Using Nsight Compute and Nsight Systems

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Objective

- CUDA ecosystem tools for understanding GPU performance
  - and system performance *as it related to GPU utilization*.
- Not covered: tools to understand host code performance
  - gprof, perf, vtune, etc

Outline

- Introduction to Profiling
- Development Model and Profiling Strategy
- Preparing for profiling
- Measuring time with CUDA Events
- Reminder / Introduction to Matrix Multiplication
- Nvidia Nsight Compute
- Nvidia Nsight Systems

Resources

- Everything used in this lecture is at github.com/cwpearson/nvidia-performance-tools

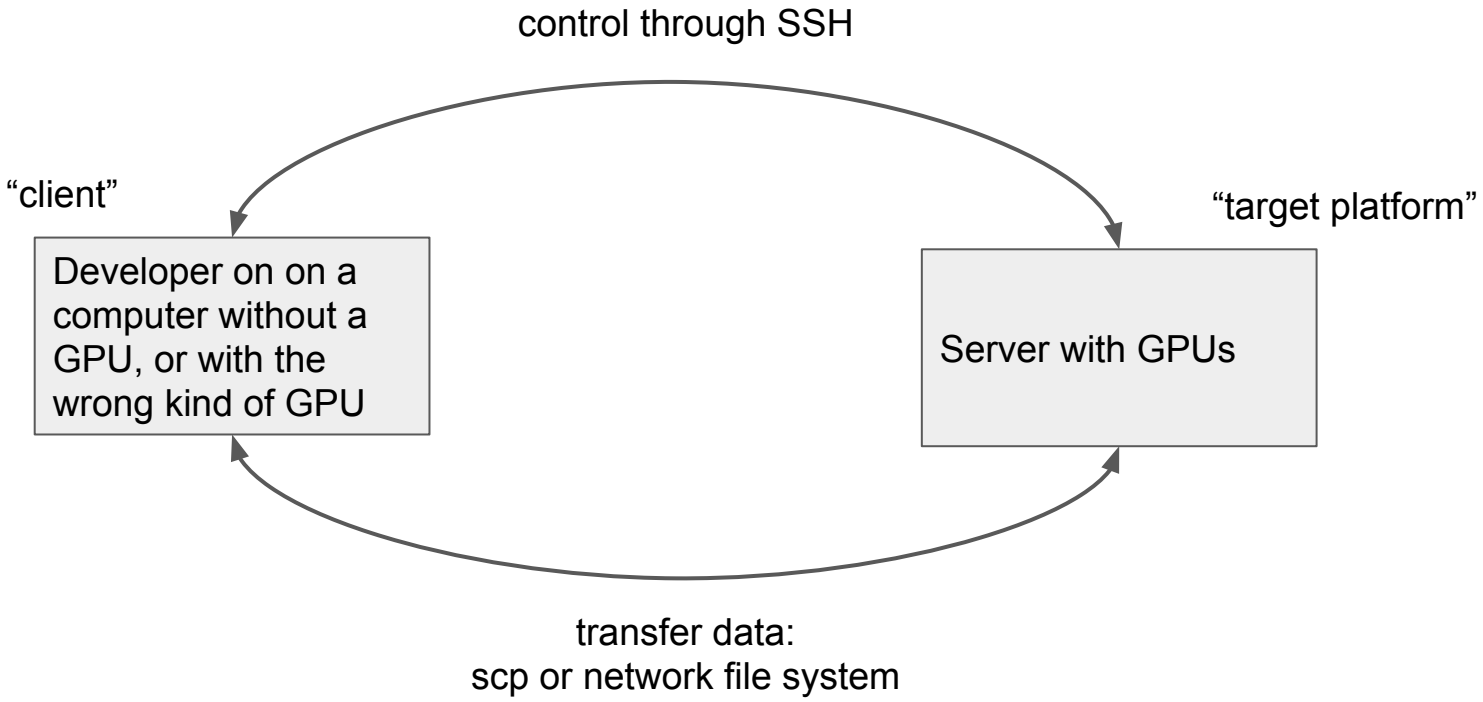
- Use it any way you want (with attribution).
  - Docker images for amd64 and ppc64le with CUDA and recent versions of Nsight
  - Matrix multiplication examples (in `sgemm/`)
  - rai_build.yml for sgemm (in `sgemm/`) if you have access to rai
  - Build and profile the examples on any system

System- and Kernel-Level Profiling

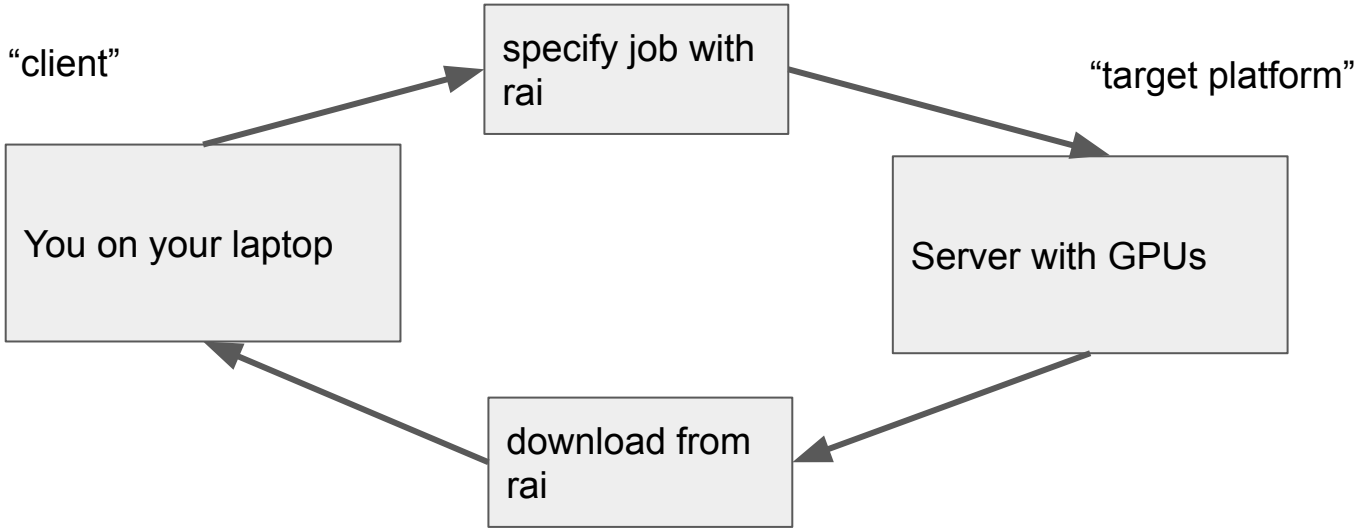
- Nsight Compute: Kernel-Level Profiling
  - How fast does the GPU execute my kernel?

- Nsight Systems: System-level Profiling:
  - how effectively is my system delivering work to the GPU?
  - What is my system doing while the GPU is working?
  - How fast is data moving to/from the GPU?
  - How much time does the CPU take to control the GPU?
  - When do asynchronous operations occur?

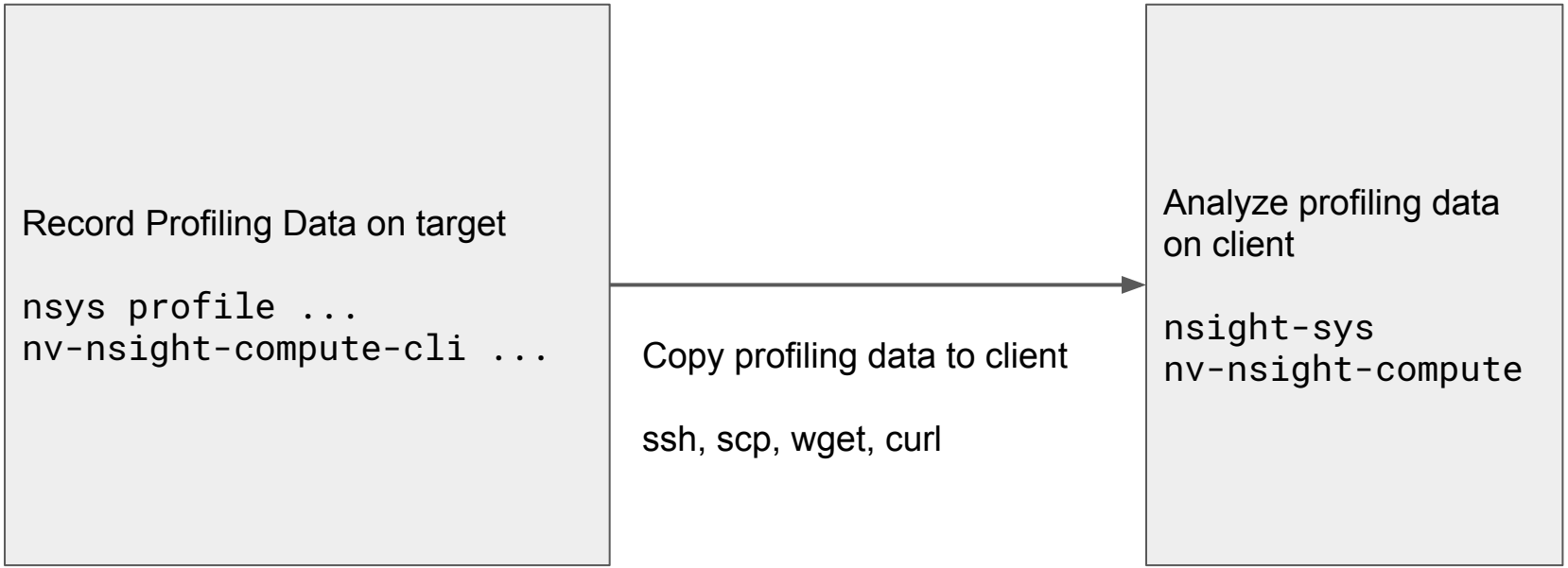
Common GPU Development Model



Our GPU Development Model



Two-Phase Profiling



Preparing for Profiling: Host Code Annotations

Nvidia Tools Extensions

`#include <nvToolsExt.h>` and link with `-lnvToolsExt`

Will show up as a named span in the Nsight System GUI

Useful for marking parts of the code for later reference.

```
nvtxRangePush("sleeping");
sleep(100);
nvtxRangePop();
```

Preparing for Profiling: Correctness

- Subtle errors that do not cause your kernel to terminate under normal conditions can cause errors with profiling
  - esp. writing outside of allocated memory
- Run your code with cuda-memcheck if profiling crashes or misbehaves
  - Automatically instruments for bad memory behavior
  - Causes something like 100x slowdown, so try small datasets first
  - Fix any errors that come up, then profile again

```
cuda-memcheck ./my-cuda-binary
```

Preparing for Profiling: Compiling

- Compile device code *with optimizations*
  - non-optimized or debug code often has many more memory references
  - nvcc by default applies many optimizations to device code
  - remove any -G flag (this flag generated debug info for device code)
- Compile device code with line number annotations
  - add -lineinfo flag to all nvcc calls
  - puts some info in the binary about what source file locations generated what machine code

```
$ nvcc -G main.cu  ──────►  $ nvcc -lineinfo main.cu
```

Preparing for Profiling: Compiling

--generate-line-info / -lineinfo

Generate line-number information for device code.

Annotates the binary with information to correlate ptx back to CUDA source code

Compiled PTX

```
.loc 1 18 12 // file 1 line 18 col 12
cvta.to.global.u64 %rd1, %rd6;
mov.u32 %r27, %ctaid.x;
mov.u32 %r1, %ntid.x;
mov.u32 %r28, %tid.x;
mad.lo.s32 %r2, %r27, %r1, %r28;
```

CUDA Source Code

```
18: int gidx = blockDim.x *
19:   blockIdx.x + threadIdx.x;
```

Preparing for Profiling: Compiling

Don’t use any of these for Nsight profiling!

--profile / -pg

Instrument generated code/executable for use by gprof (Linux only).

--debug / -g

Generate debug information for host code.

--device-debug / -G

Generate debug information for device code. Turns off all optimizations.

Don't use for profiling; use -lineinfo instead.

Preparing for Profiling: System

Nsight System uses various system hooks to accomplish profiling.

Some errors would reduce the amount or accuracy of gathered info, some will make system profiling impossible. Consult the documentation for how to correct.

An example of a GOOD output: (check with `nsys status -e`)

```
$ nsys status -e
Sampling Environment Check
Linux Kernel Paranoid Level = 2: OK
Linux Distribution = Ubuntu
Linux Kernel Version = 4.16.15-41615: OK
Linux perf_event_open syscall available: OK
Sampling trigger event available: OK
Intel(c) Last Branch Record support: Available
Sampling Environment: OK
```

Caveats:

Profiling affects the performance of your kernel!

It will help you improve the speed, but do not report the time *during* profiling as the performance of your code. Always run and time without profiling.

Following along with your own rai account

Example code / project folder at github.com/cwpearson/nvidia-performance-tools

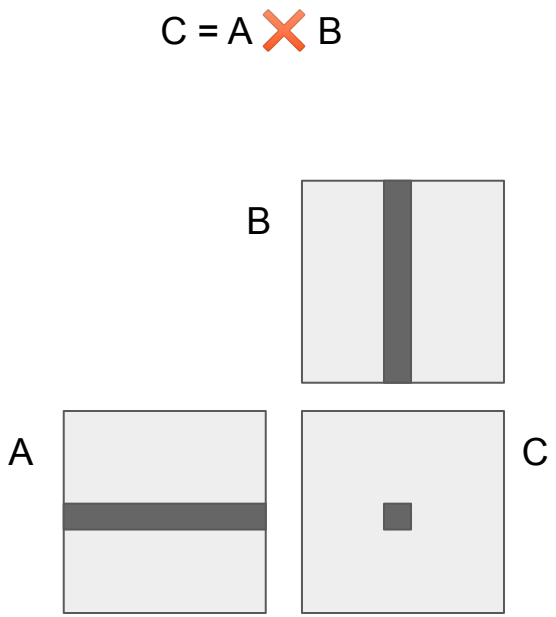
Run it through rai and retrieve the results. Rai will provide you with the URL at the end you need to download.

```
$ git clone https://github.com/cwpearson/nvidia-performance-tools.git
$ cd nvidia-performance-tools
$ cd sgemm
$ rai -p .
$ ...
$ wget http://s3.amazonaws.com/file.rai-project.com/userdata/<your job file here>
```

You will also need to install Nsight Compute and Nsight Systems on your own laptop (or use EWS) to view the resulting files.

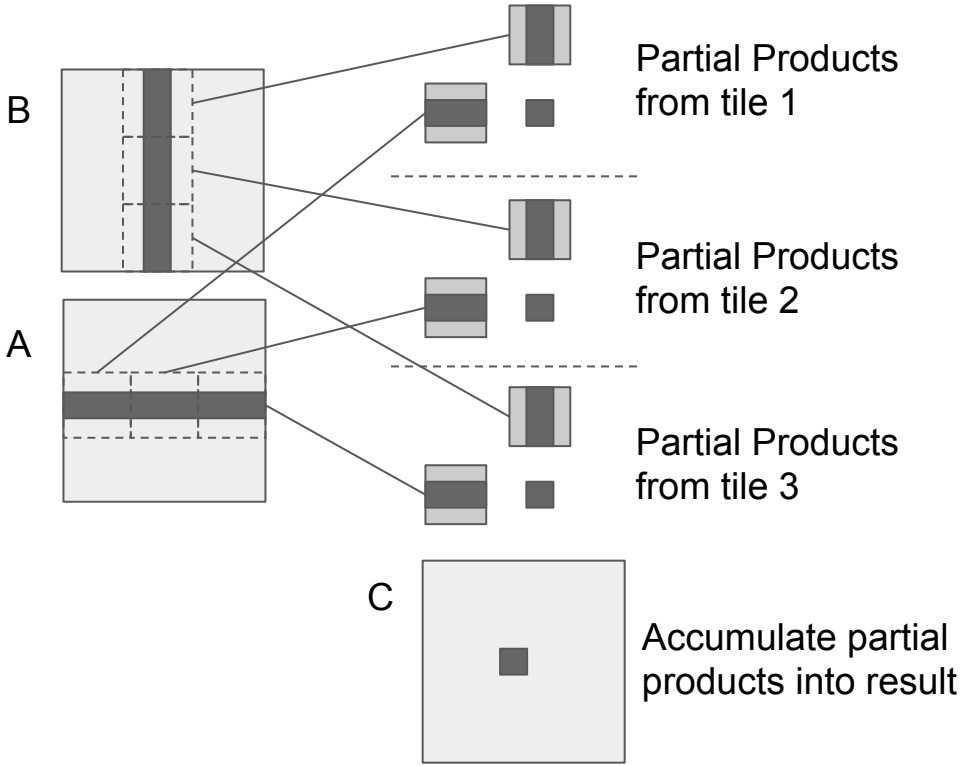
Matrix Multiplication Review

Reminder: Dense Matrix Multiplication



- Each thread produces a single product value $C_{i,j}$ by dot(A_i, B_j)
- A and C are column-major, B is row-major
  - access to B is coalesced
- Each entry of the A/B matrices loaded from global memory multiple times

Reminder: Shared-Memory Tiling



- Each thread produces a single product value $C_{i,j}$ by dot(A_i, B_j)
- Each thread block collaboratively loads tiles of A and B to accumulate partial products
  - Much reuse comes from fast shared memory instead of slow global memory

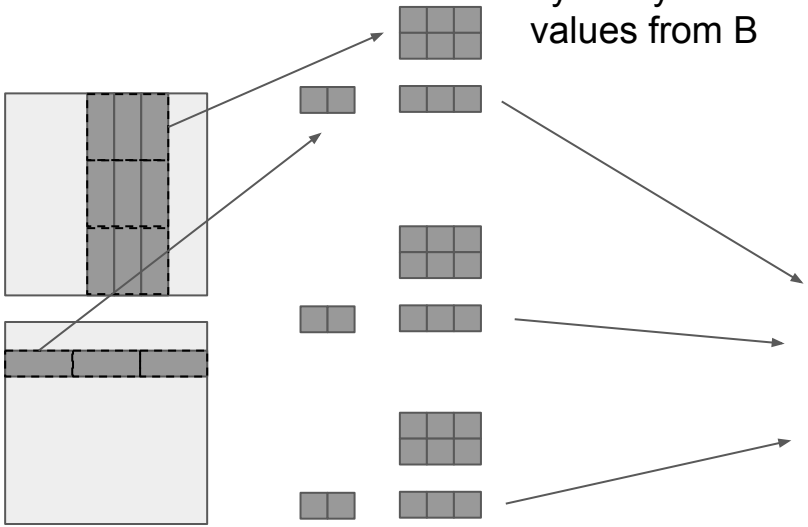
Joint Shared-Memory Register Tiling

- **Not required to understand or reproduce for ECE 408**
- Registers
  - Extremely high throughput: think 3 64-bit operands per cycle per thread
  - private to each thread: thread coarsening
- Shared Memory
  - Very high throughput
  - shared between threads: no coarsening
- Tiled requires $TILE\_SIZE^2$ shared memory per block to produce $TILE\_SIZE^2$ partial products
- Joint requires TILE_SZ_A shared memory and TILE_SZ_B * TILE_SZ_A registers to produce TILE_SZ_A * TILE_SZ_B results

Joint Shared-Memory Register Tiling

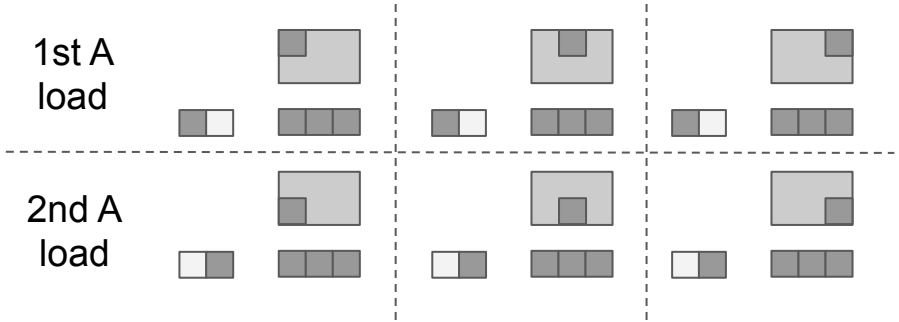
Load a tile of B into shared memory

Load values from A row and multiply by many values from B



1st A load

2nd A load



SGEMM Comparison

	A Reuse	B Reuse	Product Data per Block	SH/block	Reg/blk
Basic	1	1	1024	0	1024 * 4B 4KB
Tiled	32 (TILE_SIZE)	32 (TILE_SIZE)	1024 (TILE_SIZE2)	32*32*2 * 4B = 8KB	1024 * 4B = 4 KB
Joint	16 (TILE_SZ_B)	64 (TILE_SZ_A)	1024 (TILE_SZ_A * TILE_SZ_B)	64 * 4B = 256B	(64 * 16 + 64 * 4) * 4B = 5KB

Example Files

- Three provided files to measure kernel times
- 1-1-pinned-basic / 1_1_pinned_basic.cu
  - Basic global-memory matrix-matrix multiplication
- 1-2-pinned-tiled / 1_2_pinned_tiled.cu
  - Shared-memory tiled matrix-matrix multiplication
- 1-3-pinned-joint / 1_3_pinned_joint.cu
  - Joint shared-memory and register-tiled matrix-matrix multiplication
- Each takes following options
  - --iters <int>: how many iterations to average the measurement over (default 5)
  - --warmup <int>: how many warmup runs before measuring (default 5)

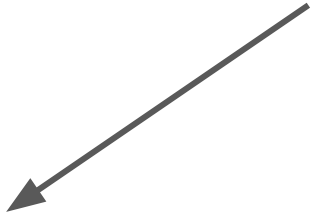
Measuring Time with CUDA Events

Terminology

- Stream (cudaStream_t)
  - A queue of sequential CUDA events. Each is executed after the prior one finishes
  - A program can use any number of CUDA streams
  - Associated with a device
- Default Stream (cudaStream_t = 0)
  - A special stream that is used when no stream is provided
- Event (cudaEvent_t)
  - Records the state of a stream
- See CUDA programing guide for stream synchronization edge cases
- *Generally*, to overlap operations:
  - different streams
  - do not use pageable memory
  - use *async CUDA runtime functions

Timing Async Operations with CUDA Events

```
cudaEvent_t start, stop;
cudaStream_t stream;
cudaStreamCreate(&stream);
cudaEventCreate(&start);
cudaEventCreate(&stop);
cudaEventRecord(start, stream);
cudaMemcpyAsync(..., stream);
kernel<<<dimGrid, dimBlock, 0, stream>>>();
cudaEventRecord(stop, stream);
cudaMemcpyAsync(..., stream);
cudaEventSynchronize(stop);
float millis;
cudaEventElapsedTime(&millis, start, stop);
```



Place and events in the stream **before** and **after** the **things you want to measure.**
Executed when the stream reaches the event, not when cudaEventRecord is called.

Wait for the final event to be reached. Could use cudaStreamSynchronize or cudaDeviceSynchronize too.

Get the time between the start and stop event.

Walkthrough

This method is used to measure the kernel times in `1_1_pinned_basic.cu`, `1_2_pinned_tiled.cu`, and `1_3_pinned_joint.cu`

These results also present in `1-1-pinned-basic.txt`

```
* Running bash -c "./1-1-pinned-basic | tee 1-1-pinned-basic.txt"
generate data
transfer to GPU
0: 3.75206
1: 3.73158
2: 3.73213
3: 3.73149
4: 3.73379
5: 3.73146 *
6: 3.73043 *
7: 3.72659 *
8: 3.73094 *
9: 3.72835 *
kernel 1787.02GFLOPS (6664784846 flop, 0.00372956s)
```

warmup runs

these contribute to reported time

average kernel performance

My Results

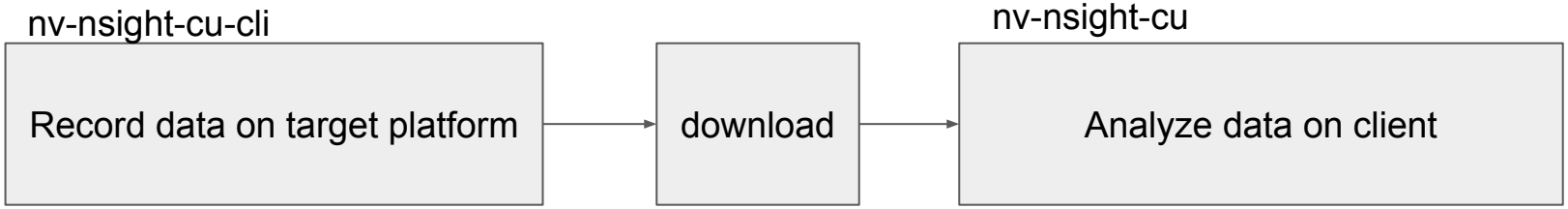
Yours may be different

Kernel	Performance	Speedup
Basic	1787 GFLOPS	-
Tiled	2585 GFLOPS	1.45
Joint	6203 GFLOPS	3.47

Kernel Profiling with Nsight Compute

Nvidia Nsight Compute

- Record and analyze detailed kernel performance metrics
- Two interfaces:
  - GUI (nv-nsight-cu)
  - CLI (nv-nsight-cu-cli)
- Directly consuming 1000 metrics is challenging, we use the GUI to help
- Use a two-part record-then-analyze flow with rai



Kernel Profiling

- Device has many performance counters to record detailed information
  - Made available as “metrics”.
  - Titan V on rai supports ~1100 metrics, some shown below
  - `$ nv-nsight-cu-cli --devices 0 --query-metrics`

lts__t_sectors_srcunit_l1_op_atom_dot_cas	# of LTS sectors from unit L1 for atomic CAS
l1tex__data_pipe_lsu_wavefronts_mem_shared_cmd_write	# of shared write wavefronts processed by Data-Stage
lts__t_sectors_srcunit_l1_aperture_sysmem_op_read	# of LTS sectors from unit L1 accessing system memory
(sysmem) for readslts__t_requests_op_red_lookup_hit	# of LTS requests for reductions that hit
lts__t_sectors_equiv_l1tagmiss_pipe_tex_mem_texture_op_ld	# of sectors requested for TLD instructions
l1tex__t_bytes_pipe_tex_lookup_miss	# of bytes requested that missed for TEX pipe
l1tex__texin_requests_mem_texture	# of texture requests (quads) sent to
TEXINl1tex__t_bytes_pipe_lsu_mem_local_op_ld_lookup_miss	# of bytes requested that missed for local
loadsl1tex__t_bytes_pipe_tex_mem_surface_op_red_lookup_miss	# of bytes requested that missed for surface reductions

...

Record kernel traces

```
$ nv-nsight-cu-cli          \
    --kernel-id ::mygemm:6 \
    --section ".*"          \
    -o 1-1-pinned-basic     \
    1-1-pinned-basic
```

Profile the 6th time the "mygemm" kernel runs

Record metrics for all report sections

Create "1-1-pinned-basic.nsight-cuprof-report"

Name of the CUDA executable to profile

Do the same for the `1-2-pinned-tiled` and `1-3-pinned-joint` files

If you're following along in rai, the `rai_build.yml` recipe does this for you when you submit the sgemm folder to rai:

```
$ cd sgemm
$ rai -p .
```

Nsight Compute Sections

A group of related measurements
The default list can be generated by
$ nv-nsight-cu-cli --list-sections

Without the --sections options, this is what would be recorded

We provide a regex that matches all sections

```
------------------------------ ------------------------------ ------- --------------------------------------------------
Identifier                     Display Name                   Enabled Filename
------------------------------ ------------------------------ ------- --------------------------------------------------
ComputeWorkloadAnalysis        Compute Workload Analysis      no      .../../../sections/ComputeWorkloadAnalysis.section
InstructionStats               Instruction Statistics         no      ...64/../../sections/InstructionStatistics.section
LaunchStats                    Launch Statistics              yes     ...1_3-x64/../../sections/LaunchStatistics.section
MemoryWorkloadAnalysis         Memory Workload Analysis       no      ...4/../../sections/MemoryWorkloadAnalysis.section
MemoryWorkloadAnalysis_Chart   Memory Workload Analysis Chart no      ..../sections/MemoryWorkloadAnalysis_Chart.section
MemoryWorkloadAnalysis_Tables  Memory Workload Analysis Tables no      .../sections/MemoryWorkloadAnalysis_Tables.section
Occupancy                      Occupancy                      yes     ...ibc_2_11_3-x64/../../sections/Occupancy.section
SchedulerStats                 Scheduler Statistics           no      ...-x64/../../sections/SchedulerStatistics.section
SourceCounters                 Source Counters                no      ...._11_3-x64/../../sections/SourceCounters.section
SpeedOfLight                   GPU Speed Of Light             yes     ...._2_11_3-x64/../../sections/SpeedOfLight.section
WarpStateStats                 Warp State Statistics          no      ...-x64/../../sections/WarpStateStatistics.section
```

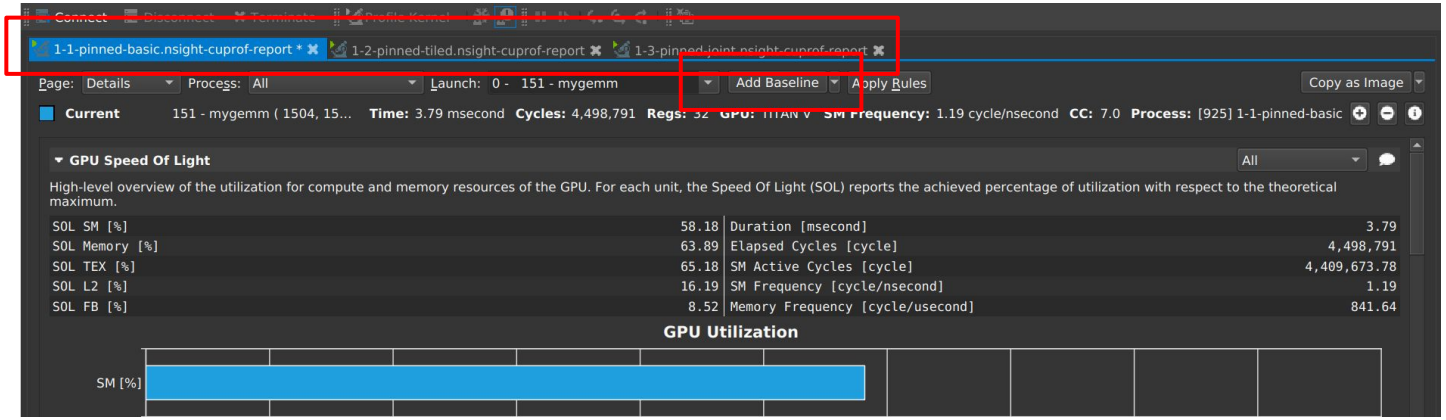
Open in Nsight Compute

Start Nsight Compute

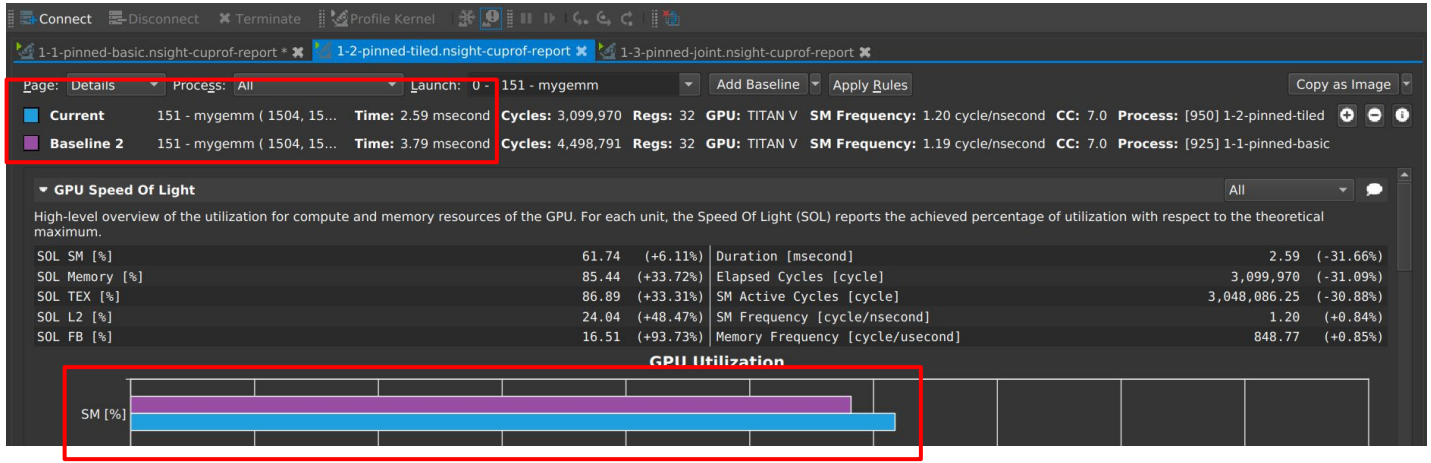
File > Open File ... > `1-1-pinned-basic.nsight-cuprof-report`

- Can open multiple files, will be open in multiple tabs
  - Can also use different runs as “baselines” for comparison in the same tab
  - Click “Add Baseline”

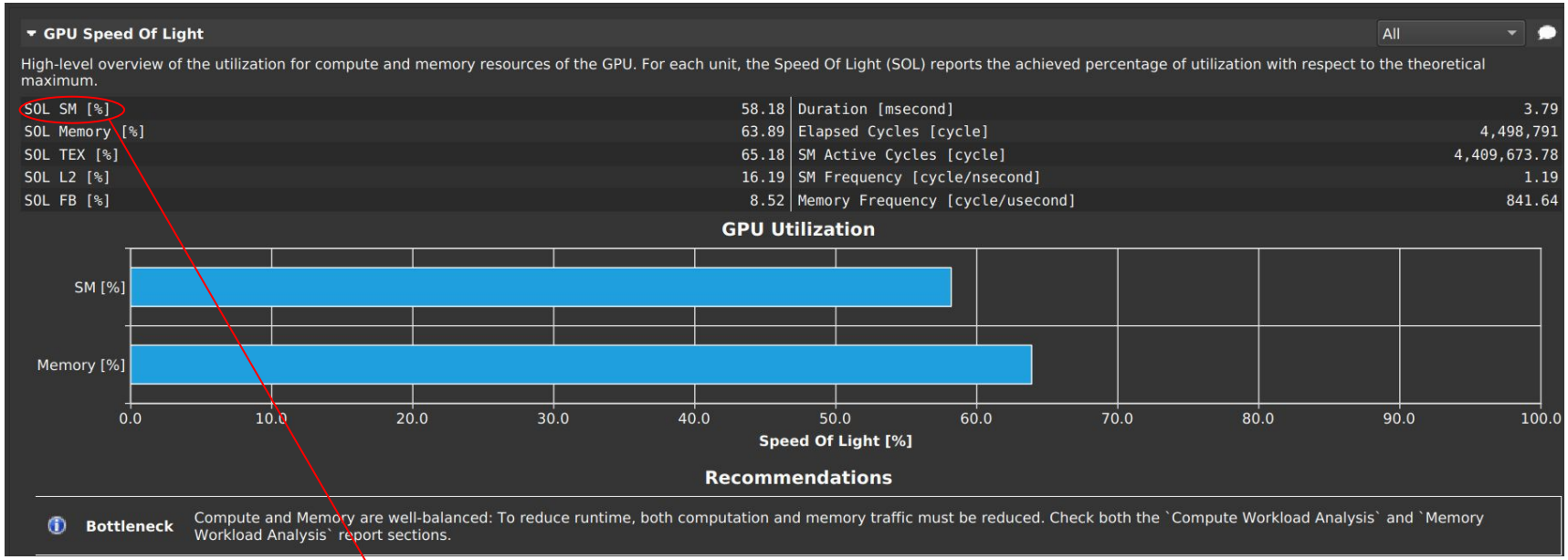
Tabs and baseline button



Next tab now has comparison



GPU Speed of Light



Mouse over each to see the associated metric

Section: GPU Speed of Light

- Achieved percentage of utilization w.r.t theoretical maximum

	Basic	Tiled	Joint
(GFLOPS)	1787	2585	6203
SoL SM	58.18	61.74	58.39
SoL Memory	63.89	85.44	71.28

1) Why isn't tiled multiplication even faster?
2) Why is joint multiplication so fast?

Workload Memory Analysis: Memory Chart

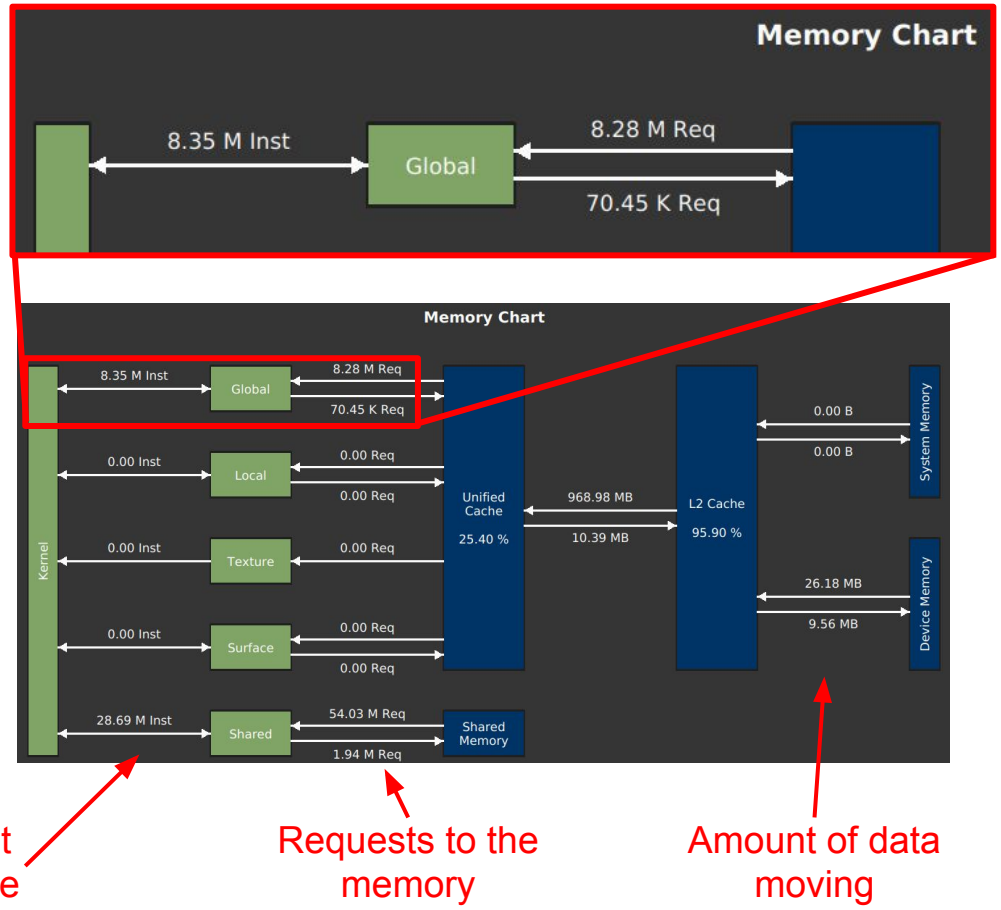
Global Memory: shared by all threads

Local Memory: private per-thread

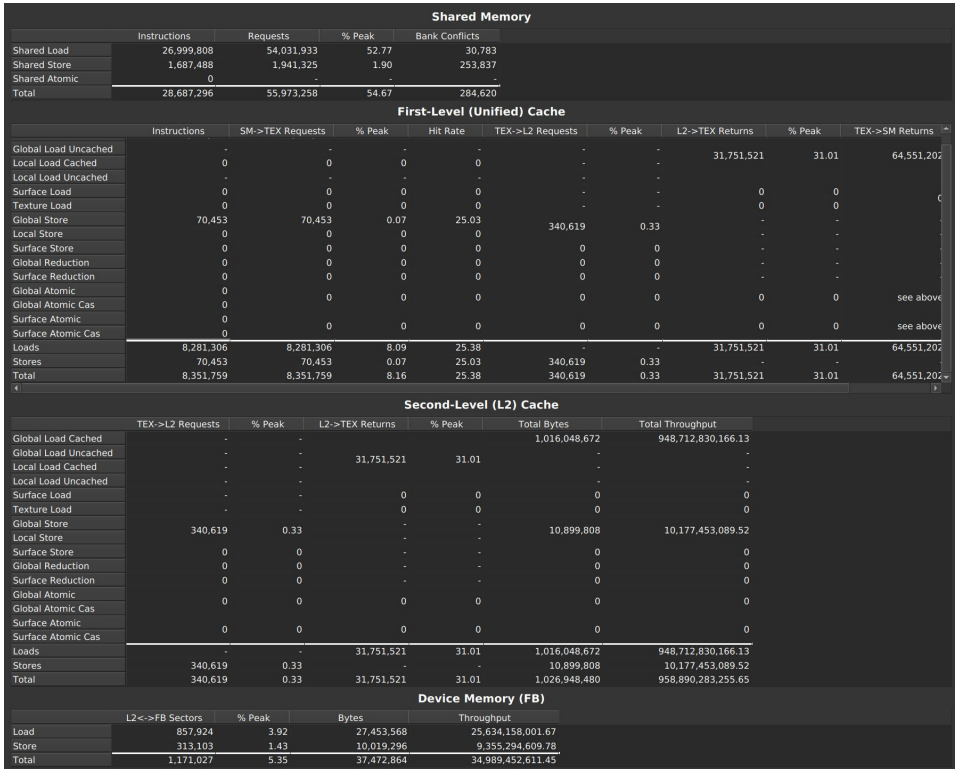
Shared Memory: shared by threads in a block

Texture/Surface: Cached for 2D spatial locality

Constant (?): Cached in the constant cache



Memory Workload Analysis: Charts



Shared Memory

	Instructions	Requests	% Peak	Bank Conflicts
Shared Load	26,999,808	54,031,933	52.77	30,783
Shared Store	1,687,488	1,941,325	1.90	253,837
Shared Atomic	0	-	-	-
Total	28,687,296	55,973,258	54.67	284,620

First-Level (Unified) Cache

	Instructions	SM->TEX Requests	% Peak	Hit Rate	TEX->L2 Requests	% Peak	L2->TEX Returns	% Peak	TEX->SM Returns
Global Load Uncached	-	-	-	-	-	-	31,751,521	31.01	64,551,202
Local Load Cached	0	0	0	0	-	-			
Local Load Uncached	-	-	-	-	-	-			
Surface Load	0	0	0	0	-	-	0	0	
Texture Load	0	0	0	0	-	-	0	0	
Global Store	70,453	70,453	0.07	25.03	340,619	0.33	-	-	
Local Store	0	0	0	0			-	-	
Surface Store	0	0	0	0	0	0	-	-	
Global Reduction	0	0	0	0	0	0	-	-	
Surface Reduction	0	0	0	0	0	0	-	-	
Global Atomic	0								
Global Atomic Cas	0	0	0	0	0	0	0	0	see above
Surface Atomic	0								
Surface Atomic Cas	0	0	0	0	0	0	0	0	see above
Loads	8,281,306	8,281,306	8.09	25.38	-	-	31,751,521	31.01	64,551,202
Stores	70,453	70,453	0.07	25.03	340,619	0.33	-	-	
Total	8,351,759	8,351,759	8.16	25.38	340,619	0.33	31,751,521	31.01	64,551,202

Second-Level (L2) Cache

	TEX->L2 Requests	% Peak	L2->TEX Returns	% Peak	Total Bytes	Total Throughput
Global Load Cached	-	-			1,016,048,672	948,712,830,166.13
Global Load Uncached	-	-	31,751,521	31.01	-	-
Local Load Cached	-	-			-	-
Local Load Uncached	-	-			-	-
Surface Load	-	-	0	0	0	0
Texture Load	-	-	0	0	0	0
Global Store	340,619	0.33	-	-	10,899,808	10,177,453,089.52
Local Store			-	-		
Surface Store	0	0	-	-	0	0
Global Reduction	0	0	-	-	0	0
Surface Reduction	0	0	-	-	0	0
Global Atomic	0	0	0	0	0	0
Global Atomic Cas						
Surface Atomic	0	0	0	0	0	0
Surface Atomic Cas						
Loads	-	-	31,751,521	31.01	1,016,048,672	948,712,830,166.13
Stores	340,619	0.33	-	-	10,899,808	10,177,453,089.52
Total	340,619	0.33	31,751,521	31.01	1,026,948,480	958,890,283,255.65

Device Memory (FB)

	L2<->FB Sectors	% Peak	Bytes	Throughput
Load	857,924	3.92	27,453,568	25,634,158,001.67
Store	313,103	1.43	10,019,296	9,355,294,609.78
Total	1,171,027	5.35	37,472,864	34,989,452,611.45

- Detailed information summarized in the Memory Chart
- Uses TEX to mean the first-level cache.

Memory Workload Analysis

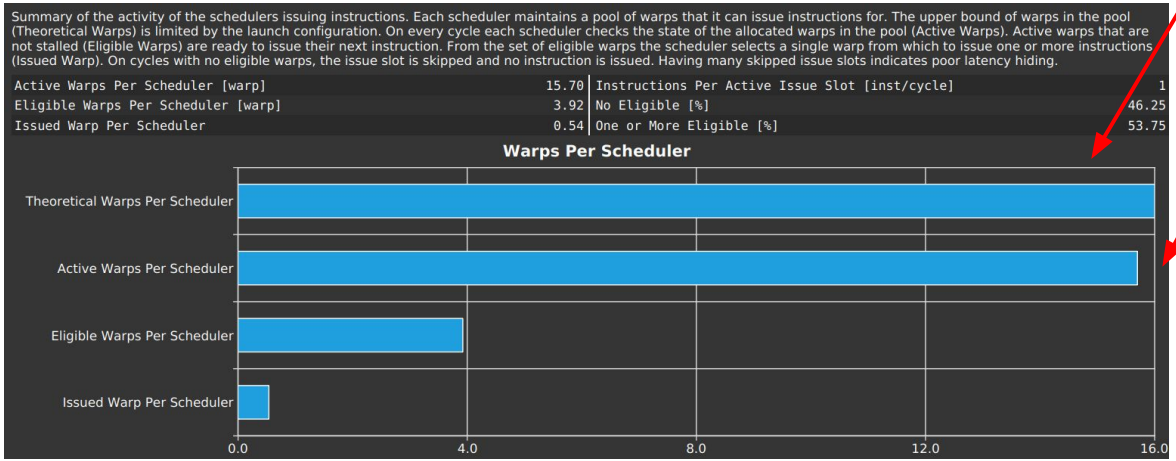
	Basic	Tiled	Joint
GFLOPS	1787	2585	6203
Speed of Light: Memory	63.89	85.44	71.28
Global Load Cached (% peak)	59.24	2.70	8.09
Global Load Cached (SM->TEX REQ)	209M	6.6M	8.2M
Shared Load (REQ)	0	160M	54M
L1 Hit Rate	94.84	74.75	25.40
Global Load (B)	197M	266M	27M
Global Store (B)	11.7M	11.9M	10M

Replaced global loads with shared loads

Total memory requests greatly reduced

Most global memory accesses already were at shared-memory speed

Scheduler Statistics



Pool of warps that the scheduler can pick from. Limited by device.

Number of warps actually given to SM: not enough work, or work imbalance

Number of warps ready to execute: waiting for barrier, watching for instruction fetch, waiting for data…

Number of issued warps: usually maximum of 1 or 2 depending on hardware.

Just because average value is good, doesn't mean warp scheduling chances are missed

	Maximum (Fermi)	Maximum (Kepler)	Scope	Limiter
Device Limit	48 Warps	64 Warps		
Theoretical Occupancy	≤48 Warps	≤64 Warps	Launch	Launch Configuration
Active Warps			Warp Launch & Complete	Scheduler Load Balancing
Stalled Warps			Cycle	
Eligible Warps			Cycle	Issue Stalls
Selected Warps	≤2 Warps	≤4 Warps	Cycle	Eligible Warps & # Warp Schedulers

Scheduler Statistics Comparison

	Basic	Tiled	Joint
GFLOPS	1787	2585	6203
Theoretical Warps / Scheduler	16	16	16
Active Warps / Scheduler	15.7	15.71	8.7
Eligible Warps / Scheduler	3.92	2.60	2.17
Issued Warps / Scheduler	0.54	0.33	0.57

(See launch statistics)

A warp is only issued every 2-3 cycles for all of these

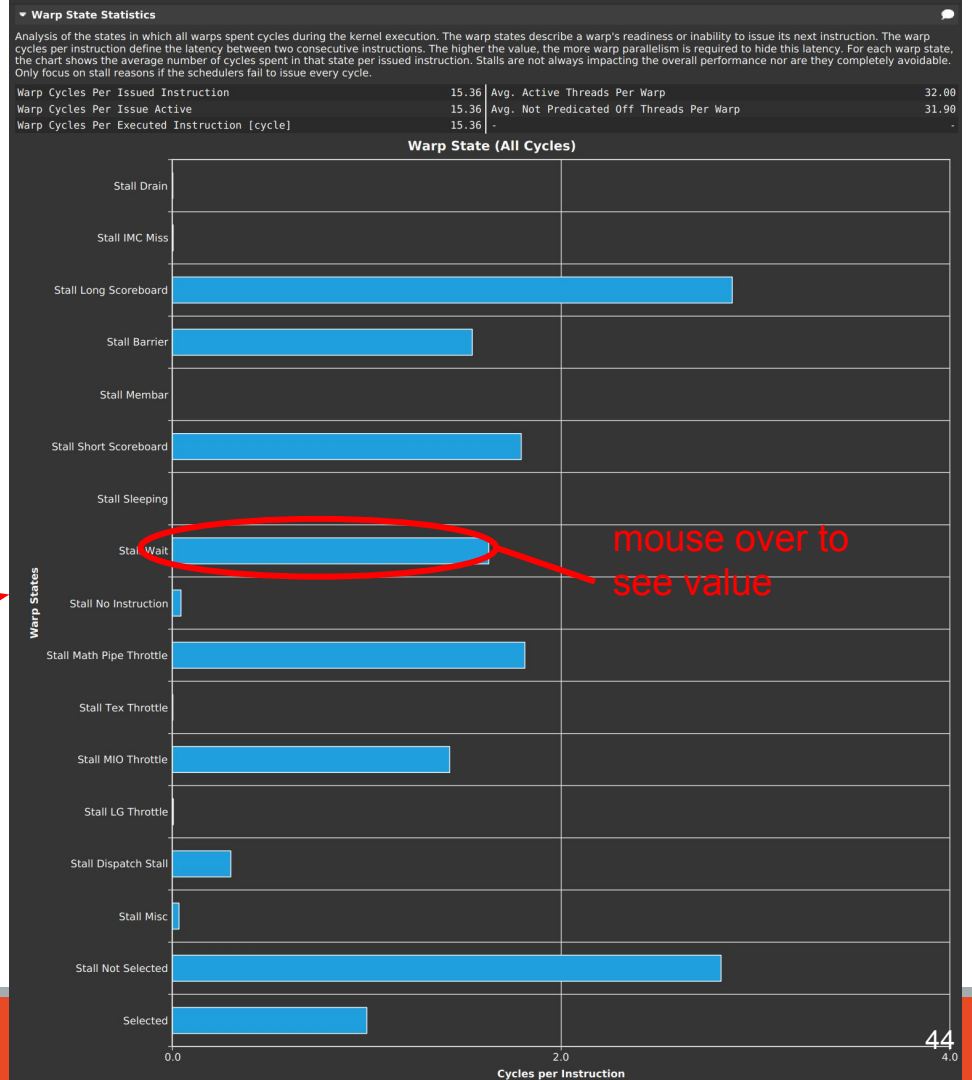
Warp State Statistics

Warp cycles per issued instructions: latency between two consecutive instructions

More latency: more warp parallelism needed to hide

Warp State: average number of cycles spent in that state for each instructions

Stalls cannot always be avoided and only really matter if instructions can't be issued every cycle



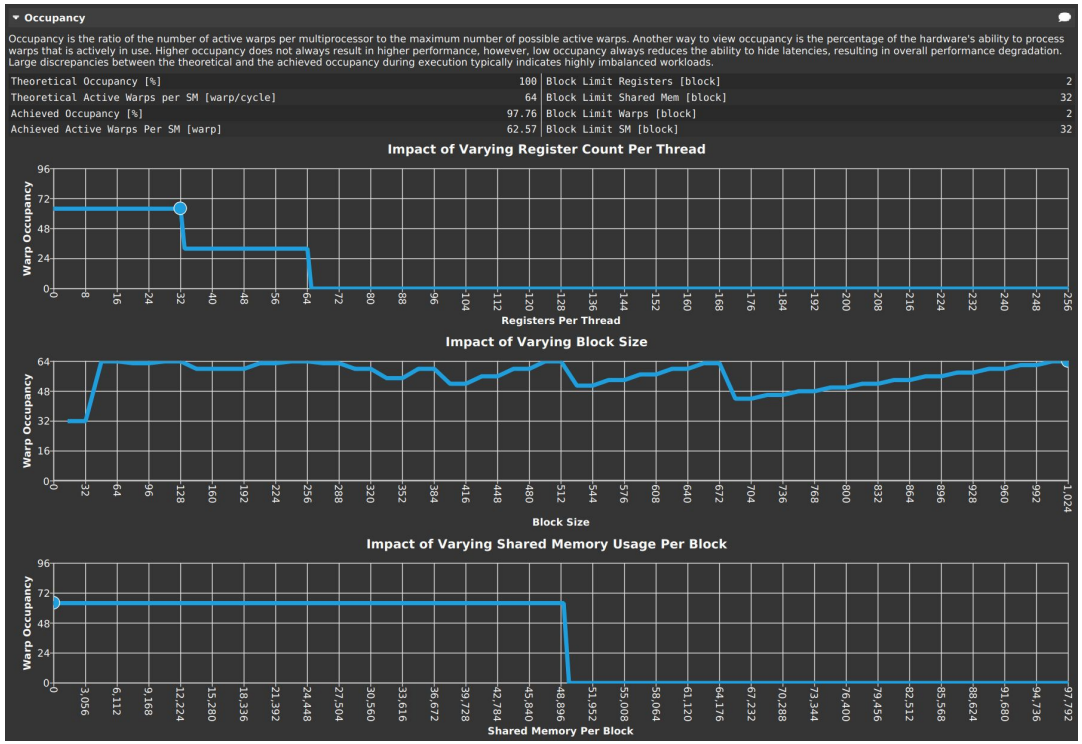
Warp State Statistics

Replaces global with shared

	Description	Basic	Tiled	Joint
GFLOPS		1787	2585	6203
Warp Cycles per Issued Instruction	latency between two consecutive instructions	29.21	47.32	15.36
Stall Long Scoreboard	Waiting for local, global, texture, or surface load	4.44	6.33	2.88
Stall Barrier	Waiting at barrier	0	4.67	1.54
Stall MIO Throttle	Waiting for MIO queue, caused by loads (incl. shared), and special math	0.01	22.74	1.43
Stall LG Throttle	Waiting for load-store-unit queue for local and global memory instructions	11.83	1.79	0
Stall Not selected	Eligible but not selected because another eligible warp was	6.89	6.82	2.82

Lower stalls across the board, but fewer warps

Section: Occupancy



Theoretical occupancy limited by device hardware and launch configuration

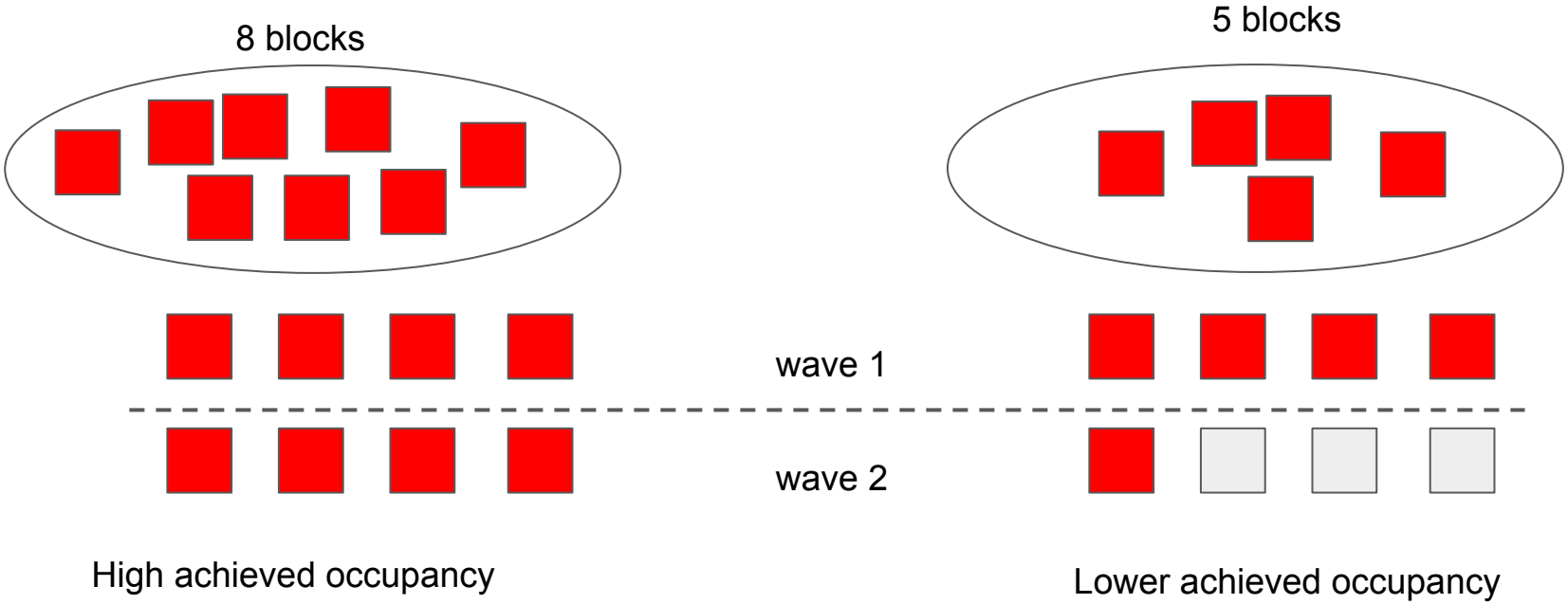
Achieved occupancy: true number of active warps as average

Lower if workload within or across blocks is imbalanced, if there are too few blocks, or the last wave is not large enough to fill GPU

Charts show how resources affect theoretical occupancy

Waves

Assume: 1 block per SM, GPU with 4 SMs



Launch Statistics & Occupancy

	Basic	Tiled	Joint
GFLOPS	1787	2585	6203
Theoretical Occupancy	100	100	75
Th. Active Warps per SM	64	64	48
Achieved Occupancy	97.76	98.34	53.93%
Waves per SM	13.81	13.81	1.18
Registers Per Thread	32	32	40

May not include registers for program counter!
Consult Nvidia's architecture whitepapers.
Titan V uses 2 additional registers for PC.

Last wave only 18% of needed warps

Instruction Hotspots

Show various metrics correlated with source code lines and PTX instructions

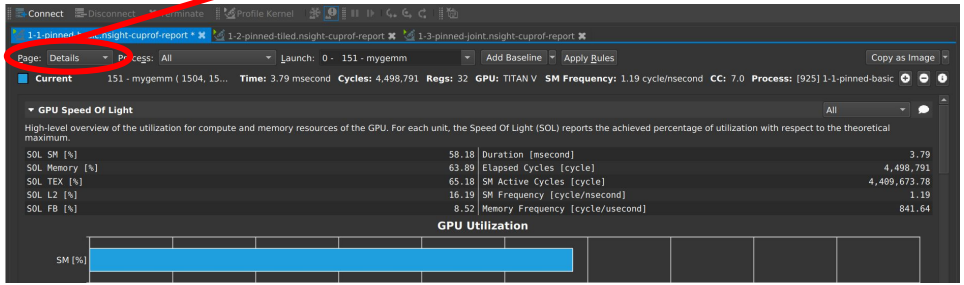
Some source code lines create many many PTX instructions: sometimes, split up a source line into many lines to get more details

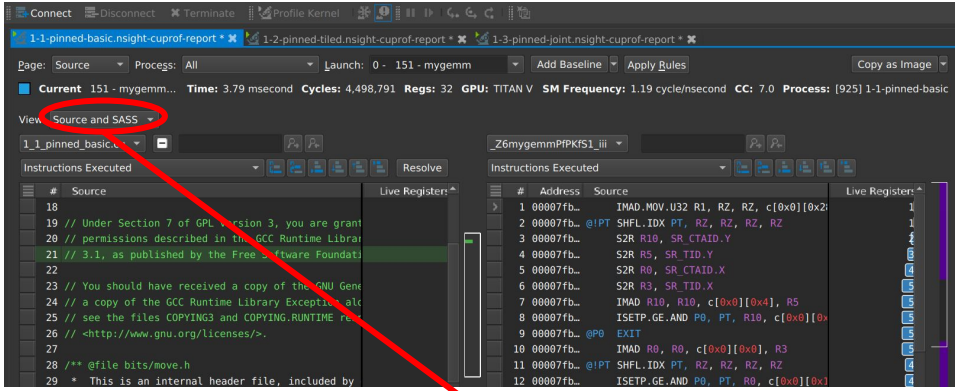
```
dst[i] = src[i] + reg;
```

vs

```
temp v = src[i];
v += reg;
dst[i] = v;
```

Switch page to “Source”

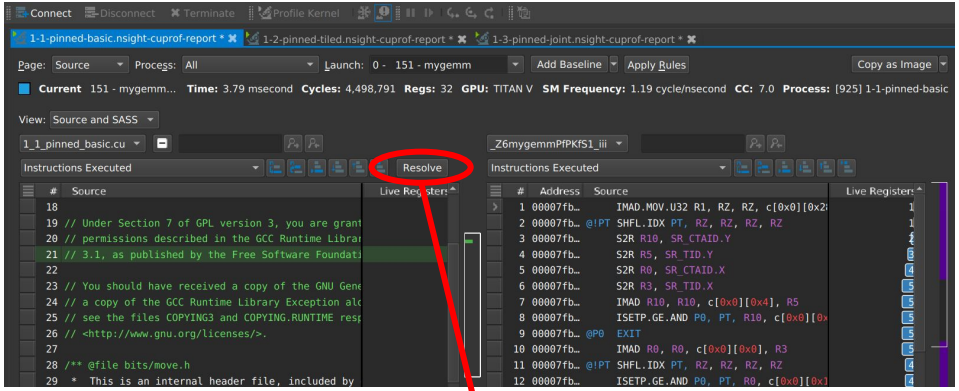




“Source and PTX” (usually) or “Source and SASS”
PTX: higher-level assembly, same between GPU models
SASS: specific code for a GPU model

Instruction Hotspots

If profiling on a different system, source file may not automatically load since paths may not match.



Click “resolve” and find your local copy of the code that was compiled or run remotely.

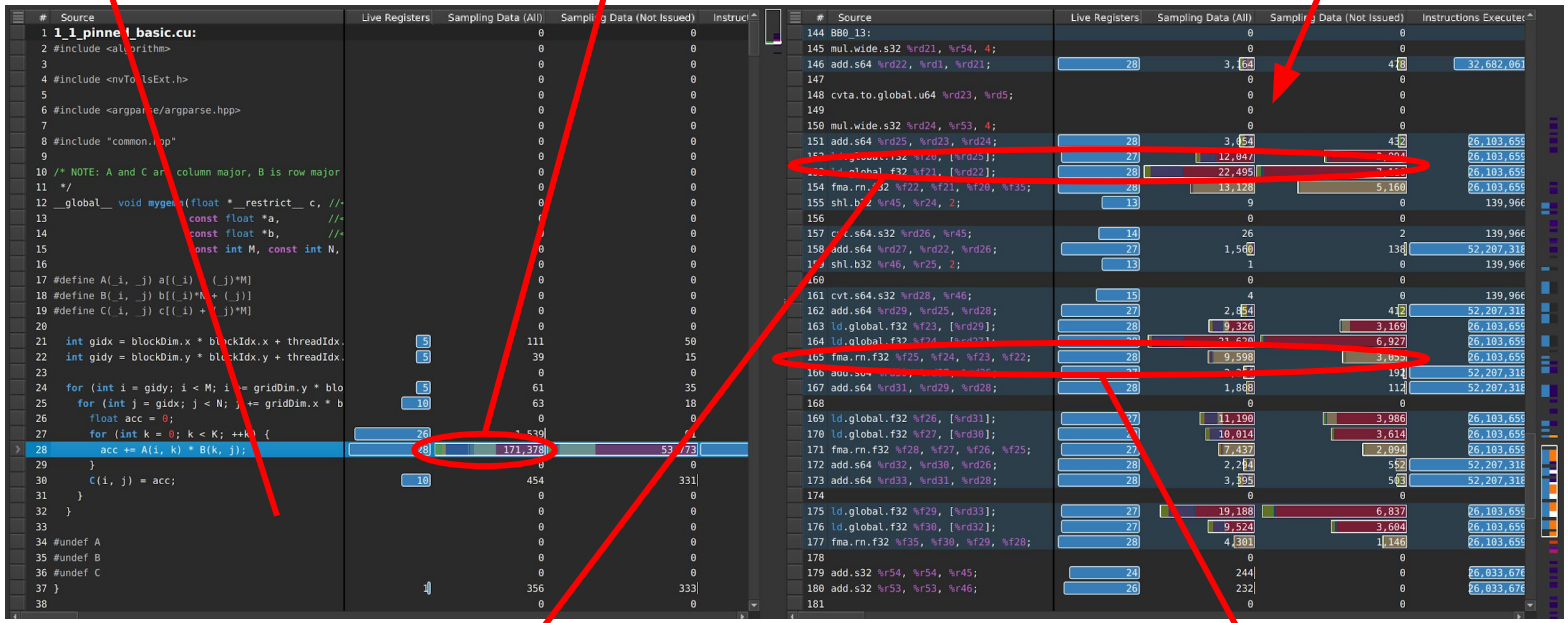
Instruction Sampling

- Every so often, the position of the program counter is recorded
- Slower instructions are more likely to be recorded
- There will be many samples in slow parts of the code, and few in fast parts of the code

Click a line to highlight lines from other side

Program counter spends most of its time on instructions from this line. Mouse over for breakdown.

Corresponding PTX/SASS lines over here.



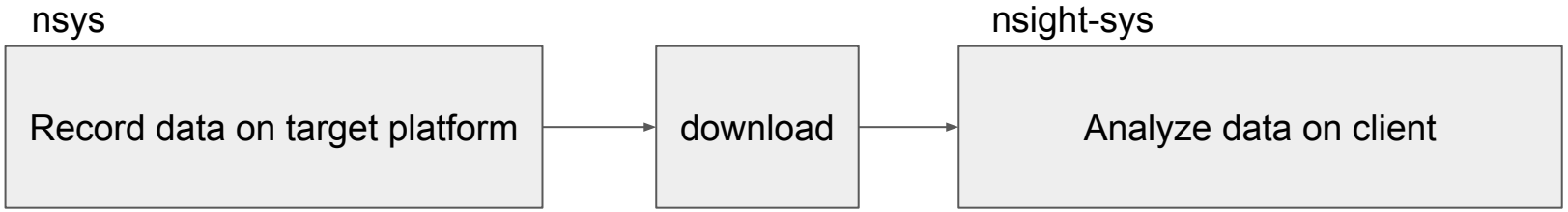
Our basic matrix multiplication spends most of its time loading from global memory

Sometimes, stalls can show in a following instruction that depends on a previous one

System Profiling with Nsight Systems

Nvidia Nsight Systems

- Deliver work to the GPU effectively
  - Understand performance of surrounding system
- Two interfaces:
  - GUI (nsight-sys)
  - CLI (nsys)
- Like Nsight Compute, use a two-part record-then-analyze flow with rai



Example Files

- Two examples to discuss
- 2-5-pinned-joint / 2_5_pinned_joint.cu
  - Joint matrix-matrix multiplication with pinned memory
- 2-6-pinned-joint-overlap / 2_6_pinned_joint_overlap.cu
  - Joint matrix-matrix multiplication with pinned memory and data transfer overlap
- Unlike previous files, these time the end-to-end copy-kernel-copy
- Same two arguments
  - `--iters` (measured iterations, default 10)
  - `--warmup` (warmup iterations, default 5)

Record kernel traces

```
$ nsys profile                \
    -o 2-5-pinned-joint       \
    2-5-pinned-joint
```

Create “2-5-pinned-basic.qdrep”

Name of the CUDA executable to profile

Do the same for 2-6-pinned-joint-overlap.

If you’re following along in rai, the `rai_build.yml` recipe does this for you when you submit the sgemm folder to rai:

```
$ cd sgemm
$ rai -p .
```

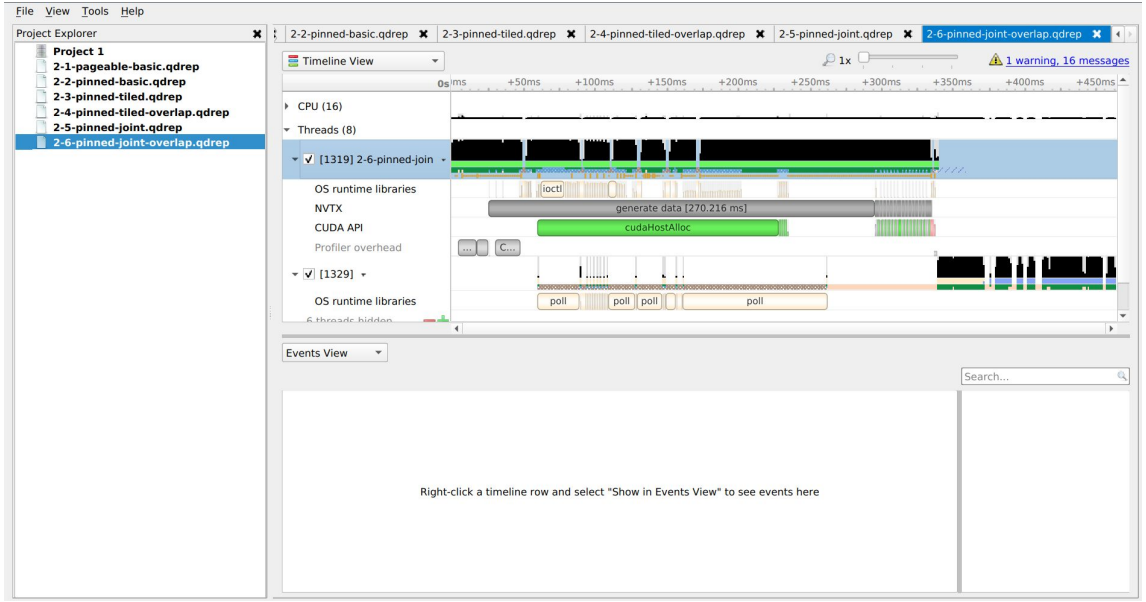
Nsight Systems

File > Open > `file.qdrqp`

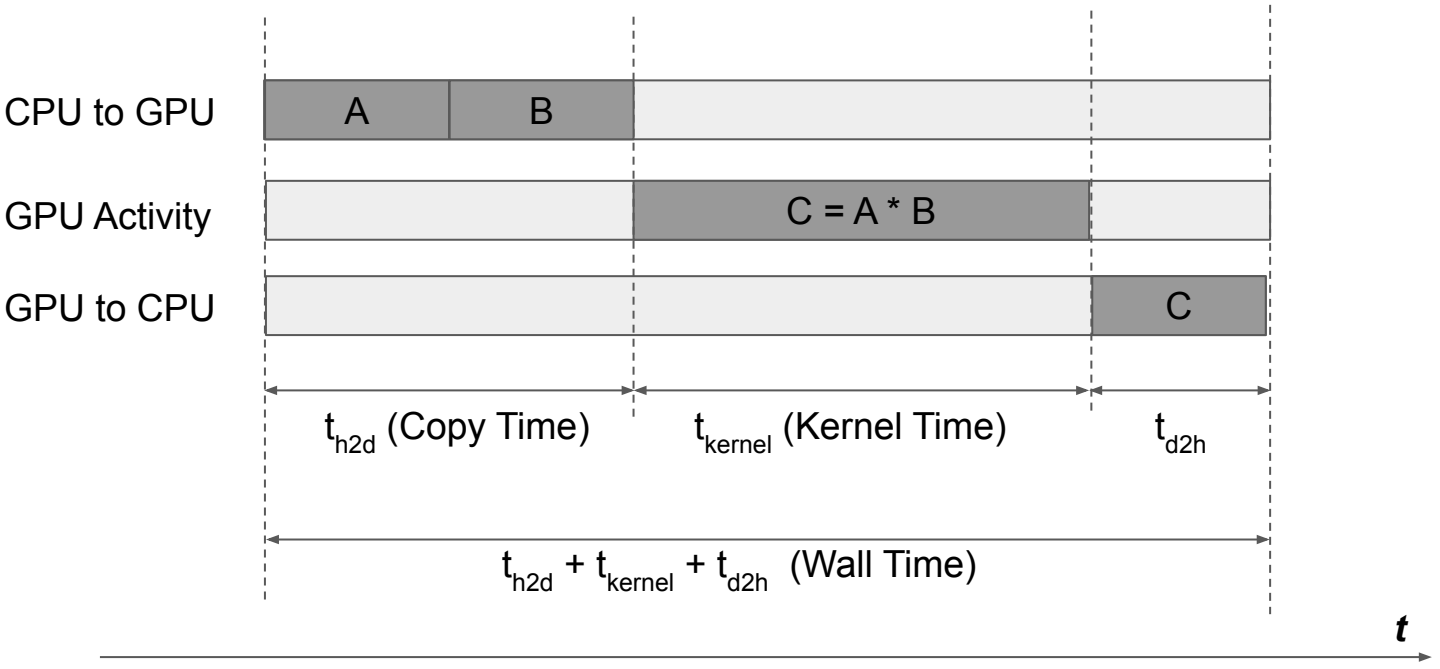
Multiple files will be open, shown on the left pane.

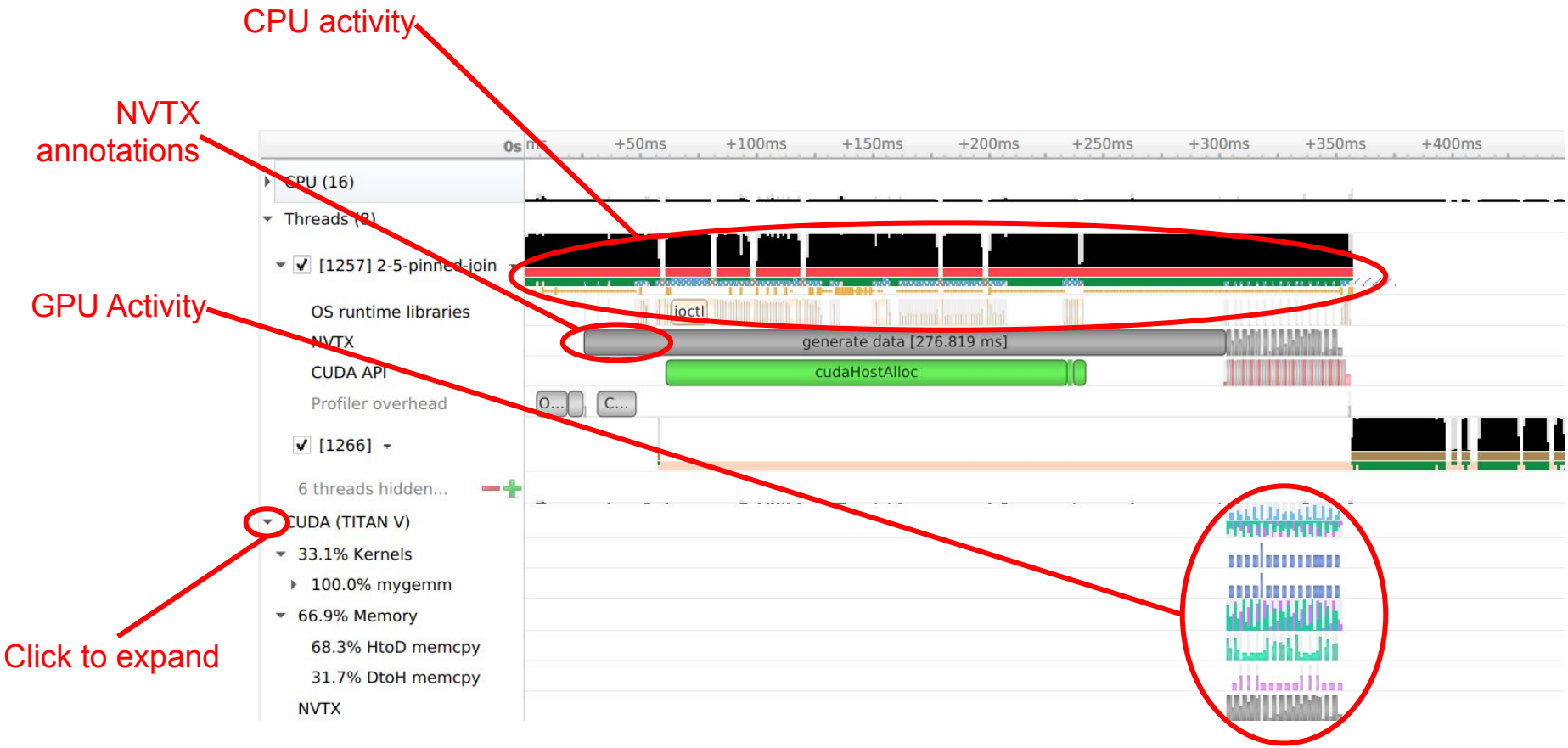
Main view is a timeline of OS calls, CUDA calls, NVTX events, CUDA API calls, and GPU activity.

Open all the `.qdrep` files from the rai build directory you downloaded.



Kernel Time vs Wall Time

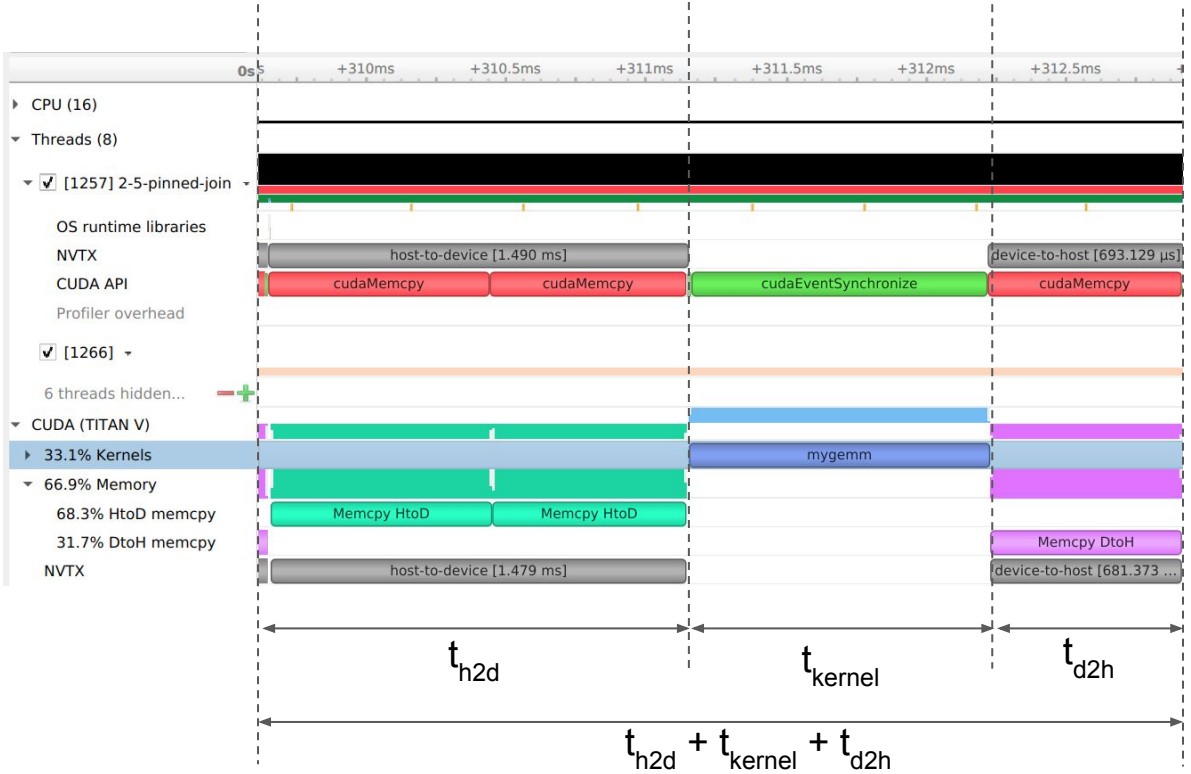



CPU activity
NVTX annotations
GPU Activity
Click to expand
0s
+50ms
+100ms
+150ms
+200ms
+250ms
+300ms
+350ms
+400ms
CPU (16)
Threads (8)
[1257] 2-5-pinned-join
OS runtime libraries
NVTX
CUDA API
Profiler overhead
[1266]
6 threads hidden...
CUDA (TITAN V)
33.1% Kernels
100.0% mygemm
66.9% Memory
68.3% HtoD memcpy
31.7% DtoH memcpy
NVTX
ioctl
generate data [276.819 ms]
cudaHostAlloc
O...
C...

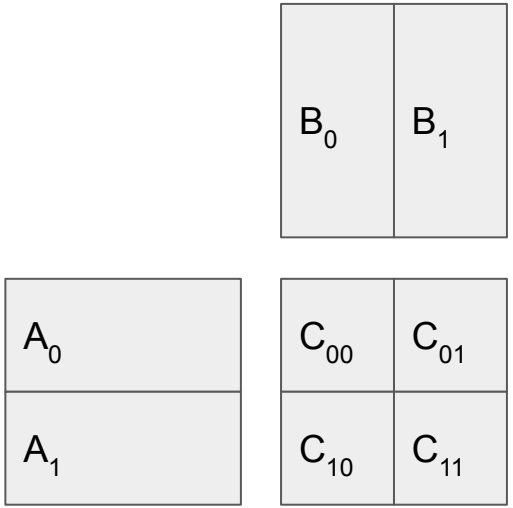
Click and drag to zoom in

Mouse over spans for more info

Real Timeline

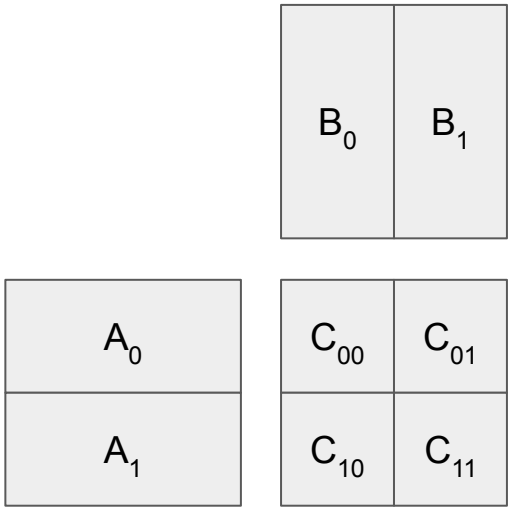


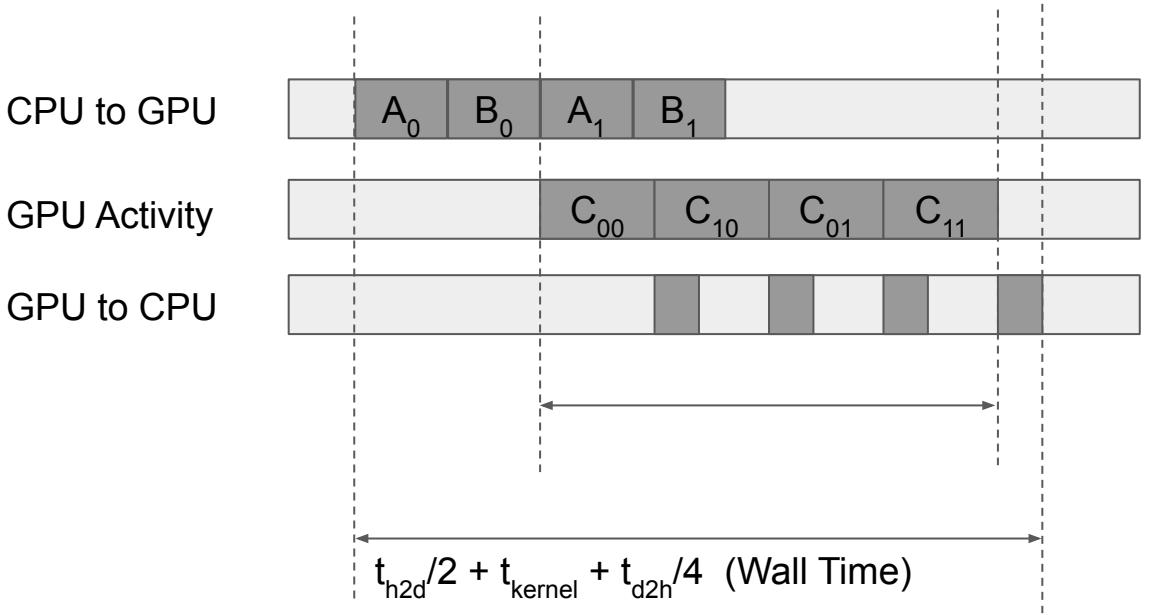
Overlap to Reduce Wall Time



- C = A * B as four multiplications.
  - $C_{00} = A_0 * B_0$: needs only A_0, B_0
  - $C_{01} = A_0 * B_1$: after C_{00}, needs only B_1
  - $C_{10} = A_1 * B_0$: after C_{01}, needs only A_1
  - $C_{11} = A_1 * B_1$: immediately after C_{10}
- Copy slices of A and B onto GPU, and immediately start the multiplication.
- Also can copy results back as soon as they're ready

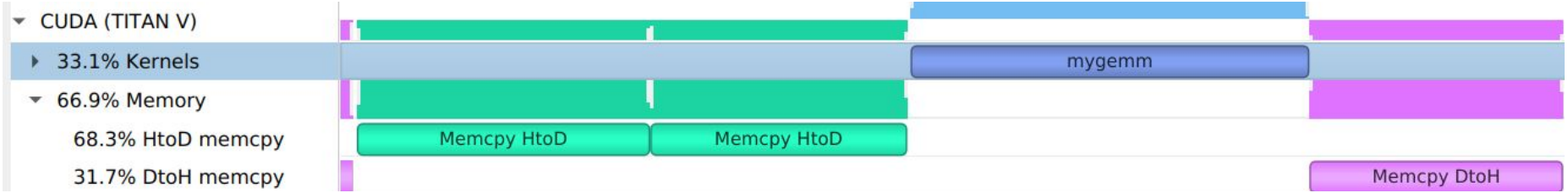
Overlap to Reduce Wall Time



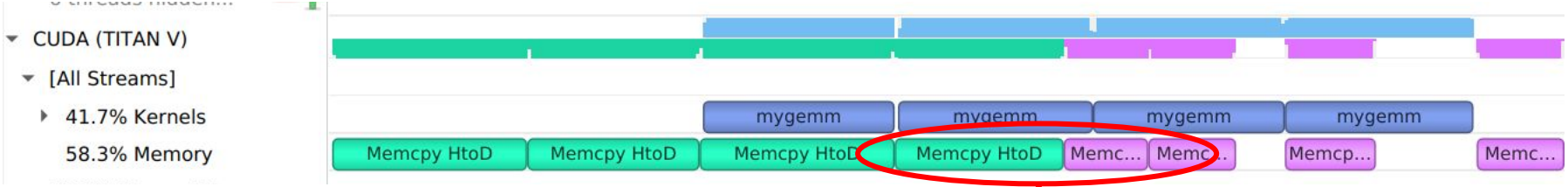


Real Timelines: Overlap

No overlap of transfer and kernel (3.5 ms)



Overlap of transfer and kernel! (2.5ms)



D2H and H2D transfers in the same stream, so they are not overlapped with each other

Questions to Explore on your Own

- Compare 2-1-pageable-basic and 2-2-pinned-basic. What is the bandwidth of the four different transfers (host-to-device and device-to-host with pageable or pinned memory)?
- Consider 1-3-pinned-joint. Can you figure out how to improve the performance of the kernel?
- Consider 2-4-pinned-tiled-overlap and 2-6-pinned-joint-overlap
  - Can you introduce a third stream to handle the device-to-host operations? Can they be overlapped with host-to-device copies? Will this improve the overall end-to-end performance?
  - If you split it into nine submatrix multiplications, can you further improve the performance? What about 16? Develop an algebraic expression to model the performance time for partitioning into P^2 submatrix multiplications.

Further Reading

- Nsight Systems Documentation
  - https://docs.nvidia.com/nsight-systems/
- Nsight Compute Documentation
  - https://docs.nvidia.com/nsight-compute/
- Nvidia Developer Blog
  - Nsight Systems Exposes GPU Optimization (May 30 2018): https://devblogs.nvidia.com/nsight-systems-exposes-gpu-optimization/
  - Using Nsight Compute to Inspect your Kernels (Sep 16 2019): https://devblogs.nvidia.com/using-nsight-compute-to-inspect-your-kernels/
  - Using Nvidia Nsight Systems in Containers and the Cloud (Jan 29 2020) : https://devblogs.nvidia.com/nvidia-nsight-systems-containers-cloud/
- Workload Memory Analysis
  - CUDA Memory Model: https://docs.nvidia.com/cuda/cuda-c-programming-guide/index.html#memory-hierarchy
  - Device Memory Access Performance Guidelines: https://docs.nvidia.com/cuda/cuda-c-programming-guide/index.html#device-memory-accesses
- Stall Reasons
  - Nsight Graphics Docs: Stall Reasons: https://docs.nvidia.com/drive/drive_os_5.1.12.0L/nsight-graphics/activities/#shaderprofiler_stallreasons
  - Issue Efficiency Nsight Visual Studio Edition: https://docs.nvidia.com/gameworks/content/developertools/desktop/analysis/report/cudaexperiments/kernellevel/issueefficiency.htm
- Occupancy:
  - Nsight Visual Studio Edition: https://docs.nvidia.com/gameworks/content/developertools/desktop/analysis/report/cudaexperiments/kernellevel/achievedoccupancy.htm

Not Discussed

- Measuring across multiple streams with CUDA events
- Profiling through the Nsight Compute GUI
  - local/remote
- Profiling through the Nsight Systems GUI
  - local/remote
- In-kernel timing with clock()/clock64()
- Custom profiling hooks with CUDA Performance Tools Interface (CUPTI)

Extra Slides

License

Preparing for Profiling: Driver

Nvidia drivers disable profiling to prevent side-channel attacks.

You may see an error when you profile, and instructions to enable.

I will not provide instructions here, as this can break your system if done wrong.

Roadmap

- SGEMM Comparison Slide
- Add Matrix Multiplication Parameters
- Server/Client Graphics
- Installing Nsight Systems and Nsight Compute
  - Linux / macOS / Windows / EWS
- Joint Matrix-Multiplication Explanation
- Definitions for Various Terms
  - Occupancy
  - Memory Hierarchy
  - Scheduling
  - cudaStreams, cudaEvents
- Description of Nsight Systems Timelines Rows

Installing Nsight Systems GUI (macOS / Windows)

- macOS
  - You probably don't have CUDA: download standalone Nsight Systems installer from Nvidia website
- Windows with CUDA
  - Nsight Systems is already installed
  - To get a newer version, download the standalone installer.
  - If multiple versions are installed, you will have multiple entries in the start menu
- Windows without CUDA
  - Download the standalone installer from the Nvidia website

Installing Nsight Systems (Illinois Linux EWS)

As of April 15, 2020.

EWS Runs Centos 7.7.

Download the Linux runfiles for Systems from the Nvidia website

```
ssh -Y <netid>@linux.ews.illinois.edu
chmod +x ././NVIDIA_Nsight_Systems_Linux_2020.2.1.71.run
./NVIDIA_Nsight_Systems_Linux_2020.2.1.71.run
Put the prefix as /home/pearson/nsight-systems-2020.2.1
```

Run as ./nsight-systems-2020.2.1/bin/nsight-sys &

Installing Nsight Compute (Illinois Linux EWS)

As of April 15, 2020.

EWS Runs Centos 7.7, has cuda 10, and an old version of Nsight Compute in /software/cuda-10/Nsight-Compute-1.0. To update:

Download the Linux runfiles for Compute

ssh -Y <netid>@linux.ews.illinois.edu
chmod +x ./nsight-compute-linux-2019.5.0.14-27346997.run
./nsight-compute-linux-2019.5.0.14-27346997.run
Put the prefix as /home/netid/NVIDIA-Nsight-Compute-2019.5
Do not try to put a symlink at /usr/…

This does not launch

Installing Nsight Systems GUI (Linux)

- Linux with CUDA
  - May already be present: `/usr/local/cuda/bin/nv-nsight-cu`
- Linux without root
  - Download the run file, and give it a prefix in a directory of your choice
  - Update your path to include the install location
- Linux with root
  - runfile: Download the runfile, be aware it may overwrite CUDA's installation
  - package: Download and install the package. Your OS may automatically handle the default version that will run. Be aware of which version you run.