gem5 GPU Accuracy Profiler (GAP)

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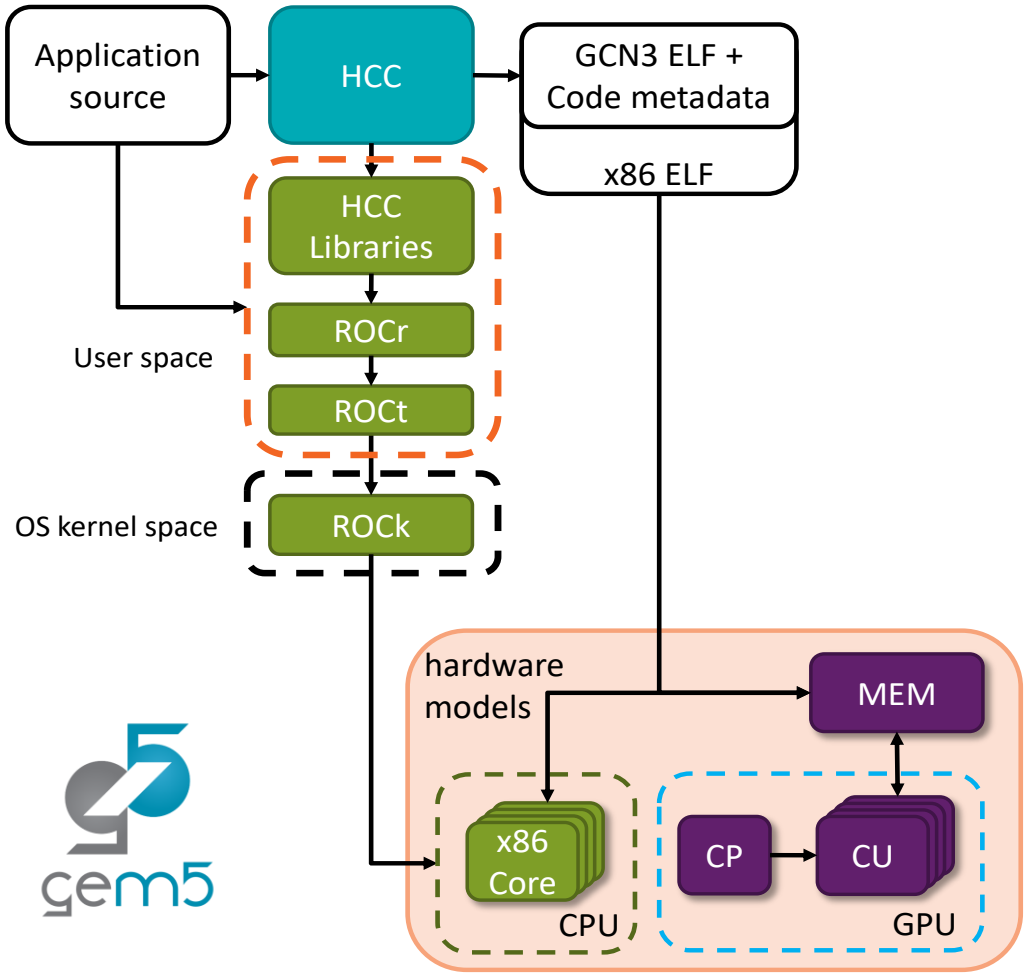
Prior CPU-GPU Support in gem5



[Gutierrez et al., HPCA '18]

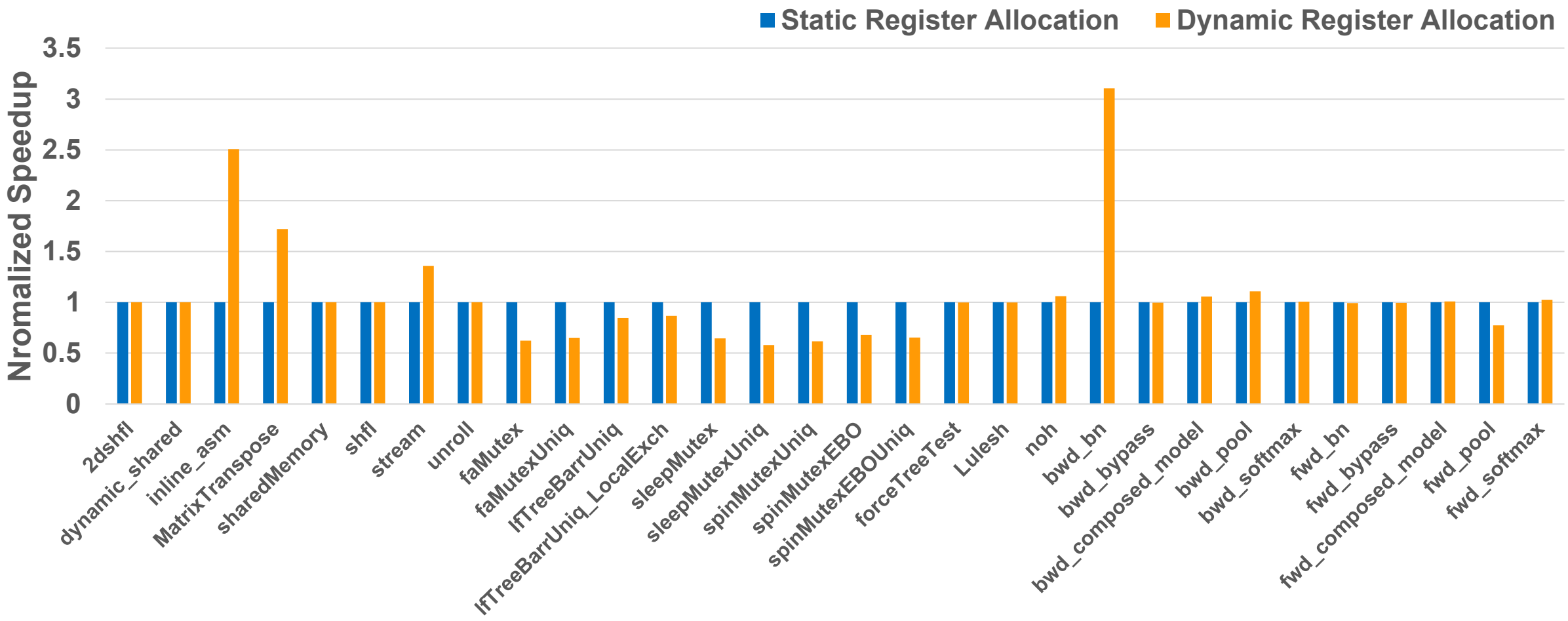
- Execution-driven, cycle-level
  - Accurately models complex CPUs & GPUs
  - Rapid prototyping of new features
  - Validate simulation with execute-in-execute
- Runs ROCm 4.0 user stack
- Simulates HIP applications

Improving Register Allocation Support

- Simple dependence tracking – only 1 wavefront/CU at a time
  - Even if sufficient registers are available for more WFs
- Issue: unrealistic relative to real GPUs
- Solution: add dynamic register allocator [Bruce et al. ISPASS '20]
  - If enough registers available, schedule additional WFs concurrently/CU
  - Potentially can utilize all WF slots depending on register requirements
  - More complex, higher performance designs possible

Intuition: Dynamic allocator significantly improves accuracy

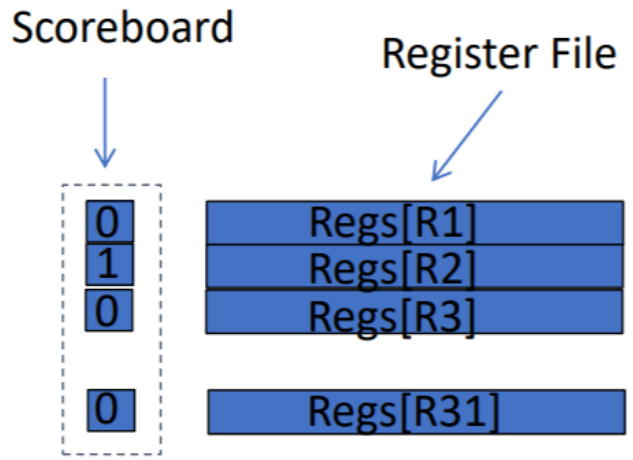
Dynamic Register Allocator Performance



Reality: dynamic register allocator 6% worse than simple – why?

Issue: Dependence Tracking

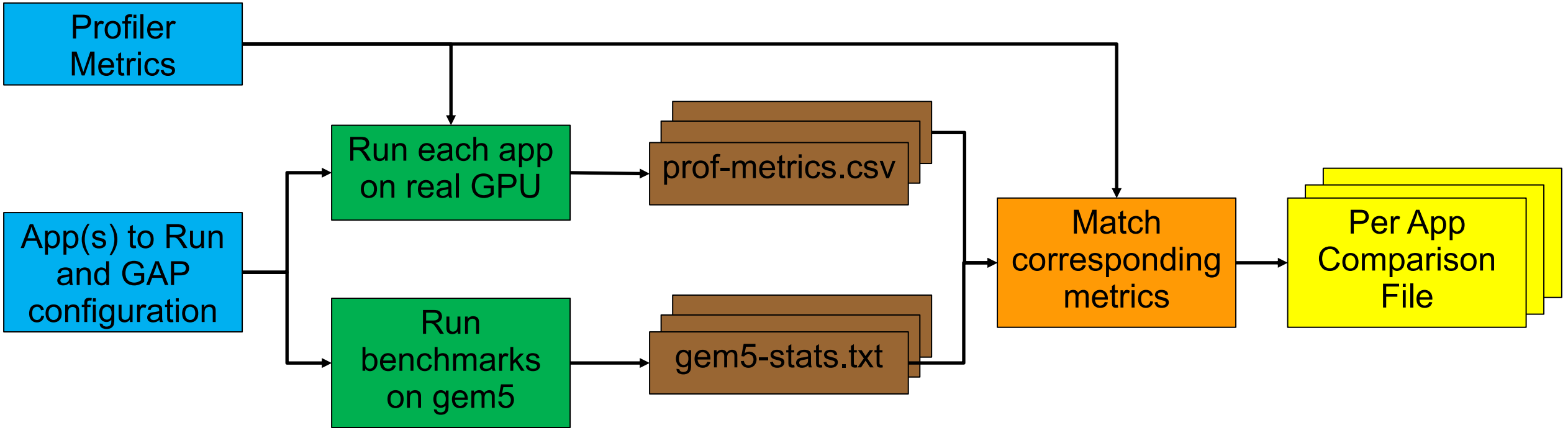
- GPU model did not track dependencies well → many stalls
  - Result: optimizing register allocation in isolation was insufficient
- Issue: Proprietary GPU dependence checking sols unknown
- Solution: simple, in-order scoreboard
  - Bit per register to track use status
  - Cleared on instruction completion
  - Checks for RAW/WAW hazards



Result: up to 44% reduction in stalls

How Does GAP Work?

- Issue: need standard approach for evaluating new configurations
- Solution: gem5 GPU Accuracy Profiler (**GAP**)



Using GAP to iteratively refine gem5 GPU models

How to Run GAP?

- Need three things:
  1. Executables to run and their input args (for both GPU & gem5)
  2. gem5 settings (i.e., input args to simulator)
  3. Metrics to collect from real GPU and gem5

- 1 & 2: configuration input file; 3: separate metrics input file
- To run: `python3 gap.py -c <configFile>`

Example Setup (Vega 20 GPU)

- Example configuration file (1/2)
  - Tells GAP what benchmark(s) to run

```
#List of executables to collect metrics from
#Include any executable specific arguments
[EXECUTABLES]
bench1 = gem5-resources/src/gpu/square/bin/square
bench2 = BabelStream/hip-stream -n 2 -s 16777216 --triad-only
…
```

Example Setup (Vega 20 GPU)

- Example configuration file (2/2)
  - Settings: tell gem5 what and where to run

```
[SETTINGS]

gem5 = /path/to/gem5 #path to the directory containing gem5

output_dir = ./outdir     #output destination directory

docker_image = gcr.io/gem5-test/gcn-gpu:v21-1 #docker image used for gem5

gem5_script = gem5/configs/example/apu_se.py #gem5 python configuration file

# Any flags input to the gem5 config file (optional)

script_flags = --num-compute-units=60 --cu-per-sa=15 --num-gpu-complex=4 --reg-alloc-
policy=dynamic  --barriers-per-cu=16 --num-tccs=8 --bw-scalor=8  --num-dirs=64 --mem-
size=16GB --mem-type=HBM_1000_4H_1x64 --vreg-file-size=16384 --sreg-file-size=800

#rocprof input file (specifies profiler behavior and which metrics to collect)

rocprof_metrics = metric.txt
```

Example Setup (Vega 20 GPU)

- Example GPU metrics file

```
pmc : FetchSize VALUInsts Wavefronts FlatVMemInsts
pmc : WriteSize SALUInsts LDSInsts VWriteInsts
pmc : MemUnitBussy MemUnitStalled TCC_HIT_sum LDSBankConflict
pmc : LDSInsts TCC_MISS_sum VALUUtilization
```

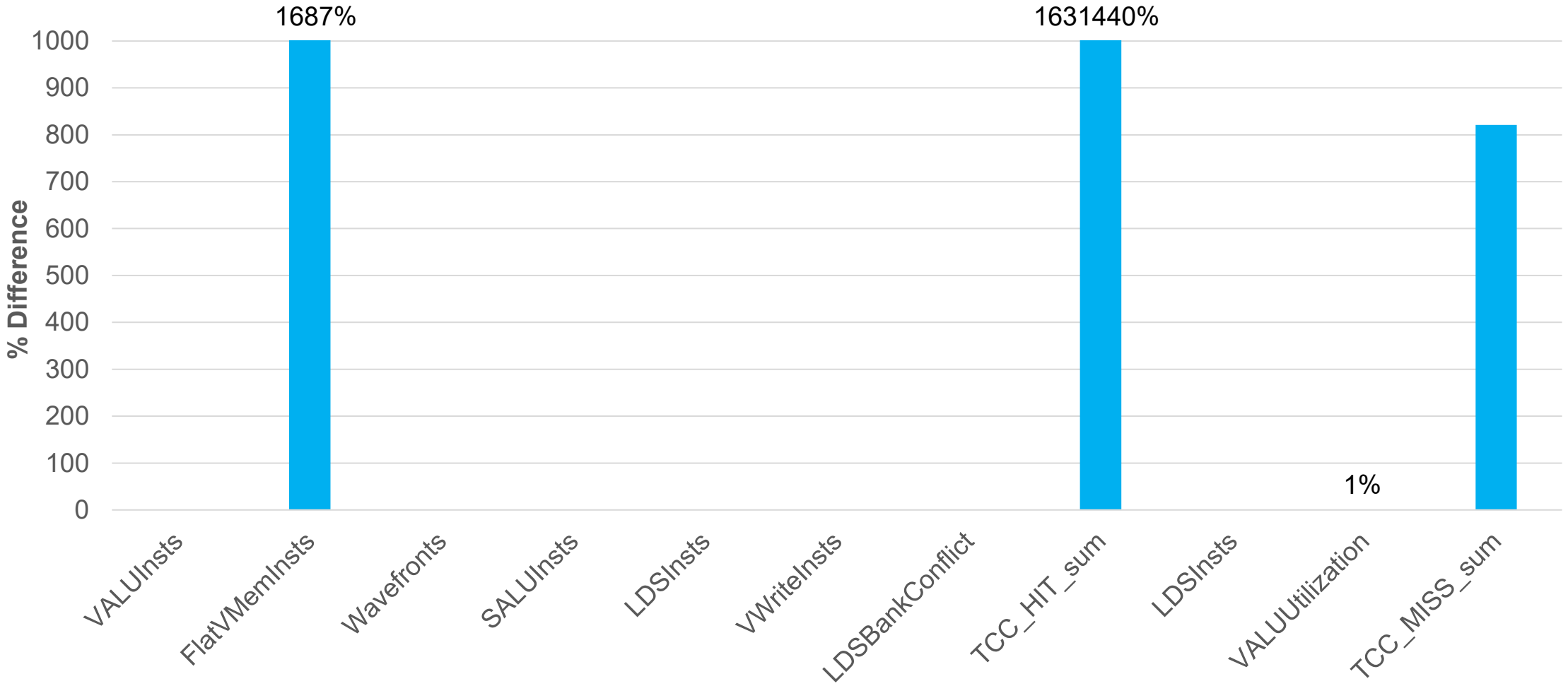
- “pmc”: tells rocprof which HW counters to collect per run
  - May need multiple lines because limited HW counters on GPU
  - rocprof will run application once per “pmc” line on real GPU

Example Results (Vega 20 GPU) (1/2)

- Example Output file (for square):

```
Metric, rocprof measurement, gem5 measurement, Absolute difference, % Difference
VALUInsts,120,120,0,0.0
FlatVMemInsts,15,268,253,1686.6666666666667
Wavefronts,2048,2048,0,0.0
SALUInsts,19,19,0,0.0
LDSInsts,0,0,0,0
VWriteInsts,0,0,0,0
LDSBankConflict,0,0,0,0
TCC_HIT_sum,184,3002034,3001850,1631440.2173913044
LDSInsts,0,0,0,0
VALUUtilization,99,100,1,1.0101010101010102
TCC_MISS_sum,63401,583906,520505,820.9728553177393
```

Example Results (Vega 20) (2/2)



Stats well correlated (<= 1% difference) for vector ALU stats, but poor for memory

Need to isolate stats for specific components to properly fix this

Next Step: Additional Microbenchmarks

- Goal: isolate behavior of different components
  - Via GAP, can refine latencies, bandwidths, etc.
- Current tests (handwritten HIP assembly kernels)
  - L1 I$ size & latency
  - L1 D$ size, latency, & bandwidth
  - LDS (scratchpad) latency & bandwidth
  - L2 $ latency & bandwidth
  - Main memory latency & bandwidth
  - GPU STREAM peak bandwidth
  - max FLOPs, Arithmetic latency for various operations, …

Conclusions & Future Work

- Having validated gem5 models is important
  - Existing GPU model does not always behave intuitively
  - Point solutions **insufficient**
- Solution: More automated framework (**GAP**)
  - Results: memory system seems to need the most attention
  - Potentially can be applied to other, non-GPU models
  - Goals:
    - Use microbenchmarks to tune for minimum absolute error in GPU model
    - Release tool (& GPU improvements) publicly
    - Performance regression testing integrated into gem5

Backup

Frequently Asked Questions (1/2)

- What do I need to use GAP?
  - A computer with a (supported in gem5) AMD GPU
- What mode(s) work with GAP?
  - Currently only SE mode support
- How does GAP run things on hardware?
  - Uses rocprof (AMD's GPU profiling tool) to run application(s)
    - User must specify metric(s) they want to compare (input file to GAP)
    - Can add a new metric (hardware counter) by updating input file
  - Compares hardware counter results to gem5 stats
    - We have created a 1-1 mapping between GPU stats and gem5 stats

Frequently Asked Questions (2/2)

- What is output format?
  - CSV
- What if gem5 has a metric rocprof doesn't (or vice-versa)?
  - GAP cannot support these at the moment
  - Could gather results, but could not compare them

More GAP Setup Info

- To run GAP user must first specify a few items for gem5
  - Must be placed under the [SETTINGS] header
  - All fields are required unless specified.

Config File Parameter	Description
gem5	Absolute path to gem5 directory
output_dir (optional)	Relative path to directory to put output in
docker_image (optional)	Docker image to run (e.g., with gem5 GPU model)
gem5_config_script	Path to gem5 Python configuration script
script_flags	Flags to pass into gem5 configuration script
rocprof_metrics	File that specifies metrics rocprof should collect
rocprof_flags (optional)	Flags to pass into rocprof