Tsukuba University Exercises

Contents

AMD Accelerator Cloud (AAC) **2**
- Login Instructions . . . 2
  - SSH-Key Generation . . . 2
  - Login with SSH-Key . . . 2
  - Login with password . . . 2
  - Login Troubleshooting . . . 3
  - Directories and Files . . . 3
- Container Environment . . . 3
  - Explore Modules . . . 4
- Slurm Information . . . 5
- Training Examples Repo . . . 5

Programming Model Exercises – Managed Memory and Single Address Space (APU) **5**
- CPU Code baseline . . . 6
- Standard GPU Code example . . . 6
- Managed Memory Code . . . 7
- APU Code – Single Address Space in HIP . . . 8
- OpenMP APU or single address space . . . 8
- RAJA Single Address Code . . . 8
- Kokkos Unified Address Code . . . 9

Introduction to OpenMP Offloading **10**
- OpenMP C Build systems: make and cmake . . . 10
  - Make . . . 10
  - CMake . . . 11
- OpenMP CXX Build systems: make and cmake . . . 12
  - Make . . . 12
  - CMake . . . 13
- OpenMP Fortran Build systems: make and cmake . . . 13
  - Make . . . 14
  - CMake . . . 14
- First OpenMP C offload: . . . 15
  - Part 1: Unified shared memory . . . 15
  - Part 2: Impact of USM . . . 17
  - Part 3: Map clauses . . . 17
- First Fortran OpenMP offload: Porting saxpy step by step and explore the discrete GPU and APU programming models: . . . 18
  - Part 1: Porting with unified shared memory enabled . . . 19
  - Part 2: explore the impact of unified shared memory . . . 20
  - Part 3: with map clauses . . . 20

Real World OpenMP Language Constructs **21**

OpenMP Single Line Compute Constructs: . . . 21
CPU version . . . 21
OpenMP Single Line Compute Constructs: . . . 23
CPU version . . . 23
OpenMP complex compute constructs in C . . . 25
Full combined compute directive . . . 25
Target directive . . . 26
Teams clause . . . 26
Split multi-level directive . . . 27
OpenMP complex compute constructs in Fortran . . . 27
Reduction exercise: . . . 28
Porting exercise: reduction . . . 28
Part 2: Port with map clause . . . 29
Porting exercise reduction of multiple scalars in one kernel . . . 29
Porting exercise reduction of multiple scalars in one kernel . . . 30
Porting exercise reduction into an array . . . 30
Porting exercise reduction of multiple scalars in one kernel . . . 30
C Code – Porting device routine exercises . . . 31
Part 1: Fortran with interface blocks . . . 32
Part 2: Fortran with modules . . . 34
C++ member function . . . 35
C++ member function external . . . 35
C++ virtual methods . . . 36
Exercise: mapping of different datatypes . . . 36
OpenMP Offloading for C++ Codes that use Classes . . . 38
The `usm` Sub-directory . . . 38
The `explicit` Sub-directory . . . 39
Submodule test – does the Fortran compiler support the new submodules feature in the Fortran 2008 standard (extension in 2003) . . . 39

Introduction to HIP Exercises **40**
HIP/basic_examples Documentation . . . 40
Table of Contents . . . 40
Find the error . . . 40
Add the device-to-host data transfer . . . 40
Complete the square elements kernel . . . 41
Complete the matrix multiply kernel . . . 41
Complete the matrix multiply kernel . . . 42
hipify the CUDA pingpong code . . . 42
Complete the matrix multiply with shared memory . . . 43

Porting Applications to HIP **43**
Hipify Examples . . . 43
Exercise 1: Manual code conversion from CUDA to HIP (10 min) . . . 43
Exercise 2: Code conversion from CUDA to HIP using HIPify tools (10 min) . . . 43
HIPifly Example: Vector Addition . . . 44
Full OpenMP Application Code . . . 45
OpenMP Application Calling a HIP Kernel . . . 45
APU Programming Model Version . . . 45
HIP application calling an OpenMP Kernel . . . 45
OpenMP and HIP Kernels in the Same Source File . . . 46

Running a Fortran to HIP interop example **46**

Explicit Memory Management . . . 47
Unified Shared Memory . . . 47

Kokkos examples **47**
Stream Triad . . . 47
Step 1: Build a separate Kokkos package . . . 47
Step 2: Modify Build . . . 48
Step 3: Add Kokkos views for memory allocation of arrays . . . 48
Step 5: Add Kokkos timers . . . 49
6. Run and measure performance with OpenMP . . . 49
Portability Exercises . . . 49

C++ Standard Parallelism on AMD GPUs **50**
hipstdpar_saxpy_foreach example . . . 50
hipstdpar_saxpy_transform example . . . 50
hipstdpar_saxpy_transform_reduce example . . . 50
Traveling Salesperson Problem . . . 50
hipstdpar_shallowwater_orig.sh . . . 51
hipstdpar_shallowwater_ver1.sh . . . 51
hipstdpar_shallowwater_ver2.sh . . . 51
hipstdpar_shallowwater_stdpar.sh . . . 51
Mix and Match . . . 52

Advanced OpenMP presentation **52**
Memory Pragmas . . . 52
One solution that miminizes data transfer . . . 54
Unified Shared Memory . . . 54
Unified Shared Memory with backwards compatibility . . . 54
APU Code – Unified Address in OpenMP . . . 54
Kernel Pragmas . . . 55

Advanced HIP **55**
Optimizing DAXPY HIP . . . 55
Inputs . . . 56
Build Code . . . 56
Run exercises . . . 56
Things to ponder about . . . 56
Notes . . . 57
Register Exercises . . . 57
Register Pressure - ROCm Blogs . . . 57
Register pressure in AMD CDNA™2 GPUs . . . 58
HIP Transpose Examples . . . 58
Transpose Read Contiguous . . . 58
Transpose Write Contiguous . . . 59
Tiled Matrix Transpose . . . 60
Transpose from the rocblas library . . . 61

GPU Aware MPI **62**
Point-to-point and collective . . . 62
OSU Benchmark . . . 62
Ghost Exchange example . . . 63
RCCL Test . . . 64

MPI Example: Ghost Exchange with OpenMP **65**
Features of the various versions . . . 65

Overview of the implementation . . . 66
Original version of Ghost Exchange . . . 66
Version 1 – Adding OpenMP target offload to original CPU code . . . 67

HIP-Python **67**
Obtaining Device Properties . . . 67
Getting Device Attributes . . . 68
Accessing HIP Streams using HIP-Python . . . 69
Calling hipBLAS from Python using HIP-Python . . . 70
Using Unified Shared Memory for hipBLAS using HIP-Python . . . 71
Calling hipFFT from Python using HIP-Python . . . 72
Unified Shared Memory version of calling hipFFT HIP-Python . . . 73
Calling RCCL from Python using HIP-Python . . . 73
Unified Shared Memory with RCCL using HIP-Python . . . 74
Cython example . . . 76
Compiling and Launching Kernels . . . 77
Kernels with arguments . . . 78
numba-HIP . . . 80

CuPy Examples **81**
Simple introduction example to CuPy for AMD GPUs . . . 81

MPI4Py examples **82**
Exploring MPI communication with MPI4Py . . . 82

AMD AI Assistant using retrieval augmented generation (RAG) **83**
Ollama . . . 83
System with a limited number of users . . . 83
System with a large number of users . . . 85

ROCgdb **86**
Saxpy Debugging . . . 86

Rocprofv3 Exercises for HIP **88**
Jacobi . . . 88
Setup environment . . . 88
Compile and run one case . . . 88
Let's profile HIP . . . 88
Let's create statistics . . . 89
Where are the kernels? . . . 89
Create pftrace file for Perfetto and Visualize . . . 90
Hardware Counters . . . 90
Tips . . . 90

Rocprofv3 Exercises for OpenMP **91**
Setup environment . . . 91
Build and run . . . 91
Basic rocprov3 profiling . . . 91
Available options . . . 91
First kernel information . . . 92
Create statistics . . . 92
Visualizing traces using `Perfetto` . . . 93
Additional features . . . 94
Hardware Counters . . . 94
Next steps . . . 94

ROCm™ Systems Profiler aka `rocprof-sys` 95
Environment setup . . . 95
Build and run . . . 95
`rocprof-sys` config . . . 96
Instrument application binary . . . 96
Run instrumented binary . . . 97
Visualizing traces using `Perfetto` . . . 97
Additional features . . . 97
Flat profiles . . . 97
Hardware counters . . . 98
Sampling . . . 98
Profiling multiple MPI processes . . . 98
Next steps . . . 98

Stream Overlap Example 98
Folder `0-Orig` . . . 99
Folder `1-split-copy-compute-hw-queues` . . . 99
Folder `2-pageable-mem` . . . 99
Self-guided tour of the Stream Overlap example . . . 99

ROCprof-compute 100

Exercise 1: Launch Parameter Tuning 100
Results on MI210 . . . 100
Initial Roofline Analysis: . . . 100
Exercise instructions: . . . 102
ROCprof-compute Command Line Comparison Feature: . . . 105
More Kernel Filtering: . . . 106
Solution Roofline . . . 107
Roofline Comparison . . . 109
Summary and Take-aways . . . 111
Results on MI300A . . . 111
Roofline Analysis: . . . 111
Exercise Instructions: . . . 112
ROCprof-compute Command Line Comparison Feature: . . . 113
More Kernel Filtering: . . . 114

Exercise 2: LDS Occupancy Limiter 116
Results on MI210 . . . 116
Initial Roofline Analysis . . . 116
Exercise Instructions: . . . 118
Solution Roofline . . . 122
Roofline Comparison . . . 124
Summary and Take-aways . . . 126
Results on MI300A . . . 126
Roofline Analysis: . . . 126

Exercise 3: Register Occupancy Limiter 130
Results on MI210 . . . 130
Initial Roofline Analysis . . . 131
Exercise Instructions: . . . 132

Solution Roofline . . . 136
Roofline Comparison . . . 138
Summary and Take-aways . . . 140
Results on MI300A . . . 140
Roofline Analysis: . . . 140

Exercise 4: Strided Data Access Patterns (and how to find them) 144
Results on MI210 . . . 145
Initial Roofline Analysis . . . 145
Exercise Instructions: . . . 146
Solution Roofline Analysis . . . 149
Roofline Comparison . . . 151
Summary and Take-aways . . . 153
Results on MI300A . . . 153

Exercise 5: Algorithmic Optimizations 158
Results on MI210: . . . 158
Initial Roofline Analysis . . . 158
Exercise Instructions: . . . 160
Solution Roofline Analysis . . . 163
Roofline Comparison . . . 165
Summary and Take-aways . . . 167
Results on MI300A . . . 167

ROCprof Trace Decoder 167
Setting up environment . . . 168
Basic test – vectorAdd . . . 168

ROCprofiler Compute Viewer 168
Saxpy . . . 168
Matrix multiply - hip version . . . 169
Matrix multiply library test (DGEMM) . . . 169

AMD Accelerator Cloud (AAC)

File: login_info/AAC/README.md at https://github.com/amd/HPCTrainingExamples

We have some small cloud based systems available for training activities. Attendees can login using the instructions below. This set of instructions assumes that users have already received their `<username>` and `<port_number>` for the container, and that they have either provided an ssh key to the training team, or they have received a password from the training team.

Login Instructions

The instructions below rely on ssh to access the AAC. If you have not sent your public key in for an account and do not have an ssh public key, start with the instructions on how to generate an ssh key. If you have sent an ssh key and received your account information, skip to the section on how to log into the system.

SSH-Key Generation

Generate an ssh key on your local system, which will be stored in `.ssh` :

```
cd $HOME
ssh-keygen -t ed25519 -N ''
```

To examine the content of your public key do:

```
cat $HOME/.ssh/id_ed25519.pub
```

NOTE: at first login, you will be presented with the AAC user agreement form. This covers the terms of use of the compute hardware as well as how we will handle your data. Scroll down with the down arrow and type `yes` when prompted. Note that if you will scroll down too much, then `no` will be received as answer and you will be logged out.

Login with SSH-Key

IMPORTANT: if you are supposed to login with an ssh key and you are prompted a password, do not type any password! Instead, type `Ctrl+C` and contact us to get some help.

To login to an AAC MI300A system using the ssh key use the `<username>` that the training team has provided you, for instance:

```
ssh <username>@aac6.amd.com -i <path/to/ssh/key> (1)
```

Login with password

For a password login, the command is the same as in `(1)` , except that it is not necessary to specify a path to the ssh key. Just type the password that has been given to you when prompted:

```
ssh <username>@aac6.amd.com
```

IMPORTANT: It is fundamental to not type the wrong password more than two times otherwise your I.P. address will be blacklisted and you will not be allowed access to AAC until we modify our firewall to get you back in. This is especially important if you are at an event where all the attendees are connecting to the same wireless network.

If you are using a password login, you can upload an ssh key with the following command to avoid using a password

```
ssh-copy-id -i <path/to/ssh/key.pub> -o UpdateHostKeys=yes <username>@aac6.amd.com
```

In the commands above `-i` points to the path of your ssh key. The `-i` option is not needed if your default key is used.

To simplify the login even further, you can add the following to your `.ssh/config` file:

```
# AMD AAC cluster
Host aac
   User <username>
   Hostname aac6.amd.com // this may be different depending on the container
   IdentityFile <path/to/ssh/key> // this points to the private key file
   ServerAliveInterval 600
   ServerAliveCountMax 30
```

The `ServerAlive*` lines in the config file may be added to avoid timeouts when idle. You can then login using:

```
ssh aac -p <port_number>
```

It may also happen that a message like the following will show after logging into AAC:

```
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@    WARNING: REMOTE HOST IDENTIFICATION HAS CHANGED!     @
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
IT IS POSSIBLE THAT SOMEONE IS DOING SOMETHING NASTY!
Someone could be eavesdropping on you right now (man-in-the-middle attack)!
It is also possible that a host key has just been changed.
```

In such a case, remove in your local system the offending keys located in `.ssh/known_hosts`, as indicated by the warning message.

Login Troubleshooting

Here are some troubleshooting tips if you cannot login to AAC following the instructions above:

1. Check the spelling of the command ssh, in particular `<username>` and password.
2. Turn off VPN if on.
3. Try logging in from a different machine if available (and migrate the ssh key to the new machine or generate a new one and send it to us).
4. Try a ***jump host***: this is a local server that you ssh to and then do a second ssh command from there.

In case none of these options work, send us the output of the ssh command followed by `-vv` and also the output of `traceroute aac6.amd.com`. Additionally, let us know if the command `ping aac6.amd.com` works on your end.

Directories and Files

```
$HOME=/home/aac/shared/teams/hackathon-testing/<group>/<username>`
```

You can copy files in or out of AAC with the `scp` or the `rsync` command.

Copy into AAC from your local system, for instance:

```
scp -i <path/to/ssh/key> <file> <username>@aac6.amd.com:~/<path/to/file>
```

Copy from AAC to your local system:

```
scp -i <path/to/ssh/key> <username>@aac6.amd.com:~/<path/to/file> .
```

To copy files in or out of the container, you can also use `rsync` as shown below:

```
rsync -avz -e "ssh -i <path/to/ssh/key>" <file> <username>@aac6.amd.com:~/<path/to/file>
```

Container Environment

Please consult the container's README to learn about the latest specs of the training container.

The software on the node is based on the Ubuntu 22.04 Operating System with one of the latest versions of the ROCm software stack. It contains multiple versions of AMD, GCC, and LLVM compilers, hip libraries, GPU-Aware MPI, AMD profiling tools and HPC community tools. The container also has modules set up with the lua modules package and a slurm package and configuration. It includes the following additional packages:

- emacs
- vim
- autotools
- cmake
- tmux
- boost
- eigen
- fftw
- gmp
- gsl
- hdf5-openmpi
- lapack
- magma
- matplotlib
- parmetis
- mpfr
- mpi4py
- openblas
- openssl
- swig
- numpy
- scipy
- h5sparse

Explore Modules

To see what modules are available do:

```
module avail
```

The output list of `module avail` should show:

```
---------------------------------- /etc/lmod/modules/Linux ----------------------------------
   clang/base    gcc/base

------------------------------- /etc/lmod/modules/LinuxPlus -------------------------------
   miniconda3/25.3.1    miniforge3/24.9.0

---------------------------------- /etc/lmod/modules/ROCm ----------------------------------
   amdclang/19.0.0-6.4.1           rocprof-tracedecoder/6.4.1
   amdflang-new/rocm-afar-7.0.5    rocprofiler-compute/6.4.1  (D)
   hipfort/6.4.1                   rocprofiler-sdk/6.4.1
   opencl/6.4.1                    rocprofiler-systems/6.4.1  (D)
   rocm/6.4.1

------------------------------- /etc/lmod/modules/ROCmPlus -------------------------------
   adios2/2.10.1    hpctoolkit/2024.01.99-next    netcdf-c/4.9.3          scorep/9.0
   fftw/3.3.10      hypre/2.33.0                  netcdf-fortran/4.6.2    tau/dev
   hdf5/1.14.6      kokkos/4.6.01                 petsc/3.23.1

------------------------------ /etc/lmod/modules/ROCmPlus-MPI ------------------------------
   mpi4py/4.0.3    openmpi/5.0.7-ucc1.4.4-ucx1.18.1
```

```
----------------------- /etc/lmod/modules/ROCmPlus-AMDResearchTools ------------------------
   rocprofiler-compute/develop    rocprofiler-systems/amd-staging

------------------------ /etc/lmod/modules/ROCmPlus-LatestCompilers -----------------------
   hipfort_from_source/6.4.1

------------------------------ /etc/lmod/modules/ROCmPlus-AI -------------------------------
   cupy/14.0.0a1    jax/0.6.0                          pytorch/2.7.1           (D)
   ftorch/dev       pytorch/2.7.1_tunableop_enabled    tensorflow/merge-250318

---------------------------------- /etc/lmod/modules/misc ----------------------------------
   hipifly/dev

  Where:
   D:  Default Module
```

There are several modules associated with each ROCm version. One is the rocm module which is needed by many of the other modules. The second is the amdclang module when using the amdclang compiler that comes bundled with ROCm. The third is the hipfort module for the Fortran interfaces to HIP. Also, there is an OpenCL module and one for each of the AMD profilers.

Compiler modules set the C, CXX, FC flags. Only one compiler module can be loaded at a time. hipcc is in the path when the rocm module is loaded. Note that there are several modules that set the compiler flags and that they set the full path to the compilers to avoid path problems.

Slurm Information

The AAC6 node is set up with Slurm. Slurm configuration is for a single queue that is shared with the rest of the node. Run the following command to get info on Slurm:

```
sinfo
```

```
PARTITION                     AVAIL  TIMELIMIT  NODES  STATE NODELIST
1CN192C4G1H_MI300A_Ubuntu22*     up 8-00:00:00      3   idle ppac-pl1-s24-[16,26,30,35],ppac-pl1-s25-40
1CN48C1G1H_MI300A_Ubuntu22       up 8-00:00:00      4   idle sh5-pl1-s12-[09,12,15,33,36]
```

The Slurm `salloc` command may be used to acquire a long term session that exclusively grants access to one or more GPUs. Alternatively, the `srun` or `sbatch` commands may be used to acquire a session with one or more GPUs and only exclusively use the session for the life of the run of an application. `squeue` will show information on who is currently running jobs.

Training Examples Repo

You can get the examples from our repository. This repository contains all the code that we normally use during our training events:

```
cd $HOME
git clone https://github.com/amd/HPCTrainingExamples.git
```

Programming Model Exercises – Managed Memory and Single Address Space (APU)

From `HPCTrainingExamples/ManagedMemory/README.md` in the training exercises repository

NOTE: these exercises have been tested on MI210 and MI300A accelerators using a container environment. To see details on the container environment (such as operating system and modules available) please see `README.md` on this repo.

The source code for these exercises is based on those in the presentation, but with details filled in so that there is a working code. You may want to examine the code in these exercises and compare it to the code in the presentation and to the code in the other exercises.

CPU Code baseline

```
git clone https://github.com/amd/HPCTrainingExamples.git
cd HPCTrainingExamples/ManagedMemory
```

First, run the standard CPU version. This is a working version of the original CPU code from the programming model presentation. The example will work with any C compiler and run on any CPU. To set up the environment, we need to set the CC environment variable to the C compiler executable. We do this by loading the amdclang module which sets `CC=/opt/rocm-<version>/llvm/bin/amdclang` . The makefile uses the CC environment which we have set. In our modules, we set the "family" to compiler so that only one compiler can be loaded at a time.

```
cd HPCTrainingExamples/ManagedMemory/CPU_Code
module load amdclang
make
```

will compile with `/opt/rocm-<version>/llvm/bin/amdclang -g -O3 cpu_code.c -o cpu_code` Then run code with

```
./cpu_code
```

Standard GPU Code example

This example shows the standard GPU explicit memory management. For this case, we must move the memory ourselves. This example will run on any AMD Instinct GPU (data center GPUs) and most workstation or desktop discrete GPUs and APUs. The AMD GPU driver and ROCm software needs to be installed.

For the environment setup, we need the ROCm bin directory added to the path. We do this by loading the ROCm module with `module load rocm` . This will set the path to the rocm bin directory. We could also do this with export `PATH=/opt/rocm-<version>/bin` or by supplying the full path `/opt/rocm-<version>/bin/hipcc` to the compile line. Note that even this may not be necessary as the ROCm install may have placed a link to `hipcc` in `/usr/bin/hipcc` during the ROCm install.

We also supply a `--offload-arch=${AMDGPU_GFXMODEL}` option to the compile line. While not necessarily required, it helps in cases where the architecture is not autodetected properly. We use the following line to query what the architecture string `AMDGPU_GFXMODEL` should be. We can also set our own `AMDGPU_GFXMODEL` variable in cases where we want to cross-compile or compile for more than one architecture.

```
AMDGPU_GFXMODEL ?= $(strip $(shell rocminfo |grep -m 1 -E gfx[^0]{1} | sed -e 's/ *Name: *//'))
```

The `AMDGPU_GFXMODEL` architecture string is `gfx90a` for MI200 series and `gfx942` for MI300A and MI300X. We can also compile for more than one architecture with `export AMDGPU_GFXMODEL="gfx90a,gfx942"` .

```
cd ../GPU_Code
make
```

This will compile with `hipcc -g -O3 --offload-arch=${AMDGPU_GFXMODEL} gpu_code.hip -o gpu_code` .

Then run the code with

```
./gpu_code
```

Managed Memory Code

In this example, we will set the `HSA_XNACK` environment variable to 1 and let the Operating System move the memory for us. This will run on AMD Instinct GPUs for the data center including MI300X, MI300A, and MI200 series. To set up the environment, `module load rocm` .

```
export HSA_XNACK=1
module load rocm
cd ../Managed_Memory_Code
make
./gpu_code
```

To understand the difference between the explicit memory management programming and the managed memory, let's compare the two codes.

```
diff gpu_code.hip ../GPU_Code/
```

You should see the following:

```
34a35,37
>    double *in_d, *out_d;
>    HIP_CHECK(hipMalloc((void **)&in_d, Msize));
>    HIP_CHECK(hipMalloc((void **)&out_d, Msize));
38a42,43
>    HIP_CHECK(hipMemcpy(in_d, in_h, Msize, hipMemcpyHostToDevice));
>
41c46
<    gpu_func<<<grid,block,0,0>>>(in_h, out_h, M);
---
>    gpu_func<<<grid,block,0,0>>>(in_d, out_d, M);
43a49
>    HIP_CHECK(hipMemcpy(out_h, out_d, Msize, hipMemcpyDeviceToHost));
```

It may be more instructive to look at the lines of hip code that are required compared to the explicit memory management GPU code.

```
grep hip ../GPU_Code/gpu_code.hip
```

which gets the following output

```
#include "hip/hip_runtime.h"
    hipError_t gpuErr = call;                           \
    if(hipSuccess != gpuErr){                           \
         __FILE__, __LINE__, hipGetErrorString(gpuErr)); \
   HIP_CHECK(hipMalloc((void **)&in_d, Msize));
   HIP_CHECK(hipMalloc((void **)&out_d, Msize));
   HIP_CHECK(hipMemcpy(in_d, in_h, Msize, hipMemcpyHostToDevice));
   HIP_CHECK(hipDeviceSynchronize());
   HIP_CHECK(hipMemcpy(out_h, out_d, Msize, hipMemcpyDeviceToHost));
```

```
grep hip gpu_code.hip
```

And for the managed memory program, we essentially get just the addition of the `hipDeviceSynchronize` call plus including the hip runtime header and the error checking macro.

```
#include "hip/hip_runtime.h"
    hipError_t gpuErr = call;                           \
    if(hipSuccess != gpuErr){                           \
         __FILE__, __LINE__, hipGetErrorString(gpuErr)); \
   HIP_CHECK(hipDeviceSynchronize());
```

APU Code – Single Address Space in HIP

We'll run the same code as we used in the managed memory example. Because the memory pointers are addressable on both the CPU and the GPU, no memory management is necessary. First, log onto an MI300A node. Then compile and run the code as follows.

```
export HSA_XNACK=1
module load rocm
cd ../APU_Code
make
./gpu_code
```

It may be confusing why we need `HSA_XNACK=1` . Even with the APU, we need to map the pointers into the GPU page map though the memory itself does not need to be copied.

OpenMP APU or single address space

For this example, we have a simple code with the loop offloading in the main code, `openmp_code` , and a second version, `openmp_code1` , with the offloaded loop in a subroutine where the compiler cannot tell the size of the array. Running this on the MI200 series, it passes, despite that it does not have a single address space. We add `export LIBOMPTARGET_INFO=-1` or for less output `export LIBOMPTARGET_INFO=$((0x1 | 0x10))` to verify that it is running on the GPU.

```
export HSA_XNACK=1
module load amdclang
cd ../OpenMP_Code
make
```

You should see some warnings that are basically telling you the AMD clang compiler is ignoring the `simd` clause is being ignored. You can remove the `simd` from the OpenMP pragmas, but at the expense of portability to some other OpenMP compilers. Now run the code.

```
./openmp_code
./openmp_code1
export LIBOMPTARGET_INFO=$((0x1 | 0x10)) # or export LIBOMPTARGET_INFO=-1
./openmp_code
./openmp_code1
```

If the executable is running on the GPU you will see some output as a result of the `LIBOMPTARGET_INFO` environment variable being set. If it is not running on the GPU, you will not see anything.

For more experimentation with this example, comment out the first line of the two source codes.

```
//#pragma omp requires unified_shared_memory
make
export LIBOMPTARGET_INFO=-1
./openmp_code
./openmp_code1
```

Now with the `LIBOMPTARGET_INFO` variable set, we get a report that memory is being copied to the device and back. The OpenMP compiler is helping out a lot more than might be expected even without an APU.

RAJA Single Address Code

First, set up the environment

```
module load amdclang
module load rocm
```

For the Raja example, we need to build the Raja code first

```
cd ~/HPCTrainingExamples/ManagedMemory/Raja_Code

PWDir=`pwd`

git clone --recursive https://github.com/LLNL/RAJA.git Raja_build
cd Raja_build

mkdir build_hip && cd build_hip

cmake -DCMAKE_INSTALL_PREFIX=${PWDir}/Raja_HIP \
      -DROCM_ROOT_DIR=/opt/rocm \
      -DHIP_ROOT_DIR=/opt/rocm \
      -DHIP_PATH=/opt/rocm/bin \
      -DENABLE_TESTS=Off \
      -DENABLE_EXAMPLES=Off \
      -DRAJA_ENABLE_EXERCISES=Off \
      -DENABLE_HIP=On \
      ..

make -j 8
make install

cd ../..

rm -rf Raja_build

export Raja_DIR=${PWDir}/Raja_HIP
```

Now we build the example. Note that we just allocated the arrays on the host with malloc. To run it on the MI200 series, we need to set the `HSA_XNACK` variable.

```
# To run with managed memory
export HSA_XNACK=1

mkdir build && cd build
CXX=hipcc cmake ..
make
./raja_code

cd ..
rm -rf build

cd ${PWDir}
rm -rf Raja_HIP

cd ..
rm -rf ${PROB_NAME}
```

Kokkos Unified Address Code

First, set up the environment

```
module load amdclang
module load rocm
```

For the Kokkos example, we also need to build the Kokkos code first

```
cd ~/HPCTrainingExamples/ManagedMemory/Kokkos_Code

PWDir=`pwd`
```

```
git clone https://github.com/kokkos/kokkos Kokkos_build
cd Kokkos_build

mkdir build_hip && cd build_hip
cmake -DCMAKE_INSTALL_PREFIX=${PWDir}/Kokkos_HIP -DKokkos_ENABLE_SERIAL=ON \
      -DKokkos_ENABLE_HIP=ON -DKokkos_ARCH_ZEN=ON -DKokkos_ARCH_VEGA90A=ON \
      -DCMAKE_CXX_COMPILER=hipcc ..

make -j 8
make install

cd ../..

rm -rf Kokkos_build

export Kokkos_DIR=${PWDir}/Kokkos_HIP
```

Now we build the example. Note that we have not had to declare the arrays in Kokkos Views.

```
# To run with managed memory
export HSA_XNACK=1

mkdir build && cd build
CXX=hipcc cmake ..
make
./kokkos_code

cd ${PWDir}
rm -rf Kokkos_HIP

cd ..
rm -rf ${PROB_NAME}
```

With recent versions of Kokkos, there is support for a single memory copy for the MI300A GPU.

`-Dkokkos_ENABLE_IMPL_HIP_UNIFIED_MEMORY=ON in Kokkos 4.4+`

Makes it easy to switch between host/device duplicate arrays to single memory copy on the MI300A.

Introduction to OpenMP Offloading

README.md from `HPCTrainingExamples/Pragma_Examples/OpenMP/C/BuildExamples` in the Training Examples repository

We start the introduction with how to compile programs using OpenMP offloading to GPUs. This leads us to how to write makefiles and CMakeLists.

OpenMP C Build systems: make and cmake

README.md in `HPCTrainingExamples/Pragma_Examples/OpenMP/C/BuildExamples` of the Training Examples repository

Build systems for make and cmake are an important starting step to working with OpenMP. We'll start with samples for C builds. We'll test them with some of our sample code to make sure your system is setup properly.

Make

```
cd HPCTrainingExamples/Pragma_Examples/OpenMP/C/BuildExamples
```

First let's take a look at the makefile

```
cat Makefile
```

The output should be

```
all: openmp_code

ROCM_GPU ?= $(strip $(shell rocminfo |grep -m 1 -E gfx[^0]{1} | sed -e 's/ *Name: *//'))

CC1=$(notdir $(CC))

ifneq ($(findstring amdclang,$(CC1)),)
  OPENMP_FLAGS = -fopenmp --offload-arch=${ROCM_GPU}
else ifneq ($(findstring clang,$(CC1)),)
  OPENMP_FLAGS = -fopenmp --offload-arch=${ROCM_GPU}
else ifneq ($(findstring gcc,$(CC1)),)
  OPENMP_FLAGS = -fopenmp -foffload=-march=${ROCM_GPU}
else ifneq ($(findstring CC,$(CC1)),)
  OPENMP_FLAGS = -fopenmp
endif

CFLAGS = -g -O3 -fstrict-aliasing ${OPENMP_FLAGS}
LDFLAGS = ${OPENMP_FLAGS} -fno-lto -lm

openmp_code: openmp_code.o
    $(CC) $(LDFLAGS) $^ -o $@

# Cleanup
clean:
    rm -f *.o openmp_code
    rm -rf build
```

```
module load amdclang
make
```

Now run the executable

```
./openmp_code
```

CMake

Looking at the CMakeLists.txt

```
cat CMakeLists.txt
```

The output should be

```
cmake_minimum_required(VERSION 3.21 FATAL_ERROR)
project(Memory_pragmas LANGUAGES C)

if (NOT CMAKE_BUILD_TYPE)
   set(CMAKE_BUILD_TYPE RelWithDebInfo)
endif(NOT CMAKE_BUILD_TYPE)

execute_process(COMMAND rocminfo COMMAND grep -m 1 -E gfx[^0]{1} COMMAND sed -e "s/ *Name: *//" OUTPUT_STRIP_TRAILI

string(REPLACE -O2 -O3 CMAKE_C_FLAGS_RELWITHDEBINFO ${CMAKE_C_FLAGS_RELWITHDEBINFO})
set(CMAKE_C_FLAGS_DEBUG "-ggdb")
set(CMAKE_C_FLAGS "-fstrict-aliasing -faligned-allocation -fnew-alignment=256")
if ("${CMAKE_C_COMPILER_ID}" STREQUAL "Clang")
   set(CMAKE_C_FLAGS "${CMAKE_C_FLAGS} -fopenmp --offload-arch=${ROCM_GPU}")
elseif ("${CMAKE_C_COMPILER_ID}" STREQUAL "GNU")
```

```
   set(CMAKE_C_FLAGS "${CMAKE_C_FLAGS} -fopenmp -foffload=-march=${ROCM_GPU}")
elseif (CMAKE_C_COMPILER_ID MATCHES "Cray")
   set(CMAKE_C_FLAGS "${CMAKE_C_FLAGS} -fopenmp")
   #the cray compiler decides the offload-arch by loading appropriate modules
   #module load craype-accel-amd-gfx942 for example
endif()

add_executable(openmp_code openmp_code.c)
```

```
module load amdclang
mkdir build && cd build && cmake ..
make
```

Now run the executable

```
./openmp_code
```

OpenMP CXX Build systems: make and cmake

README.md in `HPCTrainingExamples/Pragma_Examples/OpenMP/CXX/BuildExamples` of the Training Examples repository

Build systems for make and cmake are an important starting step to working with OpenMP. We'll show samples for CXX builds. We'll test them with some of our sample code to make sure your system is setup properly.

Make

```
cd ../../CXX/BuildExamples
```

First let's take a look at the makefile

```
cat Makefile
```

The output should be

```
all: openmp_code

ROCM_GPU ?= $(strip $(shell rocminfo |grep -m 1 -E gfx[^0]{1} | sed -e 's/ *Name: *//'))

CXX1=$(notdir $(CXX))

ifneq ($(findstring amdclang,$(CXX1)),)
  OPENMP_FLAGS = -fopenmp --offload-arch=${ROCM_GPU}
else ifneq ($(findstring clang,$(CXX1)),)
  OPENMP_FLAGS = -fopenmp --offload-arch=${ROCM_GPU}
else ifneq ($(findstring gcc,$(CXX1)),)
  OPENMP_FLAGS = -fopenmp -foffload=-march=${ROCM_GPU}
else ifneq ($(findstring CC,$(CXX1)),)
  OPENMP_FLAGS = -fopenmp
endif

CXXFLAGS = -g -O3 -fstrict-aliasing ${OPENMP_FLAGS}
LDFLAGS = ${OPENMP_FLAGS} -fno-lto -lm

openmp_code: openmp_code.o
    $(CXX) $(LDFLAGS) $^ -o $@

# Cleanup
clean:
```

```
    rm -f *.o openmp_code
    rm -rf build
```

```
module load amdclang
make
```

Now run the executable

```
./openmp_code
```

CMake

Looking at the CMakeLists.txt

```
cat CMakeLists.txt
```

The output should be

```
cmake_minimum_required(VERSION 3.21 FATAL_ERROR)
project(Memory_pragmas LANGUAGES CXX)

set (CMAKE_CXX_STANDARD 17)

if (NOT CMAKE_BUILD_TYPE)
   set(CMAKE_BUILD_TYPE RelWithDebInfo)
endif(NOT CMAKE_BUILD_TYPE)

execute_process(COMMAND rocminfo COMMAND grep -m 1 -E gfx[^0]{1} COMMAND sed -e "s/ *Name: *//" OUTPUT_STRIP_TRAILI

string(REPLACE -O2 -O3 CMAKE_CXX_FLAGS_RELWITHDEBINFO ${CMAKE_CXX_FLAGS_RELWITHDEBINFO})
set(CMAKE_CXX_FLAGS_DEBUG "-ggdb")
set(CMAKE_CXX_FLAGS "-fstrict-aliasing -faligned-allocation -fnew-alignment=256")
if ("${CMAKE_CXX_COMPILER_ID}" STREQUAL "Clang")
   set(CMAKE_CXX_FLAGS "${CMAKE_CXX_FLAGS} -fopenmp --offload-arch=${ROCM_GPU}")
elseif ("${CMAKE_CXX_COMPILER_ID}" STREQUAL "GNU")
   set(CMAKE_CXX_FLAGS "${CMAKE_CXX_FLAGS} -fopenmp -foffload=-march=${ROCM_GPU}")
elseif (CMAKE_CXX_COMPILER_ID MATCHES "Cray")
   set(CMAKE_CXX_FLAGS "${CMAKE_CXX_FLAGS} -fopenmp")
   #the cray compiler decides the offload-arch by loading appropriate modules
   #module load craype-accel-amd-gfx942 for example
endif()

add_executable(openmp_code openmp_code.cc)
```

```
module load amdclang
mkdir build && cd build && cmake ..
make
```

Now run the executable

```
./openmp_code
```

OpenMP Fortran Build systems: make and cmake

README.md in `HPCTrainingExamples/Pragma_Examples/OpenMP/Fortran/BuildExamples` of the Training Examples repository

Build systems for make and cmake are an important starting step to working with OpenMP. We'll show samples for Fortran builds. We'll test them with some of our sample code to make sure your system is setup properly.

Make

```
cd ../../Fortran/BuildExamples
```

First let's take a look at the makefile

```
cat Makefile
```

The output should be

```
all:openmp_code

ROCM_GPU ?= $(strip $(shell rocminfo |grep -m 1 -E gfx[^0]{1} | sed -e 's/ *Name: *//'))

FC1=$(notdir $(FC))

ifneq ($(findstring amdflang, $(FC1)),)
  OPENMP_FLAGS = -fopenmp --offload-arch=${ROCM_GPU}
  FREE_FORM_FLAG = -ffree-form
else ifneq ($(findstring flang, $(FC1)),)
  OPENMP_FLAGS = -fopenmp --offload-arch=${ROCM_GPU}
  FREE_FORM_FLAG = -Mfreeform
else ifneq ($(findstring gfortran,$(FC1)),)
  OPENMP_FLAGS = -fopenmp --offload=-march=$(ROCM_GPU)
  FREE_FORM_FLAG = -ffree-form
else ifneq ($(findstring ftn,$(FC1)),)
  OPENMP_FLAGS = -fopenmp
endif

FFLAGS = -g -O3 ${FREE_FORM_FLAG} ${OPENMP_FLAGS}
ifeq (${FC1},gfortran-13)
  LDFLAGS = ${OPENMP_FLAGS} -fno-lto
else
  LDFLAGS = ${OPENMP_FLAGS}
endif

openmp_code.o: openmp_code.F90
    $(FC) -c $(FFLAGS) $^

openmp_code: openmp_code.o
    $(FC) $(LDFLAGS) $^ -o $@

# Cleanup
clean:
    rm -f *.o openmp_code *.mod
    rm -rf build
```

```
module load amdflang-new
make
```

Now run the executable

```
./openmp_code
```

CMake

Looking at the CMakeLists.txt

```
cat CMakeLists.txt
```

The output should be

```
cmake_minimum_required(VERSION 3.21 FATAL_ERROR)
project(Memory_pragmas LANGUAGES Fortran)

if (NOT CMAKE_BUILD_TYPE)
   set(CMAKE_BUILD_TYPE RelWithDebInfo)
endif(NOT CMAKE_BUILD_TYPE)

execute_process(COMMAND rocminfo COMMAND grep -m 1 -E gfx[^0]{1} COMMAND sed -e "s/ *Name: *//" OUTPUT_STRIP_TRAILI

string(REPLACE -O2 -O3 CMAKE_Fortran_FLAGS_RELWITHDEBINFO ${CMAKE_Fortran_FLAGS_RELWITHDEBINFO})
set(CMAKE_Fortran_FLAGS_DEBUG "-ggdb")
message(${CMAKE_Fortran_COMPILER_ID})
if ("${CMAKE_Fortran_COMPILER_ID}" STREQUAL "Clang")
   set(CMAKE_Fortran_FLAGS "${CMAKE_Fortran_FLAGS} -fopenmp --offload-arch=${ROCM_GPU}")
elseif ("${CMAKE_Fortran_COMPILER_ID}" STREQUAL "GNU")
   set(CMAKE_Fortran_FLAGS "${CMAKE_Fortran_FLAGS} -fopenmp -foffload=-march=${ROCM_GPU}")
elseif (CMAKE_Fortran_COMPILER_ID MATCHES "Cray")
   set(CMAKE_Fortran_FLAGS "${CMAKE_Fortran_FLAGS} -fopenmp")
   #the cray compiler decides the offload-arch by loading appropriate modules
   #module load craype-accel-amd-gfx942 for example
endif()

add_executable(openmp_code openmp_code.F90)
```

```
module load amdflang-new
mkdir build && cd build && cmake ..
make
```

Now run the executable

```
./openmp_code
```

First OpenMP C offload:

README.md from `HPCTrainingExamples/Pragma_Examples/OpenMP/C/1_saxpy` in the Training Examples repository

Porting of saxpy step by step and explore the discrete GPU and APU programming models:

- Part 1: Unified shared memory after Part 1 you may want to explore the exercises 2-5 first with usm before you come to explore the behavior without USM.
- Part 2: Explore differences of `HSA_XNACK=0` and `1`
- Part 3: Map clauses

This exercise will show in a step by step solution how to port a your first kernels.

Part 1: Unified shared memory

For now, set

```
export HSA_XNACK=1
```

to make use of the APU programming model (unified memory).

There are 6 different enumerated folders. (Reccomendation: `vimdiff saxpy.cpp ../<X_saxpy_version>/saxpy.cpp` may help you to see the differences):

0) the serial CPU code.

```
cd 0_saxpy_serial_portyourself
```

Try to port this example yourself. If you are stuck, use the step by step solution in folders 1-6 and read the instructions for those exersices below. Recommendation for your first port: use `#pragma omp requires unified_shared memory` and `export HSA_XNACK=1` (before running) that you do not have to worry about map clauses. Steps 1-3 of the solution assume unified shared memory. Map clauses and investigating the behaviour of `export HSA_XNACK=0` or `=1` is added in the later steps.

- Compile the serial version. Note that `-fopenmp` is required as omp_get_wtime is used to time the loop execution.

```
amdclang++ -fopenmp saxpy.cpp -o saxpy
```

or with the cray environment (aac7):

```
CC -fopenmp saxpy.cpp -o saxpy
```

- Run the serial version.

```
./saxpy
```

Note: you can also use the Makefile.

```
make
```

instead of compiling manually.

You can now try to port the serial CPU version to the GPU

```
vi saxpy.cpp
```

and don't forget to port the Makefile (Hint: What has to be added to compile for the GPU? Note: for cray compilers)

```
vi Makefile
```

or follow the step by step solution: #### 1) Move the computation to the device

```
cd ../1_saxpy_omptarget
```

```
vi saxpy.cpp
```

add `#pragma omp target` to move the loop in the saxpy subroutine to the device. - Compile this first GPU version. Make sure you add `--offload-arch=gfx942` (on MI300A, find out what your system's gfx... is with `rocminfo`)

```
amdclang++ -fopenmp --offload-arch=gfx942 saxpy.cpp -o saxpy
```

(or use the Makefile) - Run

```
./saxpy
```

The observed time is much larger than for the CPU version. More parallelism is required!

2) Add parallelism

```
cd ../2_saxpy_teamsdistribute
vi saxpy.cpp
```

add "teams distribute" - Compile again

```
amdclang++ -fopenmp --offload-arch=gfx942 saxpy.cpp -o saxpy
```

- run again

```
./saxpy
```

The observed time is a bit better than in case 1 but still not the full parallelism is used.

3) Add multi-level parallelism

```
cd ../3_saxpy_parallelforsimd
vi saxpy.cpp
```

add "parallel for" for more parellelism - Compile again

```
amdclang++ -fopenmp --offload-arch=gfx942 saxpy.cpp -o saxpy
```

- run again

```
./saxpy
```

The observed time is much better than all previous versions. Note that the initialization kernel is a warm-up kernel here. If we do not have a warm-up kernel, the observed performance would be significantly worse. Hence the benefit of the accelerator is usually seen only after the first kernel. You can try this by commenting the !$omp target... in the initialize subroutine, then the meassured kernel is the first which touches the arrays used in the kernel.

Reccomendation: After Part 1 you may want to explore the exercises 2-5 first with usm before you come to explore the behavior without USM.

Part 2: Impact of USM

4) Explore impact of unified memory:

```
cd ../4_saxpy_nousm
vi saxpy.cpp
```

The `#pragma omp requires...` line is removed. - Compile again

```
amdclang++ -fopenmp --offload-arch=gfx942 saxpy.cpp -o saxpy
```

- run again

```
./saxpy
```

so far we worked with unfied shared memory and the APU programming model. This allows good performance on MI300A, but not on discrete GPUs. In case you will work on discrete GPUs or want to write portable code for both discrete GPUs and APUs, you have to focus on data management, too.

```
export HSA_XNACK=0
```

to get similar behaviour like on discrete GPUs (with memory copies). Compiling and running this version without any map clauses will result in much worse performance than with unified shared memory and `HSA_XNACK=1` (no memory copies on MI300A).

Part 3: Map clauses

5) map clauses this version introduces map clauses for each kernel.

```
cd ../5_saxpy_map
vi saxpy.cpp
```

see where the map clasues where added. The x vector only has to be maped "to". - Compile again

```
amdclang++ -fopenmp --offload-arch=gfx942 saxpy.cpp -o saxpy
```

- run again

```
./saxpy
```

The performance is not much better than version 4.

6) unstructured data region with enter and exit data clauses the memory is only moved once at the beginning the time to solution should be roughly in the order of magnitude of the unified shared memory version, but still slightly slower as the memory is copied like on discrete GPUs. Test yourself:

```
cd ../6_saxpy_targetdata
```

```
vi saxpy.cpp
```

- Compile again

```
amdclang++ -fopenmp --offload-arch=gfx942 saxpy.cpp -o saxpy
```

- run again

```
./saxpy
```

Additional exercise: What happens to the result, if you comment the `omp target update` ?

```
vi saxpy.cpp
```

Don't forget to recompile after commenting it.

```
amdclang++ -fopenmp --offload-arch=gfx942 saxpy.cpp -o saxpy
```

The results will be wrong! This shows, that proper validation of results is crutial when porting! Before you port a large app, think about your validation strategy before you start. Incremental testing is essential to capture such errors like missing data movement.

Note that this version uses the `new` allocator with an alignment of 128 instead of malloc to control the memory alignment. This is beneficial for improved performance.

7) parameter tuning experiment with num_teams

```
cd ../7_saxpy_numteams
vi saxpy.cpp
```

specify num_teams(...) choose a number of teams you want to test - Compile again

```
amdclang++ -fopenmp --offload-arch=gfx942 saxpy.cpp -o saxpy
```

- run again

```
./saxpy
```

investigating different numbers of teams you will find that the compiler default (without setting this) was already leading to good performance. Tuning e.g. `num_teams` or `thread_limit` may be required for some kernels, but the defaults are chosen quite well for saxpy. saxpy is a very simple kernel, this finding may differ for very complex kernels.

First Fortran OpenMP offload: Porting saxpy step by step and explore the discrete GPU and APU programming models:

README.md from `HPCTrainingExamples/Pragma_Examples/OpenMP/Fortran/1_saxpy` in the Training Examples repository

This exercise will show in a step by step solution how to port a your first kernels. This simple example will not use a Makefile to practice how to compile for the GPU or APU. All following exercises will use a Makefile.

There are 6 different enumerated folders. (Reccomendation: `vimdiff saxpy.f90 ../<X_saxpy_version>/saxpy.f90` may help you to see the differences):

First, prepare the environment (load modules, set environment variables), if you didn't do so before.

Part 1: Porting with unified shared memory enabled

For now, set

```
export HSA_XNACK=1
```

and load the amdflang-new compiler module

```
module load amdflang-new
```

to make use of the APU programming model (unified memory). 0) the serial CPU code.

```
cd 0_saxpy_serial_portyourself
```

Try to port this example yourself. If you are stuck, use the step by step solution in folders 1-6 and read the instructions for those exersices below. Recommendation for your first port: use `!$omp requires unified_shared memory` (in the code after `implicit none` in each module) and `export HSA_XNACK=1` (before running) that you do not have to worry about map clauses. Steps 1-3 of the solution assume unified shared memory. Map clauses and investigating the behaviour of `export HSA_XNACK=0` or `=1` is added in the later steps.

- Compile the serial version. Note that `-fopenmp` is required as omp_get_wtime is used to time the loop execution.

```
amdflang -fopenmp saxpy.F90 -o saxpy
```

- Run the serial version.

```
./saxpy
```

You can now try to port the serial CPU version to the GPU or follow the step by step solution: 1) Move the computation to the device

```
cd ../1_saxpy_omptarget
```

```
vi saxpy.f90
```

add `!$omp target` to move the loop in the saxpy subroutine to the device. - Compile this first GPU version. Make sure you add `--offload-arch=gfx942` (on MI300A, find out what your system's gfx... is with `rocminfo`) on aac6 or aac7 with amdflang-new:

```
amdflang -fopenmp --offload-arch=gfx942 saxpy.F90 -o saxpy
```

or on on aac7 only with ftn:

First, make sure you loaded the right module that offload is enabled before you compile with

```
ftn -fopenmp saxpy.F90 -o saxpy
```

- Run

```
./saxpy
```

The observed time is much larger than for the CPU version. More parallelism is required!

2) Add parallelism

```
cd ../2_saxpy_teamsdistribute
vi saxpy.f90
```

add "teams distribute" - Compile again - run again The observed time is a bit better than in case 1 but still not the full parallelism is used.

3) Add multi-level parallelism

```
cd ../3_saxpy_paralleldosimd
vi saxpy.f90
```

add “parallel do” for more parellelism - Compile again - run again The observed time is much better than all previous versions. Note that the initialization kernel is a warm-up kernel here. If we do not have a warm-up kernel, the observed performance would be significantly worse. Hence the benefit of the accelerator is usually seen only after the first kernel. You can try this by commenting the !$omp target... in the initialize subroutine, then the meassured kernel is the first which touches the arrays used in the kernel.

Part 2: explore the impact of unified shared memory

4) Explore impact of unified memory:

```
cd ../4_saxpy_nousm
vi saxpy.f90
```

The `!$omp requires...` line is removed. - Compile again - run again so far we worked with unfied shared memory and the APU programming model. This allows good performance on MI300A, but not on discrete GPUs. In case you will work on discrete GPUs or want to write portable code for both discrete GPUs and APUs, you have to focus on data management, too.

```
export HSA_XNACK=0
```

to get similar behaviour like on discrete GPUs (with memory copies). Compiling and running this version without any map clauses will result in much worse performance than with unified shared memory and `HSA_XNACK=1` (no memory copies on MI300A).

Part 3: with map clauses

Set

```
export HSA_XNACK=0
```

that the map clauses do have an effect on MI300A.

5) this version introduces map clauses for each kernel.

```
cd ../5_saxpy_map
vi saxpy.f90
```

see where the map clasues where added. The x vector only has to be maped “to”. - compile again - run again The performance is not much better than version 4.

6) with enter and exit data clauses the memory is only moved once at the beginning the time to solution should be roughly in the order of magnitude of the unified shared memory version, but still slightly slower as the memory is copied like on discrete GPUs. Test yourself:

```
cd ../6_saxpy_targetdata
```

```
vi saxpy.f90
```

- compile again
- run again Additional exercise: What happens to the result, if you comment the !$omp target update (in line 29)?

```
vi saxpy.f90
```

- Don’t forget to recompile after commenting it.

The results will be wrong! This shows, that proper validation of results is crutial when porting! Before you port a large app, think about your validation strategy before you start. Incremental testing is essential to capture such errors like missing data movement.

7) experiment with num_teams

```
cd ../7_saxpy_numteams
vi saxpy.f90
```

specify num_teams(...) choose a number of teams you want to test - compile again - run again investigating different numbers of teams you will find that the compiler default (without setting this) was already leading to good performance. saxpy is a very simple kernel, this finding may differ for very complex kernels.

After finishing this introductory exercise, go to the next exercise in the Fortran folder:

```
cd ../..
```

Real World OpenMP Language Constructs

README.md in `HPCTrainingExamples/Pragma_Examples/OpenMP/C/SingleLineConstructs` of the Training Exercises repository.

We start off the real world language constructs by looking at single line compute constructs.

OpenMP Single Line Compute Constructs:

We start with adding a single line directive to move the computation of a loop to the GPU. The exercises for this will utilize the saxpy example.

CPU version

This example uses OpenMP on the CPU with threading for parallelism. The pragma used is

```
#pragma omp parallel for
```

We go to the directory with the example and load the amdclang module. We can then build and run the code.

```
cd HPCTrainingExamples/Pragma_Examples/OpenMP/C/SingleLineConstructs
module load amdclang
make saxpy_cpu
./saxpy_cpu
```

You should get some output like:

```
Time of kernel: 0.188165
check output:
y[0] 4.000000
y[N-1] 4.000000
```

You can use the CPU example and port it to the GPU on your own to get more experience at a later point in time. We will step through the process in these exercises to show you how it is done.

First we will work with a very simple case. It has all the code in a single subroutine with arrays allocated on the stack. This permits the compiler to have as much information as possible. Note that we could also load the new amdflang beta which has a perfectly good amdclang compiler. Also, we have made the array size smaller so that it won't run out of stack space.

```
make saxpy_gpu_singleunit_autoalloc
./saxpy_gpu_singleunit_autoalloc
```

You will get a warning about vectorization that is telling you that you do not need the simd clause for the amdclang compiler. But it compiles fine and creates an executable. We run the executable.

```
./saxpy_gpu_singleunit_autoalloc
```

The output

```
Time of kernel: 0.016511
check output:
y[0] 4.000000
y[N-1] 4.000000
```

We note that we did not have to supply any explicit memory management such as a map clause. The compiler can detect the array sizes and that the arrays need to be moved.

Now let's move on to the next example where we dynamically allocate the arrays. We are still using a single subroutine as the previous example.

```
make saxpy_gpu_singleunit_dynamic
./saxpy_gpu_singleunit_dynamic
```

This time we get the following output on a MI200 series GPU.

```
Queue error - HSA_STATUS_ERROR_MEMORY_FAULT
Display only launched kernel:
Kernel 'omp target in main @ 19 (__omp_offloading_34_4474430_main_l19)'
OFFLOAD ERROR: Memory access fault by GPU 8 (agent 0x5ebda70) at virtual address 0x7f81e79dd000. Reasons: Unknown (
Use 'OFFLOAD_TRACK_ALLOCATION_TRACES=true' to track device allocations
Aborted (core dumped)
```

The error message makes it very clear that we are missing the data for the array. We could follow the advice to get a more detailed report if we do not know what array it is. But we'll take a simpler approach. We'll set the `HSA_XNACK` environment variable to tell the system to manage the memory for us. This will work on the data center AMD Instinct GPUs. For workstation GPUs, you may need to add an explicit map clause.

```
export HSA_XNACK=1
./saxpy_gpu_singleunit_dynamic
```

Now we get the expected output:

```
Time of kernel: 0.063025
check output:
y[0] 4.000000
y[N-1] 4.000000
```

So the compiler can sometimes help with moving the memory in very simple cases. But it doesn't take much complexity before it doesn't have enough information. We return to our original `saxpy_cpu.c` example and change the pragma to direct the compiler to offload the calculation to the GPU as already done in `saxpy_gpu_parallelfor.c` . We keep the `HSA_XNACK=1` setting from before.

```
#pragma omp target teams distribute parallel for simd
```

And building and running the example.

```
make saxpy_gpu_parallelfor
./saxpy_gpu_parallelfor
```

Output

```
Time of kernel: 0.061191
check output:
y[0] 4.000000
y[N-1] 4.000000
```

OpenMP has added a simpler loop directive that you can also use. The pragma line is pretty long for the original directive, so this should make it simpler to add to your program. The new pragma is

```
#pragma omp target teams loop
```

This form generally will produce the same results as the earlier directive. But, in principle, it may give the compiler more freedom how to generate the parallel GPU code.

```
make saxpy_gpu_loop
./saxpy_gpu_loop
```

Even the example is a bit easier to run with less typing.

The output

```
Time of kernel: 0.061429
check output:
y[0] 4.000000
y[N-1] 4.000000
```

So now we have demonstrated how easy it is to add a pragma to a loop to cause it to run on the GPU. And we have seen a little on how the managed memory capability makes the process a little easier. We can focus on parallelizing each loop rather than worrying about where our array data is located.

You can experiment with these examples on both a MI300A APU and a discrete GPU such as MI300X or MI200 series GPU. You should see a performance difference since the MI300A only has to map the pointer and not move the whole array.

We have one more example to look at. Many scientific codes have multi-dimensional data that need to be operated on. We can use the collapse clause to spread out the work from both loops rather than just the outer one. This can be helpful if the outer loop is small. But since we are always trying to generate more work and parallelism, it can also have some benefit for larger outer loops.

We'll consider the case of Fortran since 2-dimensional arrays are much easier to work with. The directive will now become

```
!$omp target teams distribute parallel do collapse(2)
```

Building and running the example

```
export HSA_XNACK=1
make saxpy_gpu_collapse
./saxpy_gpu_collapse
```

And the output

```
Time of kernel: 0.007212
check output:
y[0][0] 4.000000
y[N-1][M-1] 4.000000
```

OpenMP Single Line Compute Constructs:

README.md from `HPCTrainingExamples/Pragma_Examples/OpenMP/Fortran/SingleLineConstructs` in the Training Examples repository

We start with adding a single line directive to move the computation of a loop to the GPU. The exercises for this will utilize the saxpy example.

`NOTE` : the examples in Fortran also work without setting `HSA_XNACK=1` . The reason is that Fortran passes the array size information along with the array. So the compiler has more information to work with. In Fortran, the additional information is called the "dope" vector. It is last century slang for "give me the dope on it". We would say "beta" in today's slang.

CPU version

This example uses OpenMP on the CPU with threading for parallelism. The pragma used is

```
#pragma omp parallel for
```

We go to the directory with the example and load the amdclang module. We can then build and run the code.

```
cd HPCTrainingExamples/Pragma_Examples/OpenMP/Fortran/SingleLineConstructs
module load amdflang-new
make saxpy_cpu
./saxpy_cpu
```

You should get some output like:

```
Time of kernel: 0.151135
plausibility check:
y(1) 4.000000
y(n-1) 4.000000
```

You can use these CPU examples and port them to the GPU on your own to get more experience at a later point in time. We will step through the process in these exercises to show you how it is done.

First we will work with a very simple case. It has all the code in a single subroutine with statically allocated arrays on the stack. This permits the compiler to have as much information as possible. Note that we could also load the regular amdclang module instead of the new amdflang. Also, we have made the array size smaller so that it won't run out of stack space.

```
make saxpy_gpu_singleunit_autoalloc
./saxpy_gpu_singleunit_autoallloc
```

The output

```
Time of kernel: 0.022465
 plausibility check:
y(1) 4.000000
y(n) 4.000000
```

We note that we did not have to supply any explicit memory management such as a map clause. The compiler can detect the array sizes and that the arrays need to be moved.

Now let's move on to the next example where we dynamically allocate the arrays. We are still using a single subroutine as the previous example. Note that, unlike the C case, we are not setting `HSA_XNACK=1` to make the example run (see note at the beginning of this README):

```
make saxpy_gpu_singleunit_dynamic
./saxpy_gpu_singleunit_dynamic
```

This time we get the following output:

```
Time of kernel: 0.022440
 plausibility check:
y(1) 4.000000
y(n) 4.000000
```

We return to our original `saxpy_cpu.c` example and change the pragma to direct the compiler to offload the calculation to the GPU as already done in `saxpy_gpu_paralleldo.F90` . setting from before.

```
#pragma omp target teams distribute parallel for simd
```

And building and running the example.

```
make saxpy_gpu_paralleldo
./saxpy_gpu_paralleldo
```

Output

```
Time of kernel: 0.052156
 plausibility check:
y(1) 4.000000
y(n) 4.000000
```

OpenMP has added a simpler loop directive that you can also use. The pragma line is pretty long for the original directive, so this should make it simpler to add to your program. The new pragma is

```
#pragma omp target teams loop
```

This form generally will produce the same results as the earlier directive. But, in principle, it may give the compiler more freedom how to generate the parallel GPU code.

```
make saxpy_gpu_loop
./saxpy_gpu_loop
```

Even the example is a bit easier to run with less typing.

The output

```
Time of kernel: 0.052010
 plausibility check:
y(1) 4.000000
y(n) 4.000000
```

So now we have demonstrated how easy it is to add a pragma to a loop to cause it to run on the GPU. And we have seen a little on how the managed memory capability makes the process a little easier. We can focus on parallelizing each loop rather than worrying about where our array data is located.

You can experiment with these examples on both a MI300A APU and a discrete GPU such as MI300X or MI200 series GPU. You should see a performance difference since the MI300A only has to map the pointer and not move the whole array.

We have one less example to look at. Many scientific codes have multi-dimensional data that need to be operated on. We can use the collapse clause to spread out the work from both loops rather than just the outer one. This can be helpful if the outer loop is small. But since we are always trying to generate more work and parallelism, it can also have some benefit for larger outer loops.

We'll consider the case of Fortran since 2-dimensional arrays are much easier to work with. The directive will now become

```
!$omp target teams distribute parallel do collapse(2)
```

Building and running the example

```
make saxpy_gpu_collapse
./saxpy_gpu_collapse
```

And the output

```
Time of kernel: 0.029263
 plausibility check:
y(1,1) 4.000000
y(m,n) 4.000000
```

OpenMP complex compute constructs in C

README.md from `HPCTrainingExamples/Pragma_Examples/OpenMP/C/ComplexComputeConstructs` in the Training Examples repository

These exercises explore more complex compute constructs. We begin with breaking apart the meanings of each of the clauses in the single combined compute directive.

First retrieve the examples for this part.

```
git clone https://github.com/amd/HPCTrainingExamples
```

Full combined compute directive

We'll start with a baseline from the full combined compute directive

```
#pragma omp target teams distribute parallel for simd
```

Setting up the environment

```
module load amdclang
export HSA_XNACK=1
export LIBOMPTARGET_KERNEL_TRACE=1
```

This example is in the previous exercises on simple single line compute constructs

```
cd HPCTrainingExamples/Pragma_Examples/OpenMP/C/SingleLineConstructs
```

```
make saxpy_gpu_parallelfor
./saxpy_gpu_parallelfor
```

Check the output. It should be something like the following, but with some variation depending on the GPU model you are on.

```
DEVID:  0 SGN:5 ConstWGSize:256  args: 5 teamsXthrds:( 416X 256) reqd:(   0X   0) lds_usage:0B sgpr_count:24 vgpr_c
Time of kernel: 0.082906
```

There are 416 teams (workgroups) of size 256. There is a low vector register usage a 8. We'll also look at the run-time of 0.082906 for comparison.

Target directive

We'll start with what happens with just the target directive

cd HPCTrainingExamples/Pragma_Examples/OpenMP/C/ComplexComputeConstructs

Setting up the environment

```
module load amdclang
export HSA_XNACK=1
export LIBOMPTARGET_KERNEL_INFO=1
```

```
make saxpy_gpu_target
./saxpy_gpu_target
```

The output will be similar to the following:

```
DEVID:  0 SGN:3 ConstWGSize:257  args: 5 teamsXthrds:(   1X 256) reqd:(   0X   0) lds_usage:16B sgpr_count:16 vgpr_
Time of kernel: 5.407085
```

We only have one team of 256 workgroup size. Basically we are running serial – one thread on one team (workgroup). The runtime reflects that with 65 times longer than the combined directive.

Teams clause

The teams exercise will add the teams clause after the target directive.

```
make saxpy_gpu_target_teams
./saxpy_gpu_target_teams
```

The output

```
DEVID:  0 SGN:3 ConstWGSize:257  args: 5 teamsXthrds:( 624X 256) reqd:(   0X   0) lds_usage:16B sgpr_count:12 vgpr_
Time of kernel: 11.166301
```

There are 624 workgroups, but each one is doing all the work. This duplicates the effort and ends up taking twice the time as the target directive alone. Note that this is also creating a race condition when threads are trying to write to the same location, which produces an incorrect output that is also non deterministic. One could add `num_teams(1)` to the pragma directive to require the creation of a single team, in which case no race condition can occur.

Distribute clause Adding the distribute clause starts to get some parallelism by partitioning the work across the workgroups. But still with only one thread per workgroup.

```
make saxpy_gpu_target_teams_distribute
./saxpy_gpu_target_teams_distribute
```

Output

```
DEVID:  0 SGN:3 ConstWGSize:257  args: 5 teamsXthrds:( 624X 256) reqd:(   0X   0) lds_usage:16B sgpr_count:24 vgpr_
Time of kernel: 0.149113
```

We have more workgroups at 624 than the baseline case, but we are not using all the threads. This is using more of the compute capacity at 624/416 times as many workgroups and associated compute units. The runtime is much closer to the baseline. As a further exploration, try changing the array size in the example or trying a different kernel with more work.

parallel for without the teams distribute clauses As a further experiment, let's try just adding parallel for to engage all the threads on one workgroup. The directive is the following:

```
#pragma omp target parallel for
```

Building and running it

```
make saxpy_gpu_parallel_for
./saxpy_gpu_parallel_for
```

Output should be something like

```
DEVID:  0 SGN:2 ConstWGSize:256  args: 5 teamsXthrds:(   1X 256) reqd:(   0X   0) lds_usage:32B sgpr_count:25 vgpr_
Time of kernel: 0.126748
```

This gives a pretty good runtime while using fewer GPU compute units.

Split multi-level directive

Build both the collapse and split level C examples.

```
make saxpy_gpu_collapse
./saxpy_gpu_collapse
make saxpy_gpu_split_level
./saxpy_gpu_split_level
```

Compare the output from LIBOMPTARGET_KERNEL_TRACE=1.

```
DEVID:  0 SGN:5 ConstWGSize:256  args: 6 teamsXthrds:(3907X 256) reqd:(   0X   0) lds_usage:0B sgpr_count:29 vgpr_c

Time of kernel: 0.027777

DEVID:  0 SGN:3 ConstWGSize:257  args: 6 teamsXthrds:( 416X 256) reqd:(   0X   0) lds_usage:36B sgpr_count:27 vgpr_

Time of kernel: 0.027449
```

On your own: try different array sizes and ratios of iterations between the loop levels.

OpenMP complex compute constructs in Fortran

README.md from `HPCTrainingExamples/Pragma_Examples/OpenMP/Fortran/ComplexComputeConstructs` in the Training Examples repository

To compile:

```
module load amdclang
make
```

Note from above that you do not need to do `export HSA_XNACK=1` for these examples. These exercises explore more complex compute constructs. The exercises are analogous to those in `../../C/ComplexComputeConstructs` so we recommend you check out the instructions in the `README` located in that directory for details about the specific examples.

Reduction exercise:

README.md from `HPCTrainingExamples/Pragma_Examples/OpenMP/C/2_reduction` from the Training Examples repository.

This exercise will show how to port a reduction.

0) serial CPU version Version to port yourself. Don't forget to port the Makefile.

```
cd 0_reduction_portyourself
```

Build

```
make
```

run

```
./vecadd
```

Remember the output result for the serial version to validate the offload version. Adapt Makefile for offload. Port the example, build and run after every kernel you ported to ensure correctness.

1) solution with unified shared memory Set `export HSA_XNACK=1` to test this version.

```
cd 1_reduction_usm
```

Build

```
make
```

run

```
./reduction
```

Note: you may want to use `vimdiff <file1> <file2>` to compare your solution with this version.

2) solution with map clauses Set `export HSA_XNACK=0` to test this version.

```
cd 2_reduction_map
```

Build

```
make
```

run

```
./reduction
```

Note: you may want to use `vimdiff <file1> <file2>` to compare your solution with this version.

Porting exercise: reduction

README.md from `HPCTrainingExamples/Pragma_Examples/OpenMP/Fortran/2_reduction` from the Training Examples repository.

This exercise focusses on two things: - Part 1: how to port a reduction to the GPU - Part 2: importance of map clauses on discrete GPUs or HSA_XNACK=0 on MI300A

First, prepare the environment (loading modules, set environment variables), if you didn't do so before. ### For Part 1 and 2: serial CPU version to port 0) a version to port yourself.

```
cd 0_reduction_portyourself
vi freduce.F
```

- Only port the Makefile and the reduction itself. This exercise focusses on how to implement a reduction, not on porting the full example.

How to build all versions:

```
make
```

and run:

```
./freduce
```

The other folders 1 and 2 have different flavors of the solution: ### Part 1: Port with unified shared memory

```
cd 1_reduction_solution_usm
vi freduce.F
```

contains a sample solution for unified shared memory / APU programming model (correct output: each element 1010) run this with setting `export HSA_XNACK=1` in advance

Part 2: Port with map clause

2.1 Porting exercise

```
cd 2_reduction_solution
vi freduce.F
```

Contains a sample solution for discrete GPUs (correct output: each element 1010) run this with setting `export HSA_XNACK=0` in advance #### 2.2 Behaviour with and without USM The third folder contains an exercise to explore the behavior with and without USM:

```
cd 3_reduction_solution
vi freduce.F
```

This example intentionally does the mapping wrong (from instead of to). You can see how the result changes (output 1000 instead of 1010) when you use export `export XSA_XNACK=0` . No error is shown, but the result is wrong. Test the same wrong code with `export HSA_XNACK=1` , then the result is correct again as mapping clauses are ignored. Take home message: if you develop for both APUs and discrete GPUs on MI300A, check if the results are the same for `HSA_XNACK=0` and `=1` as map clauses will be ignored with `HSA_XNACK=1` ! Ignoring memory copies is great for code portability and performance without code changes, but be careful to include proper validation checks during development for both discrete GPUs and APUs.

Porting exercise reduction of multiple scalars in one kernel

README.md from `HPCTrainingExamples/Pragma_Examples/OpenMP/C/4_reduction_scalars` from the Training Examples repository.

This folder has two code versions:

0) a serial cpu version to port yourself. Hint: don't forget to port the Makefile.

Build:

```
make
```

Run:

```
./reduction_scalar
```

1) an openmp offload ported solution. The solution shows how you can do a reduction of multiple scalars in one kernel. Note that scalars do not need to be explicitly mapped.

Porting exercise reduction of multiple scalars in one kernel

README.md from `HPCTrainingExamples/Pragma_Examples/OpenMP/Fortran/4_reduction_scalars` from the Training Examples repository.

This folder has two code versions:

0) a serial cpu version to port yourself.

Hint: don't forget to port the Makefile.

Build:

```
make
```

Run:

```
./reduction_scalar
```

1) an openmp offload ported solution. It shows how you can do a reduction of multiple scalars in one kernel. Note that scalars do not need to be explicitly mapped.

Porting exercise reduction into an array

README.md from `HPCTrainingExamples/Pragma_Examples/OpenMP/C/6_reduction_array` from the Training Examples repository.

This folder has two code versions:

0) a serial cpu version to port yourself. Hint: don't forget to port the Makefile.

Build:

```
make
```

Run:

```
./reduction_array
```

1) an openmp offload ported solution. The solution shows how you can do a reduction of multiple values into an array in one kernel.

Porting exercise reduction of multiple scalars in one kernel

README.md from `HPCTrainingExamples/Pragma_Examples/OpenMP/Fortran/9_reduction_array` from the Training Examples repository.

This folder has two code versions:

0) a serial cpu version to port yourself.

Hint: don't forget to port the Makefile.

Build:

```
make
```

Run:

```
./reduction_scalar
```

1) an openmp offload ported solution. The solution shows how you can do a reduction of multiple values into an array in one kernel.

C Code – Porting device routine exercises

README.md from `HPCTrainingExamples/Pragma_Examples/OpenMP/C/5_device_routines` in Training Examples repository

This exercise will show how to port kernels which call a subroutine or function. Each version has a sub-folder with a - serial CPU version to port yourself and a - solution for unified memory and - a solution with map clauses.

Build and run analogous to the previous exercises.

There are three different versions:

```
cd 1_device_routine
```

Explore the serial CPU code first.

```
cd 0_device_routine_portyourself
module load amdclang
make
./device_routine
```

The rocm module will be loaded with the amdclang module. And the current rocm module will set `HSA_XNACK=1` . If there are no modules set up on your system, set the `CC` environment variable to the full path to the C compiler you want to use. Add the ROCm directory to the PATH and also the LLVM directory under ROCm. Also add the lib directory to the `LD_LIBRARY_PATH` . And finally set `HSA_XNACK` with `export HSA_XNACK=1` .

```
make
./device_routine
```

You should see the result:

```
Result: sum of x is 1000.000000
```

Now try and convert the example to run on the GPU. Start with adding `#pragma omp target teams distribute parallel` before the for loops in the main program in `device_routine.c` . Note that one of the loops also needs a `reduction(+:sum)` clause added to the target directive. How do you show the compiler to compile the function in the other file, compute.c, for the GPU? Try adding the `#pragma omp declare target` directive to the subroutine declaration in compute.c.

There are two solutions for this exercise. One with the APU programming model using unified shared memory. The other has explicit map clauses for when unified shared memory is not available or not being used. We'll look at the unified shared memory version first.

```
cd ../1_device_routine_usm
```

Look at the two C source files and compare to the originals in `0_device_routine_portyourself` . To build and run the example:

```
make
./device_routine
```

Similarly with the solution using map clauses:

```
cd ../2_device_routine_map
```

Look for the map clauses in the `device_routine.c` source file. In this case, The memory is only accessed on the GPU. So, we use map(alloc:x[0:N]) and map(release:x[0:N]) in the clauses. Build and run the examples.

```
make
./device_routine
```

```
cd 2_device_routine_wglobaldata
```

First look at the original code in `0_device_routine_wglobaldata_portyourself` .

```
cd 0_device_routine_wglobaldata_portyourself
```

Note the addition of the `global_data.c` file with the definition of the constants array. Build and run the example.

```
make
./device_routine
```

Now try modifying the example to run on the GPU. How do you use the global data from the `global_data.c` file in your device subroutine?

For the solution, lets look at the example in `1_device_routine_wglobaldata` .

```
cd 1_device_routine_wglobaldata
```

Look at the directive `#pragma omp declare target` in the `global_data.c` file. Is this necessary for your version of the compiler?

It is a bit more complicated if the data being used is dynamically allocated. We have to be sure and map it over to the GPU after the memory allocation. We can experiment with this case in the next example.

```
cd ../3_device_routine_wdynglobaldata
```

Again there is a version that you can try and port before looking at the solution.

```
cd 0_device_routine_wdynglobaldata_portyourself
```

Look at the `global_data.c` file and experiment with the right directive to move the data to the GPU.

The solution is also available.

```
cd 1_device_routine_wdynglobaldata
```

See the directives used to move the constants array to the GPU. Note that we also need to add declare target on the pointer to the array.

```
#pragma omp target enter data map(alloc:constants[0:isize])
```

In this example, we initialize the data on the GPU with:

```
#pragma omp target teams distribute parallel for
   for (int i = 0; i< isize; i++) {
      constants[i] = (double)i;
   }
```

How would this be different if we initialized the data on the CPU?

Part 1: Fortran with interface blocks

README.md from `HPCTrainingExamples/Pragma_Examples/OpenMP/Fortran/5_device_routines` in Training Examples repository

Let's start with the device routine in a separate file with an interface.

```
cd device_routine_with_interface
```

there are six code versions in enumerated folders:

```
0_device_routine_portyourself
1_device_routine_wrong
2_device_routine_usm
3_device_routine_map
4_device_routine_device_type
5_device_routine_enter_data
```

Starting with the CPU version to try and porting yourself

```
cd 0_device_routine_portyourself
```

Build and run

```
make
./device_routine
```

The result should be

```
Result: sum of x is 1000.000000000000
```

Now add the directive to the three loops in `device_compute.f90`

```
!$omp target teams distribute parallel do
```

For the last loop, it is also necessary to add `reduction(+:sum)`

This has been done for you in the `1_device_routine_wrong` directory

```
cd ../1_device_routine_wrong
```

Build the code

```
make
```

You should see an error.

```
ld.lld: error: undefined symbol: compute_
```

The compute routine is created only for the host and not for the device. So we need to add the device target directive to the compute subroutine definition in `compute.f90` .

Moving to the next version at 2_device_routine_usm directory where the device target directive has been added.

```
cd ../2_device_routine_usm
```

Note the additions. In compute.f90:

```
      subroutine compute(x)
          implicit none
          !$omp requires unified_shared_memory
          !$omp declare target
```

and in device_compute.f90

```
 program device routine
...
         implicit none
         !$omp requires unified_shared_memory

...
```

Now build and run the example

```
make
./device_routine
```

For the case where we want to do explicit memory movement, we use maps as show in `03_device_routine_map` .

```
cd ../03_device_routine_map
```

We take out the `!$omp requires unified_shared_memory` and add `map(tofrom:x)` and `map(to:x)` clauses. We can run this example as before:

```
make
./device_routine
```

Some of the other clauses that can be uses are the `device_type(nohost)` that only generates device code for the declare target clauses. Check out the example at

```
cd ../4_device_routine_device_type
make
./device_routine
```

The last example shows the use of the enter/exit data directives. This is an example of the use of unstructured data movement directives.

```
!$omp target enter data map(alloc:x(1:N))
!$omp target exit data map(delete:x)
```

These are added to the code in `5_device_routine_enter_data`

```
cd ../5_device_routine_enter_data
make
./device_routine
```

Part 2: Fortran with modules

There are three versions

```
0_device_routine_with_module_portyourself
1_device_routine_with_module
2_device_routine_with_module_usm
```

We first check out the original code in `0_device_routine_with_module_portyourself`

```
cd 0_device_routine_with_module_portyourself
```

Build and run

```
make
./device_routine
make clean
```

Now try and add the directives to port the example code to run on the device (GPU).

The solution for explicit data movement using unstructured memory directives is in `1_device_routine_with_module`

```
cd ../1_device_routine_with_module
make
./device_routine
```

Examining the two source files, we see that we first need to add the compute directives:

```
!$omp target teams distribute parallel do
!$omp target teams distribute parallel do reduction(+:sum)
```

In addition, we need the explicit memory movement directives

```
!$omp target enter data map(alloc:x(1:N))
!$omp target exit data map(delete:x)
```

But that is not all we need to do. We also need to add `!$omp declare target` in compute.f90 to tell the compiler to generate a device version of the compute subroutine.

The next example shows the unified shared memory version.

```
cd ../2_device_routine_with_module_usm
```

We need to add `!$omp requires unified_shared_memory` to both source code files since they both will have OpenMP target directives. Now we just need to add the compute directives as above and also add the `!$omp declare target` directive inside the subroutine definition in computemod.f90.

Now build and run

```
make
./device_routine
```

C++ member function

README.md from `HPCTrainingExamples/Pragma_Examples/OpenMP/CXX/5_device_routines` in Training Examples repository

The first example is where there is a compute method in the Science class that is called from a parallel target region.

```
cd 1_member_function
```

The original code is shown in `0_member_function_portyourself`

```
cd 0_member_function_portyourself
```

Try adding the `#pragma omp target teams loop` directive to the loop in the `bigscience.cc` routine to port it to run on the device.

To see the solution to the porting, see the code in `1_member_function` directory.

Looking at the loop in `bigscience.cc` :

```
#pragma omp target teams loop
   for (int k = 0; k < N; k++){
      myscienceclass.compute(&x[k], N);
   }
```

To try out the code, compile it and run it.

```
make
./bigscience
```

Note that nothing needs to be done to the class in `Science.hh` . Why is this? Basically, the defined method function in `Science.hh` is in-lined into the `bigscience.cc` file. So it is handled by the directive added around the loop in `bigscience.cc` .

C++ member function external

So what happens when the compute method is defined in a different file? For this case, let's take a look at the next example in `2_method_function_external` .

```
cd ../2_method_function_external
```

Try porting the code in `0_member_function_external_portyourself` . Note that in this example, the compute member function is defined in `Science_member_functions.cc`

For the solution, go to the `1_member_function_external` directory

```
cd ../1_member_function_external
```

Note that now we have to add `#pragma omp declare target` around the compute method definition. We also need a `#pragma omp end declare target` directive to close out the declare target region.

Let's try compiling and running the example

```
make
./bigscience
```

The next example, `2_member_function_external_data` uses a data value `init_value` from the Science class. The thing to note is that we do not need to add a `#pragma omp declare target` around the declaration in the class.

Check that this runs fine with your compiler

```
cd ../2_member_function_external_data
make
./bigscience
```

C++ virtual methods

Additional complexity in C++ classes can cause difficulties with porting to GPUs. Fundamentally, the GPU language is C with only a little support for C++. So let's take a look at a simple virtual method where class inheritance is used.

```
cd ../../3_virtual_methods
```

The original CPU C++ code is given in `0_virtual_methods_portyourself` . We create a new HotScience class that is based on the Science class. The new class is defined in `HotScience.hh` . It overrides the compute method. The method definition for the new compute function is in `HotScience_member_functions.cc` .

First, let's verify that the original code works.

```
cd 0_virtual_methods_portyourself
make
./bigscience
```

Try porting this version and see what might be required.

The solution is given in `1_virtual_methods` directory.

```
cd ../1_virtual_methods
```

Examine the source code files to see what is needed. Note that now the `#pragma omp declare target` block is needed around the method definition in `HotScience_member_functions.cc` . Let's verify that this works with your current compiler.

```
make
./bigscience
```

A special note here for the current amdclang++ compiler. With the changes to the source code, the compiler issues a warning about maybe not being mapped correctly

```
warning: type 'HotScience' is not trivially copyable and not guaranteed to be mapped correctly
```

The code still compiles and runs properly. To suppress the warning, `-Wno-openmp-mapping` has been added to CXXFLAGS in the Makefile.

Exercise: mapping of different datatypes

README.md in `HPCTrainingExamples/Pragma_Examples/OpenMP/Fortran/7_derived_types` of the Training Exercises repository.

This exercise explores the possibilities of mapping derived types. This is one of the main challenges one may encounter when porting a Fortran app to discrete GPUs. This exercise also shows that on the APU using `HSA_XNACK=1` such problems do not exist. Note: This exercise was designed for amdflang-new.

Compile the examples:

```
make
```

first, set

```
export HSA_XNACK=0
```

to explore the behaviour similar to a discrete GPU (Remark: `vimdiff file1 file2` may help to find the differences).

Explore and run the four examples:

1) The first example leaves the mapping to the compiler

Run:

```
./dtype_derived_type_automap
```

this results in a memory access fault. Hence, this implementation is wrong on a discrete GPU (or MI300A: disabling HSA_XNACK).

3) The second example adds mapping clauses for the allocatable array which is a member of the derived type

Run:

```
./dtype_derived_type
```

this again results in a memory access fault

5) The third example provides a solution: a pointer to the allocatable array is introduced

Run:

```
./dtype_pointer
```

6) In example 2 and 3 the scalars used for the range of the loop were replaced by integer numbers to see the impact of the allocatable array only. In this forth example they are re-introduced. This example shows, that mapping of scalar members of derived types is working.

Run:

```
./dtype_scalar_members
```

8) When you run the unified shared memory version with XNACK off, you will get a warning and the same memory access fault as in example 1 and two

```
./dtype_derived_type_usm
```

AMDGPU message: Running a program that requires XNACK on a system where XNACK is disabled. This may cause problems when using an OS-allocated pointer inside a target region. Re-run with HSA_XNACK=1 to remove this warning.

Now switch on unified shared memory by

```
export HSA_XNACK=1
```

Run all the five examples again. All of them should run sucessfully.

Set

```
export LIBOMPTARGET_INFO=-1
```

with the amdflang-new compiler or

```
export CRAY_ACC_DEBUG=1
```

if you work with the ftn compiler.

Run example 3 with and without unified shared memory (export HSA_XNACK=1 and HSA___XNACK=0) You are able to see host to device copies in the shown log in the case of HSA_XNACK=0. In the case of HSA_XNACK=1 those copies are gone and this message is shown:

AMDGPU device 0 info: Application configured to run in zero-copy using auto zero-copy.

Hence, if a discrete GPU program is compiled with HSA_XNACK=1 on MI300A, memory copies are automatically ignored. This makes code portable between discrete GPUs an APUs. Include !$omp requires_unified_shared_memory at the top of the program (after implicit none) such that the compiler can make full use of the APU programming model. This is shown in example code 5. When you compare the code examples, the unified_shared_memory version dtype_derived_type_usm (version 5) is very simple to implement. If you only work on an APU, this is the easiest way to port, as mapping clauses are not required to obtain good performance.

You may want to set

```
export LIBOMPTARGET_INFO=0
```

before you run the next exercise.

OpenMP Offloading for C++ Codes that use Classes

README.md in `HPCTrainingExamples/Pragma_Examples/OpenMP/CXX/cpp_classes` from the Training Examples repository

These examples show how to use OpenMP for GPU offloading in the context of a C++ code that makes uses of classes, and a programming paradigm where the most relevant members of the class are private, with their associated values accessed and modified by appropriate `get` and `set` functions.

In the present directory, you will find two subdirectories, one called `usm` and one called `explicit` .

The `usm` Sub-directory

In this context, `usm` stands for unified shared memory, which is what we are requiring for the code samples in this directory. To compile the code in the `usm` directory, do:

```
module load rocm
module load amdclang
export HSA_XNACK=1
make
```

If the `amdclang` module is not available on your system, make sure to do:

```
export CXX=$ROCM_PATH/llvm/bin/amdclang++
```

before running the `make` command.

Note that if one was to not set `HSA_XNACK=1` the code would not compile, because we are requiring unified shared memory with the following pragma line in `main.cpp` :

```
#pragma omp requires unified_shared_memory
```

You may have noticed many compiler warnings such as this one:

```
main.cpp:22:20: warning: Type 'daxpy' is not trivially copyable and not guaranteed to be mapped correctly [-Wopenmp
   22 |       double val = data.getConst() * data.getX(i) + data.getY(i);
```

From the warning, you can already see what potential issues can arise in a C++ programming paradigm like the one we decided to set ourselves in. When possible, using unified shared memory can help get around those warnings.

In the `usm` directory, there are two subdirectories, `daxpy` and `operations` .

The `daxpy` Sub-directory Here we are defining a class object to perform a daxpy operation. Notice that the daxpy operation is performed within the `main.cpp` . Moreover, we are using the `get` and `set` member functions of the daxpy class from within the target region without using any maps, thanks to the unified shared memory framework.

The `operations` Sub-Directory The code in the `operations` directory adds one layer of complexity and performs a daxpy from the `main.cpp` file but using a class called `operations` that has two members of class type: one of type `daxpy` , already mentioned before, and one of type `norm` , which will compute a user-defined norm of an input vector, in this case the output of the daxpy operation. Note that everything works seamlessly even when calling member functions from the `ops` object: these member functions are wrappers to the member functions of the `daxpy` and `norm` class members.

The `explicit` Sub-directory

This sub-directory contains example code that is meant to work even without enabling unified shared memory, meaning that it will compile and run regardless of whether `HSA_XNACK=1` . This is achieved by creating an appropriate data environment with the use of maps, as it will explained next. To compile:

```
module load rocm
module load amdclang
make
```

Again, make sure that the CXX environment variable is set as below, before running the `make` command:

```
export CXX=$ROCM_PATH/llvm/bin/amdclang++
```

The directory is named `explicit` because we are explicitly taking care of all the data movement between host and device, helping the compiler with figuring out how to perform the offload to GPU. The only sub-directory here is `daxpy` .

The `daxpy` Sub-directory The explicit memory movement scenario gets tricky really quickly, as you have seen with the numerous warning messages produced by the compiler when building the `usm` examples. Things get particularly complicated when using anything that is not just a pointer for our data members, such as for instance standard vectors, like we were doing in the `usm` directory. In the `daxpy.hpp` file where the `daxpy` class is declared, we have now included in the constructor the following pragma:

```
#pragma omp target enter data map(alloc: x_[0:N_],y_[0:N_]) map(to: a_)
```

The above pragma creates a data environment for an unstructured data region and maps x_, y_, N_ and a_ to the device. Note that we also had to explicitly map the scalars to make sure that they are available on the device when we call the `apply` function, which is defined in `daxpy.cpp` . The following pragma is included in the destructor for the class:

```
#pragma omp target exit data map(delete: x_[0:N_],y_[0:N_], a_)
```

Submodule test – does the Fortran compiler support the new submodules feature in the Fortran 2008 standard (extension in 2003)

README.md in `HPCTrainingExamples/Pragma_Examples/OpenMP/Fortran/Submodules` of the Training Exercises repository.

Try with the old flang compiler – Load the amdclang module and you get

```
make
```

```
/opt/rocm-6.4.0/llvm/bin/amdflang -c -g -O3 -fopenmp interface.f90
/opt/rocm-6.4.0/llvm/bin/amdflang -c -g -O3 -fopenmp impl.f90
F90-S-1059-The definition of subprogram module_func_impl does not have the same number of arguments as its declarat
  0 inform,   0 warnings,   1 severes, 0 fatal for module_func_impl
make: *** [Makefile:11: impl.o] Error 1
```

Try with a recent next generation flang compiler

```
make
```

```
/opt/rocmplus-6.4.0/rocm-afar-6.1.0/bin/amdflang -c -g -O3 -fopenmp interface.f90
/opt/rocmplus-6.4.0/rocm-afar-6.1.0/bin/amdflang -c -g -O3 -fopenmp impl.f90
```

Introduction to HIP Exercises

HIP/basic_examples Documentation

Table of Contents

1. `01_error_check`
2. `02_add_d2h_data_transfer`
3. `03_complete_square_elements`
4. `04_complete_matrix_multiply`
5. `05_compare_with_library`
6. `06_hipify_pingpong`
7. `07_matrix_multiply_shared`

Please refer to the individual directories for documentation specific to each exercise.

Find the error

README.md in `HPCTrainingExamples/HIP/01_error_check` of the Training Exercises repository.

Compile and run the vector addition program and use the error from the error-checking macro to decide how to fix the problem.

To compile and run:

```
$ make
```

```
$ sbatch -A <account-name> submit.sh
```

where `account-name` is your account name for the system (may be required for certain systems). A job file titled `<name-of-exercise>-%J.out` will be produced, where `%J` is the job id number of your run. To check your program output, simply run:

```
cat <name-of-exercise>-%J.out
```

Add the device-to-host data transfer

README.md in `HPCTrainingExamples/HIP/02_add_d2h_data_transfer` of the Training Exercises repository.

This example simply initializes an array of integers to 0 on the host, sends the 0s from the host array to the device array, then adds 1 to each element in the kernel, then sends the 1s back to the host array.

However, the device-to-host data transfer call (`hipMemcpy`) is missing. Please add in the missing call and run the program. Look for the TODO.

This is the API call to use:

```
hipError_t hipMemcpy(void *dst, void *src, size_t size_in_bytes, hipMemcpyKind kind)
```

To compile and run:

```
$ make
```

```
$ sbatch -A <account-name> submit.sh
```

where `account-name` is your account name for the system (may be required for certain systems). A job file titled `<name-of-exercise>-%J.out` will be produced, where `%J` is the job id number of your run. To check your program output, simply run:

```
cat <name-of-exercise>-%J.out
```

Complete the square elements kernel

README.md in `HPCTrainingExamples/HIP/03_complete_square_elements` of the Training Exercises repository.

In this exercise, there is a host array and a device array. The host array is initialized in a loop so each element is given the value of the iteration from 0 to N-1. Then the host array is copied to the device array, and the GPU kernel simply squares each element of the array. Then the results are sent back from the device array to the host array.

However, the kernel is not complete. So you must complete the kernel by adding in the line where the value is squared, and make sure to guard for going out of the array bounds. Look for the TODO.

To compile and run:

```
$ make
```

```
$ sbatch -A <account-name> submit.sh
```

where `account-name` is your account name for the system (may be required for certain systems). A job file titled `<name-of-exercise>-%J.out` will be produced, where `%J` is the job id number of your run. To check your program output, simply run:

```
cat <name-of-exercise>-%J.out
```

Complete the matrix multiply kernel

README.md in `HPCTrainingExamples/HIP//04_complete_matrix_multiply` of the Training Exercises repository.

In this exercise, a matrix multiply is performed on the GPU. In the code, the indices `row_index` and `col_index` iterate through the arrays in row-major (across the first row, then across the second row, etc.) and column-major (down the first column, then down the second column, etc.) order, respectively.

Look at the matrix multiply kernel and decide which of these two indices should define the elements of arrays A and B. Look for the TODO.

To compile and run:

```
$ make
```

```
$ sbatch -A <account-name> submit.sh
```

where `account-name` is your account name for the system (may be required for certain systems). A job file titled `<name-of-exercise>-%J.out` will be produced, where `%J` is the job id number of your run. To check your program output, simply run:

```
cat <name-of-exercise>-%J.out
```

Complete the matrix multiply kernel

README.md in `HPCTrainingExamples/HIP/05_compare_with_library` of the Training Exercises repository.

In this exercise, we will use the `matrix_multiply` kernel we completed in `04_complete_the_kernel` and compare its performance against the hipBLAS version of DGEMM.

You will not need to make any code changes. Instead, you will simply compile the code and submit the job. This will run the code under the `rocprof` profiling tool and parse the results.

To compile and run:

```
$ make
```

```
$ sbatch -A <account-name> submit.sh
```

where `account-name` is your account name for the system (may be required for certain systems). A job file titled `<name-of-exercise>-%J.out` will be produced, where `%J` is the job id number of your run. To check your program output, simply run:

```
cat <name-of-exercise>-%J.out
```

To view the resulting profile, run the python script:

```
./parse_output.py
```

It should be clear from the performance difference that using existing libraries is typically the right choice instead of re-inventing the (slower) wheel.

hipify the CUDA pingpong code

README.md in `HPCTrainingExamples/HIP/06_hipify_pingpong` of the Training Exercises repository.

This code sends data back and forth between the host and device 50 times and calculates the bandwidth.

Your job is to `hipify` the code, then compile and run it. For this exercise, it is recommend to use `hipify-perl` on the CUDA program and redirect the output to a new file titled `pingpong.cpp` . NOTE: The `#include "hip/hip_runtime.h" doesn't always get added when a code is` hipify'-ed, so it might need to be added manually.

To compile and run:

```
$ make
```

```
$ sbatch -A <account-name> submit.sh
```

where `account-name` is your assigned Frontier username. A job file titled `<name-of-exercise>-%J.out` will be produced, where `%J` is the job id number of your run. To check your program output, simply run:

```
cat <name-of-exercise>-%J.out
```

or open the file directly using `vim` .

Recall that the CPU and GPU are connected with PCIe4 (x16), which has a peak bandwidth of 32 GB/s. What percentage of the peak performance do we achieve?

Complete the matrix multiply with shared memory

README.md in `HPCTrainingExamples/HIP/07_matrix_multiply_shared` of the Training Exercises repository.

In this example, a matrix multiply is performed with shared memory, where each thread computes 1 element of the resultant matrix.

NOTE: The shared memory allocations are only of size `THREADS_PER_BLOCK` , which is smaller than the array size. So each thread must loop through its dot-product (since that's what each element of the resultant matrix is) in chunks until it completes the full dot product.

Your job in this exercise is to correctly copy the data from global memory into the shared memory arrays, then compile and run the program.

To compile and run:

```
$ make
```

```
$ sbatch -A <account-name> submit.sh
```

where `account-name` is your assigned Frontier username. A job file titled `<name-of-exercise>-%J.out` will be produced, where `%J` is the job id number of your run. To check your program output, simply run:

```
cat <name-of-exercise>-%J.out
```

Porting Applications to HIP

Hipify Examples

NOTE: these exercises have been tested on MI210 and MI300A accelerators using a container environment. To see details on the container environment (such as operating system and modules available) please see `README.md` on this repo.

Exercise 1: Manual code conversion from CUDA to HIP (10 min)

Choose one or more of the CUDA samples in `HPCTrainingExamples/HIPIFY/mini-nbody/cuda` directory. Manually convert it to HIP. Tip: for example, the cudaMalloc will be called hipMalloc. You can choose from `nbody-block.cu, nbody-orig.cu, nbody-soa.cu`

You'll want to compile on the node you've been allocated so that hipcc will choose the correct GPU architecture.

Exercise 2: Code conversion from CUDA to HIP using HIPify tools (10 min)

Use the `hipify-perl` script to "hipify" the CUDA samples you used to manually convert to HIP in Exercise 1. hipify-perl is in `$ROCM_PATH/hip/bin` directory and should be in your path.

First test the conversion to see what will be converted

```
hipify-perl -examine nbody-orig.cu
```

You'll see the statistics of HIP APIs that will be generated. The output might be different depending on the ROCm version.

```
[HIPIFY] info: file 'nbody-orig.cu' statistics:
  CONVERTED refs count: 7
  TOTAL lines of code: 91
  WARNINGS: 0
[HIPIFY] info: CONVERTED refs by names:
```

```
  cudaFree => hipFree: 1
  cudaMalloc => hipMalloc: 1
  cudaMemcpyDeviceToHost => hipMemcpyDeviceToHost: 1
  cudaMemcpyHostToDevice => hipMemcpyHostToDevice: 1
```

`hipify-perl` is in `$ROCM_PATH/hip/bin` directory and should be in your path. In some versions of ROCm, the script is called `hipify-perl` .

Now let's actually do the conversion.

```
hipify-perl nbody-orig.cu > nbody-orig.cpp
```

Compile the HIP programs.

```
hipcc -DSHMOO -I ../ nbody-orig.cpp -o nbody-orig
```

The `#define SHMOO` fixes some timer printouts. Add `--offload-arch=<gpu_type>` to specify the GPU type and avoid the autodetection issues when running on a single GPU on a node.

- Fix any compiler issues, for example, if there was something that didn't hipify correctly.
- Be on the lookout for hard-coded Nvidia specific things like warp sizes and PTX.

Run the program

```
./nbody-orig
```

A batch version of Exercise 2 is:

```
#!/bin/bash
#SBATCH -N 1
#SBATCH --ntasks=1
#SBATCH --gpus=1
#SBATCH -p LocalQ
#SBATCH -t 00:10:00

pwd
module load rocm

cd HPCTrainingExamples/HIPIFY/mini-nbody/cuda
hipify-perl -print-stats nbody-orig.cu > nbody-orig.cpp
hipcc -DSHMOO -I ../ nbody-orig.cpp -o nbody-orig
./nbody-orig
```

Notes:

- Hipify tools do not check correctness
- `hipconvertinplace-perl` is a convenience script that does `hipify-perl -inplace -print-stats` command

HIPifly Example: Vector Addition

Original author was Trey White, at the time with HPE and now with ORNL.

The HIPifly method for converting CUDA code to HIP, is straight-forward and works with minimal modifications to the source code. This example applies the HIPifly method to a simple vector addition problem offloaded to the GPU using CUDA.

All CUDA functions are defined in the `src/gpu_functions.cu` file. By including the `hipifly.h` file when using HIP, all the CUDA functions will be automatically replaced with the analogous HIP function during compile time.

By default, the program is compiled for NVIDIA GPUs using `nvcc` . To compile for CUDA just run `make` .

To compile for AMD GPUs using `hipcc` run `make DFLAGS=-DENABLE_HIP` . Note that the Makefile applies different GPU compilation flags when compiling for CUDA or for HIP.

The paths to the CUDA or the ROCm software stack as `CUDA_PATH` or `ROCM_PATH` are needed to compile.

After compiling run the program: `./vector_add` # HIP and OpenMP Interoperability

README.md in `HPCTrainingExamples/HIP-OpenMP/CXX` from the Training Examples in repository. If the `amdclang` is not available in your system, make sure to do `export CXX=amdclang++` .

Full OpenMP Application Code

The first example is just a straightforward openmp offload version of saxpy. Any C++ compiler that supports OpenMP offload to hip should work.

```
cd HPCTrainingExamples/HIP-OpenMP/CXX/saxpy_openmp_offload
module load rocm
module load amdclang
make
```

OpenMP Application Calling a HIP Kernel

Now we move on to an OpenMP main calling a HIP version of the saxpy kernel. Note that we have to get the device version of the array pointers to pass into the HIP kernel, using `use_device_ptr(x,y)` .

```
cd HPCTrainingExamples/HIP-OpenMP/CXX/saxpy_openmp_hip
module load rocm
module load amdclang
unset HSA_XNACK
make
```

Try to create an equivalent version of the code in `saxpy_openmp.cc` that uses `omp target enter data` and `omp target exit data` instead of `omp target data` .

APU Programming Model Version

With the APU programming model the explicit memory management handled with OpenMP in the `saxpy_open_hip` directory can now be removed. The code has to be run after setting `HSA_XNACK=1` to enable unified shared memory:

```
cd HPCTrainingExamples/HIP-OpenMP/CXX/saxpy_APU
module load rocm
module load amdclang
export HSA_XNACK=1
make
```

HIP application calling an OpenMP Kernel

The next example does the converse of what we saw: it is a HIP application code calling an OpenMP kernel for saxpy executing on the GPU:

```
cd HPCTrainingExamples/HIP-OpenMP/CXX/saxpy_hip_openmp
module load rocm
module load amdclang
unset HSA_XNACK
make
```

Try to create a version that leverages the APU progamming model, in a similar way done for the OpenMP application calling a HIP kernel.

OpenMP and HIP Kernels in the Same Source File

You can put both OpenMP and HIP code in the same source file with some care. The next hands-on exercise shows how in the code in `HPCTrainingExamples/HIP-OpenMP/daxpy` . We have code that uses both OpenMP and HIP. These require two separate passes with compilers: one with amdclang++ and the other with hipcc. Go to the directory containing the example and set up the environment:

```
cd HPCTrainingExamples/HIP-OpenMP/CXX/daxpy
module load rocm
module load amdclang
```

View the source code file daxpy.cc and note the two #ifdef blocks.

The first one is **DEVICE_CODE** that we want to compile with hipcc.

The second is **HOST_CODE** that we will use the C++ compiler to compile.

All of the HIP calls and variables are in the first block. The second block contains the OpenMP pragmas.

While we can use hipcc to compile standard C++ code, it will not work on code with OpenMP pragmas. The call to the HIP daxpy kernel occurs near the end of the host code block. We could split out these two code blocks into separate files, but this may be more intrusive with a code design.

Now we can take a look at the Makefile we use to compile the code in the single file. In the file, we create two object files for the executable to be dependent on.

We then compile one with the CXX compiler with `-D__HOST_CODE__` defined.

The second object file is compiled using hipcc and with `-D__DEVICE_CODE__` defined.

This doesn't completely solve all the issues with separate translation units, but it does help workaround some code organization constraints.

Now on to building and running the example.

```
make
./daxpy
```

Running a Fortran to HIP interop example

README.md `HPCTrainingExamples/Pragma_Examples/OpenMP/Fortran/8_interop` from the Training Examples repository

This is a simple example to demonstrate fortran to HIP interoperability

```
module load rocm
module load amdflang-new
make
```

run the code:

```
./interop
```

Code will run to completion if it passes verification ## Calling GEMM from Fortran

README.md in `HPCTrainingExamples/HIP-OpenMP/F/Calling_DGEMM` from the Training Examples repository

The files in this directory show how to call a rocblas dgemm function from an OpenMP application code written in Fortran. If the `amdclang` module is not available in your system, set `FC=amdflang` or to the next generation AMD Fortran compiler.

Explicit Memory Management

In this explicit memory management example, a target data region is created, from which a wrapper to the rocblas dgemm is called. Pay particular attention to the items passed to the wrapper call. Also notice the use `use_device_addr(A,B,C)` before the call to the wrapper.

What happens if you instead use `use_device_ptr(A,B,C)` ? Check the output by setting `OMPLIBTARGET_INFO=-1` . Remember that the behavior of OpenMP directives may be different across languages, such as Fortran and C++.

To compile and run:

```
module load rocm
module load amdclang
make
```

Unified Shared Memory

In the `usm` directory, we are showing how the code can be simplified rather dramatically by removing all the explicit data management due to the use of unified shared memory, setting HSA_XNACK=1. To compile and run:

```
module load rocm
module load amdclang
make
```

Try to use hipfort to avoid having to include the explicit rocm_interface that we are using in this example.

Kokkos examples

Stream Triad

Step 1: Build a separate Kokkos package

NOTE: these exercises have been tested on MI210 and MI300A accelerators using a container environment. To see details on the container environment (such as operating system and modules available) please see `README.md` on this repo.

```
cd $HOME/HPCTraining/Examples
git clone https://github.com/kokkos/kokkos Kokkos_build
cd Kokkos_build
```

Build Kokkos with OpenMP backend

```
mkdir build_openmp && cd build_openmp
cmake -DCMAKE_INSTALL_PREFIX=${HOME}/Kokkos_OpenMP -DKokkos_ENABLE_SERIAL=On \
      -DKokkos_ENABLE_OPENMP=On ..

make -j 8
make install

cd ..
```

Build Kokkos with HIP backend

```
mkdir build_hip && cd build_hip
cmake -DCMAKE_INSTALL_PREFIX=${HOME}/Kokkos_HIP -DKokkos_ENABLE_SERIAL=ON \
      -DKokkos_ENABLE_HIP=ON -DKokkos_ARCH_ZEN=ON -DKokkos_ARCH_VEGA90A=ON \
      -DCMAKE_CXX_COMPILER=hipcc ..

make -j 8; make install
cd ..
```

Set Kokkos_DIR to point to external Kokkos package to use

```
export Kokkos_DIR=${HOME}/Kokkos_HIP
```

Step 2: Modify Build

Get example

```
git clone --recursive https://github.com/EssentialsOfParallelComputing/Chapter13 Chapter13
cd Chapter13/Kokkos/StreamTriad
cd Orig
```

Test serial version with

```
mkdir build && cd build; cmake ..; make; ./StreamTriad
```

If the run fails (SEGV), try reducing the size of the arrays, by reducing the value of the nsize variable in StreamTriad.cc.

Add to CMakeLists.txt

```
(add) find_package(Kokkos REQUIRED)
add_executables(StreamTriad ....)
(add) target_link_libraries(StreamTriad Kokkos::kokkos)
```

Retest with

```
cmake ..; make
```

and run ./StreamTriad again

Check Ver1 for solution. These modifications have already been made in Ver1 version.

Step 3: Add Kokkos views for memory allocation of arrays

(peek at ver4/StreamTriad.cc to see the end result)

Add include file

```
#include <Kokkos_Core.hpp>
```

Add initialize and finalize

```
Kokkos::initialize(argc, argv);  {

} Kokkos::finalize();
```

Replace static array declarations with Kokkos views

```
int nsize=80000000;
Kokkos::View<double *> a( "a", nsize);
Kokkos::View<double *> b( "b", nsize);
Kokkos::View<double *> c( "c", nsize);
```

Rebuild and run

```
CXX=hipcc cmake ..
make
./StreamTriad
```

Step 4: Add Kokkos execution pattern - parallel_for Change for loops to Kokkos parallel fors.

At start of loop

```
Kokkos::parallel_for(nsize, KOKKOS_LAMBDA (int i) {
```

At end of loop, replace closing brace with

```
});
```

Rebuild and run. Add environment variables as Kokkos message suggests:

```
export OMP_PROC_BIND=spread
export OMP_PLACES=threads
export OMP_PROC_BIND=true
```

How much speedup do you observe?

Step 5: Add Kokkos timers

Add Kokkos calls

```
Kokkos::Timer timer;
timer.reset(); // for timer start
time_sum += timer.seconds();
```

Remove

```
#include <timer.h>
struct timespec tstart;
cpu_timer_start(&tstart);
time_sum += cpu_timer_stop(tstart);
```

6. Run and measure performance with OpenMP

Find out how many virtual cores are on your CPU

```
lscpu
```

First run with a single processor:

Average runtime _____

Then run the OpenMP version:

Average runtime _____

Portability Exercises

1. Rebuild Stream Triad using Kokkos build with HIP

Set Kokkos_DIR to point to external Kokkos build with HIP

```
export Kokkos_DIR=${HOME}/Kokkos_HIP/lib/cmake/Kokkos_HIP
cmake ..
make
```

2. Run and measure performance with AMD Radeon GPUs

HIP build with ROCm

Ver4 - Average runtime is _____ msecs

C++ Standard Parallelism on AMD GPUs

Here are some instructions on how to compile and run some tests that exploit C++ standard parallelism, which is available with ROCm, starting from version 6.1.1. Hence, please double check the version of ROCm you are using to make sure it has HIPSTDPAR enabled. HIPSTDPAR relies on the LLVM compiler, the hipstdpar header only library, and rocThrust.

NOTE: these exercises have been tested on MI210 and MI300A accelerators using a container environment. To see details on the container environment (such as operating system and modules available) please see `README.md` on this repo.

```
git clone https://github.com/amd/HPCTrainingExamples.git
```

hipstdpar_saxpy_foreach example

```
export HSA_XNACK=1
module load amdclang

cd ~/HPCTrainingExamples/HIPStdPar/CXX/saxpy_foreach

make
export AMD_LOG_LEVEL=3
./saxpy
clean
```

hipstdpar_saxpy_transform example

```
export HSA_XNACK=1
module load amdclang

cd ~/HPCTrainingExamples/HIPStdPar/CXX/saxpy_transform

make
export AMD_LOG_LEVEL=3
./saxpy
clean
```

hipstdpar_saxpy_transform_reduce example

```
export HSA_XNACK=1
module load amdclang

cd ~/HPCTrainingExamples/HIPStdPar/CXX/saxpy_transform_reduce

make
export AMD_LOG_LEVEL=3
./saxpy
clean
```

Traveling Salesperson Problem

```
#!/bin/bash

git clone https://github.com/pkestene/tsp
cd tsp
git checkout 51587
wget -q https://raw.githubusercontent.com/ROCm/roc-stdpar/main/data/patches/tsp/TSP.patch

patch -p1 < TSP.patch
```

```
cd stdpar

export HSA_XNACK=1
module load amdclang
export STDPAR_CXX=$CXX
export ROCM_GPU=`rocminfo |grep -m 1 -E gfx[^0]{1} | sed -e 's/ *Name: *//'`
export STDPAR_TARGET=${ROCM_GPU}

export AMD_LOG_LEVEL=3 #optional

make tsp_clang_stdpar_gpu
./tsp_clang_stdpar_gpu 13 #or more...

make clean
cd ../..
rm -rf tsp
```

hipstdpar_shallowwater_orig.sh

```
cd ~/HPCTrainingExamples/HIPStdPar/CXX/ShallowWater_Orig

mkdir build && cd build
cmake ..
make
./ShallowWater

cd ..
rm -rf build
```

hipstdpar_shallowwater_ver1.sh

```
cd ~/HPCTrainingExamples/HIPStdPar/CXX/ShallowWater_Ver1

mkdir build && cd build
cmake ..
make
./ShallowWater

cd ..
rm -rf build
```

hipstdpar_shallowwater_ver2.sh

```
export HSA_XNACK=1
module load amdclang

cd ~/HPCTrainingExamples/HIPStdPar/CXX/ShallowWater_Ver2

make
#export AMD_LOG_LEVEL=3
./ShallowWater

make clean
```

hipstdpar_shallowwater_stdpar.sh

```
export HSA_XNACK=1
module load amdclang
```

```
cd ~/HPCTrainingExamples/HIPStdPar/CXX/ShallowWater_StdPar

make
#export AMD_LOG_LEVEL=3
./ShallowWater

make clean
```

Mix and Match

The examples contained in the MixandMatch directory demonstrate how to correctly combine StdPar with other commonly used programming models, such as OpenMP and HIP.

All examples require the user to specify the path to the StdPar header in the Makefile:

```
module load rocm
export STDPAR_PATH=${ROCM_PATH}/include/thrust/system/hip/hipstdpar
export HSA_XNACK=1
```

Note HIPSTDPAR assumes the device is HMM enabled and setting `HSA_XNACK` to one is also required. In devices where HMM is not enabled, the additional compilation flag `--hipstdpar-interpose-alloc` needs to be included. This will instruct the compiler to replace all dynamic memory allocations with compatible with `hipManagedMemory` allocations.

- omp_stdpar: demonstrates how to integrate StdPar and OpenMP within the same application. It utilizes object-oriented programming techniques to implement the same interface in specialized ways.
- std_cpu_gpu: shows how to combine StdPar sections using `par` and `par_unseq` to run on both the CPU and GPU within the same application.
- hip_stdpar: illustrates how to use HIP routines to allocate and transfer data to GPU buffers for use in StdPar sections.
- atomic_stdpar_omp: explains how atomic operations can be safely performed within a StdPar section using the `par_unseq` policy. The example also includes an equivalent OpenMP implementation.

Advanced OpenMP presentation

README.md in `HPCTrainingExamples/Pragma_Examples/OpenMP/CXX/memory_pragmas` from Training Exercises repository

Memory Pragmas

Setup your environment

```
module load amdclang
   or
export CXX=<C++ Compiler>
      Example: export CXX=amdclang++

export LIBOMPTARGET_INFO=-1
export LIBOMPTARGET_KERNEL_TRACE=[1,2]
export OMP_TARGET_OFFLOAD=MANDATORY
```

You can also be more selective in the output generated by using the individual bit masks

```
export LIBOMPTARGET_INFO=$((0x01 | 0x02 | 0x04 | 0x08 | 0x10 | 0x20))
```

The first example code uses just a single pragma with a map clause at the computational loop.

```
mem1.cc:#pragma omp target teams distribute parallel for simd map(to: x[0:n], y[0:n]) map(from: z[0:n])
```

Examine this code and then compile and run. There is a map clause on pragma line just before computational loop

```
mkdir build && cd build
cmake ..
make
./mem1
```

You should get some output like the following

```
Libomptarget device 0 info: Entering OpenMP kernel at mem1.cc:89:1 with 5 arguments:
Libomptarget device 0 info: firstprivate(n)[4] (implicit)
Libomptarget device 0 info: from(z[0:n])[80000]
Libomptarget device 0 info: firstprivate(a)[8] (implicit)
Libomptarget device 0 info: to(x[0:n])[80000]
Libomptarget device 0 info: to(y[0:n])[80000]
Libomptarget device 0 info: Creating new map entry with HstPtrBase=0x0000000001772200, ...
Libomptarget device 0 info: Creating new map entry with HstPtrBase=0x000000000174b0e0, ...
Libomptarget device 0 info: Copying data from host to device, HstPtr=0x000000000174b0e0, ...
Libomptarget device 0 info: Creating new map entry with HstPtrBase=0x000000000175e970, ...
Libomptarget device 0 info: Copying data from host to device, HstPtr=0x000000000175e970, ...
Libomptarget device 0 info: Mapping exists with HstPtrBegin=0x0000000001772200, ...
Libomptarget device 0 info: Mapping exists with HstPtrBegin=0x000000000174b0e0, ...
Libomptarget device 0 info: Mapping exists with HstPtrBegin=0x000000000175e970, ...
Libomptarget device 0 info: Mapping exists with HstPtrBegin=0x000000000175e970, ...
Libomptarget device 0 info: Mapping exists with HstPtrBegin=0x000000000174b0e0, ...
Libomptarget device 0 info: Mapping exists with HstPtrBegin=0x0000000001772200, ...
Libomptarget device 0 info: Copying data from device to host, TgtPtr=0x00007f617c420000, ...
Libomptarget device 0 info: Removing map entry with HstPtrBegin=0x000000000175e970, ...
Libomptarget device 0 info: Removing map entry with HstPtrBegin=0x000000000174b0e0, ...
Libomptarget device 0 info: Removing map entry with HstPtrBegin=0x0000000001772200, ...
-Timing in Seconds: min=0.010115, max=0.010115, avg=0.010115
-Overall time is 0.010505
Last Value: z[9999]=7.000000
```

Explore examples 2 through 5 and observe the output produced when the `LIBOMPTARGET_INFO` environment variable is set.

Mem2 pattern : Add enter/exit data alloc/delete when memory is created/freed

After new `mem2.cc:#pragma omp target enter data map(alloc: x[0:n], y[0:n], z[0:n])`

Loop around computational loop and keep map on computational loop. The map to/from should check if the data exists. If not, it will allocate/delete it. Then it will do the copies to and from. This will increment the Reference Counter and decrement it at end of loop. `mem2.cc:#pragma omp target teams distribute parallel for simd ma`

Before delete `mem2.cc:#pragma omp target exit data map(delete: x[0:n], y[0:n], z[0:n])`

Mem3 pattern: Replacing map to/from with updates to bypass unneeded device memory check

After new `mem3.cc:#pragma omp target enter data map(alloc: x[0:n], y[0:n], z[0:n])`

Before computational loop. Data should be copied. Reference counter should not change. `mem3.cc:#pragma omp target upd`
`mem3.cc:#pragma omp target teams distribute parallel for simd`

After computational loop `mem3.cc:#pragma omp target update from (z[0:n])`

Before delete `mem3.cc:#pragma omp target exit data map(delete: x[0:n], y[0:n], z[0:n])`

Mem4 pattern: Replacing delete with release to use Reference Counting

```
mem4.cc:#pragma omp target enter data map(alloc: x[0:n], y[0:n], z[0:n])
mem4.cc:#pragma omp target exit data map(release: x[0:n], y[0:n], z[0:n])
mem4.cc:#pragma omp target teams distribute parallel for simd map(always to: x[0:n], y[0:n]) map(always from: z[
```

Mem5 pattern: Using enter data map to/from alloc/delete to reduce memory copies

```
mem5.cc:#pragma omp target enter data map(to: x[0:n], y[0:n]) map(alloc: z[0:n])
mem5.cc:#pragma omp target exit data map(from: z[0:n]) map(delete: x[0:n], y[0:n])
mem5.cc:#pragma omp target teams distribute parallel for simd map(to:x[0:n], y[0:n]) map(from: z[0:n])
```

One solution that miminizes data transfer

Mem6 pattern: Using enter data alloc/delete with update clause at end

```
mem6.cc:#pragma omp target enter data map(alloc: x[0:n], y[0:n], z[0:n])
mem6.cc:#pragma omp target teams distribute parallel for simd
mem6.cc:#pragma omp target update from(z[0])
mem6.cc:#pragma omp target exit data map(delete: x[0:n], y[0:n], z[0:n])
mem6.cc:#pragma omp target teams distribute parallel for simd
```

Unified Shared Memory

Mem7 pattern: Using Unified Shared Memory to automatically move data

```
mem7.cc:#pragma omp requires unified_shared_memory
mem7.cc:#pragma omp target teams distribute parallel for simd
mem7.cc:#pragma omp target teams distribute parallel for simd
```

For this example, `HSA_XNACK=1` needs to be set

```
export HSA_XNACK=1
make mem7
./mem7
```

Unified Shared Memory with backwards compatibility

Mem8 pattern: Demonstrating Unified Shared Memory with maps for backward compatibility

```
set HSA_XNACK=1 at runtime

mem8.cc:#pragma omp requires unified_shared_memory
mem8.cc:#pragma omp target enter data map(alloc: x[0:n], y[0:n], z[0:n])
mem8.cc:#pragma omp target teams distribute parallel for simd
mem8.cc:#pragma omp target update from(z[0])
mem8.cc:#pragma omp target exit data map(delete: x[0:n], y[0:n], z[0:n])
mem8.cc:#pragma omp target teams distribute parallel for simd
```

APU Code – Unified Address in OpenMP

We now switch to how unified address programming would look in other languages. The language we will work with the most will be OpenMP. We'll start by looking at the unified address code shown in slide 31 and 32. It is also in the mem12.cc file in the directory given below. You should also compare it to the original GPU code using explicit memory management in mem1.cc through mem6.cc.

We'll now run the unified address example if we have access to an MI300A GPU. If you don't have access to an MI300A, we'll also run nearly the same code in mem7.cc with managed memory on the MI200 series GPUs. We'll be looking at all of the versions of this code in the Advanced OpenMP presentation.

```
cd ~/HPCTrainingExamples/Pragma_Examples/OpenMP/CXX/memory_pragmas
module load amdclang
```

```
make mem12
./mem12
```

Kernel Pragmas

README.md in `HPCTrainingExamples/Pragma_Examples/OpenMP/CXX/kernel_pragmas` from Training Exercises repository

Download the exercises and go to the directory with the kernel pragma examples

```
git clone https://github.com/amd/HPCTrainingExamples.git
cd HPCTrainingExamples/Pragma_Examples/OpenMP/CXX/kernel_pragmas
```

Setup your environment. You should unset the `LIBOMPTARGET_INFO` environment from previous exercise.

```
unset LIBOMPTARGET_INFO
```

```
export CXX=amdclang++
export LIBOMPTARGET_KERNEL_TRACE=1
export OMP_TARGET_OFFLOAD=MANDATORY
export HSA_XNACK=1
```

The base version 1 code is the Unified Shared memory example from the previous exercises

```
mkdir build && cd build
cmake ..
make kernel1
./kernel1
```

`Kernel2 : add num_threads(64)`

`Kernel3 : add num_threads(64) thread_limit(64)`

On your own: Uncomment line in CMakeLists.txt with -faligned-allocation -fnew-alignment=256

Another option is to add the attribute `(std::align_val_t(128) )` to each new line. For example:

```
double *x = new (std::align_val_t(128) ) double[n];
```

Advanced HIP

README.md from `HPCTrainingExamples/HIP-Optimizations/daxpy` from the Training Examples repository.

Optimizing DAXPY HIP

In this exercise, we will progressively make changes to optimize the DAXPY kernel on GPU. Any AMD GPU can be used to test this.

DAXPY Problem:

```
Z = aX + Y
```

where `a` is a scalar, `X` , `Y` and `Z` are arrays of double precision values.

In DAXPY, we load 2 FP64 values (8 bytes each) and store 1 FP64 value (8 bytes). We can ignore the scalar load because it is constant. We have 1 multiplication and 1 addition operation for the 12 bytes moved per element of the array. This yields a low arithmetic intensity of 2/24. So, this kernel is not compute bound, so we will only measure the achieved memory bandwith instead of FLOPS.

Inputs

- `N` , the number of elements in `X` , `Y` and `Z` . `N` may be reset to suit some optimizations. Choose a sufficiently large array size to see some differences in performance.

Build Code

```
git clone https://github.com/amd/HPCTrainingExamples.git
cd HPCTrainingExamples/HIP-Optimizations/daxpy
make
```

Run exercises

```
./daxpy_1 10000000
./daxpy_2 10000000
./daxpy_3 10000000
./daxpy_4 10000000
./daxpy_5 10000000
```

Things to ponder about

`daxpy_1` This shows a naive implementation of the daxpy problem on the GPU where only 1 wavefront is launched and the 64 work-items in that wavefront loop over the entire array and process 64 elements at a time. We expect this kernel to perform very poorly because it simply utilizes a part of 1 CU, and leaves the rest of the GPU unutilized.

`daxpy_2` This time, we are launching multiple wavefronts, each work-item now processing only 1 element of each array. This launches `N/64` wavefronts, enough to be scheduled on all CUs. We see a big improvement in performance here.

`daxpy_3` In this experiment, we check to see if launching larger workgroups can help lower our kernel launch overhead because we launch fewer workgroups if each workgroup has 256 work-items. In this case too, an improvement in measured bandwidth achieved is seen.

`daxpy_4` If we ensured that the array has a multiple of `BLOCK_SIZE` elements so that all work-items in each workgroup have an element to process, then we can avoid the conditional statement in the kernel. This could reduce some instructions in the kernel.. Do we see any improvement? In this trivial case, this does not matter. Nevertheless, it is something we could keep in mind.

Question: What happens if `BLOCK_SIZE` is `1024` ? Why?

`daxpy_5` In this experiment, we will use double2 type in the kernel to see if the compiler can generate `global_load_dwordx4` instructions instead of `global_load_dwordx2` instructions. So, with same number of load and store instructions, we are able to read/write two elements from each array in each thread. This should help amortize on the cost of index calculations.

To show this difference, we need to generate the assembly for these two kernels. To generate the assembly code for these kernels, ensure that the `-g --save-temps` flags are passed to `hipcc` . Then you can find the assembly code in `daxpy_*-host-x86_64-unknown-linux-gnu.s` files. Examining `daxpy_3` and `daxpy_5` , we see the two cases (edited here for clarity):

`daxpy_3` :

```
    global_load_dwordx2 v[2:3], v[2:3], off
    v_mov_b32_e32 v6, s5
```

```
    global_load_dwordx2 v[4:5], v[4:5], off
    v_add_co_u32_e32 v0, vcc, s4, v0
    v_addc_co_u32_e32 v1, vcc, v6, v1, vcc
    s_waitcnt vmcnt(0)
    v_fmac_f64_e32 v[4:5], s[6:7], v[2:3]
    global_store_dwordx2 v[0:1], v[4:5], off
```

`daxpy_5` :

```
    global_load_dwordx4 v[0:3], v[0:1], off
    v_mov_b32_e32 v10, s5
    global_load_dwordx4 v[4:7], v[4:5], off
    s_waitcnt vmcnt(0)
    v_fmac_f64_e32 v[4:5], s[6:7], v[0:1]
    v_add_co_u32_e32 v0, vcc, s4, v8
    v_fmac_f64_e32 v[6:7], s[6:7], v[2:3]
    v_addc_co_u32_e32 v1, vcc, v10, v9, vcc
    global_store_dwordx4 v[0:1], v[4:7], off
```

We observe that, in the `daxpy_5` case, there are two `v_fmac_f64_e32` instructions as expected, one for each element being processed.

Notes

- Before timing kernels, it is best to launch the kernel at least once as warmup so that those initial GPU launch latencies do not affect your timing measurements.
- The timing loop is typically several hundred iterations.
- You may find that the various optimizations work differently in MI210 vs MI300A devices, and this may be due to differences in hardware architecture.

Register Exercises

In this set of examples, we explore

- VGPRs – Vector General Purpose Registers
- SGPRs – Scalar General Purpose Registers
- Occupancy

Register Pressure - ROCm Blogs

For these exercises, retrieve them with

```
git clone https://github.com/AMD/HPCTrainingExamples
cd HPCTrainingExamples/rocm-blogs-codes/registerpressure
```

Set up your environment

```
module load rocm
```

The exercises were tested on an MI210 with ROCm version 6.4.1.

Get the compiler resource report for the lbm.cpp kernel. Use the proper gfx model code in the compile command.

```
hipcc -c --offload-arch=gfx90a -Rpass-analysis=kernel-resource-usage lbm.cpp
```

Output should be something like

```
lbm.cpp:16:1: remark:     SGPRs: 100 [-Rpass-analysis=kernel-resource-usage]
lbm.cpp:16:1: remark:     VGPRs: 104 [-Rpass-analysis=kernel-resource-usage]
lbm.cpp:16:1: remark:     AGPRs: 0 [-Rpass-analysis=kernel-resource-usage]
lbm.cpp:16:1: remark:     ScratchSize [bytes/lane]: 0 [-Rpass-analysis=kernel-resource-usage]
```

```
lbm.cpp:16:1: remark:     Dynamic Stack: False [-Rpass-analysis=kernel-resource-usage]
lbm.cpp:16:1: remark:     Occupancy [waves/SIMD]: 4 [-Rpass-analysis=kernel-resource-usage]
lbm.cpp:16:1: remark:     SGPRs Spill: 0 [-Rpass-analysis=kernel-resource-usage]
lbm.cpp:16:1: remark:     VGPRs Spill: 0 [-Rpass-analysis=kernel-resource-usage]
lbm.cpp:16:1: remark:     LDS Size [bytes/block]: 0 [-Rpass-analysis=kernel-resource-usage
```

Repeat for the other cases

Remove unnecessary math functions pow(current_phi, 2.0) on line 37 can be changed to current_phi * current_phi

This C function raises the argument to a floating point power in software. It is not a very efficient way to do the operation and also consumes a lot of registers.

```
hipcc -c --offload-arch=gfx90a -Rpass-analysis=kernel-resource-usage lbm_1_nopow.cpp
```

Rearrange code so variables are declared close to use

```
hipcc -c --offload-arch=gfx90a -Rpass-analysis=kernel-resource-usage lbm_2_rearrange.cpp
```

Add restrict attribute to function arguments

```
hipcc -c --offload-arch=gfx90a -Rpass-analysis=kernel-resource-usage lbm_3_restrict.cpp
```

Try exploring other ways of reducing the number of VGPRs.

One way which might help is to use `__global__ __launch_bounds__(256) void kernel` Try different workgroup sizes for launch bounds. Valid sizes would be 64, 128, 256, 512, and 1024. Smaller should lead to fewer VGPRs.

Register pressure in AMD CDNA™2 GPUs

Sample codes for the following blog:

https://rocm.blogs.amd.com/software-tools-optimization/register-pressure/README.html

HIP Transpose Examples

README.md from `HPCTrainingExamples/HIP/transpose` from the Training Examples repository.

In this set of examples, we explore

- Using LDS (Local Data Share or Shared Memory)
- Coalesced reads and writes

For these exercises, retrieve them with

```
git clone https://github.com/AMD/HPCTrainingExamples
cd HPCTrainingExamples/HIP/transpose
```

Set up your environment

```
module load rocm
```

The exercises were tested on an MI210 with ROCm version 6.4.1.

Transpose Read Contiguous

In this example, we will read the matrix data in a contiguous manner. This means that the data read varies quickest by the second index – data[slow][fast]. This is the normal C and C++ convention. The data must be in a single block of memory. On the host side, we allocate the data arrays as 1D arrays. A macro is defined on the device side to make it clearer how the indices vary.

Examine the file `transpose_kernel_read_contiguous.cpp` . Note that the 2D matrix is read in contiguos order and written out with striding though memory – Transpose: output[X][Y] = input[Y][X].

```
#define GIDX(y, x, sizex) y * sizex + x

__global__ void transpose_kernel_read_contiguous(
  double* __restrict__ input, double* __restrict__ output,
  int srcHeight, int srcWidth) {
    // Calculate source global thread indices
    const int srcX = blockIdx.x * blockDim.x + threadIdx.x;
    const int srcY = blockIdx.y * blockDim.y + threadIdx.y;

    // Boundary check
    if (srcY < srcHeight && srcX < srcWidth) {
        // Transpose: output[x][y] = input[y][x]
        const int input_gid = GIDX(srcY,srcX,srcWidth);
        const int output_gid = GIDX(srcX,srcY,srcHeight); // flipped axis
        output[output_gid] = input[input_gid];
    }
}
```

Build the transpose read contiguous application and run it.

```
make transpose_read_contiguous
./transpose_read_contiguous
```

The output for the last matrix size should look like

```
Testing Matrix dimensions: 8192 x 8192
Input size: 512.00 MB
Output size: 512.00 MB
========================================
Basic Transpose, Read Contiguous - Average Time: 4450.20 micros
========================================
Verification: PASSED
```

Transpose Write Contiguous

What happens if we make the writes contiguous instead of the reads? Let's take a look at the kernel for that case.

```
#define GIDX(y, x, sizex) y * sizex + x

__global__ void transpose_kernel_write_contiguous(
  double* __restrict__ input, double* __restrict__ output,
  int srcHeight, int srcWidth) {
    // Calculate destination global thread indices
    const int dstX = blockIdx.x * blockDim.x + threadIdx.x;
    const int dstY = blockIdx.y * blockDim.y + threadIdx.y;
    const int dstWidth = srcHeight;
    const int dstHeight = srcWidth;

    // Boundary check
    if (dstY < dstHeight && dstX < dstWidth) {
        // Transpose: output[y][x] = input[x][y]
        const int input_gid = GIDX(dstX,dstY,srcWidth); // flipped axis
        const int output_gid = GIDX(dstY,dstX,dstWidth);

        output[output_gid] = input[input_gid];
    }
}
```

Now the write order for the output array is contiguous. Let's compile and run it.

```
make transpose_write_contiguous
./transpose_write_contiguous
```

The output for the last matrix size should look like

```
Testing Matrix dimensions: 8192 x 8192
Input size: 512.00 MB
Output size: 512.00 MB
=======================================
Basic Transpose, Write Contiguous - Average Time: 2901.80 micros
=======================================
Verification: PASSED
```

We get a substantial speedup. So it is more important to have contiguous (coalesced) writes than reads.

Can we do better than this? If we use a shared memory tile, we can make both the read and write contiguous.

Tiled Matrix Transpose

The kernel code for the matrix transpose with a shared memory tile is a little more complicated.

```
#define GIDX(y, x, sizex) y * sizex + x
#define PAD 1

/* Use a **shared-memory tile** (`TILE_SIZE × (TILE_SIZE+PAD)`) to stage the data.
 *    Pad the shared-memory tile to avoid bank conflicts.
 * Load the tile from the **row-major source** (contiguous reads).
 * `__syncthreads()`.
 * Write the transposed tile back to the **row-major destination** (`output[col][row]`),
 *    which is now a **contiguous write** pattern.
 */

__global__ void transpose_kernel_tiled(
   double* __restrict input, double* __restrict output,
   const int srcHeight, const int srcWidth)
{
    // thread coordinates in the source matrix
    const int tx = threadIdx.x;
    const int ty = threadIdx.y;

    // source global coordinates this thread will read
    const int srcX = blockIdx.x * TILE_SIZE + tx;
    const int srcY = blockIdx.y * TILE_SIZE + ty;

    // allocate a shared (LDS) memory tile with padding to avoid bank conflicts
    __shared__ double tile[TILE_SIZE][TILE_SIZE + PAD];

    // Read from global memory into tile with coalesced reads
    if (srcY < srcHeight && srcX < srcWidth) {
        tile[ty][tx] = input[GIDX(srcY, srcX, srcWidth)];
    } else {
        tile[ty][tx] = 0.0;                // guard value - never used for writes
    }

    // Synchronize to make sure all of the tile is updated before using it
    __syncthreads();

    // destination global coordinates this thread will write
    const int dstY = blockIdx.x * TILE_SIZE + ty; // swapped axes
```

```
    const int dstX = blockIdx.y * TILE_SIZE + tx;

    // Write back to global memory with coalesced writes
    if (dstY < srcWidth && dstX < srcHeight) {
        output[GIDX(dstY, dstX, srcWidth)] = tile[tx][ty];
    }
}
```

Compiling and running the tiled transpose.

```
make transpose_tiled
./transpose_tiled
```

The output from the last matrix size

```
Testing Matrix dimensions: 8192 x 8192
Input size: 512.00 MB
Output size: 512.00 MB
=======================================
Tiled Transpose, Read and Write Contiguous - Average Time: 2686.40 micros
=======================================
Verification: PASSED
```

We get a little speedup over the contiguous write approach.

Transpose from the rocblas library

Now let's try the rocblas transpose routine. We no longer need a kernel since that will be provided by the rocblas library. The host code is also simpler, though you do need to know how to call the rocblas library routine.

Here is the code required to call the rocblas transpose routine

```
// See https://github.com/ROCm/rocBLAS/blob/develop/clients/samples/example_c_dgeam.c
//   for an example how to use the transpose library routine in rocblas

// Create handle to rocblas library
rocblas_handle handle;
rocblas_status roc_status=rocblas_create_handle(&handle);
CHECK_ROCBLAS_STATUS(roc_status);

// scalar arguments will be from host memory
roc_status = rocblas_set_pointer_mode(handle, rocblas_pointer_mode_host);
CHECK_ROCBLAS_STATUS(roc_status);

// set up the parameters needed for the transpose operation
const double alpha = 1.0;
const double beta  = 0.0;

// For transpose: C= alpha * op(A) + beta * B
// where op(A) = A^T and B is the zero matrix
rocblas_operation transa = rocblas_operation_transpose;
rocblas_operation transb = rocblas_operation_none;

// Call rocblas_geam for the transpose operation
roc_status =  rocblas_dgeam(handle,
                  transa, transb,
                  width, height,
                  &alpha, d_input, width,
                  &beta, d_output, width,
                  d_output, width);
```

```
CHECK_ROCBLAS_STATUS(roc_status);

hipCheck( hipDeviceSynchronize() );
```

Now let's build and run this version.

```
make transpose_rocblas
./transpose_rocblas
```

```
ROCBlas Transpose - Average Time: 3638.60 micros
```

So this is a little slower than some of our custom version, but it may be because the rocblas routine has to be for general use.

Transpose timed comparison For convenience, we have written a version which will run all the transpose kernels and report a comparison between them.

```
make transpose_timed
./transpose_timed
```

The last part of the output should be something like:

```
Performance Summary:
Basic read contiguous   4439.60 micros
Basic write contiguous  2899.80 micros
Tiled - both contiguous 2686.80 micros
ROCBlas                 3638.60 micros
Speedup (Write Contiguous):        1.53x
Speedup (Tiled - Both Contiguous): 1.65x
Speedup (ROCBlas):                 1.22x
Verification: PASSED
```

GPU Aware MPI

README.md from `HPCTrainingExamples/MPI-examples` from the Training Examples repository.

Point-to-point and collective

NOTE: these exercises have been tested on MI210 and MI300A accelerators using a container environment. To see details on the container environment (such as operating system and modules available) please see `README.md` on this repo.

Allocate at least two GPUs and set up your environment

```
module load openmpi rocm
export OMPI_CXX=hipcc
```

Find the code and compile

```
cd HPCTrainingExamples/MPI-examples
mpicxx -o ./pt2pt ./pt2pt.cpp
```

Set the environment variable and run the code

```
mpirun -n 2 -mca pml ucx ./pt2pt
```

OSU Benchmark

Get the OSU micro-benchmark tarball and extract it

```
mkdir OMB
cd OMB
```

```
wget https://mvapich.cse.ohio-state.edu/download/mvapich/osu-micro-benchmarks-7.3.tar.gz
tar -xvf osu-micro-benchmarks-7.3.tar.gz
```

Create a build directory and cd to osu-micro-benchmarks-7.3

```
mkdir build
cd osu-micro-benchmarks-7.3
module load rocm openmpi
```

Build and install OSU micro-benchmarks

```
./configure --prefix=`pwd`/../build/ \
                CC=`which mpicc` \
                CXX=`which mpicxx` \
                CPPFLAGS=-D__HIP_PLATFORM_AMD__=1 \
                --enable-rocm \
                --with-rocm=${ROCM_PATH}
make -j12
make install
```

If you get the error "cannot include hip/hip_runtime_api.h", grep for **HIP__PLATFORM__HCC** and replace it with **HIP__PLATFORM__AMD** in configure.ac and configure files.

Check if osu microbenchmark is actually built

```
ls -l ../build/libexec/osu-micro-benchmarks/mpi/
```

if you see files collective, one-sided, pt2pt, and startup, your build is successful.

Allocate 2 GPUs, and make those visible

```
export HIP_VISIBLE_DEVICES=0,1
```

Make sure GPU-Aware communication is enabled and run the benchmark

```
mpirun -n 2 -mca pml ucx ../build/libexec/osu-micro-benchmarks/mpi/pt2pt/osu_bw \
                -m $((16*1024*1024)) D D
```

Notes: - Try different pairs of GPUs. - Run the command "rocm-smi –showtopo" to see the link type between the pairs of GPUs. - How does the bandwidth vary for xGMI connected GPUs vs PCIE connected GPUs?

Ghost Exchange example

The Ghost Exchange example is a simplified instance of what we believe a real scientific application code that uses MPI might look like. There are OpenMP and HIP versions of this example in 2D, each of which has multiple implementations tackling progressive code improvements. For detailed instructions, see the dedicated directory. Low detail, quick start instructions are reported here for people that want to experiment quickly and are OK with filling in the blanks on their own.

For what follows, we focus on the 2D OpenMP version set, which begins with a CPU only version that can be compiled and run as below:

```
module load amdclang openmpi
git clone https://github.com/amd/HPCTrainingExamples.git
cd HPCTrainingExamples/MPI-examples/GhostExchange/GhostExchange_ArrayAssign/Orig
mkdir build && cd build
cmake ..
make -j
mpirun -n 8 --mca pml ucx ./GhostExchange -x 4  -y 2  -i 20000 -j 20000 -h 2 -t -c -I 1000
```

We can improve this performance by using process placement so that we are using all the memory channels.

On MI210 nodes, we have 2 NUMA per node. So we can assign 4 ranks per NUMA when running with 8 ranks:

```
mpirun -n 8 --mca pml ucx --bind-to core --map-by ppr:4:numa --report-bindings ./GhostExchange \
                    -x 4  -y 2  -i 20000 -j 20000 -h 2 -t -c -I 1000
```

On MI300A node, we have 4 NUMA per node. So we can assign 2 ranks per NUMA when running with 8 ranks:

```
mpirun -n 8 --mca pml ucx --bind-to core --map-by ppr:2:numa --report-bindings ./GhostExchange \
                    -x 4  -y 2  -i 20000 -j 20000 -h 2 -t -c -I 1000
```

Let's consider the OpenMP version from now on: in Ver1, the original CPU implementation is ported to GPU using OpenMP and unified shared memory (or single memory space when running on MI300A). This is enabled with `export HSA_XNACK=1` as shown below. For MI210 we have:

```
export HSA_XNACK=1
cd ../Ver1
mkdir build && cd build
cmake ..
make -j
mpirun -n 8 --mca pml ucx --bind-to core --map-by ppr:4:numa -x HIP_VISIBLE_DEVICES=0,1,2,3,4,5,6,7 \
                    ./GhostExchange -x 4  -y 2  -i 20000 -j 20000 -h 2 -t -c -I 1000
```

Alternatively, on MI300A, we can run with:

```
mpirun -n 8 --mca pml ucx --bind-to core --map-by ppr:2:numa -x HIP_VISIBLE_DEVICES=0,1,2,3,4,5,6,7 \
                    ./GhostExchange -x 4  -y 2  -i 20000 -j 20000 -h 2 -t -c -I 1000
```

The MPI communication buffers up to this point were allocated on the CPU, we can allocate them on the GPU and save memory on the CPU, while at the same time leveraging GPU-aware MPI, as shown in Ver3. For MI210:

```
export HSA_XNACK=1
cd ../Ver3
mkdir build && cd build
cmake ..
make -j
mpirun -n 8 --mca pml ucx --bind-to core --map-by ppr:4:numa -x HIP_VISIBLE_DEVICES=0,1,2,3,4,5,6,7 \
                    ./GhostExchange -x 4  -y 2  -i 20000 -j 20000 -h 2 -t -c -I 1000
```

Alternatively, on MI300A, we can run with:

```
mpirun -n 8 --mca pml ucx --bind-to core --map-by ppr:2:numa -x HIP_VISIBLE_DEVICES=0,1,2,3,4,5,6,7 \
                    ./GhostExchange -x 4  -y 2  -i 20000 -j 20000 -h 2 -t -c -I 1000
```

Memory allocations can be expensive for the GPU. This next version just allocates the MPI buffers dynamically once in the main routine.

```
export HSA_XNACK=1
cd ../Ver4
mkdir build && cd build
cmake ..
make -j
mpirun -n 8 --mca pml ucx --bind-to core --map-by ppr:4:numa -x HIP_VISIBLE_DEVICES=0,1,2,3,4,5,6,7 \
                    ./GhostExchange -x 4  -y 2  -i 20000 -j 20000 -h 2 -t -c -I 1000
```

Alternatively, on MI300A, we can run with:

```
mpirun -n 8 --mca pml ucx --bind-to core --map-by ppr:2:numa -x HIP_VISIBLE_DEVICES=0,1,2,3,4,5,6,7 \
                   ./GhostExchange -x 4  -y 2  -i 20000 -j 20000 -h 2 -t -c -I 1000
```

Two more versions are available in the dedicated directory, which are not discussed here.

RCCL Test

To run RCCL test, follow these steps:

```
module load rocm
module load openmpi
git clone https://github.com/ROCm/rccl-tests.git
cd rccl-tests/
make MPI=1 MPI_HOME=$MPI_PATH HIP_HOME=$ROCM_PATH
```

where above `MPI_PATH` and `ROCM_PATH` are set by loading the `openmpi` and `rocm` modules respectively, according to the installation of OpenMPI and ROCm provided in our HPCTrainingDock repo.

After successful build, you should be able to see the executables in `./build` directory. You can run the collectives with:

```
./build/all_reduce_perf -b 4M -e 128M -f 2 -g 4
```

The above command will run for 4M (`-b`) to 128M (`-e`) messages, with a multiplication factor between sizes equal to 2 (`-f`), and using 4 GPUs (`-g`).

MPI Example: Ghost Exchange with OpenMP

README.md from `HPCTrainingExamples/MPI-examples/GhostExchange/GhostExchange_ArrayAssign` from the Training Examples repository.

In this version of the Ghost Exchange example we use OpenMP to perform the necessary computations in parallel on GPUs.These computations are for instance data initialization and solution advancement. When running in parallel, each MPI process will execute the prescribed kernels in parallel, and these will execute in parallel on the GPU, thanks to OpenMP. We begin with an original implementation that can run in parallel thanks to MPI but is CPU only, meaning that the computations will run in serial on the CPU on a per process basis. Several improved versions are provided which are outlined in the next paragraph.

Features of the various versions

The Ghost Exchange example with OpenMP contains several implementations at various stages of performance optimization. Generally speaking, however, the various versions follow the same basic algorithm, what changes is where the computation happens, or the data movement and location. See below a breakdown of the features of the various versions:

- **Orig**: this is a CPU-only implementation that runs in parallel with MPI, and serves as the starting point for further optimizations. It is recommended to start here.
- **Ver1**: this version is a variation of Orig that uses OpenMP and unified shared memory to offload the computations to the GPUs. Memory can be moved to the GPU using map clauses with OpenMP, however it is much easier to not have to worry about explicit memory management for an initial port, which is what the unified shared memory allows. Note that arrays allocated on the CPU are used for MPI communication, henche GPU aware MPI is not used in this version. To enable unified shared memory, `export HSA_XNACK=1` before running the example.
- **Ver2**: this is a variation of Ver1, adding `roctx` ranges to get more easily readable profiling output. This change does not affect performance.
- **Ver3**: this is a variation of Ver2, allocating the communication buffers on GPU using the OpenMP API.
- **Ver4**: this is a variation of Ver2, exploring dynamically allocating communication buffers on the CPU using malloc.
- **Ver5**: this is a variation of Ver4, where the solution array is unrolled from a 2D array into a 1D array.
- **Ver6**: this is a variation of Ver5, using explicit memory management directives to specify when data movement should happen. In this context unified shared memory is not required and therefore one could `unset HSA_XNACK` .

Overview of the implementation

The code is controlled with the following arguments: - `-i imax -j jmax` : set the total problem size to `imax*jmax` cells. - `-x nprocx -y nprocy` : set the number of MPI processes in the x and y direction respectively, with `nprocx*nprocy` total processes. - `-h nhalo` : number of halo layers, the minimum value dictated by the mathematical operator in this case is one, but it can be made bigger to increase the communication work, for experimentation. - `-t` : legacy argument used to include MPI barriers before the ghost exchange. Currently has no impact. - `-c` : include as input argument to include the ghost cells in the corners of the MPI subdomains during the ghost exchange. - `-p` : include as input argument to print the solution field (including values on the halo). Printing is limited above by the size of the problem.

The kernel used to advance the solution is a blur kernel, that modifies the value of a given element by averaging the values at a 5-point stencil location centered at the given element:

```
xnew[j][i] = (x[j][i] + x[j][i-1] + x[j][i+1] + x[j-1][i] + x[j+1][i])/5.0
```

The halo exchange happens in a two-step fashion as shown in the image below, from the book Parallel and high performance computing, by Robey and Zamora:

[image](ghost_exchange2.png" >

Above, a ghost cell on a process is delimited by a dashed outline, while cells owned by a process are marked with a solid line. Communication is represented with arrows and colors representing the original data, and the location that data is being communicated and copied to. We see that each process communicates based on the part of the problem it owns: the process that owns the central portion of data must communicate in all four directions, while processes on the corner only have to communicate in two directions only.

We now describe how to compile and run some of the above versions. Note that the modules that will be loaded next rely on the model installation described in the HPCTrainingDock repo.

Original version of Ghost Exchange

```
module load openmpi amdclang
```

Setting `HSA_XNACK=1` now for all of the following runs, except for Ver6, for which it is not needed.

```
export HSA_XNACK=1
export MAX_ITER=1000
```

Build the code

```
cd Orig
mkdir build && cd build
cmake ..
make -j
```

Run the example

```
echo "Orig Ver: Timing for CPU version with 4 ranks"
mpirun -n 4  ./GhostExchange -x 2  -y 2  -i 20000 -j 20000 -h 1 -c -I ${MAX_ITER}
```

Note the time that it took to run and the time for each part of the application.

Now we will try and run it with some simple affinity settings. These map the 4 process to separate NUMA regions and binds the process to the core

```
echo "Orig Ver: Timing for CPU version with 4 ranks with affinity"
mpirun  -n 4  --bind-to core     -map-by ppr:1:numa  --report-bindings ./GhostExchange -x 2  -y 2  -i 20000 -j 2000
```

Here are other affinity settings that you can try. These are for larger number of ranks and GPUs. Note that the number of processes per resource (ppr) increases

```
echo "Orig Ver: Timing for CPU version with 16 ranks"
mpirun -n 16  ./GhostExchange -x 4  -y 4  -i 20000 -j 20000 -h 1 -t -c -I ${MAX_ITER}
echo "Orig Ver: Timing for CPU version with 16 ranks with affinity"
mpirun -n 16  --bind-to core     -map-by ppr:2:numa  --report-bindings ./GhostExchange -x 4  -y 4  -i 20000 -j 2000
mpirun -n 64  --bind-to core     -map-by ppr:8:numa  --report-bindings ./GhostExchange -x 8  -y 8  -i 20000 -j 2000
mpirun -n 256 ./GhostExchange -x 16 -y 16 -i 20000 -j 20000 -h 1 -t -c
mpirun -n 16  --bind-to core     -map-by ppr:2:numa  ./GhostExchange -x 4  -y 4  -i 20000 -j 20000 -h 1 -t -c
mpirun -n 64  --bind-to core     -map-by ppr:8:numa  ./GhostExchange -x 8  -y 8  -i 20000 -j 20000 -h 1 -t -c
mpirun -n 256 --bind-to hwthread -map-by ppr:32:numa ./GhostExchange -x 16 -y 16 -i 20000 -j 20000 -h 1 -t -c -I ${
```

Version 1 – Adding OpenMP target offload to original CPU code

Build the example

```
cd ../../Ver1
mkdir build && cd build
cmake ..
make -j
```

Now run the example

```
echo "Ver 1: Timing for GPU version with 4 ranks with compute pragmas"
mpirun -n 4  --bind-to core     -map-by ppr:1:numa  --report-bindings ./GhostExchange -x 2  -y 2  -i 20000 -j 20000
```

Adding affinity script

```
echo "Ver 1: Timing for GPU version with 4 ranks with compute pragmas"
mpirun -n 4  --bind-to core     -map-by ppr:1:numa  --report-bindings ../../affinity_script.sh ./GhostExchange -x 2
```

You can export the environment variable below to check that the kernels are indeed executing on the GPU:

```
export LIBOMPTARGET_INFO=-1
```

Version 2 through 6 can be run similarly. For version 6, we recommend to `unset HSA_XNACK` since explicit memory management is implemented in this example. On MI300A, having `HSA_XNACK=1` set will make OpenMP ignore the map clauses.

HIP-Python

README.md from `HPCTrainingExamples/Python/hip-python` in the Training Examples repository

For these examples, get a GPU with salloc or srun.

```
salloc -N 1 --ntasks 16 --gpus=1 --time=01:00:00
or
srun -N 1 --ntasks 16 --gpus=1 --time=01:00:00 --pty /bin/bash
```

Be sure and free up the GPU when you are done with the exercises.

The first test is to check that the hip-python environment is set up correctly.

```
module load rocm hip-python
python -c 'from hip import hip, hiprtc' 2> /dev/null && echo 'Success' || echo 'Failure'
```

HIP-Python has an extensive capability for retrieving device properties and attributes. We'll take a look at the two main functions – higGetDeviceProperties and hipDeviceGetAttribute.

Obtaining Device Properties

We'll take a look at the higGetDeviceProperties function first. Copy the following code into a file named `hipGetDevicePropeties_example.py` or pull the example down with

```
git clone https://github.com/AMD/HPCTrainingExamples
cd HPCTrainingExamples/Python/hip-python
```

The `hipGetDeviceProperties_example.py` file

```
from hip import hip

def hip_check(call_result):
    err = call_result[0]
    result = call_result[1:]
    if len(result) == 1:
        result = result[0]
    if isinstance(err, hip.hipError_t) and err != hip.hipError_t.hipSuccess:
        raise RuntimeError(str(err))
    return result

props = hip.hipDeviceProp_t()
hip_check(hip.hipGetDeviceProperties(props,0))

for attrib in sorted(props.PROPERTIES()):
    print(f"props.{attrib}={getattr(props,attrib)}")
print("ok")
```

Try it by loading the proper modules and running it with python3.

```
module load rocm hip-python
python3 hipGetDeviceProperties_example.py
```

Some of the useful properties that can be obtained are:

```
props.managedMemory=1
props.name=b'AMD Instinct MI210'
props.warpSize=64
```

Getting Device Attributes

The second function to get device information is hipDeviceGetAttribute. Copy the following into `hipDeviceGetAttribute_example.py` or use the file in the hip-python examples.

```
from hip import hip

def hip_check(call_result):
    err = call_result[0]
    result = call_result[1:]
    if len(result) == 1:
        result = result[0]
    if isinstance(err, hip.hipError_t) and err != hip.hipError_t.hipSuccess:
        raise RuntimeError(str(err))
    return result

device_num = 0

for attrib in (
   hip.hipDeviceAttribute_t.hipDeviceAttributeMaxBlockDimX,
   hip.hipDeviceAttribute_t.hipDeviceAttributeMaxBlockDimY,
   hip.hipDeviceAttribute_t.hipDeviceAttributeMaxBlockDimZ,
   hip.hipDeviceAttribute_t.hipDeviceAttributeMaxGridDimX,
   hip.hipDeviceAttribute_t.hipDeviceAttributeMaxGridDimY,
   hip.hipDeviceAttribute_t.hipDeviceAttributeMaxGridDimZ,
   hip.hipDeviceAttribute_t.hipDeviceAttributeWarpSize,
):
```

```
    value = hip_check(hip.hipDeviceGetAttribute(attrib,device_num))
    print(f"{attrib.name}: {value}")
print("ok")
```

Run this file.

```
module load rocm hip-python
python3 hipDeviceGetAttribute_example.py
```

Output

```
hipDeviceAttributeMaxBlockDimX: 1024
hipDeviceAttributeMaxBlockDimY: 1024
hipDeviceAttributeMaxBlockDimZ: 1024
hipDeviceAttributeMaxGridDimX: 2147483647
hipDeviceAttributeMaxGridDimY: 65536
hipDeviceAttributeMaxGridDimZ: 65536
hipDeviceAttributeWarpSize: 64
ok
```

Accessing HIP Streams using HIP-Python

In the HIP streams example, we'll see how to create streams from Python and pass array data to the stream routines from Python arrays.

The code in the file hipstreams_example.py.

```
import ctypes
import random
import array

from hip import hip

def hip_check(call_result):
    err = call_result[0]
    result = call_result[1:]
    if len(result) == 1:
        result = result[0]
    if isinstance(err, hip.hipError_t) and err != hip.hipError_t.hipSuccess:
        raise RuntimeError(str(err))
    return result

# inputs
n = 100
x_h = array.array("i",[int(random.random()*10) for i in range(0,n)])
num_bytes = x_h.itemsize * len(x_h)
x_d = hip_check(hip.hipMalloc(num_bytes))

stream = hip_check(hip.hipStreamCreate())
hip_check(hip.hipMemcpyAsync(x_d,x_h,num_bytes,hip.hipMemcpyKind.hipMemcpyHostToDevice,stream))
hip_check(hip.hipMemsetAsync(x_d,0,num_bytes,stream))
hip_check(hip.hipMemcpyAsync(x_h,x_d,num_bytes,hip.hipMemcpyKind.hipMemcpyDeviceToHost,stream))
hip_check(hip.hipStreamSynchronize(stream))
hip_check(hip.hipStreamDestroy(stream))

# deallocate device data
hip_check(hip.hipFree(x_d))

for i,x in enumerate(x_h):
    if x != 0:
```

```
        raise ValueError(f"expected '0' for element {i}, is: '{x}'")
print("ok")
```

Now run this example.

```
module load rocm hip-python
python3 hipstreams_example.py
```

Calling hipBLAS from Python using HIP-Python

In the file hipblas_numpy_example.py, the hipBLAS library Saxpy routine is called. It operates on a numpy data array.

```
import ctypes
import math
import numpy as np

from hip import hip
from hip import hipblas

def hip_check(call_result):
    err = call_result[0]
    result = call_result[1:]
    if len(result) == 1:
        result = result[0]
    if isinstance(err,hip.hipError_t) and err != hip.hipError_t.hipSuccess:
        raise RuntimeError(str(err))
    elif isinstance(err,hipblas.hipblasStatus_t) and err != hipblas.hipblasStatus_t.HIPBLAS_STATUS_SUCCESS:
        raise RuntimeError(str(err))
    return result

num_elements = 100

# input data on host
alpha = ctypes.c_float(2)
x_h = np.random.rand(num_elements).astype(dtype=np.float32)
y_h = np.random.rand(num_elements).astype(dtype=np.float32)

# expected result
y_expected = alpha*x_h + y_h

# device vectors
num_bytes = num_elements * np.dtype(np.float32).itemsize
x_d = hip_check(hip.hipMalloc(num_bytes))
y_d = hip_check(hip.hipMalloc(num_bytes))

# copy input data to device
hip_check(hip.hipMemcpy(x_d,x_h,num_bytes,hip.hipMemcpyKind.hipMemcpyHostToDevice))
hip_check(hip.hipMemcpy(y_d,y_h,num_bytes,hip.hipMemcpyKind.hipMemcpyHostToDevice))

# call hipblasSaxpy + initialization & destruction of handle
handle = hip_check(hipblas.hipblasCreate())
hip_check(hipblas.hipblasSaxpy(handle, num_elements, ctypes.addressof(alpha), x_d, 1, y_d, 1))
hip_check(hipblas.hipblasDestroy(handle))

# copy result (stored in y_d) back to host (store in y_h)
hip_check(hip.hipMemcpy(y_h,y_d,num_bytes,hip.hipMemcpyKind.hipMemcpyDeviceToHost))

# compare to expected result
if np.allclose(y_expected,y_h):
```

```
    print("ok")
else:
    print("FAILED")
#print(f"{y_h=}")
#print(f"{y_expected=}")

# clean up
hip_check(hip.hipFree(x_d))
hip_check(hip.hipFree(y_d))
```

Using Unified Shared Memory for hipBLAS using HIP-Python

We can also take advantage of the single address space on the MI300A or the managed memory that moves the data from host to device and back for us on the other AMD Instinct GPUs. It simplifies the code because the memory does not have to be duplicated on the CPU and GPU. The code is in the file hipblas_numpy_USM_example.py.

```
import ctypes
import math
import numpy as np

from hip import hip
from hip import hipblas

def hip_check(call_result):
    err = call_result[0]
    result = call_result[1:]
    if len(result) == 1:
        result = result[0]
    if isinstance(err,hip.hipError_t) and err != hip.hipError_t.hipSuccess:
        raise RuntimeError(str(err))
    elif isinstance(err,hipblas.hipblasStatus_t) and err != hipblas.hipblasStatus_t.HIPBLAS_STATUS_SUCCESS:
        raise RuntimeError(str(err))
    return result

num_elements = 100

# input data on host
alpha = ctypes.c_float(2)
x_h = np.random.rand(num_elements).astype(dtype=np.float32)
y_h = np.random.rand(num_elements).astype(dtype=np.float32)

# expected result
y_expected = alpha*x_h + y_h

# call hipblasSaxpy + initialization & destruction of handle
handle = hip_check(hipblas.hipblasCreate())
hip_check(hipblas.hipblasSaxpy(handle, num_elements, ctypes.addressof(alpha), x_h, 1, y_h, 1))
hip_check(hipblas.hipblasDestroy(handle))

# compare to expected result
if np.allclose(y_expected,y_h):
    print("ok")
else:
    print("FAILED")
#print(f"{y_h=}")
#print(f"{y_expected=}")
```

To run this unified shared memory example, we also need the environment variable `HSA_XNACK` set to one.

```
module load rocm hip-python
export HSA_XNACK=1
python3 hipblas_numpy_USM_example.py
```

Calling hipFFT from Python using HIP-Python

The HIP FFT library can also be called from Python. We create a plan, perform the FFT, and then destroy the plan. This file is `hipfft_numpy_example.py` .

```
import numpy as np
from hip import hip, hipfft

def hip_check(call_result):
    err = call_result[0]
    result = call_result[1:]
    if len(result) == 1:
        result = result[0]
    if isinstance(err, hip.hipError_t) and err != hip.hipError_t.hipSuccess:
        raise RuntimeError(str(err))
    if isinstance(err, hipfft.hipfftResult) and err != hipfft.hipfftResult.HIPFFT_SUCCESS:
        raise RuntimeError(str(err))
    return result

# initial data
N = 100
hx = np.zeros(N,dtype=np.cdouble)
hx[:] = 1 - 1j

# copy to device
dx = hip_check(hip.hipMalloc(hx.size*hx.itemsize))
hip_check(hip.hipMemcpy(dx, hx, dx.size, hip.hipMemcpyKind.hipMemcpyHostToDevice))

# create plan
plan = hip_check(hipfft.hipfftPlan1d(N, hipfft.hipfftType.HIPFFT_Z2Z, 1))

# execute plan
hip_check(hipfft.hipfftExecZ2Z(plan, idata=dx, odata=dx, direction=hipfft.HIPFFT_FORWARD))
hip_check(hip.hipDeviceSynchronize())

# copy to host and free device data
hip_check(hip.hipMemcpy(hx,dx,dx.size,hip.hipMemcpyKind.hipMemcpyDeviceToHost))
hip_check(hip.hipFree(dx))

if not np.isclose(hx[0].real,N) or not np.isclose(hx[0].imag,-N):
     raise RuntimeError("element 0 must be '{N}-j{N}'.")
for i in range(1,N):
   if not np.isclose(abs(hx[i]),0):
        raise RuntimeError(f"element {i} must be '0'")

hip_check(hipfft.hipfftDestroy(plan))
print("ok")
```

Run this examples with:

```
module load rocm hip-python
python3 hipfft_numpy_example.py
```

Unified Shared Memory version of calling hipFFT HIP-Python

The code is much simplier if we take advantage of the unified shared memory or managed memory. We can just use the host versions of the data directly. The simpler code is in hipfft_numpy_USM_example.py

```
import numpy as np
from hip import hip, hipfft

def hip_check(call_result):
    err = call_result[0]
    result = call_result[1:]
    if len(result) == 1:
        result = result[0]
    if isinstance(err, hip.hipError_t) and err != hip.hipError_t.hipSuccess:
        raise RuntimeError(str(err))
    if isinstance(err, hipfft.hipfftResult) and err != hipfft.hipfftResult.HIPFFT_SUCCESS:
        raise RuntimeError(str(err))
    return result

# initial data
N = 100
hx = np.zeros(N,dtype=np.cdouble)
hx[:] = 1 - 1j

# create plan
plan = hip_check(hipfft.hipfftPlan1d(N, hipfft.hipfftType.HIPFFT_Z2Z, 1))

# execute plan
hip_check(hipfft.hipfftExecZ2Z(plan, idata=hx, odata=hx, direction=hipfft.HIPFFT_FORWARD))
hip_check(hip.hipDeviceSynchronize())

if not np.isclose(hx[0].real,N) or not np.isclose(hx[0].imag,-N):
     raise RuntimeError("element 0 must be '{N}-j{N}'.")
for i in range(1,N):
   if not np.isclose(abs(hx[i]),0):
        raise RuntimeError(f"element {i} must be '0'")

hip_check(hipfft.hipfftDestroy(plan))
print("ok")
```

Run this with:

```
module load rocm hip-python
export HSA_XNACK=1
python3 hipfft_numpy_USM_example.py
```

Calling RCCL from Python using HIP-Python

We can also call the RCCL communication library from Python using HIP-Python. An example of this is shown in rccl_example.py.

```
import numpy as np
from hip import hip, rccl

def hip_check(call_result):
    err = call_result[0]
    result = call_result[1:]
    if len(result) == 1:
        result = result[0]
    if isinstance(err, hip.hipError_t) and err != hip.hipError_t.hipSuccess:
```

```
        raise RuntimeError(str(err))
    if isinstance(err, rccl.ncclResult_t) and err != rccl.ncclResult_t.ncclSuccess:
        raise RuntimeError(str(err))
    return result

# init the communicators
num_gpus = hip_check(hip.hipGetDeviceCount())
comms = np.empty(num_gpus,dtype="uint64") # size of pointer type, such as ncclComm
devlist = np.array(range(0,num_gpus),dtype="int32")
hip_check(rccl.ncclCommInitAll(comms, num_gpus, devlist))

# init data on the devices
N = 4
ones = np.ones(N,dtype="int32")
zeros = np.zeros(ones.size,dtype="int32")
dxlist = []
for dev in devlist:
    hip_check(hip.hipSetDevice(dev))
    dx = hip_check(hip.hipMalloc(ones.size*ones.itemsize)) # items are bytes
    dxlist.append(dx)
    hx = ones if dev == 0 else zeros
    hip_check(hip.hipMemcpy(dx,hx,dx.size,hip.hipMemcpyKind.hipMemcpyHostToDevice))

# perform a broadcast
hip_check(rccl.ncclGroupStart())
for dev in devlist:
    hip_check(hip.hipSetDevice(dev))
    hip_check(rccl.ncclBcast(dxlist[dev], N, rccl.ncclDataType_t.ncclInt32, 0, int(comms[dev]), None))
    # conversion to Python int is required to not let the numpy datatype to be interpreted as single-element Py_buf
hip_check(rccl.ncclGroupEnd())

# download and check the output; confirm all entries are one
hx = np.empty(N,dtype="int32")
for dev in devlist:
    dx=dxlist[dev]
    hx[:] = 0
    hip_check(hip.hipMemcpy(hx,dx,dx.size,hip.hipMemcpyKind.hipMemcpyDeviceToHost))
    for i,item in enumerate(hx):
        if item != 1:
            raise RuntimeError(f"failed for element {i}")

# clean up
for dx in dxlist:
    hip_check(hip.hipFree(dx))
for comm in comms:
    hip_check(rccl.ncclCommDestroy(int(comm)))
    # conversion to Python int is required to not let the numpy datatype to be interpreted as single-element Py_buf

print("ok")
```

Running this example:

```
module load rocm hip-python
python3 rcc_example.py
```

Unified Shared Memory with RCCL using HIP-Python

We can also use the host data directly by relying on the unified shared memory or the managed memory on the AMD Instinct GPUs. The code for this is shown in rccl_USM_example.py

```
import numpy as np
from hip import hip, rccl

def hip_check(call_result):
    err = call_result[0]
    result = call_result[1:]
    if len(result) == 1:
        result = result[0]
    if isinstance(err, hip.hipError_t) and err != hip.hipError_t.hipSuccess:
        raise RuntimeError(str(err))
    if isinstance(err, rccl.ncclResult_t) and err != rccl.ncclResult_t.ncclSuccess:
        raise RuntimeError(str(err))
    return result

# init the communicators
num_gpus = hip_check(hip.hipGetDeviceCount())
comms = np.empty(num_gpus,dtype="uint64") # size of pointer type, such as ncclComm
devlist = np.array(range(0,num_gpus),dtype="int32")
hip_check(rccl.ncclCommInitAll(comms, num_gpus, devlist))

# init data on the devices
N = 4
ones = np.ones(N,dtype="int32")
zeros = np.zeros(ones.size,dtype="int32")
dxlist = []
for dev in devlist:
    hip_check(hip.hipSetDevice(dev))
    hx = ones if dev == 0 else zeros
    dxlist.append(hx)

# perform a broadcast
hip_check(rccl.ncclGroupStart())
for dev in devlist:
    hip_check(hip.hipSetDevice(dev))
    hip_check(rccl.ncclBcast(dxlist[dev], N, rccl.ncclDataType_t.ncclInt32, 0, int(comms[dev]), None))
    # conversion to Python int is required to not let the numpy datatype to be interpreted as single-element Py_buf
hip_check(rccl.ncclGroupEnd())

# download and check the output; confirm all entries are one
hx = np.empty(N,dtype="int32")
for dev in devlist:
    hx=dxlist[dev]
    for i,item in enumerate(hx):
        if item != 1:
            raise RuntimeError(f"failed for element {i}")

# clean up
for comm in comms:
    hip_check(rccl.ncclCommDestroy(int(comm)))
    # conversion to Python int is required to not let the numpy datatype to be interpreted as single-element Py_buf

print("ok")
```

Running this version requires setting `HSA_XNACK` to one as in the previous unified shared memory examples.

```
module load rocm hip-python
export HSA_XNACK=1
python3 rcc_USM_example.py
```

Cython example

We can also speed up Python code by compiling it using the Cython package. To demonstrate this, we create a simple array sum routine. The source code is in the file array_sum.pyx.

```
from hip import hip, hiprtc

def array_sum(double[:, ::1] A):
    cdef int m = A.shape[0]
    cdef int n = A.shape[1]
    cdef int i, j
    cdef double result = 0

    for i in range(m):
        for k in range(n):
            result += A[i, k]

    return result
```

And define the interface to the array sum routine in `array_sum.pyx` .

```
from hip cimport chip, chiprtc

def array_sum(double[:, ::1] A):
```

To compile the python routine, we need a setup.py file that gives the directions to compile a routine with the project compiler. We'll define the compiler, the paths, libraries, and compiler flags.

```
import os, sys

array_sum = "array_sum"

from setuptools import Extension, setup
from Cython.Build import cythonize

ROCM_PATH=os.environ.get("ROCM_PATH", "/opt/rocm")
HIP_PLATFORM = os.environ.get("HIP_PLATFORM", "amd")

if HIP_PLATFORM not in ("amd", "hcc"):
   raise RuntimeError("Currently only HIP_PLATFORM=amd is supported")

def create_extension(name, sources):
   global ROCM_PATH
   global HIP_PLATFORM
   rocm_inc = os.path.join(ROCM_PATH,"include")
   rocm_lib_dir = os.path.join(ROCM_PATH,"lib")
   rocm_libs = ["amdhip64"]
   platform = HIP_PLATFORM.upper()
   cflags = ["-D", f"__HIP_PLATFORM_{platform}__"]

   return Extension(
      name,
      sources=sources,
      include_dirs=[rocm_inc],
      library_dirs=[rocm_lib_dir],
      libraries=rocm_libs,
      language="c",
      extra_compile_args=cflags,
   )

setup(
```

```
   ext_modules = cythonize(
      [create_extension(array_sum, [f"{array_sum}.pyx"]),],
      compiler_directives=dict(language_level=3),
      compile_time_env=dict(HIP_PYTHON=True),
   )
)
```

We will need to bring in the Cython package, so we create a virtual environment.

```
python3 -m venv cython_example
source cython_example/bin/activate
```

Then we set up the environment by loading the rocm and hip-python module and installing cython.

```
module load rocm hip-python
pip3 import cython
```

Compile the array_sum python code with setup.py build

```
python3 setup.py build
```

Finally we clean up afterwards.

```
deactivate
rm -rf cython_example
```

Compiling and Launching Kernels

We can also create our own C programs and compile them with the hiprtc module for a Just-In_Time (JIT) compile capability. This example shows a C routine called `print_tid()` that is encoded as a string. The string is then converted into program source and compiled. We use the ability to query the device parameters to get the GPU architecture to compile for.

```
from hip import hip, hiprtc

def hip_check(call_result):
    err = call_result[0]
    result = call_result[1:]
    if len(result) == 1:
        result = result[0]
    if isinstance(err, hip.hipError_t) and err != hip.hipError_t.hipSuccess:
        raise RuntimeError(str(err))
    elif (
        isinstance(err, hiprtc.hiprtcResult)
        and err != hiprtc.hiprtcResult.HIPRTC_SUCCESS
    ):
        raise RuntimeError(str(err))
    return result


source = b"""\
extern "C" __global__ void print_tid() {
  printf("tid: %d\\n", (int) threadIdx.x);
}
"""

prog = hip_check(hiprtc.hiprtcCreateProgram(source, b"print_tid", 0, [], []))

props = hip.hipDeviceProp_t()
hip_check(hip.hipGetDeviceProperties(props,0))
arch = props.gcnArchName
```

```
print(f"Compiling kernel for {arch}")

cflags = [b"--offload-arch="+arch]
err, = hiprtc.hiprtcCompileProgram(prog, len(cflags), cflags)
if err != hiprtc.hiprtcResult.HIPRTC_SUCCESS:
    log_size = hip_check(hiprtc.hiprtcGetProgramLogSize(prog))
    log = bytearray(log_size)
    hip_check(hiprtc.hiprtcGetProgramLog(prog, log))
    raise RuntimeError(log.decode())
code_size = hip_check(hiprtc.hiprtcGetCodeSize(prog))
code = bytearray(code_size)
hip_check(hiprtc.hiprtcGetCode(prog, code))
module = hip_check(hip.hipModuleLoadData(code))
kernel = hip_check(hip.hipModuleGetFunction(module, b"print_tid"))
#
hip_check(
    hip.hipModuleLaunchKernel(
        kernel,
        *(1, 1, 1), # grid
        *(32, 1, 1),  # block
        sharedMemBytes=0,
        stream=None,
        kernelParams=None,
        extra=None,
    )
)

hip_check(hip.hipDeviceSynchronize())
hip_check(hip.hipModuleUnload(module))
hip_check(hiprtc.hiprtcDestroyProgram(prog.createRef()))

print("ok")
```

To run the example of creating a kernel and launching it:

```
module load rocm hip-python
python3 create_launch_C_kernel.py
```

Kernels with arguments

It is a little more complicated to launch a kernel with arguments. The program is `scale_vector()` and it has six arguments. We add an "extra" field with the six arguments as part of the launch kernel call. This example is in `kernel_with_arguments.py` .

```
import ctypes
import array
import random
import math

from hip import hip, hiprtc

def hip_check(call_result):
    err = call_result[0]
    result = call_result[1:]
    if len(result) == 1:
        result = result[0]
    if isinstance(err, hip.hipError_t) and err != hip.hipError_t.hipSuccess:
        raise RuntimeError(str(err))
    elif (
        isinstance(err, hiprtc.hiprtcResult)
```

```
        and err != hiprtc.hiprtcResult.HIPRTC_SUCCESS
    ):
        raise RuntimeError(str(err))
    return result

source = b"""\
extern "C" __global__ void scale_vector(float factor, int n, short unused1, int unused2, float unused3, float *x) {
  int tid = threadIdx.x + blockIdx.x * blockDim.x;
  if ( tid == 0 ) {
    printf("tid: %d, factor: %f, x*: %lu, n: %lu, unused1: %d, unused2: %d, unused3: %f\\n",tid,factor,x,n,(int) un
  }
  if (tid < n) {
     x[tid] *= factor;
  }
}
"""

prog = hip_check(hiprtc.hiprtcCreateProgram(source, b"scale_vector", 0, [], []))

props = hip.hipDeviceProp_t()
hip_check(hip.hipGetDeviceProperties(props,0))
arch = props.gcnArchName

print(f"Compiling kernel for {arch}")

cflags = [b"--offload-arch="+arch]
err, = hiprtc.hiprtcCompileProgram(prog, len(cflags), cflags)
if err != hiprtc.hiprtcResult.HIPRTC_SUCCESS:
    log_size = hip_check(hiprtc.hiprtcGetProgramLogSize(prog))
    log = bytearray(log_size)
    hip_check(hiprtc.hiprtcGetProgramLog(prog, log))
    raise RuntimeError(log.decode())
code_size = hip_check(hiprtc.hiprtcGetCodeSize(prog))
code = bytearray(code_size)
hip_check(hiprtc.hiprtcGetCode(prog, code))
module = hip_check(hip.hipModuleLoadData(code))
kernel = hip_check(hip.hipModuleGetFunction(module, b"scale_vector"))

# kernel launch

## inputs
n = 100
x_h = array.array("f",[random.random() for i in range(0,n)])
num_bytes = x_h.itemsize * len(x_h)
x_d = hip_check(hip.hipMalloc(num_bytes))
print(f"{hex(int(x_d))=}")

## upload host data
hip_check(hip.hipMemcpy(x_d,x_h,num_bytes,hip.hipMemcpyKind.hipMemcpyHostToDevice))

factor = 1.23

## expected result
x_expected = [a*factor for a in x_h]

block = hip.dim3(x=32)
grid = hip.dim3(math.ceil(n/block.x))

## launch
```

```
hip_check(
    hip.hipModuleLaunchKernel(
        kernel,
        *grid,
        *block,
        sharedMemBytes=0,
        stream=None,
        kernelParams=None,
        extra=(
          ctypes.c_float(factor), # 4 bytes
          ctypes.c_int(n),  # 8 bytes
          ctypes.c_short(5), # unused1, 10 bytes
          ctypes.c_int(2), # unused2, 16 bytes (+2 padding bytes)
          ctypes.c_float(5.6), # unused3 20 bytes
          x_d, # 32 bytes (+4 padding bytes)
        )
    )
)

# copy result back
hip_check(hip.hipMemcpy(x_h,x_d,num_bytes,hip.hipMemcpyKind.hipMemcpyDeviceToHost))

for i,x_h_i in enumerate(x_h):
    if not math.isclose(x_h_i,x_expected[i],rel_tol=1e-6):
        raise RuntimeError(f"values do not match, {x_h[i]=} vs. {x_expected[i]=}, {i=}")

hip_check(hip.hipFree(x_d))

hip_check(hip.hipModuleUnload(module))
hip_check(hiprtc.hiprtcDestroyProgram(prog.createRef()))

print("ok")
```

Run this example with:

```
module load rocm hip-python
python3 kernel_with_args.py
```

numba-HIP

A simple numba-HIP vector addition example

```
from numba import hip

@hip.jit
def f(a, b, c):
   # like threadIdx.x + (blockIdx.x * blockDim.x)
   tid = hip.grid(1)
   size = len(c)

   if tid < size:
       c[tid] = a[tid] + b[tid]

print("Ok")
```

To run the example

```
module load rocm hip-python
python3 numba-hip.py
```

An alternative approach to changing all the `@cuda.jit` to `@hip.jit` is to have numba-hip pose as CUDA. We do this with the addition of the following two lines:

```
hip.pose_as_cuda()
from numba import cuda
```

```
from numba import hip

hip.pose_as_cuda()
from numba import cuda

@cuda.jit
def f(a, b, c):
   # like threadIdx.x + (blockIdx.x * blockDim.x)
   tid = cuda.grid(1)
   size = len(c)

   if tid < size:
       c[tid] = a[tid] + b[tid]

print("Ok")
```

Running this example

```
module load rocm hip-python
python3 numba-hip-cuda-posing.py
```

CuPy Examples

README.md from `HPCTrainingExamples/Python/cupy` in the Training Examples repository

NOTE: these exercises have been tested on MI210 and MI300A accelerators using a container environment. To see details on the container environment (such as operating system and modules available) please see `README.md` on this repo.

Simple introduction example to CuPy for AMD GPUs

To run this example,

```
module load cupy
python cupy_array_sum.py
```

The output should look like the following:

```
CuPy Array: [1 2 3 4 5]
Squared CuPy Array: [ 1  4  9 16 25]
NumPy Array: [5 6 7 8 9]
CuPy Array from NumPy: [5 6 7 8 9]
Addition Result on GPU: [ 6  8 10 12 14]
Result on CPU: [ 6  8 10 12 14]
```

What is actually happening here? What is on the GPU and what is on the CPU? Let's try and see more.

```
export AMD_LOG_LEVEL=1
python cupy_array_sum.py
```

Now our output is:

```
:1:hip_memory.cpp           :3721: 1083559518128d us:  Cannot get amd_mem_obj for ptr: 0x46b8a5f0
CuPy Array: [1 2 3 4 5]
Squared CuPy Array: [ 1  4  9 16 25]
NumPy Array: [5 6 7 8 9]
```

```
:1:hip_memory.cpp           :3721: 1083560370823d us:  Cannot get amd_mem_obj for ptr: 0x483ba890
CuPy Array from NumPy: [5 6 7 8 9]
Addition Result on GPU: [ 6  8 10 12 14]
Result on CPU: [ 6  8 10 12 14]
```

The warning is from the AMD logging functions and doesn't impact the run. Now let's increase the log level for the run.

```
export AMD_LOG_LEVEL=3
python cupy_array_sum.py
```

Now we see lots of output that shows the hip calls and the operations on the GPU.

```
....
hipMemcpyAsync ( 0x559ea98f65f0, 0x7f4556800000, 40, hipMemcpyDeviceToHost, stream:<null> )
Signal = (0x7f4d5efff280), Translated start/end = 1083534945452078 / 1083534945453358, Elapsed = 1280 ns, ticks sta
Host active wait for Signal = (0x7f4d5efff200) for -1 ns
Set Handler: handle(0x7f4d5efff180), timestamp(0x559eaabead90)
Host active wait for Signal = (0x7f4d5efff180) for -1 ns
hipMemcpyAsync: Returned hipSuccess : : duration: 5948d us
hipStreamSynchronize ( stream:<null> )
Handler: value(0), timestamp(0x559eaa7e7350), handle(0x7f4d5efff180)
hipStreamSynchronize: Returned hipSuccess :
hipSetDevice ( 0 )
hipSetDevice: Returned hipSuccess :
CuPy Array: [1 2 3 4 5]
....
```

MPI4Py examples

README.md from `HPCTrainingExamples/Python/mpi4py` in the Training Examples repository

NOTE: these exercises have been tested on MI210 and MI300A accelerators using a container environment. To see details on the container environment (such as operating system and modules available) please see `README.md` on this repo.

Exploring MPI communication with MPI4Py

First set up the environment

```
module load mpi4py cupy
```

Add `print("Rank is:", rank)` right after the rank is set at line 10.

Then run the python program

```
mpirun -n 4 python mpi4py_cupy.py
```

You should see the following output, but it might be in a different order

```
Rank is: 3
Rank is: 1
Rank is: 2
Rank is: 0
Starting allreduce test...
Starting bcast test...
Starting send-recv test...
Success
```

To verify if the program is running on the GPU

```
export AMD_LOG_LEVEL=3
mpirun -n 4 python mpi4py_cupy.py
```

You will get a lot of output including whole programs.

AMD AI Assistant using retrieval augmented generation (RAG)

README.md from `HPCTrainingExamples/MLExamples/RAG_LangChainDemo` in the Training Examples repository

We will be using retrieval augmented generation (RAG) to create an AMD AI assistant you can interact with to answer questions on AMD GPU software and programming.

With RAG, pre-trained, parametric-memory generation models are endowed with a non-parametric memory through a general-purpose fine-tuning approach. This means that you can supply the most up to date content to a pre existing model and, without additional training, use this new material as context to adjust the answers of the pre-existing model to fit your needs.

Ollama

The main building block we will use is **Ollama**, which is a platform to interact with large language models. Running the AI assistant needs the Ollama server to run the LLM model on which it is based: to install Ollama see these instructions.

Consider the sequence of commands below: note that the first command below will kill all ollama processes already running on your system

```
pkill -f ollama
ollama serve &
ollama pull llama3.3:70b
```

The `ollama serve &` command will run Ollama in the background. If this command does not work because Ollama's default port (11434) is already in use, set `OLLAMA_HOST` appropriately, then run `ollama serve &` again. A way to set `OLLAMA_HOST` properly is to just increase by one the port number (so for example `export OLLAMA_HOST=127.0.0.1:11435`). Then the `Llama3.3` model with 70 billion parameters is pulled.

To test that Ollama is working you can do:

```
ollama run llama3.3:70b
```

The above command will run the LLM locally, you can interact with it through the prompt and then exit with `/bye` .

We will show two ways of creating the AI assistant depending on the number of users in your system.

System with a limited number of users

In this case, we assume the system has a small number of users, and that it can sustain the case where all of them are running Ollama locally. The bigger in terms of parameters the models pulled from Ollama, the larger the memory requirements, hence if the number of users is large and the models are big, you could quickly finish up all the memory in the system. This is why we recommend the approach below only if the amount of users on the system is limited.

Setting up The first thing to do, is to install the necessary software requirements: one could do it using `conda` (see here for how we setup the `miniconda3` module invoked below):

```
module load miniconda3
conda create -y -n amd_ai_assistant
conda activate amd_ai_assistant
git clone https://github.com/amd/HPCTrainingExamples.git
cd HPCTrainingExamples/MLExamples/RAG_LangChainDemo
pip3 install -r requirements.txt
```

The installation of the requirements (last line above) will take quite a bit of time. If you do not want to use `conda`, and feel like you are aware of what you keep in your `PYTHONPATH`, you can do this instead:

```
mkdir ai_assistant_deps
cd ai_assistant_deps
export AI_ASSISTANT_DEPS=$PWD
cd ..
git clone https://github.com/amd/HPCTrainingExamples.git
cd HPCTrainingExamples/MLExamples/RAG_LangChainDemo
pip3 install -r requirements.txt --target=$AI_ASSISTANT_DEPS
export PYTHONPATH=$AI_ASSISTANT_DEPS:$PYTHONPATH
```

Note that it is **very** important to specify the target option when doing the installation with `pip` because that's where you specify the installation directory. In this way you will (hopefully) avoid messing up other Python packages you may have already installed in your local directory. The last line above will add the packages you just installed to your `PYTHONPATH` so they will be visible when you want to do `import <package>` in your Python scripts.

In the present directory, there currently are three versions of the AI assistant script you can run:

1. amd_ai_assistant.py
2. instinct_chat.py
3. instinct_chat_4_llm.py

We recommend you begin with `amd_ai_assistant.py` since it is the most complete, optimized and up to date of the three scripts.

All the above scripts will implement a retrieval augmented generation (RAG) model by scraping the web to get information on AMD and AMD software to provide the necessary context to pre trained LLMs to be able to answer AMD specific questions leveraging the info from those specific websites. We initially focus on `amd_ai_assistant.py` for the reasons mentioned above. To see what websites and content is scraped in `amd_ai_assistant.py`, look at the urls in the `scrape_all` function:

```
async def scrape_all(rocm_version):
    rocm_docs_url=rocm_version
    if rocm_version == "latest":
       rocm_docs_url=rocm_version
    else:
       rocm_docs_url=f"docs-{rocm_version}"
    main_urls = [
        f"https://rocm.docs.amd.com/en/{rocm_docs_url}/",
        "https://rocm.blogs.amd.com/verticals-ai.html",
        "https://rocm.blogs.amd.com/verticals-ai-page2.html",
        "https://rocm.blogs.amd.com/verticals-ai-page3.html",
        "https://rocm.blogs.amd.com/verticals-ai-page4.html",
        "https://rocm.blogs.amd.com/verticals-ai-page5.html",
        "https://rocm.blogs.amd.com/verticals-ai-page6.html",
        "https://rocm.blogs.amd.com/verticals-ai-page7.html",
        "https://rocm.blogs.amd.com/verticals-ai-page8.html",
        "https://rocm.blogs.amd.com/verticals-ai-page9.html",
        "https://rocm.blogs.amd.com/verticals-ai-page10.html",
        "https://rocm.blogs.amd.com/verticals-ai-page11.html",
        "https://rocm.blogs.amd.com/verticals-ai-page12.html",
```

```
"https://rocm.blogs.amd.com/verticals-ai-page13.html",
"https://rocm.blogs.amd.com/verticals-ai-page14.html",
"https://rocm.blogs.amd.com/verticals-hpc.html",
                        .
                        .
                        .
```

You can edit the above list adding or removing urls at your discretion. Note that you can decide the level of recursion by which links at the above urls will be scraped (default is one level of recursion):

```
TIMEOUT = 5  # seconds
MAX_DEPTH = 1
CRAWL_DELAY = 1  # seconds delay between requests to avoid overload
CONCURRENT_REQUESTS = 5  # Limit max concurrent requests for politeness
```

Above, if you modify `MAX_DEPTH` to two for example, starting from the above urls, the script will scrape links at those urls and then the links at the links. Let's assume that Ollama is running effectively on the background and you pulled `LLama3.3:70b` (which is the LLM `mad_ai_assistant.py` will be relying on for RAG): to run the code do:

```
cd HPCTrainingExamples/MLExamples/RAG_LangChainDemo
python3 amd_ai_assistant.py --rocm-version <rocm_version> --scrape
```

The above flags will specify what ROCm version to pull the documentation of, and also that we want to force scraping: this is because the script will save the scraped data locally so that the next time you run the script it will not scrape again, unless you force it with the `--scrape` option. Without scraping again, you will be immediately be supplied the prompt to interact with the model, saving considerable time:

```
AMD AI Assistant Ready! Type your questions. Type 'exit', 'quit' or 'bye' to stop.

Prompt:
```

The script called `instinct_chat.py` has either the option to be used from command line, or to use a web user interface. The default is to use the command line option, to use the web interface (provided by Gradio) run it with:

```
cd HPCTrainingExamples/MLExamples/RAG_LangChainDemo
python3 instinct_chat.py --webui
```

otherwise, just omit the `--webui` option and you will get the command line prompt. Then copy paste the link displayed on terminal to your browser and you will get to the web user interface. Note that if you are running this script on a cluster, you will need to take care of the proper ssh tunneling to be able to open the user interface from your local browser. The script `instinct_chat_4_llm.py` only works with the Gradio web interface so running it with:

```
cd HPCTrainingExamples/MLExamples/RAG_LangChainDemo
python3 instinct_chat_4_llm.py
```

will give you the web interface option by default. The above script considers `llama3.3:70b` , `gemma2:27b` , `mistral-large` and `phi3:14b` to provide four answers to your prompt that will be displayed side by side in the Gradio interface. Remember to pull all these four models with Ollama before running the script.

System with a large number of users

On a system with a large number of users, having each one of them run Ollama locally might be prohibitive. In such a case it could be helpful to have Ollama run on a dedicated node and then have users hop onto a web interface to interact with the models. This can be done in various ways, here we report one way to achieve it: below we assume Ollama is already installed and Podman is used as containers manager: 1. Ssh to the host system (something similar to `ssh $USER@aac6.amd.com`) 2. Ssh to the compute node on the host system (this is where Ollama will run) 3. Add this line: `host: 0.0.0.0`

to the `.ollama/config.yaml` 4. Run `export OLLAMA_HOST=0.0.0.0:<port_number>` (for instance the port number might be 11435) 5. Run `export OLLAMA_PORT=<port_number>` 6. Run: `ollama serve &` to have Ollama run in the background 7. Run: `ollama pull <some_model>` : this step is not striclty necessary as you will be able to pull models as admin user of the Open WebUI 8. Run: `podman pull ghcr.io/open-webui/open-webui:ollama` : this command will pull the image you will run 9. Run: `podman run -d -p 3000:8080 -e OLLAMA_BASE_URL=http://<host_sys_IP_address>:<port_number> --g` : this command will run the container using the image pulled at the previous step 10. From your local machine run: `ssh -L 3000:<compute_node>:3000 <host address>` (for instance could be `aac6.amd.com`) 11. Type this in the address bar of your browser (such as Microsoft Edge): `localhost:3000` 12. Create an admin account and make sure to remember the password you set. This is all done locally so if you remove the Open WebUI data from your host system you will be allowed to start over (you will lose all the data though, so make sure to take note of the password).

Troubleshooting tips If you encounter unexpected behavior while setting up Open WebUI here is something you can do:

1. Kill Ollama

```
ps aux | grep 'ollama serve'
sudo pkill -f "ollama serve"
```

2. Stop and remove the container on Podman

```
podman stop open-webui-ollama
podman rm open-webui-ollama
```

3. If you get `505:internal error` when accessing `localhost:3000` , keep refreshing the page and it should get you there

Careful to not remove the volume (that you can see by doing `podman volume ls`) otherwise you will lose all the local data such as knowledge base, admin login info, user list etc.

ROCgdb

NOTE: these exercises have been tested on MI210 and MI300A accelerators using a container environment. To see details on the container environment (such as operating system and modules available) please see `README.md` on this repo.

We show a simple example on how to use the main features of the ROCm debugger `rocgdb` .

Saxpy Debugging

Let us consider the `saxpy` kernel in the HIP examples:

```
cd HPCTrainingExamples/HIP/saxpy
```

Get an allocation of a GPU and load software modules:

```
salloc -N 1 --gpus=1
module load rocm
```

You can see some information on the GPU you will be running on by doing:

```
rocm-smi
```

To introduce an error in your program, comment out the `hipMalloc` calls at line 71 and 72, then compile with:

```
mkdir build && cd build
cmake ..
make VERBOSE=1
```

Running the program, you will see the expected runtime error:

```
./saxpy
Memory access fault by GPU node-2 (Agent handle: 0x2284d90) on address (nil). Reason: Unknown.
Aborted (core dumped)
```

To run the code with the `rocgdb` debugger, do:

```
rocgdb saxpy
```

Note that there are also two options for graphical user interfaces that can be turned on by doing:

```
rocgdb -tui saxpy
cgdb -d rocgdb saxpy
```

For the latter command above, you need to have `cgdb` installed on your system.

In the debugger, type `run` (or just `r`) and you will get an error similar to this one:

```
Thread 3 "saxpy" received signal SIGSEGV, Segmentation fault.
[Switching to thread 3, lane 0 (AMDGPU Lane 1:2:1:1/0 (0,0,0)[0,0,0])]
0x00007ffff7ec1094 in saxpy() at saxpy.cpp:57
57    y[i] += a*x[i];
```

Note that the cmake build type is set to `RelWithDebInfo` (see line 8 in CMakeLists.txt). With this build type, the debugger will be aware of the debug symbols. If that was not the case (for instance if compiling in `Release` mode), running the code with the debugger you would get an error message ***without*** line info, and also a warning like this one:

```
Reading symbols from saxpy...
(No debugging symbols found in saxpy)
```

The error report is at a thread on the GPU. We can display information on the threads by typing `info threads` (or `i th`). It is also possible to move to a specific thread with `thread <ID>` (or `t <ID>`) and see the location of this thread with `where`. For instance, if we are interested in the thread with ID 1:

```
i th
th 1
where
```

You can add breakpoints with `break` (or `b`) followed by the line number. For instance to put a breakpoint right after the `hipMalloc` lines do `b 72`.

When possible, it is also advised to compile without optimization flags (so using `-O0`) to avoid seeing breakpoints placed on lines different than those specified with the breakpoint command.

You can also add a breakpoint directly at the start of the GPU kernel with `b saxpy`. To run to the next breakpoint, type `continue` (or `c`).

To list all the breakpoints that have been inserted type `info break` (or `i b`):

```
(gdb) i b
Num     Type           Disp Enb Address            What
1       breakpoint     keep y   0x000000000020b334 in main() at /HPCTrainingExamples/HIP/saxpy/saxpy.hi
2       breakpoint     keep y   0x000000000020b350 in main() at /HPCTrainingExamples/HIP/saxpy/saxpy.hi
```

A breakpoint can be removed with `delete <Num>` (or `d <Num>`): note that `<Num>` is the breakpoint ID displayed above. For instance, to remove the breakpoint at line 74, you have to do `d 1`.

To proceed to the next line you can do `next` (or `n`). To step into a function, do `step` (or `s`) and to get out do `finish`. Note that if a breakpoint is at a kernel, doing `n` or `s` will switch between different threads. To avoid this behavior, it is necessary to disable the breakpoint at the kernel with `disable <Num>` .

It is possible to have information on the architecture (below shown on MI250):

```
(gdb) info agents
  Id State Target Id                  Architecture Device Name                              Cores Threads
* 1  A     AMDGPU Agent (GPUID 64146) gfx90a       Aldebaran/MI200 [Instinct MI250X/MI250] 416   3328
```

We can also get information on the thread grid:

```
(gdb) info dispatches
  Id   Target Id                       Grid      Workgroup Fence   Kernel Function
* 1    AMDGPU Dispatch 1:1:1 (PKID 0) [256,1,1] [128,1,1] B|Aa|Ra saxpy(int, float const*, int, float*,
```

For the rocgdb documentation, please see: `/opt/rocm-<version>/share/doc/rocgdb` .

Rocprofv3 Exercises for HIP

Jacobi

Setup environment

```
module load rocm
module load amdclang
module load openmpi
```

- Download examples repo (if necessary) and navigate to the `jacobi` exercises

```
cd ~/HPCTrainingExamples/HIP/jacobi
```

Compile and run one case

```
make clean
make
mpirun -np 2 ./Jacobi_hip -g 2 1
```

Let's profile HIP

```
mpirun -np 2 rocprofv3 --hip-trace -- ./Jacobi_hip -g 2 1
```

Note that there is an output message showing that the output csv files are placed into a subdirectory. There are two files per MPI process: one with the HW information (`XXXXX_agent_info.csv`) and for the HIP API `XXXXX_hip_api_trace.csv` where XXXXX are numbers.

```
"Domain","Function","Process_Id","Thread_Id","Correlation_Id","Start_Timestamp","End_Timestamp"
"HIP_COMPILER_API","__hipRegisterFatBinary",1389712,1389712,1,4762229062888604,4762229062892624
"HIP_COMPILER_API","__hipRegisterFunction",1389712,1389712,2,4762229062903414,4762229062910744
"HIP_COMPILER_API","__hipRegisterFatBinary",1389712,1389712,3,4762229062911814,4762229062911924
...
"HIP_RUNTIME_API","hipGetDeviceCount",1389712,1389712,9,4762229067837299,4762229201986925
"HIP_RUNTIME_API","hipStreamCreate",1389712,1389712,10,4762229253999055,4762229484333519
"HIP_RUNTIME_API","hipStreamCreate",1389712,1389712,11,4762229484352199,4762229502251764
"HIP_RUNTIME_API","hipEventCreateWithFlags",1389712,1389712,12,4762229502311284,4762229502317444
"HIP_RUNTIME_API","hipEventCreateWithFlags",1389712,1389712,13,4762229502318894,4762229502319244
"HIP_RUNTIME_API","hipEventCreateWithFlags",1389712,1389712,14,4762229502320134,4762229502320454
...
```

Correlation_Id: Unique identifier for correlation between HIP and HSA async calls during activity tracing.

Start_Timestamp: Begin time in nanoseconds (ns) when the kernel begins execution.

End_Timestamp: End time in ns when the kernel finishes execution.

Let's create statistics

```
mpirun -np 2 rocprofv3 --stats --hip-trace -- ./Jacobi_hip -g 2 1
```

Now there are two extra files per MPI process. The first is called `XXXXX_domain_stats.csv` . The contents are

```
"Name","Calls","TotalDurationNs","AverageNs","Percentage","MinNs","MaxNs","StdDev"
"HIP_API",24044,1660103043,69044.378764,100.00,79,297454413,1941729.969641
```

The second is called `XXXXX_hip_api_stats.csv` and the contents are:

```
"Name","Calls","TotalDurationNs","AverageNs","Percentage","MinNs","MaxNs","StdDev"
"hipMemcpy",1005,1248355080,1242144.358209,75.20,427157,16960295,594564.020099
"hipMemset",1,297454413,297454413.000000,17.92,297454413,297454413,0.00000000e+00
"hipStreamSynchronize",2000,62408983,31204.491500,3.76,14160,11567558,259729.446877
"hipStreamCreate",2,13571635,6785817.500000,0.8175,6588338,6983297,279278.187191
"hipInit",1,10837633,10837633.000000,0.6528,10837633,10837633,0.00000000e+00
"hipLaunchKernel",5002,9285550,1856.367453,0.5593,1030,501227,10801.917865
"hipMemcpy2DAsync",1000,7495461,7495.461000,0.4515,1500,5522446,174573.470155
"hipEventRecord",2000,3031773,1515.886500,0.1826,750,7250,627.097396
"hipMemcpyAsync",1000,2597421,2597.421000,0.1565,2040,36110,1201.163919
"hipFree",4,1466101,366525.250000,0.0883,3380,1380181,676012.011385
"hipDeviceSynchronize",1001,713007,712.294705,0.0429,540,3060,200.535668
"hipEventElapsedTime",1000,603200,603.200000,0.0363,449,3090,174.077112
"__hipPushCallConfiguration",5002,572690,114.492203,0.0345,80,15670,223.429644
"__hipPopCallConfiguration",5002,535744,107.105958,0.0323,79,14360,265.450993
"hipHostMalloc",3,497417,165805.666667,0.0300,92599,233828,70757.088651
"hipMalloc",7,336148,48021.142857,0.0202,1820,171208,57008.652464
"hipHostFree",2,294098,147049.000000,0.0177,118099,175999,40941.482631
"__hipRegisterFatBinary",3,26819,8939.666667,1.616e-03,80,26599,15293.460705
"__hipRegisterFunction",5,8520,1704.000000,5.132e-04,170,7530,3257.518995
"hipGetDeviceCount",1,8380,8380.000000,5.048e-04,8380,8380,0.00000000e+00
"hipEventCreate",2,1690,845.000000,1.018e-04,260,1430,827.314934
"hipSetDevice",1,1280,1280.000000,7.710e-05,1280,1280,0.00000000e+00
```

The column Percentage means how much percentage of the execution time this command takes, in this case we have all the calls of a specific HIP API in the same row, as you can see the column Calls of how times this HIP command was called.

Where are the kernels?

```
mpirun -np 2 rocprofv3 --stats --kernel-trace --hip-trace -- ./Jacobi_hip -g 2 1
```

We have two more files per MPI process. The first is called `XXXXX_kernel_stats.csv` :

```
"Name","Calls","TotalDurationNs","AverageNs","Percentage","MinNs","MaxNs","StdDev"
"JacobiIterationKernel(int, double, double, double const*, double const*, double*, double*)",1000,545275480,545275.
"NormKernel1(int, double, double, double const*, double*)",1001,410964270,410553.716284,32.43,401121,421282,2773.93
"LocalLaplacianKernel(int, int, int, double, double, double const*, double*)",1000,285486734,285486.734000,22.53,27
"HaloLaplacianKernel(int, int, int, double, double, double const*, double const*, double*)",1000,13996851,13996.851
"__amd_rocclr_copyBuffer",1001,7823550,7815.734266,0.6173,6720,9280,672.661144
"NormKernel2(int, double const*, double*)",1001,3754094,3750.343656,0.2962,3520,4320,105.963559
"__amd_rocclr_fillBufferAligned",1,5920,5920.000000,4.671e-04,5920,5920,0.00000000e+00
```

The second file is called `XXXXX_kernel_trace.csv` . It has detailed information on each kernel dispatch.

```
"Kind","Agent_Id","Queue_Id","Thread_Id","Dispatch_Id","Kernel_Id","Kernel_Name","Correlation_Id","Start_Timestamp"
_Size_X","Workgroup_Size_Y","Workgroup_Size_Z","Grid_Size_X","Grid_Size_Y","Grid_Size_Z"
"KERNEL_DISPATCH",8,1,252734,1,10,"__amd_rocclr_fillBufferAligned",15,4484384343929154,4484384343935074,0,0,256,1,1
"KERNEL_DISPATCH",8,2,252734,2,18,"NormKernel1(int, double, double, double const*, double*)",33,4484384527705139,44
"KERNEL_DISPATCH",8,2,252734,3,17,"NormKernel2(int, double const*, double*)",36,4484384528106260,4484384528109780,0
"KERNEL_DISPATCH",8,1,252734,4,13,"__amd_rocclr_copyBuffer",37,4484384528126420,4484384528135540,0,0,512,1,1,512,1,
...
```

In order to have information for each Kernel call, remove the `--stats`

Create pftrace file for Perfetto and Visualize

```
mpirun -np 2 rocprofv3 --kernel-trace --hip-trace --output-format pftrace  -- ./Jacobi_hip -g 2 1
```

Now we have only pftrace files, one per MPI process.

- Merge the pftraces, if you want: `cat *_results.pftrace > jacobi.pftrace`
- Download the trace on your laptop and load the file on Perfetto. `scp -P 7002 aac6.amd.com:<path_to_file>/jacobi`

1. Open a browser and go to https://ui.perfetto.dev/.
2. Click on `Open trace file` in the top left corner.
3. Navigate to the `jacobi.pftrace` or the file before the merging, that you just downloaded.
4. Use the keystrokes W,A,S,D to zoom in and move right and left in the GUI

```
Navigation
w/s Zoom in/out
a/d Pan left/right
```

Feel free to use various flags as they were presented in the presentation

Hardware Counters

Read about hardware counters available for the GPU on this system (look for gfx90a section)

```
less $ROCM_PATH/lib/rocprofiler/gfx_metrics.xml
```

Create a `rocprof_counters.txt` file with the counters you would like to collect

```
vi rocprof_counters.txt
```

Content for `rocprof_counters.txt` :

```
pmc: VALUUtilization VALUBusy FetchSize WriteSize MemUnitStalled
pmc: GPU_UTIL CU_OCCUPANCY MeanOccupancyPerCU MeanOccupancyPerActiveCU
```

Execute with the counters we just added:

```
mpirun -np 2 rocprofv3 -i rocprof_counters.txt --kernel-trace --hip-trace -- ./Jacobi_hip -g 2 1
```

You'll notice that `rocprofv3` runs 2 passes, one for each set of counters we have in that file. Now the data are in two different folders, one for each MPI process, pmc_1 and pmc_2.

Explore the content of the pmc_* directories.

Try to use the `--hsa-trace` option also.

Tips

Do not forget for OMP Offloading information to declare the `--kernel-trace`

Rocprofv3 Exercises for OpenMP

In this series of examples, we will demonstrate profiling with rocprofv3 on a platform using an AMD Instinct™ MI300 GPU. ROCm releases (6.2+) now include rocprofv3.

Note that the focus of this exercise is on rocprofv3 profiler, not on how to achieve optimal performance on MI300A. This exercise was last tested with ROCm 6.4.2 on MI300A MPCDF Viper-GPU.

The examples are based on Fortran+OpenMP Jacobi porting example from HPCTrainingExamples.

Setup environment

Download examples repo and navigate to the Fortran+OpenMP Jacobi example exercises:

```
git clone https://github.com/amd/HPCTrainingExamples.git
cd HPCTrainingExamples/Pragma_Examples/OpenMP/Fortran/7_jacobi/1_jacobi_usm
```

Load the necessary modules, including flang-new compiler (module name for flang-new compiler on your system might differ, check for `rocm-afar-drop` , `amd-llvm` or something similar).

```
module load rocm
module load amdflang-new
```

For now unset `HSA_XNACK` environment variable:

```
export HSA_XNACK=0
```

Build and run

No profiling yet, just check that the code compiles and runs correctly.

```
make clean
make FC=amdflang
./jacobi -m 1024
```

This run should show output that looks like this:

```
Domain size:  1024 x  1024
Starting Jacobi run
Iteration:    0 - Residual: 4.42589E-02
Iteration:  100 - Residual: 1.25109E-03
Iteration:  200 - Residual: 7.43407E-04
Iteration:  300 - Residual: 5.48292E-04
Iteration:  400 - Residual: 4.41773E-04
Iteration:  500 - Residual: 3.73617E-04
Iteration:  600 - Residual: 3.25807E-04
Iteration:  700 - Residual: 2.90186E-04
Iteration:  800 - Residual: 2.62490E-04
Iteration:  900 - Residual: 2.40262E-04
Iteration: 1000 - Residual: 2.21976E-04
Stopped after 1000 iterations with residue: 2.21976E-04
Total Jacobi run time: ***** sec.
Measured lattice updates: 0.087 LU/s
Effective Flops:   1.5 GFlops
Effective device bandwidth: 0.008 TB/s
Effective AI=0.177
```

Basic rocprov3 profiling

Available options

Inspect rocprofv3 available options:

```
rocprofv3 -h
```

NOTE: When profing OpenMP offloading, do not forget to use `--kernel-trace` option.

First kernel information

Collect first profiles (do not forget `--` between rocprofv3 options and application binary).

```
rocprofv3 --kernel-trace -- ./jacobi -m 1024
```

rocprofv3 should generate 2 output files (XXXXX numbers are corresponding to the process id):

1. `XXXXX_agent_info.csv` with information for the used hardware APU/GPU and CPU.
2. `XXXXX_kernel_traces.csv` with information per each call of the kernel.

Check those output files using (adapt file paths if needed):

```
cat *_agent_info.csv
echo
head *_kernel_trace.csv
```

The output should be:

```
"Node_Id","Logical_Node_Id","Agent_Type","Cpu_Cores_Count","Simd_Count","Cpu_Core_Id_Base","Simd_Id_Base","Max_Wave
0,0,"CPU",48,0,0,0,0,0,0,0,0,1,48,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,3700,0,0,0,0,0,0,25,0,0,0,1763021218530103933,0,0
1,1,"CPU",48,0,64,0,0,0,0,0,0,1,48,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,3700,0,0,0,0,0,0,25,0,0,0,1763021218530103933,0,
2,2,"CPU",48,0,128,0,0,0,0,0,0,1,48,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,3700,0,0,0,0,0,0,25,0,0,0,1763021218530103933,0
3,3,"CPU",48,0,192,0,0,0,0,0,0,1,48,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,3700,0,0,0,0,0,0,25,0,0,0,1763021218530103933,0
4,4,"GPU",0,912,0,2147487744,8,64,0,64,64,6,228,24,24,1,10,4,32,90402,4098,29856,256,0,128,2,10,8,24,3700,2100,19,1
5,5,"GPU",0,912,0,2147487784,8,64,0,64,64,6,228,24,24,1,10,4,32,90402,4098,29856,256,1,136,2,10,8,24,3700,2100,19,1
6,6,"GPU",0,912,0,2147487824,8,64,0,64,64,6,228,24,24,1,10,4,32,90402,4098,29856,256,2,144,2,10,8,24,3700,2100,19,1
7,7,"GPU",0,912,0,2147487864,8,64,0,64,64,6,228,24,24,1,10,4,32,90402,4098,29856,256,3,152,2,10,8,24,3700,2100,19,1

"Kind","Agent_Id","Queue_Id","Kernel_Id","Kernel_Name","Correlation_Id","Start_Timestamp","End_Timestamp","Private_
"KERNEL_DISPATCH",4,1,2,"__omp_offloading_32_2f3c6__QMnorm_modPnorm_l26",1,5329321973213203,5329321973322123,0,4360
"KERNEL_DISPATCH",4,1,4,"__omp_offloading_32_2f3c3__QMlaplacian_modPlaplacian_l23",2,5329321976381800,5329321976429
"KERNEL_DISPATCH",4,1,1,"__omp_offloading_32_2f3c0__QMboundary_modPboundary_conditions_l24",3,5329321979189038,5329
"KERNEL_DISPATCH",4,1,3,"__omp_offloading_32_2f3c7__QMupdate_modPupdate_l23",4,5329321985289126,5329321985337166,0,
"KERNEL_DISPATCH",4,1,2,"__omp_offloading_32_2f3c6__QMnorm_modPnorm_l26",5,5329321987888094,5329321987980254,0,4360
"KERNEL_DISPATCH",4,1,4,"__omp_offloading_32_2f3c3__QMlaplacian_modPlaplacian_l23",6,5329321990242479,5329321990289
"KERNEL_DISPATCH",4,1,1,"__omp_offloading_32_2f3c0__QMboundary_modPboundary_conditions_l24",7,5329321992966432,5329
"KERNEL_DISPATCH",4,1,3,"__omp_offloading_32_2f3c7__QMupdate_modPupdate_l23",8,5329321997343879,5329321997389119,0,
"KERNEL_DISPATCH",4,1,2,"__omp_offloading_32_2f3c6__QMnorm_modPnorm_l26",9,5329321999929225,5329322000021345,0,4360
```

So the kernel trace file shows each kernel call, with its start and end timestamp. This can lead to a very large output file.

Create statistics

One can create kernel statistics file using `--stats` option:

```
rocprofv3 --stats --kernel-trace -- ./jacobi -m 1024
```

This creates two additional output files:

1. `XXXXX_kernel_stats.csv` with statistics grouped by each kernel.
2. `XXXXX_domain_stats.csv` with statistics grouped by domain, such as KERNEL_DISPATCH, HIP_API, etc.

The content of kernel stats file should resemble the following:

```
"Name","Calls","TotalDurationNs","AverageNs","Percentage","MinNs","MaxNs","StdDev"
"__omp_offloading_32_2f3c6__QMnorm_modPnorm_l26",1001,87995483,87907.575425,43.77,80200,108480,3547.283930
```

```
"__omp_offloading_32_2f3c7__QMupdate_modPupdate_l23",1000,52197887,52197.887000,25.96,48320,69880,3052.411702
"__omp_offloading_32_2f3c3__QMlaplacian_modPlaplacian_l23",1000,51095558,51095.558000,25.41,43720,60640,3253.741764
"__omp_offloading_32_2f3c0__QMboundary_modPboundary_conditions_l24",1000,9759423,9759.423000,4.85,7640,13080,673.67
```

In this file, all the calls to a specific OpenMP block are in the same row, and you can see in the column Calls how times this OpenMP block was called. The column Percentage means how much percentage of the execution time this OpenMP block takes.

In many cases, simply checking the kernel stats file might be sufficient for your profiling!

If it is not, continue by visualizing the traces.

Visualizing traces using `Perfetto`

Create trace file suitable for `Perfetto` . If the application execution is short (such as this example), consider using `--sys-trace` option to collect as much information as possible:

```
rocprofv3 --runtime-trace --output-format pftrace -- ./jacobi -m 1024
```

This should generate a pftrace file.

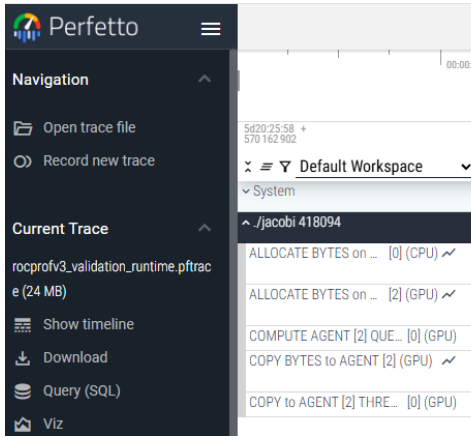
Download the trace to your laptop:

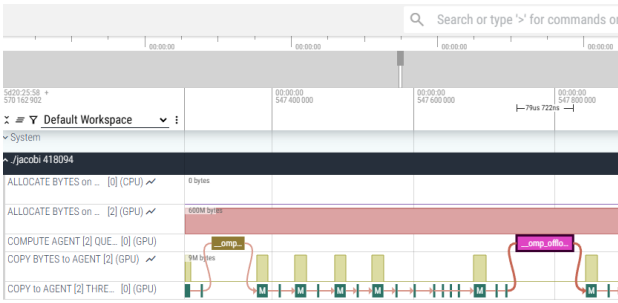
```
scp -P <port> aac6.amd.com:<path_to_file>/XXXXX_results.pftrace jacobi.pftrace
```

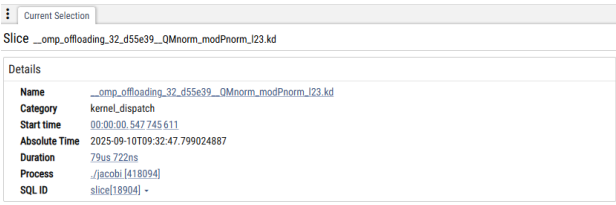
Now on your laptop:

1. Open a browser and go to https://ui.perfetto.dev/.
2. Click on `Open trace file` in the top left corner.
3. Navigate to the `jacobi.pftrace` , inspect kernels and event flows.
4. Use the keystrokes W,A,S,D to zoom in and move right and left in the GUI.

Below, you can see an example of how the trace file would be visualized in `Perfetto` :







If you zoom in, you should be able to see OpenMP kernels in more details:

Additional features

Hardware Counters

Read about hardware counters available for the GPU on this system (look for gfx942 section):

```
less $ROCM_PATH/lib/rocprofiler/gfx_metrics.xml
```

Create an `input_counters.txt` counters input file with the counters you would like to collect, for example:

```
echo "pmc: VALUUtilization VALUBusy FetchSize WriteSize MemUnitStalled" > input_counters.txt
echo "pmc: GPU_UTIL CU_OCCUPANCY MeanOccupancyPerCU MeanOccupancyPerActiveCU" >> input_counters.txt
```

Note that not all the GPUs have the same counters, so if profile the counters above generates errors, consider testing a single counter (e.g., `VALUUtilization` only).

Execute with the counters you just added:

```
 rocprofv3 -i input_counters.txt --kernel-trace -- ./jacobi -m 1024
```

You'll notice that rocprofv3 runs 2 passes, one for each set of counters we have in that file. Now the data is in two different folders: pmc_1 and pmc_2. Explore the content of the pmc_* directories.

```
head pmc_1/*_counter_collection.csv
echo
head pmc_2/*_counter_collection.csv
```

Next steps

Try to add `export HSA_XNACK=1` , and check the performance. Is it better or worse? Repeat the profiling commands and compare the outputs. What is the overhead of profiling?

**Explore the example with roctx markers which discusses a common performance optimization for applications on MI300A in

```
cd Example_Allocations_and_MemoryPool_MI300A/Fortran/README.md
```

Finally, try to profile your own application!

ROCm™ Systems Profiler aka `rocprof-sys`

NOTE: extensive documentation on how to use `rocprof-sys` for the GhostExchange examples is also available as `README.md` in this exercises repo. Here, we show how to use `rocprof-sys` tools considering the example in HPCTrainingExamples/HIP/jacobi.

In this series of examples, we will demonstrate profiling with `rocprof-sys` on a platform using an AMD Instinct™ MI250X GPU. ROCm 6.3.2 release includes the `rocprofiler-systems` packge that you can install.

Note that the focus of this exercise is on `rocprof-sys` profiler, not on how to achieve optimal performance on MI250X.

First, start by cloning HPCTrainingExamples repository and loading ROCm:

```
git clone https://github.com/amd/HPCTrainingExamples.git
```

Environment setup

For this training, one requires recent ROCm (>=6.3) which contains `rocprof-sys` , as well as an MPI installation.

```
module load rocm/6.3.2
module load openmpi
```

Build and run

No profiling yet, just check that the code compiles and runs correctly.

```
cd HPCTrainingExamples/HIP/jacobi
make
mpirun -np 1 ./Jacobi_hip -g 1 1
```

The above run should show output that looks like this:

```
Topology size: 1 x 1
Local domain size (current node): 4096 x 4096
Global domain size (all nodes): 4096 x 4096
Rank 0 selecting device 0 on host TheraC63
Starting Jacobi run.
Iteration:   0 - Residual: 0.022108
Iteration: 100 - Residual: 0.000625
Iteration: 200 - Residual: 0.000371
Iteration: 300 - Residual: 0.000274
Iteration: 400 - Residual: 0.000221
Iteration: 500 - Residual: 0.000187
Iteration: 600 - Residual: 0.000163
Iteration: 700 - Residual: 0.000145
Iteration: 800 - Residual: 0.000131
Iteration: 900 - Residual: 0.000120
Iteration: 1000 - Residual: 0.000111
Stopped after 1000 iterations with residue 0.000111
Total Jacobi run time: 1.2876 sec.
Measured lattice updates: 13.03 GLU/s (total), 13.03 GLU/s (per process)
Measured FLOPS: 221.51 GFLOPS (total), 221.51 GFLOPS (per process)
Measured device bandwidth: 1.25 TB/s (total), 1.25 TB/s (per process)
```

`rocprof-sys` config

First, generate the `rocprof-sys` configuration file, and ensure that this file is known to `rocprof-sys` .

```
rocprof-sys-avail -G ~/.rocprofsys.cfg
export ROCPROFSYS_CONFIG_FILE=~/.rocprofsys.cfg
```

Second, inspect configuration file, possibly changing some variables. For example, one can modify the following lines:

```
ROCPROFSYS_PROFILE                              = true
ROCPROFSYS_USE_ROCTX                            = true
ROCPROFSYS_SAMPLING_CPUS                        = 0
```

You can see what flags can be included in the config file by doing:

```
rocprof-sys-avail --categories rocprofsys
```

To add brief descriptions, use the `-bd` option:

```
rocprof-sys-avail -bd --categories rocprofsys
```

Note that the list of flags displayed by the commands above may not include all actual flags that can be set in the config. For a full list of options, please read the rocprof-sys documentation.

You can also create a configuration file with description per option. Beware, this is quite verbose:

```
rocprof-sys-avail -G ~/rocprofsys_all.cfg --all
```

Instrument application binary

You can instrument the binary, and inspect which functions were instrumented (note that you need to change `<TIMESTAMP>` according to your generated folder path).

```
rocprof-sys-instrument -o ./Jacobi_hip.inst -- ./Jacobi_hip
for f in $(ls rocprofsys-Jacobi_hip.inst-output/<TIMESTAMP>/instrumentation/*.txt); do echo $f; cat $f; echo "#####
```

Currently `rocprof-sys` will instrument by default only the functions with >1024 instructions, so you may need to change it by using `-i #inst` or by adding `--function-include function_name` to select the functions you are interested in. Check more options using `rocprof-sys-instrument --help` or by reading the rocprof-sys documentation.

Let's instrument the most important Jacobi kernels.

```
rocprof-sys-instrument --function-include 'Jacobi_t::Run' 'JacobiIteration' -o ./Jacobi_hip.inst -- ./Jacobi_hip
```

The output should show that only these functions have been instrumented:

```
...
[rocprof-sys][exe] Finding instrumentation functions...
[rocprof-sys][exe]    1 instrumented funcs in JacobiIteration.hip
[rocprof-sys][exe]    1 instrumented funcs in JacobiRun.hip
[rocprof-sys][exe]    1 instrumented funcs in Jacobi_hip
...
```

This can also be verified with:

```
$ cat rocprofsys-Jacobi_hip.inst-output/<TIMESTAMP>/instrumentation/instrumented.txt

  StartAddress   AddressRange  #Instructions  Ratio Linkage Visibility  Module                    Function
      0x226440           332             71   4.68  unknown    unknown JacobiIteration.hip       JacobiIteration
      0x224ad0           677            146   4.64  unknown    unknown JacobiRun.hip             Jacobi_t::Run
      0x226370           205             38   5.39  unknown    unknown Jacobi_hip                __device_stub__
```

Run instrumented binary

Now that we have a new application binary where the most important functions are instrumented, we can profile it using `rocprof-sys-run` under the `mpirun` environment.

```
mpirun -np 1 rocprof-sys-run -- ./Jacobi_hip.inst -g 1 1
```

Check the command line output generated by `rocprof-sys-run` , it contains some useful overviews and **paths to generated files**. Observe that the overhead to the application runtime is small. If you had previously set `ROCPROFSYS_PROFILE=true` , inspect `wall_clock-0.txt` which includes information on the function calls made in the code, such as how many times these calls have been called (`COUNT`) and the time in seconds they took in total (`SUM`).

In many cases, simply checking the wall_clock files might be sufficient for your profiling!

If it is not, continue by visualizing the trace.

Visualizing traces using `Perfetto`

Copy generated `perfetto-trace-0.proto` file to your local machine, and using the Chrome browser open the web page https://ui.perfetto.dev/:

Click `Open trace file` and select the `perfetto-trace-0.proto` file. Below, you can see an example of how the trace file would be visualized on `Perfetto` :

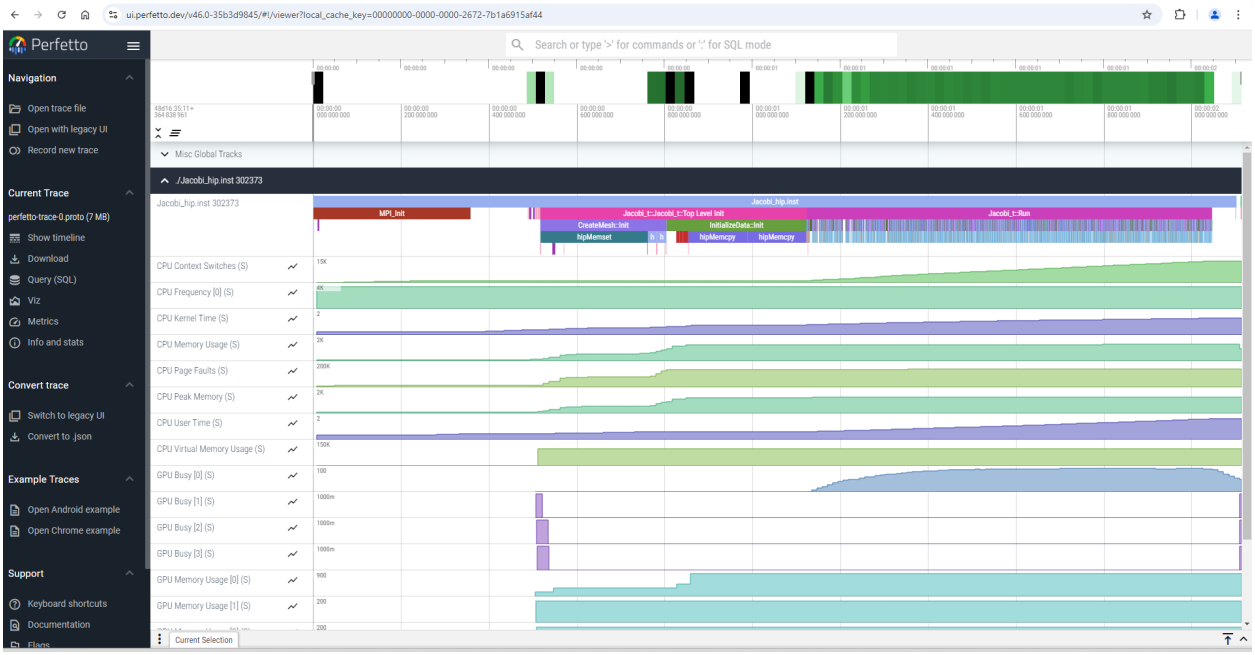


Figure 1: jacobi_hip-perfetto_screenshot

If there is an error opening trace file, try using an older `Perfetto` version, e.g., by opening the web page https://ui.perfetto.dev/v46.0-35b3d9845/#!/.

Additional features

Flat profiles

Append advanced option `ROCPROFSYS_FLAT_PROFILE=true` to `~/.rocprofsys.cfg` or prepend it to the `mpirun` command:

```
ROCPROFSYS_FLAT_PROFILE=true mpirun -np 1 rocprof-sys-run -- ./Jacobi_hip.inst -g 1 1
```

`wall_clock-0.txt` file now shows overall time in seconds for each function.

Note the significant total execution time for `hipMemcpy` and `Jacobi_t::Run` calls.

Hardware counters

To see a list of all the counters for all the devices on the node, do:

```
rocprof-sys-avail --all
```

Select the counter you are interested in, and then declare them in your configuration file (or prepend to your `mpirun` command):

```
ROCPROFSYS_ROCM_EVENTS = VALUUtilization,FetchSize
```

Run the instrumented binary, and you will observe an output file for each hardware counter specified. You should also see a row for each hardware counter in the `Perfetto` trace generated by `rocprof-sys` .

Note that you do not have to instrument again after making changes to the config file. Just running the instrumented binary picks up the changes.

```
ROCPROFSYS_ROCM_EVENTS=VALUUtilization,FetchSize mpirun -np 1 rocprof-sys-run -- ./Jacobi_hip.inst -g 1 1
cat rocprof-sys-Jacobi_hip.inst-output/<TIMESTAMP>/rocprof-device-0-VALUUtilization-0.txt
```

Sampling

To reduce the overhead of profiling, one can use call stack sampling. Set the following in your configuration file (or prepend to your `mpirun` command):

```
ROCPROFSYS_USE_SAMPLING = true
ROCPROFSYS_SAMPLING_FREQ = 100
```

Execute the instrumented binary, inspect `sampling*` files and visualize the `Perfetto` trace:

```
mpirun -np 1 rocprof-sys-run -- ./Jacobi_hip.inst -g 1 1
ls rocprofsys-Jacobi_hip.inst-output/<TIMESTAMP>/* | grep sampling
```

Profiling multiple MPI processes

Run the instrumented binary with multiple MPI ranks. Note separate output files for each rank, including `perfetto-trace-*.proto` and `wall_clock-*.txt` files.

```
mpirun -np 2 rocprof-sys-run -- ./Jacobi_hip.inst -g 2 1
```

Inspect output text files. Then visualize `perfetto-trace-*.proto` files in `Perfetto` . Note that one can merge multiple trace files into a single one using simple concatenation:

```
cat perfetto-trace-*.proto > merged.proto
```

Next steps

Try to use `rocprof-sys` to profile GhostExchange examples.

Finally, try to profile your own application!

Stream Overlap Example

This example is based on example 2 from Chapter 6 of the HIP Book: “Accelerated Computing with HIP”, by Yifan Sun, Trinayan Baruah, and David R. Kaeli. The example demonstrates how to overlap data transfer and computation using HIP streams. The included directories step through different versions of the example.

Each directory contains a `README.md` file that includes a description of the version and instructions for building and running the example.

This multi-streamed example is traced with ROCm Systems Profiler, formerly known as Omnitrace. ROCm Systems Profiler is now available in ROCm 6.2.0+ version package directly and does not need to be installed separately anymore. The figures included in the `figs` directory, however, are generated using `Omnitrace v.1.11.3` . The command line trace instructions are included in the `README.md` file in each directory.

Folder `0-Orig`

This is the original version of the example. It demonstrates the basic structure of the example and provides a starting point for the other versions. The memory copies and kernel execution are done together sequentially in each of the multiple streams.

Folder `1-split-copy-compute-hw-queues`

This version of the example splits the host to device (and vice versa) memory copies and the kernel execution into separate loops over multiple streams. This allows for overlap of memory copies across across multiple streams in addition to overlap of kernel computations over multiple streams. This also enables overlap of data copies and kernel computations.

This example also exploits the environment variable controlling the GPU maximum hardware queues (`GPU_MAX_HW_QUEUES`) to achieve better performance for a multi-streamed application.

Folder `2-pageable-mem`

This version of the example uses *pageable* memory for data transfers instead of pinned memory. This example is to demonstrate how pageable memory degrades performance of a multi-streamed application. Ideally, pinned memory should be used for data transfers in a multi-streamed application wherever possible (depending on available memory resources).

Self-guided tour of the Stream Overlap example

The interested reader can follow these steps sequentially to understand the performance implications of use of multiple streams to overlap data transfers and kernel computations. The results shared in folder `figs` are obtained from running the example on an AMD Instinct MI250 single GCD.

1. Build the baseline example in `0-Orig` directory. The build and run instructions can be found in the `README.md` file in the directory.
2. Then run the example using multiple streams. Specifically choose 1, 2, and 4 streams and observe the performance improvements. Specifically note if the reduction in runtime scales linearly with the number of streams. See the figures in `figs/streams[1,2,4]_noQ_seq_copy.png` for reference.
3. Increase the number of streams to 8 and observe the performance degradation. This is because the GPU has a limited hardware resources and increasing the number of streams beyond the GPU's capability will degrade performance. See the figure in `figs/streams8_noQ_seq_copy.png` for reference.
4. Switch to `1-split-copy-compute-hw-queues` directory and build and run the example. Observe the performance improvements if any. Ideally, the performance improvement is only marginal. See the figure in `figs/streams8_noQ_split_copy.png` for reference.
5. Set the environment variable `GPU_MAX_HW_QUEUES` to 8 and observe the performance improvements. This is because the default number of hardware queues is 4. Increasing the number of hardware queues will improve the performance of a multi-streamed application, especially when the number of streams is more than the default number of hardware queues. Note that, the performance improvement is possible if the GPU resource is not yet fully saturated, for example, with limited register

pressure, or limited shared memory usage. The performance improvement is clearly visible in the figure `figs/streams8_Q_split_copy.png` .

6. [Optional] Switch to `2-pageable-mem` directory and build and run the example. Observe the performance degradation due to use of pageable memory for data transfers. Ideally, pinned memory should be used for data transfers in a multi-streamed application
7. Repeat the above steps for a different GPU and observe the performance implications.

ROCprof-compute

In this directory, users can find a variety of examples aimed at showcasing some of the most important features of ROCprof-compute. For each example, an initial implementation labeled `problem` will be modified in order to show an improvement in performance using the ROCprof-compute tools. The improved implementation will be reffered to as `solution` . Please refer to the single sub-directories `README.md` files for details.

Exercise 1: Launch Parameter Tuning

Simple kernel implementing a version of yAx, to demonstrate effects of Launch Parameters on kernel execution time.

Client-side installation instructions are available in the official rocprof-compute documentation, and provide all functionality demonstrated here.

If your system has an older version of ROCprof-compute, please refer to the archived READMEs in the `archive` directory and use a ROCm version lesser than `6.0.0` .

Background: Acronyms and terms used in this exercise

yAx: a vector-matrix-vector product, yAx, where y and x are vectors, and A is a matrix

FP(32/16): 32- or 16-bit Floating Point numeric types

FLOPs: Floating Point Operations Per second

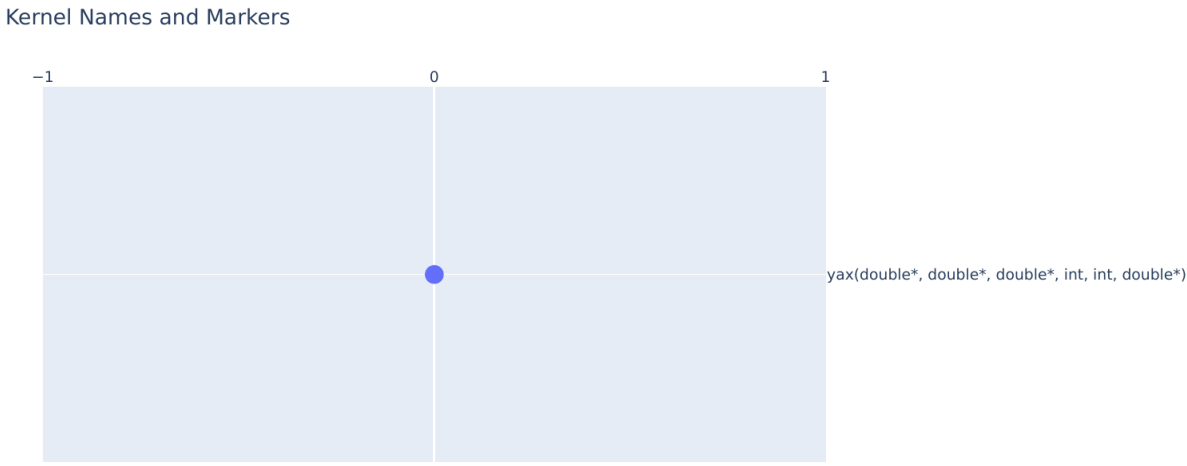
HBM: High Bandwidth Memory is globally accessible from the GPU, and is a level of memory above the L2 cache

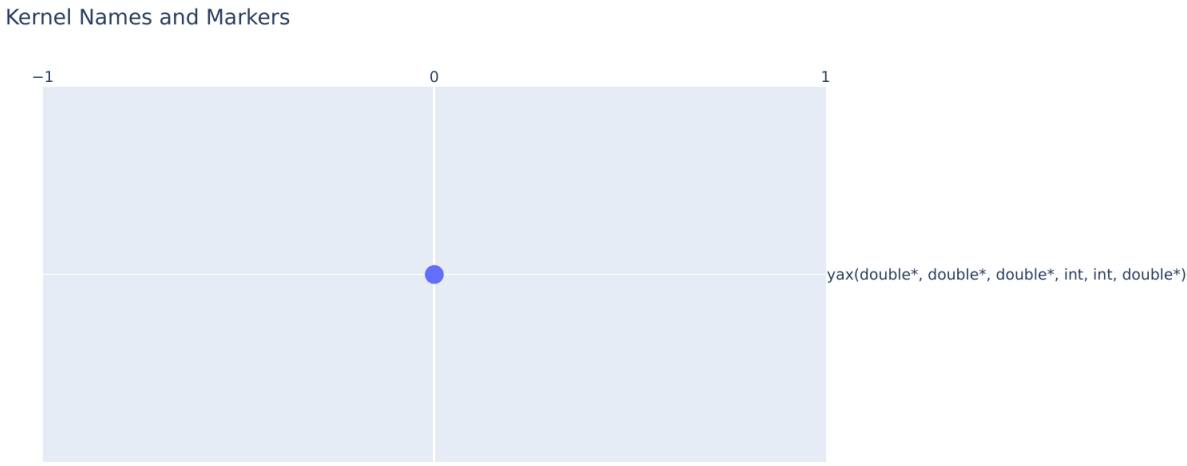
Results on MI210

In this section, we show results obtained running this exercise on a system with MI210s, on a recent commit of ROCprof-compute version `2.0.0` and ROCm `6.0.0` . **Any ROCprof-compute version `2.0.0` or greater is incompatible with versions of ROCm less than `6.0.0` .**

Initial Roofline Analysis:

The roofline model is a way to gauge kernel performance in terms of maximum achievable bandwidth and floating-point operations. It can be used to determine how efficiently a kernel makes use of the available hardware. It is a key tool in initially determining which kernels are performing well, and which kernels should be able to perform better. Below are roofline plots for the yAx kernel in problem.cpp:

Roofline Type	Roofline Legend
FP32/FP64	

Roofline Type	Roofline Legend
FP16/INT8	

These plots were generated by running:

```
rocprof-compute profile -n problem_roof_only --roof-only --kernel-names -- ./problem.exe
```

The plots will appear as PDF files in the `./workloads/problem_roof_only/MI200` directory, if generated on MI200 hardware.

We see that the kernel's performance is not near the achievable bandwidth possible on the hardware, which makes it a good candidate to consider optimizing.

Exercise instructions:

From the roofline we were able to see that there is room for improvement in this kernel. One of the first things to check is whether or not we have reasonable launch parameters for this kernel.

To get started, build and run the problem code:

```
make
./problem.exe
```

(*simulated output*)

```
yAx time: 2911 ms
```

The runtime of the problem should be very slow, due to sub-optimal launch parameters. Let's confirm this hypothesis by looking at the rocprof-compute profile. Start by running:

```
rocprof-compute profile -n problem --no-roof -- ./problem.exe
```

This command requires rocprof-compute to run your code a few times to collect all the necessary hardware counters. - `-n problem` names the workload, meaning that the profile will appear in the `./workloads/problem/MI200/` directory, if you are profiling on an MI200 device. - `--no-roof` turns off the roofline, which will save some profiling time by avoiding the collection of achievable bandwidths and FLOPs on the device. - Everything after the `--` is the command that will be profiled.

After the profiling data is collected, we can view the profile by using this command:

```
rocprof-compute analyze -p workloads/problem/MI200 --dispatch 1 --block 7.1.0 7.1.1 7.1.2
```

This allows us to view nicely formatted profiling data directly in the command line. The command given here has a few arguments that are noteworthy: - `-p workloads/problem/MI200` must point to the output directory of your profile run. For the above `rocprof-compute profile` command, this will be `workloads/problem/MI200` . - `--dispatch 1` filters kernel statistics by dispatch ID. In this case kernel 0 was a "warm-up" kernel, and kernel 1 is what the code reports timings for. - `--block` displays only the requested metrics, in this case we want metrics specific to Launch Parameters: - `7.1.0` is the Grid Size - `7.1.1` is the Workgroup Size - `7.1.2` is the Total Wavefronts Launched

The output of the `rocprof-compute analyze` command should look something like this:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

Analysis mode = cli
[analysis] deriving ROCprof-compute metrics...

0. Top Stats
0.1 Top Kernels
-----------------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count |      Sum(ns) |     Mean(ns) |   Median(ns) |    Pct |
|----|--------------------------------------------|---------|--------------|--------------|--------------|--------|
|  0 | yax(double*, double*, double*, int, int,   |    1.00 | 751342314.00 | 751342314.00 | 751342314.00 | 100.00 |
|    |  double*) [clone .kd]                      |         |              |              |              |        |
-----------------------------------------------------------------------------------------------------------------------

-----------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                          |   GPU_ID |
|----|---------------|----------------------------------------------------------------------|----------|
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd]        |        2 |
-----------------------------------------------------------------------------------------------



7. Wavefront
7.1 Wavefront Launch Stats
-------------------------------------------------------------------------
| Metric_ID   | Metric           |    Avg |    Min |    Max | Unit       |
|-------------|------------------|--------|--------|--------|------------|
| 7.1.0       | Grid Size        | 256.00 | 256.00 | 256.00 | Work items |
|-------------|------------------|--------|--------|--------|------------|
| 7.1.1       | Workgroup Size   |  64.00 |  64.00 |  64.00 | Work items |
|-------------|------------------|--------|--------|--------|------------|
| 7.1.2       | Total Wavefronts |   4.00 |   4.00 |   4.00 | Wavefronts |
-------------------------------------------------------------------------
```

Looking through this data we see: - Workgroup Size (`7.1.1`) is 64 threads, which corresponds with the

size of a wavefront. - Total Wavefronts (`7.1.2`) shows that we are launching only 4 Wavefronts.

We can definitely get better performance by adjusting the launch parameters of our kernel. Either try out some new values for the launch bounds, or run the provided solution to see its performance:

```
cd solution
make
./solution.exe
```

(*simulated output*)

```
yAx time: 70 ms
```

We get much better performance with the new launch parameters. Note that in general it can be difficult to find the most optimal launch parameters for a given kernel due to the many factors that impact performance, so determining launch parameters experimentally is usually necessary.

We should also confirm that our updated launch parameters are reported by rocprof-compute, we need to run:

```
rocprof-compute profile -n solution --no-roof -- ./solution.exe
```

This command is the same as before, except the workload name has changed to `solution` . Once the `profile` command has completed, run:

```
rocprof-compute analyze -p workloads/solution/MI200 --dispatch 1 --block 7.1.0 7.1.1 7.1.2
```

Again, this command largely uses the same arguments as before, except for the workload name. The output should look something like this:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

Analysis mode = cli
[analysis] deriving ROCprof-compute metrics...

0. Top Stats
0.1 Top Kernels
-----------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count |     Sum(ns) |    Mean(ns) |   Median(ns) |    Pct |
|----|--------------------------------------------|---------|-------------|-------------|--------------|--------|
|  0 | yax(double*, double*, double*, int, int, |    1.00 | 69512860.00 | 69512860.00 |  69512860.00 | 100.00 |
|    |  double*) [clone .kd]                      |         |             |             |              |        |
-----------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                  |   GPU_ID |
|----|---------------|--------------------------------------------------------------|----------|
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        2 |
-----------------------------------------------------------------------------------------


7. Wavefront
7.1 Wavefront Launch Stats
-------------------------------------------------------------------------------
| Metric_ID   | Metric           |       Avg |       Min |       Max | Unit       |
|-------------|------------------|-----------|-----------|-----------|------------|
| 7.1.0       | Grid Size        | 131072.00 | 131072.00 | 131072.00 | Work items |
|-------------|------------------|-----------|-----------|-----------|------------|
| 7.1.1       | Workgroup Size   |     64.00 |     64.00 |     64.00 | Work items |
|-------------|------------------|-----------|-----------|-----------|------------|
```

```
| 7.1.2       | Total Wavefronts |   2048.00 |   2048.00 |   2048.00 | Wavefronts |
-------------------------------------------------------------------------------
```

Looking through this data we see: - Workgroup Size (`7.1.1`) corresponds to the first argument of the block launch parameter - Total Wavefronts (`7.1.2`) corresponds to the first index of the grid launch parameter - Grid size (`7.1.0`) is Workgroup Size (`7.1.1`) times Total Wavefronts (`7.1.2`)

ROCprof-compute Command Line Comparison Feature:

On releases newer than ROCprof-compute 1.0.10, the comparison feature of rocprof-compute can be used to quickly compare two profiles. To use this feature, use the command:

```
rocprof-compute analyze -p workloads/problem/MI200 -p solution/workloads/solution/MI200 --dispatch 1 --block 7.1.0
```

This feature sets the first `-p` argument as the baseline, and the second as the comparison workload. In this case, problem is set as the baseline and is compared to solution. The output should look like:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | || __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

Analysis mode = cli
[analysis] deriving ROCprof-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
-------------------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count | Count      |   Abs Diff |      Sum(ns) | Sum(ns)
-----|--------------------------------------------|---------|------------|------------|--------------|---------------
|  0 | yax(double*, double*, double*, int, int, |    1.00 | 1.0 (0.0%) |       0.00 | 751342314.00 | 69512860.0 (-9
|    |  double*) [clone .kd]                      |         |            |            |              |
-------------------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
-----------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                    |   GPU_ID |
-----|---------------|----------------------------------------------------------------|----------
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        2 |
-----------------------------------------------------------------------------------------------



--------------------------------------------------------------------------------
7. Wavefront
7.1 Wavefront Launch Stats
-------------------------------------------------------------------------------------------------------------------------
| Metric_ID   | Metric           |    Avg | Avg                 |   Abs Diff |    Min | Min                 |    Ma
--------------|------------------|--------|---------------------|------------|--------|---------------------|------
| 7.1.0       | Grid Size        | 256.00 | 131072.0 (51100.0%) |  130816.00 | 256.00 | 131072.0 (51100.0%) | 256.0
--------------|------------------|--------|---------------------|------------|--------|---------------------|------
| 7.1.1       | Workgroup Size   |  64.00 | 64.0 (0.0%)         |       0.00 |  64.00 | 64.0 (0.0%)         |  64.0
--------------|------------------|--------|---------------------|------------|--------|---------------------|------
| 7.1.2       | Total Wavefronts |   4.00 | 2048.0 (51100.0%)   |    2044.00 |   4.00 | 2048.0 (51100.0%)   |   4.0
-------------------------------------------------------------------------------------------------------------------------
```

Note that the comparison workload shows the percentage difference from the baseline. This feature can be used to quickly compare filtered stats to make sure code changes fix known issues.

More Kernel Filtering:

For this exercise, it is appropriate to filter the `rocprof-compute analyze` command with the `--dispatch 1` argument. This `--dispatch 1` argument filters the data shown to only include the kernel invocation with dispatch ID 1, or the second kernel run during profiling.

However, there is another way to filter kernels that may be more applicable in real use-cases. Typically real codes launch many kernels, and only a few of them take most of the overall kernel runtime. To see a ranking of the top kernels that take up most of the kernel runtime in your code, you can run:

```
rocprof-compute analyze -p workloads/problem/MI200 --list-stats
```

This command will output something like:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

Analysis mode = cli
[analysis] deriving ROCprof-compute metrics...

Detected Kernels (sorted descending by duration)
----------------------------------------------------------------------
|    | Kernel_Name                                                   |
-----|---------------------------------------------------------------
|  0 | yax(double*, double*, double*, int, int, double*) [clone .kd] |
----------------------------------------------------------------------

Dispatch list
-----------------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                   |   GPU_ID |
-----|---------------|---------------------------------------------------------------|-----------
|  0 |             0 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        2 |
-----|---------------|---------------------------------------------------------------|-----------
|  1 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        2 |
-----------------------------------------------------------------------------------------------------
```

Using ROCprof-compute versions greater than `2.0.0` , `--list-stats` will list all kernels launched by your code, in order of runtime (largest runtime first). The number displayed beside the kernel in the output can be used to filter `rocprof-compute analyze` commands. **Note that this will display aggregated stats for kernels of the same name**, meaning that the invocations could differ in terms of launch parameters, and vary widely in terms of work completed. This filtering is accomplished with the `-k` argument:

```
rocprof-compute analyze -p workloads/problem/MI200 -k 0 --block 7.1.0 7.1.1 7.1.2
```

Which should show something like:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

Analysis mode = cli
[analysis] deriving ROCprof-compute metrics...

0. Top Stats
0.1 Top Kernels
-----------------------------------------------------------------------------------------------------------------------------------
```

```
|    | Kernel_Name                                |   Count |       Sum(ns) |     Mean(ns) |   Median(ns) |    Pct |
|----|--------------------------------------------|---------|---------------|--------------|--------------|--------|
|  0 | yax(double*, double*, double*, int, int,   |    2.00 | 1501207023.00 | 750603511.50 | 750603511.50 | 100.00 |
|    |  double*) [clone .kd]                      |         |               |              |              |        |
```

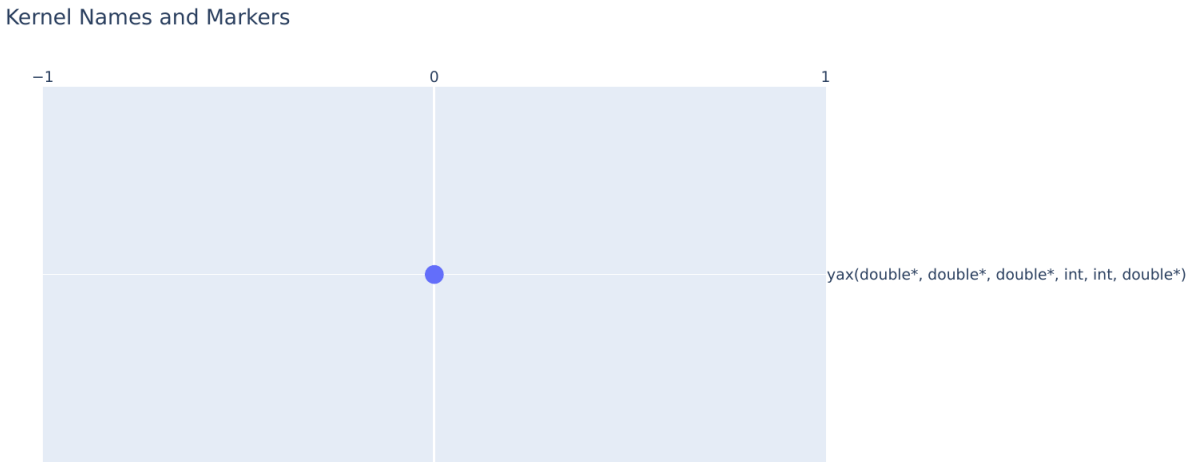
```
|    |   Dispatch_ID | Kernel_Name                                                    |   GPU_ID |
|----|---------------|----------------------------------------------------------------|----------|
|  0 |             0 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        2 |
|  1 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        2 |
```

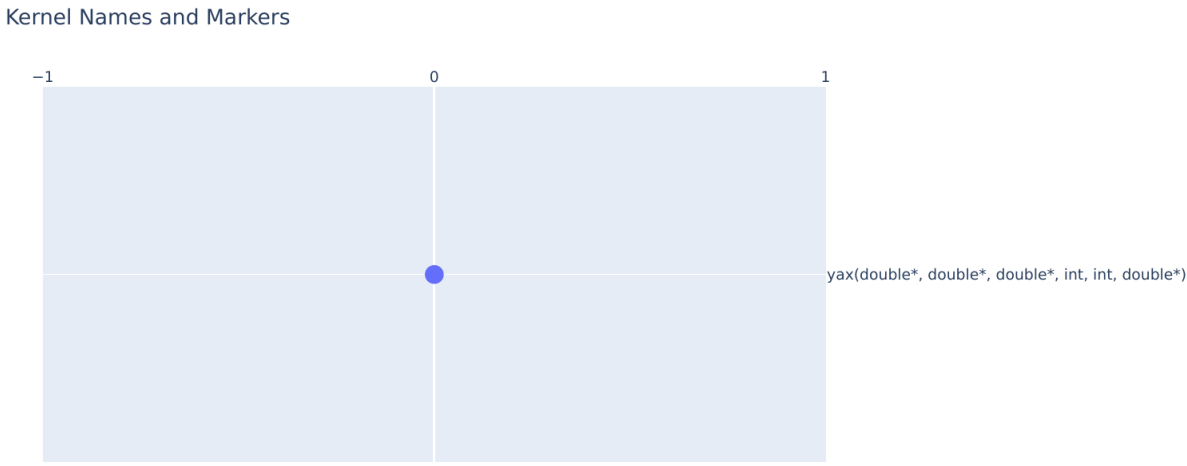
```
7. Wavefront
7.1 Wavefront Launch Stats
| Metric_ID   | Metric           |    Avg |    Min |    Max | Unit       |
|-------------|------------------|--------|--------|--------|------------|
| 7.1.0       | Grid Size        | 256.00 | 256.00 | 256.00 | Work items |
| 7.1.1       | Workgroup Size   |  64.00 |  64.00 |  64.00 | Work items |
| 7.1.2       | Total Wavefronts |   4.00 |   4.00 |   4.00 | Wavefronts |
```

Note that the 'count' field in Top Stat is 2 here, where filtering by dispatch ID displays a count of 1, indicating that filtering with `-k` returns aggregated stats for two kernel invocations in this case. Also note that the "Top Stats" table will still show all the top kernels but the rightmost column titled "S" (think "Selected") will have an asterisk beside the kernel for which data is being displayed. Also note that the dispatch list displays two entries rather than the one we see when we filter by `--dispatch 1` .

Solution Roofline

We've demonstrated better performance than problem.cpp in solution.cpp, but could we potentially do better? To answer that we again turn to the roofline model:

Roofline Type	Roofline Legend
FP32/FP64	

Roofline Type	Roofline Legend
FP16/INT8	

These plots were generated with:

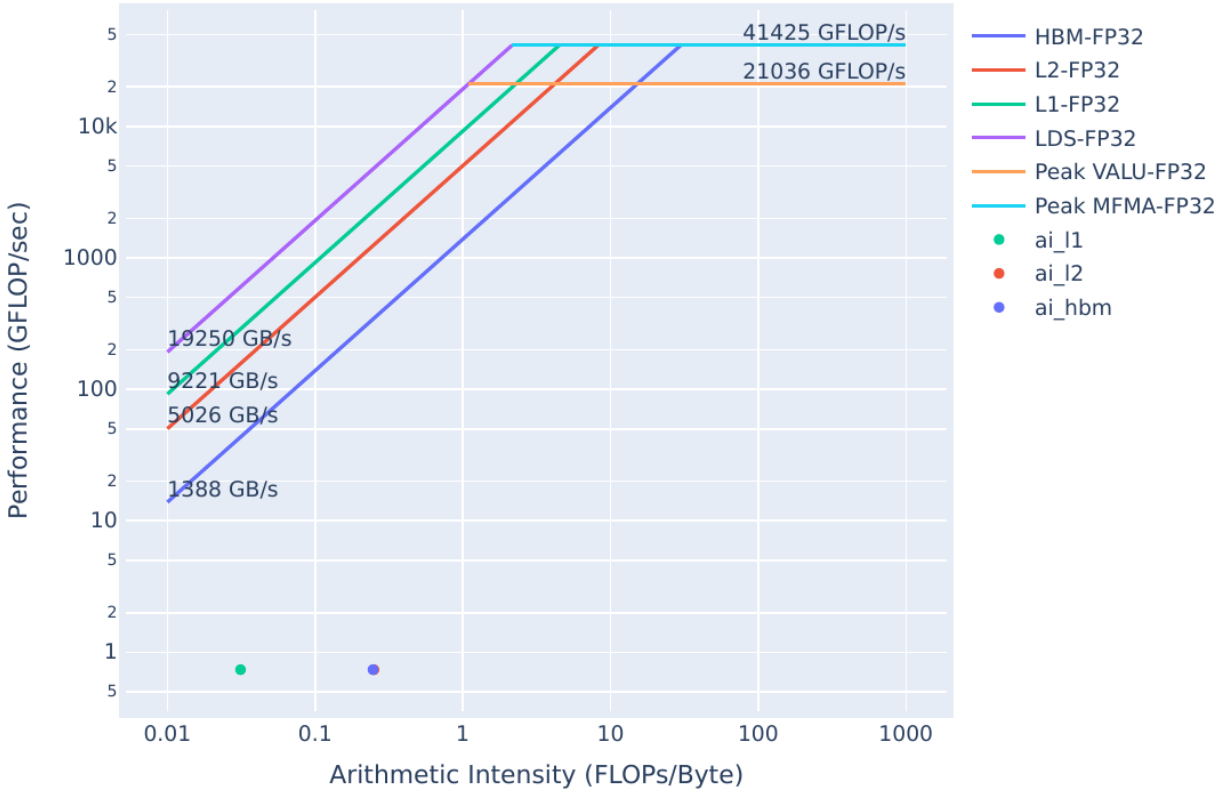
```
rocprof-compute profile -n solution_roof_only --roof-only --kernel-names -- ./solution.exe
```

The plots will appear as PDF files in the `./workloads/solution_roof_only/MI200` directory, if generated on MI200 hardware.

We see that the solution is solidly in the bandwidth-bound regime, but even still there seems to be room for improvement. Further performance improvements will be a topic for later exercises.

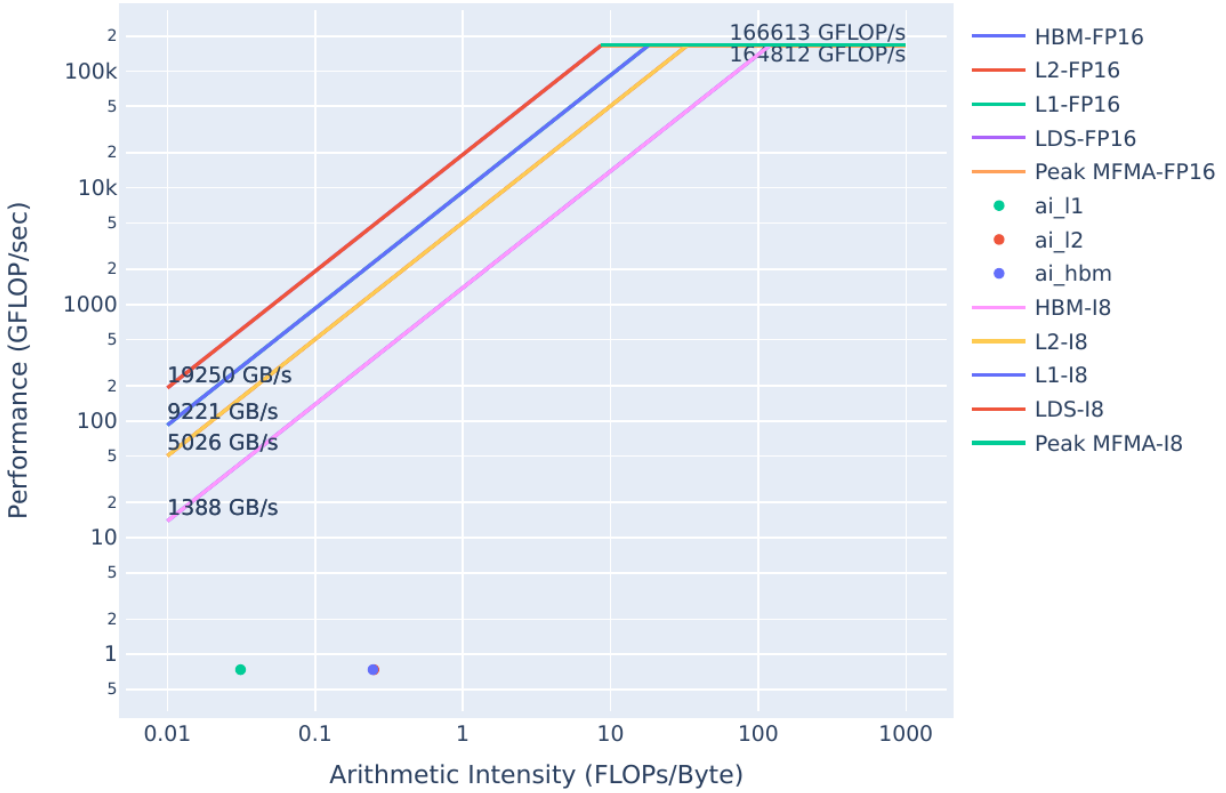
Roofline Comparison

Roofline Type	Problem Roofline



FP32/FP64

Roofline Type	Problem Roofline



FP16/INT8

We see that the solution has drastically increased performance over the problem code, as shown by the solution points moving up closer to the line plotted by the bandwidth limit.

Note: on statically generated roofline images, it is possible for the L1, L2, or HBM points to overlap and hide one another.

Summary and Take-aways

Launch parameters should be the first check in optimizing performance, due to the fact that they are usually easy to change, but can have a large performance impact if they aren't tuned to your workload. It is difficult to predict the optimal launch parameters for any given kernel, so some experimentation may be required to achieve the best performance.

Results on MI300A

In this section, we show results obtained running this exercise on a system with MI300A, using ROCm `6.2.1` and the associated ROCprof-compute, version `6.2.1` .

Roofline Analysis:

At present (September 28th 2024), rooflines are disabled on MI300A.

Exercise Instructions:

As for the MI210 case, build and run the problem code:

```
make
./problem.exe
```

(*simulated output*)

```
yAx time: 540 ms
```

Once again, we launch the following command:

```
rocprof-compute profile -n problem --no-roof -- ./problem.exe
```

Followed by:

```
rocprof-compute analyze -p workloads/problem/MI300A_A1 --dispatch 1 --block 7.1.0 7.1.1 7.1.2
```

Then inspect the output:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

   INFO Analysis mode = cli
   INFO [analysis] deriving ROCprof-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
----------------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count |      Sum(ns) |     Mean(ns) |   Median(ns) |    Pct |
|----|--------------------------------------------|---------|--------------|--------------|--------------|--------|
|  0 | yax(double*, double*, double*, int, int, |    1.00 | 541264224.00 | 541264224.00 | 541264224.00 | 100.00 |
|    |  double*) [clone .kd]                      |         |              |              |              |        |
----------------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
-----------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                    |   GPU_ID |
|----|---------------|----------------------------------------------------------------|----------|
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        4 |
-----------------------------------------------------------------------------------------------


--------------------------------------------------------------------------------
7. Wavefront
7.1 Wavefront Launch Stats
-------------------------------------------------------------------------
| Metric_ID   | Metric           |    Avg |    Min |    Max | Unit       |
|-------------|------------------|--------|--------|--------|------------|
| 7.1.0       | Grid Size        | 256.00 | 256.00 | 256.00 | Work items |
|-------------|------------------|--------|--------|--------|------------|
| 7.1.1       | Workgroup Size   |  64.00 |  64.00 |  64.00 | Work items |
|-------------|------------------|--------|--------|--------|------------|
| 7.1.2       | Total Wavefronts |   4.00 |   4.00 |   4.00 | Wavefronts |
-------------------------------------------------------------------------
```

As for the MI210 case, the workgroup size is 64 and the number of Wavefronts launched is 4.

To see improved performance, we turn to the code in the `solution` directory:

```
cd solution
make
./solution.exe
```

(*simulated output*)

```
yAx time: 9.7 ms
```

For the MI210 case, the compute time was about 42 times smaller when going from `problem` to `solution` . For the MI300A case, we see it is about 70 times smaller.

To visually confirm the updated launch parameters in the `solution` code, run:

```
rocprof-compute profile -n solution --no-roof -- ./solution.exe
rocprof-compute analyze -p workloads/solution/MI300A_A1 --dispatch 1 --block 7.1.0 7.1.1 7.1.2
```

Then see the number of Wavefronts now being 2048:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

   INFO Analysis mode = cli
   INFO [analysis] deriving ROCprof-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
----------------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count |    Sum(ns) |   Mean(ns) |   Median(ns) |    Pct |
|----|--------------------------------------------|---------|------------|------------|--------------|--------|
|  0 | yax(double*, double*, double*, int, int,   |    1.00 | 9482864.00 | 9482864.00 |   9482864.00 | 100.00 |
|    |  double*) [clone .kd]                      |         |            |            |              |        |
----------------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
-----------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                    |   GPU_ID |
|----|---------------|----------------------------------------------------------------|----------|
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        4 |
-----------------------------------------------------------------------------------------------


--------------------------------------------------------------------------------
7. Wavefront
7.1 Wavefront Launch Stats
-------------------------------------------------------------------------------
| Metric_ID   | Metric           |       Avg |       Min |       Max | Unit       |
|-------------|------------------|-----------|-----------|-----------|------------|
| 7.1.0       | Grid Size        | 131072.00 | 131072.00 | 131072.00 | Work items |
|-------------|------------------|-----------|-----------|-----------|------------|
| 7.1.1       | Workgroup Size   |     64.00 |     64.00 |     64.00 | Work items |
|-------------|------------------|-----------|-----------|-----------|------------|
| 7.1.2       | Total Wavefronts |   2048.00 |   2048.00 |   2048.00 | Wavefronts |
-------------------------------------------------------------------------------
```

ROCprof-compute Command Line Comparison Feature:

We can compare the performance of `problem` and `solution` using `rocprof-compute analyze` :

```
rocprof-compute analyze -p workloads/problem/MI300A_A1/ -p solution/workloads/solution/MI300A_A1/ --dispatch 1 --bl
```

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

   INFO Analysis mode = cli
   INFO [analysis] deriving ROCprof-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
-------------------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count | Count      |   Abs Diff |      Sum(ns) | Sum(ns)
-----|--------------------------------------------|---------|------------|------------|--------------|---------------
|  0 | yax(double*, double*, double*, int, int,   |    1.00 | 1.0 (0.0%) |       0.00 | 541264224.00 | 9482864.0 (-98
|    |  double*) [clone .kd]                      |         |            |            |              |
-------------------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
-----------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                    |   GPU_ID |
-----|---------------|----------------------------------------------------------------|----------
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        4 |
-----------------------------------------------------------------------------------------------


--------------------------------------------------------------------------------
7. Wavefront
7.1 Wavefront Launch Stats
-------------------------------------------------------------------------------------------------------------------------
| Metric_ID   | Metric           |    Avg | Avg                 |   Abs Diff |    Min | Min                 |    Ma
--------------|------------------|--------|---------------------|------------|--------|---------------------|------
| 7.1.0       | Grid Size        | 256.00 | 131072.0 (51100.0%) |  130816.00 | 256.00 | 131072.0 (51100.0%) | 256.0
--------------|------------------|--------|---------------------|------------|--------|---------------------|------
| 7.1.1       | Workgroup Size   |  64.00 | 64.0 (0.0%)         |       0.00 |  64.00 | 64.0 (0.0%)         |  64.0
--------------|------------------|--------|---------------------|------------|--------|---------------------|------
| 7.1.2       | Total Wavefronts |   4.00 | 2048.0 (51100.0%)   |    2044.00 |   4.00 | 2048.0 (51100.0%)   |   4.0
-------------------------------------------------------------------------------------------------------------------------
```

Note that the new execution time for `solution` is about 1.75% of the original execution time for `problem` .

More Kernel Filtering:

Run the following command to once again see a ranking of the top kernels that take up most of the kernel runtime:

```
cd ..
rocprof-compute analyze -p workloads/problem/MI300A_A1/ --list-stats
```

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

   INFO Analysis mode = cli
   INFO [analysis] deriving ROCprof-compute metrics...

--------------------------------------------------------------------------------
```

```
Detected Kernels (sorted descending by duration)
--------------------------------------------------------------------
|    | Kernel_Name                                                   |
-----|---------------------------------------------------------------
|  0 | yax(double*, double*, double*, int, int, double*) [clone .kd] |
--------------------------------------------------------------------

--------------------------------------------------------------------------------
Dispatch list
-------------------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                   |   GPU_ID |
-----|---------------|---------------------------------------------------------------|-----------
|  0 |             0 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        4 |
-----|---------------|---------------------------------------------------------------|-----------
|  1 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        4 |
-------------------------------------------------------------------------------------------------------
```

To see aggregated stats for the `yax` kernel, run

```
rocprof-compute analyze -p workloads/problem/MI300A_A1/ -k 0 --block 7.1.0 7.1.1 7.1.2
```

Which will show an output similar to this one:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|
   INFO Analysis mode = cli
   INFO [analysis] deriving ROCprof-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
-----------------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count |       Sum(ns) |     Mean(ns) |   Median(ns) |    Pct |
-----|--------------------------------------------|---------|---------------|--------------|--------------|--------|-
|  0 | yax(double*, double*, double*, int, int, |    2.00 | 1083496775.00 | 541748387.50 | 541748387.50 | 100.00 |
|    |  double*) [clone .kd]                      |         |               |              |              |        |
-----------------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
-------------------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                   |   GPU_ID |
-----|---------------|---------------------------------------------------------------|-----------
|  0 |             0 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        4 |
-----|---------------|---------------------------------------------------------------|-----------
|  1 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        4 |
-------------------------------------------------------------------------------------------------------



--------------------------------------------------------------------------------
7. Wavefront
7.1 Wavefront Launch Stats
-------------------------------------------------------------------------
| Metric_ID   | Metric           |    Avg |    Min |    Max | Unit       |
--------------|------------------|--------|--------|--------|-------------
| 7.1.0       | Grid Size        | 256.00 | 256.00 | 256.00 | Work items |
--------------|------------------|--------|--------|--------|-------------
| 7.1.1       | Workgroup Size   |  64.00 |  64.00 |  64.00 | Work items |
--------------|------------------|--------|--------|--------|-------------
```

```
| 7.1.2       | Total Wavefronts |   4.00 |   4.00 |   4.00 | Wavefronts |
--------------------------------------------------------------------------------
```

Exercise 2: LDS Occupancy Limiter

Simple kernel implementing a version of yAx, to demonstrate the downside of allocating a large amount of LDS, and the benefit of using a smaller amount of LDS due to occupancy limits.

Background: Acronyms and terms used in this exercise

Wavefront: A collection of threads, usually 64.

Workgroup: A collection of Wavefronts (at least 1), which can be scheduled on a Compute Unit (CU)

LDS: Local Data Store is Shared Memory that is accessible to the entire workgroup on a Compute Unit (CU)

CU: The Compute Unit is responsible for executing the User's kernels

SPI: Shader Processor Input, also referred to as the Workgroup Manager, is responsible for scheduling workgroups on Compute Units

Occupancy: A measure of how many wavefronts are executing on the GPU on average through the duration of the kernel

PoP: Percent of Peak refers to the ratio of an achieved value and a theoretical or actual maximum. In terms of occupancy, it is how many wavefronts on average were on the device divided by how many can fit on the device.

yAx: a vector-matrix-vector product, yAx, where y and x are vectors, and A is a matrix

```
      <li><strong>FP(32/16):</strong> 32- or 16-bit Floating Point numeric types</li>
      <li><strong>FLOPs:</strong> Floating Point Operations Per second</li>
      <li><strong>HBM:</strong> High Bandwidth Memory is globally accessible from the GPU, and is a level of memory
 </ul>
```

Results on MI210

Note: This exercise was tested on a system with MI210s, on rocprof-compute version `2.0.0` and ROCm `6.0.2` **ROCprof-compute** `2.0.0` **is incompatible with ROCm versions lesser than** `6.0.0`

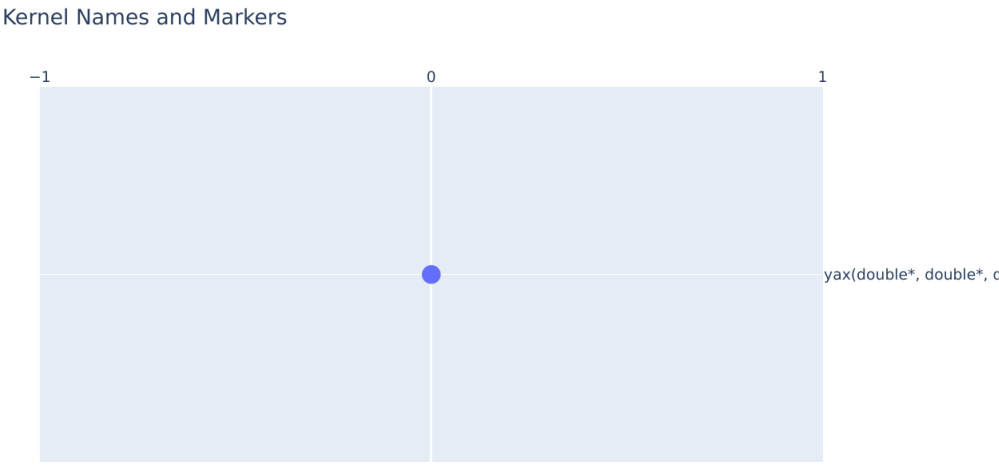
Initial Roofline Analysis

In this exercise we're using a problem code that is slightly different than where we left off in Exercise 1. Regardless, to get started we need to get a roofline by running:

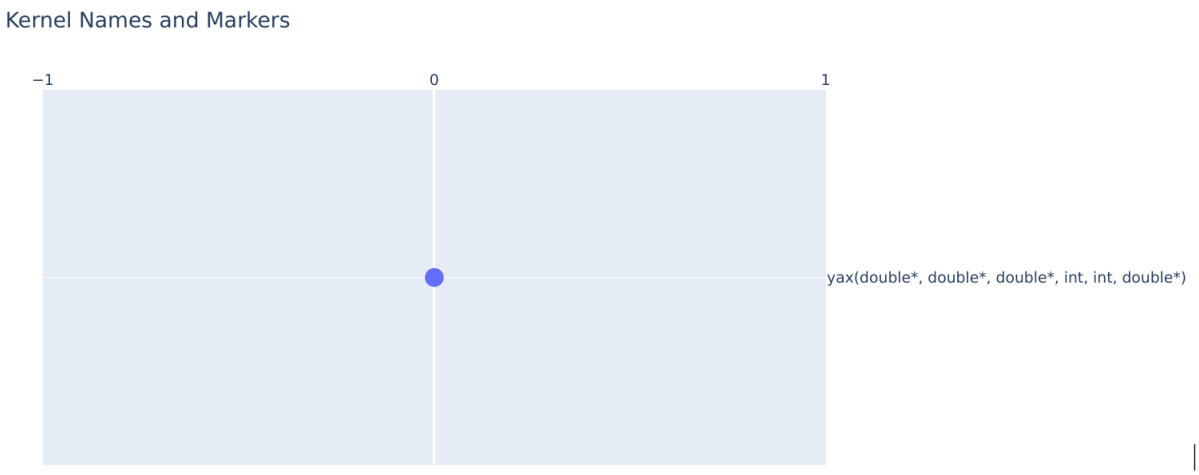
```
rocprof-compute profile -n problem_roof_only --roof-only --kernel-names -- ./problem.exe
```

The plots will appear as PDF files in the `./workloads/problem_roof_only/MI200` directory, if generated on MI200 hardware.

For convenience, the resulting plots on a representative system are below: | Roofline Type | Roofline Legend | Roofline Plot | |————|————————————————|————————————



——————————| |FP32/FP64 |



| |FP16/INT8 | |
|

We see that there looks to be room for improvement here. We'll use rocprof-compute to see what the current limiters are.

Exercise Instructions:

First, we should get an idea of the code's runtime:

```
make
./problem.exe
```

(*simulated output*)

```
yAx time: 140 ms
```

This problem.cpp uses LDS allocations to move the x vector closer to the compute resources, a common optimization. However, we see that it ends up slower than the previous solution that didn't use LDS at all. In kernels that request a lot of LDS, it is common to see that the LDS usage limits the occupancy of the kernel. That is, more wavefronts cannot be resident on the device, because all of them need more LDS than is available. We need to confirm this hypothesis, let's start by running:

```
rocprof-compute profile -n problem --no-roof -- ./problem.exe
```

The usage of `rocprof-compute profile` arguments can be found here, or by running `rocprof-compute profile --help` .

This `rocprof-compute profile` command will take a minute or two to run, as rocprof-compute must run your code a few times to collect all the hardware counters.

Note: For large scientific codes, it can be useful to profile a small representative workload if possible, as profiling a full run may take prohibitively long.

Once the profiling run completes, let's take a look at the occupancy stats related to LDS allocations:

```
rocprof-compute analyze -p workloads/problem/MI200 --dispatch 1 --block 2.1.15 6.2.7
```

The metrics we're looking at are: - `2.1.15` Wavefront occupancy – a measure of how many wavefronts, on average, are active on the device - `6.2.7` SPI: Insufficient CU LDS – indicates whether wavefronts are not able to be scheduled due to insufficient LDS

The SPI section (`6.2`) generally shows what resources limit occupancy, while Wavefront occupancy (`2.1.15`) shows how severely occupancy is limited in general. As of ROCprof-compute version `2.0.0` , the SPI 'insufficient' fields are a percentage showing how frequently a given resource prevented the SPI from scheduling a wavefront. If more than one field is nonzero, the relative magnitude of the nonzero fields correspond to the relative severity of the corresponding occupancy limitation (a larger percentage means a resource limits occupancy more than another resource with a smaller percentage), but it is usually impossible to closely correlate the SPI 'insufficient' percentage with the overall occupancy limit. This could mean you reduce a large percentage in an 'insufficient' resource field to zero, and see overall occupancy only increase by a comparatively small amount.

Background: A note on occupancy's relation to performance

Occupancy has a fairly complex relation to achieved performance. In cases where the device is not saturated (where resources are available, but are unused) there is usually performance that can be gained by increasing occupancy, but not always. For instance, adversarial data access patterns (see exercise 4-StridedAccess) can cause occupancy increases to result in degraded performance, due to overall poorer cache utilization. Typically adding to occupancy gains performance up to a point beyond which performance degrades, and this point may have already been reached by an application before optimizing.

The output of the `rocprof-compute analyze` command should look similar to this:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

Analysis mode = cli
[analysis] deriving ROCprof-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
--------------------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count |      Sum(ns) |     Mean(ns) |   Median(ns) |    Pct |
|----|--------------------------------------------|---------|--------------|--------------|--------------|--------|
|  0 | yax(double*, double*, double*, int, int,   |    1.00 | 176224652.00 | 176224652.00 | 176224652.00 | 100.00 |
|    |  double*) [clone .kd]                      |         |              |              |              |        |
--------------------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
-----------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                  |   GPU_ID |
|----|---------------|--------------------------------------------------------------|----------|
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        8 |
-----------------------------------------------------------------------------------------------



--------------------------------------------------------------------------------
2. System Speed-of-Light
```

```
2.1 Speed-of-Light
-------------------------------------------------------------------------------------
| Metric_ID   | Metric              |    Avg | Unit       |    Peak |   Pct of Peak |
--------------|---------------------|--------|------------|---------|----------------
| 2.1.15      | Wavefront Occupancy | 103.00 | Wavefronts | 3328.00 |          3.10 |
-------------------------------------------------------------------------------------


-------------------------------------------------------------------------------
6. Workgroup Manager (SPI)
6.2 Workgroup Manager - Resource Allocation
-----------------------------------------------------------------------
| Metric_ID   | Metric              |   Avg |   Min |   Max | Unit   |
--------------|---------------------|-------|-------|-------|---------
| 6.2.7       | Insufficient CU LDS | 79.01 | 79.01 | 79.01 | Pct    |
-----------------------------------------------------------------------
```

Looking through this data we see: - Wavefront occupancy (`2.1.15`) is 3%, which is very low - Insufficient CU LDS (`6.2.7`) contains a fairly large percentage, which indicates our occupancy is currently limited by LDS allocations.

There are two solution directories, which correspond to two ways that this occupancy limit can be addressed. First, we have `solution-no-lds` , which completely removes the LDS usage. Let's build and run this solution:

```
cd solution-no-lds
make
./solution.exe
```

(*simulated output*)

```
yAx time: 70 ms
```

We see that the runtime is much better for this solution than the problem, let's see if removing LDS did indeed increase occupancy:

```
rocprof-compute profile -n solution --no-roof -- ./solution.exe
```

(*output omitted*)

Once the profile command completes, run:

```
rocprof-compute analyze -p workloads/solution/MI200 --dispatch 1 --block 2.1.15 6.2.7
```

The output should look something like:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

Analysis mode = cli
[analysis] deriving ROCprof-compute metrics...

-------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
-----------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                              |   Count |     Sum(ns) |    Mean(ns) |   Median(ns) |    Pct |
-----|------------------------------------------|---------|-------------|-------------|--------------|---------
|  0 | yax(double*, double*, double*, int, int, |    1.00 | 69513618.00 | 69513618.00 |  69513618.00 | 100.00 |
|    |  double*) [clone .kd]                    |         |             |             |              |        |
```

```
--------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
--------------------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                                |   GPU_ID |
|----|---------------|----------------------------------------------------------------------------|----------|
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        8 |
--------------------------------------------------------------------------------------------------------


--------------------------------------------------------------------------------
2. System Speed-of-Light
2.1 Speed-of-Light
-------------------------------------------------------------------------------------
| Metric_ID   | Metric              |    Avg | Unit       |    Peak |   Pct of Peak |
|-------------|---------------------|--------|------------|---------|---------------|
| 2.1.15      | Wavefront Occupancy | 451.15 | Wavefronts | 3328.00 |         13.56 |
-------------------------------------------------------------------------------------


--------------------------------------------------------------------------------
6. Workgroup Manager (SPI)
6.2 Workgroup Manager - Resource Allocation
-----------------------------------------------------------------------
| Metric_ID   | Metric              |   Avg |   Min |   Max | Unit   |
|-------------|---------------------|-------|-------|-------|--------|
| 6.2.7       | Insufficient CU LDS |  0.00 |  0.00 |  0.00 | Pct    |
-----------------------------------------------------------------------
```

Looking through this data we see: - Wave occupancy (`2.1.15`) is 10% higher than in problem.cpp - Insufficient CU LDS (`6.2.7`) is now zero, indicating solution-no-lds is not occupancy limited by LDS allocations.

Can we get some runtime advantage from using smaller LDS allocations?

This is the solution implemented in the `solution` directory:

```
cd ../solution
make
./solution.exe
```

(*simulated output*)

```
yAx time: 50 ms
```

This solution, rather than removing the LDS allocation, simply reduces the amount of LDS requested to address the occupancy limit. This gives us the benefit of having some data pulled closer than it was in `solution-no-lds` which is validated through the speedup we see. But is this solution still occupancy limited by LDS?

```
rocprof-compute profile -n solution --no-roof -- ./solution.exe
```

(*output omitted*)

Once the profile command completes, run:

```
rocprof-compute analyze -p workloads/solution/MI200 --dispatch 1 --block 2.1.15 6.2.7
```

The output should look something like:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __   _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \ | | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
```

```
              |_|                                       |_|

Analysis mode = cli
[analysis] deriving ROCprof-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
-----------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                              |   Count |     Sum(ns) |    Mean(ns) |   Median(ns) |    Pct |
|----|------------------------------------------|---------|-------------|-------------|--------------|--------|
|  0 | yax(double*, double*, double*, int, int, |    1.00 | 51238856.00 | 51238856.00 |  51238856.00 | 100.00 |
|    |  double*) [clone .kd]                    |         |             |             |              |        |
-----------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
-----------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                   |   GPU_ID |
|----|---------------|---------------------------------------------------------------|----------|
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        8 |
-----------------------------------------------------------------------------------------------



--------------------------------------------------------------------------------
2. System Speed-of-Light
2.1 Speed-of-Light
-------------------------------------------------------------------------------------
| Metric_ID   | Metric              |    Avg | Unit       |    Peak |   Pct of Peak |
|-------------|---------------------|--------|------------|---------|---------------|
| 2.1.15      | Wavefront Occupancy | 494.05 | Wavefronts | 3328.00 |         14.85 |
-------------------------------------------------------------------------------------



--------------------------------------------------------------------------------
6. Workgroup Manager (SPI)
6.2 Workgroup Manager - Resource Allocation
-----------------------------------------------------------------------
| Metric_ID   | Metric              |   Avg |   Min |   Max | Unit    |
|-------------|---------------------|-------|-------|-------|---------|
| 6.2.7       | Insufficient CU LDS |  0.00 |  0.00 |  0.00 | Pct     |
-----------------------------------------------------------------------
```

Looking at this data we see: - Wave Occupancy (`2.1.15`) is even higher than before - Insufficient CU LDS (`6.2.7`) shows we are not occupancy limited by LDS allocations.

Pulling some data from global device memory to LDS can be an effective optimization strategy, if occupancy limits are carefully avoided.

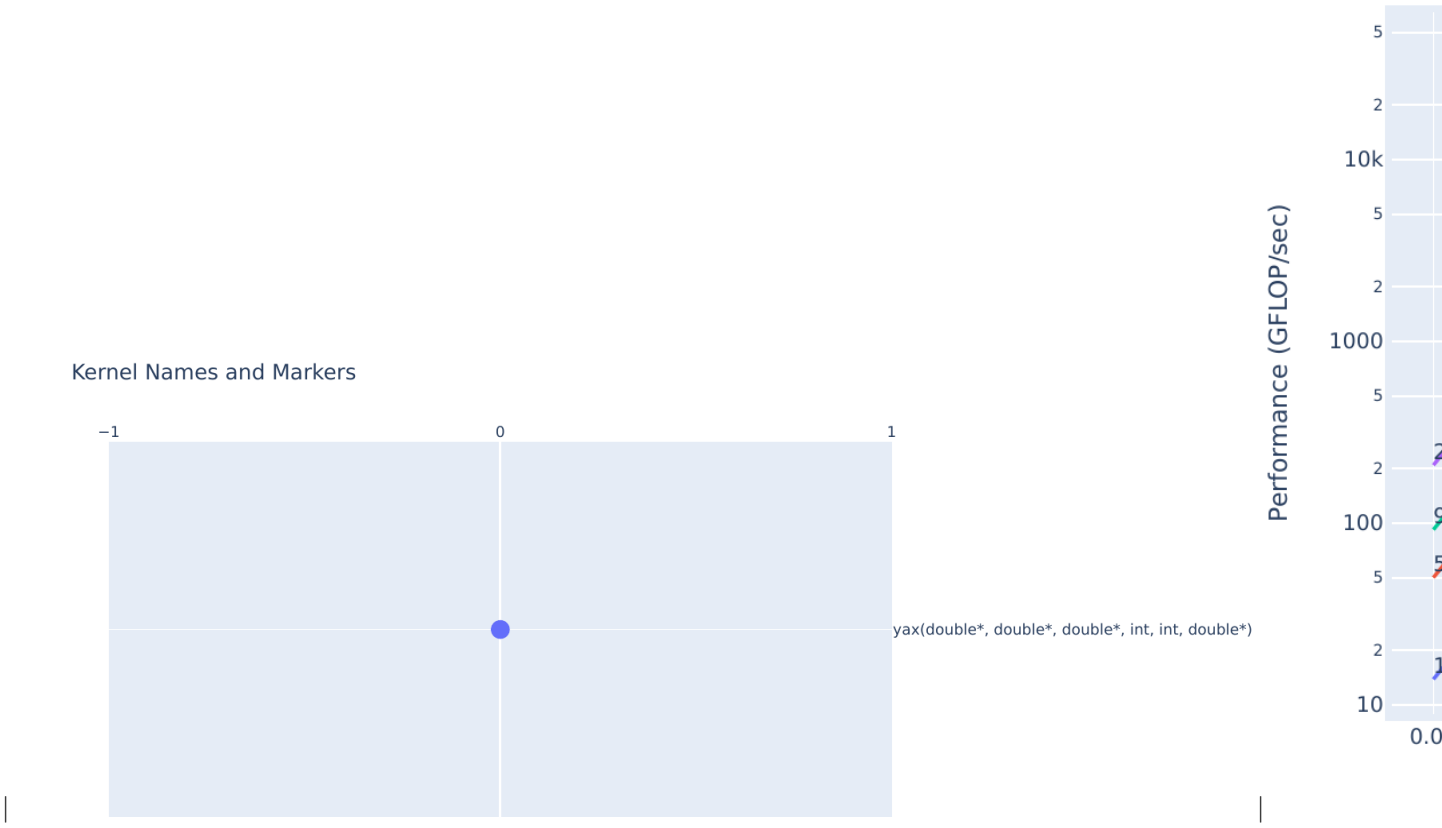
Solution Roofline

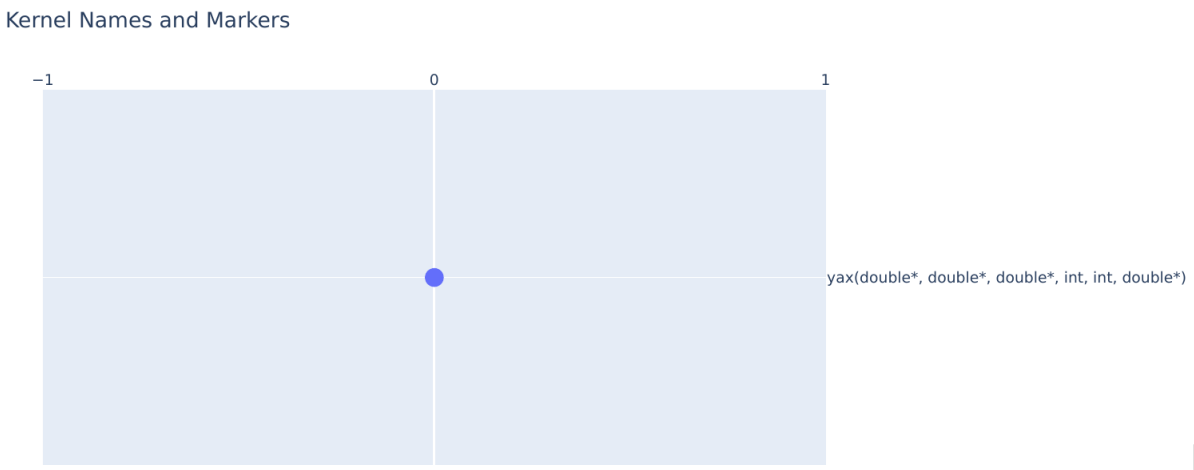
Let's take a look at the roofline for `solution` , which can be generated with:

```
rocprof-compute profile -n solution_roof_only --roof-only -- ./solution.exe
```

The plots will appear as PDF files in the `./workloads/problem_roof_only/MI200` directory, if generated on MI200 hardware.

The plots are shown here: | Roofline Type | Roofline Legend | Roofline Plot | |————|————————————|————————————————————| |FP32/FP64


Kernel Names and Markers
−1
0
1
yax(double*, double*, double*, int, int, double*)
Performance (GFLOP/sec)
5
2
10k
5
2
1000
5
2
100
5
2
10
0.0

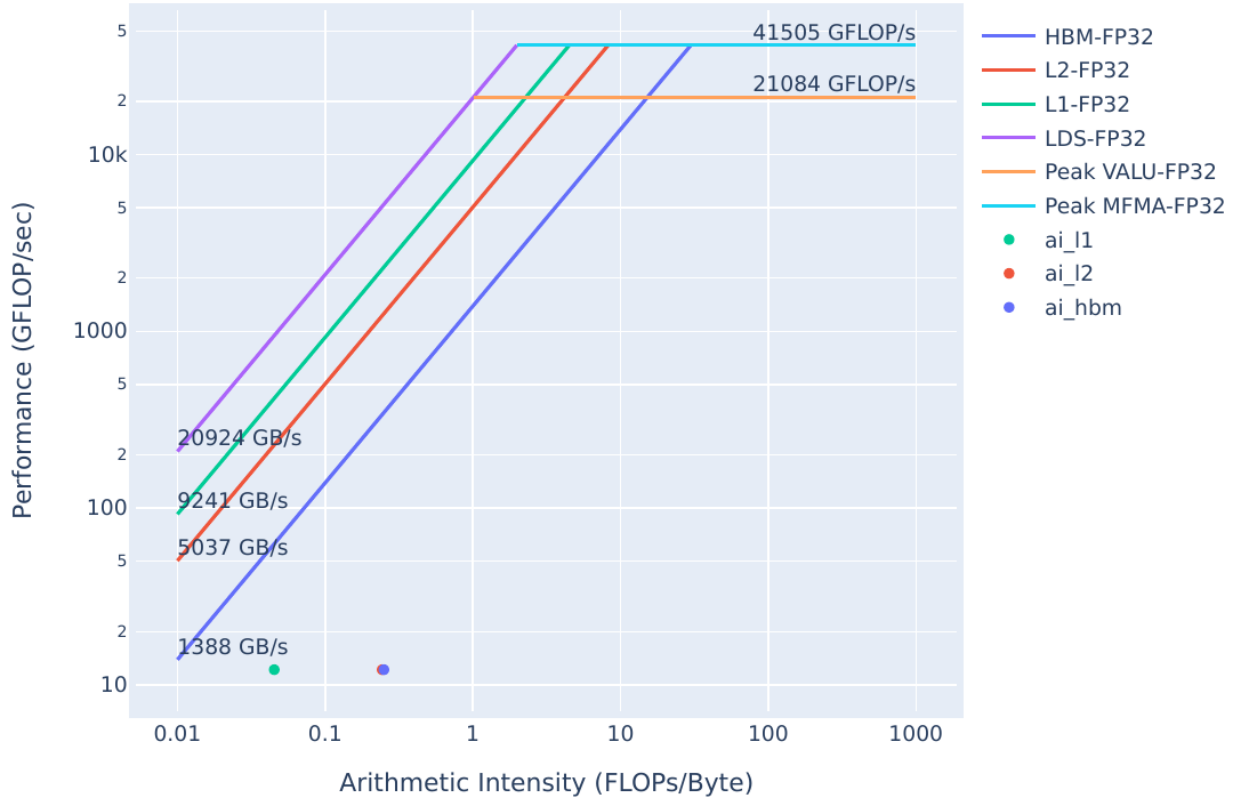


| |FP16/INT8 | |
|

We see that there is still room to move the solution roofline up towards the bandwidth limit.

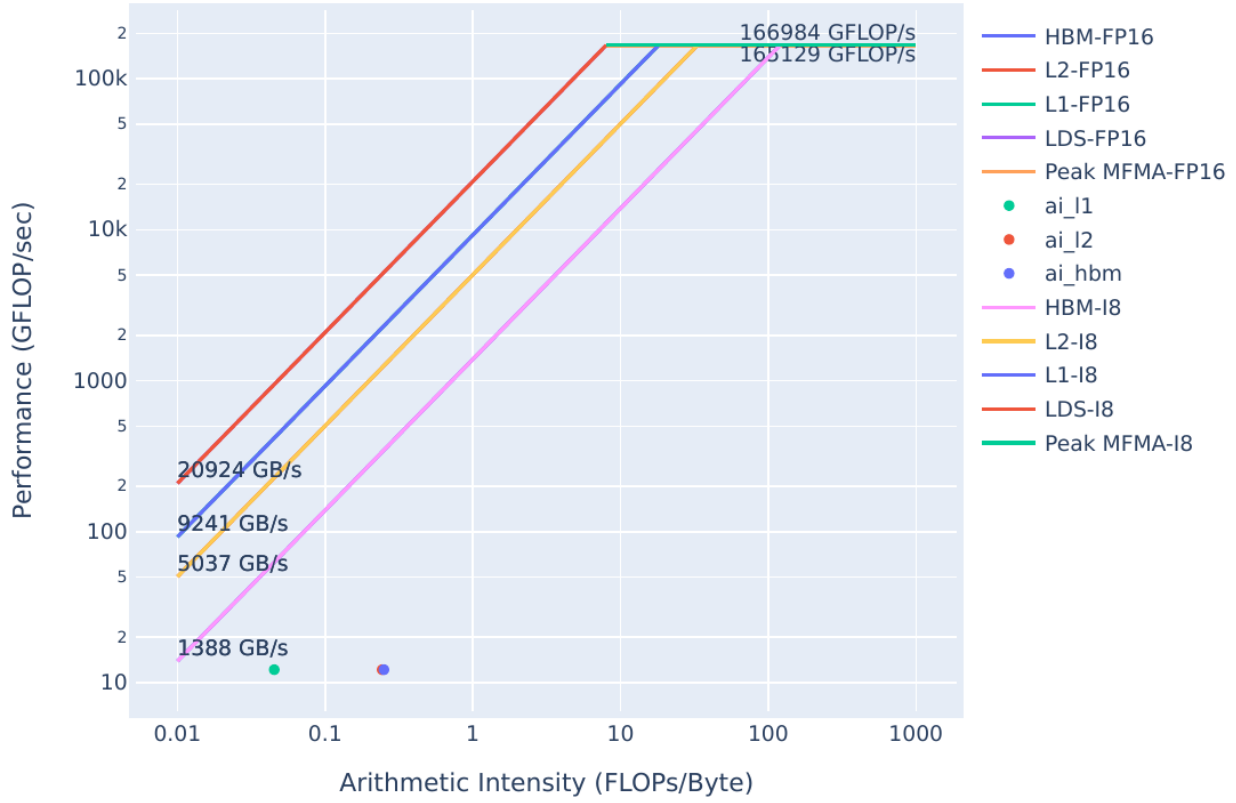
Roofline Comparison

Roofline Type	Problem Roofline



FP32/FP64

Roofline Type	Problem Roofline



FP16/INT8

Again, we see that the solution's optimizations have resulted in the kernel moving up in the roofline, meaning the solution executes more efficiently than the problem.

Summary and Take-aways

Using LDS can be very helpful in reducing global memory reads where you have repeated use of the same data. However, large LDS allocations can also negatively impact performance by limiting the amount of wavefronts that can be resident in the device at any given time. Be wary of LDS usage, and check the SPI stats to ensure your LDS usage is not negatively impacting occupancy.

Results on MI300A

In this section, we show results obtained running this exercise on a system with MI300A, using ROCm `6.2.1` and the associated ROCprof-compute, version `6.2.1` .

Roofline Analysis:

At present (September 28th 2024), rooflines are disabled on MI300A.

As for the MI210 case, build and run the problem code:

```
make
./problem.exe
```

(*simulated output*)

```
yAx time: 7.27 ms
```

Unlike the MI210 case, the runtime of `problem` is already smaller than it was for the previous `solution` on example `1-LaunchParameters` .

Once again, we launch the following command to collect complete profiling data for analysis:

```
rocprof-compute profile -n problem --no-roof -- ./problem.exe
```

Followed by:

```
rocprof-compute analyze -p workloads/problem/MI300A_A1 --dispatch 1 --block 2.1.15 6.2.7
```

Then inspect the output:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __   _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

   INFO Analysis mode = cli
   INFO [analysis] deriving ROCprof-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
----------------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count |    Sum(ns) |   Mean(ns) |   Median(ns) |    Pct |
|----|--------------------------------------------|---------|------------|------------|--------------|--------|
|  0 | yax(double*, double*, double*, int, int, |    1.00 | 7241298.00 | 7241298.00 |   7241298.00 | 100.00 |
|    |  double*) [clone .kd]                      |         |            |            |              |        |
----------------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
-----------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                    |   GPU_ID |
|----|---------------|----------------------------------------------------------------|----------|
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        4 |
-----------------------------------------------------------------------------------------------


--------------------------------------------------------------------------------
2. System Speed-of-Light
2.1 Speed-of-Light
-------------------------------------------------------------------------------
| Metric_ID   | Metric              |    Avg | Unit       |    Peak |   Pct of Peak |
|-------------|---------------------|--------|------------|---------|---------------|
| 2.1.15      | Wavefront Occupancy | 177.86 | Wavefronts | 7296.00 |          2.44 |
-------------------------------------------------------------------------------


--------------------------------------------------------------------------------
6. Workgroup Manager (SPI)
6.2 Workgroup Manager - Resource Allocation
-----------------------------------------------------------------------
| Metric_ID   | Metric              |   Avg |   Min |   Max | Unit   |
|-------------|---------------------|-------|-------|-------|--------|
| 6.2.7       | Insufficient CU LDS | 58.11 | 58.11 | 58.11 | Pct    |
-----------------------------------------------------------------------
```

The results are similar to the MI210 case, in terms of Wavefront Occupancy (`2.44%` , for MI210 it was

`3.10%`) and Insufficient CU LDS (around `58%` , for MI210 it was `79%`). Let us look first at the solution that completely eliminates LDS usage:

```
cd solution-no-lds
make
./solution.exe
```

(*simulated output*)

```
yAx time: 9.79 ms
```

As in the MI210 case, completely eliminating LDS usage makes the runtime worse.

Let's run the following commands and inspect the output:

```
rocprof-compute profile -n solution --no-roof -- ./solution.exe
rocprof-compute analyze -p workloads/solution/MI300A_A1/ --dispatch 1 --block 2.1.15 6.2.7
```

Output:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

   INFO Analysis mode = cli
   INFO [analysis] deriving ROCprof-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
-----------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count |    Sum(ns) |   Mean(ns) |   Median(ns) |    Pct |
|----|--------------------------------------------|---------|------------|------------|--------------|--------|
|  0 | yax(double*, double*, double*, int, int, |    1.00 | 9484503.00 | 9484503.00 |   9484503.00 | 100.00 |
|    |  double*) [clone .kd]                      |         |            |            |              |        |
-----------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
-----------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                    |   GPU_ID |
|----|---------------|----------------------------------------------------------------|----------|
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        4 |
-----------------------------------------------------------------------------------------------



--------------------------------------------------------------------------------
2. System Speed-of-Light
2.1 Speed-of-Light
-------------------------------------------------------------------------------
| Metric_ID   | Metric              |    Avg | Unit       |    Peak |   Pct of Peak |
|-------------|---------------------|--------|------------|---------|---------------|
| 2.1.15      | Wavefront Occupancy | 437.16 | Wavefronts | 7296.00 |          5.99 |
-------------------------------------------------------------------------------



--------------------------------------------------------------------------------
6. Workgroup Manager (SPI)
6.2 Workgroup Manager - Resource Allocation
-----------------------------------------------------------------------
| Metric_ID   | Metric              |   Avg |   Min |   Max | Unit   |
|-------------|---------------------|-------|-------|-------|--------|
```

```
| 6.2.7       | Insufficient CU LDS |  0.00 |  0.00 |  0.00 | Pct    |
--------------------------------------------------------------------
```

From the ouput above, we see that Insufficient CU LDS is now zero as expected, and that Wavefront Occupancy has gone up to around `6%` from `2.44%` that it was before for MI210. Next, let's compare these results with the code in the `solution` directory: this implementation reduces the amount of LDS requested to address the occupancy limit, but still uses some LDS to speed up memory accesses. First, run:

```
cd ../solution
make
./solution.exe
```

(*simulated output*)

```
yAx time: 5.80 ms
```

This shows that an appropriate reduction of LDS usage did improve the performance of the example. To see the specific values of the metrics of interest, we run:

```
rocprof-compute profile -n solution --no-roof -- ./solution.exe
rocprof-compute analyze -p workloads/solution/MI300A_A1 --dispatch 1 --block 2.1.15 6.2.7
```

With output:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

   INFO Analysis mode = cli
   INFO [analysis] deriving ROCprof-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
-----------------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count |    Sum(ns) |   Mean(ns) |   Median(ns) |    Pct |
|----|--------------------------------------------|---------|------------|------------|--------------|--------|
|  0 | yax(double*, double*, double*, int, int, |    1.00 | 5766574.00 | 5766574.00 |   5766574.00 | 100.00 |
|    |  double*) [clone .kd]                      |         |            |            |              |        |
-----------------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
-----------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                    |   GPU_ID |
|----|---------------|----------------------------------------------------------------|----------|
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        4 |
-----------------------------------------------------------------------------------------------



--------------------------------------------------------------------------------
2. System Speed-of-Light
2.1 Speed-of-Light
-------------------------------------------------------------------------------------
| Metric_ID   | Metric              |    Avg | Unit       |    Peak |   Pct of Peak |
|-------------|---------------------|--------|------------|---------|---------------|
| 2.1.15      | Wavefront Occupancy | 421.57 | Wavefronts | 7296.00 |          5.78 |
-------------------------------------------------------------------------------------



--------------------------------------------------------------------------------
```

```
6. Workgroup Manager (SPI)
6.2 Workgroup Manager - Resource Allocation
-----------------------------------------------------------------------
| Metric_ID   | Metric              |   Avg |   Min |   Max | Unit   |
--------------|---------------------|-------|-------|-------|---------
| 6.2.7       | Insufficient CU LDS |  0.00 |  0.00 |  0.00 | Pct    |
-----------------------------------------------------------------------
```

We see that the example is still not occupancy limited by LDS allocations (Insufficient CU LDS is zero). The Wavefront Occupancy has remained approximately the same. As seen above, the runtime has improved by approximately `20%` (going from `7.27` ms of `problem.exe` , to the current time of `5.8` ms).

Exercise 3: Register Occupancy Limiter

More complex yAx implementation to demonstrate a register limited kernel using an innocuous looking function call. The register limit no longer shows up for recent versions of ROCm on certain accelerators. Nevertheless, this exercise is useful for learning how to find register limited kernels using ROCprof-compute and asks you to imagine the limiter exists for the sake of the exercise. This is an example of how many things influence performance bugs: they exist on hardware, with a software stack, at a certain time. They may never exist outside that context.

Background: Acronyms and terms used in this exercise

VGPR: Vector General Purpose Register, holds distinct values for each thread in a wavefront

SGPR: Scalar General Purpose Register, holds a single value for all threads in a workgroup

AGPR: Accumulation vector General Purpose Register, used for Matrix Fused Multiply-Add (MFMA) instructions, or low-cost register spills

Wavefront: A collection of threads, usually 64.

Workgroup: A collection of Wavefronts (at least 1), which can be scheduled on a Compute Unit (CU)

LDS: Local Data Store is Shared Memory that is accessible to the entire workgroup on a Compute Unit (CU)

CU: The Compute Unit is responsible for executing the User's kernels

SPI: Shader Processor Input, also referred to as the Workgroup Manager, is responsible for scheduling workgroups on Compute Units

Occupancy: A measure of how many wavefronts are executing on the GPU on average through the duration of the kernel

PoP: Percent of Peak refers to the ratio of an achieved value and a theoretical or actual maximum. In terms of occupancy, it is how many wavefronts on average were on the device divided by how many can fit on the device.

yAx: a vector-matrix-vector product, yAx, where y and x are vectors, and A is a matrix

```
      <li><strong>FP(32/16):</strong> 32- or 16-bit Floating Point numeric types</li>
      <li><strong>FLOPs:</strong> Floating Point Operations Per second</li>
      <li><strong>HBM:</strong> High Bandwidth Memory is globally accessible from the GPU, and is a level of memory
 </ul>
```

Results on MI210

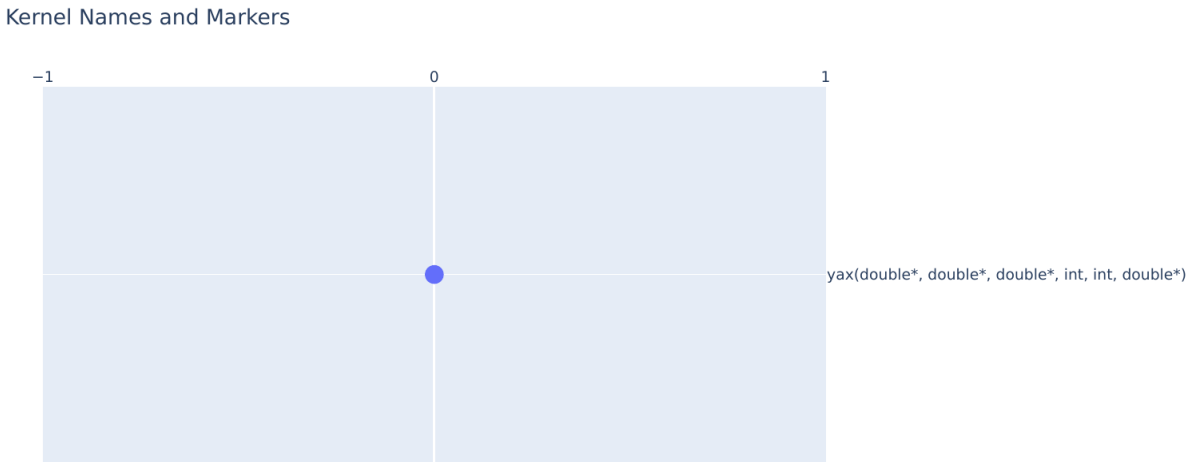
Note: This exercise was tested on a system with MI210s, on rocprof-compute version `2.0.0` and ROCm `6.0.2` **ROCprof-compute `2.0.0` is incompatible with ROCm versions lesser than `6.0.0`**

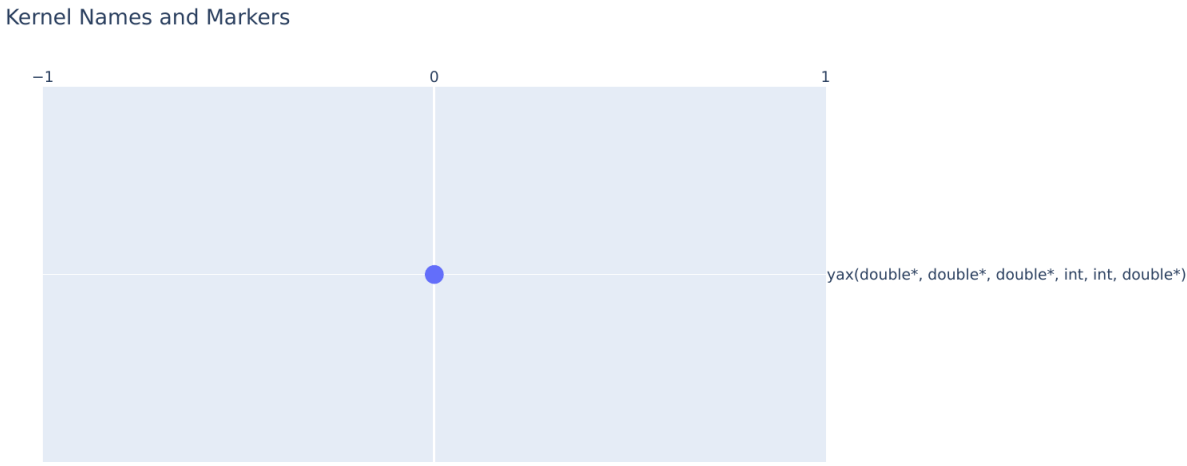
Initial Roofline Analysis

This kernel is slightly different from the one we used in previous exercises. Let's see how well it measures up in the roofline:

Roofline Type	Roofline Legend

FP32/FP64



Roofline Type	Roofline Legend
FP16/INT8	

You can generate these plots by running:

```
rocprof-compute profile -n problem_roof_only --roof-only --kernel-names -- ./problem.exe
```

The plots will appear as PDF files in the `./workloads/problem_roof_only/MI200` directory, if generated on MI200 hardware.

We see that the kernel is still a considerable amount below the maximum achievable bandwidth, so there should still be room for improvement.

Exercise Instructions:

Let's get an idea of the runtime of this code:

```
make
./problem.exe
```

(*simulated output*)

```
yAx time 71 ms
```

We see that this kernel seems to be on par with some of our other exercises, but let's see what rocprof-compute shows us:

```
rocprof-compute profile -n problem --no-roof -- ./problem.exe
```

(*lots of output from this command*)

```
rocprof-compute analyze -p workloads/problem/MI200 --dispatch 1 --block 2.1.15 6.2.5 7.1.5 7.1.6 7.1.7
```

- `2.1.15` Shows Wavefront occupancy
- `6.2.5` Shows Insufficient SIMD VGPRs – indicating if this kernel is occupancy limited by VGPR usage
- `7.1.5-7` Shows the register usage: VGPRs, SGPRs, and AGPRs

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

   INFO Analysis mode = cli
   INFO [analysis] deriving ROCprof-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
--------------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count |     Sum(ns) |    Mean(ns) |   Median(ns) |    Pct |
|----|--------------------------------------------|---------|-------------|-------------|--------------|--------|
|  0 | yax(double*, double*, double*, int, int,   |    1.00 | 77266823.00 | 77266823.00 |  77266823.00 | 100.00 |
|    |  double*) [clone .kd]                      |         |             |             |              |        |
--------------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
-----------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                    |   GPU_ID |
|----|---------------|----------------------------------------------------------------|----------|
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        8 |
-----------------------------------------------------------------------------------------------


--------------------------------------------------------------------------------
2. System Speed-of-Light
2.1 Speed-of-Light
-------------------------------------------------------------------------------
| Metric_ID   | Metric              |    Avg | Unit       |    Peak |   Pct of Peak |
|-------------|---------------------|--------|------------|---------|---------------|
| 2.1.15      | Wavefront Occupancy | 433.52 | Wavefronts | 3328.00 |         13.03 |
-------------------------------------------------------------------------------


--------------------------------------------------------------------------------
6. Workgroup Manager (SPI)
6.2 Workgroup Manager - Resource Allocation
-------------------------------------------------------------------------
| Metric_ID   | Metric                  |   Avg |   Min |   Max | Unit   |
|-------------|-------------------------|-------|-------|-------|--------|
| 6.2.5       | Insufficient SIMD VGPRs |  0.10 |  0.10 |  0.10 | Pct    |
-------------------------------------------------------------------------


--------------------------------------------------------------------------------
7. Wavefront
7.1 Wavefront Launch Stats
-----------------------------------------------------------------
| Metric_ID   | Metric   |    Avg |    Min |    Max | Unit      |
|-------------|----------|--------|--------|--------|-----------
```

```
| 7.1.5       | VGPRs    |  92.00 |  92.00 |  92.00 | Registers |
--------------|----------|--------|--------|--------|------------
| 7.1.6       | AGPRs    | 132.00 | 132.00 | 132.00 | Registers |
--------------|----------|--------|--------|--------|------------
| 7.1.7       | SGPRs    |  48.00 |  48.00 |  48.00 | Registers |
-------------------------------------------------------------
```

Looking at this data, we see: - Insufficient SIMD VGPRs (`6.2.5`) shows that we are slightly occupancy limited by VGPRs - VGPRs (`7.1.5`) shows we are using a moderate amount of VGPRs and we are using 132 AGPRs (`7.1.6`), which can indicate low-cost register spills in the absence of MFMA instructions.

In problem.cpp, the limiter is due to a call to `assert` that checks if our result is zeroed out on device. To make sure the problem is gone in solution.cpp, let's look at the solution code:

```
cd solution
make
./solution.exe
```

(*simulated output*)

```
yAx time: 70 ms
```

Our runtime seems fairly similar with or without the `assert` , but we should also check that rocprof-compute reports that our limiters are gone:

```
rocprof-compute profile -n solution --no-roof -- ./solution.exe
```

(*omitted output*)

```
rocprof-compute analyze -p workloads/solution/MI200 --dispatch 1 --block 2.1.15 6.2.5 7.1.5 7.1.6 7.1.7
```

The output of this command should look something like:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

   INFO Analysis mode = cli
   INFO [analysis] deriving ROCprof-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
-------------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count |     Sum(ns) |    Mean(ns) |   Median(ns) |    Pct |
-----|--------------------------------------------|---------|-------------|-------------|--------------|---------
|  0 | yax(double*, double*, double*, int, int, |    1.00 | 71714804.00 | 71714804.00 |  71714804.00 | 100.00 |
|    |  double*) [clone .kd]                      |         |             |             |              |        |
-------------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
-----------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                          |   GPU_ID |
-----|---------------|----------------------------------------------------------------------|-----------
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        8 |
-----------------------------------------------------------------------------------------------



--------------------------------------------------------------------------------
2. System Speed-of-Light
2.1 Speed-of-Light
--------------------------------------------------------------------------------
```

```
| Metric_ID   | Metric               |    Avg | Unit       |    Peak |   Pct of Peak |
|-------------|----------------------|--------|------------|---------|---------------|
| 2.1.15      | Wavefront Occupancy | 439.96 | Wavefronts | 3328.00 |         13.22 |
-------------------------------------------------------------------------------


--------------------------------------------------------------------------------
6. Workgroup Manager (SPI)
6.2 Workgroup Manager - Resource Allocation
--------------------------------------------------------------------------
| Metric_ID   | Metric                   |   Avg |   Min |   Max | Unit   |
|-------------|--------------------------|-------|-------|-------|--------|
| 6.2.5       | Insufficient SIMD VGPRs |  0.00 |  0.00 |  0.00 | Pct    |
--------------------------------------------------------------------------


--------------------------------------------------------------------------------
7. Wavefront
7.1 Wavefront Launch Stats
-------------------------------------------------------------
| Metric_ID   | Metric   |   Avg |   Min |   Max | Unit      |
|-------------|----------|-------|-------|-------|-----------|
| 7.1.5       | VGPRs    | 32.00 | 32.00 | 32.00 | Registers |
|-------------|----------|-------|-------|-------|-----------|
| 7.1.6       | AGPRs    |  0.00 |  0.00 |  0.00 | Registers |
|-------------|----------|-------|-------|-------|-----------|
| 7.1.7       | SGPRs    | 96.00 | 96.00 | 96.00 | Registers |
-------------------------------------------------------------
```

Looking at this data, we see: - Insufficient SIMD VGPRs (`6.2.5`) shows we are now not occupancy limited by VGPR usage. - VGPRs (`7.1.5`) are down by 60, AGPRs (`7.1.6`) are down by 132, and SGPRs (`7.1.7`) are up, showing more efficient register usage. - Wave Occupancy (`2.1.26`) shows our occupancy is slightly increased.

More generally, you can use this command to look at all SPI "insufficient resource" stats in the same screen, to determine if any resource is currently limiting occupancy. In fact, we can use this to ensure our problem implementation no longer has any SPI-related occupancy limiters with the newer version of ROCm:

```
rocprof-compute analyze -p workloads/problem/MI200 --dispatch 1 --block 6.2
```

Which will show output similar to this (note, fields `6.2.4` to `6.2.8` show resources which currently limit occupancy):

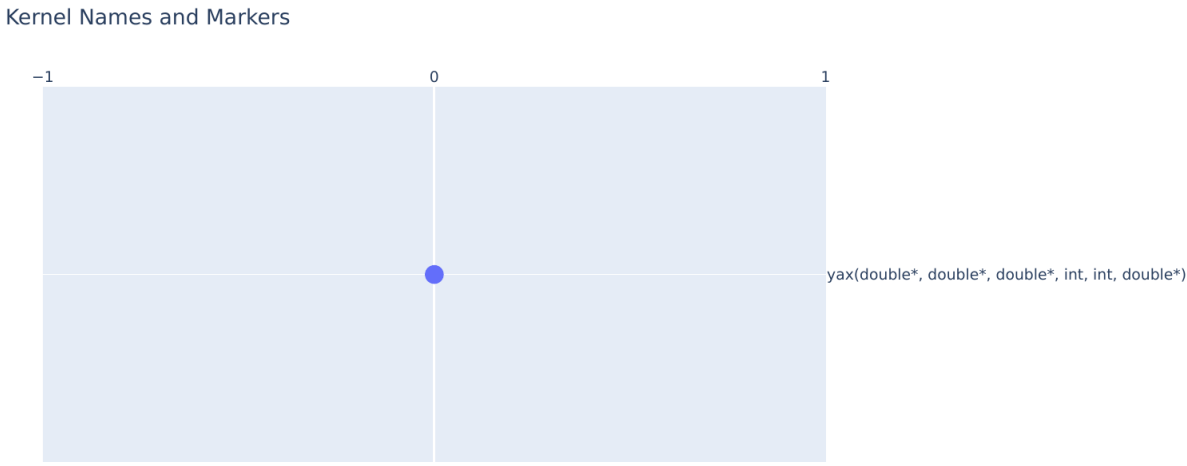
```
 _ __ ___   ___ _ __  _ __ ___  / |       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \ | |_____ / __/ _ \| '_ ` _ \| '_ \| | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

Analysis mode = cli
[analysis] deriving ROCprof-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
-----------------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count |     Sum(ns) |    Mean(ns) |   Median(ns) |    Pct |
|----|--------------------------------------------|---------|-------------|-------------|--------------|--------|
|  0 | yax(double*, double*, double*, int, int, |    1.00 | 69960451.00 | 69960451.00 |  69960451.00 | 100.00 |
|    |  double*) [clone .kd]                      |         |             |             |              |        |
```

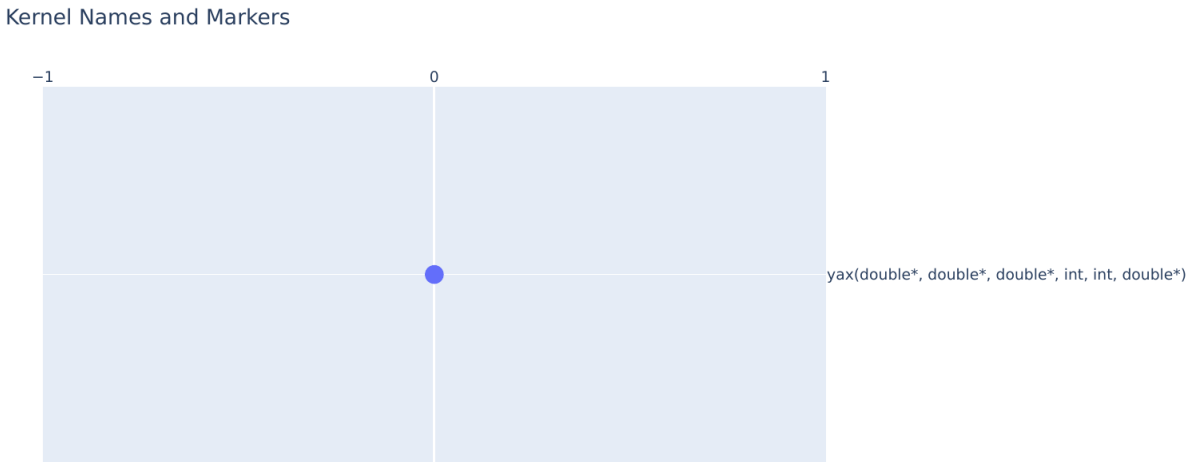
```
0.2 Dispatch List
|    |   Dispatch_ID | Kernel_Name                                                                |   GPU_ID |
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        8 |
```

```
6. Workgroup Manager (SPI)
6.2 Workgroup Manager - Resource Allocation
| Metric_ID   | Metric                                |   Avg |   Min |   Max | Unit   |
| 6.2.0       | Not-scheduled Rate (Workgroup Manager) |  0.00 |  0.00 |  0.00 | Pct    |
| 6.2.1       | Not-scheduled Rate (Scheduler-Pipe)    |  0.00 |  0.00 |  0.00 | Pct    |
| 6.2.2       | Scheduler-Pipe Stall Rate              |  0.00 |  0.00 |  0.00 | Pct    |
| 6.2.3       | Scratch Stall Rate                     |  0.00 |  0.00 |  0.00 | Pct    |
| 6.2.4       | Insufficient SIMD Waveslots            |  0.00 |  0.00 |  0.00 | Pct    |
| 6.2.5       | Insufficient SIMD VGPRs                |  0.00 |  0.00 |  0.00 | Pct    |
| 6.2.6       | Insufficient SIMD SGPRs                |  0.00 |  0.00 |  0.00 | Pct    |
| 6.2.7       | Insufficient CU LDS                    |  0.00 |  0.00 |  0.00 | Pct    |
| 6.2.8       | Insufficient CU Barriers               |  0.00 |  0.00 |  0.00 | Pct    |
| 6.2.9       | Reached CU Workgroup Limit             |  0.00 |  0.00 |  0.00 | Pct    |
| 6.2.10      | Reached CU Wavefront Limit             |  0.00 |  0.00 |  0.00 | Pct    |
```

Solution Roofline

With similar performance, we expect to see similar plots in the roofline for problem and solution:

Roofline Type	Roofline Legend
FP32/FP64	

Roofline Type	Roofline Legend
FP16/INT8	

You can generate these plots with:

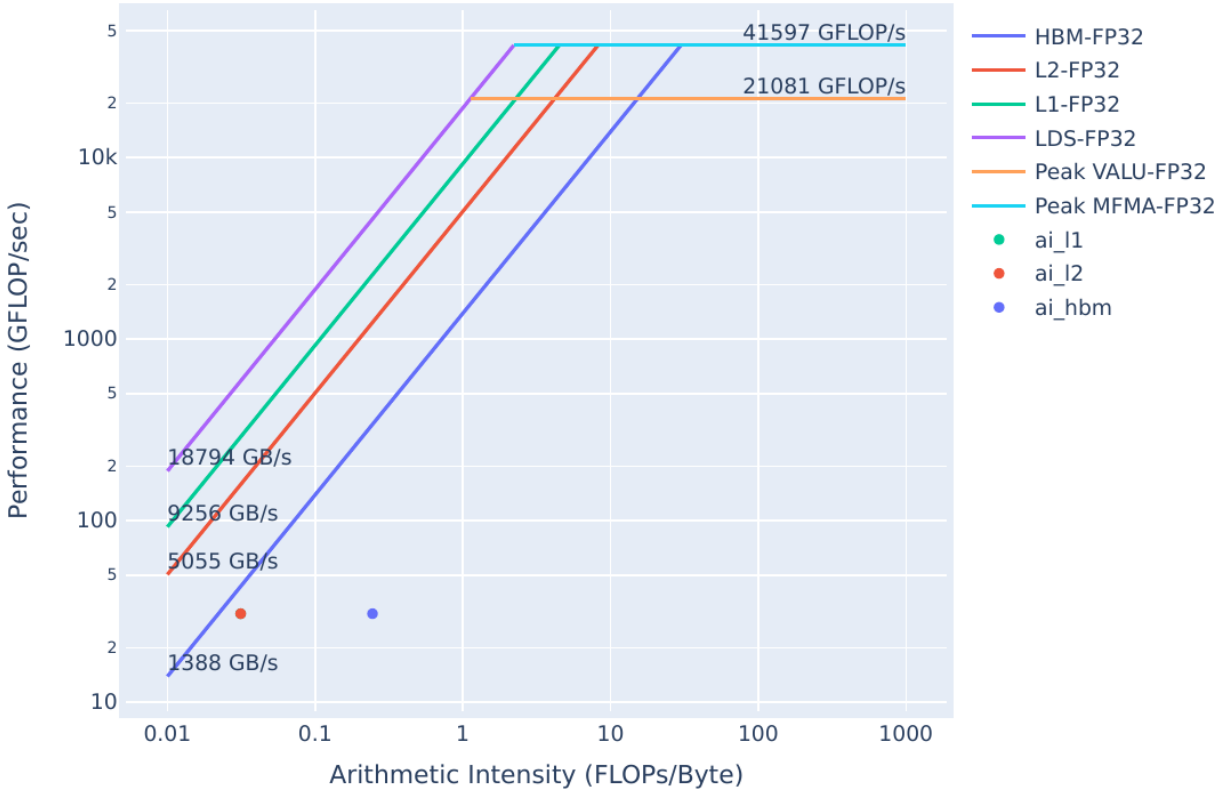
```
rocprof-compute profile -n problem_roof_only --roof-only --kernel-names -- ./problem.exe
```

The plots will appear as PDF files in the `./workloads/problem_roof_only/MI200` directory, if generated on MI200 hardware.

The plots are indistinguishable, which is further confirmation performance is now unchanged between problem and solution. However, we see there is still room for improvement as this kernel is not getting the maximum achievable bandwidth.

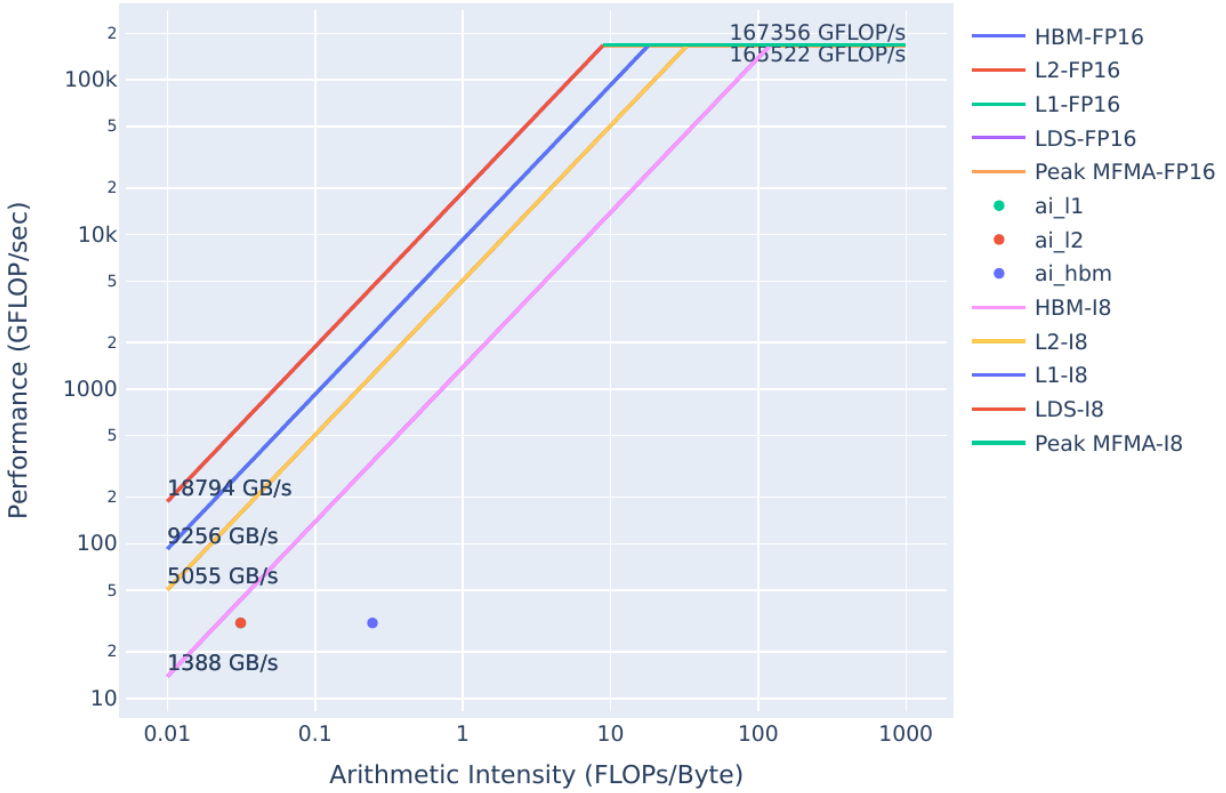
Roofline Comparison

Roofline Type	Problem Roofline



FP32/FP64

Roofline Type Problem Roofline



FP16/INT8

Summary and Take-aways

Function calls inside kernels can have surprisingly adverse performance side-effects. However, performance issues in general may be subject to compiler versions or other environment details. Calling assert, printf and even excessive use of math functions (e.g. pow, sin, cos) can limit performance in difficult-to-predict ways. If you see unexpected resource usage, try eliminating or reducing the use of these sorts of function calls.

Results on MI300A

In this section, we show results obtained running this exercise on a system with MI300A, using ROCm `6.2.1` and the associated ROCprof-compute, version `6.2.1` .

Roofline Analysis:

At present (September 28th 2024), rooflines are disabled on MI300A.

As for the MI210 case, build and run the problem code:

```
make
./problem.exe
```

(*simulated output*)

```
yAx time: 10 ms
```

Let's run the following commands to explore some metrics:

```
rocprof-compute profile -n problem --no-roof -- ./problem.exe
rocprof-compute analyze -p workloads/problem/MI300A_A1 --dispatch 1 --block 2.1.15 6.2.5 7.1.5 7.1.6 7.1.7
```

Then explore the output:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

   INFO Analysis mode = cli
   INFO [analysis] deriving ROCprof-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
-------------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count |     Sum(ns) |    Mean(ns) |   Median(ns) |    Pct |
-----|--------------------------------------------|---------|-------------|-------------|--------------|---------
|  0 | yax(double*, double*, double*, int, int, |    1.00 | 10064928.00 | 10064928.00 |  10064928.00 | 100.00 |
|    |  double*) [clone .kd]                      |         |             |             |              |        |
-------------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
-----------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                          |   GPU_ID |
-----|---------------|----------------------------------------------------------------------|-----------
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        4 |
-----------------------------------------------------------------------------------------------



--------------------------------------------------------------------------------
2. System Speed-of-Light
2.1 Speed-of-Light
-------------------------------------------------------------------------------
| Metric_ID   | Metric              |    Avg | Unit       |    Peak |   Pct of Peak |
--------------|---------------------|--------|------------|---------|----------------
| 2.1.15      | Wavefront Occupancy | 432.15 | Wavefronts | 7296.00 |          5.92 |
-------------------------------------------------------------------------------



--------------------------------------------------------------------------------
6. Workgroup Manager (SPI)
6.2 Workgroup Manager - Resource Allocation
-----------------------------------------------------------------------
| Metric_ID   | Metric                  |   Avg |   Min |   Max | Unit   |
--------------|-------------------------|-------|-------|-------|---------
| 6.2.5       | Insufficient SIMD VGPRs |  0.06 |  0.06 |  0.06 | Pct    |
-----------------------------------------------------------------------



--------------------------------------------------------------------------------
7. Wavefront
7.1 Wavefront Launch Stats
-------------------------------------------------------------------
| Metric_ID   | Metric   |    Avg |    Min |    Max | Unit      |
--------------|----------|--------|--------|--------|------------
| 7.1.5       | VGPRs    |  92.00 |  92.00 |  92.00 | Registers |
--------------|----------|--------|--------|--------|------------
| 7.1.6       | AGPRs    | 132.00 | 132.00 | 132.00 | Registers |
```

```
-------------|----------|--------|--------|--------|------------
| 7.1.7       | SGPRs    |  48.00 |  48.00 |  48.00 | Registers |
-------------------------------------------------------------
```

As expected, there is minor limiting due to Insufficient SIMD VGPRs, which is similar to the MI210 case. A similar scenario is seen when running solution:

```
cd solution
make
./solution.exe
```

(*simulated output*)

```
yAx time: 9.82 ms
```

The runtime is practically the same as the `problem` implementation. For performance metrics, let's run:

```
rocprof-compute profile -n solution --no-roof -- ./solution.exe
rocprof-compute analyze -p workloads/solution/MI300A_A1 --dispatch 1 --block 2.1.15 6.2.5 7.1.5 7.1.6 7.1.7
```

With output:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

   INFO Analysis mode = cli
   INFO [analysis] deriving ROCprof-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
-----------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count |    Sum(ns) |   Mean(ns) |   Median(ns) |    Pct |
-----|--------------------------------------------|---------|------------|------------|--------------|---------
|  0 | yax(double*, double*, double*, int, int, |    1.00 | 9794300.00 | 9794300.00 |   9794300.00 | 100.00 |
|    |  double*) [clone .kd]                      |         |            |            |              |        |
-----------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
-----------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                    |   GPU_ID |
-----|---------------|----------------------------------------------------------------|----------
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        4 |
-----------------------------------------------------------------------------------------------



--------------------------------------------------------------------------------
2. System Speed-of-Light
2.1 Speed-of-Light
-------------------------------------------------------------------------------
| Metric_ID   | Metric              |    Avg | Unit       |    Peak |   Pct of Peak |
--------------|---------------------|--------|------------|---------|----------------
| 2.1.15      | Wavefront Occupancy | 430.69 | Wavefronts | 7296.00 |          5.90 |
-------------------------------------------------------------------------------



--------------------------------------------------------------------------------
6. Workgroup Manager (SPI)
6.2 Workgroup Manager - Resource Allocation
--------------------------------------------------------------------------
```

```
| Metric_ID   | Metric                   |   Avg |   Min |   Max | Unit   |
--------------|--------------------------|-------|-------|-------|---------
| 6.2.5       | Insufficient SIMD VGPRs |  0.00 |  0.00 |  0.00 | Pct    |
-------------------------------------------------------------------------


--------------------------------------------------------------------------------
7. Wavefront
7.1 Wavefront Launch Stats
---------------------------------------------------------------
| Metric_ID   | Metric   |    Avg |    Min |    Max | Unit      |
--------------|----------|--------|--------|--------|------------
| 7.1.5       | VGPRs    |  32.00 |  32.00 |  32.00 | Registers |
--------------|----------|--------|--------|--------|------------
| 7.1.6       | AGPRs    |   0.00 |   0.00 |   0.00 | Registers |
--------------|----------|--------|--------|--------|------------
| 7.1.7       | SGPRs    | 112.00 | 112.00 | 112.00 | Registers |
---------------------------------------------------------------
```

Just like the case of MI210, the Wavefront Launch Stats differ between `problem` and `solution`. As we did for MI210, let's run:

```
cd ..
rocprof-compute analyze -p workloads/problem/MI300A_A1 --dispatch 1 --block 6.2
```

With output:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

   INFO Analysis mode = cli
   INFO [analysis] deriving ROCprof-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
-----------------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count |     Sum(ns) |    Mean(ns) |   Median(ns) |    Pct |
-----|--------------------------------------------|---------|-------------|-------------|--------------|---------
|  0 | yax(double*, double*, double*, int, int, |    1.00 | 10226783.00 | 10226783.00 |  10226783.00 | 100.00 |
|    |  double*) [clone .kd]                      |         |             |             |              |        |
-----------------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
-------------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                          |   GPU_ID |
-----|---------------|----------------------------------------------------------------------|----------
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        4 |
-------------------------------------------------------------------------------------------------


--------------------------------------------------------------------------------
6. Workgroup Manager (SPI)
6.2 Workgroup Manager - Resource Allocation
-------------------------------------------------------------------------------------------
| Metric_ID   | Metric                                 |   Avg |   Min |   Max | Unit   |
--------------|----------------------------------------|-------|-------|-------|---------
| 6.2.0       | Not-scheduled Rate (Workgroup Manager) |  0.01 |  0.01 |  0.01 | Pct    |
```

```
--------------|---------------------------------------|-------|-------|-------|---------
| 6.2.1       | Not-scheduled Rate (Scheduler-Pipe)   |  0.03 |  0.03 |  0.03 | Pct     |
--------------|---------------------------------------|-------|-------|-------|---------
| 6.2.2       | Scheduler-Pipe Stall Rate             |  0.02 |  0.02 |  0.02 | Pct     |
--------------|---------------------------------------|-------|-------|-------|---------
| 6.2.3       | Scratch Stall Rate                    |  0.00 |  0.00 |  0.00 | Pct     |
--------------|---------------------------------------|-------|-------|-------|---------
| 6.2.4       | Insufficient SIMD Waveslots           |  0.00 |  0.00 |  0.00 | Pct     |
--------------|---------------------------------------|-------|-------|-------|---------
| 6.2.5       | Insufficient SIMD VGPRs               |  0.06 |  0.06 |  0.06 | Pct     |
--------------|---------------------------------------|-------|-------|-------|---------
| 6.2.6       | Insufficient SIMD SGPRs               |  0.00 |  0.00 |  0.00 | Pct     |
--------------|---------------------------------------|-------|-------|-------|---------
| 6.2.7       | Insufficient CU LDS                   |  0.00 |  0.00 |  0.00 | Pct     |
--------------|---------------------------------------|-------|-------|-------|---------
| 6.2.8       | Insufficient CU Barriers              |  0.00 |  0.00 |  0.00 | Pct     |
--------------|---------------------------------------|-------|-------|-------|---------
| 6.2.9       | Reached CU Workgroup Limit            |  0.00 |  0.00 |  0.00 | Pct     |
--------------|---------------------------------------|-------|-------|-------|---------
| 6.2.10      | Reached CU Wavefront Limit            |  0.00 |  0.00 |  0.00 | Pct     |
-----------------------------------------------------------------------------------------
```

Exercise 4: Strided Data Access Patterns (and how to find them)

This exercise uses a simple implementation of a yAx kernel to show how difficult strided data access patterns can be to spot in code, and demonstrates how to use rocprof-compute to begin to diagnose them.

Background: Acronyms and terms used in this exercise

L1: Level 1 Cache, the first level cache local to the Compute Unit (CU). If requested data is not found in the L1, the request goes to the L2

L2: Level 2 Cache, the second level cache, which is shared by all Compute Units (CUs) on a GPU. If requested data is not found in the L2, the request goes to HBM

HBM: High Bandwidth Memory is globally accessible from the GPU, and is a level of memory above the L2 cache

CU: The Compute Unit is responsible for executing the User's kernels

yAx: a vector-matrix-vector product, yAx, where y and x are vectors, and A is a matrix

FP(32/16): 32- or 16-bit Floating Point numeric types

Background: What is a "Strided Data Access Pattern"?

Strided data patterns happen when each thread in a wavefront has to access data locations which have a lot of space between them. For instance, in the algorithm we've been using, each thread works on a row, and those rows are contiguous in device memory. This scenario is depicted below: [image](striding.PNG"/> Here the memory addresses accessed by threads at each step of the computation have a lot of space between them, which is suboptimal for memory systems, especially on GPUs. To fix this, we have to re-structure the matrix A so that the columns of the matrix are contiguous, which will result in the rows striding, as seen below: [image](no_stride.PNG"/> This new data layout has each block of threads accessing a contiguous chunk of device memory, and will use the memory system of the device much more efficiently. Importantly, the only thing that changed is the physical layout of the memory, so the result of this computation will be the same as the result of the previous data layout.

Results on MI210

Note: This exercise was tested on a system with MI210s, on rocprof-compute version `2.0.0` and ROCm `6.0.2` **ROCperf-compute** `2.0.0` **is incompatible with ROCm versions lesser than** `6.0.0`

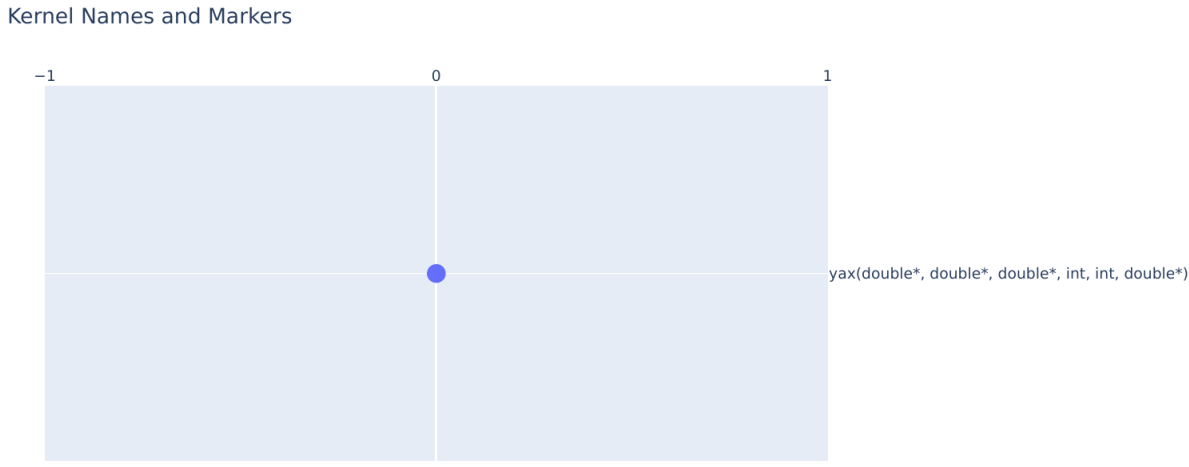
Initial Roofline Analysis

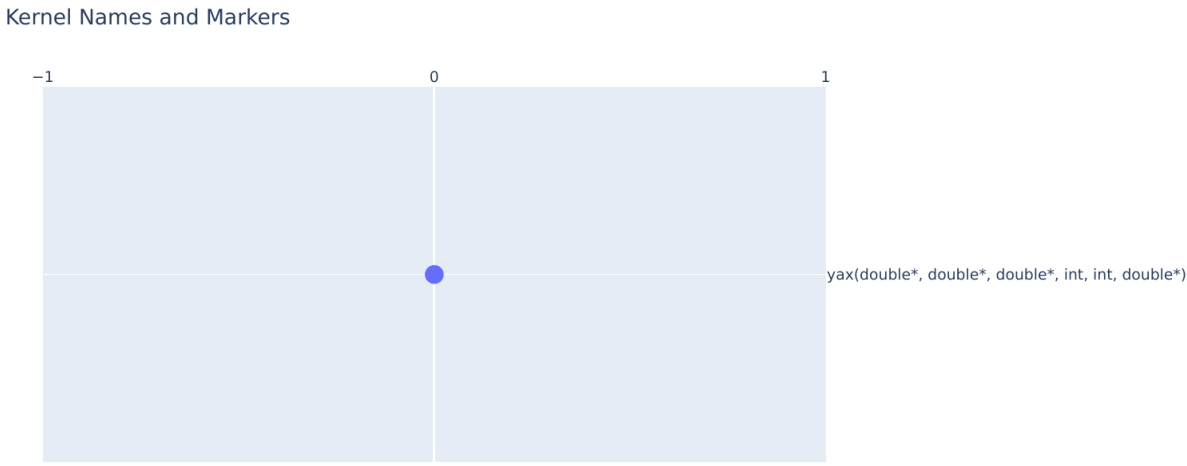
To start, we want to check the roofline of `problem.exe` , to make sure we are able to improve it. These plots can be generated with:

```
rocprof-compute profile -n problem_roof_only --roof-only --kernel-names -- ./problem.exe
```

The plots will appear as PDF files in the `./workloads/problem_roof_only/MI200` directory, if generated on MI200 hardware.

They are also provided below for easy reference:

Roofline Type	Roofline Legend
FP32/FP64	

Roofline Type	Roofline Legend
FP16/INT8	

We have plenty of space to improve this kernel, the next step is profiling.

Exercise Instructions:

To start, let's build and run the problem executable:

```
make
./problem.exe
```

(*simulated output*)

```
yAx time: 70 ms
```

From our other experiments, this time seems reasonable. Let's look closer at the memory system usage with rocprof-compute:

```
rocprof-compute profile -n problem --no-roof -- ./problem.exe
```

(*omitted output*)

```
rocprof-compute analyze -p workloads/problem/MI200 --dispatch 1 --block 16.1 17.1
```

> Previous examples have used specific fields inside metrics, but we can also request a group of metrics with just two numbers (i.e. 16.1 vs. 16.1.1)

These requested metrics are: - `16.1` L1 memory speed-of-light stats - `17.1` L2 memory speed-of-light stats

The speed-of-light stats are a more broad overview of how the memory systems are used throughout execution of your kernel. As such, they're great statistics for seeing if the memory system is generally being used efficiently or not. Output from the `analyze` command should look like this:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

Analysis mode = cli
[analysis] deriving ROCperf-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
-----------------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count |     Sum(ns) |    Mean(ns) |   Median(ns) |    Pct |
|----|--------------------------------------------|---------|-------------|-------------|--------------|--------|
|  0 | yax(double*, double*, double*, int, int, |    1.00 | 70270856.00 | 70270856.00 |  70270856.00 | 100.00 |
|    |  double*) [clone .kd]                      |         |             |             |              |        |
-----------------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
-------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                  |   GPU_ID |
|----|---------------|--------------------------------------------------------------|----------|
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        8 |
-------------------------------------------------------------------------------------------


--------------------------------------------------------------------------------
16. Vector L1 Data Cache
16.1 Speed-of-Light
-------------------------------------------------
| Metric_ID   | Metric      |   Avg | Unit        |
|-------------|-------------|-------|-------------|
| 16.1.0      | Hit rate    |  0.00 | Pct of peak |
|-------------|-------------|-------|-------------|
| 16.1.1      | Bandwidth   |  8.64 | Pct of peak |
|-------------|-------------|-------|-------------|
| 16.1.2      | Utilization | 87.71 | Pct of peak |
|-------------|-------------|-------|-------------|
| 16.1.3      | Coalescing  | 25.00 | Pct of peak |
-------------------------------------------------


--------------------------------------------------------------------------------
17. L2 Cache
17.1 Speed-of-Light
-----------------------------------------------------------------
| Metric_ID   | Metric                        |    Avg | Unit   |
|-------------|-------------------------------|--------|--------|
| 17.1.0      | Utilization                   |  98.66 | Pct    |
|-------------|-------------------------------|--------|--------|
| 17.1.1      | Bandwidth                     |  28.10 | Pct    |
|-------------|-------------------------------|--------|--------|
| 17.1.2      | Hit Rate                      |  93.45 | Pct    |
|-------------|-------------------------------|--------|--------|
| 17.1.3      | L2-Fabric Read BW             | 125.05 | Gb/s   |
```

```
-------------|------------------------------|--------|---------
| 17.1.4      | L2-Fabric Write and Atomic BW |   0.00 | Gb/s   |
-----------------------------------------------------------------
```

Looking at this data, we see: - L1 Cache Hit (`16.1.0`) is 0%, so the kernel's memory requests are never found in the L1. - L2 Cache Hit (`17.1.2`) is 93.46%, so most requests are found in the L2, with about 7% needing to go out to HBM. - We are never finding data in the L1 and generating a lot of requests to the L2, so restructuring our data accesses should provide better performance

Since our implementation of yAx simply uses 1 for all values in y, A, and x, we do not have to change how we populate our data. Since A is implemented as a flat array, we don't need to change our allocation either. >In real-world use-cases, these considerations add non-trivial development overhead, so data access patterns may be non-trivial to change.

To observe the performance effects of a different data access pattern, we simply need to change our indexing scheme. Let's see how this performs by running `solution` :

```
cd solution
make
./solution.exe
```

(*simulated output*)

```
yAx time: 12 ms
```

We see the runtime here is significantly better than our previous kernel, but we need to check how the caches behave now:

```
rocprof-compute profile -n solution --no-roof -- ./solution.exe
```

(*output omitted*)

```
rocprof-compute analyze -p workloads/solution/MI200 --dispatch 1 --block 16.1 17.1
```

The output from this analyze command should look like:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

Analysis mode = cli
[analysis] deriving ROCperf-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
-----------------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count |     Sum(ns) |    Mean(ns) |   Median(ns) |    Pct |
|----|--------------------------------------------|---------|-------------|-------------|--------------|--------|
|  0 | yax(double*, double*, double*, int, int, |    1.00 | 12364156.00 | 12364156.00 |  12364156.00 | 100.00 |
|    |  double*) [clone .kd]                      |         |             |             |              |        |
-----------------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
-------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                    |   GPU_ID |
|----|---------------|----------------------------------------------------------------|----------|
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        8 |
-------------------------------------------------------------------------------------------


--------------------------------------------------------------------------------
```

```
16. Vector L1 Data Cache
16.1 Speed-of-Light
-------------------------------------------------
| Metric_ID   | Metric      |   Avg | Unit        |
--------------|-------------|-------|--------------
| 16.1.0      | Hit rate    | 49.98 | Pct of peak |
--------------|-------------|-------|--------------
| 16.1.1      | Bandwidth   | 12.29 | Pct of peak |
--------------|-------------|-------|--------------
| 16.1.2      | Utilization | 98.12 | Pct of peak |
--------------|-------------|-------|--------------
| 16.1.3      | Coalescing  | 25.00 | Pct of peak |
-------------------------------------------------


--------------------------------------------------------------------------------
17. L2 Cache
17.1 Speed-of-Light
---------------------------------------------------------------
| Metric_ID   | Metric                        |    Avg | Unit   |
--------------|-------------------------------|--------|---------
| 17.1.0      | Utilization                   |  98.56 | Pct    |
--------------|-------------------------------|--------|---------
| 17.1.1      | Bandwidth                     |  10.03 | Pct    |
--------------|-------------------------------|--------|---------
| 17.1.2      | Hit Rate                      |   0.52 | Pct    |
--------------|-------------------------------|--------|---------
| 17.1.3      | L2-Fabric Read BW             | 694.86 | Gb/s   |
--------------|-------------------------------|--------|---------
| 17.1.4      | L2-Fabric Write and Atomic BW |   0.00 | Gb/s   |
---------------------------------------------------------------
```

Looking at this data, we see: - L1 Cache Hit (`16.1.0`) is around 50%, so half the requests to the L1 need to go to the L2. - L2 Cache Hit (`17.1.2`) is 0.52%, so almost all the requests to the L2 have to go out to HBM. - L2-Fabric Read BW (`17.1.3`) has increased significantly, due to the increase in L2 cache misses requiring HBM reads.

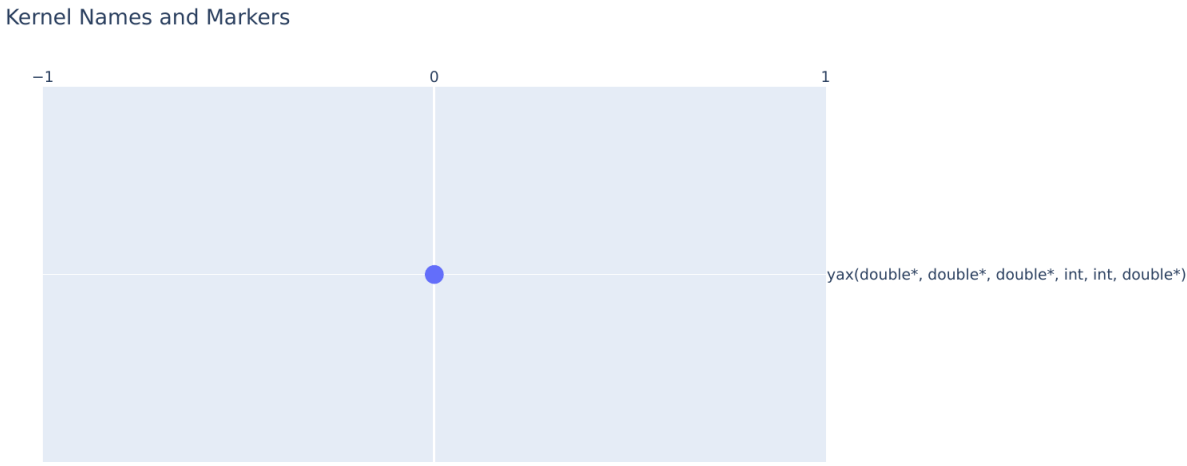
Solution Roofline Analysis

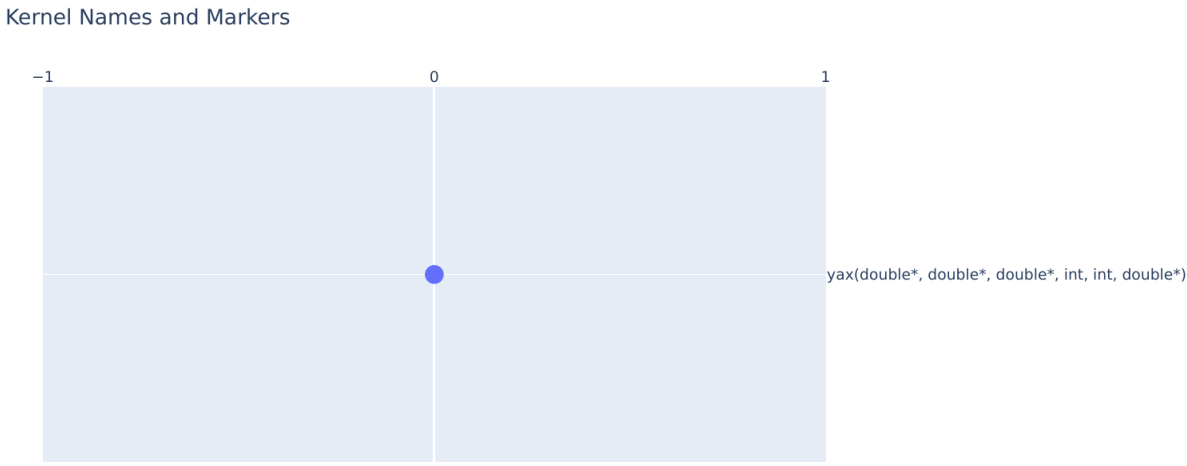
We should check where our new kernel stands on the roofline. These plots can be generated with:

```
rocprof-compute profile -n solution_roof_only --roof-only --kernel-names -- ./solution.exe
```

The plots will appear as PDF files in the `./workloads/problem_roof_only/MI200` directory, if generated on MI200 hardware.

They are also provided below for easy reference:

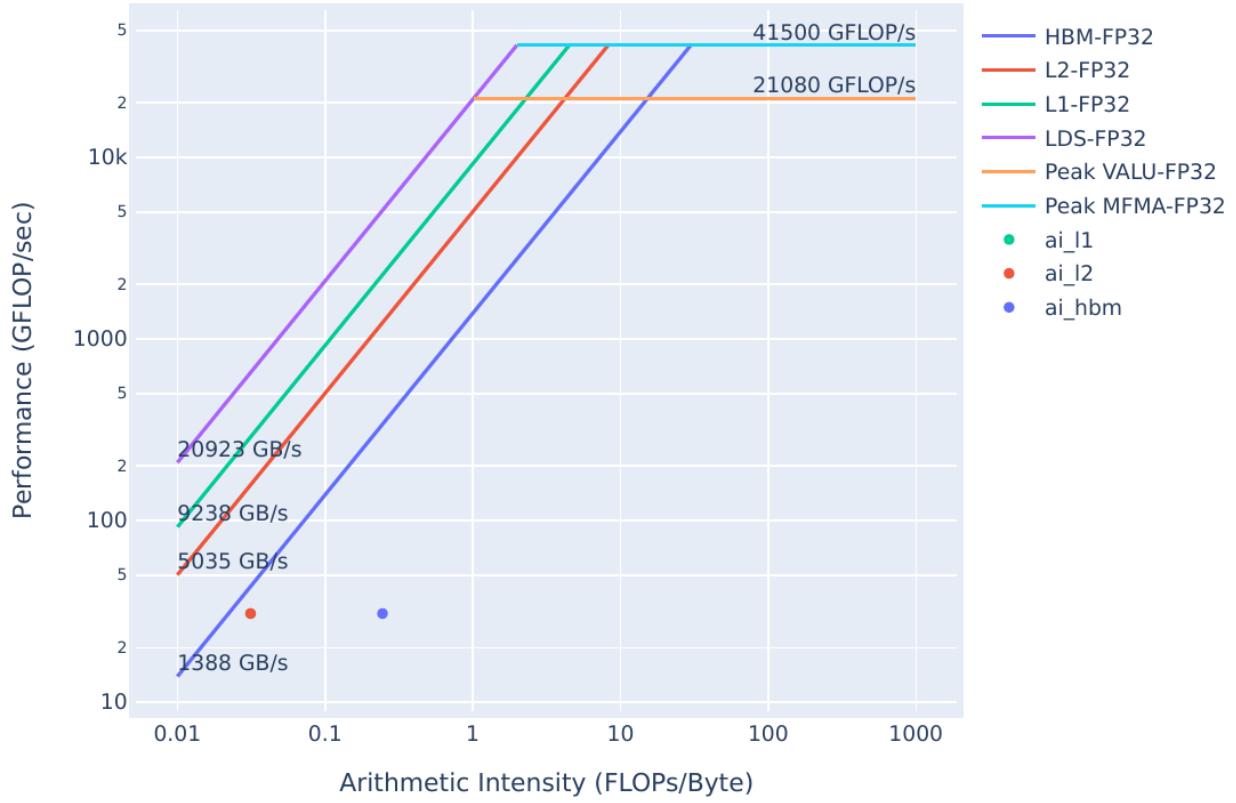
Roofline Type	Roofline Legend
FP32/FP64	

Roofline Type	Roofline Legend
FP16/INT8	

We appear to be very close to being bound by the HBM bandwidth from the fp32 roofline. To get more performance we need to look closer at our algorithm.

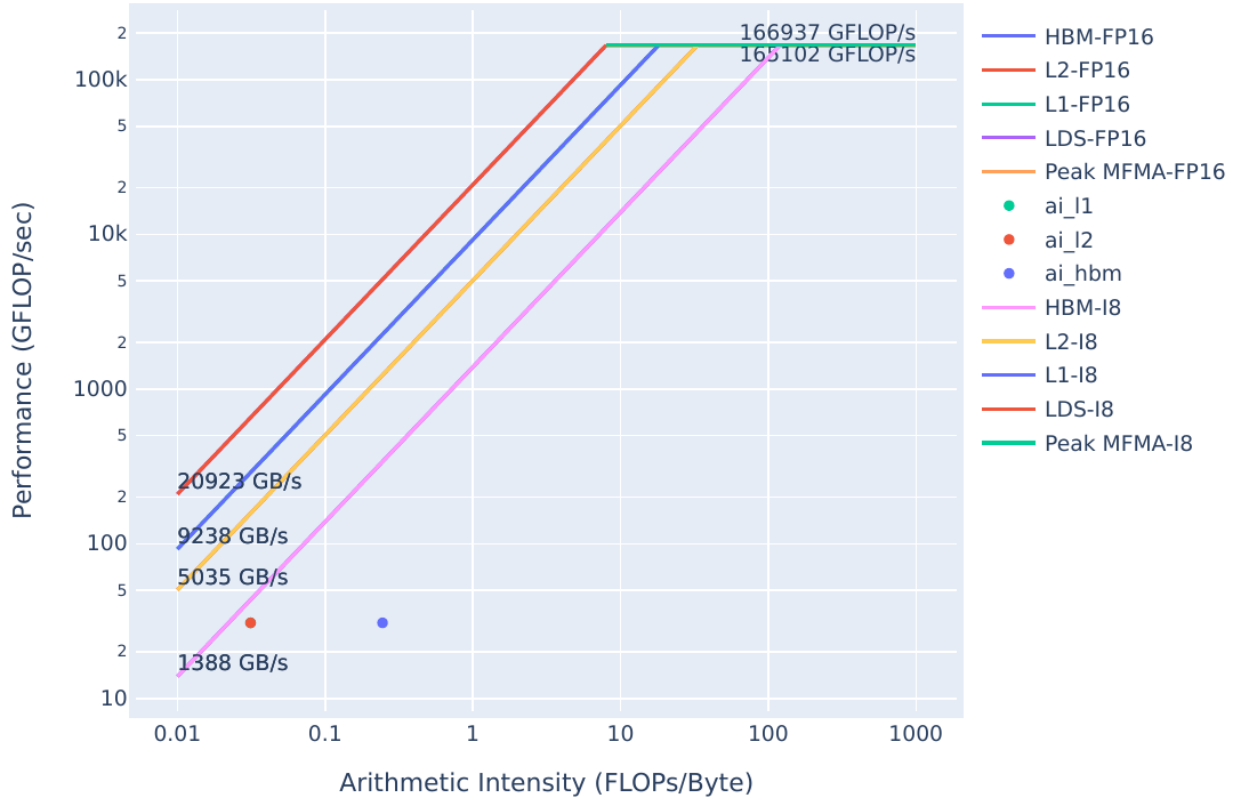
Roofline Comparison

Roofline Type	Problem Roofline



FP32/FP6

Roofline Type Problem Roofline



FP16/INT8

We see that the HBM roofline point moves up, while the L1/L2 points move up and to the right from problem to solution. This means that our arithmetic intensity is increasing for the caches, so we are moving less data through the caches to do the same computation.

Summary and Take-aways

This exercise illustrates the at times insidious nature of strided data access patterns. They can be difficult to spot in code, but profiling more readily shows when adversarial access patterns occur, by showing poor cache hit rates, low cache bandwidth, and potentially low utilization. Data access patterns can be non-trivial to change, so these sorts of optimizations can involve significant development and validation overhead.

Results on MI300A

Note: Roofline is not available on MI300A at the time of this writing

For MI300A, if we run the problem.exe and solution.exe, we see different performance.

Running the problem:

```
./problem.exe
```

Shows a runtime like this:

```
9.64 milliseconds
```

While running solution:

```
./solution.exe
```

Shows a runtime like this:

```
12.17 milliseconds
```

Now, if we use rocprof-compute to profile these executables we see much the same stats for MI300A as MI200:

```
rocprof-compute analyze -p workloads/problem/MI300A_A1 --dispatch 1 --block 16.1 17.1
```

Shows

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

   INFO Analysis mode = cli
   INFO [analysis] deriving ROCperf-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
-----------------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count |    Sum(ns) |   Mean(ns) |   Median(ns) |    Pct |
|----|--------------------------------------------|---------|------------|------------|--------------|--------|
|  0 | yax(double*, double*, double*, int, int,   |    1.00 | 9599042.00 | 9599042.00 |   9599042.00 | 100.00 |
|    |  double*) [clone .kd]                      |         |            |            |              |        |
-----------------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
-----------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                   |   GPU_ID |
|----|---------------|---------------------------------------------------------------|----------|
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        4 |
-----------------------------------------------------------------------------------------------


--------------------------------------------------------------------------------
16. Vector L1 Data Cache
16.1 Speed-of-Light
---------------------------------------------------
| Metric_ID   | Metric      |   Avg | Unit        |
|-------------|-------------|-------|-------------|
| 16.1.0      | Hit rate    |  0.00 | Pct of peak |
|-------------|-------------|-------|-------------|
| 16.1.1      | Bandwidth   | 23.36 | Pct of peak |
|-------------|-------------|-------|-------------|
| 16.1.2      | Utilization | 85.90 | Pct of peak |
|-------------|-------------|-------|-------------|
| 16.1.3      | Coalescing  | 25.00 | Pct of peak |
---------------------------------------------------


--------------------------------------------------------------------------------
17. L2 Cache
17.1 Speed-of-Light
-----------------------------------------------------------------
| Metric_ID   | Metric                        |    Avg | Unit   |
|-------------|-------------------------------|--------|--------|
| 17.1.0      | Utilization                   |  96.87 | Pct    |
```

```
--------------|-------------------------------|--------|---------
| 17.1.1      | Bandwidth                     |  55.52 | Pct     |
--------------|-------------------------------|--------|---------
| 17.1.2      | Hit Rate                      |  93.67 | Pct     |
--------------|-------------------------------|--------|---------
| 17.1.3      | L2-Fabric Read BW             | 908.10 | Gb/s    |
--------------|-------------------------------|--------|---------
| 17.1.4      | L2-Fabric Write and Atomic BW |   0.01 | Gb/s    |
-----------------------------------------------------------------
```

While analyzing the solution with:

```
rocprof-compute analyze -p workloads/solution/MI300A_A1 --dispatch 1 --block 16.1 17.1
```

Shows:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

   INFO Analysis mode = cli
   INFO [analysis] deriving ROCperf-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
-------------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count |     Sum(ns) |    Mean(ns) |   Median(ns) |    Pct |
-----|--------------------------------------------|---------|-------------|-------------|--------------|---------
|  0 | yax(double*, double*, double*, int, int, |    1.00 | 12104495.00 | 12104495.00 |  12104495.00 | 100.00 |
|    |  double*) [clone .kd]                      |         |             |             |              |        |
-------------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
-----------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                    |   GPU_ID |
-----|---------------|----------------------------------------------------------------|-----------
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        4 |
-----------------------------------------------------------------------------------------------



--------------------------------------------------------------------------------
16. Vector L1 Data Cache
16.1 Speed-of-Light
-----------------------------------------------------
| Metric_ID   | Metric      |    Avg | Unit        |
--------------|-------------|--------|--------------
| 16.1.0      | Hit rate    |  75.00 | Pct of peak |
--------------|-------------|--------|--------------
| 16.1.1      | Bandwidth   |   4.63 | Pct of peak |
--------------|-------------|--------|--------------
| 16.1.2      | Utilization | 100.00 | Pct of peak |
--------------|-------------|--------|--------------
| 16.1.3      | Coalescing  |  25.00 | Pct of peak |
-----------------------------------------------------



--------------------------------------------------------------------------------
17. L2 Cache
```

```
17.1 Speed-of-Light
-------------------------------------------------------------------
| Metric_ID   | Metric                         |    Avg | Unit   |
--------------|--------------------------------|--------|---------
| 17.1.0      | Utilization                    |  98.72 | Pct    |
--------------|--------------------------------|--------|---------
| 17.1.1      | Bandwidth                      |   2.77 | Pct    |
--------------|--------------------------------|--------|---------
| 17.1.2      | Hit Rate                       |   0.68 | Pct    |
--------------|--------------------------------|--------|---------
| 17.1.3      | L2-Fabric Read BW              | 710.06 | Gb/s   |
--------------|--------------------------------|--------|---------
| 17.1.4      | L2-Fabric Write and Atomic BW  |   0.01 | Gb/s   |
-------------------------------------------------------------------
```

So we see a slowdown despite increasing our L1 hit rate (`16.1.0`) by a large amount. Let's see how the runtime compares to the number of cycles required for problem and solution, as well as atomic latencies per channel for both approaches:

```
rocprof-compute analyze -p workloads/problem/MI300A_A1 -p workloads/solution/MI300A_A1 --dispatch 1 --block 7.2.0 7
```

Which shows:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

   INFO Analysis mode = cli
   INFO [analysis] deriving ROCperf-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
-------------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count | Count      |   Abs Diff |    Sum(ns) | Sum(ns)
-----|--------------------------------------------|---------|------------|------------|------------|-----------------
|  0 | yax(double*, double*, double*, int, int,   |    1.00 | 1.0 (0.0%) |       0.00 | 9599042.00 | 12104495.0 (26.1
|    |  double*) [clone .kd]                      |         |            |            |            |
-------------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
-----------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                    |   GPU_ID |
-----|---------------|----------------------------------------------------------------|----------
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        4 |
-----------------------------------------------------------------------------------------------



--------------------------------------------------------------------------------
7. Wavefront
7.2 Wavefront Runtime Stats
-------------------------------------------------------------------------------------------------------------------
| Metric_ID   | Metric                |         Avg | Avg                 |   Abs Diff |         Min | Min
--------------|-----------------------|-------------|---------------------|------------|-------------|-------------
| 7.2.0       | Kernel Time (Nanosec) |  9599042.00 | 12104495.0 (26.1%)  | 2505453.00 |  9599042.00 | 12104495.0 (
--------------|-----------------------|-------------|---------------------|------------|-------------|-------------
| 7.2.1       | Kernel Time (Cycles)  | 19350602.00 | 25141619.0 (29.93%) | 5791017.00 | 19350602.00 | 25141619.0 (
-------------------------------------------------------------------------------------------------------------------
```

```
--------------------------------------------------------------------------------
17. L2 Cache
17.2 L2 - Fabric Transactions
--------------------------------------------------------------------------------------------------------------------------------
| Metric_ID   | Metric         |     Avg | Avg              |   Abs Diff |     Min | Min
|     Max | Max              | Unit   |
--------------|----------------|---------|------------------|------------|---------|------------------|---------|--
| 17.2.11     | Atomic Latency | 6406.73 | 9547.67 (49.03%) |    3140.94 | 6406.73 | 9547.67 (49.03%) | 6406.73 | 9
--------------------------------------------------------------------------------------------------------------------------------
```

Atomic Latency `17.2.11` shows that our solution is more stressful on atomics, likely due to our more highly optimized cache access. Fixing striding ironically caused our threads to issue atomics more quickly, degrading our performance!

To fix this, we can attempt to mitigate contention by doing what is called a "shuffle reduction" on each wavefront. This utilizes a HIP intrinsic called `__shfl_down` to reduce numbers across threads in a wavefront without requiring atomics. These implementations can be found in `mi300a_problem` and mi300a_solution‘. The code contained in those subdirectories simply implements this shuffle reduction, which allows both problem and solution to only have the first thread of each wavefront issue the atomic add, rather than all threads.

Let's run mi300a_problem.exe and mi300a_solution.exe to see if this addresses our problem:

```
./mi300a_problem.exe
```

shows:

```
yAx time: 9.577708 milliseconds
```

While

```
./mi300a_solution.exe
```

Shows:

```
yAx time: 12.381036 milliseconds
```

Strangely, this seems to have little effect on our runtimes. The reader may notice that these problems are running very quickly, and the reader would be right. The mi300a_problem.exe and mi300a_solution.exe both provide an argument to test different problem sizes. Since we assume our matrix in question is square (for the time being this is an arbitrary assumption – the kernel is capable of handling rectangular matrices as well), increasing the argument by one increases the problem size nonlinearly. Let's try running at problem size 15:

```
./mi300a_problem.exe 15
```

Shows

```
yAx time: 312.857488 milliseconds
```

And

```
./mi300a_solution.exe 15
```

Shows

```
yAx time: 25.878859 milliseconds
```

It appears that at a smaller problem size, this kernel is more bounded by atomic contention than efficient cache memory usage. It is important to test different problem sizes to ensure that a run of a code being profiled is representative, otherwise the limiters shown in profiling may point optimizations in the wrong direction for a full scale run. As proof of this, you can try manually setting the problem.cpp and solution.cpp problem size to 15, and see that they run in a similar amount of time to mi300a_problem and mi300a_solution. At scale, the memory bandwidth dominates this specific kernel.

Exercise 5: Algorithmic Optimizations

A simple yAx kernel, and more efficient, but more complex yAx kernel to demonstrate algorithmic improvements.

Background: Acronyms and terms used in this exercise

L1: Level 1 Cache, the first level cache local to the Compute Unit (CU). If requested data is not found in the L1, the request goes to the L2

L2: Level 2 Cache, the second level cache, which is shared by all Compute Units (CUs) on a GPU. If requested data is not found in the L2, the request goes to HBM

HBM: High Bandwidth Memory is globally accessible from the GPU, and is a level of memory above the L2 cache

CU: The Compute Unit is responsible for executing the User's kernels

yAx: a vector-matrix-vector product, yAx, where y and x are vectors, and A is a matrix

FP(32/16): 32- or 16-bit Floating Point numeric types

Background: yAx Algorithmic Improvement Explanation

Our approach up to this point could be described as having each thread sum up a row, as illustrated below: [image](threadrows.PNG“/> However, this is not efficient in the way the parallelism is expressed. Namely, we could add up all the partial sums for each row in parallel. This would make our approach to be: give a rows to wavefronts, and have the threads inside each wavefront sum up partial sums in parallel. Then, we reduce the partial sums atomically with shared memory, before completing the computation and reducing the final answer using global atomics. This approach expresses more of the parallelism that is available, and would look something like the figure below: [image](wavefrontrow.PNG”/> The expressed parallelism in each approach roughly corresponds to the number of red arrows in each figure.

Results on MI210:

Note: This exercise was tested on a system with MI210s, on rocprof-compute version `2.0.0` and ROCm `6.1.2` **ROCprof-compute** `2.0.0` **is incompatible with ROCm versions lesser than** `6.0.0`

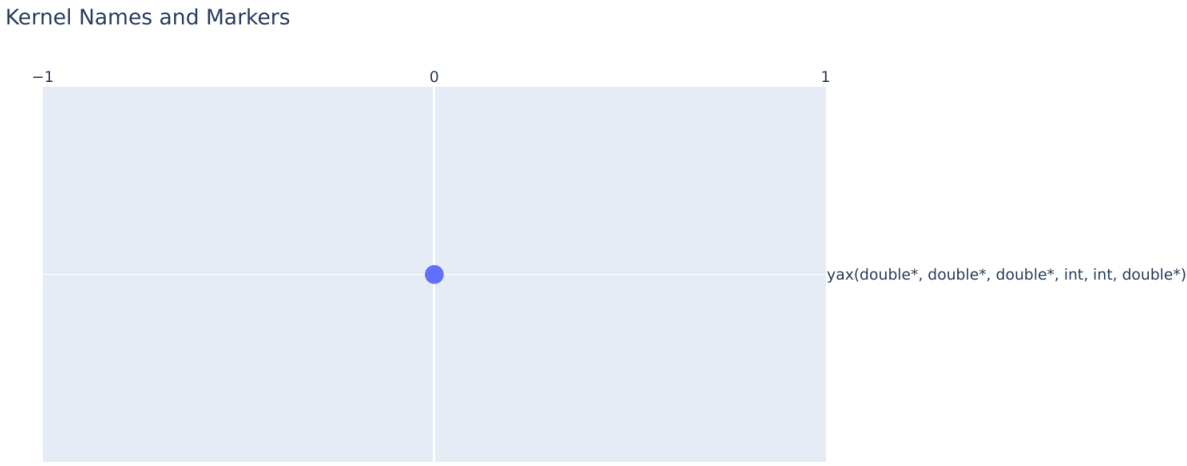
Initial Roofline Analysis

We should start by doing a roofline to see where the problem executable stands. These plots can be generated with:

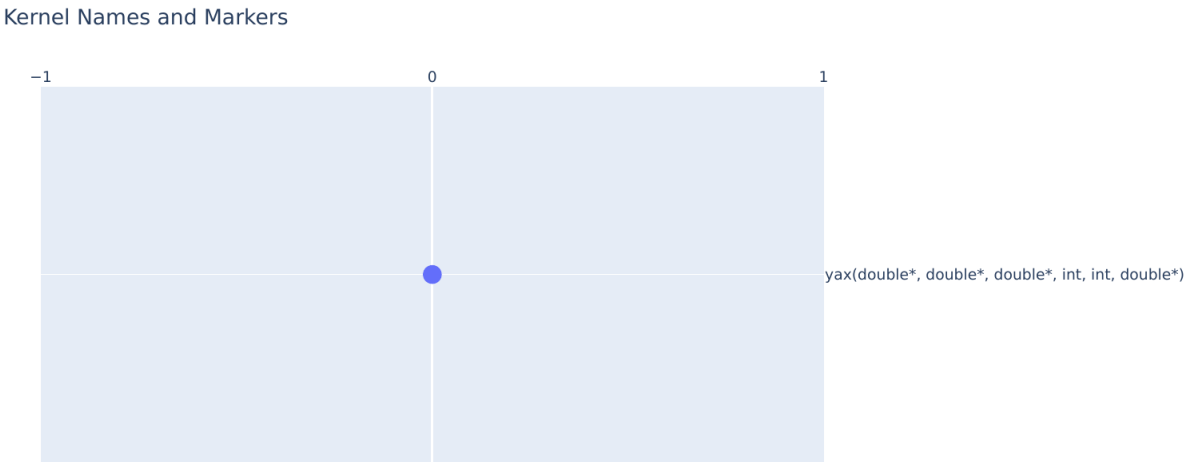
```
rocprof-compute profile -n problem_roof_only --roof-only --kernel-names -- ./problem.exe
```

The plots will appear as PDF files in the `./workloads/problem_roof_only/MI200` directory, if generated on MI200 hardware.

They are also provided below for easy reference:

Roofline Type	Roofline Legend
FP32/FP64	

Roofline Type Roofline Legend



FP16/INT8

The performance of this kernel looks pretty close to being HBM bandwidth bound. In the case of algorithmic optimizations, there may not be obvious evidence other than a suspicion that poor usage of hardware resources may be improved by changing the overall approach. In this case, we should be able to make better usage of both L1 and L2 resources by using wavefronts more efficiently to better parallelize our computation.

Exercise Instructions:

To start, let's profile `problem.exe` :

```
make
./problem.exe
```

(*simulated output*)

```
yAx time 12 ms
```

This should be in line with our last solution. From the last exercise, we saw this output from `rocprof-compute analyze` for this kernel:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

Analysis mode = cli
```

```
[analysis] deriving ROCprof-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
--------------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count |     Sum(ns) |    Mean(ns) |   Median(ns) |    Pct |
|----|--------------------------------------------|---------|-------------|-------------|--------------|--------|
|  0 | yax(double*, double*, double*, int, int,   |    1.00 | 12364156.00 | 12364156.00 |  12364156.00 | 100.00 |
|    |  double*) [clone .kd]                      |         |             |             |              |        |
--------------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
-----------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                    |   GPU_ID |
|----|---------------|----------------------------------------------------------------|----------|
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        8 |
-----------------------------------------------------------------------------------------------


--------------------------------------------------------------------------------
16. Vector L1 Data Cache
16.1 Speed-of-Light
-------------------------------------------------
| Metric_ID   | Metric      |   Avg | Unit        |
|-------------|-------------|-------|-------------|
| 16.1.0      | Hit rate    | 49.98 | Pct of peak |
|-------------|-------------|-------|-------------|
| 16.1.1      | Bandwidth   | 12.29 | Pct of peak |
|-------------|-------------|-------|-------------|
| 16.1.2      | Utilization | 98.12 | Pct of peak |
|-------------|-------------|-------|-------------|
| 16.1.3      | Coalescing  | 25.00 | Pct of peak |
-------------------------------------------------


--------------------------------------------------------------------------------
17. L2 Cache
17.1 Speed-of-Light
---------------------------------------------------------------
| Metric_ID   | Metric                        |    Avg | Unit   |
|-------------|-------------------------------|--------|--------|
| 17.1.0      | Utilization                   |  98.56 | Pct    |
|-------------|-------------------------------|--------|--------|
| 17.1.1      | Bandwidth                     |  10.03 | Pct    |
|-------------|-------------------------------|--------|--------|
| 17.1.2      | Hit Rate                      |   0.52 | Pct    |
|-------------|-------------------------------|--------|--------|
| 17.1.3      | L2-Fabric Read BW             | 694.86 | Gb/s   |
|-------------|-------------------------------|--------|--------|
| 17.1.4      | L2-Fabric Write and Atomic BW |   0.00 | Gb/s   |
---------------------------------------------------------------
```

Looking at this data again, we see: - L1 Cache Hit (`16.1.0`) is about 50%, which is fairly low for a “well performing” kernel. - L2 Cache Hit (`17.1.2`) is about 0%, which is very low to consider this kernel “well performing”.

This data indicates that we should be able to make better usage of our memory system, so let’s apply the algorithmic optimization present in `solution.cpp` :

```
cd solution
```

```
make
./solution.exe
```

(*simulated output*)

```
yAx time: 7.7 ms
```

It should be noted again that algorithmic optimizations are usually the most expensive optimizations to implement, as they usually entail re-conceptualizing the problem in a way that allows for a more efficient solution. However, as we see here, algorithmic optimization *can* result in impressive speedups. A better runtime is not proof that we are using our caches more efficiently, we have to profile the solution:

```
rocprof-compute profile -n solution --no-roof -- ./solution.exe
```

(*output omitted*)

```
rocprof-compute analyze -p workloads/solution/MI200 --dispatch 1 --block 16.1 17.1
```

The output for the solution should look something like:

```
 _ __ ___   ___ _ __  _ __ ___  / _|       ___ ___  _ __ ___  _ __  _   _| |_ ___
| '__/ _ \ / __| '_ \| '__/ _ \| |_ _____ / __/ _ \| '_ ` _ \| '_ \| | | | | __/ _ \
| | | (_) | (__| |_) | | | (_) |  _|_____| (_| (_) | | | | | | |_) | |_| | ||  __/
|_|  \___/ \___| .__/|_|  \___/|_|        \___\___/|_| |_| |_| .__/ \__,_|\__\___|
               |_|                                          |_|

   INFO Analysis mode = cli
   INFO [analysis] deriving ROCprof-compute metrics...

--------------------------------------------------------------------------------
0. Top Stats
0.1 Top Kernels
--------------------------------------------------------------------------------------------------------------------
|    | Kernel_Name                                |   Count |    Sum(ns) |   Mean(ns) |   Median(ns) |    Pct |
|----|--------------------------------------------|---------|------------|------------|--------------|--------|
|  0 | yax(double*, double*, double*, int, int, |    1.00 | 7774568.00 | 7774568.00 |   7774568.00 | 100.00 |
|    |  double*) [clone .kd]                      |         |            |            |              |        |
--------------------------------------------------------------------------------------------------------------------
0.2 Dispatch List
-----------------------------------------------------------------------------------------------
|    |   Dispatch_ID | Kernel_Name                                                   |   GPU_ID |
|----|---------------|---------------------------------------------------------------|----------|
|  0 |             1 | yax(double*, double*, double*, int, int, double*) [clone .kd] |        2 |
-----------------------------------------------------------------------------------------------



--------------------------------------------------------------------------------
16. Vector L1 Data Cache
16.1 Speed-of-Light
-------------------------------------------------
| Metric_ID   | Metric      |   Avg | Unit        |
|-------------|-------------|-------|-------------|
| 16.1.0      | Hit rate    | 71.52 | Pct of peak |
|-------------|-------------|-------|-------------|
| 16.1.1      | Bandwidth   | 39.06 | Pct of peak |
|-------------|-------------|-------|-------------|
| 16.1.2      | Utilization | 97.85 | Pct of peak |
|-------------|-------------|-------|-------------|
| 16.1.3      | Coalescing  | 25.00 | Pct of peak |
-------------------------------------------------
```

```
--------------------------------------------------------------------------------
17. L2 Cache
17.1 Speed-of-Light
-------------------------------------------------------------------
| Metric_ID   | Metric                         |     Avg | Unit   |
--------------|--------------------------------|---------|---------
| 17.1.0      | Utilization                    |   91.55 | Pct    |
--------------|--------------------------------|---------|---------
| 17.1.1      | Bandwidth                      |   20.44 | Pct    |
--------------|--------------------------------|---------|---------
| 17.1.2      | Hit Rate                       |   21.23 | Pct    |
--------------|--------------------------------|---------|---------
| 17.1.3      | L2-Fabric Read BW              | 1110.67 | Gb/s   |
--------------|--------------------------------|---------|---------
| 17.1.4      | L2-Fabric Write and Atomic BW  |    0.00 | Gb/s   |
-------------------------------------------------------------------
```

Looking at this data, we see: - L1 Cache Hit (`16.1.0`) shows 71.52%, which is an increase of 1.43x over 49.98% for problem. - L2 Cache Hit (`17.1.2`) shows 21.23%, which is an increase of 40x over 0.52% for problem. - L2-Fabric Read BW (`17.1.3`) shows 1110.67 Gb/s, an increase of 1.6x over 694.86 Gb/s for problem.

Notice that the ratio between the runtimes in this case: 12/7.7 = 1.56x, which aligns closely with the L2-Fabric Read BW increases, suggesting this kernel is bounded primarily by memory bandwidth.

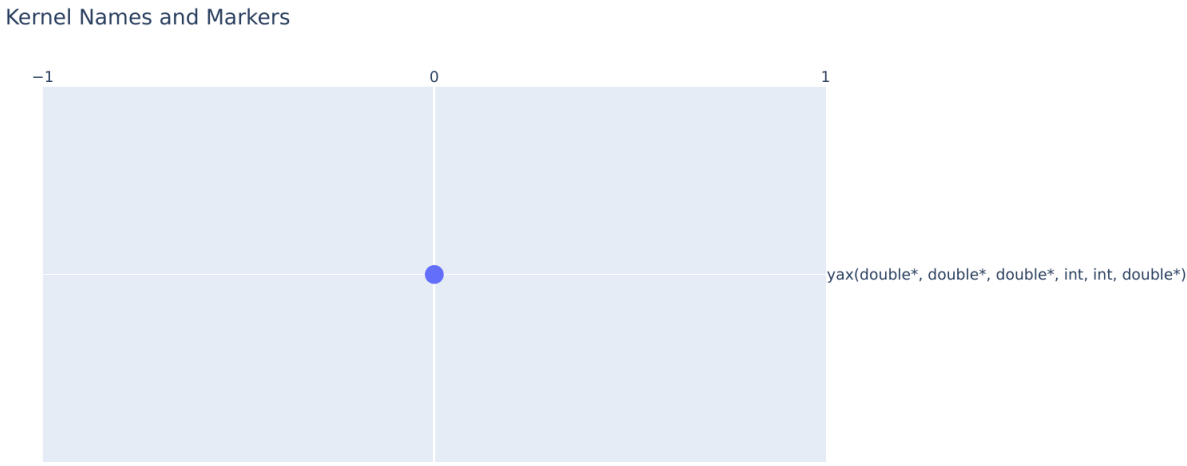
Solution Roofline Analysis

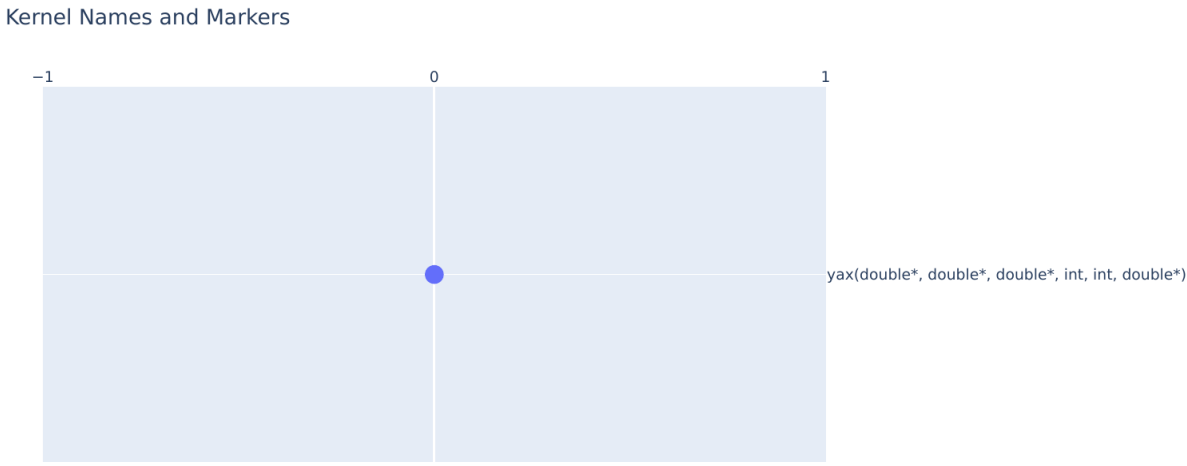
As a final step, we should check how this new implementation stacks up with the roofline. These plots can be generated with:

```
rocprof-compute profile -n solution_roof_only --roof-only --kernel-names -- ./solution.exe
```

The plots will appear as PDF files in the `./workloads/solution_roof_only/MI200` directory, if generated on MI200 hardware.

They are also provided below for easy reference:

Roofline Type	Roofline Legend
FP32/FP64	

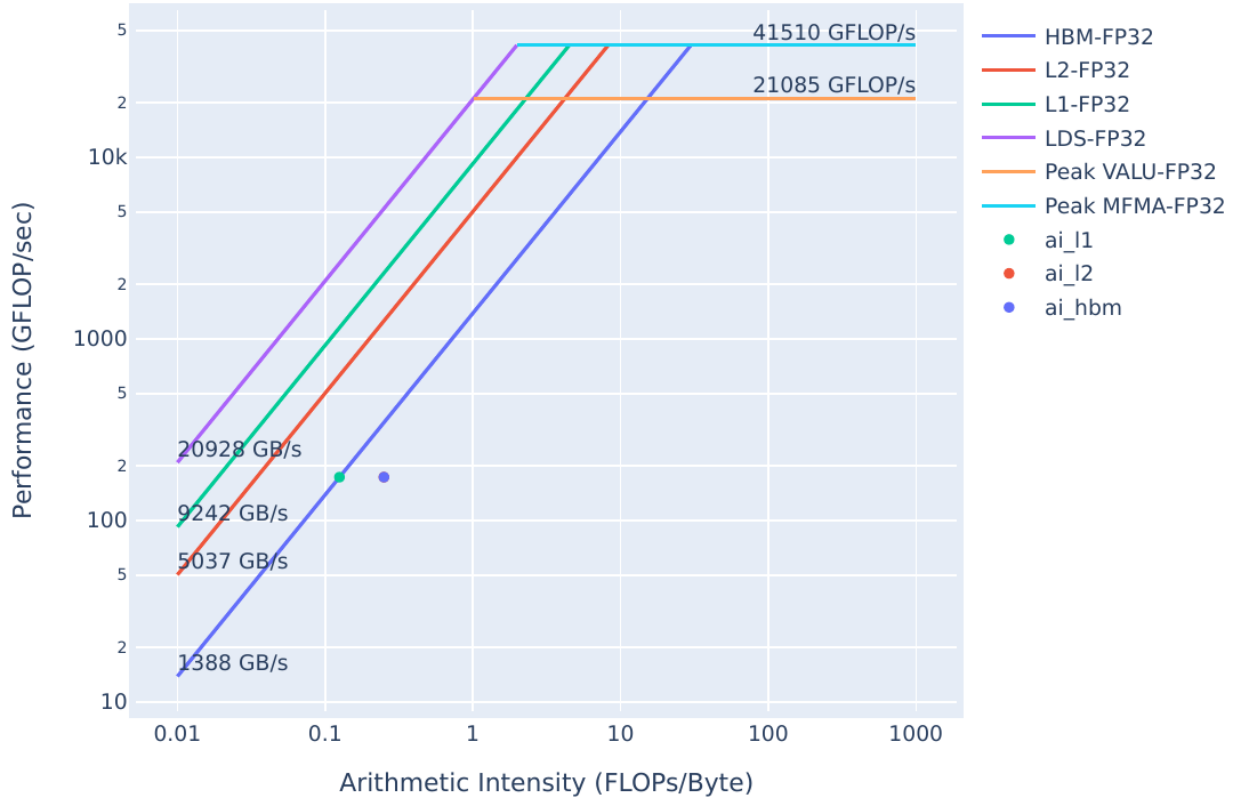
Roofline Type	Roofline Legend
FP16/INT8	

As the ROCprof-compute stats indicate, we are more efficiently using the L1 cache, which shows in the roofline as a decrease in Arithmetic Intensity for that cache layer. We have a high hit rate in L1, with a comparatively lower hit rate in L2, and we were able to increase our L2-Fabric bandwidth for the same problem size, more efficiently requesting data from HBM.

Roofline Comparison

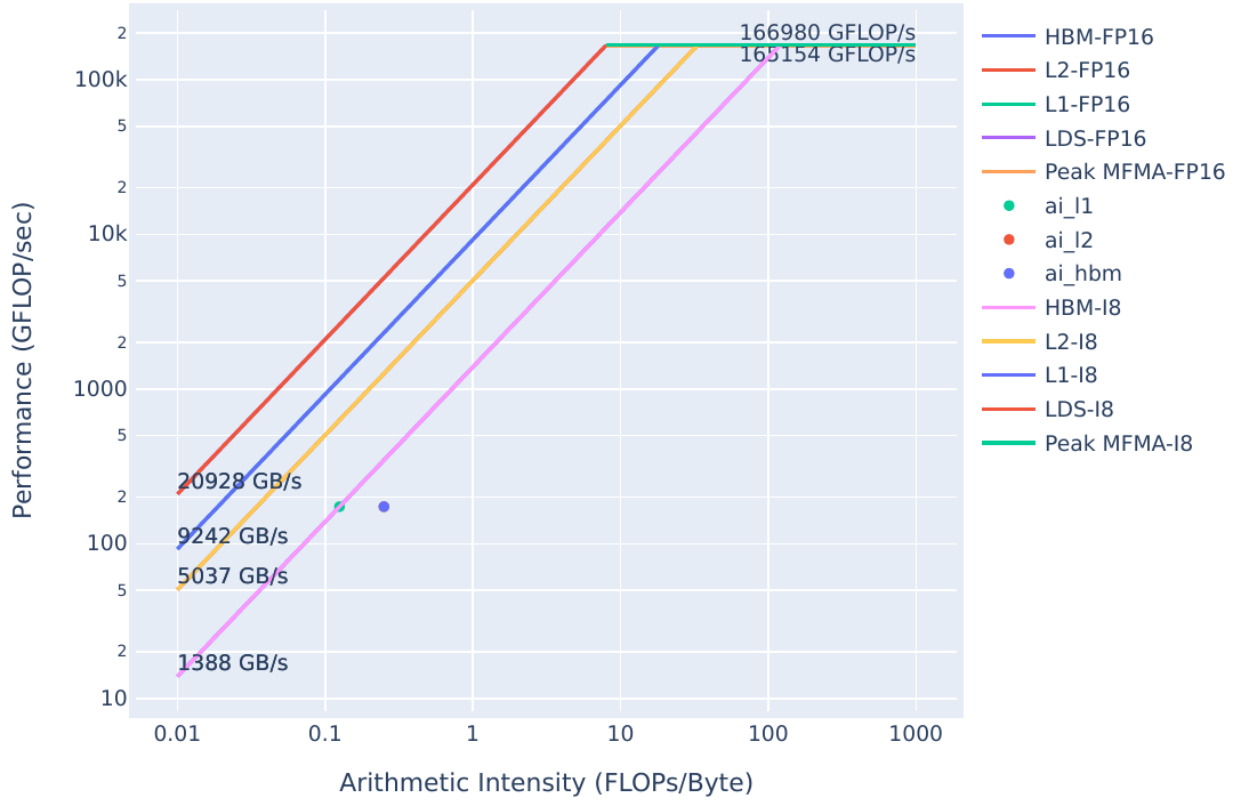
The comparison of these two rooflines is fairly straightforward.

Roofline Type	Problem Roofline



FP32/FP64

Roofline Type	Problem Roofline



FP16/INT8

We see now that the optimization we apply in this example makes the kernel get very close to the HBM bandwidth-bound line. The fact that our kernel falls under the bandwidth line also confirms our suspicion that this kernel is, in fact, in the bandwidth bound regime.

Summary and Take-aways

This algorithmic optimization is able to work more efficiently out of the L1 and L2. Algorithmic optimizations are all but guaranteed to have significant development overhead, but finding a more efficient algorithm can have large impacts to performance. If profiling reveals inefficient use of the memory hardware, it could be worth thinking about alternative algorithms.

Results on MI300A

Under construction...

To run the rocprofv3 trace decoder

ROCprof Trace Decoder

The hands-on exercises will go through how to collect trace decoder output. For how to install the ROCProf trace decoder on pre-ROCm 7.0 versions. See the instructions at https://github.com/amd/HPCTrainingDock

in the HPCTrainingDock/tools/scripts/rocprofiler-sdk_setup.sh script. This script will install the rocprofiler-sdk, aqlprofile and rocprof-trace-decoder packages into a separate directory and then prepend those paths before the ROCm paths.

Setting up environment

If the ROCProf trace decoder is installed with a module, load the appropriate module. With the ROCm 7.0 version, the ROCProf trace decoder will be integrated into ROCm software.

```
module load rocprofiler-sdk
```

All of these exercises are from the AMD HPC Training Examples which can be retrieved with the following:

```
git clone https://github.com/amd/HPCTrainingExamples
```

The examples will be either in the HPCTrainingExamples/HIP or HPCTrainingExamples/rocprof-tracedecoder directories.

Basic test – vectorAdd

```
cd HPCTrainingExamples/HIP/vectorAdd
```

```
make vectoradd
./vectoradd
rocprofv3 --att -d tracedecoder_vectorAdd -- ./vectoradd
```

Transfer the files in the `tracedecoder_vectorAdd` directory to your local machine and read them into ROCprof Compute Viewer

Cleaning up afterwards

```
make clean
rm -rf tracedecoder_vectorAdd
```

ROCprofiler Compute Viewer

The trace decoder data can be viewed in a separate program called ROCprofiler Compute Viewer. There are pre-built binaries for Microsoft Windows and source code that can be compiled for others systems.

Now start up the ROCprof Compute Viewer.

Untar the data on your local system.

tar -xzvf tracedecoder_vectorAdd.tgz Open up the data file by using the import tab at the upper left. Select one of the ui_output_agent* files in the tracedecoder_vectorAdd directory.

This will open up the Instructions view with the source and ISA windows.

Further exploration:

- Open up the summary view and see an overview of the kernel operation.
- Open up the Wave States to see the timeline view of the instructions
- Go to the HotSpot Timeline view to see the instructions used during the kernel
- Examine the Compute Unit timeline view to see the compute units operation
  - Use the WaveView zoon setting on the control panel on the left to zoom in and out to see all of the timeline or zoom in to a specific part.

Saxpy

```
cd HPCTrainingExamples/HIP/saxpy
```

```
make saxpy
./saxpy
rocprofv3 --att -d tracedecoder_saxpy -- ./saxpy
```

Transfer the files in `tracedecoder_saxpy` to your local machine and read them into ROCprof Compute Viewer

Cleaning up afterwards

```
make clean
rm -rf tracedecoder_saxpy
```

Matrix multiply - hip version

```
cd HPCTrainingExamples/HIP/dgemm
```

```
mkdir build && cd build
cmake -DCMAKE_BUILD_TYPE=RelWithDebInfo ..
make
bin/dgemm -m 8192 -n 8192 -k 8192 -i 3 -r 10 -d 0,1,2,3 -o dgemm.csv
rocprofv3 --att -d tracedecoder_dgemm_hip -- bin/dgemm -m 8192 -n 8192 -k 8192 -i 3 -r 10 -d 0,1,2,3 -o dgemm.csv
```

Transfer the files in `tracedecoder_dgemm_hip` to your local machine and read them into ROCprof Compute Viewer

Cleaning up afterwards

```
make clean
rm -rf tracedecoder_dgemm_hip
cd ..
rm -rf build
```

Matrix multiply library test (DGEMM)

```
cd HPCTrainingExamples/rocprof-tracedecoder
```

```
make
rocprofv3 --att -att-perfcounters "SQ_INSTS_LDS SQ_INSTS_VMEM SQ_INSTS_VMEM_WR SQ_INSTS_VMEM_RD" -d tracedecoder_dg
```

Transfer files in `tracedecoder_dgemm_library` to your local system

Cleaning up afterwards

“ make clean rm -rf tracedecoder_dgemm_library

```
# Example of How to Use the Scripts in the HPCTrainingDock

Begin by cloning the repo and getting to the `rocm` directory:
```

git clone https://github.com/amd/HPCTrainingDock.git cd HPCTrainingDock/rocm/scripts

```
We will consider the script to install the latest rocm-afar drop with the latest [amdflang compiler](https://rocm.b
The first thing to do is to run the script with the `--help` option to see what are the input flags for the script
```

./flang-new_setup.sh –help

```
The output will be similar to this:
```

./flang-new_setup.sh: line 4: rocminfo: command not found Usage: WARNING: when specifying –install-path and –module-path, the directories have to already exist because the script checks for write permissions –amdgpu-gfxmodel [AMDGPU_GFXMODEL] default autodetected –module-path [MODULE_PATH] default /etc/lmod/modules/ROCm/amdflang-new –install-path [UNTAR_DIR_INPUT] default /opt/rocmplus-6.0

–rocm-version [ROCM_VERSION] default 6.2.0 –build-flang-new [BUILD_FLANGNEW] default 0 –afar-number [AFAR_NUMBER] default 8248 –flang-release-number [FLANG_RELEASE_NUMBER] default 7.0.5 –help: print this usage information

Note from the above output that there is a message saying that `rocminfo` has not been found: it is used to autodet

From the above list of commands, the `--module-path` will specify the destination of a lua module file that will be

```
if [ -d "$UNTAR_DIR" ]; then
   # don't use sudo if user has write access to install path
   if [ -w ${UNTAR_DIR} ]; then
      SUDO=""
   else
      echo "WARNING: using an install path that requires sudo"
   fi
else
   # if install path does not exist yet, the check on write access will fail
   echo "WARNING: using sudo, make sure you have sudo privileges"
fi
```

Note above that in case the directory exists and the user has write access, `SUDO=""` so no `sudo` will be used.
To check what is the latest drop, visit [this](https://repo.radeon.com/rocm/misc/flang/) website: as of September 1

We will install the script in our home directory and use the latest drop, with ROCm version 6.4.3. To do so, we fir

mkdir -p $HOME/flang-new_install mkdir -p $HOME/flang-new_module

Then execute the script (let's assume we are considering an MI300A so gfx942):

./flang-new_setup.sh –amdgpu-gfxmodel gfx942 –install-path $HOME/flang-new_install
–module-path $HOME/flang-new_module –rocm-version 6.4.3
–build-flang-new 1 –afar-number 8473 –flang-release-number 7.1.1

The output you can expect after executing the above command is:

========== Starting flang-new Install with ROCM_VERSION: 6.4.3 BUILD_FLANGNEW: 1 Archive will be untarred in: /home/sysadmin/flang-new_install ARCHIVE_NAME is rocm-afar-8473-drop-7.1.1 FULL_ARCHIVE_NAME is rocm-afar-8473-drop-7.1.1-ubuntu ARCHIVE_DIR is rocm-afar-7.1.1 INSTALL_DIR or UNTAR_DIR is /home/sysadmin/flang-new_install Looking for the file: https://repo.radeon.com/rocm/misc/flang/rocm-afar-8473-drop-7.1.1-ubuntu.tar.bz2 ==========

========== Installing flang-new ==========

If you now do `module avail` you should see

———————————————————————- /etc/lmod/modules/ROCm ———————————————————————
———————————————————————- amdclang/19.0.0-6.4.3 hipfort/6.4.3 rocm/6.4.3 rocprofiler-sdk/6.4.3 amdflang-new/rocm-afar-7.1.1 opencl/6.4.3 rocprofiler-compute/6.4.3 (D) rocprofiler-systems/6.4.3 (D) “‘