GPUscout

Locating Data Movement-related Bottlenecks on (for now NVidia) GPUs

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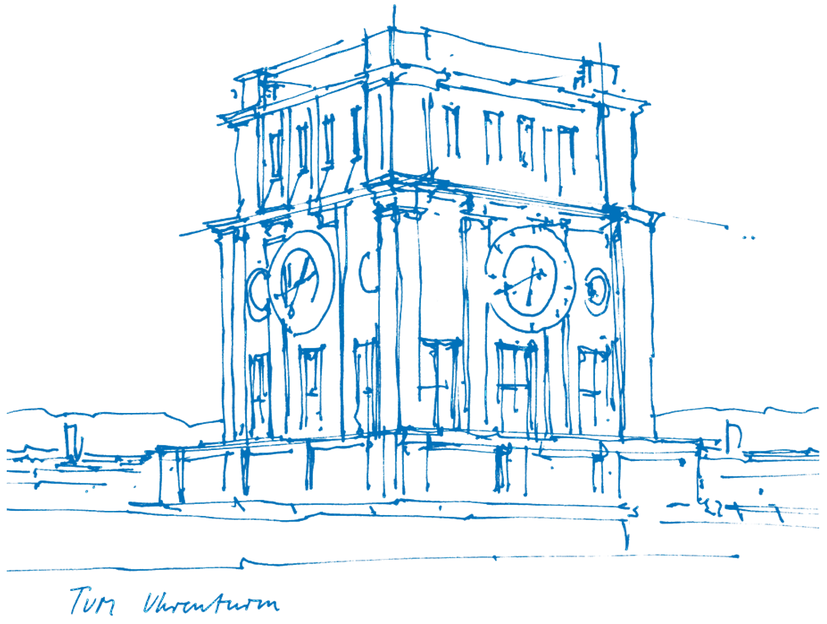


GPUscout

A tool for identifying data movement-related bottlenecks in GPU kernels

- *Only data movements within a GPU*
- *Only NVidia GPUs for now*

Main objectives

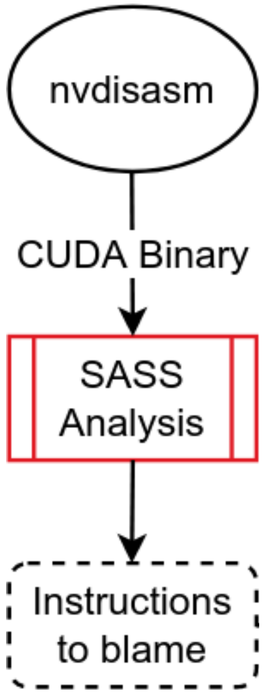
- Discovers and identifies the problematic behaviour
- Provides information about the severity and offers metrics to verify improvements
- Points the user directly to detected instruction and line of source code

What GPUscout builds on?

…on NVidia GPUs.

1. **SASS** (and PTX)
    - Assmeblies in CUDA
2. CUPTI
    - Provides data for profiling and tracing tools
    - GPUscout uses the **PC Sampling API** of CUPTI (Warp stalls)
        - Provides: stall reasons, source code line
3. Nsight Compute CLI (**ncu**)
    - Kernel-wide performance counters

Architecture of GPUscout



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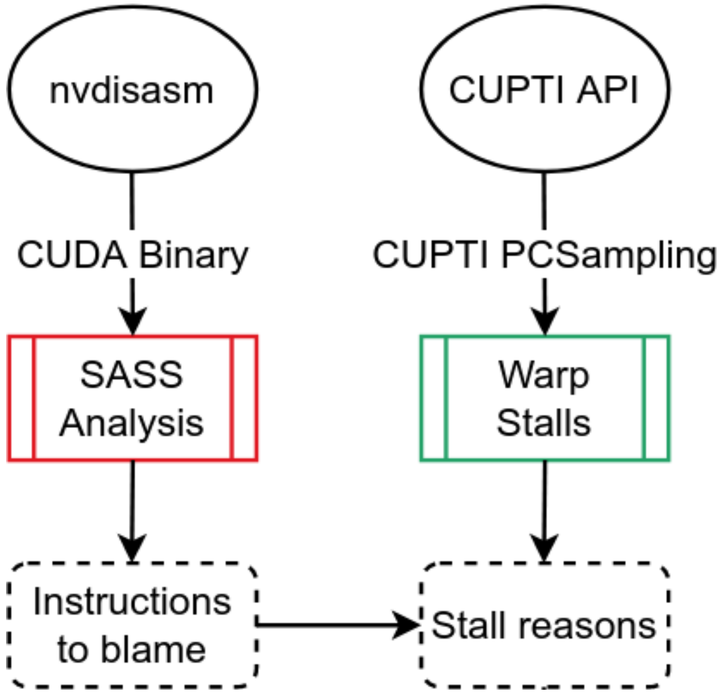
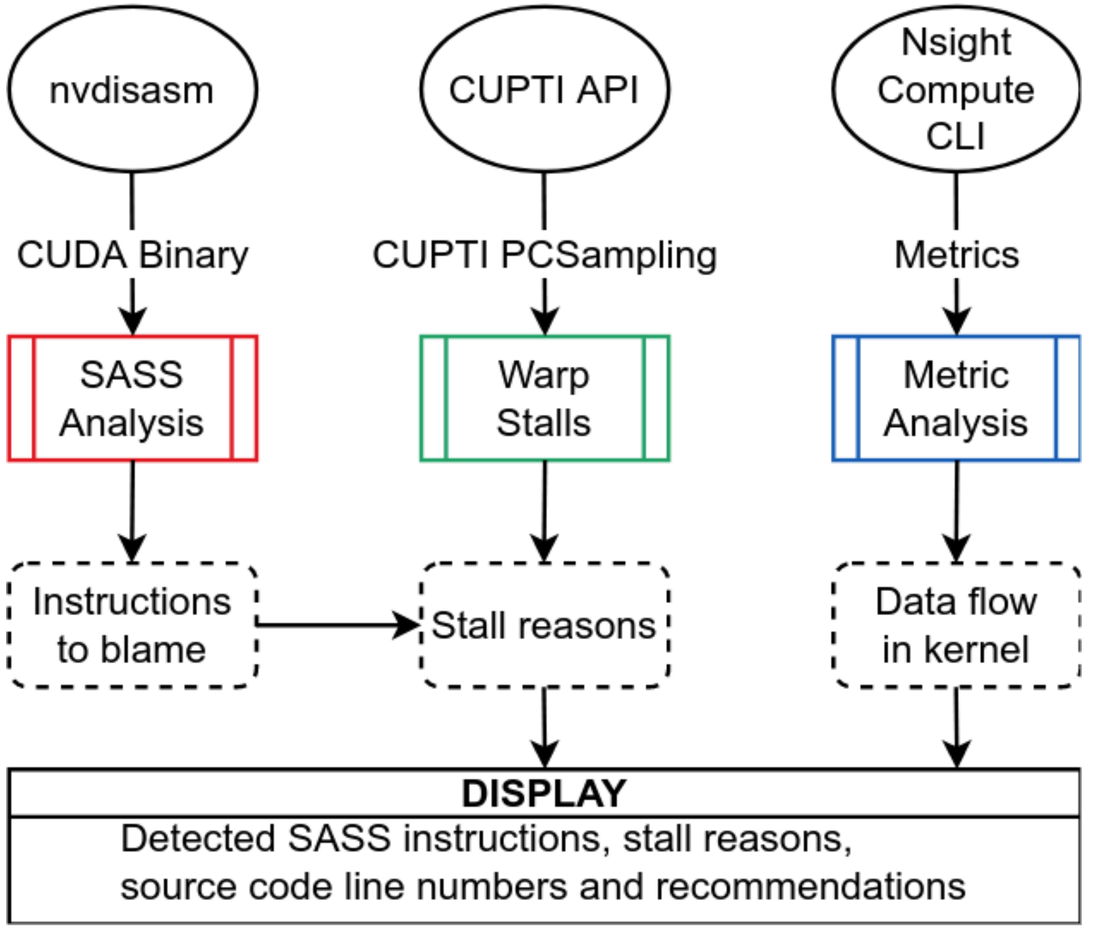


Architecture of GPUscout



Bottlenecks Analysis

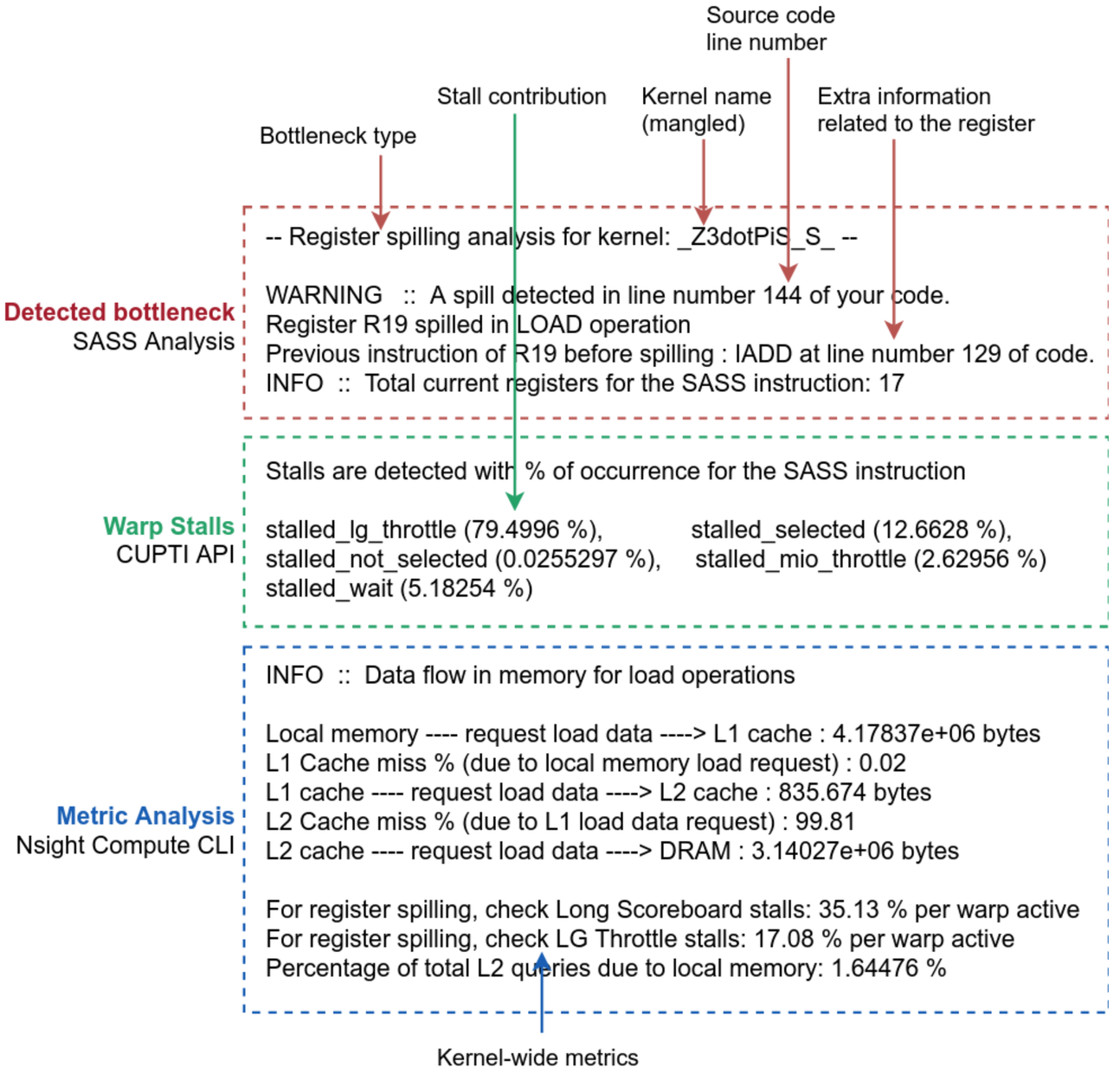
- **SASS analysis** at heart of GPUscout
  - Searching for specific code patterns
- **Warp stalls** for identified code line
- Kernel-wide **metrics** provide overview of data movements
- Additional metrics displayed for specific bottlenecks

Analyses

1. Vectorized Loads
2. Register Spilling
3. Shared Memory
4. Shared Atomics
5. Read-only Cache
6. Texture Memory
7. Datatype Conversions

…we want to add more!

GPUscout Analysis



Mixbench

Use-case 1

Mixbench

Use-case 1

- Benchmarking suite for mixed operational intensity kernels
- CUDA implementation mixbench-cuda
- Executes MAD operations

GPUscout analysis:

1. Use Shared Memory
2. Use Vectorized Loads

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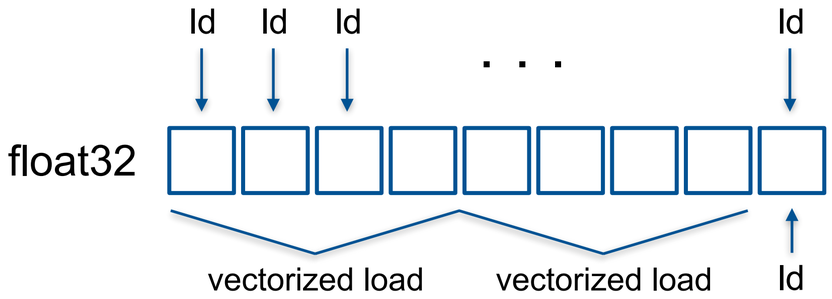
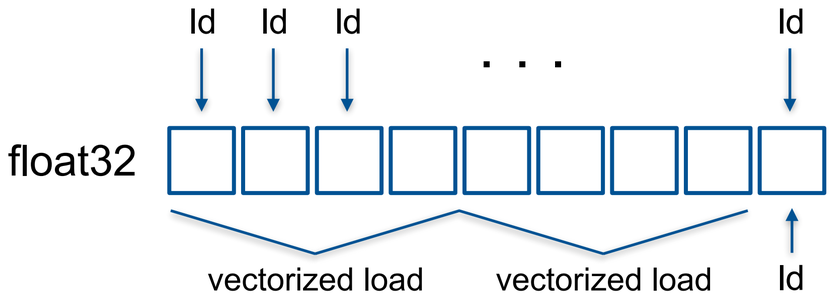


Mixbench

Use-case 1

2. Use Vectorized Loads




```
for(int j=0; j<granularity; j++)
 tmps[j] = g_data[...];
 ...
 for(int i=0; i<compute_iterations; i++)
  tmps[j] = mad(tmps[j],tmps[j],seed);
```

```
for(int j=0; j<granularity/4; j++)
 reinterpret_cast<float4*>(tmps)[j] =
  reinterpret_cast<float4*>(g_data)[...];
 ...
 for(int i=0; i<compute_iterations; i++)
  reinterpret_cast<float4*>(tmps)[j] =
   mad(reinterpret_cast<float4*>(tmps)[j],
   reinterpret_cast<float4*>(tmps)[j],seed);
```

Mixbench

Use-case 1

2. Use Vectorized Loads

Warp stalls:

\+ Long scoreboard ↓ **62%** (originally 70%)

Metric Analysis:

– SM Occupancy ↓ **83%** (originally 92%)

➡ **Speedup of 3.77x**

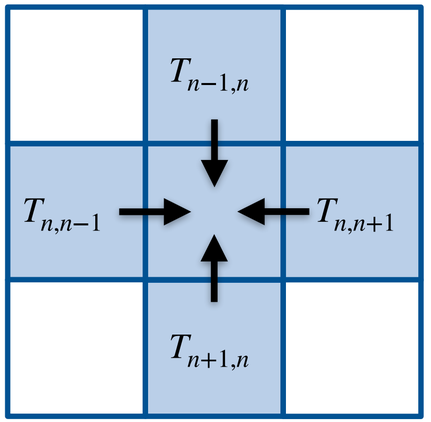
Heat Transfer Simulation

Use-case 2

Heat Transfer Simulation

Use-case 2

- Jacobi iterative solver for 2D
- $T_{NEW} = T_{OLD} + k * (T_{TOP} + T_{BOTTOM} + T_{LEFT} + T_{RIGHT} - 4 * T_{OLD})$
- GPUscout analysis:
  1. Use Texture Memory (or Use Shared memory)
  2. Use Vectorized Loads
  3. Using __restrict__ keyword
  4. Minimizing Datatype Conversions



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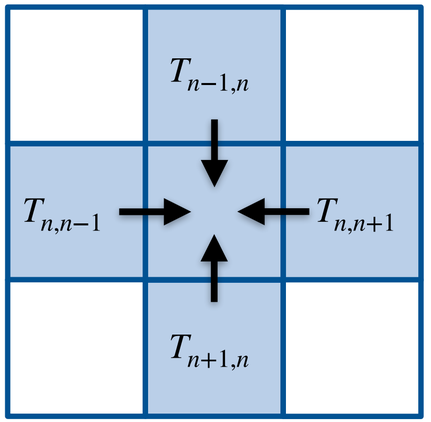

Heat Transfer Simulation

Use-case 2

1. Use Texture Memory

```
== texture memory analysis for kernel: 2D-stencil-naive  ==
WARNING  ::  Use texture memory for register number (written-to): R4 at line
↪  number 6 of your code. The data is read from register number: R4
No spatial locality found for the register data
Stalls are detected with % of occurence for the SASS instruction
stalled_wait (66.6667 %), stalled_selected (33.3333 %)

WARNING  ::  Use texture memory for register number (written-to): R28 at line
↪  number 6 of your code. The data is read from register number: R2
Spatial locality found for the register data
Stalls are detected with % of occurence for the SASS instruction
stalled_wait (14.2857 %), stalled_lg_throttle (85.7143 %)

INFO  ::  Check data flow in texture memory, if you modify your code to use
↪  textures
Kernel ---- request load data ----> Texture Memory 0 instructions
Texture memory ---- request load data ----> L1 cache 0 bytes
L1 Cache miss % (due to texture memory load request) 100
L1 cache ---- request load data ----> L2 cache (due to texture memory load
↪  request) 0 bytes
L2 Cache miss % (due to L1 load data request) 23.89
L2 cache ---- request load data ----> DRAM 0 bytes
If using texture memory, check Tex Throttle: 0 %
If using texture memory, check Long Scoreboard: 37.79 %
```

Heat Transfer Simulation

Use-case 2

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Kernel Metrics

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stalled_wait: Warp stalled waiting for a execution dependency of a fixed-latency instruction. Caused mostly because of an already highly optimized kernel.

stalled_lg_throttle: Warp stalled waiting for the L1 instruction queue for local and global (LG) memory operations. Caused mostly because of executing local or global memory instructions too frequently.

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1. Use Texture Memory
   - – TEX throttle ↑ **25%** (originally 0%)
   - \+ Long Scoreboard ↓ **27%** (originally 38%)
   - \+ Throughput ↑ **61%**

➡ **Performance improvement of 39.2%**

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3. Using __restrict__ keyword

Heat Transfer Simulation

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➡ Performance improvement of only **0.3%**

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4. Minimizing Datatype Conversions
    - Impossible to avoid

Next Steps

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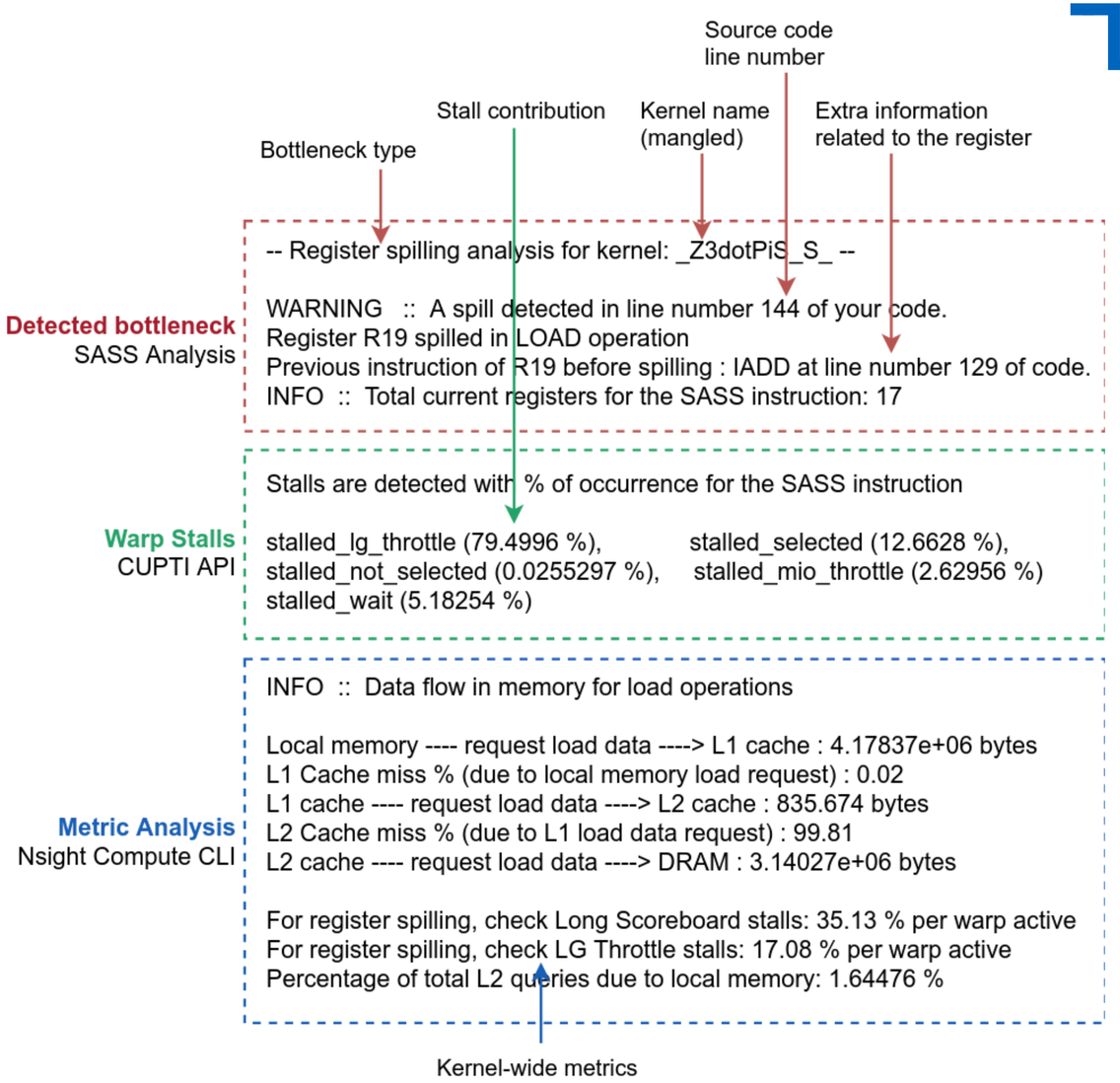
- **Interactive visual front-end** (work just started)



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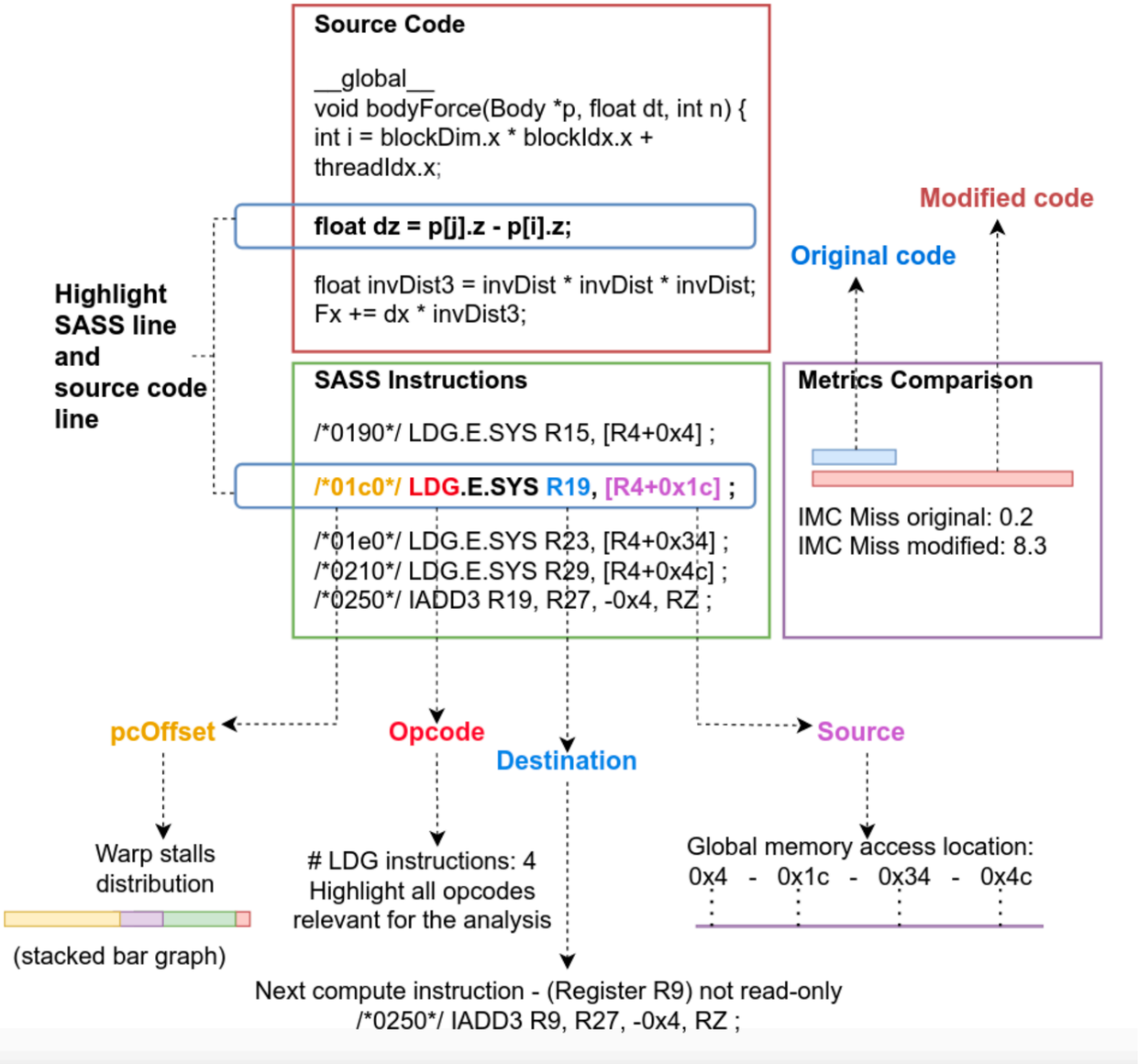

Next Steps

- **Interactive visual front-end** (work just started)
- **Add GPU memory topology information**
  - We have data available through the sys-sage library
- **Extend to AMD GPUs** (work just started)
  - *Is the SW and HW support on AMD side sufficient?*
- Add more analyses/bottlenecks
  - Coalescing, ???
- Smaller tweaks:
  - Option to analyze only a specific kernel, specific bottlenecks

GPUscout

- A tool that focuses on detecting memory-based bottlenecks on NVidia GPU kernels
- Combines static code analysis, sampling PC Stalls, and providing kernel-wide metrics
- Attributes the observed pattern directly to the related source code line
- GPUscout recommendations bring a speedup of 3.77x and 1.64x on presented kernels

Try out GPUscout and get in touch with us!

https://github.com/caps-tum/GPUscout

spack install gpuscout

stepan.vanecek@tum.de