Portable and Transparent Host-Device Communication Optimization for GPGPU Environments

Christos Margiolas, Michael F.P. O'Boyle

University of Edinburgh
Institute for Computing Systems Achritecture

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Host-Device Communication

What is Host-Device Communication?

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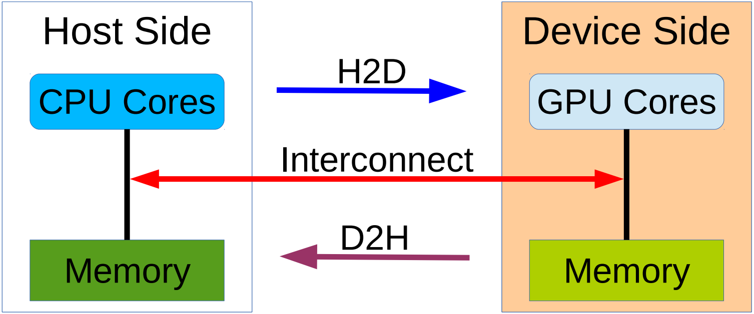

- H2D: Host to Device Communication
- D2H: Device to Host Communication

Computation Offloading

Why Host-Device Communication is required?

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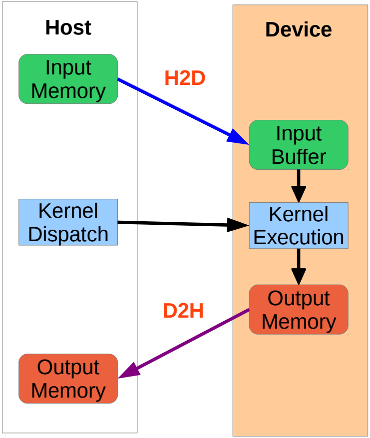

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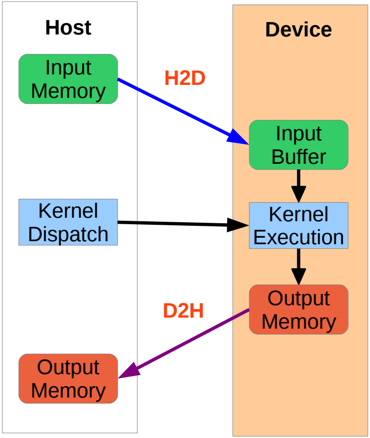

Computation offloading requires:

- **H2D** Transfer of Input Data
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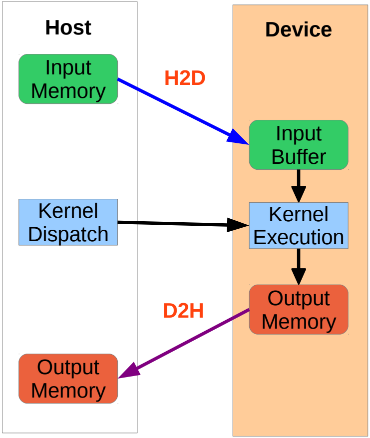

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Communication Overhead

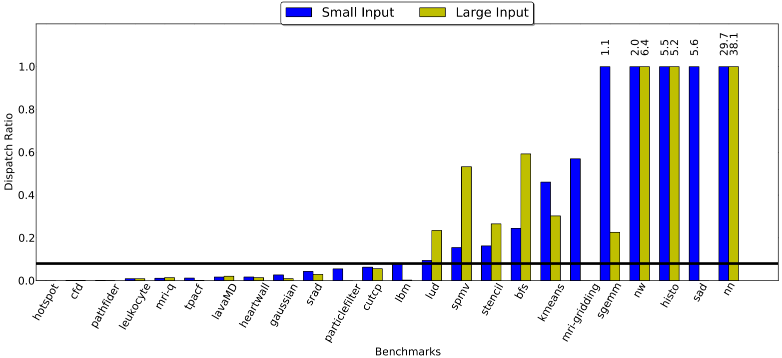
What is the impact of communication overhead on application execution?

Quantifying the communication overhead

$$\text{Dispatch Ratio} = \frac{\text{Cumulative Host-Device Communication Time}}{\text{Cumulative Device Computation Time}}$$

Quantifying the communication overhead (2)

Dispatch Ratio across Parboil and Rodinia benchmarks



Communication Overhead

Significant to extremely high overhead for 12 benchmarks in total.

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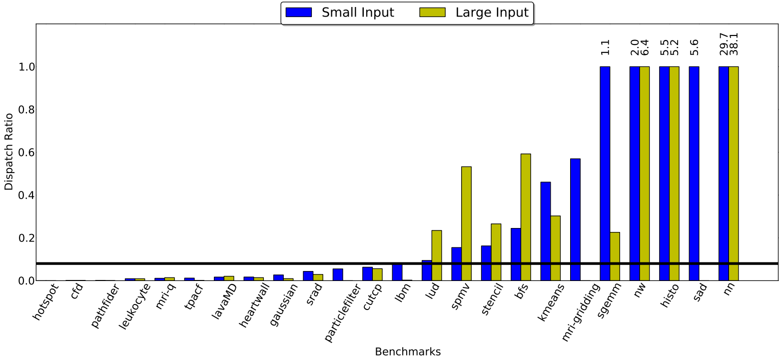

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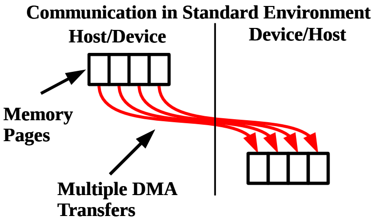
Reducing Communication Overhead

Can we reduce the communication overhead?

Memory Allocation affects Communication Performance



Standard Allocation:

- Mem. Pages Swappable
- Transfer per page
- Unsteady Performance

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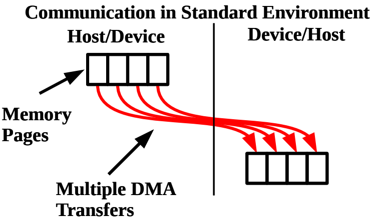

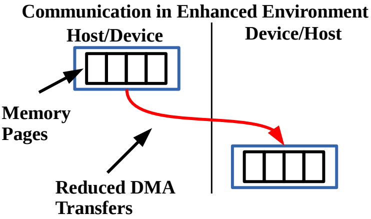

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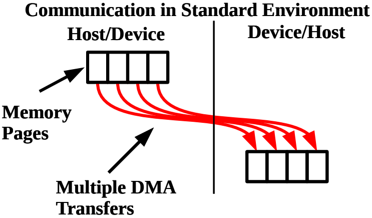

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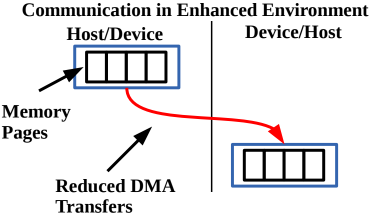

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Issue 1: Platform capabilities

Multiple allocation policies available and affect Host-Device Communication. Need to quantify and compare them.

Few Mem. Allocations used in Host-Device Communication

```
s=malloc(...);
… code...
a=malloc(...);
H2D(s);
...code...
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D2H(r);
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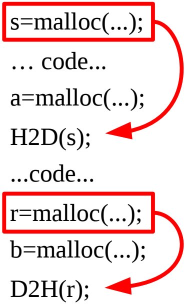
Few Mem. Allocations used in Host-Device Communication



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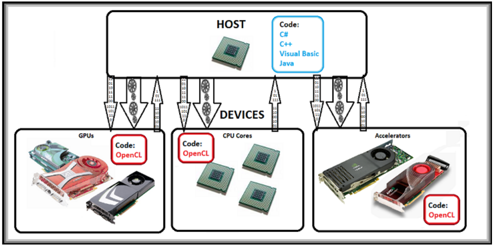
Issue 2: Application Behavior

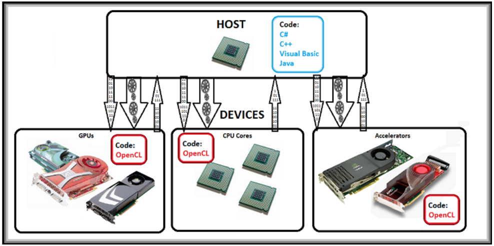
Need to **detect the memory allocations that are used in Host-Device communication**. The goal is to serve them with the allocation policy that leads to the highest communication rates.

Portability and Transparency



Processor Types:
CPUs,GPUs,HSA,DSPs,FPGAs
Programming Interface:
OpenCL

Portability and Transparency



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Target Platform remains unknown until the execution time.

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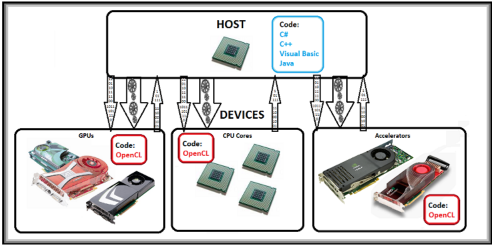

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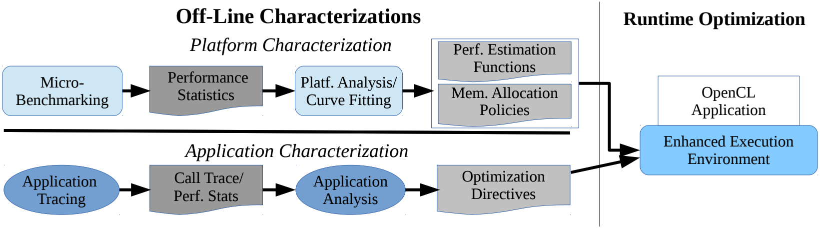
Issue 3: Portability and Transparency

Need for optimizations portable across platforms and transparent to applications and runtime libraries.

Optimization Overview



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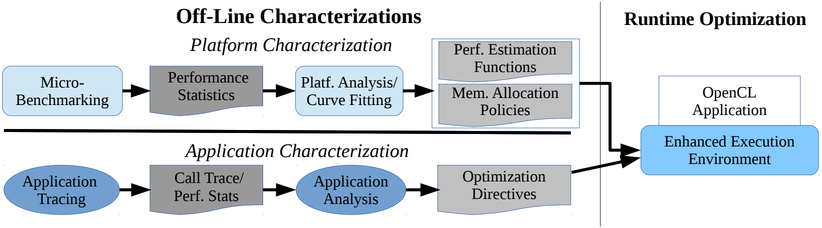

- **Platform Characterization** discovers the memory allocation and host-device communication capabilities of the platform.

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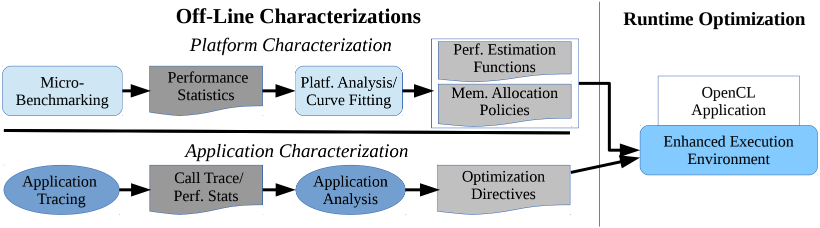

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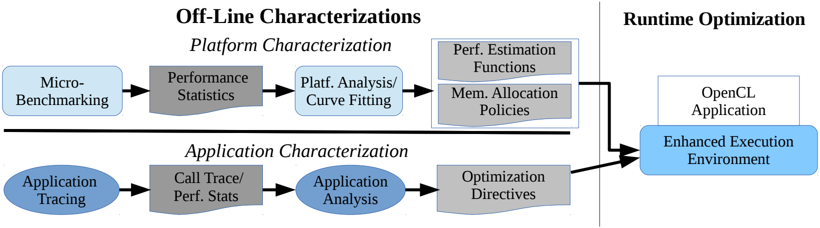

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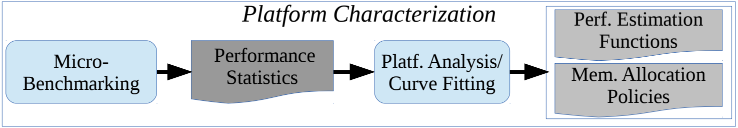
- **Application Characterization** detects the memory allocations that are used in host-device communication.
- **Runtime Optimization** uses both characterizations for the runtime optimization of the application.

Platform Characterization / Micro-benchmarking



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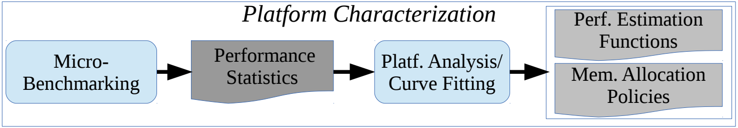

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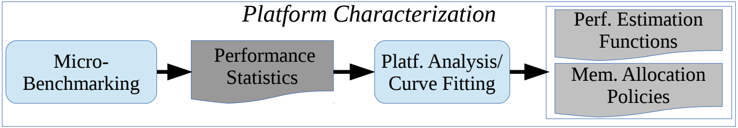

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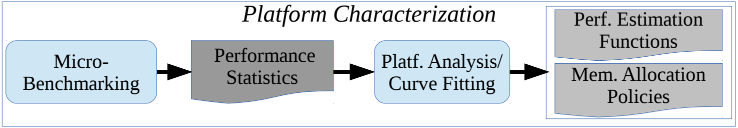

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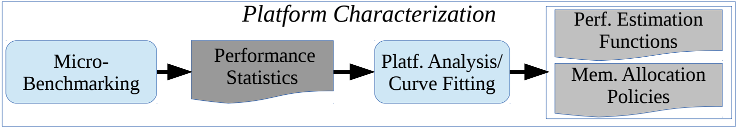

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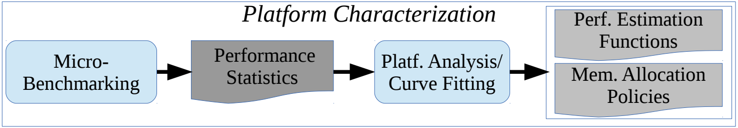

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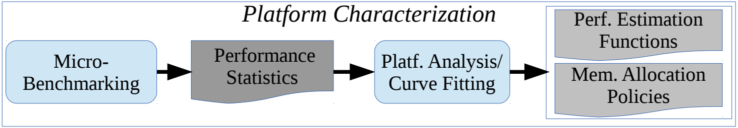

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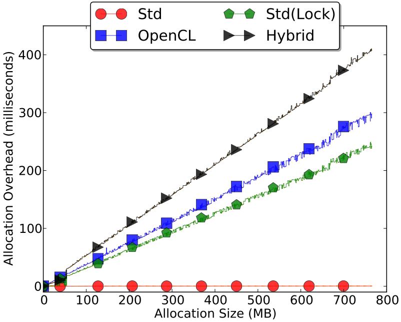
- **Standard**, the standard memory allocator.
- **OpenCL**, allocation via OpenCL library.
- **Standard with Locking**, allocation with memory locking via POSIX.
- **Hybrid**, combination of OpenCL and POSIX policies.

Platform Characterization / Performance Estim. Functions

Allocation Overhead



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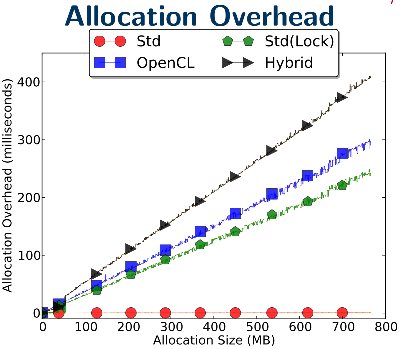

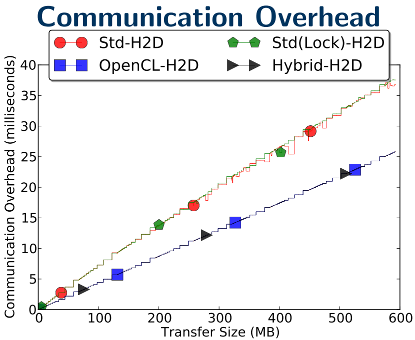

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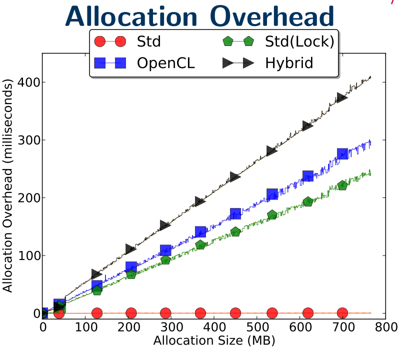

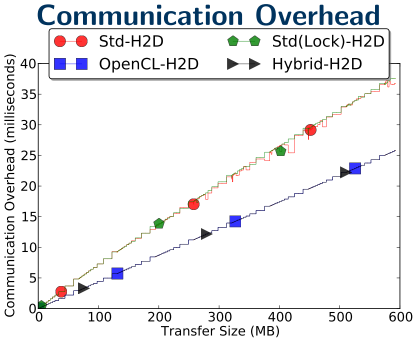

Remark: Policies with high allocation overhead lead to low communication overhead.

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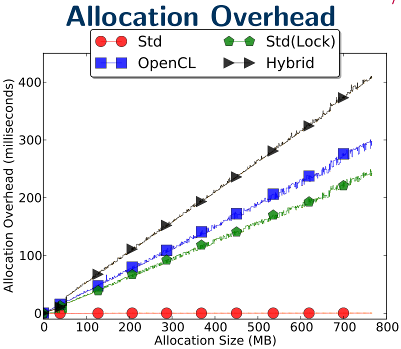

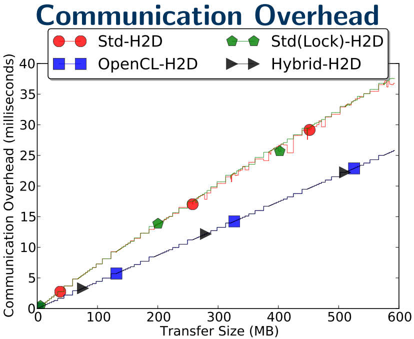

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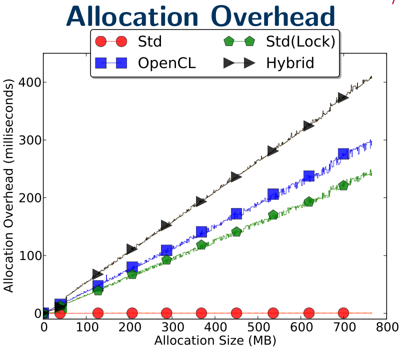

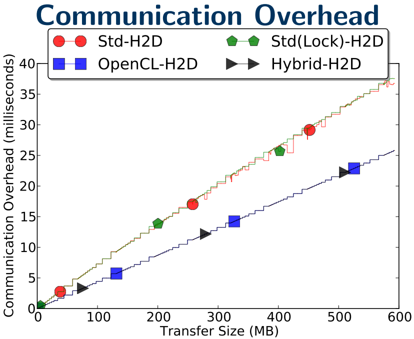

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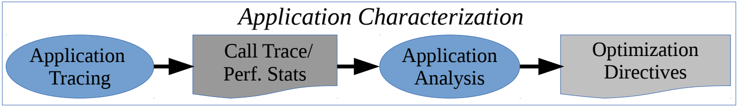
- **allocation_overhead(alloc_policy, size);**
- **communication_overhead(alloc_policy, size);**

Application Characterization / Tracing (1)



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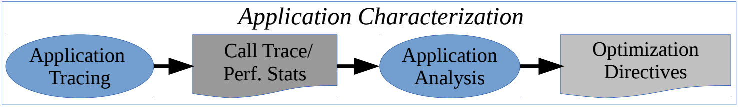

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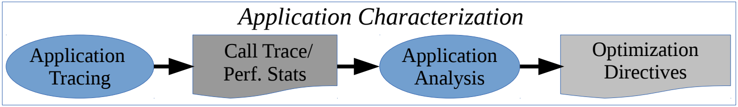

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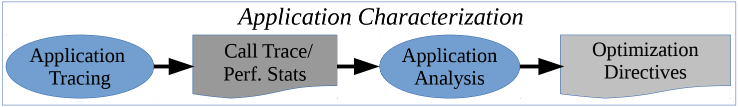

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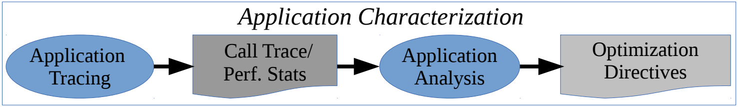

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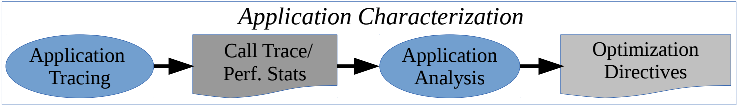

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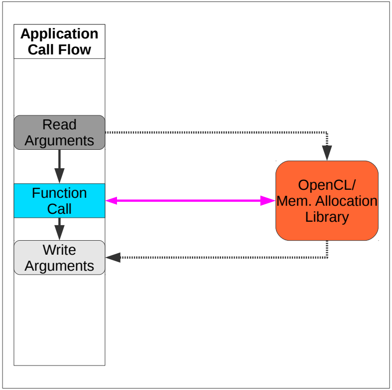
Important Feature

Trace compression guarantees that the trace remains the same regardless of the input size.

Application Characterization / Tracing (2)

Standard Function Call



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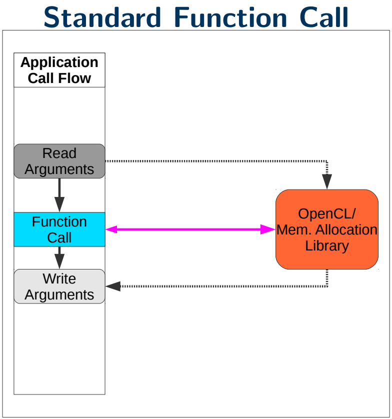

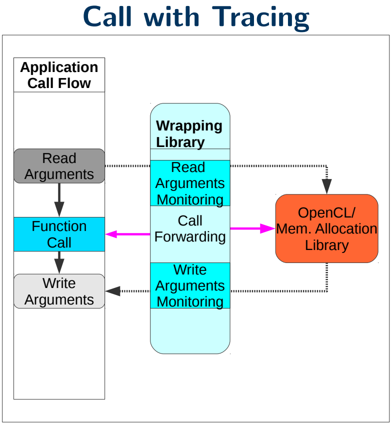

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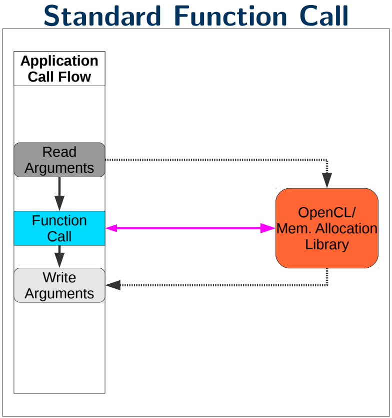

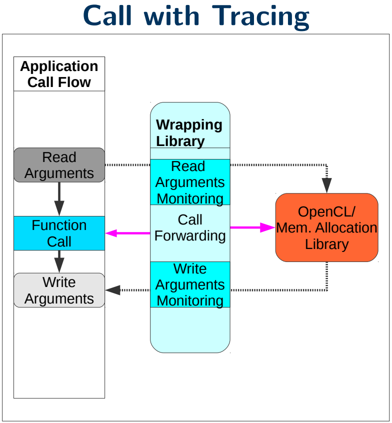

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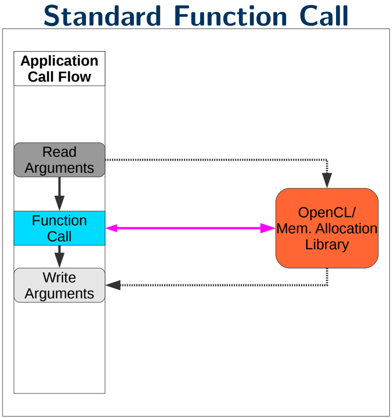

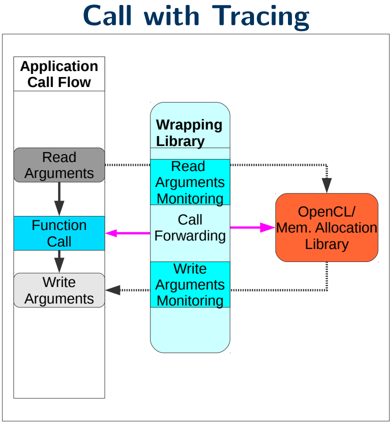

- Tracing is performed via a wrapping library.
- An SSA scheme is used for tracking the updates of non-scalar data objects, such as OpenCL Memory Buffers.

Application Characterization / Application Analysis

The analysis operates on the compressed trace in two stages.

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1: Optimization Eligibility Heuristic:

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An application is eligible if:

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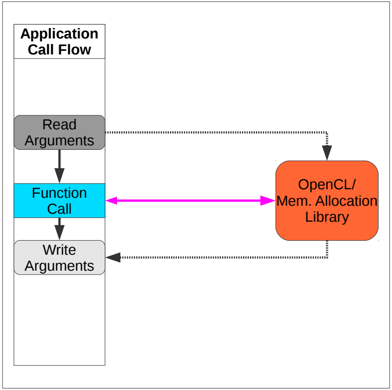
2: Memory Allocation Detection:
If the application is eligible, **the detection of memory allocations used in host-device communication** takes place.

Runtime Optimization
Standard Function Call



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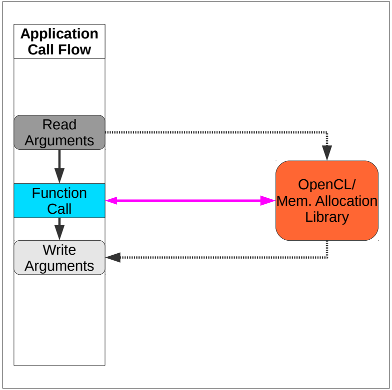
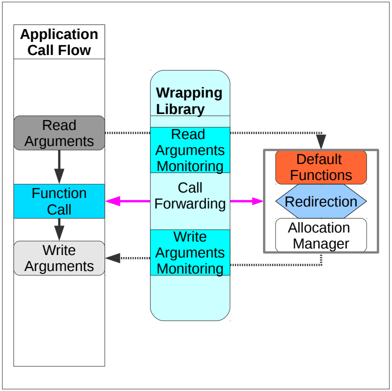


Call with Optimization



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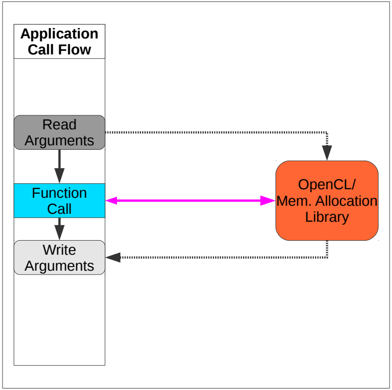

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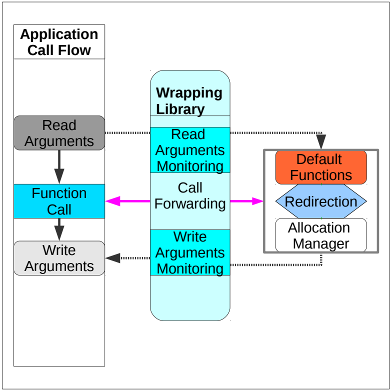

- Redirection of the annotated allocations to the best policy.

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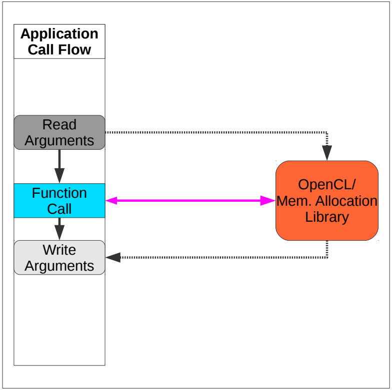

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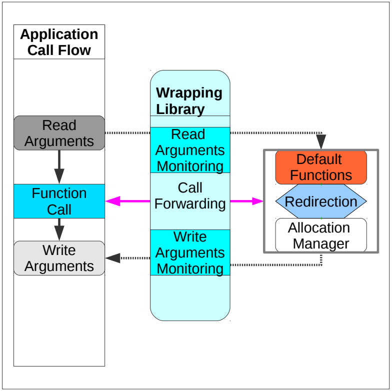

- Redirection of the annotated allocations to the best policy.
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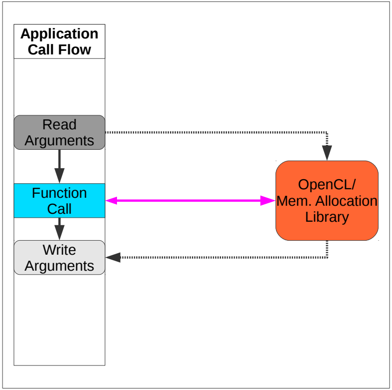
Runtime Optimization

Standard Function Call



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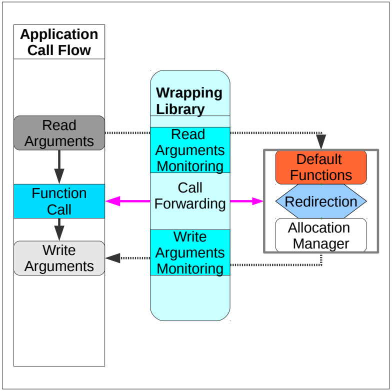

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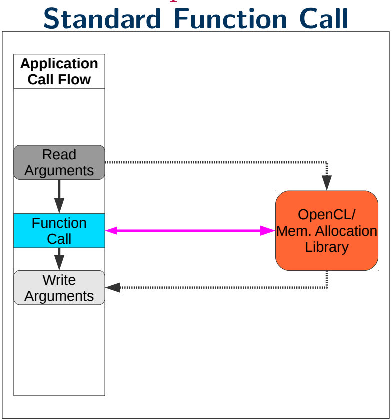

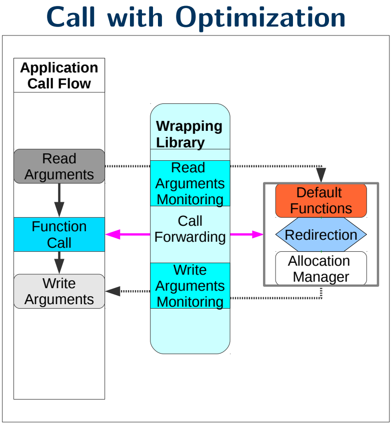

- Redirection of the annotated allocations to the best policy.
- Both Platform and Application characterizations required.
- User-space memory allocators for policies with high overhead.
- Safety. If an application presents an unexpected behavior, the optimization falls back to the default behavior.

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Platforms:

We evaluate on **three** platform configurations.

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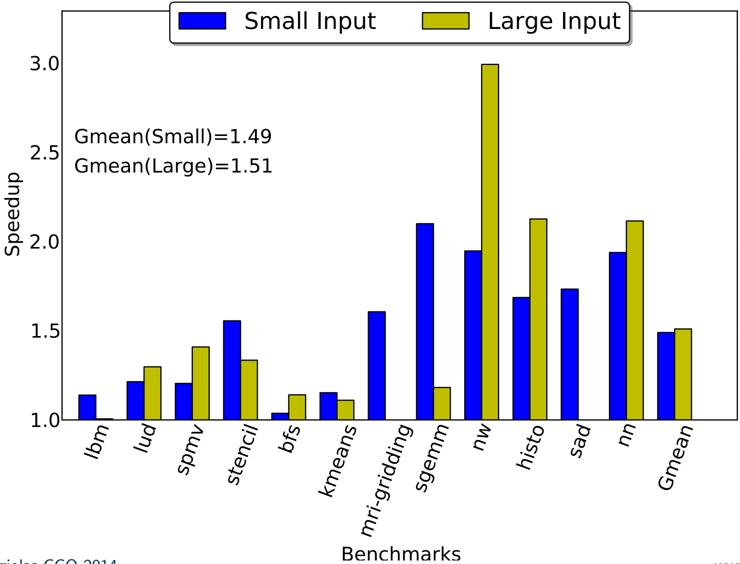
Use of the smallest and largest available datasets.

Performance Evaluation on GTX Platform



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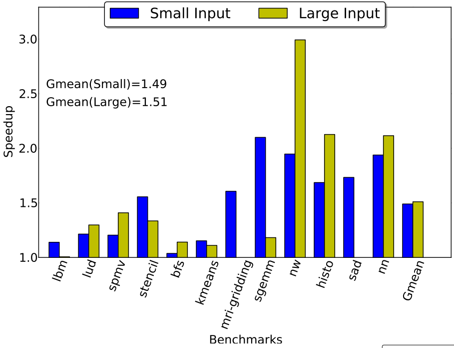
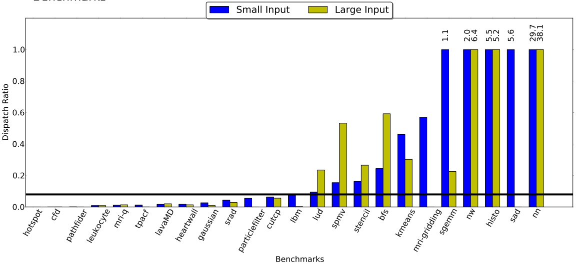


- Speedups from 1.05x to 3.0x.
- Gmean speedup remains roughly stable across datasets.
- Speedup gains proportional to dispatch ratio.



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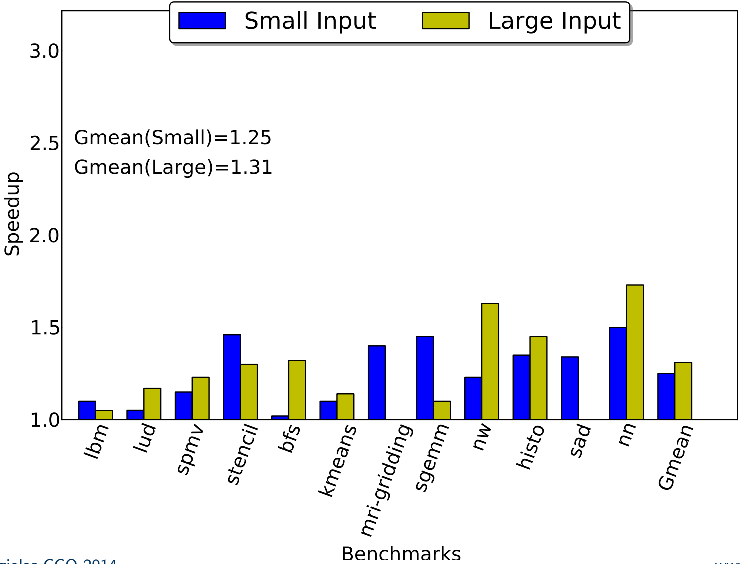

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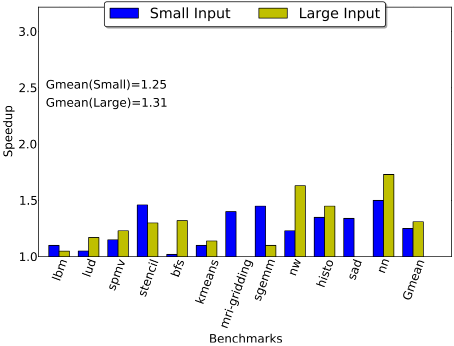

- Speedups ranging from 1.05x to 1.7x.
- Similar gmean speedup for both datasets.

AMD Platform presents lower speedups than the NVIDIA one.
Two are the main reasons:

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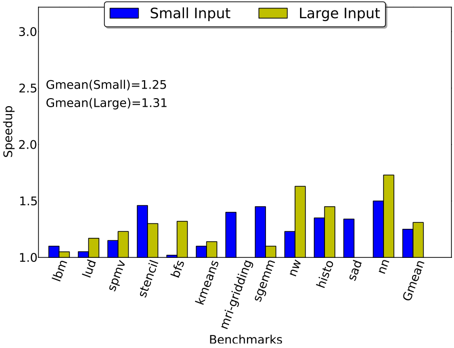

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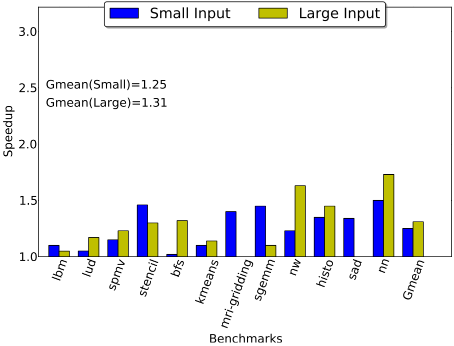

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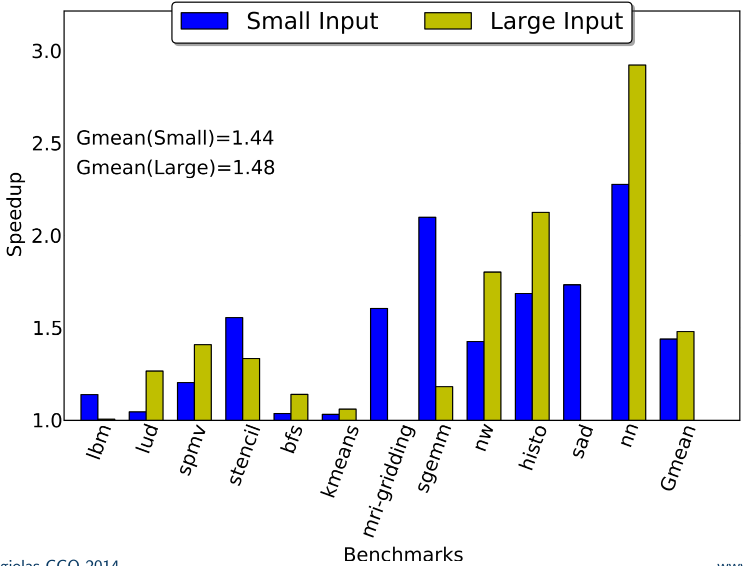
- AMD OpenCL restricts allocations with memory locking to low sizes.

Performance Evaluation on K20 Platform



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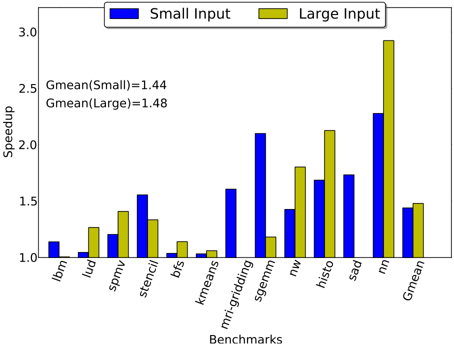

- Speedups from 1.1x to 2.9x.
- Gmean speedup roughly stable for both datasets.

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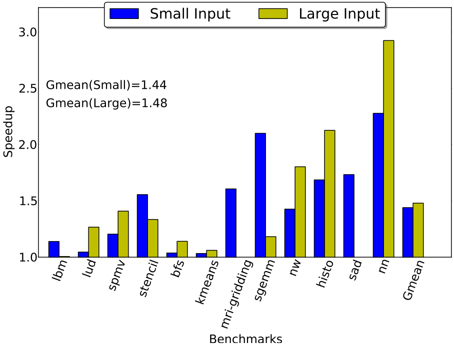

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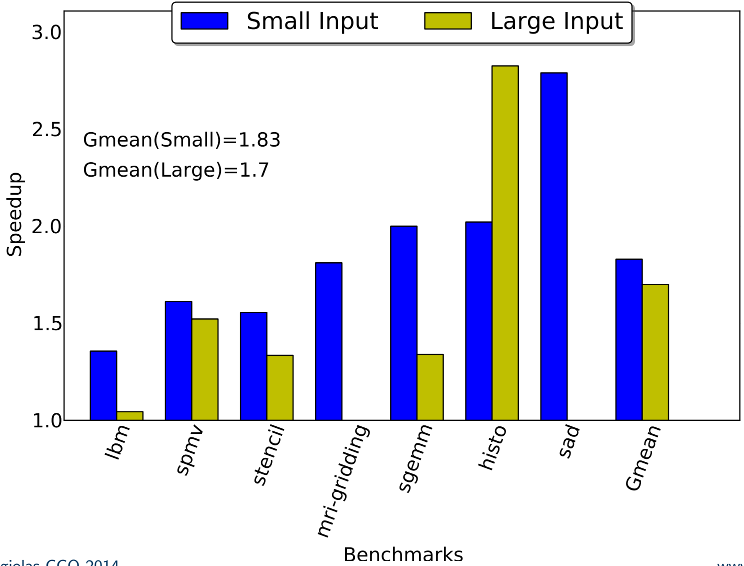
The performance gains are similar to the one of GTX platform. We notice only significant difference for **nn** and **nw** benchmarks.

Performance Evaluation with Tuned Benchmarks

- Parboil provides tuned versions of its benchmarks for NVIDIA.
- The benchmarks now have faster kernels for NVIDIA GPUs.
- We evaluate our optimization on GTX Platform.

Performance Evaluation on GTX Platform (Tuned Parboil)



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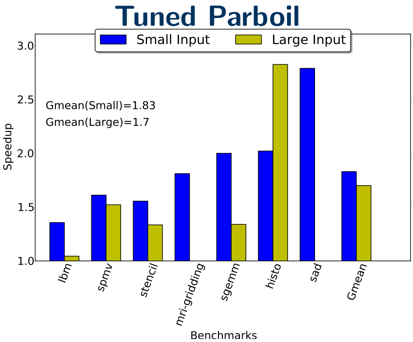

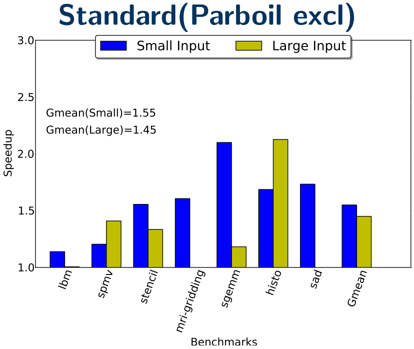

- Our optimization now delivers about 25% higher speedups.

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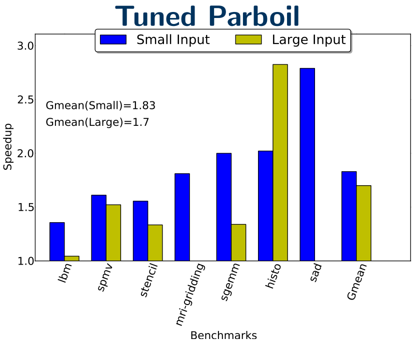

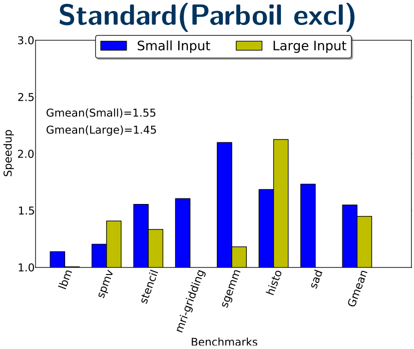

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In fact, optimized kernels expose further the communication overhead and our optimization has additional effect.

Future Work

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  - Special Memory Allocation policies targeting data placement.

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- Is portable across platforms.
- Is transparent to applications, Runtime and OS.
- Automatically detects platform capabilities and application behavior.
- Requires no application code modification or recompilation.

Thank you!

Special Forces (1) / Tracing

Code Sample

```
segm=malloc(SIZE);
clSetKernelArg(kernel, ...., &buf);
for(i=0; i<n; i++)
{
   do_smth(&segm);
   clEnqueueWriteBuffer(..., buf, segm, ...);
   clEnqueueNDRangeKernel(..., kernel, ...);
   clEnqueueReadBuffer(..., buf, ..., segm);
}
```

Special Forces (2) / Tracing

Performed Function Calls

Call	Def	Use
malloc	s0	
karg	k1	b0,k0
wbuffer	b1	b0,s0,q0
kexec	b2	b1,k1,q0
rbuffer	s1	b2,s0,q0
wbuffer	b3	b2,s1,q0
kexec	b4	b3,k1,q0
rbuffer	s2	b4,s0,q0
...	n-3 loop iterations	...
wbuffer	b2n+1	b2n,sn,q0
kexec	b2n+2	b2n+1,k1,q0
rbuffer	sn+1	b2n+2,s0,q0

Compressed Call Trace

Call	Def	Use
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karg	k1	b0,k0
wbuffer(#n)	b1	b0,s0,q0
kexec(#n)	b2	b1,k1,q0
rbuffer(#n)	s1	b2,s0,q0

Special Forces (3) / Analysis Algorithm

Allocation Detection Algorithm

```
for each c in the Call Trace
 if c is a host-device communication that involves a memory segment s
  retrieve s', the first state of s (through SSA)
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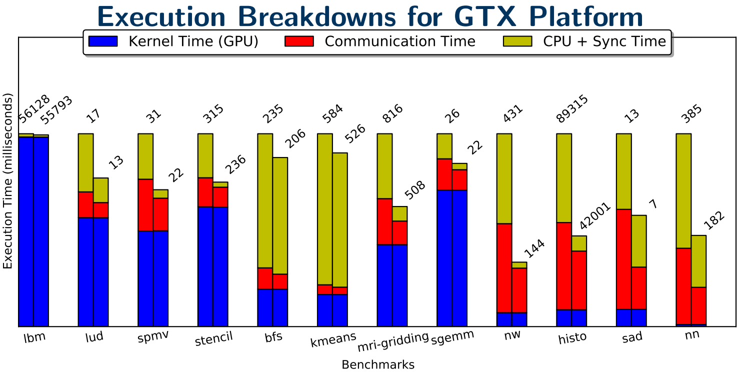
- The compressed trace is given as input.
- It detects the memory allocations that are used for host-device communication.
- It outputs the annotated allocations for the runtime optimizer.

Special Forces (4) / Execution Breakdowns



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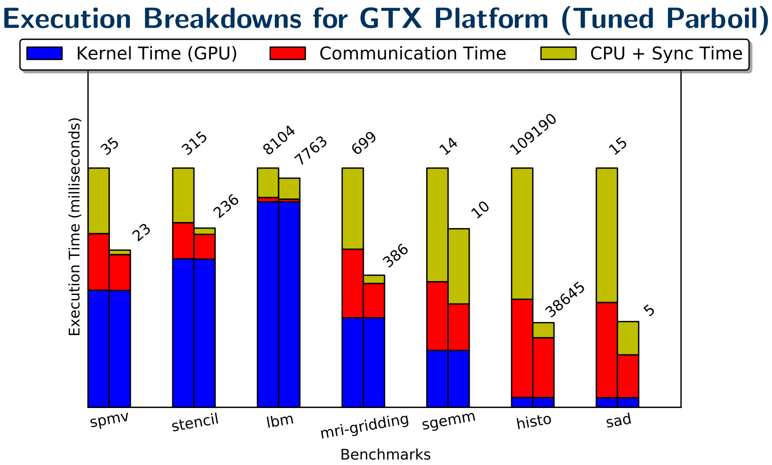

Special Forces (6) / Tuned Parboil Ratio Comp