# Performance Evaluation of OpenCL Standard Support (and Beyond)

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# Background

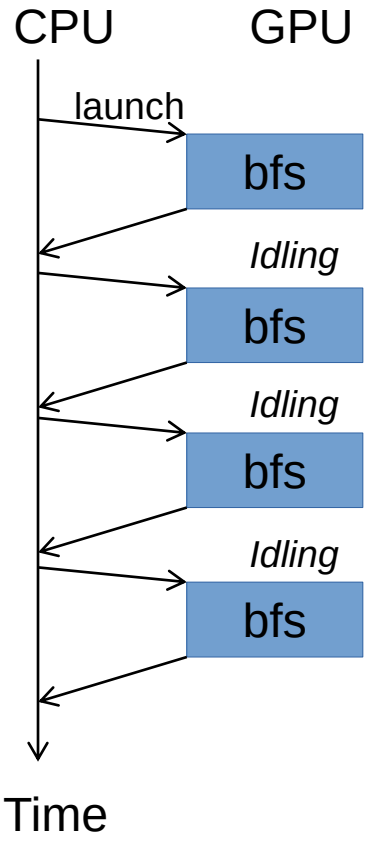
- IrGL: DSL for (Irregular) Graph Analytic Kernels
  - Wrote a compiler from IrGL to CUDA
  - Fastest graph kernels
  - Pai and Pingali, “A compiler for throughput optimization of graph algorithms on GPUs”, OOPSLA 2016
- Teamed up with Tyler and Ally to target OpenCL

# IrGL Key Insight

- Graph algorithms suffer 3 bottlenecks
- Need 3 key optimizations for high performance
  - Iteration Outlining
  - Nested Parallelism (*not* OpenCL NP)
  - Cooperative Conversion

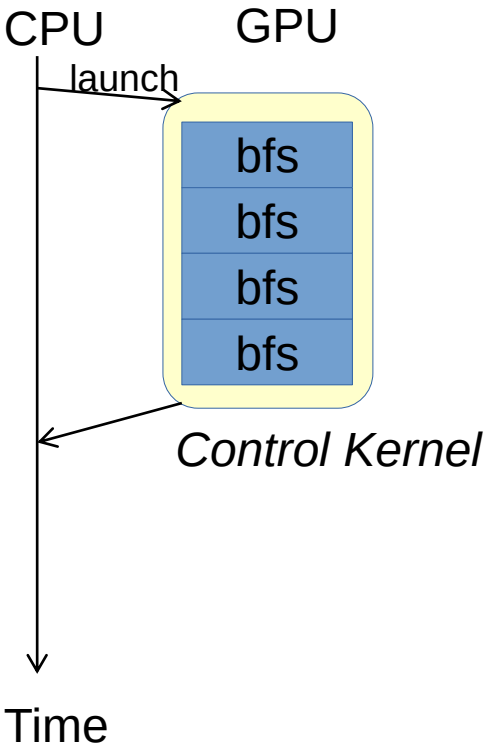
# Problem: CPU—GPU Launch

- Most graph algorithms are iterative
  - Repeat until fixpoint
- If time per iteration is small (average ~20us for BFS), launch throughput can't keep up



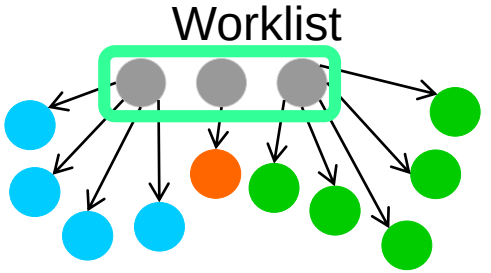
# Optimization #1: Iteration Outlining

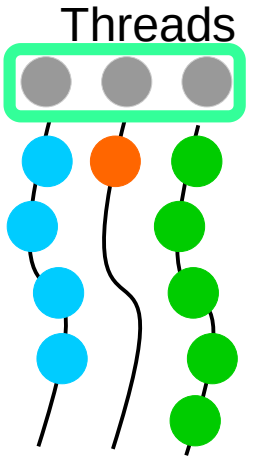
- Compiler generates a control kernel that "launches" child kernels
  - Actually inlines them
- Need a global barrier between "kernel invocations" (now function calls)



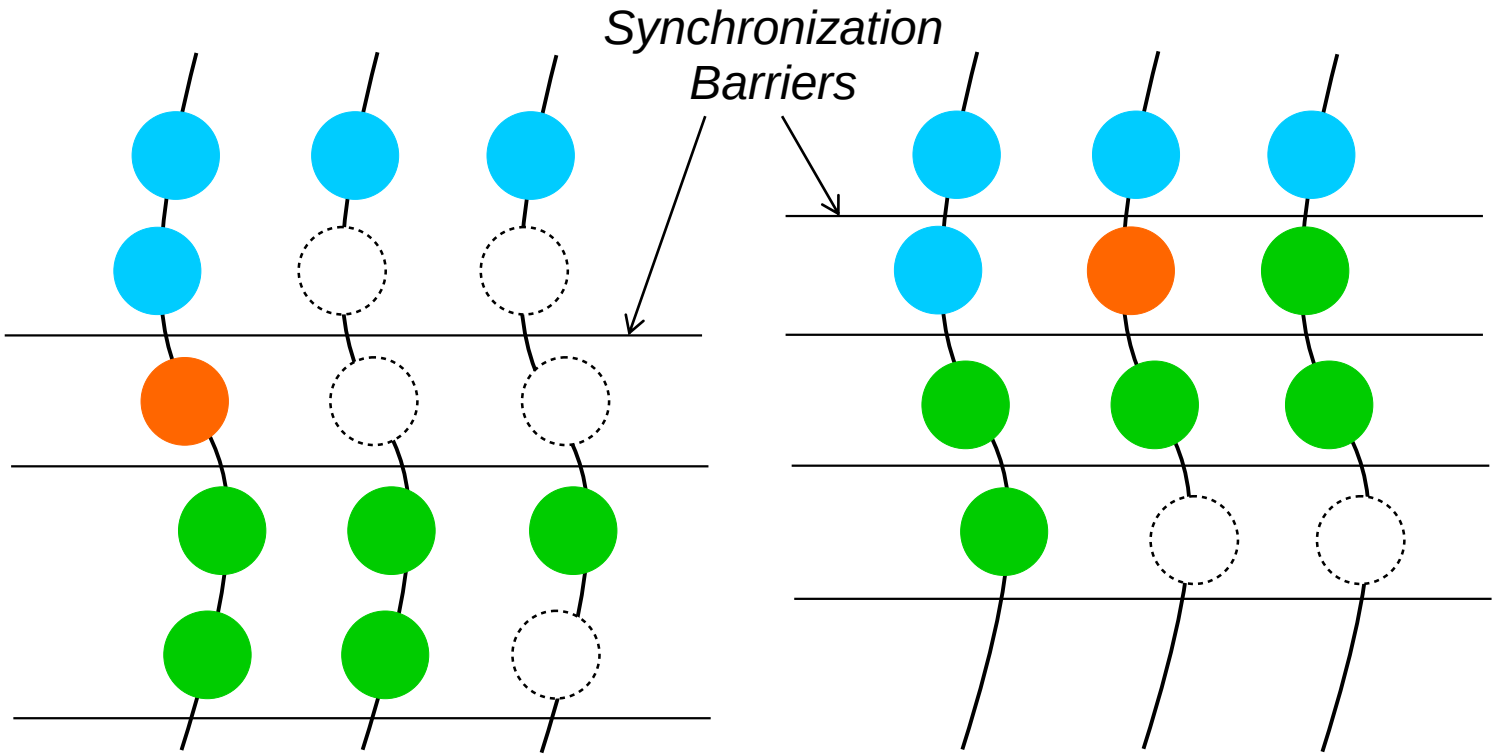
# Problem: Load Imbalance

- Graph algorithms usually two *parallel* nested loops
  - Outer loop over nodes
  - Inner loop over edges of a node
- Graph edge distribution



# Optimization #2: Nested Parallelism



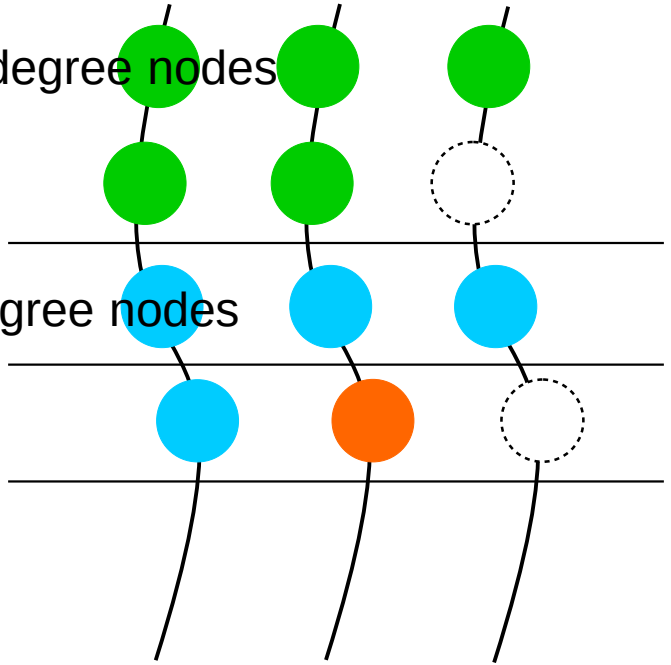

Work-group (WG) Scheduling

Fine-grained (FG) Scheduling

# NP: Multiple Schedulers

Use Work-group (WG) for high-degree nodes

Use fine-grained (FG) for low-degree nodes

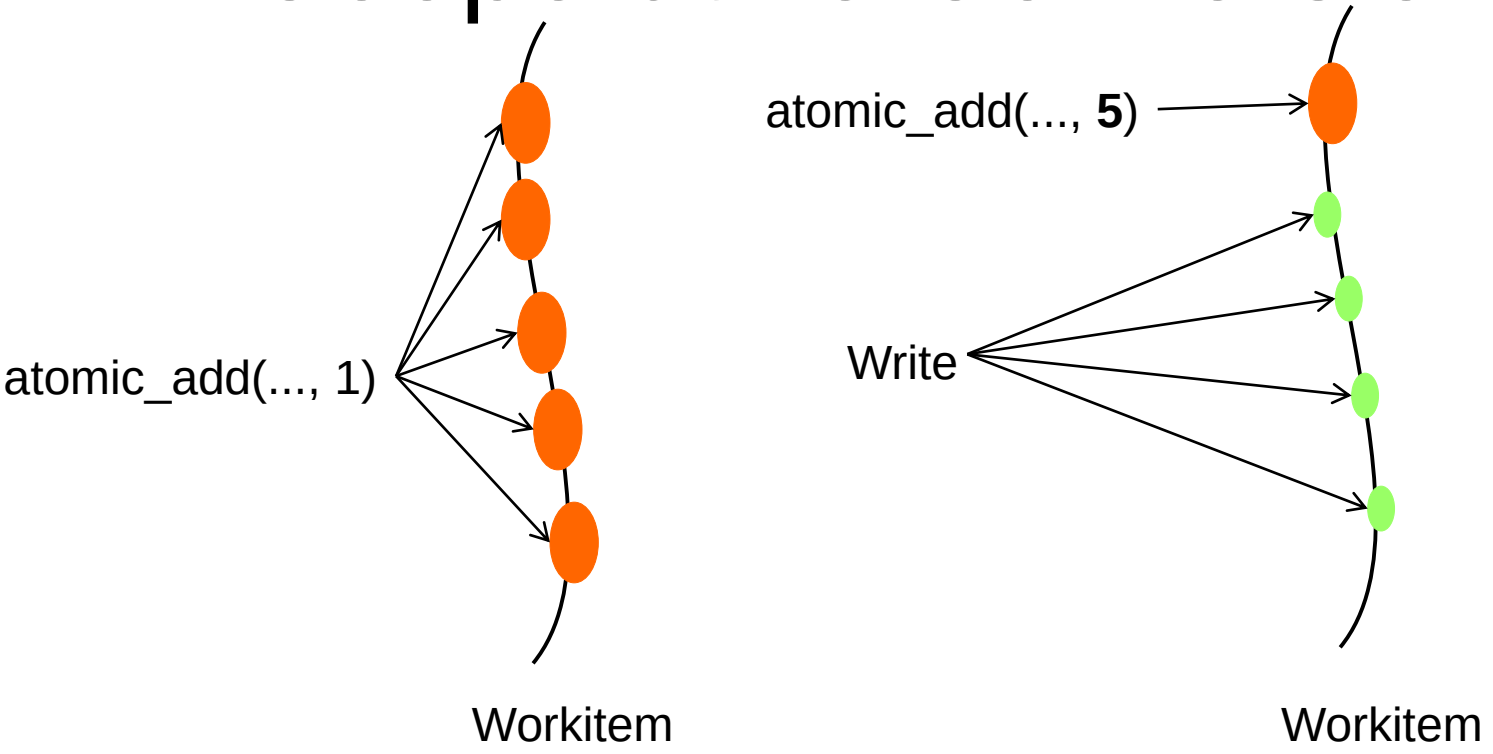


Work-group (WG) + Finegrained (FG) Scheduling

# Implementing IrGL NP in OCL

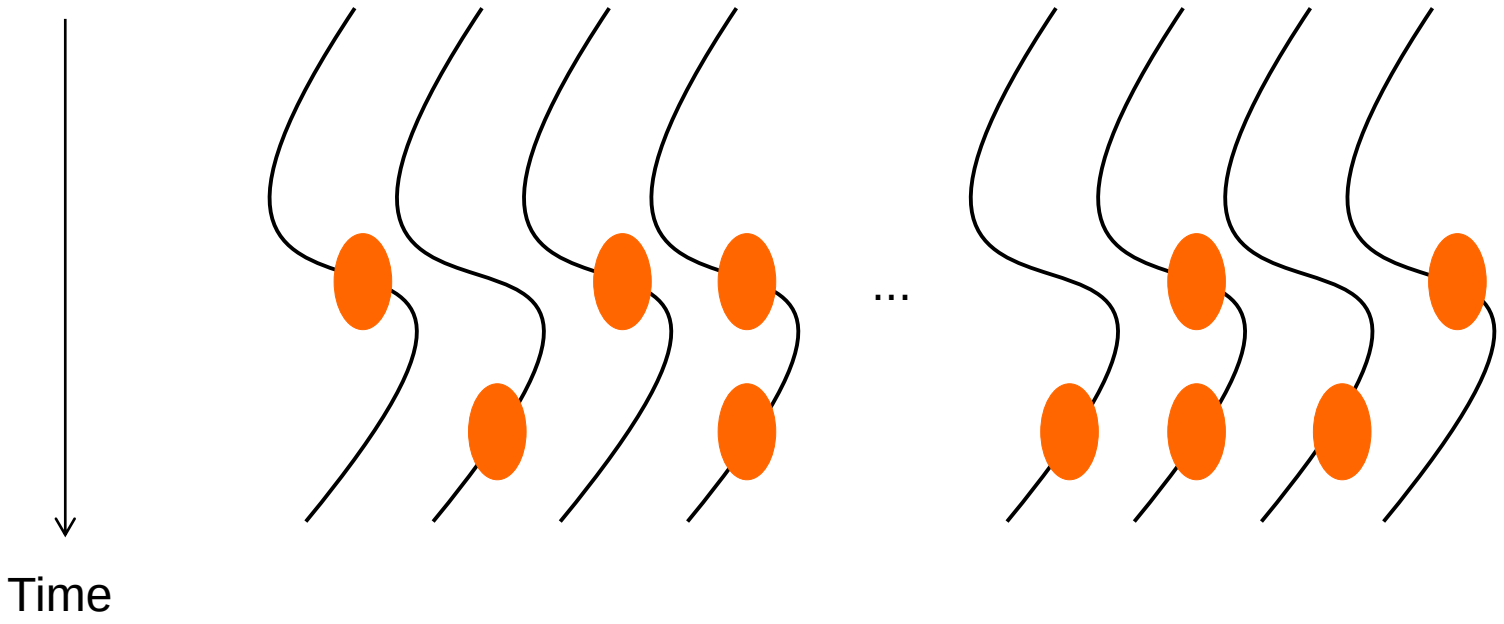
- Support any combination of *three* schedulers
  - workgroup (wg)
  - subgroup (sg)
  - finegrained (fg)
- Workgroup and Finegrained schedulers require:
  - local memory and workgroup barriers
- Subgroup scheduler requires:

# Optimization #3: Cooperative Conversion



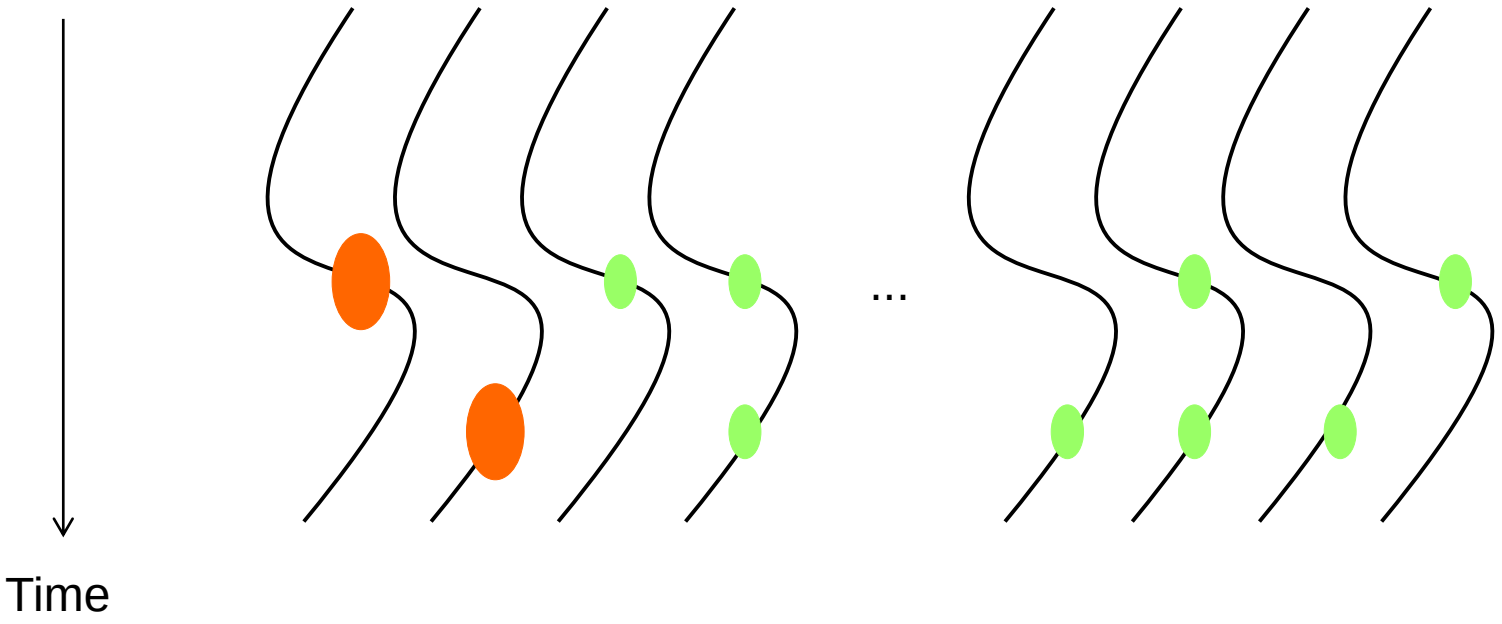
# Dynamic aggregation problem

```
if(edge.dst.level == INF)
        Worklist_push(edge.dst)
```



# Aggregate across workitems

```
if(edge.dst.level == INF)
        Worklist_push(edge.dst)
```



# Implementing Coop-Conv in OCL

- Supports aggregation:
  - within a workitem
  - across a subgroup
  - across all workitems of a workgroup
- Workitems use prefix scans for aggregation, requiring barriers
  - Unlike CUDA, even subgroup aggregation requires barriers – OCL does not support

# GPUs We Used

| Vendor | GPU | OpenCL version |
|---|---|---|
| ARM | Mali 4 | 1.2 |
| NVIDIA | GTX 1080 | 1.2 |
| | Quadro M4000 | 1.2 |
| AMD | R9 | 2.0 |
| Intel | HD 5500 | 2.0 |
| | Iris 6100 | 2.0 |

# Portable C11-style Atomics (OCL2)

- Required for: coop-conv, wg, and oitergb
  - Supported by Intel and AMD (already OpenCL 2.0)
- NVIDIA: Hardware support available, so just use PTX intrinsics
- ARM: Use memory fences and hope for the best
  - Verify correctness using application test suites

# Portable subgroups (OCL2.1)

- Required for:
  - coop-conv,
  - nested parallelism (sg)
- NVIDIA: Use PTX intrinsics
- Intel and AMD: Use vendor-specific extensions
  - Intel subgroup sizes can vary per kernel!
- ARM: Assume subgroup size of 1

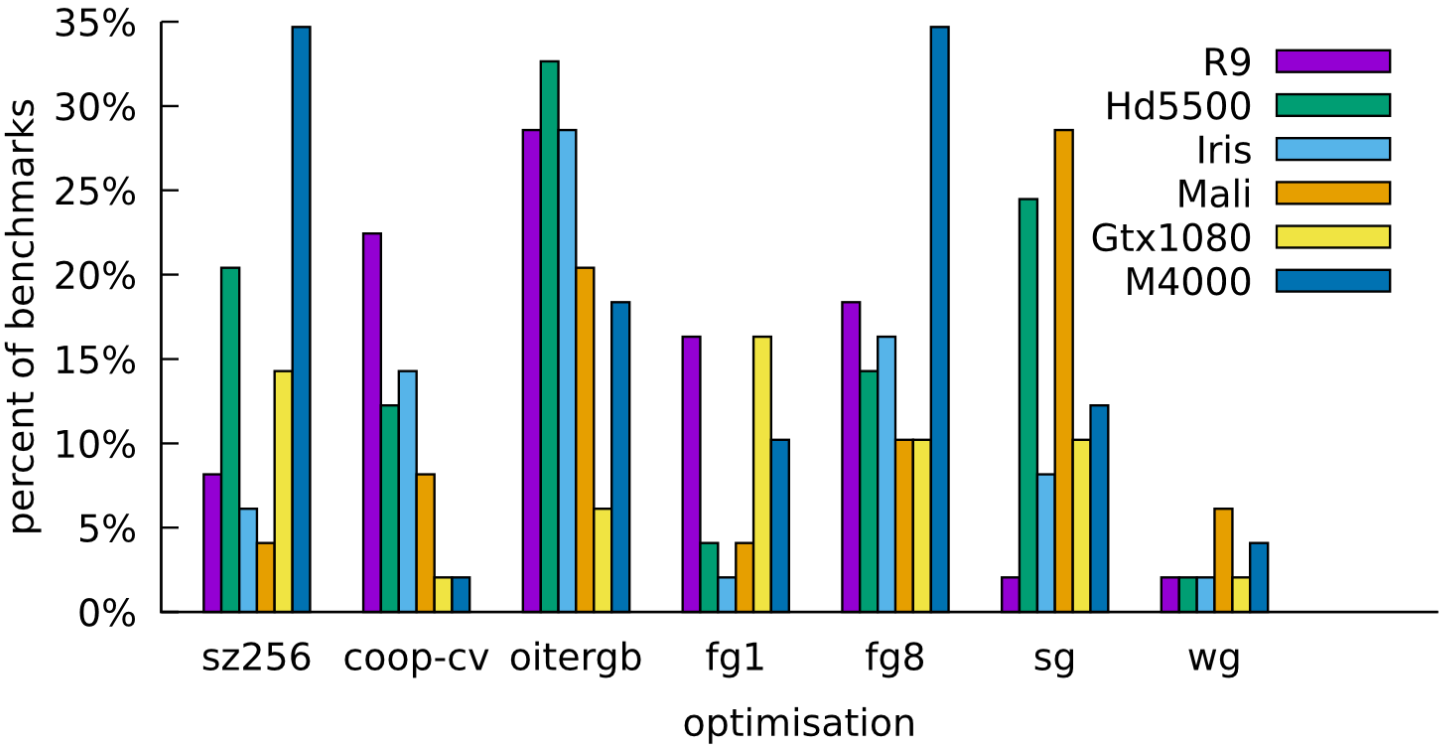
# Portable global barriers (OCL-FP)

- Required for: Iteration Outlining (oitergb)
- Assume occupancy-bound architecture
- Kernel includes a prologue to detect how many workgroups are running (can undercount)
  - All workgroups with ID greater than this count exit
- Details in: Sorensen et al., “Portable inter-workgroup barrier synchronisation for GPUs”

# Experimental Setup

- 17 graph algorithms
- 3 graph inputs: Road, Random, R-MAT
- 6 GPUs, from 4 vendors (NVIDIA, Intel, ARM and AMD)

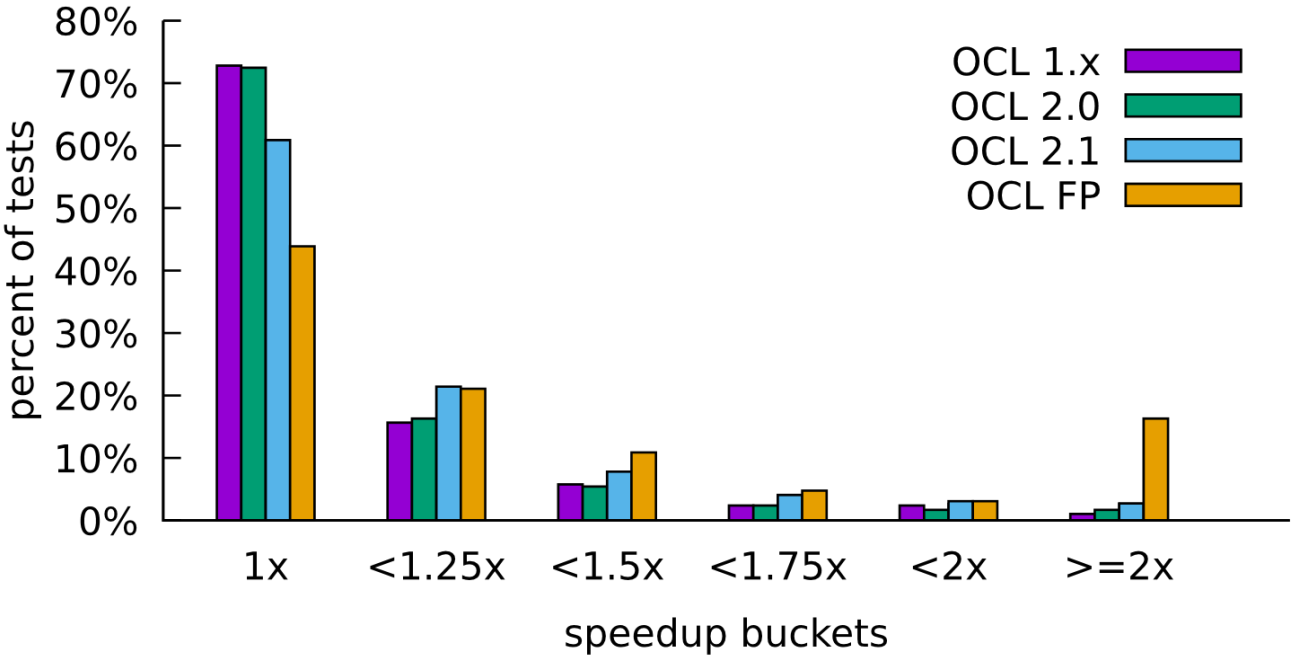
# Portability of Optimisations



# Portability of Optimisations (contd.)

- All optimisations required to achieve speedup for some fraction of architecture + benchmark + input combinations
- Optimisations are not NVIDIA-specific

# OpenCL Speedup Classes



# Conclusion

- Newer OpenCL features lead to better performance
- Best performance obtained when OCL-FP features are used – though these are not yet supported

# Thank you!

- For more details, see Tyler's PhD Thesis

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