

- Run collection and performance model
- Select accuracy and overhead preset
- Select target device model

Offload Advisor: CLI interface

1. Use \$APM/collect.py script to run required analysis types:

```
advixe-python $APM/collect.py --config=<target> <my_project_directory>  
-- ./myapp [app_parameters]
```

2. Generate Offload report:

```
advixe-python $APM/analyze.py <my_project_directory> -o <path-to-report-dir>
```

There are lots options both for collect.py and analyze.py to tune hardware and software parameters

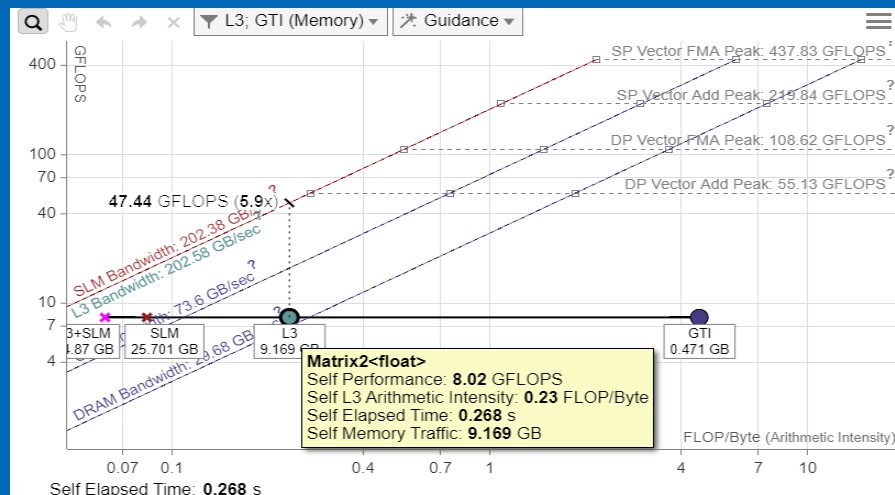
Intel® Advisor

GPU Roofline

GPU Roofline chart

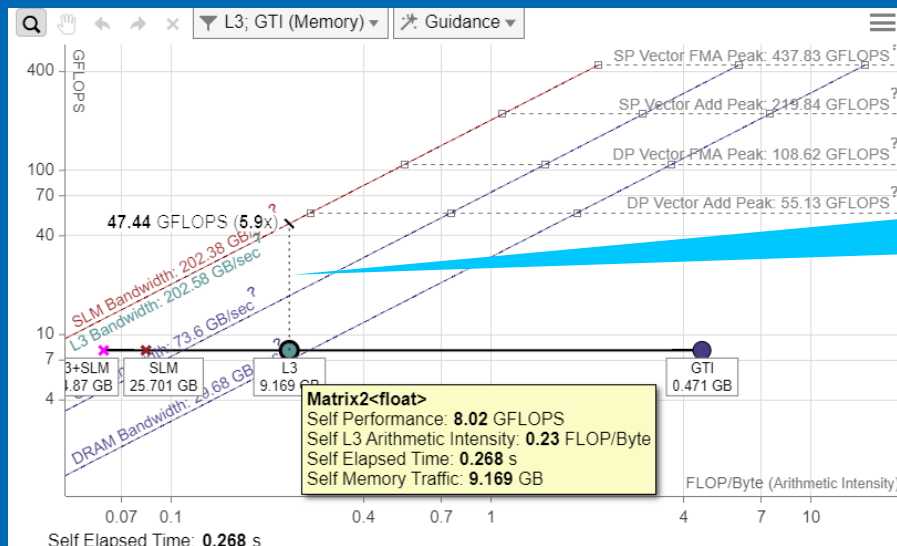
GPU Roofline Performance Insights

- Highlights poor performing loops
- Shows performance 'headroom' for each loop
 - Which can be improved
 - Which are worth improving
- Shows likely causes of bottlenecks
 - Memory bound vs. compute bound
- Suggests next optimization steps



Intel® Advisor GPU Roofline

See how close you are to the system maximums (rooflines)



Roofline indicates room for improvement

Select offload modelling perspective

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- Left Sidebar:** A vertical toolbar with various icons. The second icon from the top, representing a perspective selector, is highlighted with a red box.
- Main Content Area:**
 - CPU Parallelism and Memory:** Contains three tiles: "Vectorization", "CPU Roofline", and "Threading".
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 - Identify high-impact opportunities to offload your code to an accelerator.
 - Determine potential benefit and key bottlenecks even before running the code on the accelerator.
 - Get reasons why certain regions are not recommended for offloading.

Three blue callout boxes with white text provide instructions:

- "Open perspective selector" points to the perspective selector icon in the sidebar.
- "Select GPU Roofline" points to the "GPU Roofline" tile in the Accelerators Modeling and Roofline section.
- "Press 'Choose' button" points to the "Choose" button in the Offload Modeling Perspective section.

GPU Roofline: CLI interface

Run 2 collections with **--profile-gpu** option:

```
advixe-cl -collect=survey --profile-gpu --project-dir=<my_project_directory>  
-- ./myapp [app_parameters]
```

```
advixe-cl -collect=tripcounts --flop --profile-gpu --project-  
dir=<my_project_directory> -- ./myapp [app_parameters]
```

Generate a GPU Roofline report:

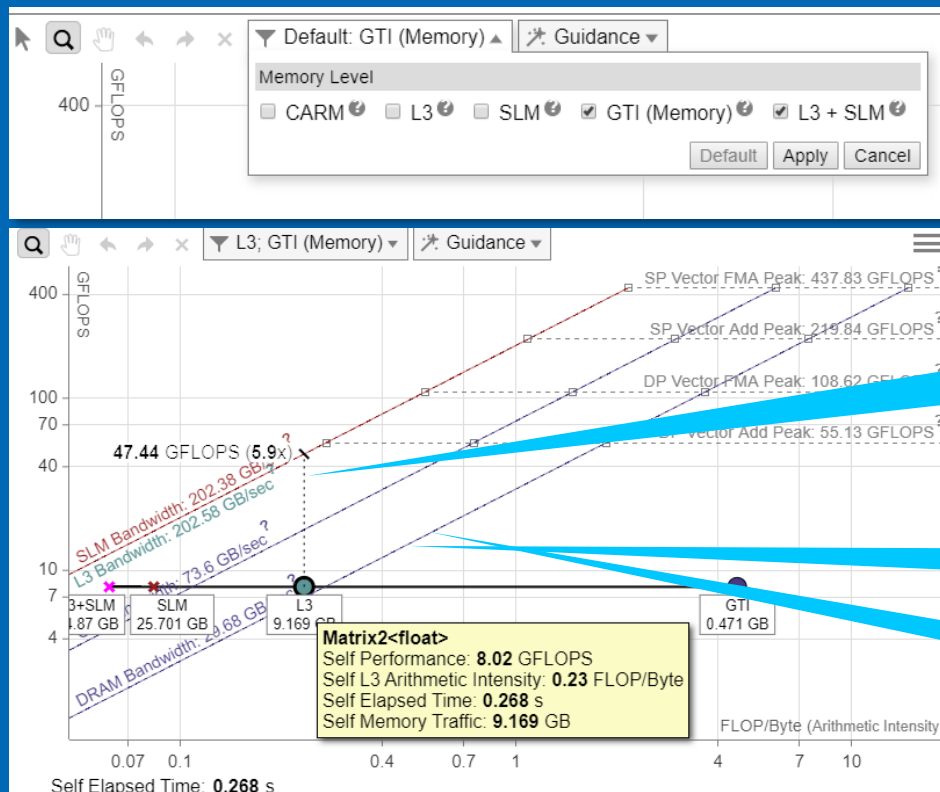
```
advixe-cl --report=roofline --gpu --project-dir=<my_project_directory> --  
report-output=roofline.html
```

Generate a GPU Roofline report for **integer** operations:

```
advixe-cl --report=roofline --gpu -data-type=int --project-  
dir=<my_project_directory> --report-output=roofline.html
```

Open the generated roofline.html in a web browser to visualize GPU performance.

Find Effective Optimization Strategies



Configure levels to display

Shows performance headroom for each loop

Likely bottlenecks

Suggests optimization next steps

Links

[Intel oneAPI](#)

[Intel® VTune™ Profiler](#)

[GPU Offload Analysis](#)

[GPU Compute/Media Hotspots Analysis](#)

[Intel Advisor](#)

[Intel Advisor Cookbooks](#)

[DPC ++ spec page](#)

[Sample apps on Github](#)

Questions

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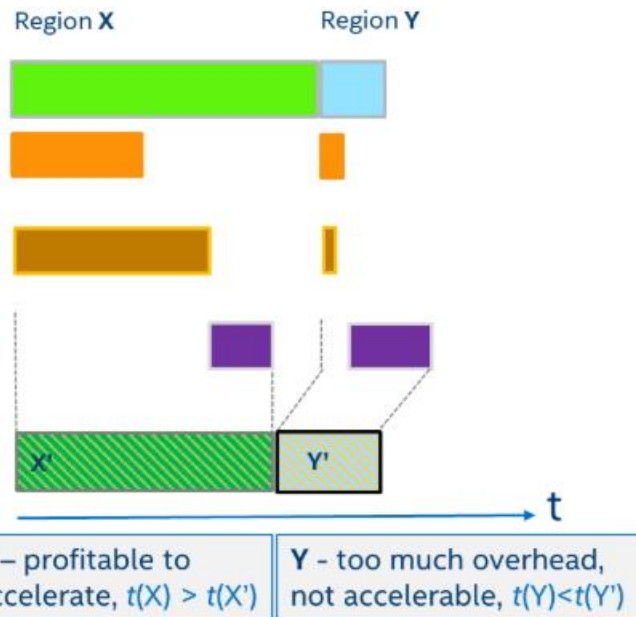
Backup

Performance model

Execution time on baseline platform (CPU)

- Estimated execution time on accelerator, assuming bound exclusively by **Compute**
- Estimated execution time on accelerator, Estimate assuming bound exclusively by caches/memory
- Offload Tax estimate (data transfer + invoke)

Final estimated time on target GPU platform



$$t_{\text{region}} = \max(t_{\text{compute}}, t_{\text{memory subsystem}}) + t_{\text{data transfer tax}} + t_{\text{kernel launch}}$$

Set Up System for GPU Analysis

Install the Intel® oneAPI software

<https://software.intel.com/content/www/us/en/develop/tools/oneapi.html>

Linux* systems: Linux kernel 4.14 and higher

Switch to a root mode

or

- Add your username to the *video* group
- Set the value of `dev.i915.perf_stream_paranoid` sysctl option to 0
- Disable Hangcheck

```
sudo sh -c "echo N> /sys/module/i915/parameters/enable_hangcheck"
```

Windows: You can install a GPU driver for your system from <https://downloadcenter.intel.com>.

Please visit

<https://software.intel.com/content/www/us/en/develop/documentation/advisor-user-guide/top/intel-advisor-beta-gpu-roofline.html>

Python API

Create Python scripts for data analysis with Python API

How to print collected data

```
advixe-python /advisor_install_dir/pythonapi/examples/survey_gpu.py  
/work_dir/project_name
```

```
carm_traffic_gb : 0.698458  
computing_task : SumPointsKernel  
computing_task_average_time : 0.000250667  
computing_task_id : 3  
computing_task_instance_count : 150  
computing_task_purpose : Compute  
computing_task_simd_width : 32  
computing_task_svm_usage_type :  
computing_task_total_time : 0.0376  
computing_threads_started : 2698  
data_transferred_size :  
data_transferred_total_gb_sec :  
elapsed_time : 0.0376
```

```
gpu_compute_performance_fp_ai : 4.00678  
gpu_compute_performance_gflop : 0.0384192  
gpu_compute_performance_gflops : 1.02179  
gpu_compute_performance_gintop : 0.135245  
gpu_compute_performance_gintops : 3.59693  
gpu_compute_performance_gmixop : 0.173664  
gpu_compute_performance_gmixops : 4.61872  
gpu_compute_performance_int_ai : 14.1048  
gpu_compute_performance_mix_ai : 18.1116  
gpu_memory_bandwidth_gb_sec_read : 0.248483  
gpu_memory_bandwidth_gb_sec_write : 0.00653106  
gpu_memory_data_transferred_gb_read : 0.00934298  
gpu_memory_data_transferred_gb_write : 0.000245568
```

```
SumPointsKernel: 3  
? : : ? : 0.0622656  
? : : SYNC : 0.0028152  
FP : 32: BASIC : 0.0384192  
FP : 32: MOVE : 0.0380736  
FP : 16: MOVE : 1.44e-05  
INT: 32: BASIC : 0.0990432  
INT: 32: FMA : 0.000936  
INT: 32: STORE : 0.000216  
INT: 32: LOAD : 0.0148032  
INT: 32: SLM_STORE: 0.0238176  
INT: 32: SLM_LOAD : 0.0196704  
INT: 32: MOVE : 0.0462312  
INT: 32: BIT : 0.0037584  
INT: 64: BASIC : 0.029952  
INT: 64: MOVE : 0.0001512  
INT: 16: BASIC : 0.0012096  
INT: 16: MOVE : 0.0003816  
INT: 16: BIT : 0.0003456
```