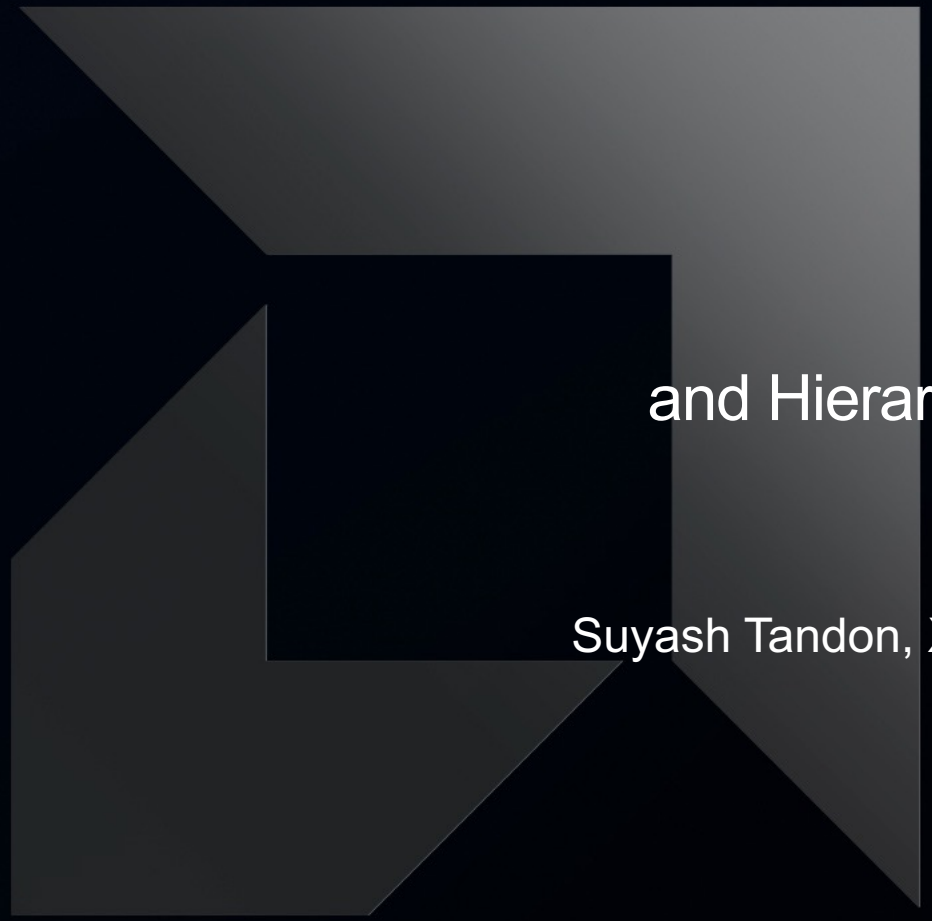


Introduction to Omniperf

and Hierarchical Roofline on AMD Instinct™ MI200 GPUs

Suyash Tandon, Xiaomin Lu, Noah Wolfe, George Markomanolis, Bob Robey

Presenter: Sam Antao

PDC Introduction to GPUs practical course

Sept 22nd, 2023

AMD

together we advance_

Background – AMD Profilers

ROC-profiler (rocprof)

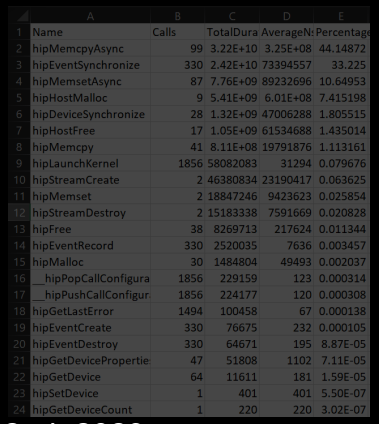
Hardware Counters	Raw collection of GPU counters and traces	
	Counter collection with user input files	Counter results printed to a CSV
Traces and timelines	Trace collection support for	
	CPU copy	HIP API	HSA API	GPU Kernels
Visualisation	Traces visualized with Perfetto	

Omnitrace

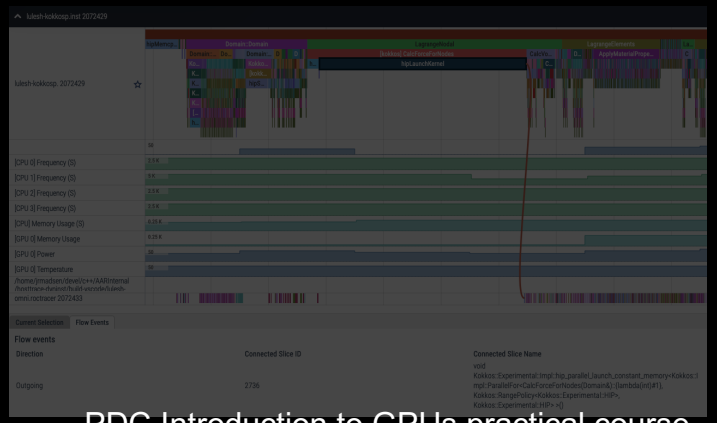
Trace collection	Comprehensive trace collection				
	CPU	GPU			
Supports	CPU copy	HIP API	HSA API	GPU Kernels	
	OpenMP®	MPI	Kokkos	p-threads	multi-GPU
Visualisation	Traces visualized with Perfetto				

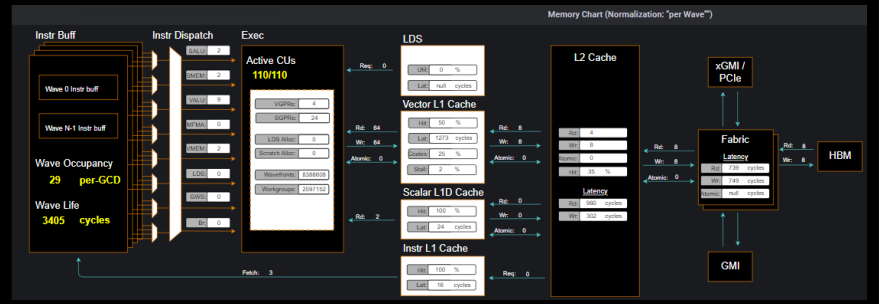
Omniperf

Performance Analysis	Automated collection of hardware counters			
	Analysis	Visualisation		
Supports	Speed of Light	Memory chart	Rooflines	Kernel comparison
Visualisation	With Grafana or standalone GUI			



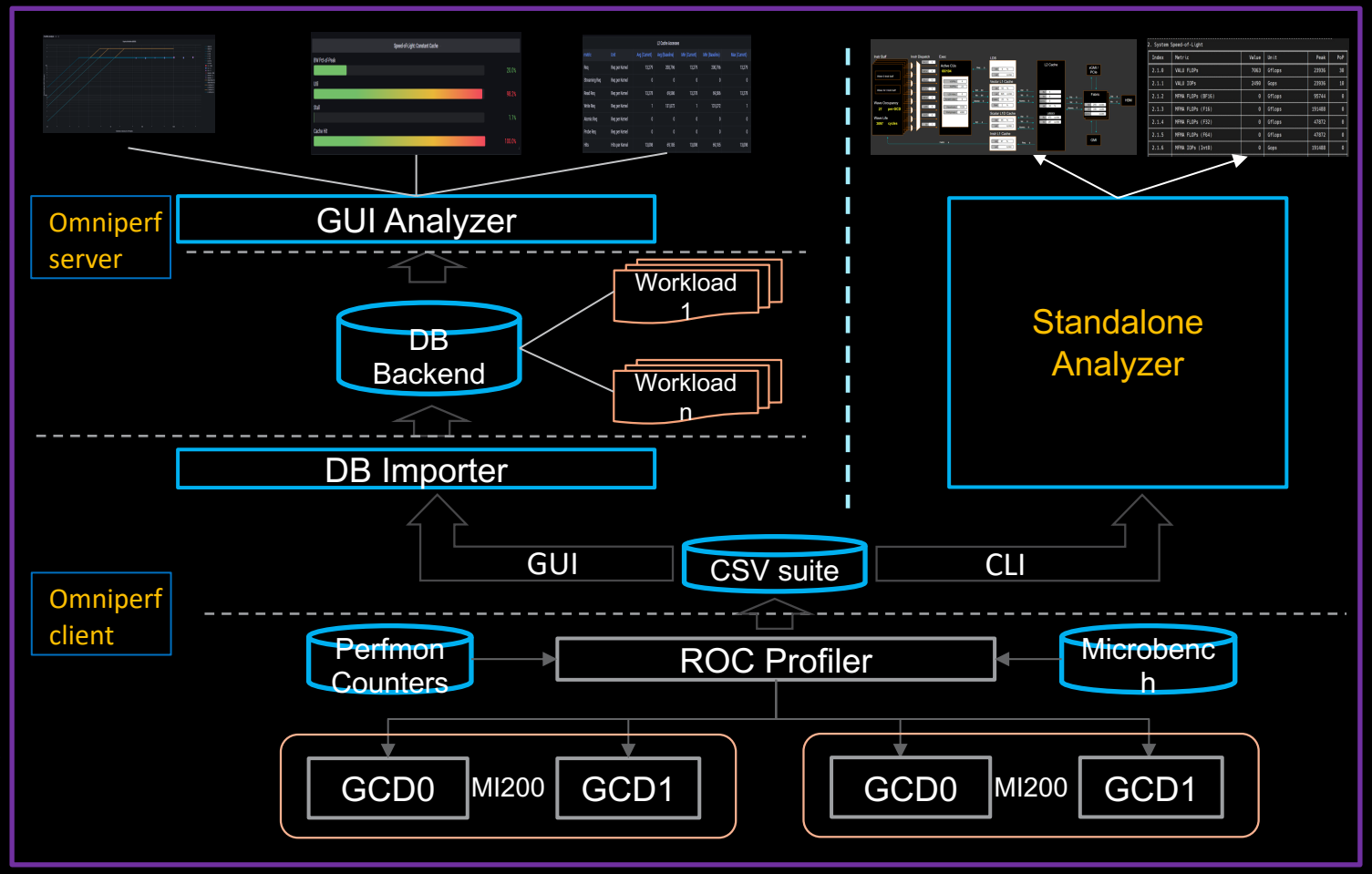
Name	Calls	TotalDura	AverageN	Percentage
hipMemcpyAsync	99	3.22E+10	3.25E+08	44.14872
hipEventSynchronize	330	2.42E+10	73394557	33.225
hipMemsetAsync	87	7.76E+09	89232696	10.64953
hipHostMalloc	9	5.41E+09	6.01E+08	7.415198
hipDeviceSynchronize	28	1.32E+09	47006288	1.805515
hipHostFree	17	1.05E+09	61534688	1.435014
hipMemcpy	41	8.11E+08	19791876	1.113161
hipLaunchKernel	1856	58082083	31294	0.079676
hipStreamCreate	2	46380834	23190417	0.063625
hipMemset	2	18847246	9423623	0.025854
hipStreamDestroy	2	15183338	7591669	0.020828
hipFree	38	8269713	217624	0.011344
hipEventRecord	330	2520035	7636	0.003457
hipMalloc	30	1484804	49493	0.002037
__hipPopCallConfigura	1856	229159	123	0.000314
__hipPushCallConfigur	1856	224177	120	0.000308
hipGetLastError	1494	100458	67	0.000138
hipEventCreate	330	76675	232	0.000105
hipEventDestroy	330	64671	195	8.87E-05
hipGetDevicePropertie	47	51808	1102	7.11E-05
hipGetDevice	64	11611	181	1.59E-05
hipSetDevice	1	401	401	5.50E-07
hipGetDeviceCount	1	220	220	3.02E-07





Omniperf: Automated Collection of Hardware Counters and Analysis

AMD Research Tool	Repository: https://github.com/AMDResearch/omniperf
	✗ Not part of ROCm stack; Built on top of ROC-profiler
Integrated Performance Analyzer for AMD GPUs	Speed-of-Light; Roofline; Memory chart; Baseline comparison
	Sub-system performance analysis
	LDS; vL1D; L2 Cache; HBM
	Shader Compute; Wavefront; Instruction mix; Latencies
INSTINCT™ Support	MI200; MI100
User Interfaces	Grafana™ GUI; Standalone GUI; Command Line (CLI)



Refer to current documentation for recent updates

Omniperf features

Omniperf Features	
MI200 support	Roofline Analysis Panel (*Supported on MI200 only, SLES 15 SP3 or RHEL8*)
MI100 support	Command Processor (CP) Panel
Standalone GUI Analyzer	Shader Processing Input (SPI) Panel
Grafana/MongoDB GUI Analyzer	Wavefront Launch Panel
Dispatch Filtering	Compute Unit - Instruction Mix Panel
Kernel Filtering	Compute Unit - Pipeline Panel
GPU ID Filtering	Local Data Share (LDS) Panel
Baseline Comparison	Instruction Cache Panel
Multi-Normalizations	Scalar L1D Cache Panel
System Info Panel	Texture Addresser and Data Panel
System Speed-of-Light Panel	Vector L1D Cache Panel
Kernel Statistic Panel	L2 Cache Panel
Memory Chart Analysis Panel	L2 Cache (per-Channel) Panel

Omniperf

- Omniperf is an integrated performance analyzer for AMD GPUs built on ROCprofiler
- Omniperf executes the code many times to collect various hardware counters (over 100 counters default behavior)
- Using specific filtering options (kernel, dispatch ID, metric group), the overhead of profiling can be reduced
- Roofline analysis is supported on MI200 GPUs
- Omniperf shows many panels of metrics based on hardware counters, we will show a few here
- Typical Omniperf workflows:
  - Profile + Analyze with CLI or visualize with standalone GUI
  - Profile + Import to database and visualize with Grafana
- Omniperf targets MI100 and MI200 and future generation AMD GPUs
- Omniperf requires to use just 1 MPI process

- For problems, create an issue here: https://github.com/AMDResearch/omniperf/issues

Client-side installation (if required)

Download the latest version from here: https://github.com/AMDResearch/omniperf/releases

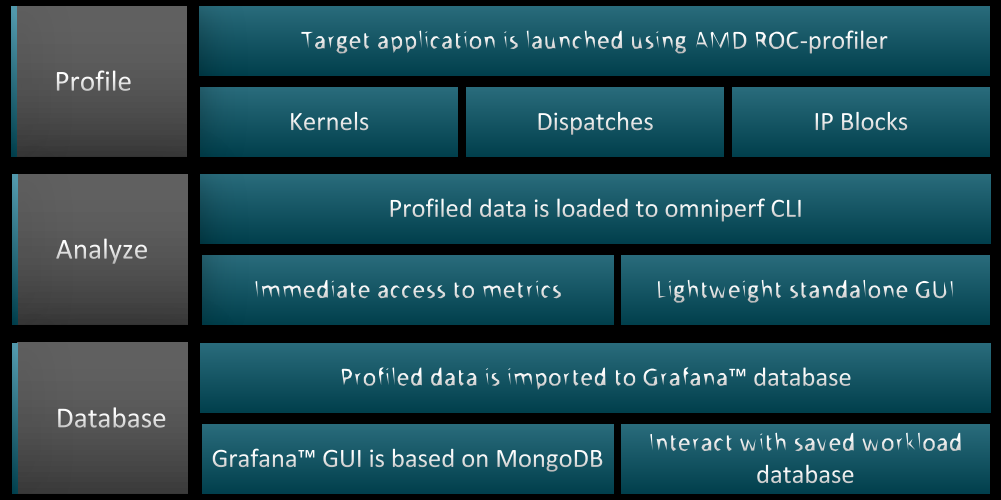
Full documentation: https://amdresearch.github.io/omniperf/

```
wget https://github.com/AMDResearch/omniperf/releases/download/v1.0.8-PR2/omniperf-v1.0.8-PR2.tar.gz

tar zxvf omniperf-v1.0.8-PR2.tar.gz

cd omniperf-v1.0.8-PR2/
python3 -m pip install -t ${INSTALL_DIR}/python-libs -r requirements.txt
mkdir build
cd build
export PYTHONPATH=$INSTALL_DIR/python-libs:$PYTHONPATH
cmake -DCMAKE_INSTALL_PREFIX=${INSTALL_DIR}/1.0.8 \
        -DPYTHON_DEPS=${INSTALL_DIR}/python-libs \
        -DMOD_INSTALL_PATH=${INSTALL_DIR}/modulefiles ..
make install
export PATH=$INSTALL_DIR/1.0.8/bin:$PATH
```

Omniperf modes



Basic command-line syntax:

Profile:

```
$ omniperf profile -n workload_name [profile options]
                    [roofline options] -- <CMD> <ARGS>
```

Analyze:

```
$ omniperf analyze -p
<path/to/workloads/workload_name/mi200/>
```

To use a lightweight standalone GUI with CLI analyzer:

```
$ omniperf analyze -p
<path/to/workloads/workload_name/mi200/> --gui
```

Database:

```
$ omniperf database <interaction type> [connection options]
```

For more information or help use -h/--help/? flags:

```
$ omniperf profile --help
```

For problems, create an issue here: https://github.com/AMDResearch/omniperf/issues
Documentation: https://amdresearch.github.io/omniperf

Omniperf profiling

We use the example sample/vcopy.cpp from the Omniperf installation folder:

```
$ wget https://github.com/AMDResearch/omniperf/raw/main/sample/vcopy.cpp
```

Compile with hipcc:

```
$ hipcc –o vcopy vcopy.cpp
```

Profile with Omniperf:

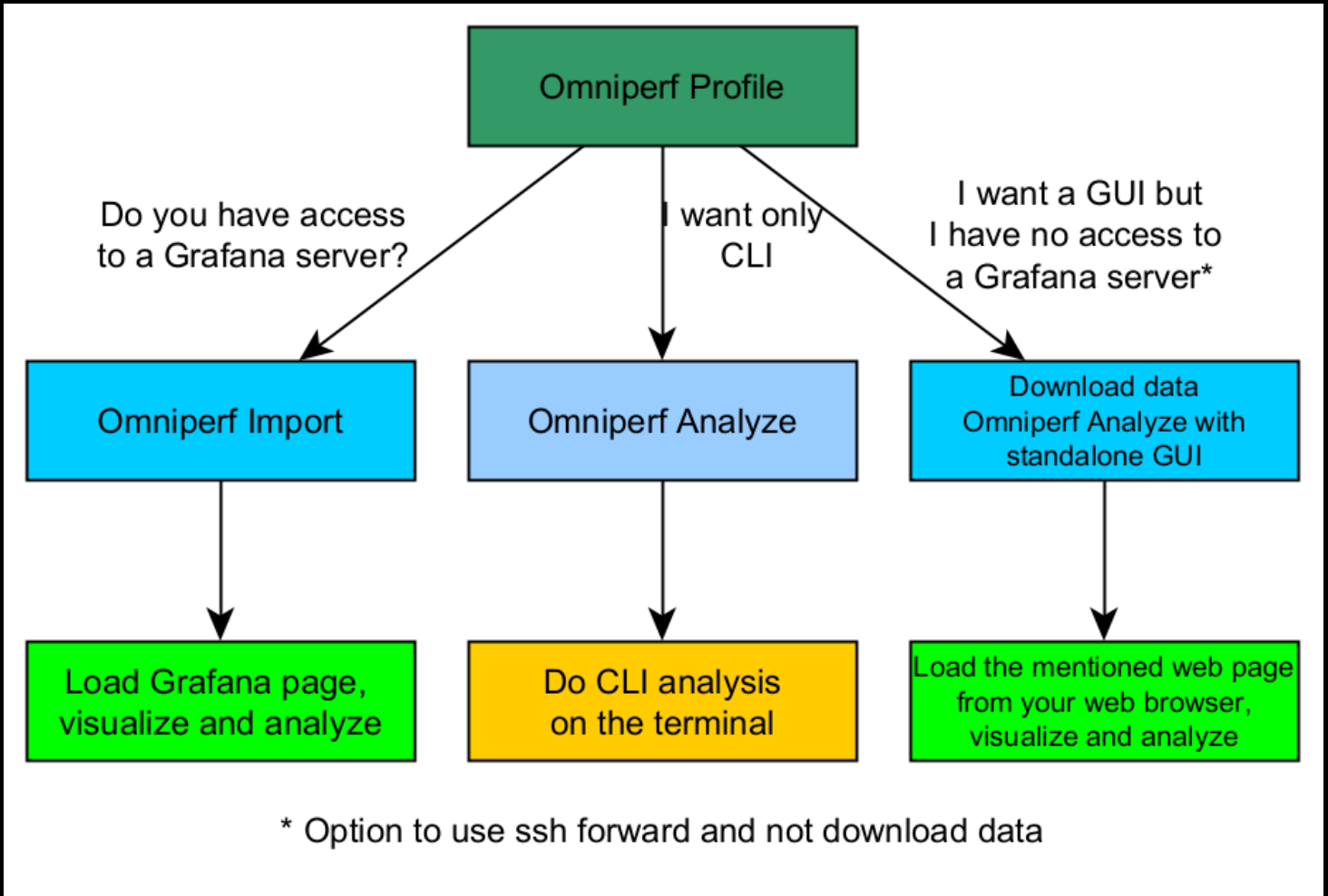
```
$ omniperf profile –n vcopy_all -- ./vcopy 1048576 256
…
--------------
Profile only
--------------

omniperf ver:  1.0.4
Path:  /pfs/lustrep4/scratch/project_462000075/markoman/omniperf-
1.0.4/build/workloads
Target:  mi200
Command:  ./vcopy 1048576 256
Kernel Selection:  None
Dispatch Selection:  None
IP Blocks: All
```

A new directory will be created called `workloads/vcopy_all`

Note: Omniperf executes the code as many times as required to collect all HW metrics. Use kernel/dispatch filters especially when trying to collect roofline analysis.

Omniperf workflows



Omniperf analyze

We use the example sample/vcopy.cpp from the Omniperf installation folder:

```
$ wget https://github.com/AMDResearch/omniperf/raw/main/sample/vcopy.cpp
```

Compile with hipcc:

```
$ hipcc –o vcopy vcopy.cpp
```

Profile with Omniperf:

```
$ omniperf profile –n vcopy_all -- ./vcopy 1048576 256
```

A new directory will be created called `workloads/vcopy_all`

Analyze the profiled workload:

```
$ omniperf analyze –p workloads/vcopy_all/mi200/ &> vcopy_analyze.txt
```

0. Top Stat

	KernelName	Count	Sum(ns)	Mean(ns)	Median(ns)	Pct
0	vecCopy(double*, double*, double*, int, int) [clone .kd]	1	341123.00	341123.00	341123.00	100.0

2. System Speed-of-Light

Index	Metric	Value	Unit	Peak	PoP
2.1.0	VALU FLOPs	0.00	Gflop	23936.0	0.0
2.1.1	VALU IOPs	89.14	Giop	23936.0	0.37242200388114116
2.1.2	MFMA FLOPs (BF16)	0.00	Gflop	95744.0	0.0
2.1.3	MFMA FLOPs (F16)	0.00	Gflop	191488.0	0.0
2.1.4	MFMA FLOPs (F32)	0.00	Gflop	47872.0	0.0
2.1.5	MFMA FLOPs (F64)	0.00	Gflop	47872.0	0.0
2.1.6	MFMA IOPs (Int8)	0.00	Giop	191488.0	0.0
2.1.7	Active CUs	58.00	Cus	110	52.72727272727273
2.1.8	SALU Util	3.69	Pct	100	3.6862586934167525
2.1.9	VALU Util	5.90	Pct	100	5.895531580380328
2.1.10	MFMA Util	0.00	Pct	100	0.0
2.1.11	VALU Active Threads/Wave	32.71	Threads	64	51.10526315789473
2.1.12	IPC - Issue	0.08	Instr/cycle	5	10.576640831030312

7.1 Wavefront Launch Stats

Index	Metric	Avg	Min	Max	Unit
7.1.0	Grid Size	1048576.00	1048576.00	1048576.00	Work items
7.1.1	Workgroup Size	256.00	256.00	256.00	Work items
7.1.2	Total Wavefronts	16384.00	16384.00	16384.00	Wavefronts
7.1.3	Saved Wavefronts	0.00	0.00	0.00	Wavefronts
7.1.4	Restored Wavefronts	0.00	0.00	0.00	Wavefronts
7.1.5	VGPRs	44.00	44.00	44.00	Registers
7.1.6	SGPRs	48.00	48.00	48.00	Registers
7.1.7	LDS Allocation	0.00	0.00	0.00	Bytes
7.1.8	Scratch Allocation	16496.00	16496.00	16496.00	Bytes

Omniperf Analyze

- Execute omniperf analyze –h to see various options
- Use specific IP block (-b) Example: -b 0 shows the Top Stat block shown below

Top kernels:

```
$ srun -n 1 --gpus 1 omniperf analyze -p workloads/vcopy_all/mi200/ -b 0
```

IP Block of wavefronts

```
$ srun -n 1 --gpus 1 omniperf analyze -p workloads/vcopy_all/mi200/ -b 7.1.2
```

```
--------------------------------------------------------------------------------
0. Top Stat
```

	KernelName	Count	Sum(ns)	Mean(ns)	Median(ns)	Pct
0	vecCopy(double*, double*, double*, int, int) [clone .kd]	1	20960.00	20960.00	20960.00	100.00

```
--------------------------------------------------------------------------------
7. Wavefront
7.1 Wavefront Launch Stats
```

Index	Metric	Avg	Min	Max	Unit
7.1.2	Total Wavefronts	16384.00	16384.00	16384.00	Wavefronts

Omniperf analyze

To see available options and usage instructions:

```
 $ omniperf analyze -h
...

Help:
  -h, --help                    show this help message and exit

General Options:
  -v, --version                 show program's version number and exit
  -V, --verbose                 Increase output verbosity

Analyze Options:
  -p  [ ...], --path  [ ...]                Specify the raw data root dirs or desired results directory.
  -o , --output                             Specify the output file.
  --list-kernels                            List kernels. Top 10 kernels sorted by duration (descending order).
  --list-metrics                            List metrics can be customized to analyze on specific arch:
                                               gfx906
                                               gfx908
                                               gfx90a
  -b  [ ...], --metric  [ ...]              Specify IP block/metric id(s) from --list-metrics for filtering.
  -k  [ ...], --kernel  [ ...]              Specify kernel id(s) from --list-kernels for filtering.
  --dispatch  [ ...]                        Specify dispatch id(s) for filtering.
  --gpu-id  [ ...]                          Specify GPU id(s) for filtering.
  -n , --normal-unit                        Specify the normalization unit: (DEFAULT: per_wave)
                                               per_wave
                                               per_cycle
                                               per_second
                                               per_kernel
  --config-dir                              Specify the directory of customized configs.
  -t , --time-unit                          Specify display time unit in kernel top stats: (DEFAULT: ns)
                                               s
                                               ms
                                               us
                                               ns
  --decimal                                 Specify the decimal to display. (DEFAULT: 2)
  --cols  [ ...]                            Specify column indices to display.
  -g                                        Debug single metric.
  --dependency                              List the installation dependency.
  --gui [GUI]                               Activate a GUI to interate with Omniperf metrics.
                                            Optionally, specify port to launch application (DEFAULT: 8050)
```

Easy things you can check

- Are all the CUs being used?
  - If not, more parallelism is required (for most of the cases)
- Are all the VGPRs being spilled?
  - Try smaller workgroup sizes
- Is the code Integer limited?
  - Try reducing the integer ops, usually in the index calculation

Omniperf analyze with standalone GUI

We use the example sample/vcopy.cpp from the Omniperf installation folder:

```
$ wget https://github.com/AMDResearch/omniperf/raw/main/sample/vcopy.cpp
```

Compile with hipcc:

```
$ hipcc –o vcopy vcopy.cpp
```

Profile with Omniperf:

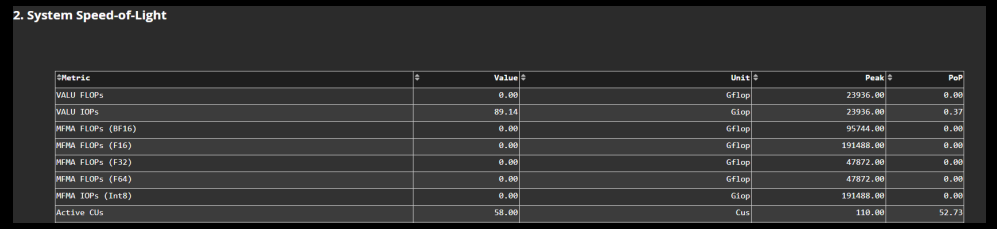
```
$ omniperf profile –n vcopy_all -- ./vcopy 1048576 256
```

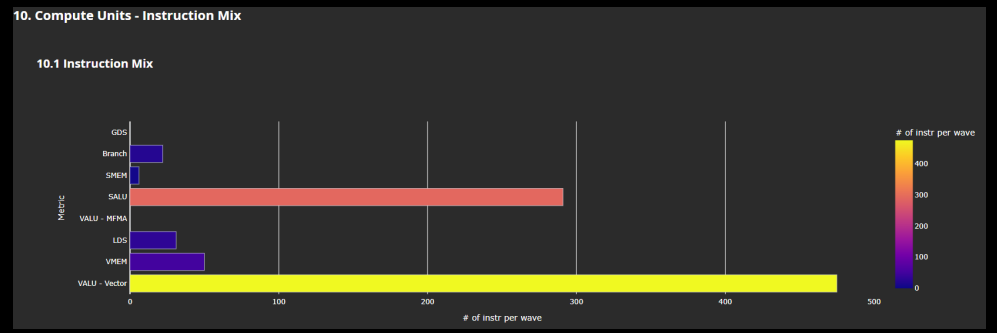
A new directory will be created called `workloads/vcopy_all`

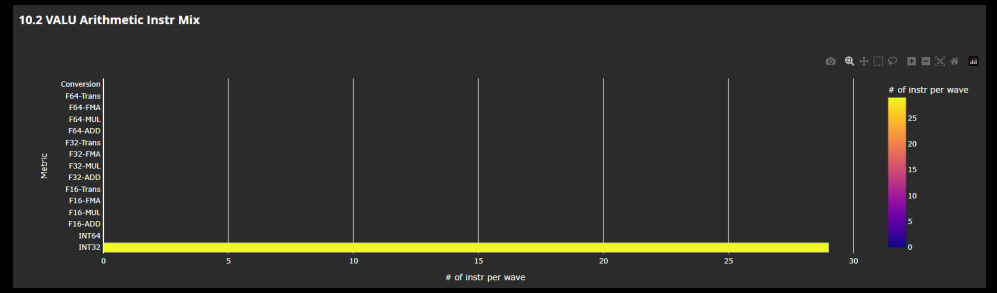
Analyze the profiled workload:

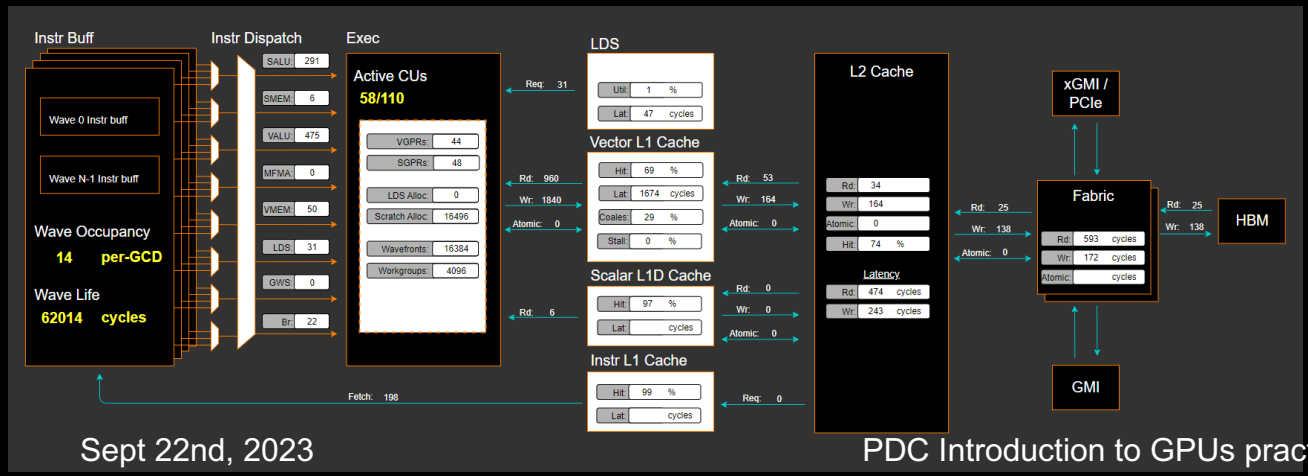
```
$ omniperf analyze –p workloads/vcopy_all/mi200/ --gui
```

Open web page http://IP:8050/









Omniperf analyze with Grafana™ GUI

We use the example sample/vcopy.cpp from the Omniperf installation folder:

```
$ wget https://github.com/AMDResearch/omniperf/raw/main/sample/vcopy.cpp
```

Compile with hipcc:

```
$ hipcc –o vcopy vcopy.cpp
```

Profile with Omniperf:

```
$ omniperf profile –n vcopy_all -- ./vcopy 1048576 256
```

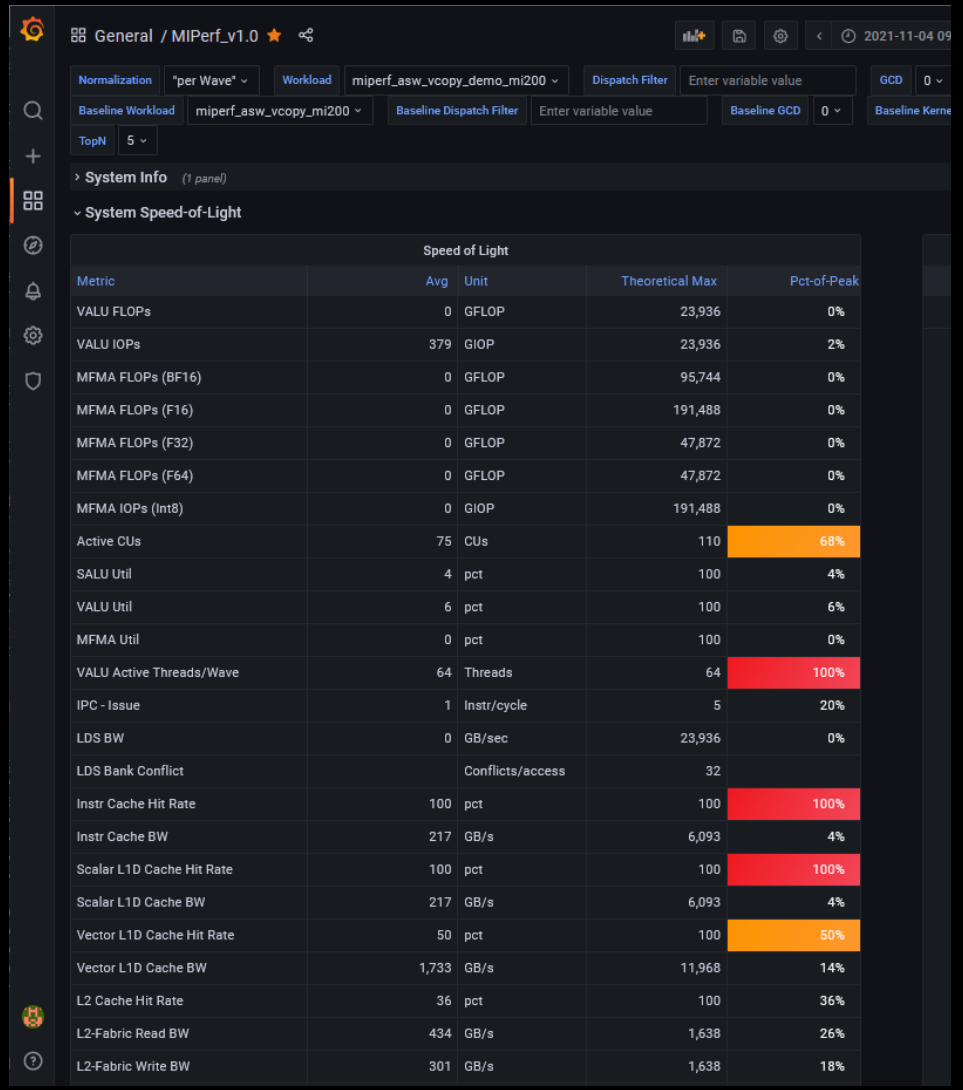
A new directory will be created called `workloads/vcopy_all`

Import the database to analyze in Grafana™ GUI:

```
$ omniperf database --import [connection options] -w workloads/vcopy_demo/mi200/
ROC Profiler:  /usr/bin/rocprof

--------
Import Profiling Results
--------

Pulling data from  /root/test/workloads/vcopy_demo/mi200
The directory exists
Found sysinfo file
KernelName shortening enabled
Kernel name verbose level: 2
Password:
Password recieved
-- Conversion & Upload in Progress –
… …
9 collections added.
Workload name uploaded
-- Complete! --
```



Speed of Light

Metric	Avg	Unit	Theoretical Max	Pct-of-Peak
VALU FLOPs	0	GFLOP	23,936	0%
VALU IOPs	379	GIOP	23,936	2%
MFMA FLOPs (BF16)	0	GFLOP	95,744	0%
MFMA FLOPs (F16)	0	GFLOP	191,488	0%
MFMA FLOPs (F32)	0	GFLOP	47,872	0%
MFMA FLOPs (F64)	0	GFLOP	47,872	0%
MFMA IOPs (Int8)	0	GIOP	191,488	0%
Active CUs	75	CUs	110	68%
SALU Util	4	pct	100	4%
VALU Util	6	pct	100	6%
MFMA Util	0	pct	100	0%
VALU Active Threads/Wave	64	Threads	64	100%
IPC - Issue	1	Instr/cycle	5	20%
LDS BW	0	GB/sec	23,936	0%
LDS Bank Conflict		Conflicts/access	32	
Instr Cache Hit Rate	100	pct	100	100%
Instr Cache BW	217	GB/s	6,093	4%
Scalar L1D Cache Hit Rate	100	pct	100	100%
Scalar L1D Cache BW	217	GB/s	6,093	4%
Vector L1D Cache Hit Rate	50	pct	100	50%
Vector L1D Cache BW	1,733	GB/s	11,968	14%
L2 Cache Hit Rate	36	pct	100	36%
L2-Fabric Read BW	434	GB/s	1,638	26%
L2-Fabric Write BW	301	GB/s	1,638	18%

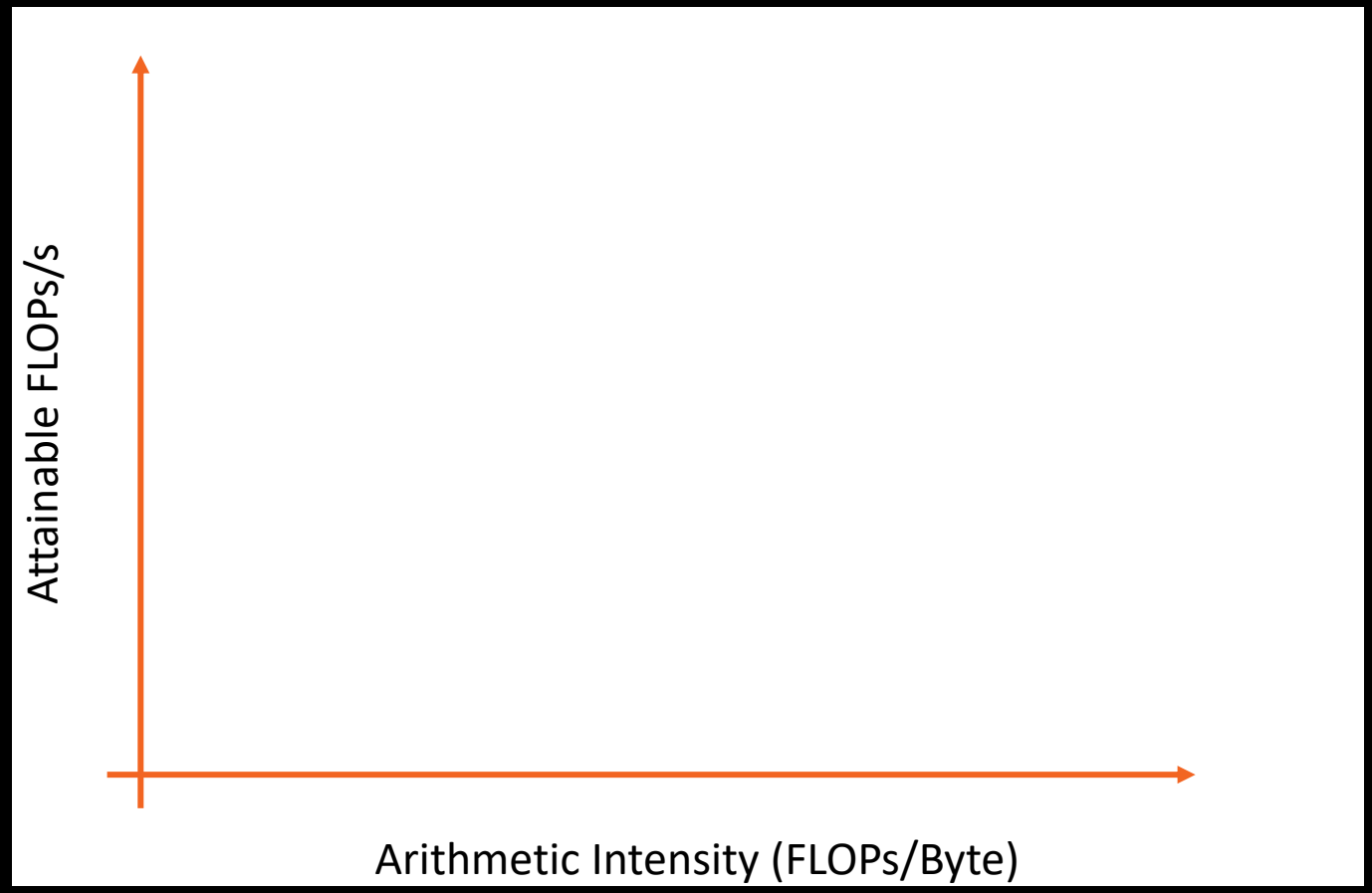
Background - What is a roofline?

Background – What is Roofline

- Attainable FLOPs/s
  - FLOPs/s rate as measured empirically on a given device
  - FLOP = floating point operation
  - FLOP counts for common operations
    - Add: 1 FLOP
    - Mul: 1 FLOP
    - FMA: 2 FLOP
  - FLOPs/s = Number of floating-point operations performed per second

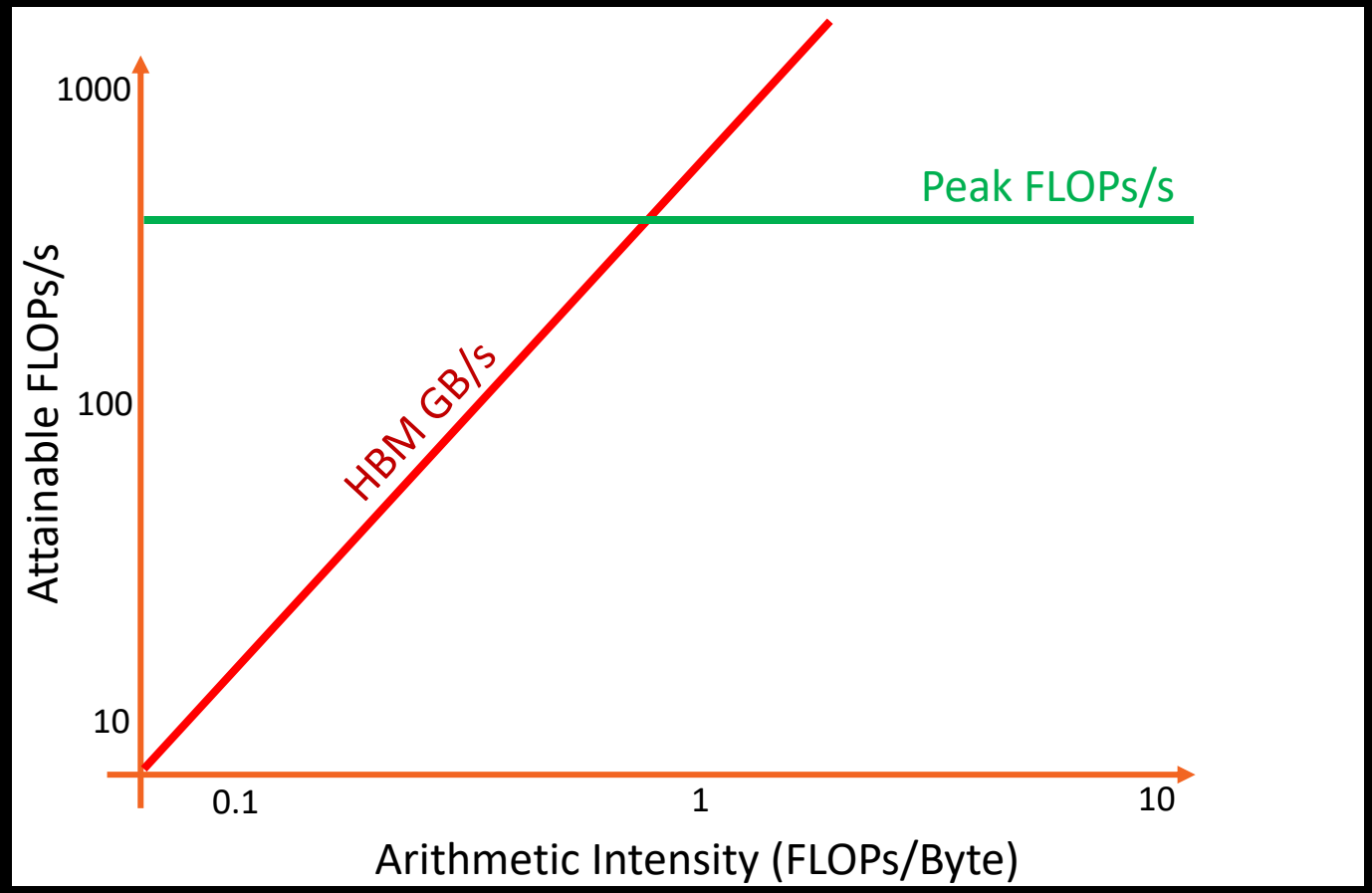
Background – What is Roofline

- Arithmetic Intensity (AI)
  - characteristic of the workload indicating how much compute (FLOPs) is performed per unit of data movement (Byte)
  - Ex: x[i] = y[i] + c
    - FLOPs = 1
    - Bytes = 1xRD + 1xWR = 4 + 4 = 8
    - AI = 1 / 8



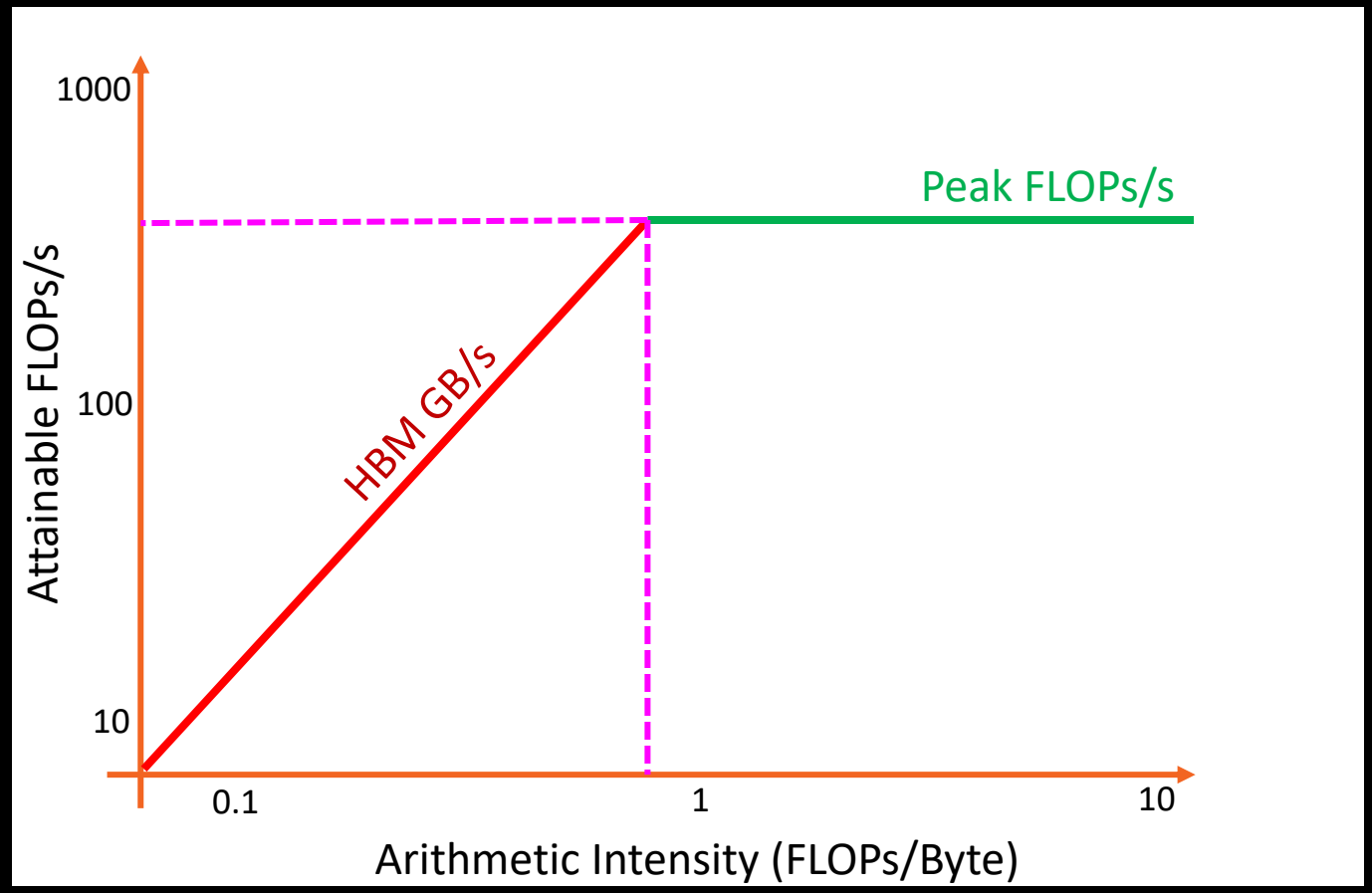
Background – What is Roofline

- Roofline Limiters
  - Compute
    - Peak FLOPs/s
  - Memory BW
    - AI * Peak GB/s
- Note:
  - These are empirically measured values
  - Different SKUs will have unique plots
  - Individual devices within a SKU will have slightly different plots based on thermal solution, system power, etc.
  - Omniperf uses suite of simple kernels to empirically derive these values
  - These are NOT theoretical values indicating peak performance under “unicorn” conditions



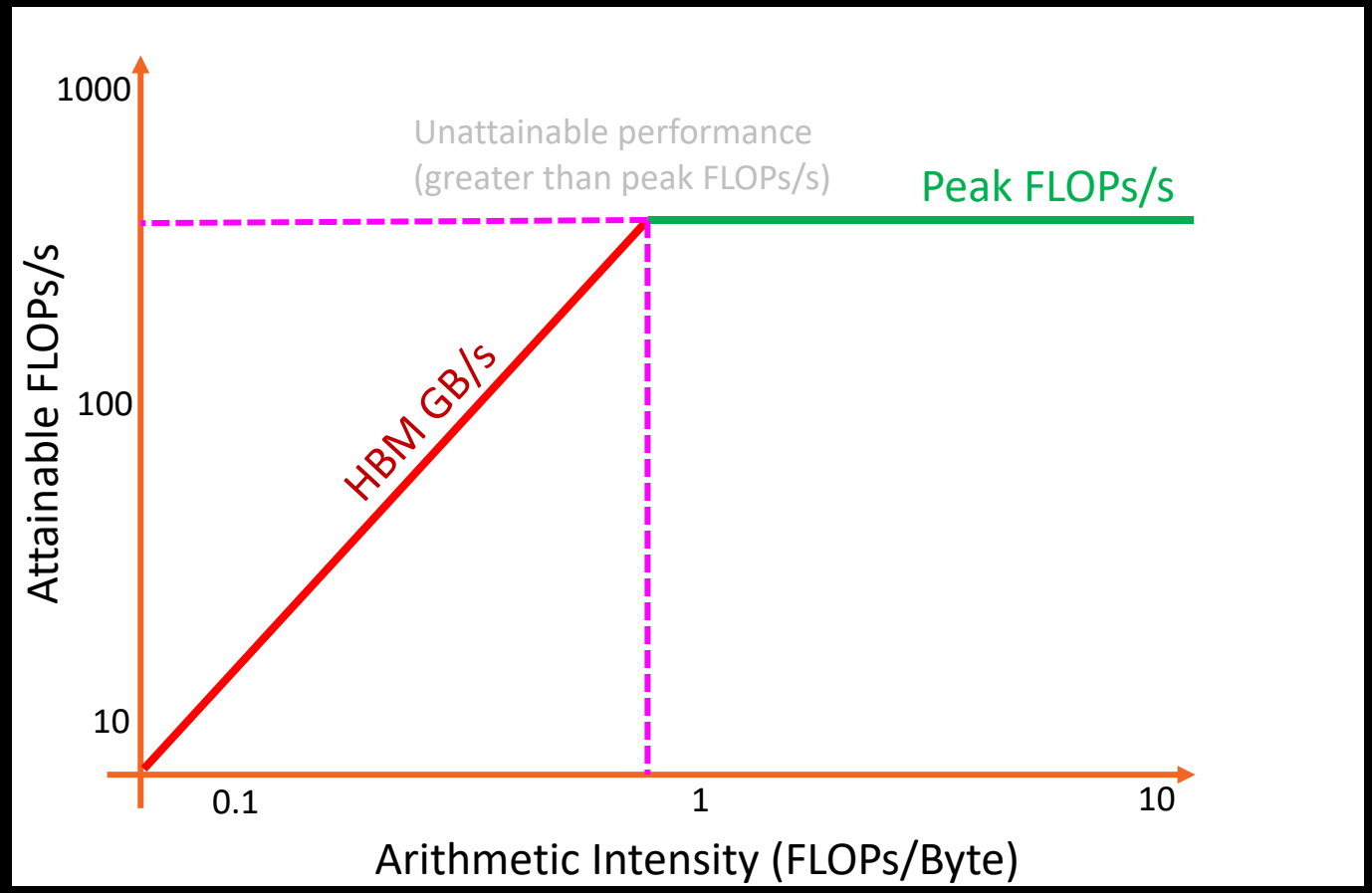
Background – What is Roofline

- Attainable FLOPs/s =
  - $min \begin{cases} Peak\ FLOPs/s \\ AI * Peak\ GB/s \end{cases}$
- Machine Balance:
  - Where $AI = \frac{Peak\ FLOPs/s}{Peak\ GB/s}$
  - Typical machine balance: 5-10 FLOPs/B
    - **40-80** FLOPs per double to exploit compute capability
  - MI250x machine balance: ~16 FLOPs/B
    - **128** FLOPs per double to exploit compute capability



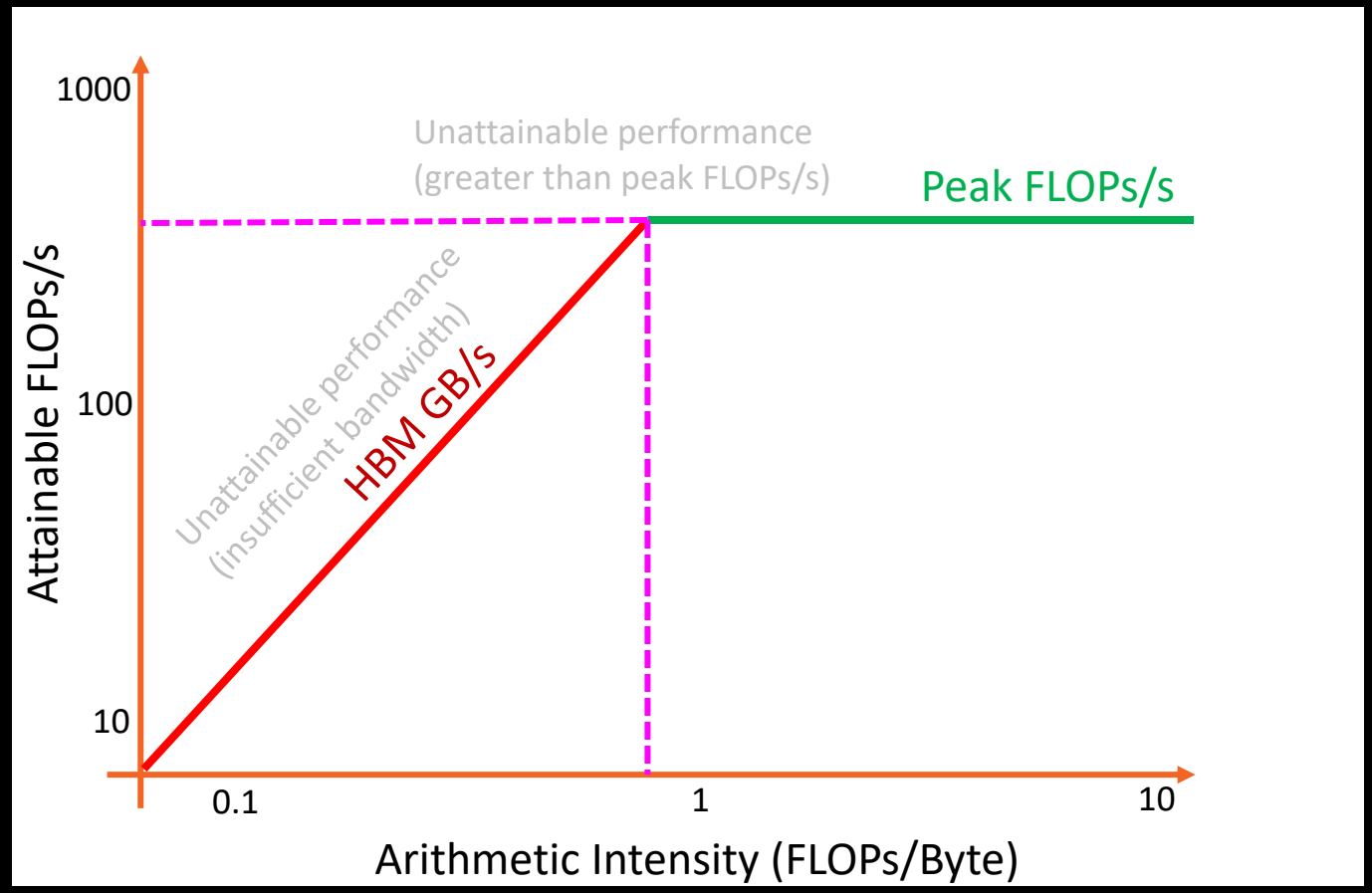
Background – What is Roofline

- Attainable FLOPs/s =
  - $min \begin{cases} Peak\ FLOPs/s \\ AI * Peak\ GB/s \end{cases}$
- Machine Balance:
  - Where $AI = \frac{Peak\ FLOPs/s}{Peak\ GB/s}$
- Five Performance Regions:
  - Unattainable Compute



Background – What is Roofline

- Attainable FLOPs/s =
  - $min \begin{cases} Peak\ FLOPs/s \\ AI * Peak\ GB/s \end{cases}$
- Machine Balance:
  - Where $AI = \frac{Peak\ FLOPs/s}{Peak\ GB/s}$
- Five Performance Regions:
  - Unattainable Compute
  - Unattainable Bandwidth



Note:

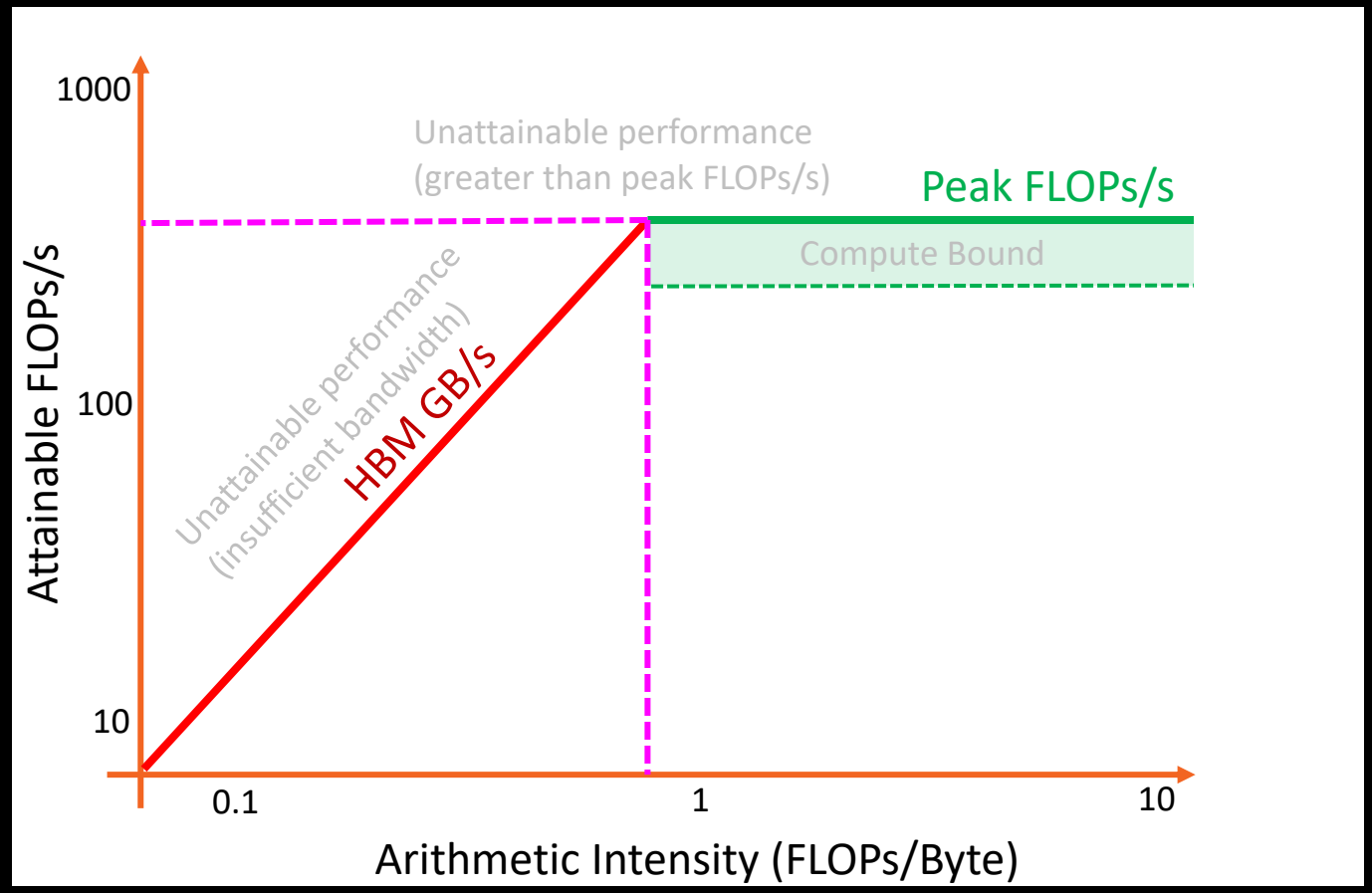
FLOP: Floating Point Operation

FLOPs: plural

FLOPS: Floating Point Operations per Second (alternately FLOPs/s)

Background – What is Roofline

- Attainable FLOPs/s =
  - $min \begin{cases} Peak\ FLOPs/s \\ AI * Peak\ GB/s \end{cases}$
- Machine Balance:
  - Where $AI = \frac{Peak\ FLOPs/s}{Peak\ GB/s}$
- Five Performance Regions:
  - Unattainable Compute
  - Unattainable Bandwidth
  - Compute Bound



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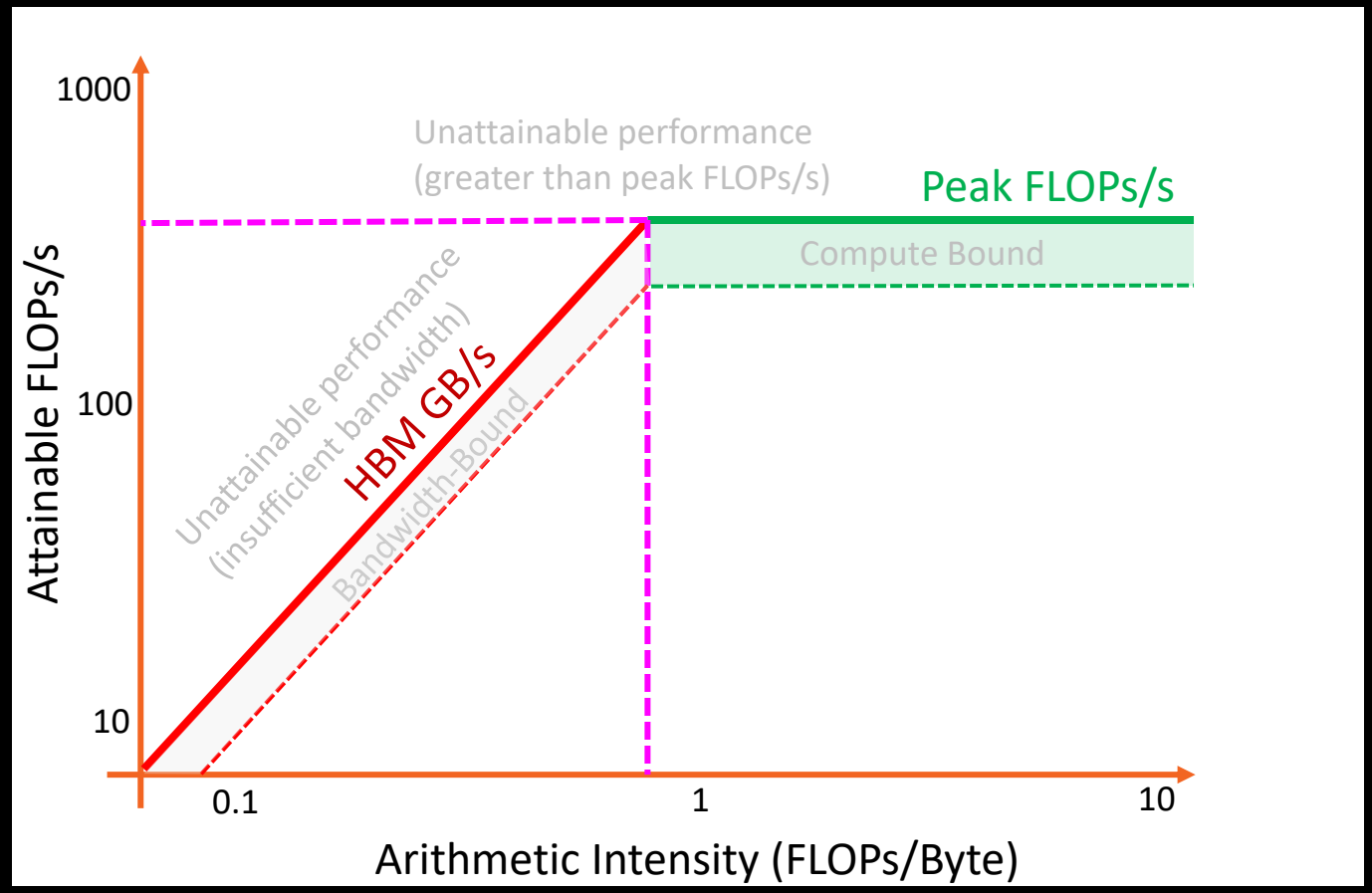
  - Unattainable Bandwidth
  - Compute Bound
  - Bandwidth Bound



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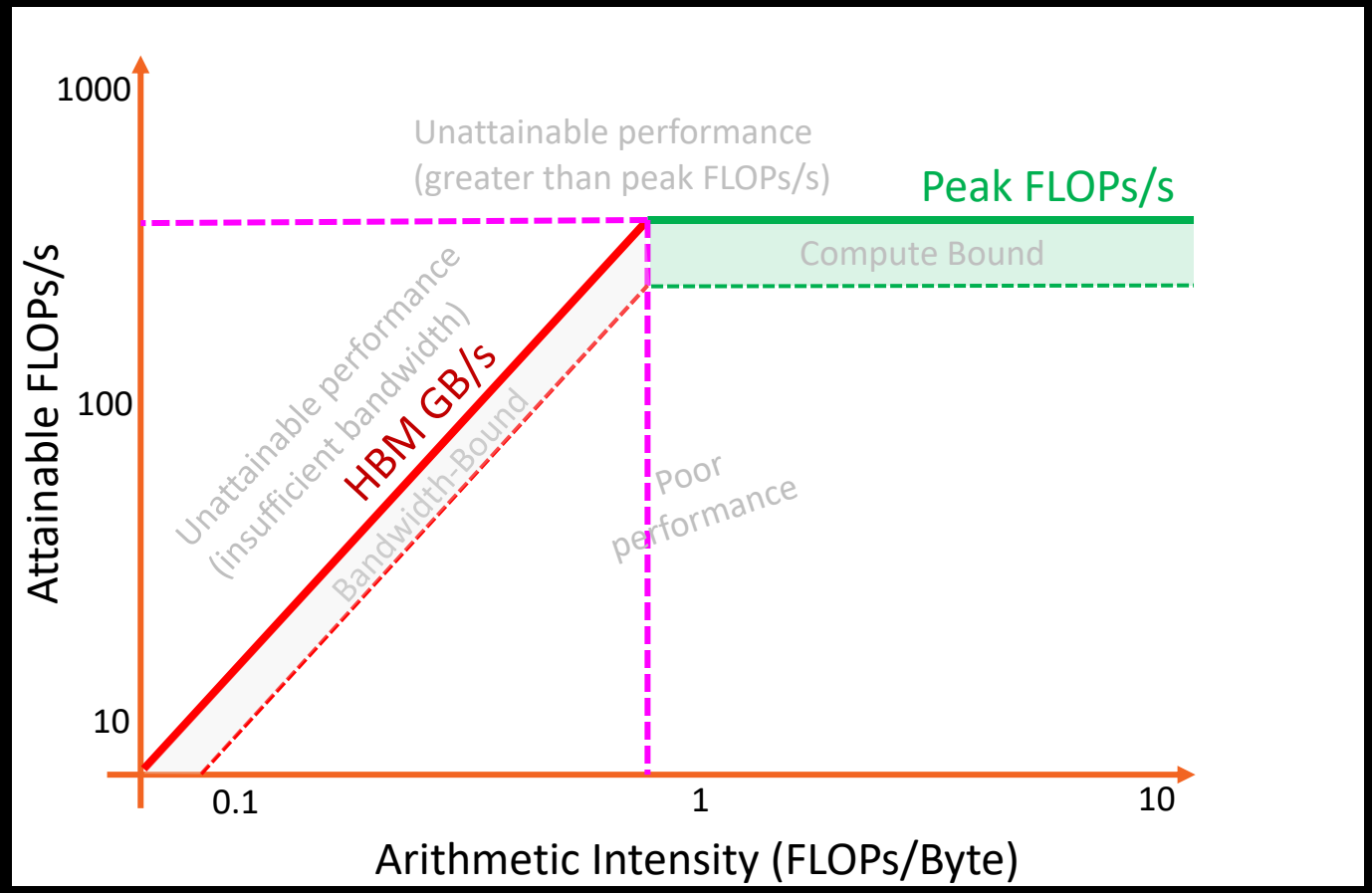
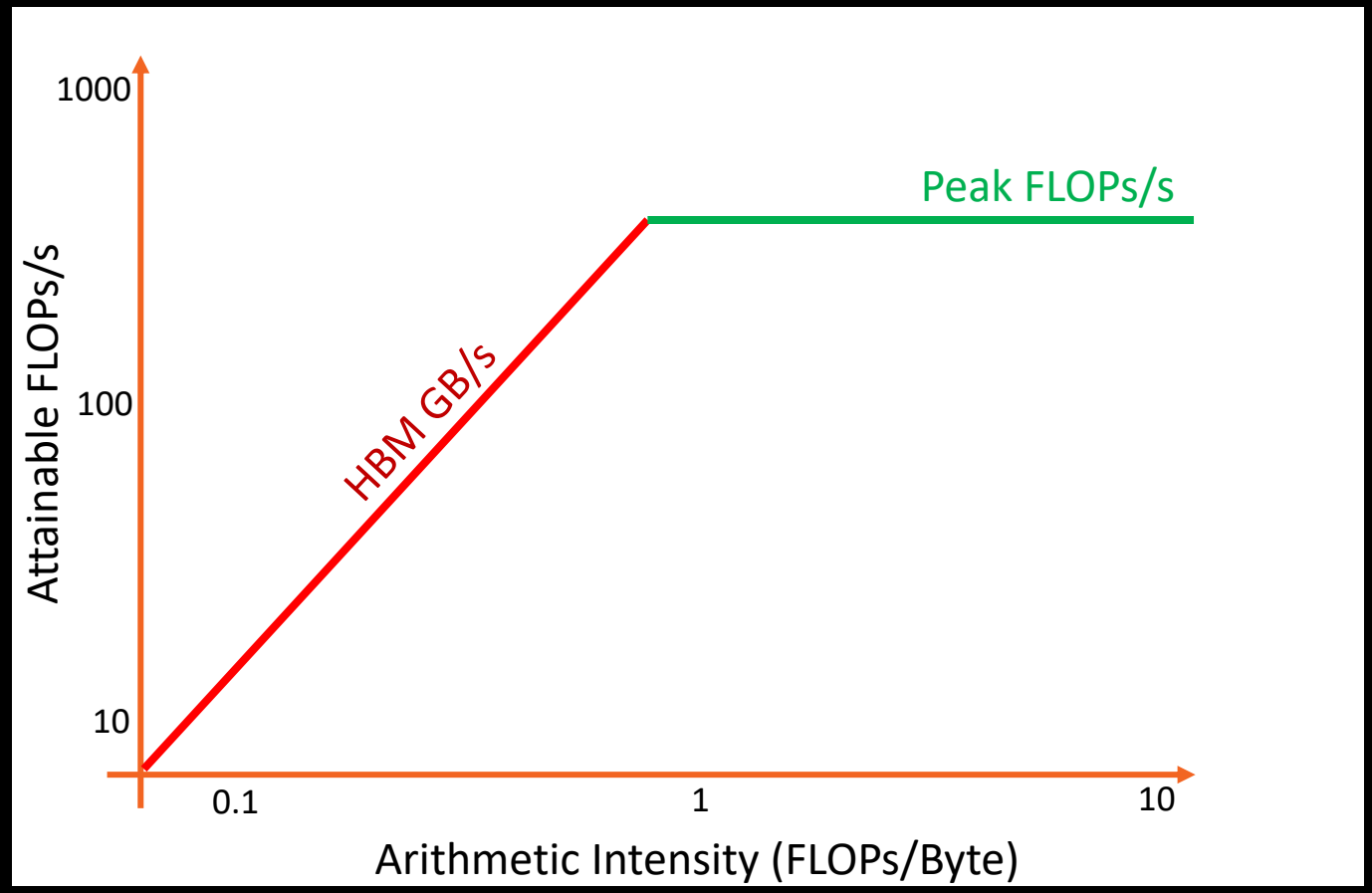
- Machine Balance:
  - Where $AI = \frac{Peak\ FLOPs/s}{Peak\ GB/s}$
- Five Performance Regions:
  - Unattainable Compute
  - Unattainable Bandwidth
  - Compute Bound
  - Bandwidth Bound
  - Poor Performance



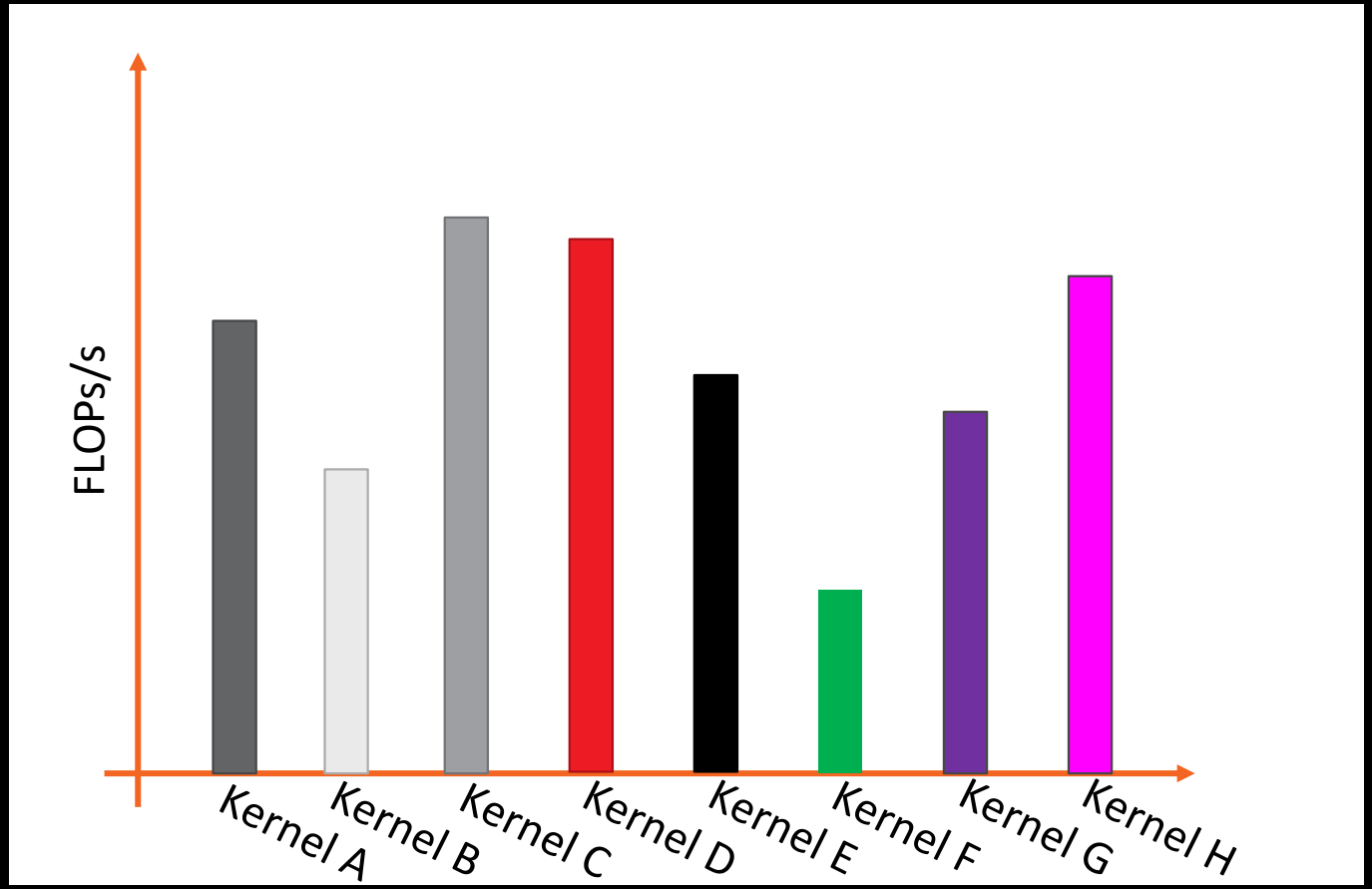
Background – What is Roofline

- Attainable FLOPs/s =
  - $min \begin{cases} Peak\ FLOPs/s \\ AI * Peak\ GB/s \end{cases}$
- Final result is a single roofline plot presenting the peak attainable performance (in terms of FLOPs/s) on a given device based on the arithmetic intensity of any potential workload
- We have an application independent way of measuring and comparing performance on any platform



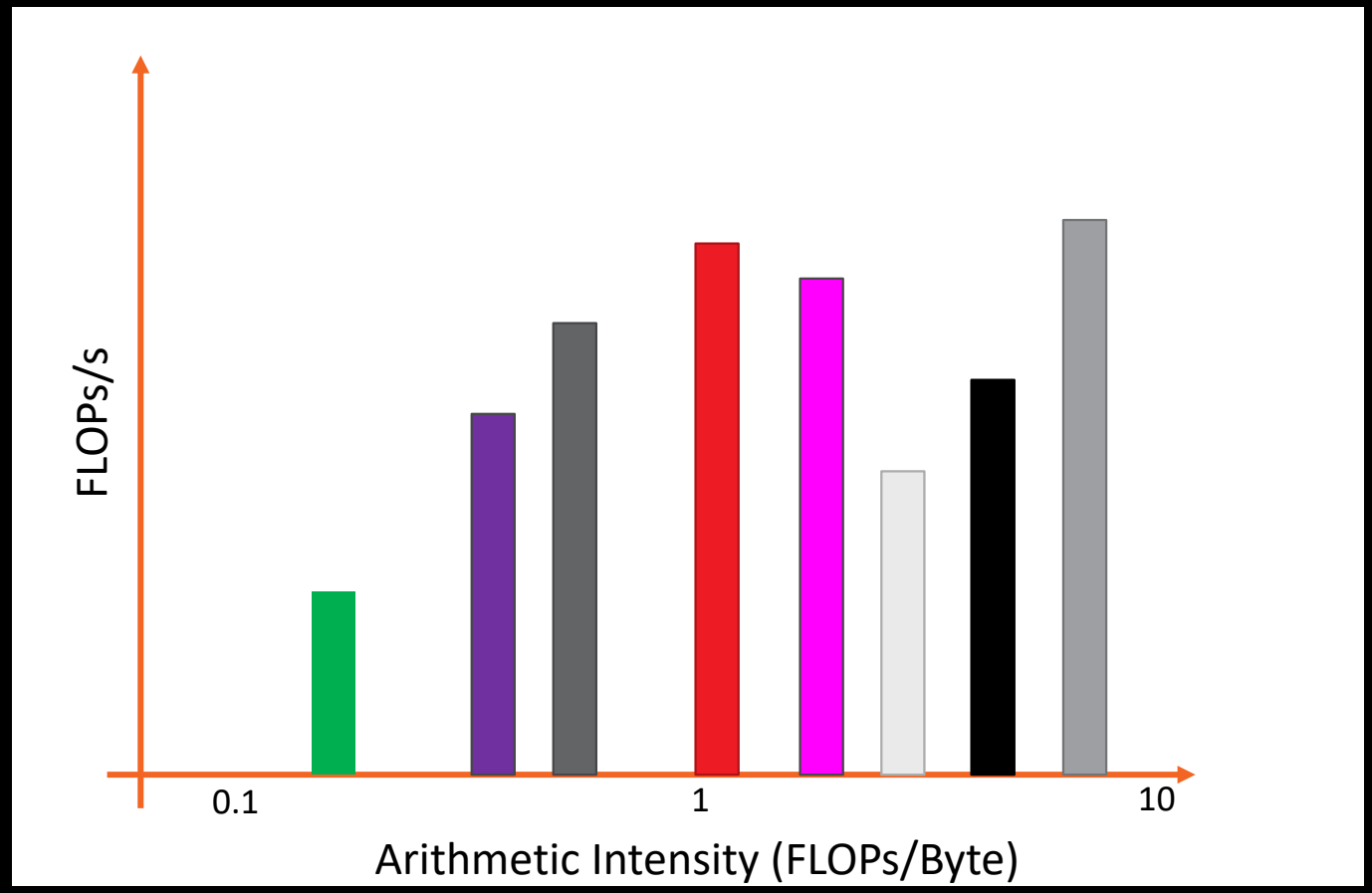
Background – What is “Good” Performance?

- Example:
  - We run a number of kernels and measure FLOPs/s



Background – What is “Good” Performance?

- Example:
  - We run a number of kernels and measure FLOPs/s
  - Sort kernels by arithmetic intensity



Background – What is “Good” Performance?

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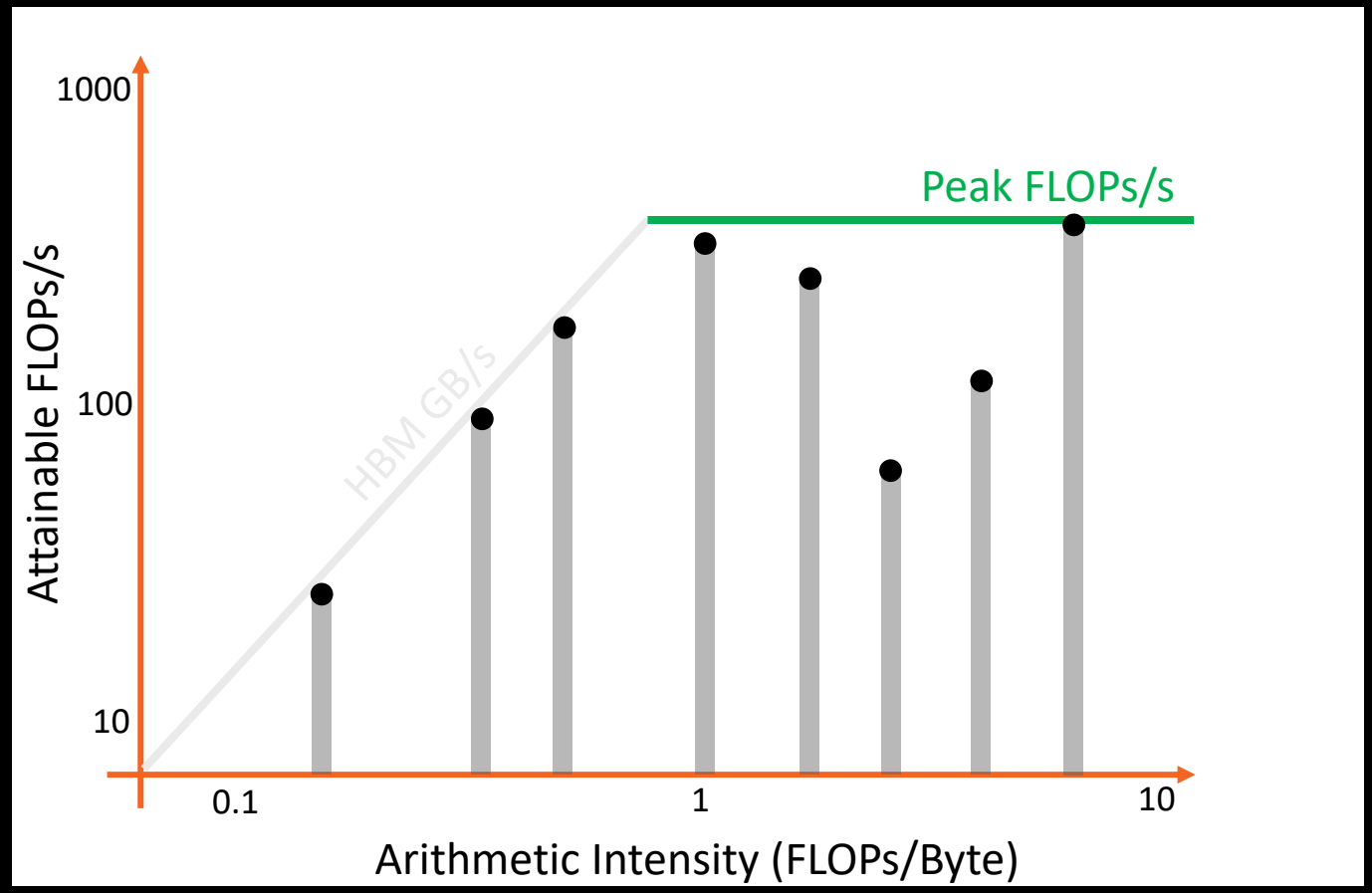
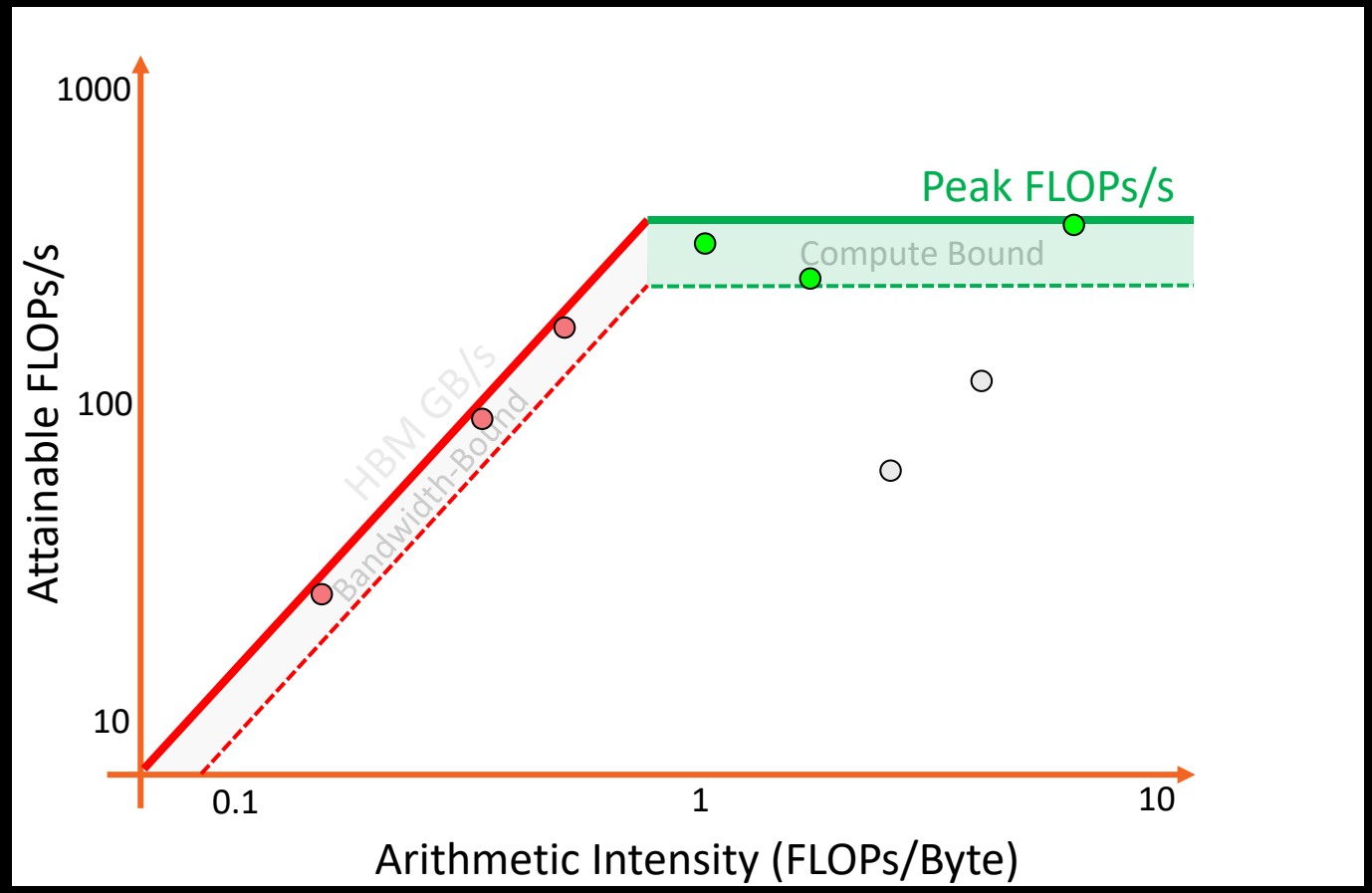
  - We run a number of kernels and measure FLOPs/s
  - Sort kernels by arithmetic intensity
  - Compare performance relative to hardware capabilities



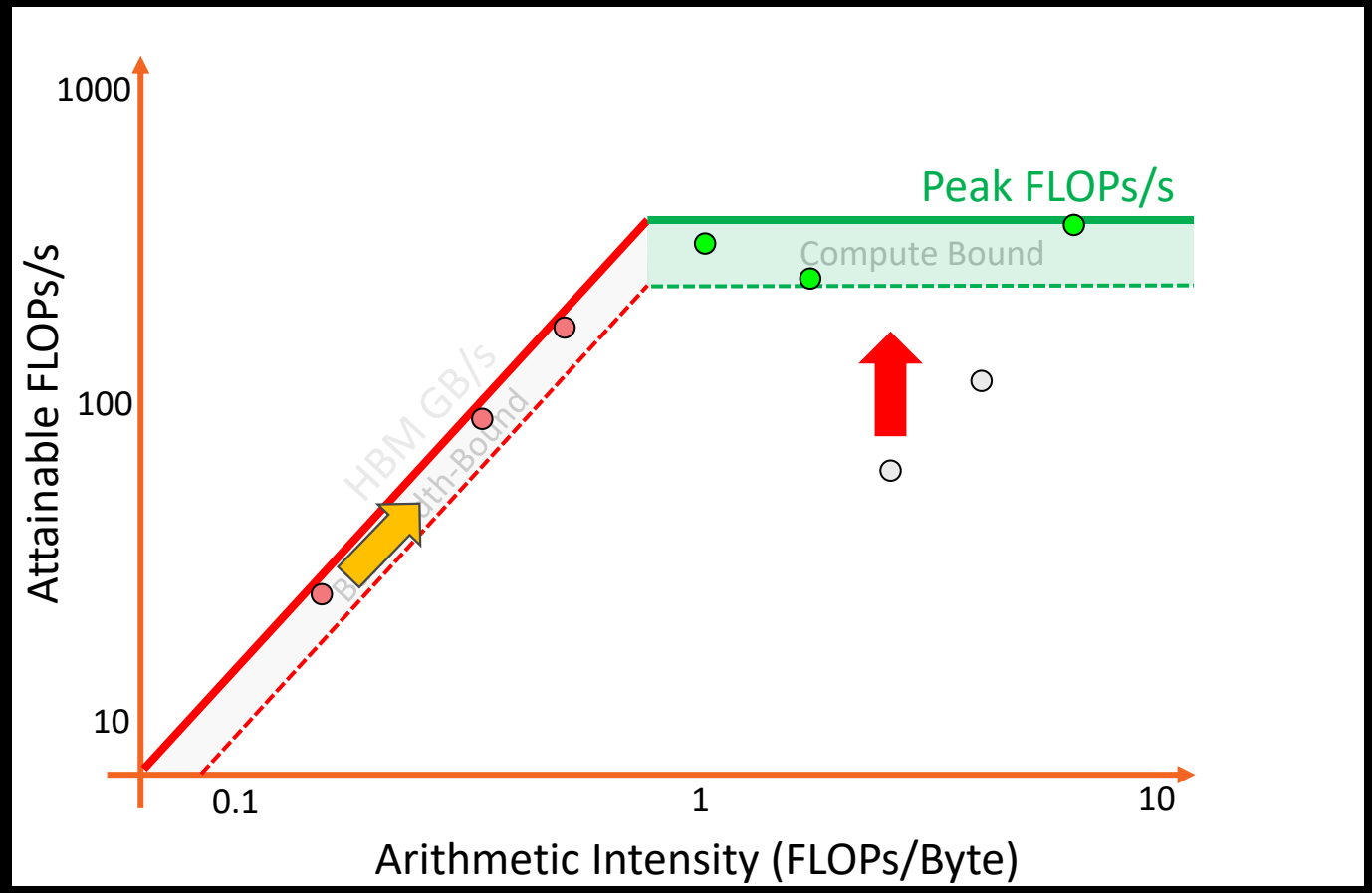
Background – What is “Good” Performance?

- Example:
  - We run a number of kernels and measure FLOPs/s
  - Sort kernels by arithmetic intensity
  - Compare performance relative to hardware capabilities
  - Kernels near the roofline are making good use of computational resources
    - Kernels can have low performance (FLOPS/s), but make good use of BW



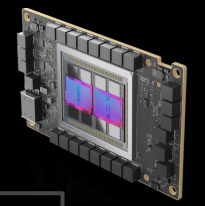
Background – What is “Good” Performance?

- Example:
  - We run a number of kernels and measure FLOPs/s
  - Sort kernels by arithmetic intensity
  - Compare performance relative to hardware capabilities
  - Kernels near the roofline are making good use of computational resources
    - Kernels can have low performance (FLOPS/s), but make good use of BW
  - Increase arithmetic intensity when bandwidth limited
    - Reducing data movement increases AI
  - Kernels not near the roofline *should** have optimizations that can be made to get closer to the roofline



Roofline Calculations on AMD Instinct™ MI200 GPUs

Overview - AMD Instinct™ MI200 Architecture



Graphics Compute Die (GCD)

Compute Unit
Local Data Share (LDS)
Scalar Unit | SIMD0 | SIMD1 | SIMD2 | SIMD3
SGPR | VGPR | VGPR | VGPR | VGPR
Vector L1 Data Cache (vL1D)

Compute Unit
Local Data Share (LDS)
Scalar Unit | SIMD0 | SIMD1 | SIMD2 | SIMD3
SGPR | VGPR | VGPR | VGPR | VGPR
Vector L1 Data Cache (vL1D)

... ...

Compute Unit
Local Data Share (LDS)
Scalar Unit | SIMD0 | SIMD1 | SIMD2 | SIMD3
SGPR | VGPR | VGPR | VGPR | VGPR
Vector L1 Data Cache (vL1D)

L2 Cache (L2)

(Peer GCD)

Data Fabric

Remote Socket (CPU, GPU)

Memory Controller

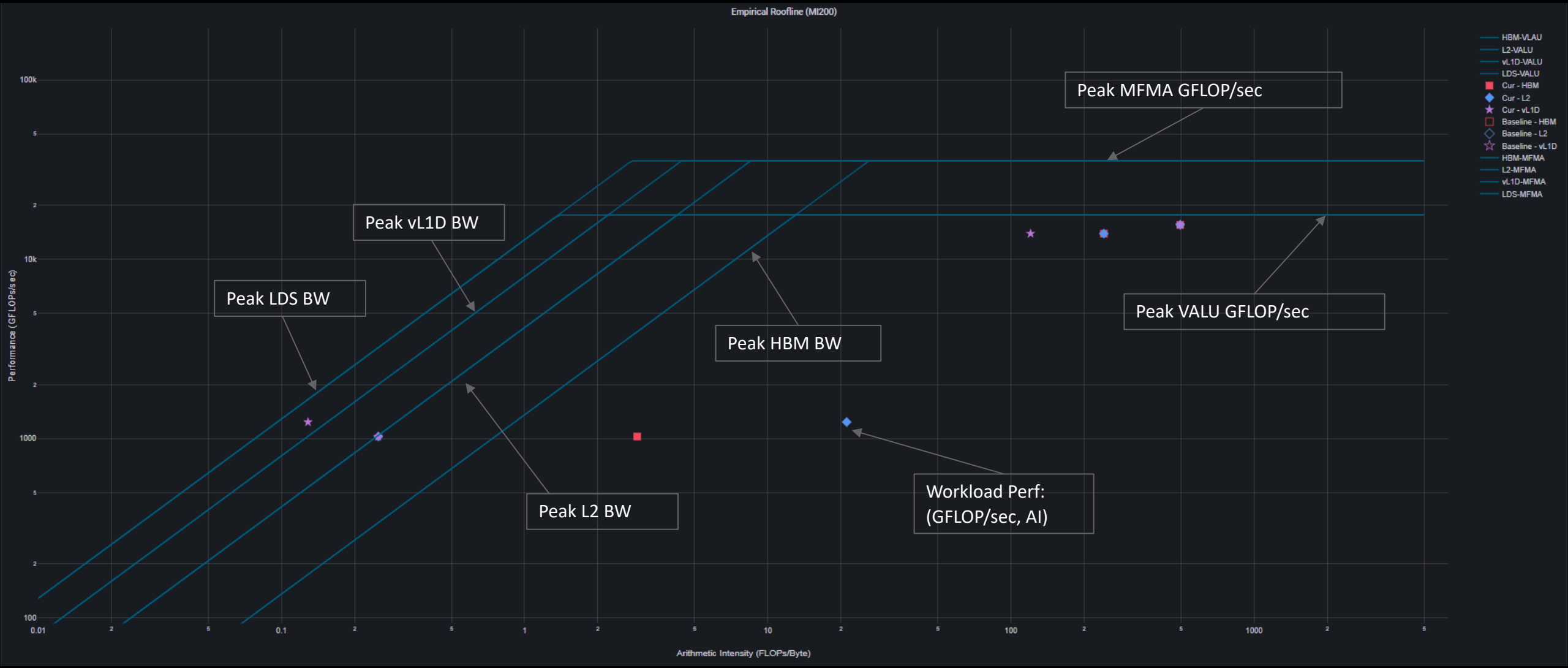
(GCD1)

(GCD2)

HBM Memory

HBM Memory

Empirical Hierarchical Roofline on MI200 - Overview



Empirical Hierarchical Roofline on MI200 – Roofline Benchmarking

- Empirical Roofline Benchmarking
  - Measure achievable Peak FLOPS
    - VALU: F32, F64
    - MFMA: F16, BF16, F32, F64
  - Measure achievable Peak BW
    - LDS
    - Vector L1D Cache
    - L2 Cache
    - HBM

```
10:57:35 amd@node-bp126-014a utils ±|master ✗|→ ./roofline
Total detected GPU devices: 2
GPU Device 0: Profiling...
 99% [|||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||| ]
HBM BW, GPU ID: 0, workgroupSize:256, workgroups:2097152, experiments:100, Total Bytes=8589934592, Duration=6.2 ms, Mean=1382.7 GB/sec, stdev=2.6 GB/s
 99% [|||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||| ]
L2 BW, GPU ID: 0, workgroupSize:256, workgroups:8192, experiments:100, Total Bytes=687194767360, Duration=157.3 ms, Mean=4321.3 GB/sec, stdev=59.1 GB/s
 99% [|||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||| ]
L1 BW, GPU ID: 0, workgroupSize:256, workgroups:16384, experiments:100, Total Bytes=26843545600, Duration=3.3 ms, Mean=8262.6 GB/sec, stdev=5.9 GB/s
 99% [|||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||| ]
LDS BW, GPU ID: 0, workgroupSize:256, workgroups:16384, experiments:100, Total Bytes=33554432000, Duration=1.8 ms, Mean=18780.4 GB/sec, stdev=33.0 GB/s
nSize:134217728, 268435456000
 99% [|||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||| ]
Peak FLOPs (FP32), GPU ID: 0, workgroupSize:256, workgroups:16384, experiments:100, Total FLOPS=274877906944, Duration=14.482 ms, Mean=18977.7 GFLOPs/sec, stdev=3.6 GFLOPs/s
 99% [|||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||| ]
Peak FLOPs (FP64), GPU ID: 0, workgroupSize:256, workgroups:16384, experiments:100, Total FLOPS=137438953472, Duration=7.5 ms, Mean=18336.156250.1 GFLOPs/sec, stdev=5.0 GFLOPs/s
 99% [|||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||| ]
Peak MFMA FLOPs (BF16), GPU ID: 0, workgroupSize:256, workgroups:16384, experiments:100, Total FLOPS=2147483648000, Duration=14.0 ms, Mean=153763.7 GFLOPs/sec, stdev=61.0 GFLOPs/s
 99% [|||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||| ]
Peak MFMA FLOPs (F16), GPU ID: 0, workgroupSize:256, workgroups:16384, experiments:100, Total FLOPS=2147483648000, Duration=14.5 ms, Mean=147890.9 GFLOPs/sec, stdev=32.2 GFLOPs/s
 99% [|||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||| ]
Peak MFMA FLOPs (F32), GPU ID: 0, workgroupSize:256, workgroups:16384, experiments:100, Total FLOPS=536870912000, Duration=14.4 ms, Mean=37200.4 GFLOPs/sec, stdev=9.3 GFLOPs/s
 99% [|||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||| ]
Peak MFMA FLOPs (F64), GPU ID: 0, workgroupSize:256, workgroups:16384, experiments:100, Total FLOPS=268435456000, Duration=7.3 ms, Mean=36978.4 GFLOPs/sec, stdev=10.0 GFLOPs/s
```

- Internally developed micro benchmark algorithms
  - Peak VALU FLOP: axpy
  - Peak MFMA FLOP: Matrix multiplication based on MFMA intrinsic
  - Peak LDS/vL1D/L2 BW: Pointer chasing
  - Peak HBM BW: Streaming copy

Empirical Hierarchical Roofline on MI200 – Perfmon counters

- Weight
  - ADD: 1
  - MUL: 1
  - FMA: 2
  - Transcendental: 1
- FLOP Count
  - VALU: derived from VALU math instructions (assuming 64 active threads)
  - MFMA: count FLOP directly, in unit of 512
- Transcendental Instructions (7 in total)
  - e^x, $\log(x)$: F16, F32
  - $\frac{1}{x}$, $\sqrt{x}$, $\frac{1}{\sqrt{x}}$: F16, F32, F64
  - $\sin x$, $\cos x$: F16, F32
- Profiling Overhead
  - Require 3 application replays

v_rcp_f64_e32 v[4:5], v[2:3]
v_sin_f32_e32 v2, v2
v_cos_f32_e32 v2, v2
v_rsq_f64_e32 v[6:7], v[2:3]
v_sqrt_f32_e32 v3, v2
v_log_f32_e32 v2, v2
v_exp_f32_e32 v2, v2

ID	HW Counter	Category
1	SQ_INSTS_VALU_ADD_F16	FLOP counter
2	SQ_INSTS_VALU_MUL_F16	FLOP counter
3	SQ_INSTS_VALU_FMA_F16	FLOP counter
4	SQ_INSTS_VALU_TRANS_F16	FLOP counter
5	SQ_INSTS_VALU_ADD_F32	FLOP counter
6	SQ_INSTS_VALU_MUL_F32	FLOP counter
7	SQ_INSTS_VALU_FMA_F32	FLOP counter
8	SQ_INSTS_VALU_TRANS_F32	FLOP counter
9	SQ_INSTS_VALU_ADD_F64	FLOP counter
10	SQ_INSTS_VALU_MUL_F64	FLOP counter
11	SQ_INSTS_VALU_FMA_F64	FLOP counter
12	SQ_INSTS_VALU_TRANS_F64	FLOP counter
13	SQ_INSTS_VALU_INT32	IOP counter
14	SQ_INSTS_VALU_INT64	IOP counter
15	SQ_INSTS_VALU_MFMA_MOPS_I8	IOP counter

ID	HW Counter	Category
16	SQ_INSTS_VALU_MFMA_MOPS_F16	FLOP counter
17	SQ_INSTS_VALU_MFMA_MOPS_BF16	FLOP counter
18	SQ_INSTS_VALU_MFMA_MOPS_F32	FLOP counter
19	SQ_INSTS_VALU_MFMA_MOPS_F64	FLOP counter
20	SQ_LDS_IDX_ACTIVE	LDS Bandwidth
21	SQ_LDS_BANK_CONFLICT	LDS Bandwidth
22	TCP_TOTAL_CACHE_ACCESSES_sum	vL1D Bandwidth
23	TCP_TCC_WRITE_REQ_sum	L2 Bandwidth
24	TCP_TCC_ATOMIC_WITH_RET_REQ_sum	L2 Bandwidth
25	TCP_TCC_ATOMIC_WITHOUT_RET_REQ_sum	L2 Bandwidth
26	TCP_TCC_READ_REQ_sum	L2 Bandwidth
27	TCC_EA_RDREQ_sum	HBM Bandwidth
28	TCC_EA_RDREQ_32B_sum	HBM Bandwidth
29	TCC_EA_WRREQ_sum	HBM Bandwidth
30	TCC_EA_WRREQ_64B_sum	HBM Bandwidth

Empirical Hierarchical Roofline on MI200 - Arithmetic

$$\begin{aligned}\text{Total\_FLOP} = \quad & 64 * (\text{SQ\_INSTS\_VALU\_ADD\_F16} + \text{SQ\_INSTS\_VALU\_MUL\_F16} + \text{SQ\_INSTS\_VALU\_TRANS\_F16} + 2 * \text{SQ\_INSTS\_VALU\_FMA\_F16}) \\ & + 64 * (\text{SQ\_INSTS\_VALU\_ADD\_F32} + \text{SQ\_INSTS\_VALU\_MUL\_F32} + \text{SQ\_INSTS\_VALU\_TRANS\_F32} + 2 * \text{SQ\_INSTS\_VALU\_FMA\_F32}) \\ & + 64 * (\text{SQ\_INSTS\_VALU\_ADD\_F64} + \text{SQ\_INSTS\_VALU\_MUL\_F64} + \text{SQ\_INSTS\_VALU\_TRANS\_F64} + 2 * \text{SQ\_INSTS\_VALU\_FMA\_F64}) \\ & + 512 * \text{SQ\_INSTS\_VALU\_MFMA\_MOPS\_F16} \\ & + 512 * \text{SQ\_INSTS\_VALU\_MFMA\_MOPS\_BF16} \\ & + 512 * \text{SQ\_INSTS\_VALU\_MFMA\_MOPS\_F32} \\ & + 512 * \text{SQ\_INSTS\_VALU\_MFMA\_MOPS\_F64}\end{aligned}$$

$$\text{Total\_IOP} = 64 * (\text{SQ\_INSTS\_VALU\_INT32} + \text{SQ\_INSTS\_VALU\_INT64})$$

$$LDS_{BW} = 32 * 4 * (\text{SQ\_LDS\_IDX\_ACTIVE} - \text{SQ\_LDS\_BANK\_CONFLICT})$$

$$vL1D_{BW} = 64 * \text{TCP\_TOTAL\_CACHE\_ACCESSES\_sum}$$

$$\begin{aligned}L2_{BW} = \quad & 64 * \text{TCP\_TCC\_READ\_REQ\_sum} \\ & + 64 * \text{TCP\_TCC\_WRITE\_REQ\_sum} \\ & + 64 * (\text{TCP\_TCC\_ATOMIC\_WITH\_RET\_REQ\_sum} + \\ & \text{TCP\_TCC\_ATOMIC\_WITHOUT\_RET\_REQ\_sum})\end{aligned}$$

$$\begin{aligned}HBM_{BW} = \quad & 32 * \text{TCC\_EA\_RDREQ\_32B\_sum} + 64 * (\text{TCC\_EA\_RDREQ\_sum} - \\ & \text{TCC\_EA\_RDREQ\_32B\_sum}) \\ & + 32 * (\text{TCC\_EA\_WRREQ\_sum} - \text{TCC\_EA\_WRREQ\_64B\_sum}) + 64 * \\ & \text{TCC\_EA\_WRREQ\_64B\_sum}\end{aligned}$$

$$AI_{LDS} \frac{TOTAL\_FLOP}{LDS_{BW}}$$

$$AI_{vL1D} \frac{TOTAL\_FLOP}{vL1D_{BW}}$$

$$AI_{L2} \frac{TOTAL\_FLOP}{L2_{BW}}$$

$$AI_{HBM} = \frac{TOTAL\_FLOP}{HBM_{BW}}$$

**** All calculations are subject to change***

Empirical Hierarchical Roofline on MI200 - Manual Rocprof

- For those who like getting their hands dirty
- Generate input file
  - See example roof-counters.txt →
- Run rocprof

```
foo@bar:~$ rocprof -i roof-counters.txt --timestamp on ./myCoolApp
```

- Analyze results
  - Load *results.csv* output file in csv viewer of choice
  - Derive final metric values using equations on previous slide
- Profiling Overhead
  - Requires one application replay for each pmc line

```
## roof-counters.txt

# FP32 FLOPs
pmc: SQ_INSTS_VALU_ADD_F32 SQ_INSTS_VALU_MUL_F32 SQ_INSTS_VALU_FMA_F32 SQ_INSTS_VALU_TRANS_F32

# HBM Bandwidth
pmc: TCC_EA_RDREQ_sum TCC_EA_RDREQ_32B_sum TCC_EA_WRREQ_sum TCC_EA_WRREQ_64B_sum

# LDS Bandwidth
pmc: SQ_LDS_IDX_ACTIVE SQ_LDS_BANK_CONFLICT

# L2 Bandwidth
pmc: TCP_TCC_READ_REQ_sum TCP_TCC_WRITE_REQ_sum TCP_TCC_ATOMIC_WITH_RET_REQ_sum
TCP_TCC_ATOMIC_WITHOUT_RET_REQ_sum

# vL1D Bandwidth
pmc: TCP_TOTAL_CACHE_ACCESSES_sum
```

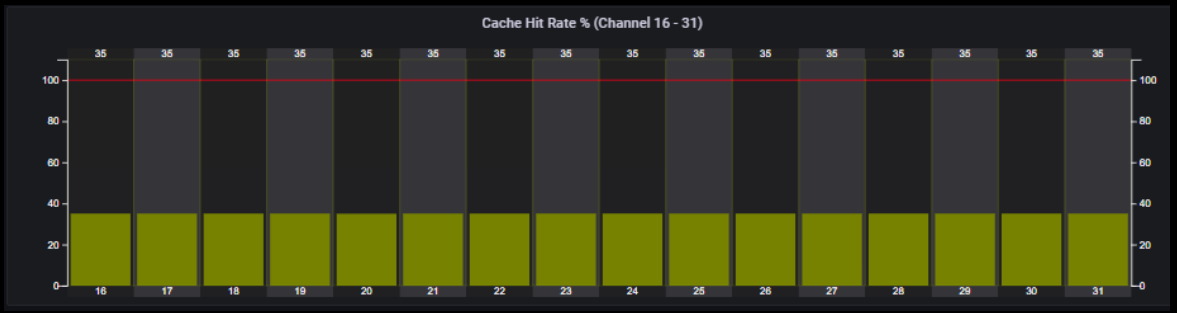
Omniperf Performance Analyzer (cont..)

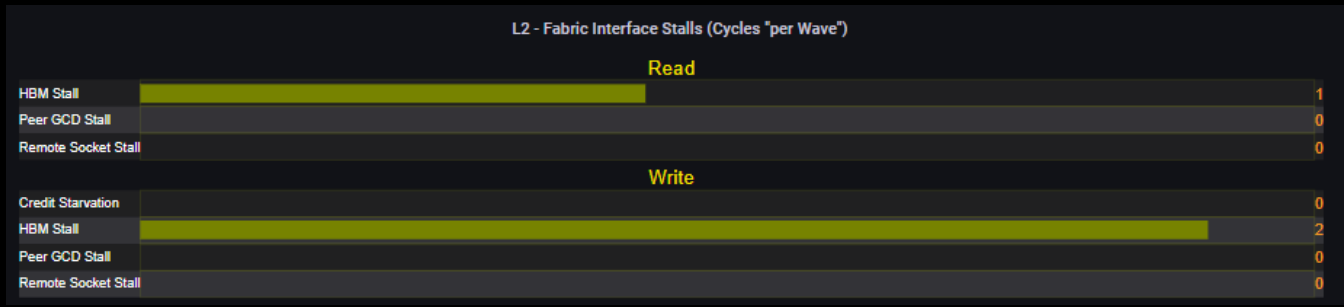
Subsystem performance analysis

Memory subsystems	L2 Cache	HBM access	LDS	vL1D
Omniperf tooling support	L2 Cache SOL	L2 fabric metrics	Per-channel statistics	

L2 - Fabric Transactions

Metric	Avg	Min	Max	Unit
Read BW	693,148,700,953	664,565,016,054	695,197,543,698	Bytes per Sec
Write BW	692,659,558,092	664,096,634,666	694,705,946,653	Bytes per Sec
Read (32B)	0	0	0	Req per Sec
Read (Uncached 32...	2,304,240	1,434,649	2,370,898	Req per Sec
Read (64B)	10,830,448,452	10,383,828,376	10,862,461,620	Req per Sec
HBM Read	10,830,362,679	10,383,764,324	10,862,381,992	Req per Sec
Write (32B)	0	0	0	Req per Sec
Write (Uncached 32...	0	0	0	Req per Sec
Write (64B)	10,822,805,595	10,376,509,917	10,854,780,416	Req per Sec
HBM Write	10,822,801,389	10,376,488,102	10,854,762,613	Req per Sec
Read Latency	739	732	801	Cycles
Write Latency	749	737	784	Cycles
Atomic Latency				Cycles
Read Stall	3	2	3	pct
Write Stall	6	5	8	pct





Shader compute components

Shader compute | Wavefront life | Instruction mix | Floating/ Integer Ops | Compute pipeline

MFMA Arithmetic Instr Mix

MFMA Instr	Count
MFMA-I8	0
MFMA-F16	0
MFMA-BF16	0
MFMA-F32	0
MFMA-F64	995

Wavefront Runtime Stats

Metric	Avg	Min	Max	Unit
Kernel Time (Nanosec)	6,197,098	6,178,719	6,463,519	ns
Kernel Time (Cycles)	9,007,899	8,905,122	9,137,368	Cycle
Instr/wavefront	18	18	18	Instr/wavefro...
Wave Cycles	3,405	3,335	3,455	Cycles/wave
Dependency Wait Cycles	3,209	3,186	3,240	Cycles/wave
Issue Wait Cycles	165	112	193	Cycles/wave
Active Cycles	64	64	64	Cycles/wave
Wavefront Occupancy	3,198	3,166	3,210	Wavefronts

Omniperf profile – Roofline only

Profile with roofline:

```
$ omniperf profile -n roofline_case_app --roof-only -- <CMD> <ARGS>
```

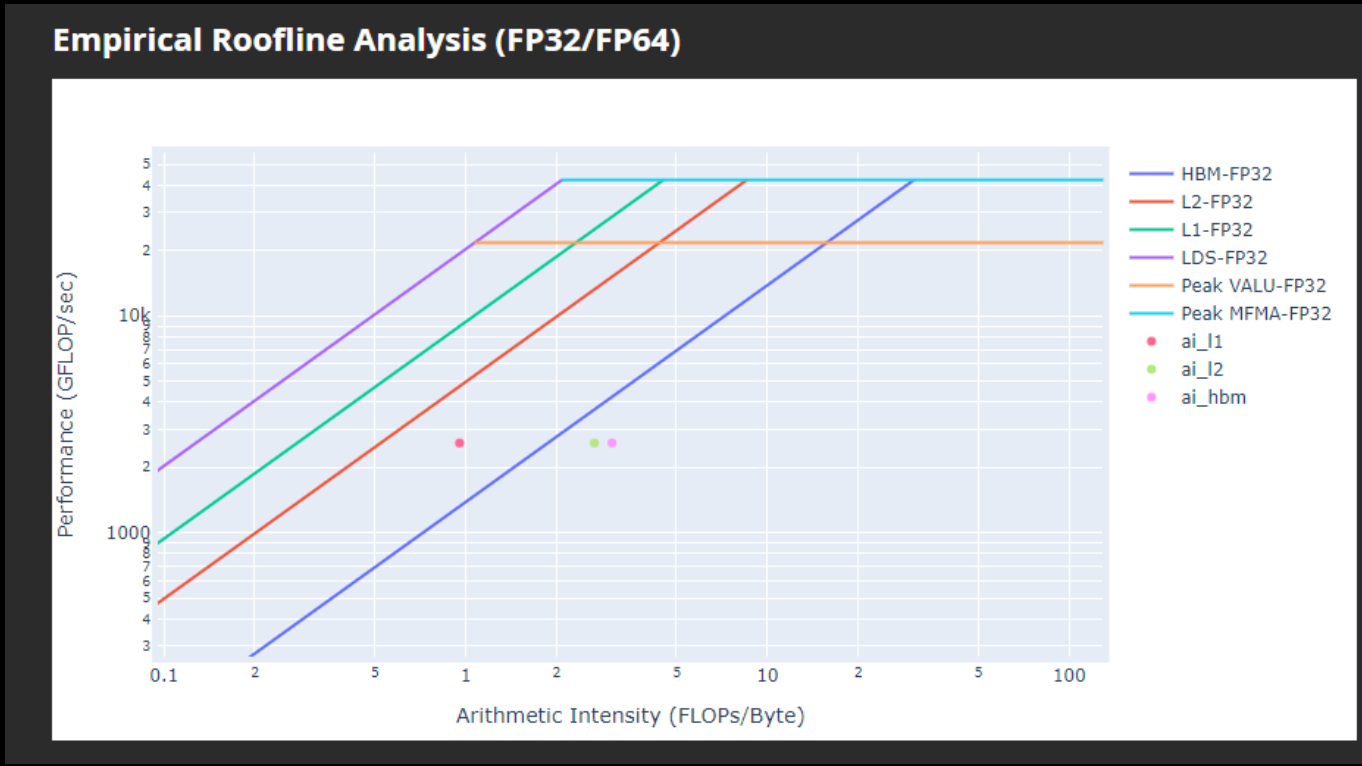
Analyze the profiled workload:

```
$ omniperf analyze -p path/to/workloads/roofline_case_app/mi200 --gui
```

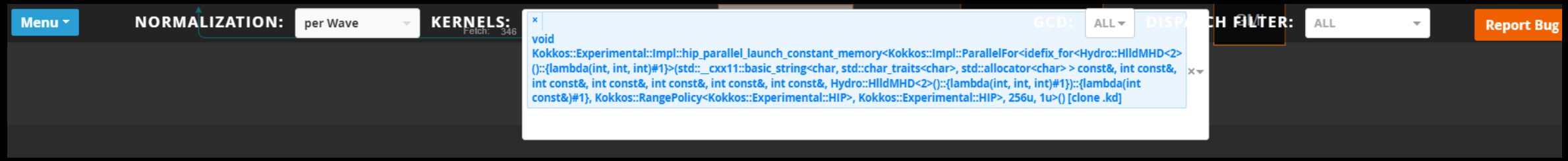
Open web page http://IP:8050/

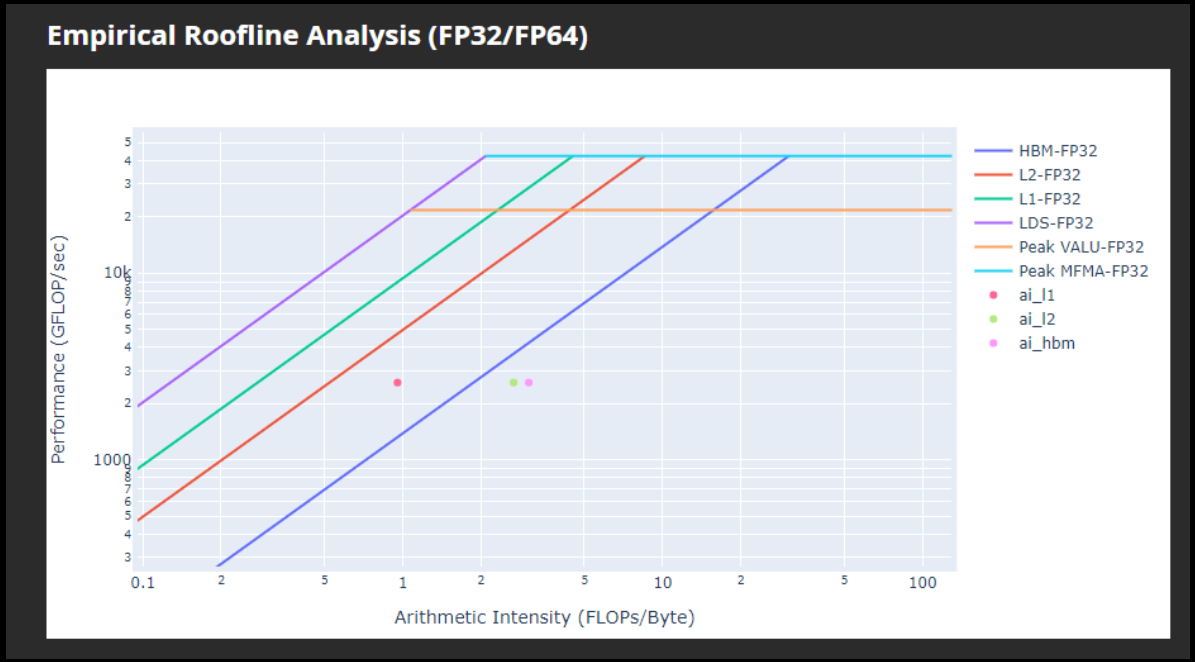
When profile with --roof-only, a PDF with the roofline will be created. In order to see the name of the kernels, add the --kernel-names and a second PDF will be created with names for the kernel markers:

```
$ omniperf profile -n roofline_case_app --roof-only --kernel-names -- <CMD> <ARGS>
```



Roofline Analysis – Kokkos code





- Roofline: the first-step characterization of workload performance
  - Workload characterization
    - Compute bound
    - Memory bound
    - Performance margin
    - L1/L2 cache accesses
- Thorough SoC perf analysis for each subsystem to identify bottlenecks
  - HBM
  - L1/L2
  - LDS
  - Shader compute
  - Wavefront dispatch
- Omniperf tooling support
  - Roofline plot (float, integer)
  - Baseline roofline comparison
  - Kernel statistics

SPI Resource Allocation

- Dispatch Bound
  - Wavefront dispatching failure due to resources limitation
    - Wavefront slots
    - VGPR
    - SGPR
    - LDS allocation
    - Barriers
    - Etc.
  - Omniperf tooling support
    - Shader Processor Input (SPI) metrics

6.2 SPI Resource Allocation

Metric	Avg	Min	Max	Unit
Wave request Failed (CS)	613303.00	613303.00	613303.00	Cycles
CS Stall	356961.00	356961.00	356961.00	Cycles
CS Stall Rate	62.95	62.95	62.95	Pct
Scratch Stall	0.00	0.00	0.00	Cycles
Insufficient SIMD Waveslots	0.00	0.00	0.00	Simd
Insufficient SIMD VGPRs	16252333.00	16252333.00	16252333.00	Simd
Insufficient SIMD SGPRs	0.00	0.00	0.00	Simd
Insufficient CU LDS	0.00	0.00	0.00	Cu
Insufficient CU Barries	0.00	0.00	0.00	Cu
Insufficient Bulky Resource	0.00	0.00	0.00	Cu
Reach CU Threadgroups Limit	0.00	0.00	0.00	Cycles
Reach CU Wave Limit	0.00	0.00	0.00	Cycles
VGPR Writes	4.00	4.00	4.00	Cycles/wave
SGPR Writes	5.00	5.00	5.00	Cycles/wave

What if Grafana and web GUI crashes when loading performance data? (real case)

When profiling produces too large data…

- We had an application that the realistic case was dispatching 6.7 million calls to kernels
- Executing Omniperf without any options, it would take up to 36 hours to finish while single non instrumented execution takes less than 1 hour.
- HW counters add overhead
- We had totally around 9 GB of profiling data from 1 MPI process
- Uploading the data to a Grafana server was crashing Grafana server and we had to reboot the service
- Using standalone GUI was never finishing loading the data

- Omniperf profile has an option called –k where you define which specific kernel to profile. You can define the id 0-9 of the top 10 kernels.
- This creates profiling data **only** for the selected kernel
- This way you can split the profiling data to 10 executions, one per kernel:
  - You can use different resources to do the experiments in parallel (remember there can be performance variation between different GPUs)
  - You can visualize each kernel

Profile with roofline for a specific kernel:

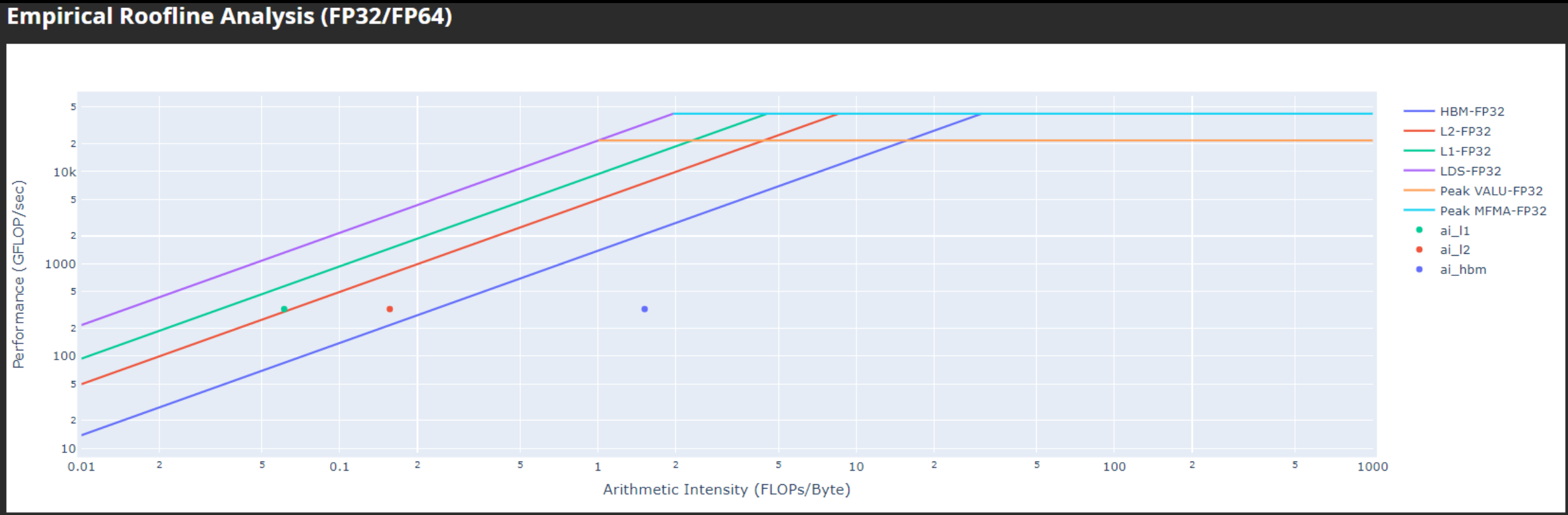
```
 $ srun -N 1 -n 1 --ntasks-per-node=1 --gpus=1 --hint=nomultithread omniperf profile -n kernel_roof
-k kernel_name --roof-only  -- ./binary args
```

Example – DAXPY with a loop in the kernel

DAXPY – with a loop in the kernel

```
#include <hip/hip_runtime.h>

__constant__ double a = 1.0f;

__global__
void daxpy (int n, double const* x, int incx, double* y, int incy)
{
    int i = blockDim.x * blockIdx.x + threadIdx.x;
    if (i < n)
       for(int ll=0;ll<20;ll++) {
        y[i] = a*x[i] + y[i];
       }
}

int main()
{
    int n = 1<<24;
    std::size_t size = sizeof(double)*n;

    double* d_x;
    double *d_y;
    hipMalloc(&d_x, size);
    hipMalloc(&d_y, size);

    int num_groups = (n+255)/256;
    int group_size = 256;
    daxpy<<<num_groups, group_size>>>(n, d_x, 1, d_y, 1);
    hipDeviceSynchronize();
```

Roofline



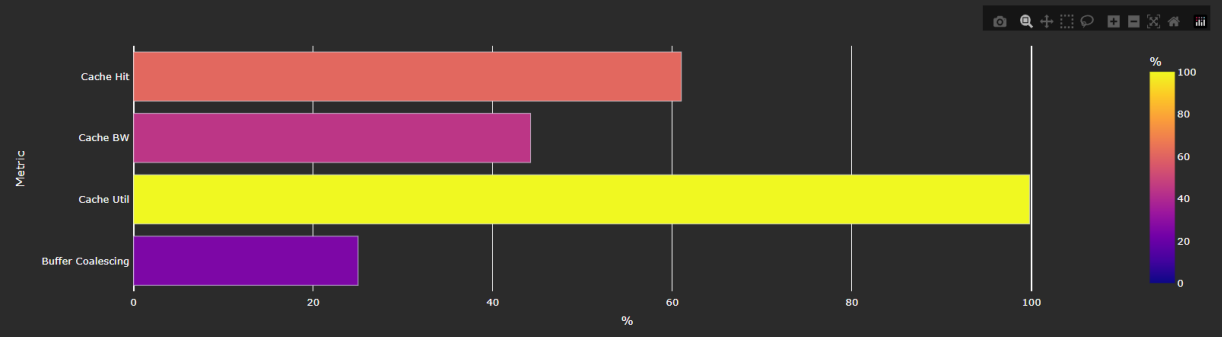
- Performance: almost 330 GFLOPs

Kernel execution time and L1D Cache Accesses

KernelName	Count	Sum(ns)	Mean(ns)	Median(ns)	Pct
daxpy(int, double const*, int, double*, int) [clone .kd]	1.00	2024491.00	2024491.00	2024491.00	100.00

16. Vector L1 Data Cache

16.1 Speed-of-Light



16.2 L1D Cache Stalls

Metric	Mean	Min	Max	unit
Stalled on L2 Data	73.69	73.69	73.69	Pct
Stalled on L2 Req	19.47	19.47	19.47	Pct
Tag RAM Stall (Read)	0.00	0.00	0.00	Pct
Tag RAM Stall (Write)	0.00	0.00	0.00	Pct
Tag RAM Stall (Atomic)	0.00	0.00	0.00	Pct

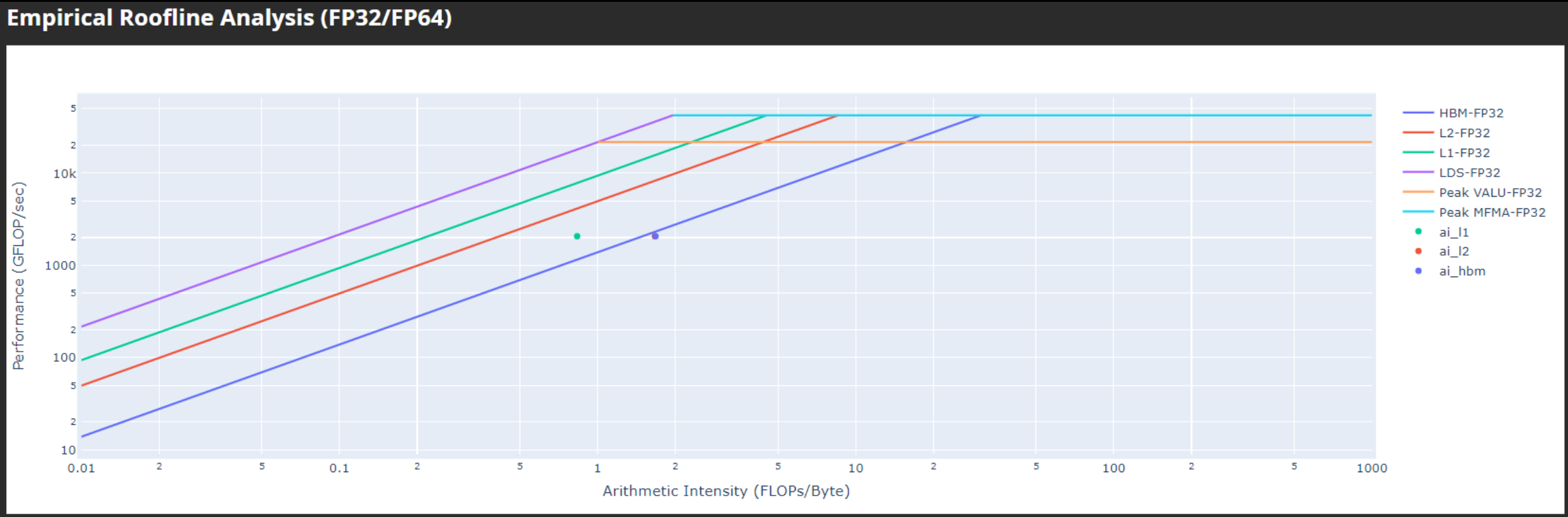
16.3 L1D Cache Accesses

Metric	Avg	Min	Max	Unit
Total Req	2624.00	2624.00	2624.00	Req per wave
Read Req	1344.00	1344.00	1344.00	Req per wave
Write Req	1280.00	1280.00	1280.00	Req per wave
Atomic Req	0.00	0.00	0.00	Req per wave
Cache BW	5291.66	5291.66	5291.66	Gb/s
Cache Accesses	656.00	656.00	656.00	Req per wave
Cache Hits	400.16	400.16	400.16	Req per wave
Cache Hit Rate	61.00	61.00	61.00	Pct

DAXPY – with a loop in the kernel - Optimized

```
#include <hip/hip_runtime.h>

__constant__ double a = 1.0f;

__global__
void daxpy (int n, double const* __restrict__ x, int incx, double* __restrict__ y, int incy)
{
    int i = blockDim.x * blockIdx.x + threadIdx.x;
    if (i < n)
       for(int ll=0;ll<20;ll++) {
        y[i] = a*x[i] + y[i];
       }
}

int main()
{
    int n = 1<<24;
    std::size_t size = sizeof(double)*n;

    double* d_x;
    double *d_y;
    hipMalloc(&d_x, size);
    hipMalloc(&d_y, size);

    int num_groups = (n+255)/256;
    int group_size = 256;
    daxpy<<<num_groups, group_size>>>(n, d_x, 1, d_y, 1);
    hipDeviceSynchronize();
```

Roofline - Optimized



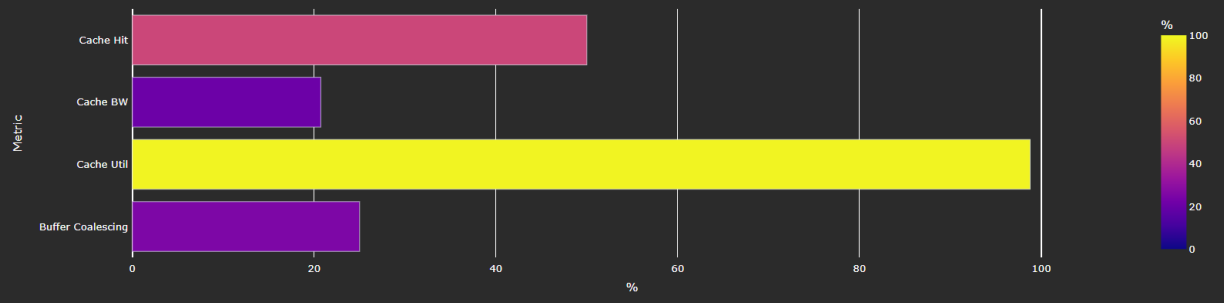
- Performance: almost 2 TFLOPs

Kernel execution time and L1D Cache Accesses - Optimized

KernelName	Count	Sum(ns)	Mean(ns)	Median(ns)	Pct
daxpy(int, double const*, int, double*, int) [clone .kd]	1.00	323522.00	323522.00	323522.00	100.00

6.2 times faster!

16.1 Speed-of-Light



16.2 L1D Cache Stalls

Metric	Mean	Min	Max	unit
Stalled on L2 Data	79.08	79.08	79.08	Pct
Stalled on L2 Req	15.17	15.17	15.17	Pct
Tag RAM Stall (Read)	0.00	0.00	0.00	Pct
Tag RAM Stall (Write)	0.00	0.00	0.00	Pct
Tag RAM Stall (Atomic)	0.00	0.00	0.00	Pct

16.3 L1D Cache Accesses

Metric	Avg	Min	Max	Unit
Total Req	192.00	192.00	192.00	Req per wave
Read Req	128.00	128.00	128.00	Req per wave
Write Req	64.00	64.00	64.00	Req per wave
Atomic Req	0.00	0.00	0.00	Req per wave
Cache BW	2480.60	2480.60	2480.60	Gb/s
Cache Accesses	48.00	48.00	48.00	Req per wave
Cache Hits	24.00	24.00	24.00	Req per wave
Cache Hit Rate	50.00	50.00	50.00	Pct
Invalidate	0.00	0.00	0.00	Req per wave

Questions?

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