SnuCL D

A Distributed OpenCL Framework using Redundant Computation and Data Replication

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Outline

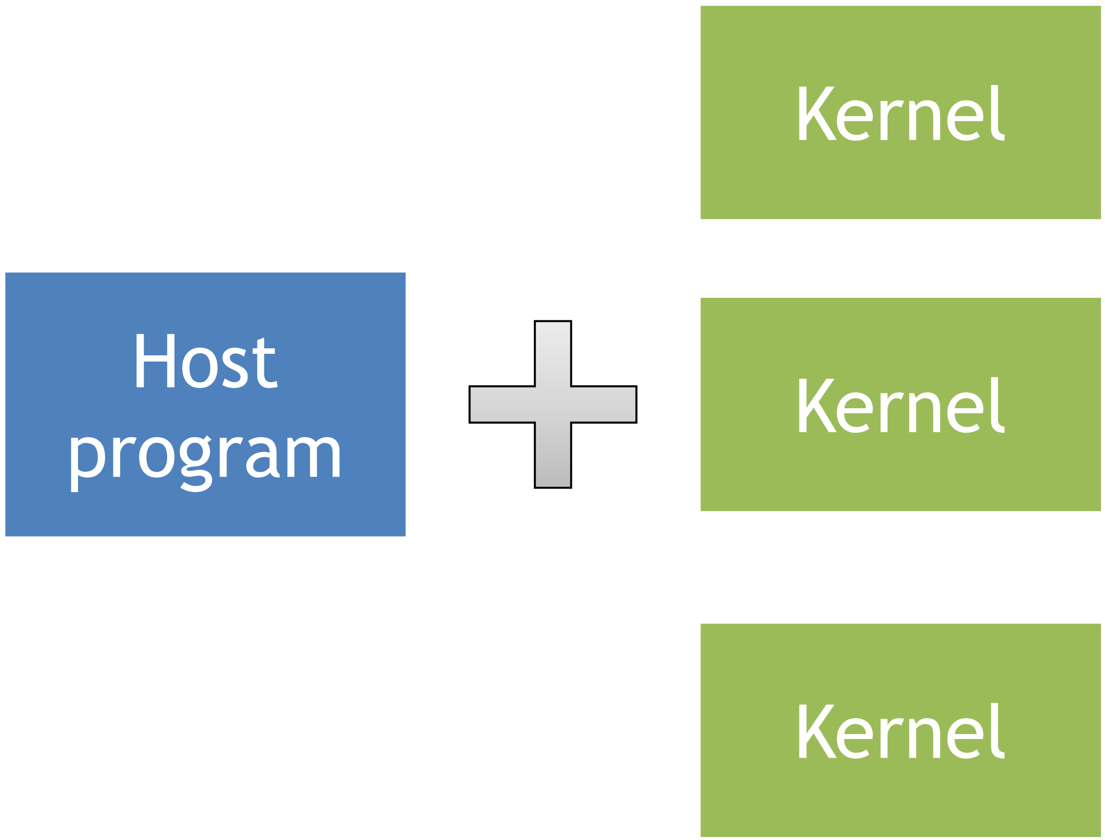
- OpenCL programming model
- Previous approaches for clusters
- Overview of SnuCL-D
- Correctness problems
- Optimization techniques
- Limitation
- Conclusion

Introduction

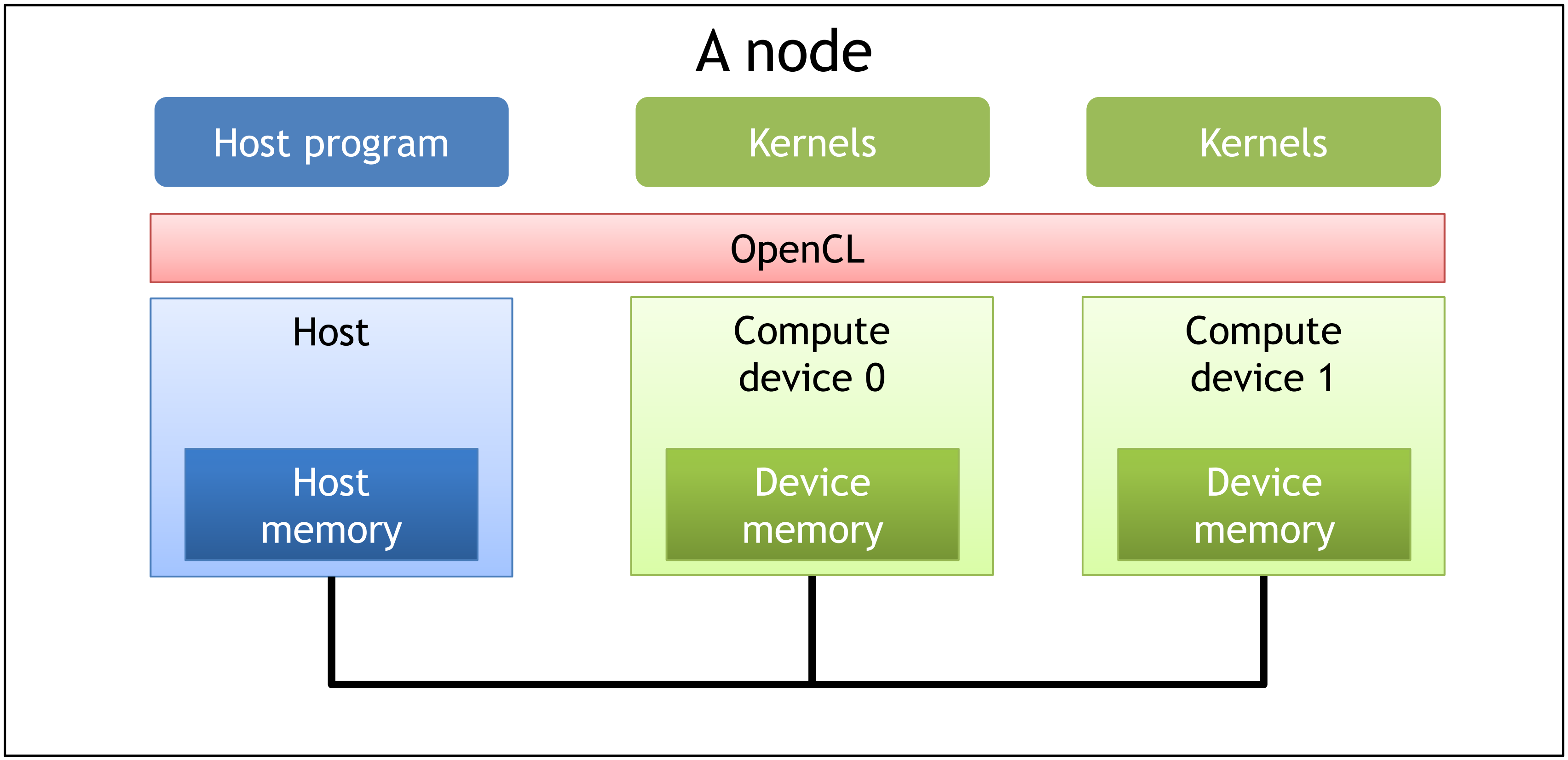
- Heterogeneous systems
  - Different types of processors
    - E.g., CPUs+GPUs

- Major programming models
  - CUDA and OpenCL

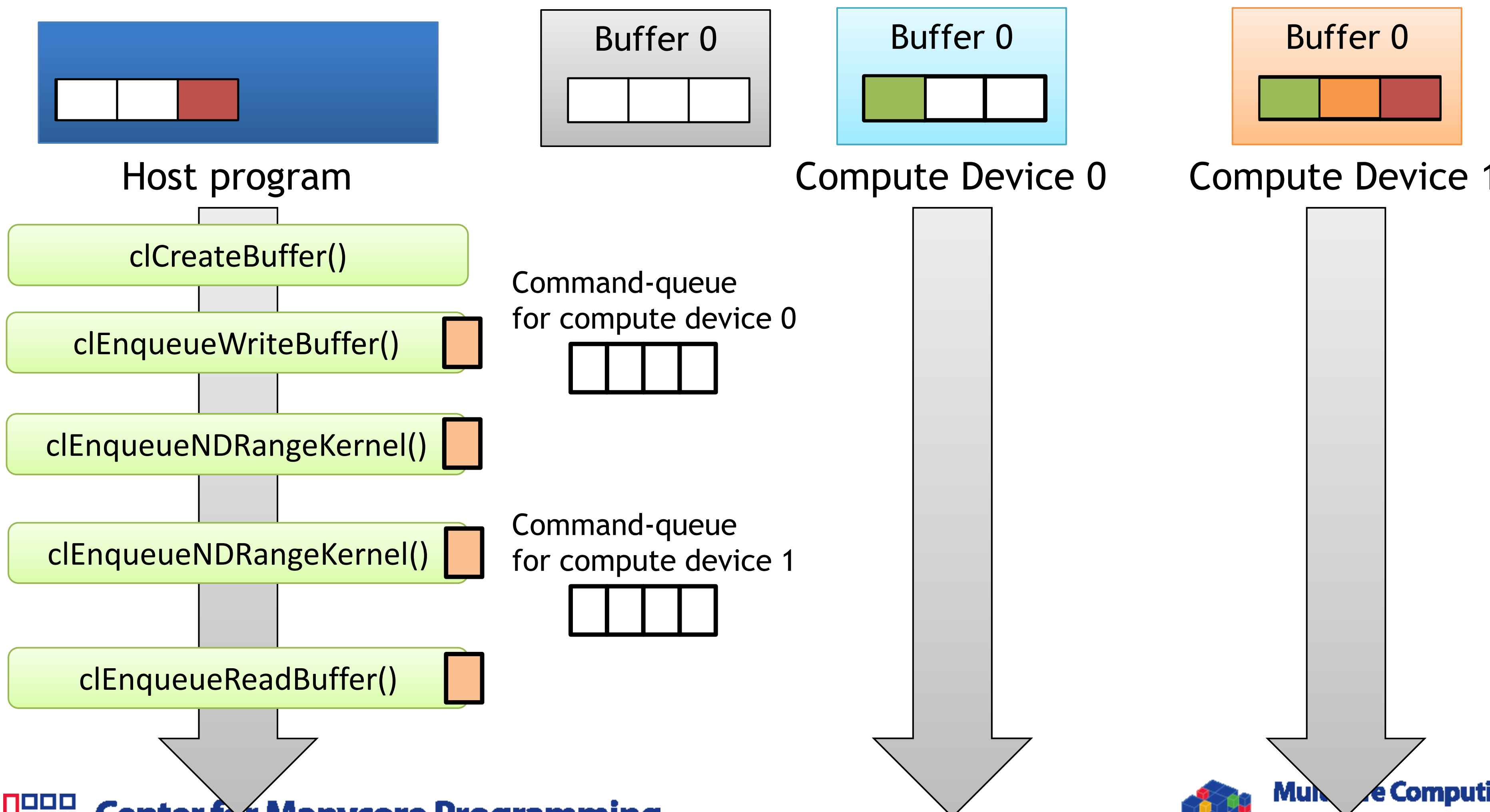
OpenCL Program



OpenCL Platform Model

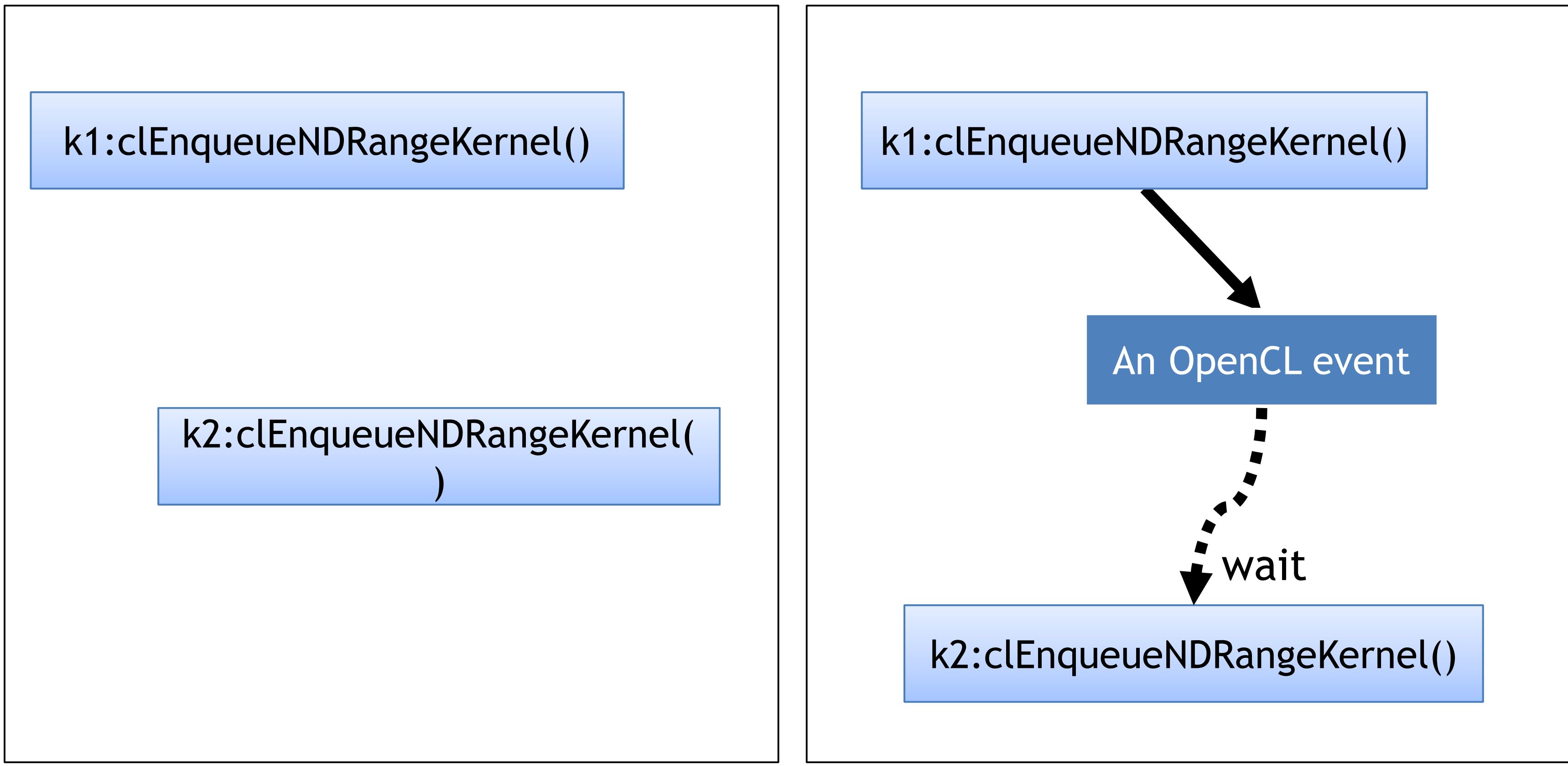


OpenCL Programming Model

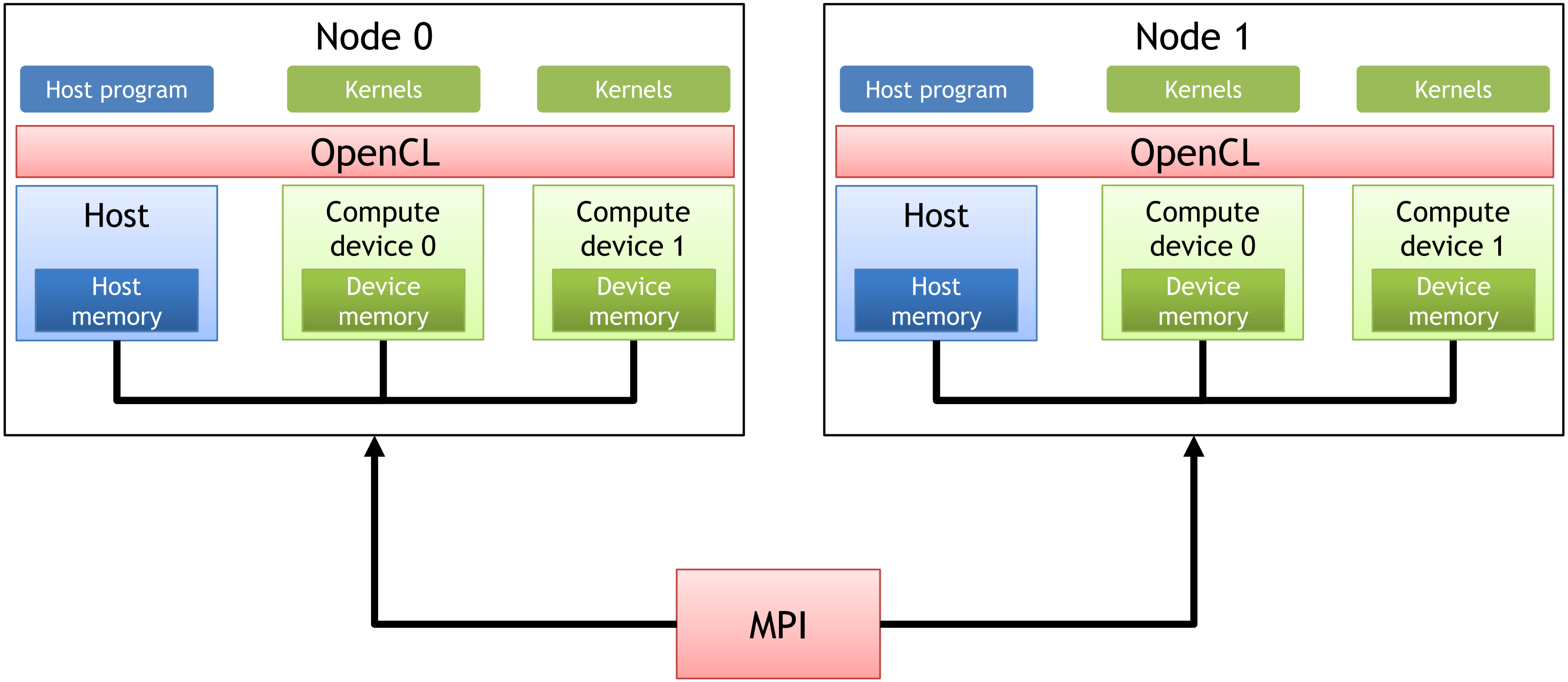


Order of Commands

Unordered **Ordered**



OpenCL for Heterogeneous Clusters



MPI+OpenCL: cumbersome and error-prone

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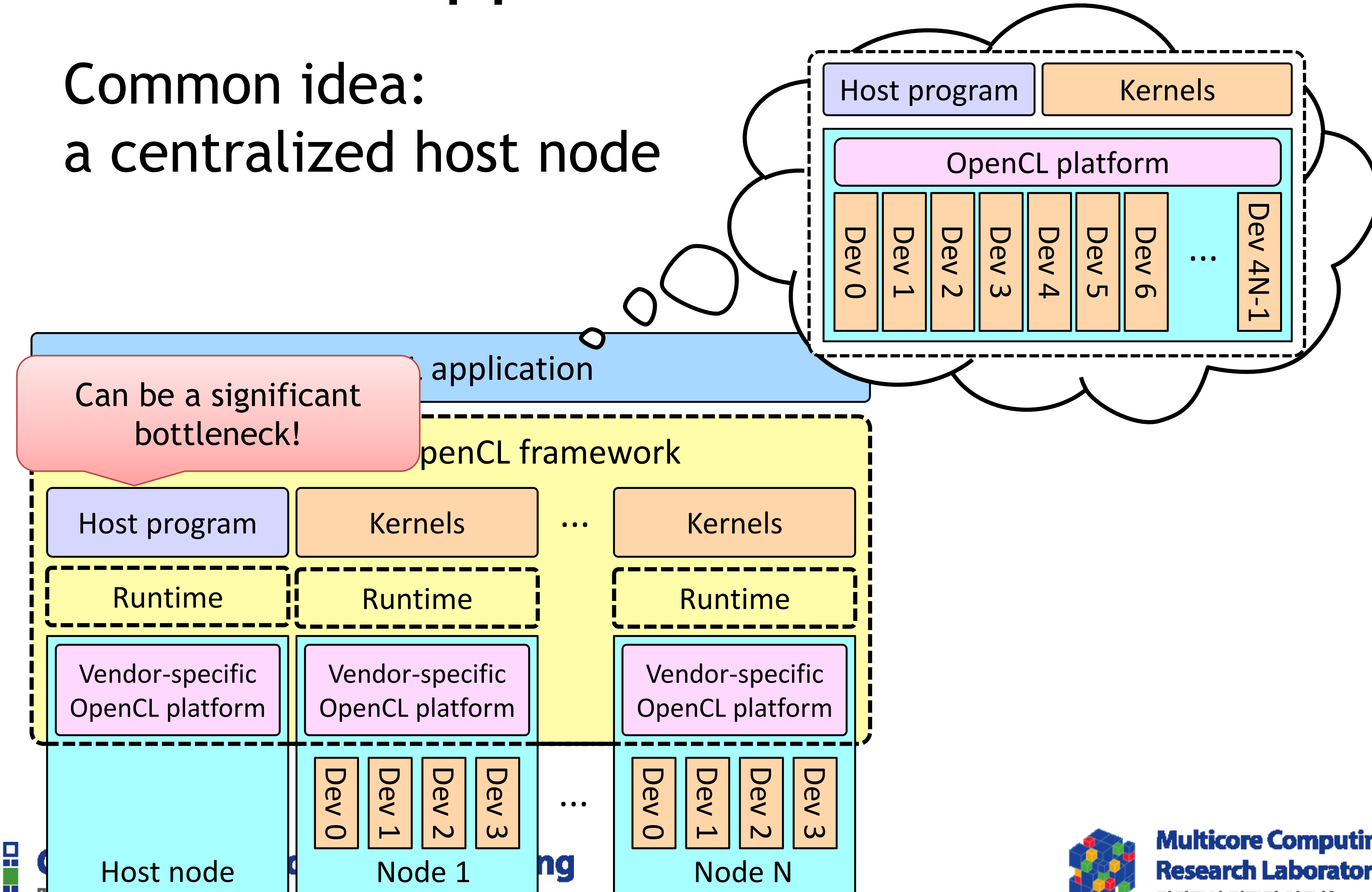
Previous Approaches for Clusters

Common idea:
a centralized host node



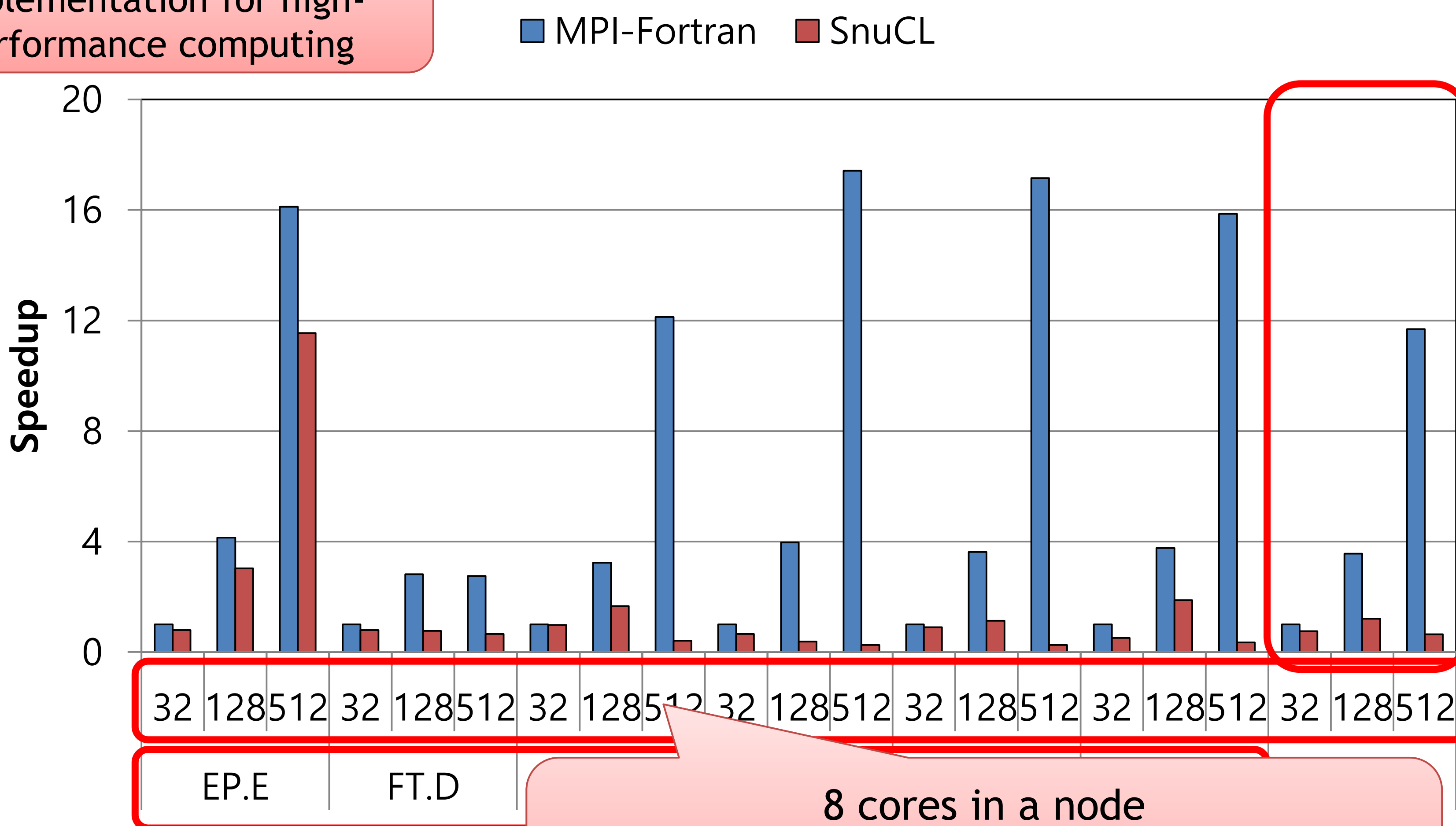
Centralized Approaches

- clOpenCL
- Hybrid OpenCL
- SocketCL
- dOpenCL
- CLara
- SnuCL
- DistributedCL
- CLuMPI
- rCUDA
- DS-CUDA

Evaluates it on a large number of nodes (256 nodes)

MPI-Fortran vs. SnuCL

The most efficient implementation for high-performance computing



8 cores in a node
1 core / MPI process
A set of 4 cores / OpenCL compute device

Goals

- Develop a scalable OpenCL framework for clusters
  - Comparable to MPI-Fortran
  - Achieve ease of programming with high performance
- Key idea
  - Eliminate the centralized host node
    - Redundant host computation
    - Data replication
- SnuCL-D
  - The successor of SnuCL
  - A distributed OpenCL framework

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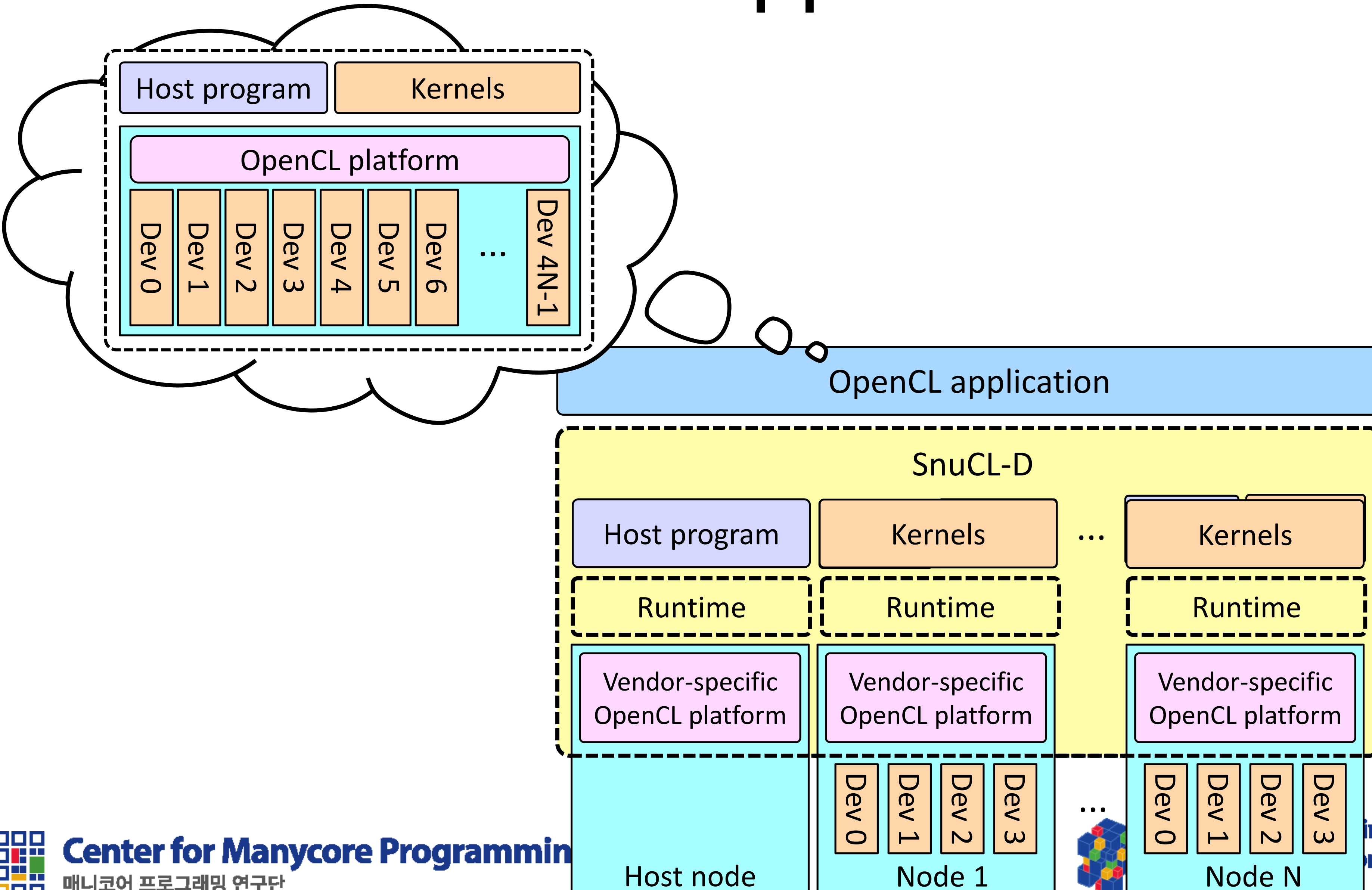
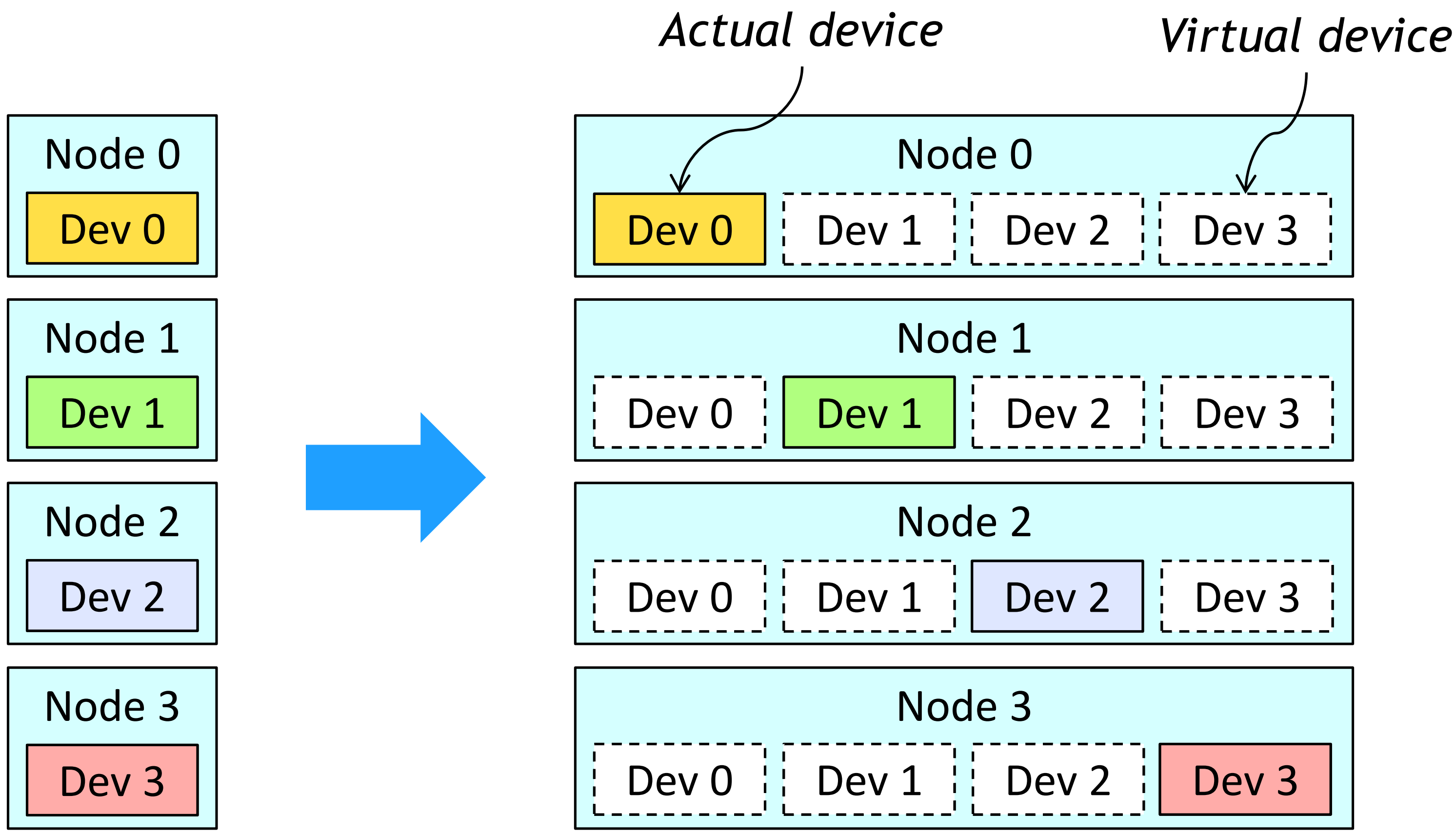
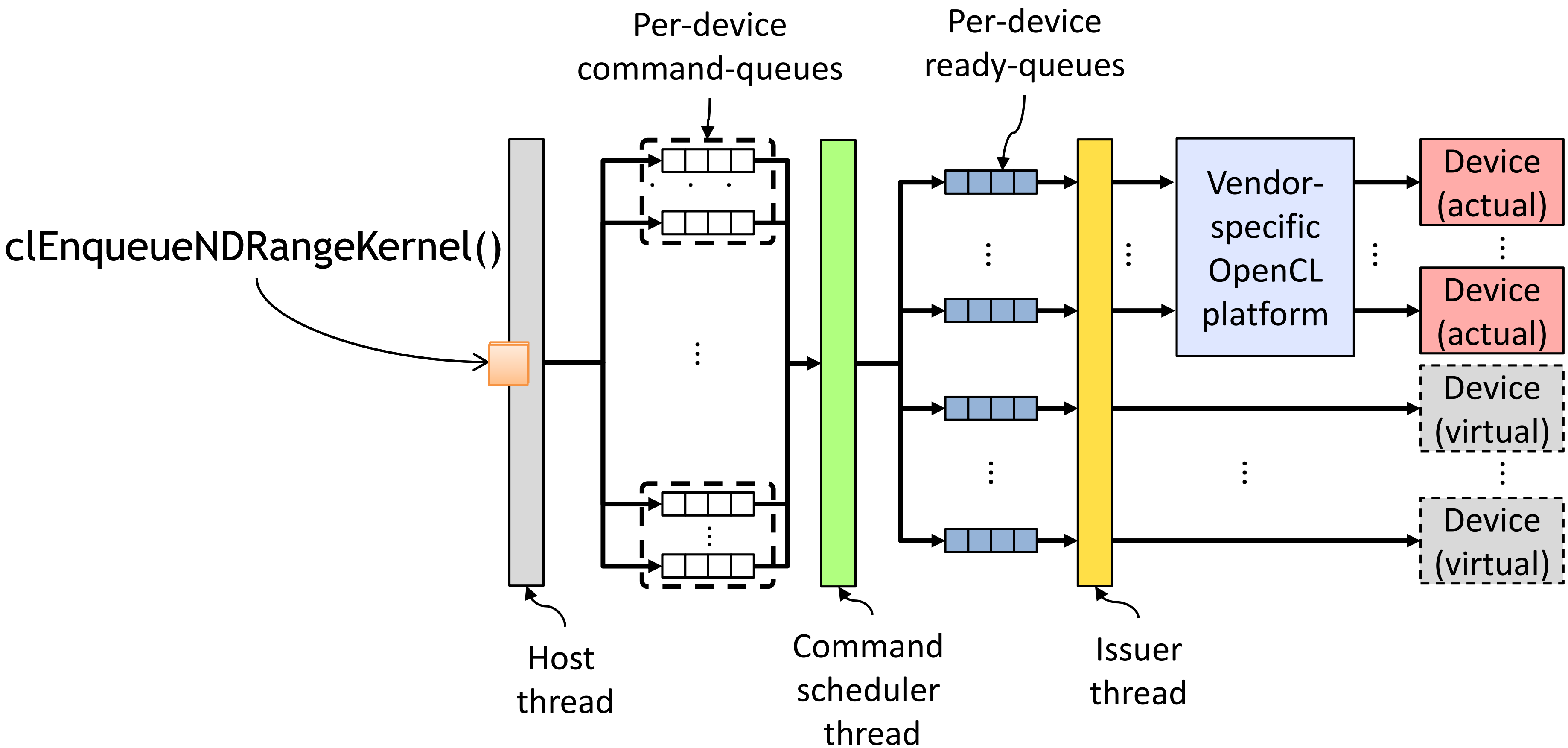
SnuCL-D's Approach



Remote Device Virtualization



SnuCL-D Runtime



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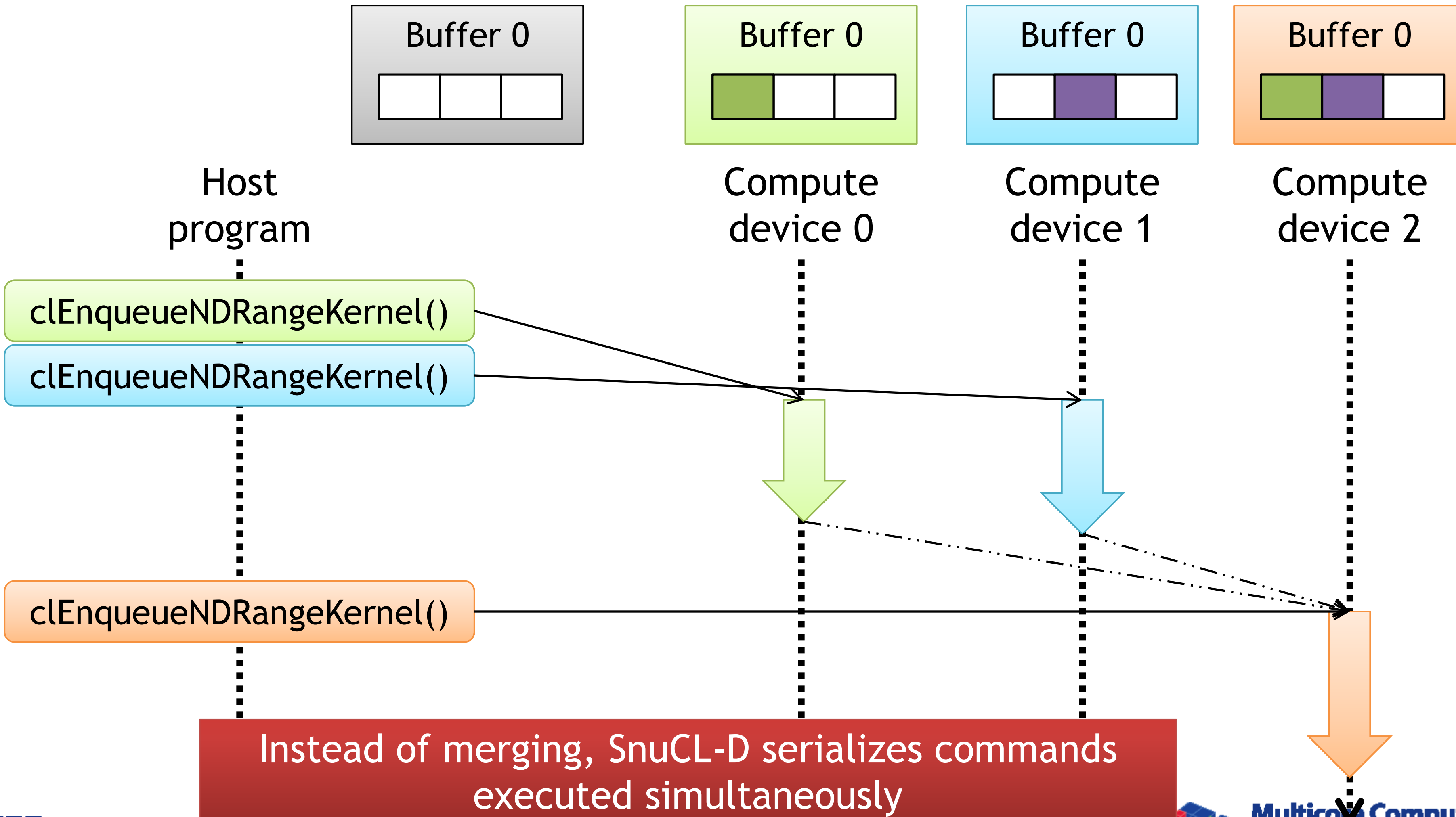
Correctness Problems

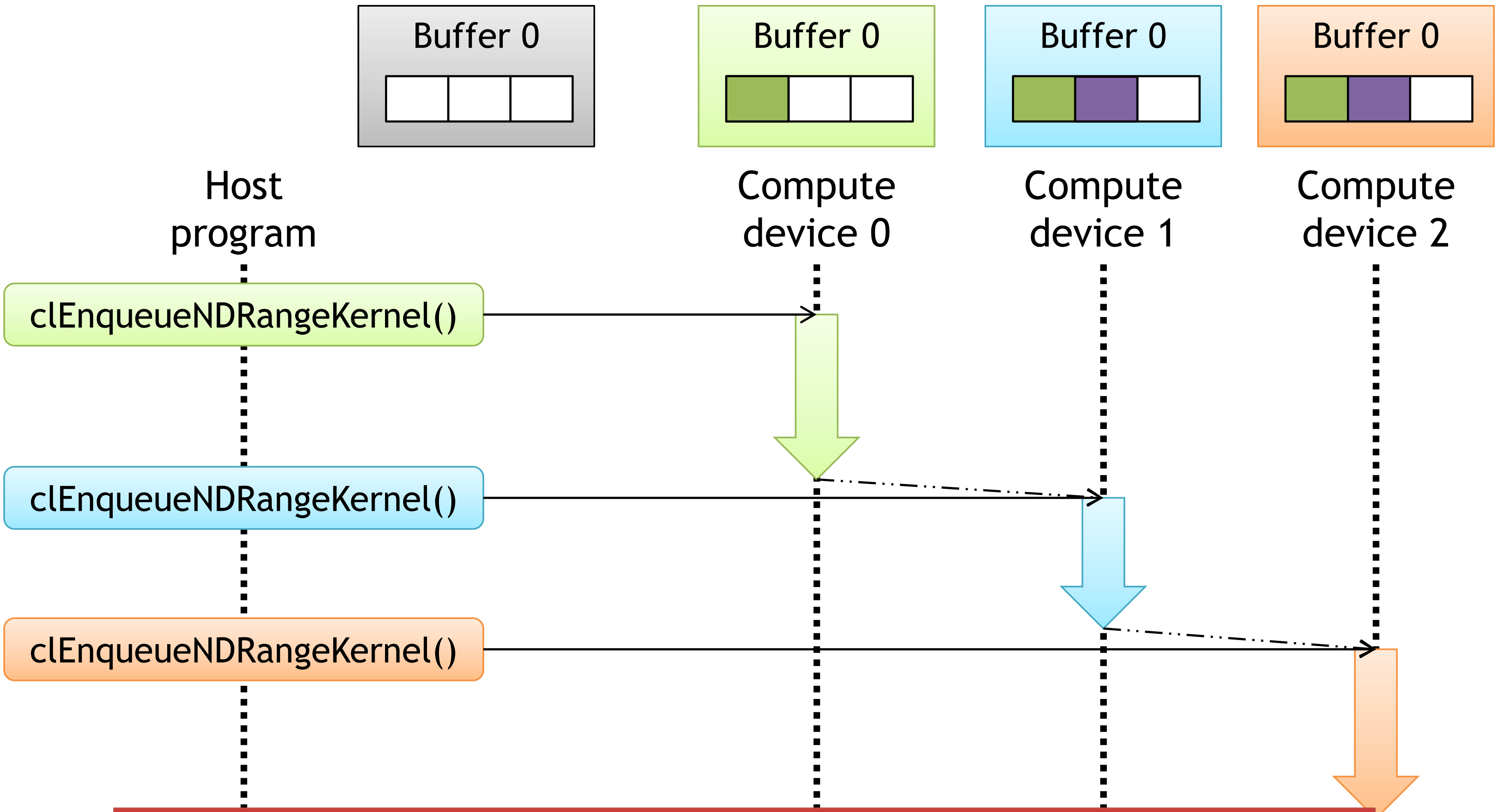
- Consistency problem
- Non-determinacy problem

Consistency Problem (Simultaneous Accesses)



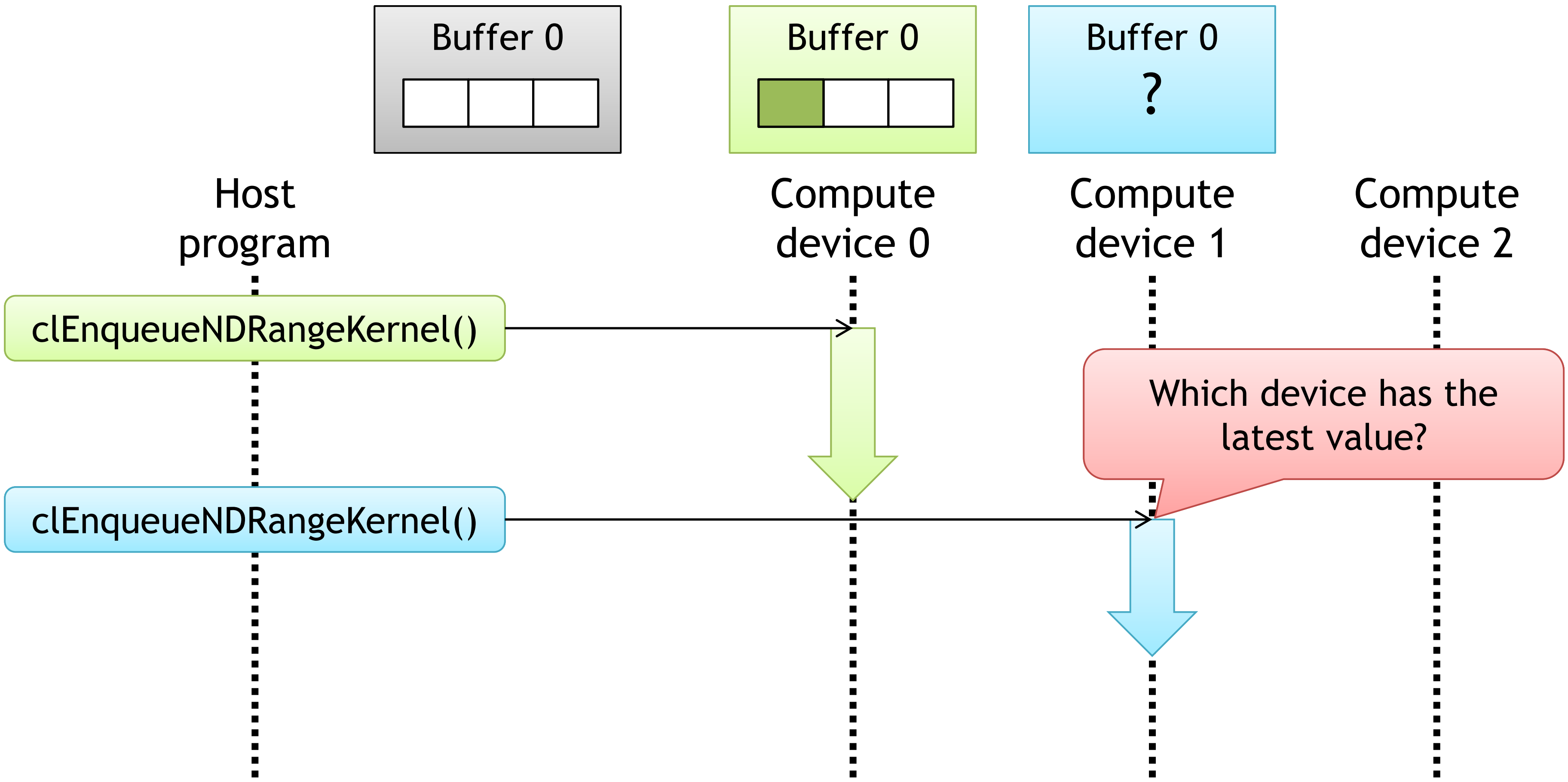
Instead of merging, SnuCL-D serializes commands executed simultaneously

Consistency Problem (Simultaneous Accesses)



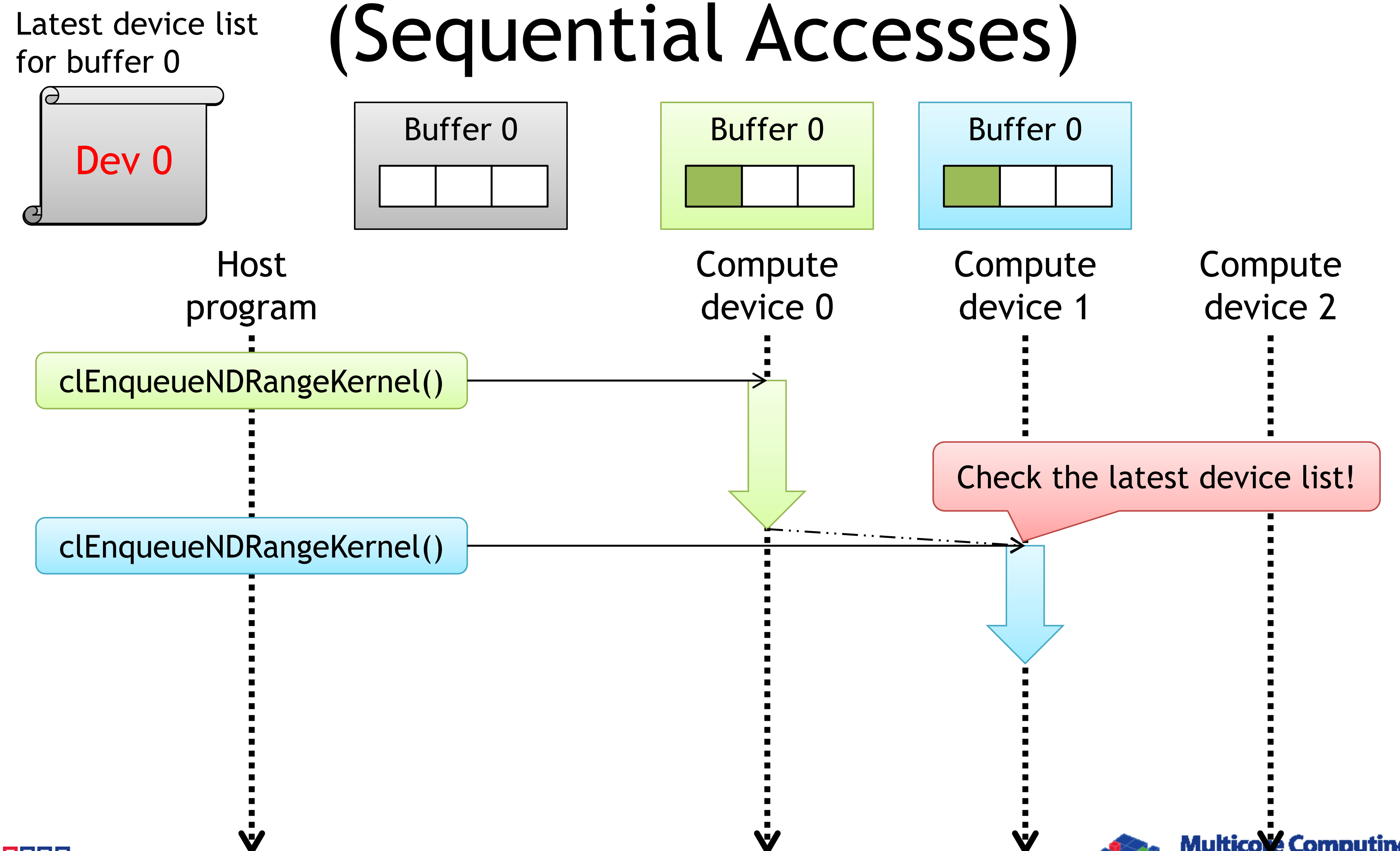
There is no simultaneous accesses by multiple commands in SnuCL-D

Consistency Problem (Sequential Accesses)



SnuCL-D maintains the latest device list for each memory object

Consistency Problem (Sequential Accesses)



Correctness Problems

- Consistency problem
  - Solved by serialization and latest device lists
- Non-determinacy problem

Non-deterministic Command Scheduling (Single-threaded Host Programs)

- Problem
  - Redundant command scheduling on every node
  - If there is no enforced order between commands,
    - Command execution order can be different across nodes
    - May cause a deadlock, data inconsistency, etc.
- Solution
  - The enqueueing order is fixed
    - The order of clEnqueue…() calls
  - SnuCL-D enforces the enqueueing order

Non-deterministic Command Scheduling (Multi-threaded Host Programs)

- Problem
  - Even the enqueueing order is not guaranteed

- Solution
  - Can be solved by deterministic multithreading
    - E. D. Berger [OOPSLA 09], C. Bienia [PACT 08], T. Liu [SOSP 11], M. Olszewski [ASPLOS 09]
  - Using this, we can make the enqueueing order deterministic

- Single-threaded host programs are more common
  - SnuCL-D assumes single-threaded host programs

Non-deterministic Result of a Function Call

- Problem
  - The result of a function call can be different across nodes
  - E.g., file I/O and srand()
- Solution
  - Use global synchronization between nodes
  - After designating a root node, the root node performs the call in the host program
  - The others receive the result from the root

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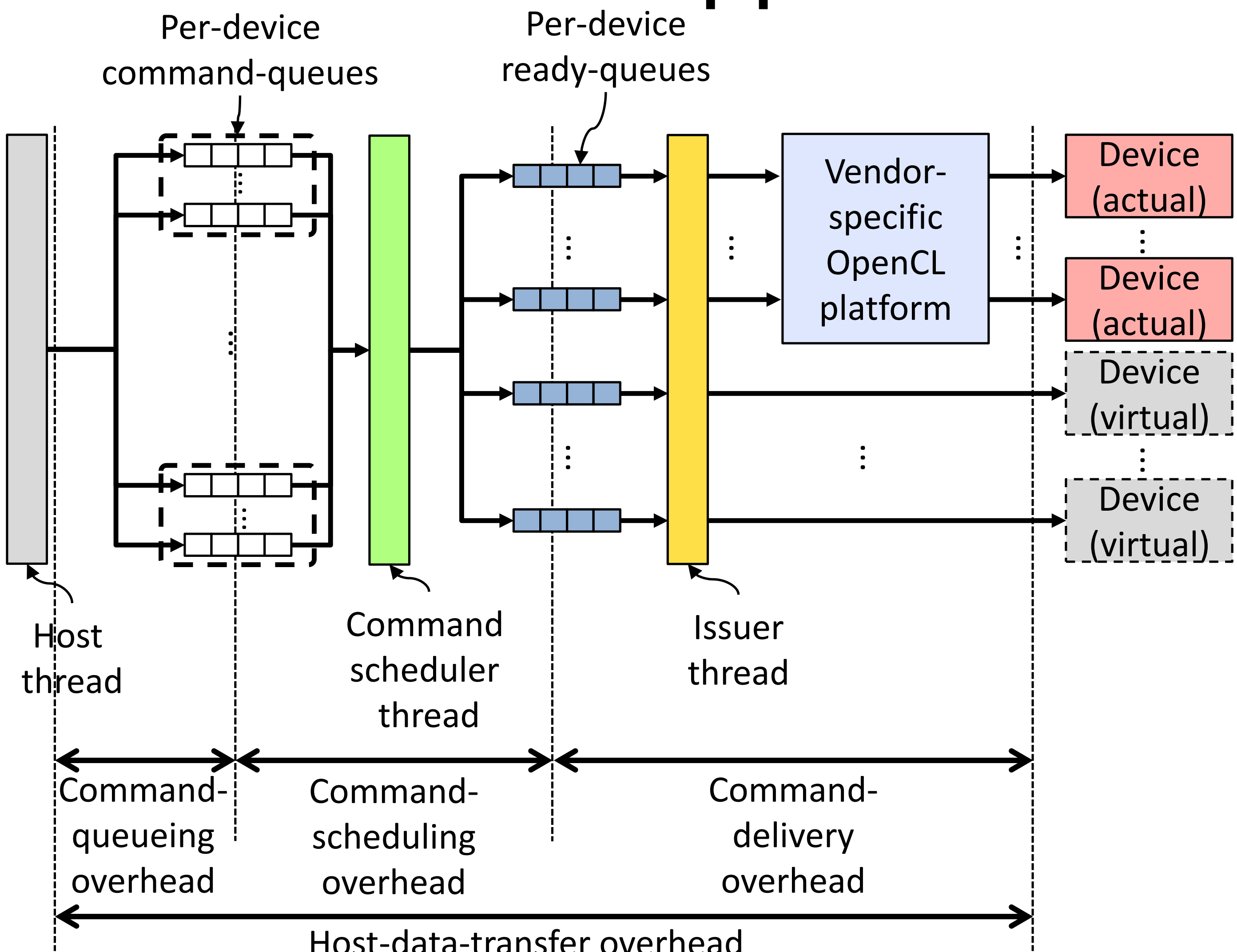
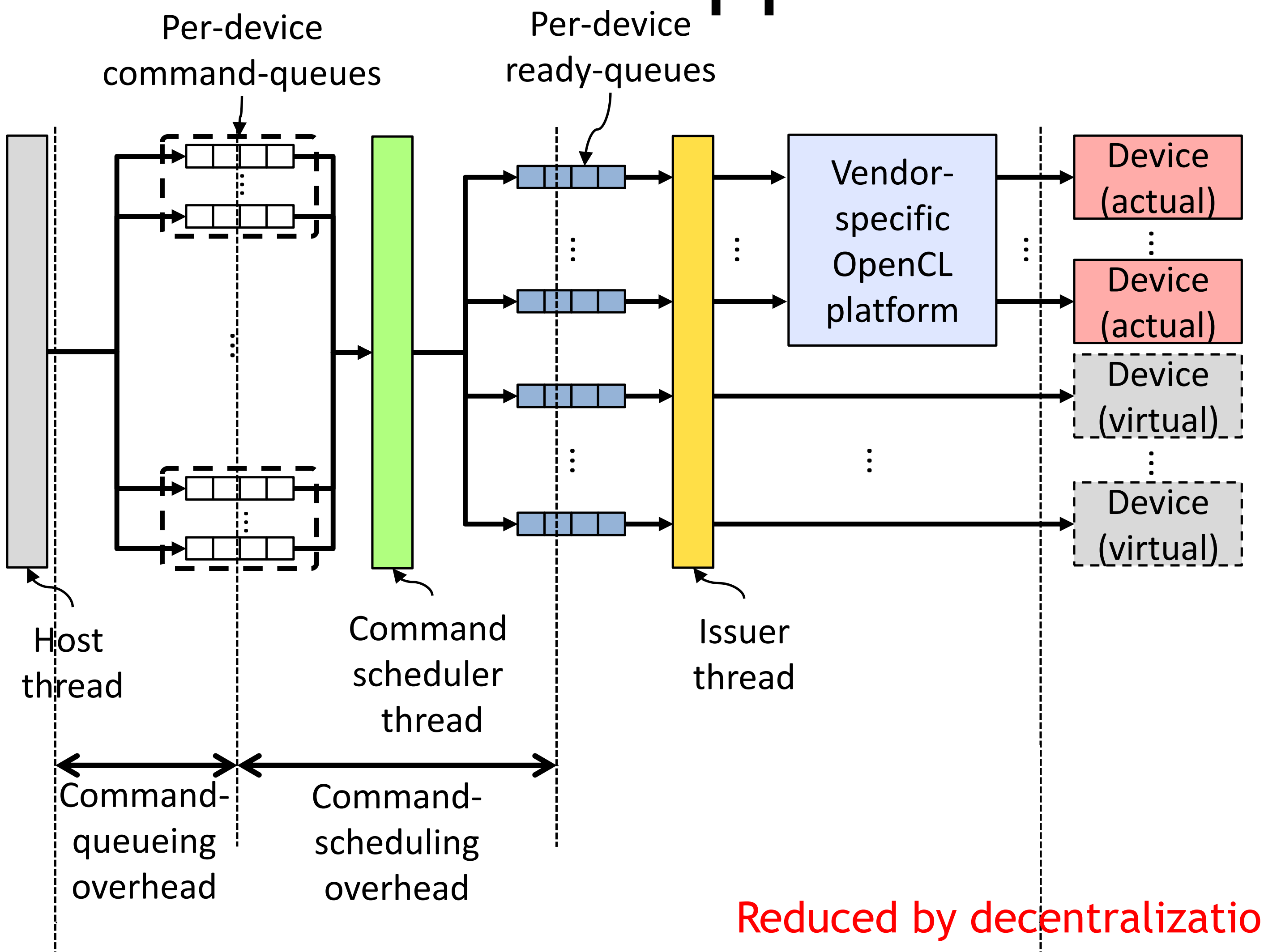
Runtime Overheads of Centralized Approaches



Decentralization Technique

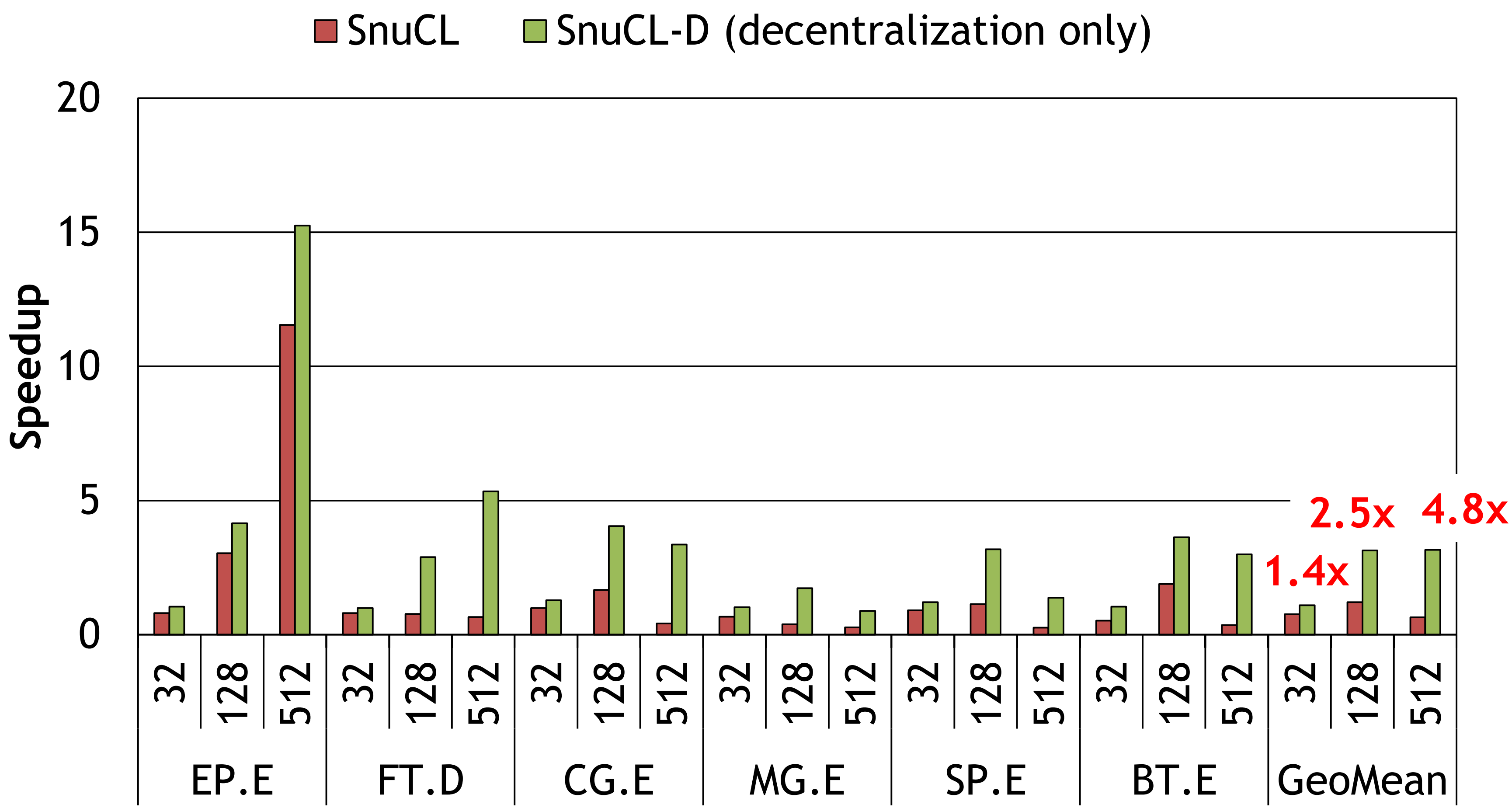
- To reduce
  - Command-delivery overhead
  - Host-data-transfer overhead
- The host program is executed on every node
  - Redundant computation
  - Data replication
- Remote device virtualization
  - Deliver commands to only actual devices

Runtime Overheads of Centralized Approaches

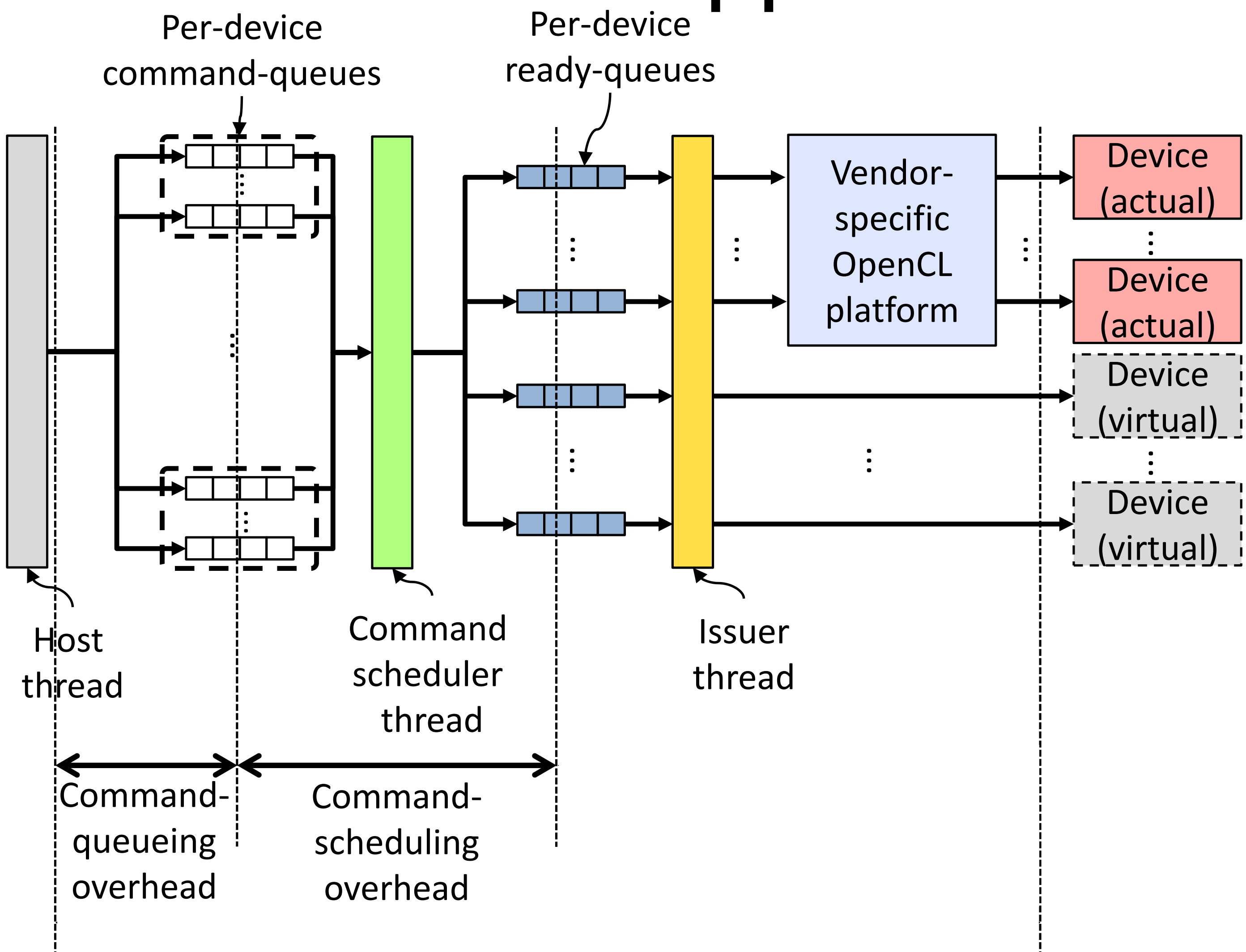


Reduced by decentralization

Performance



Runtime Overheads of Centralized Approaches

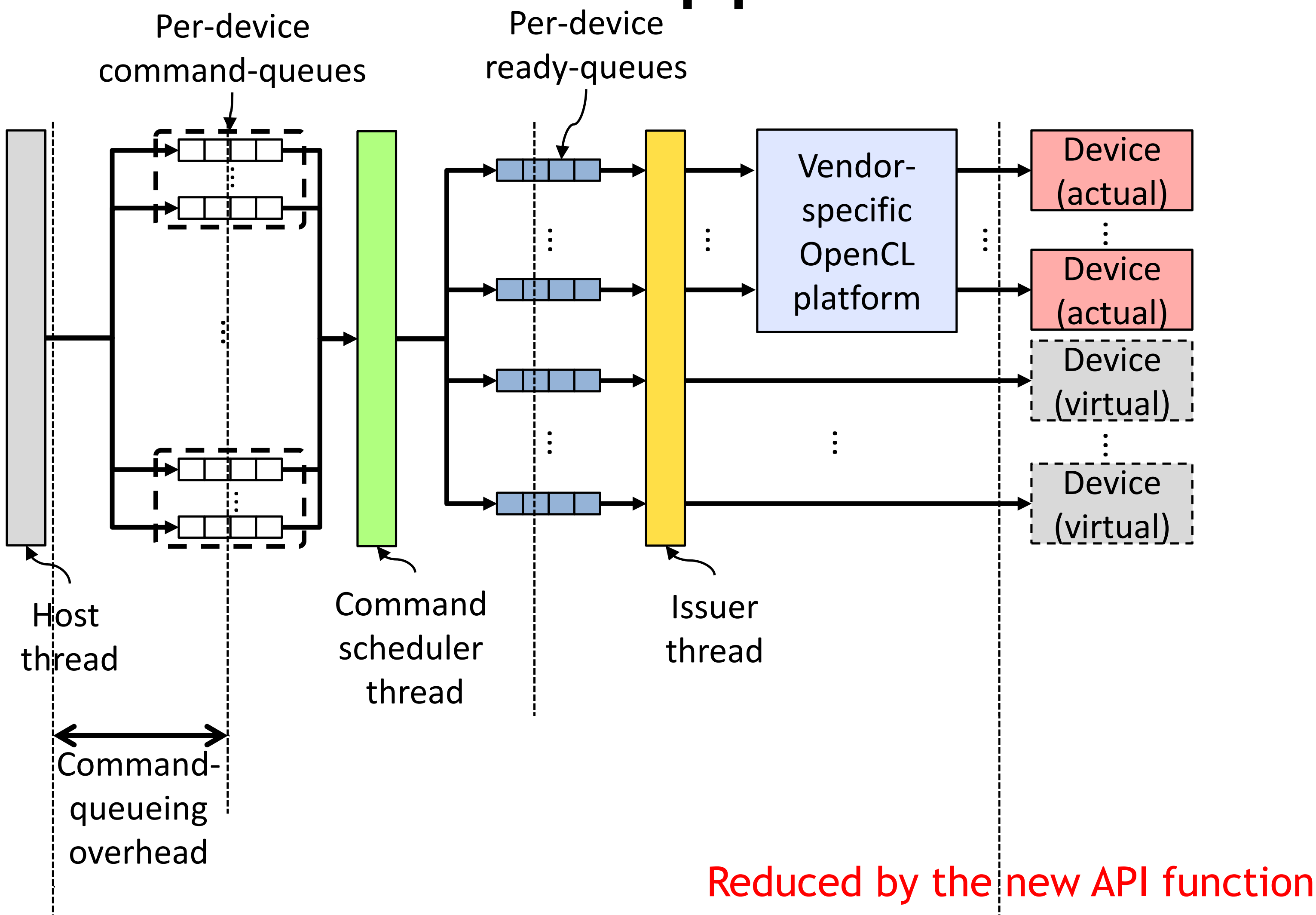


New API Function

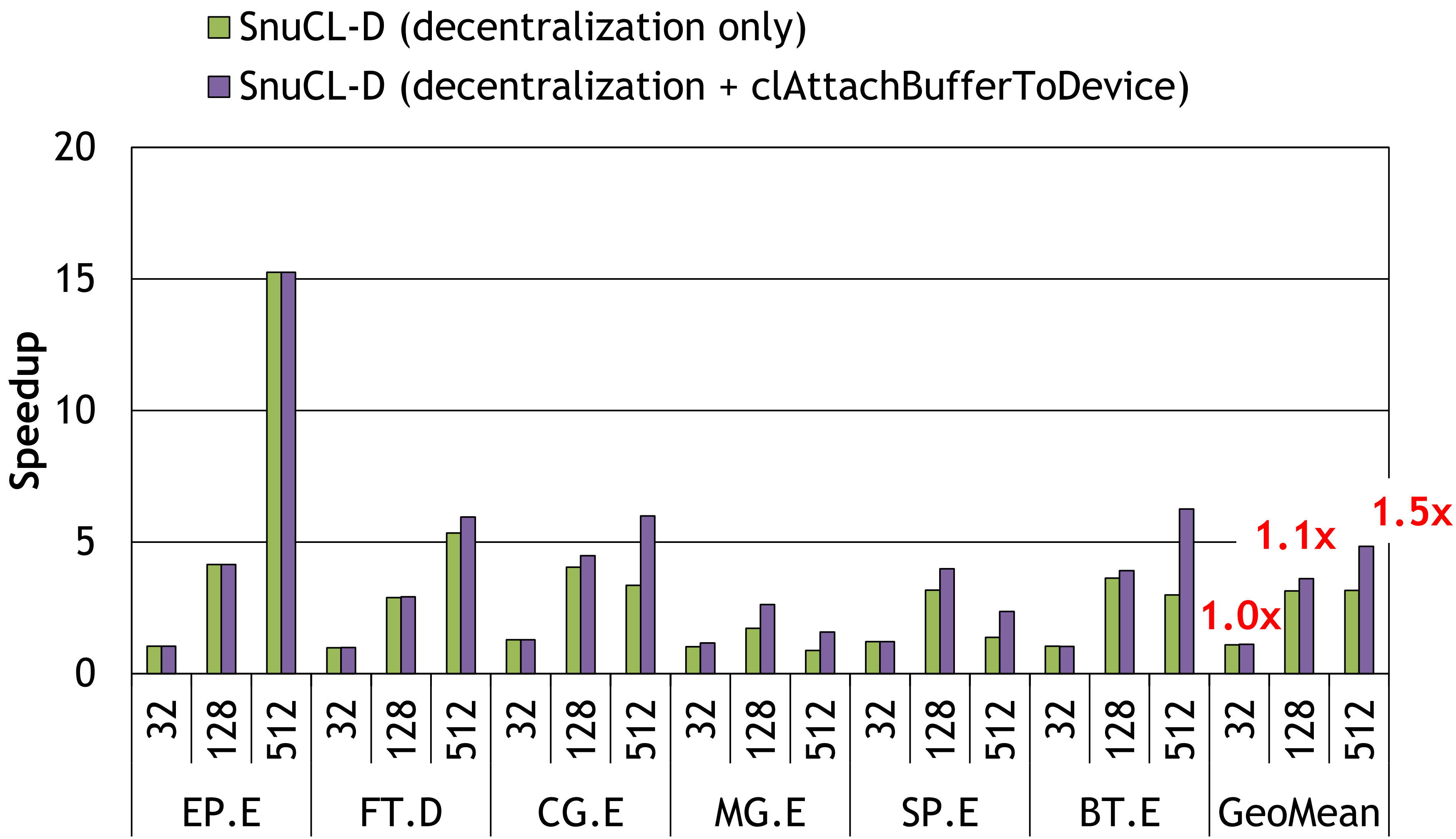
```
void clAttachBufferToDevice(cl_mem m, cl_device_id d);
```

- In OpenCL,
  - Memory object ***m*** is not bound to any devices
  - Scheduling overhead
    - Need to maintain latest device lists (consistency management)
- If this function is called,
  - SnuCL-D assumes
    - ***d*** always has the latest copy of ***m***
  - Scheduling overhead reduced
    - No need to maintain latest device lists

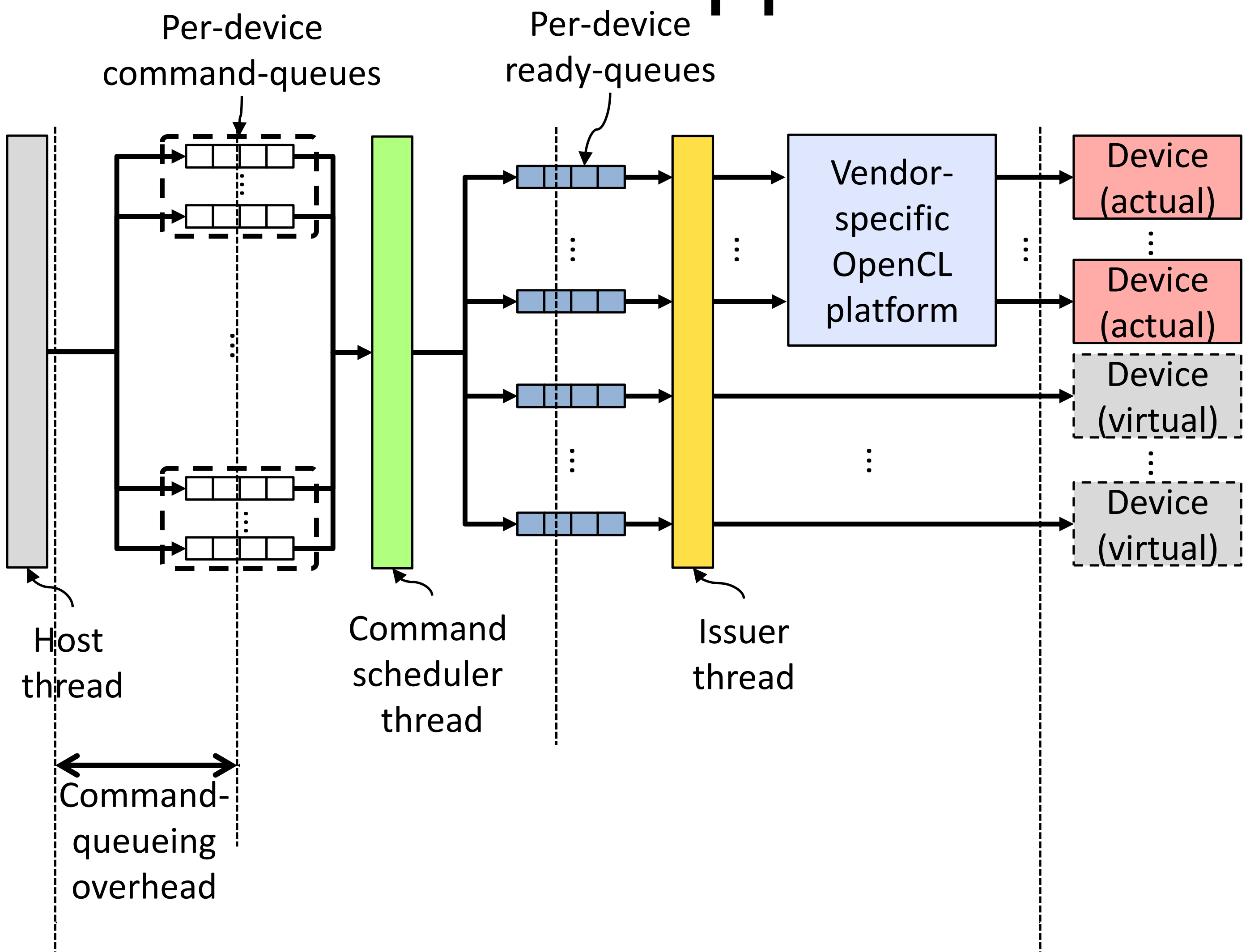
Runtime Overheads of Centralized Approaches



Performance



Runtime Overheads of Centralized Approaches



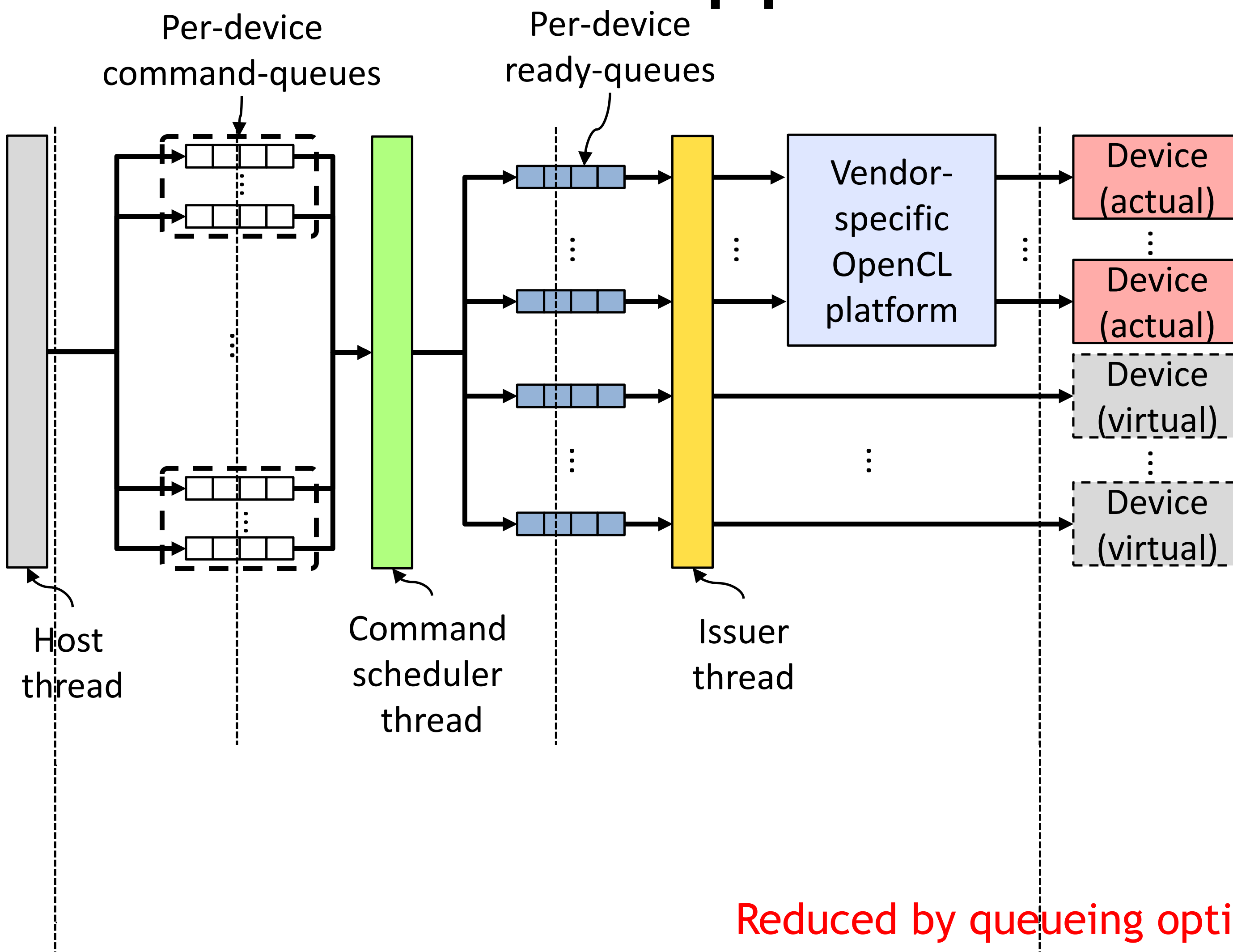
Queueing Optimization

- Two conditions under which commands for a virtual device do not need to be enqueued
  - No events in the event wait list
  - Each memory object is attached

- If the two conditions are met by a command
  - Discarding it does not affect correctness

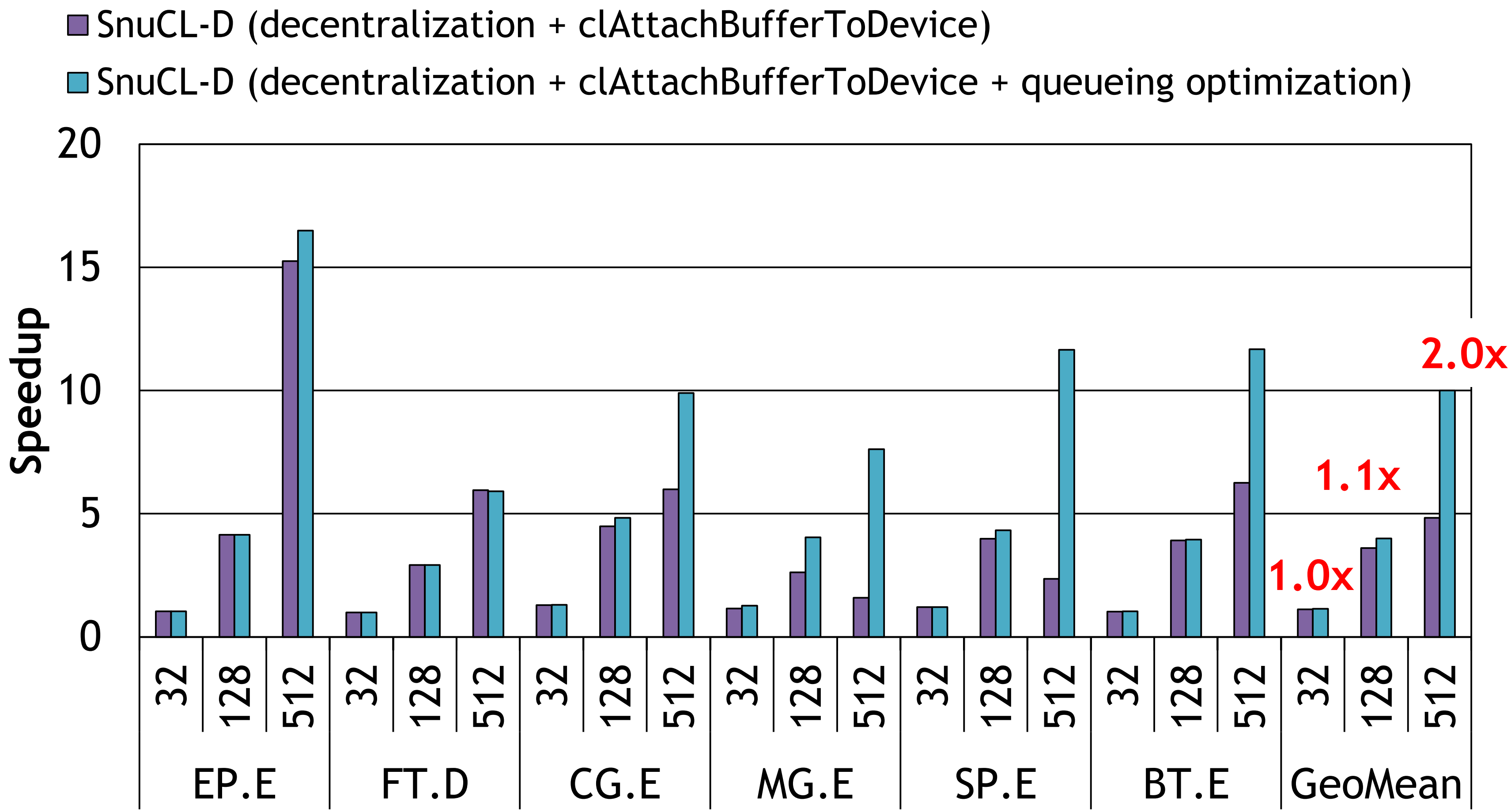
- The commands can be safely discarded when enqueued

Runtime Overheads of Centralized Approaches

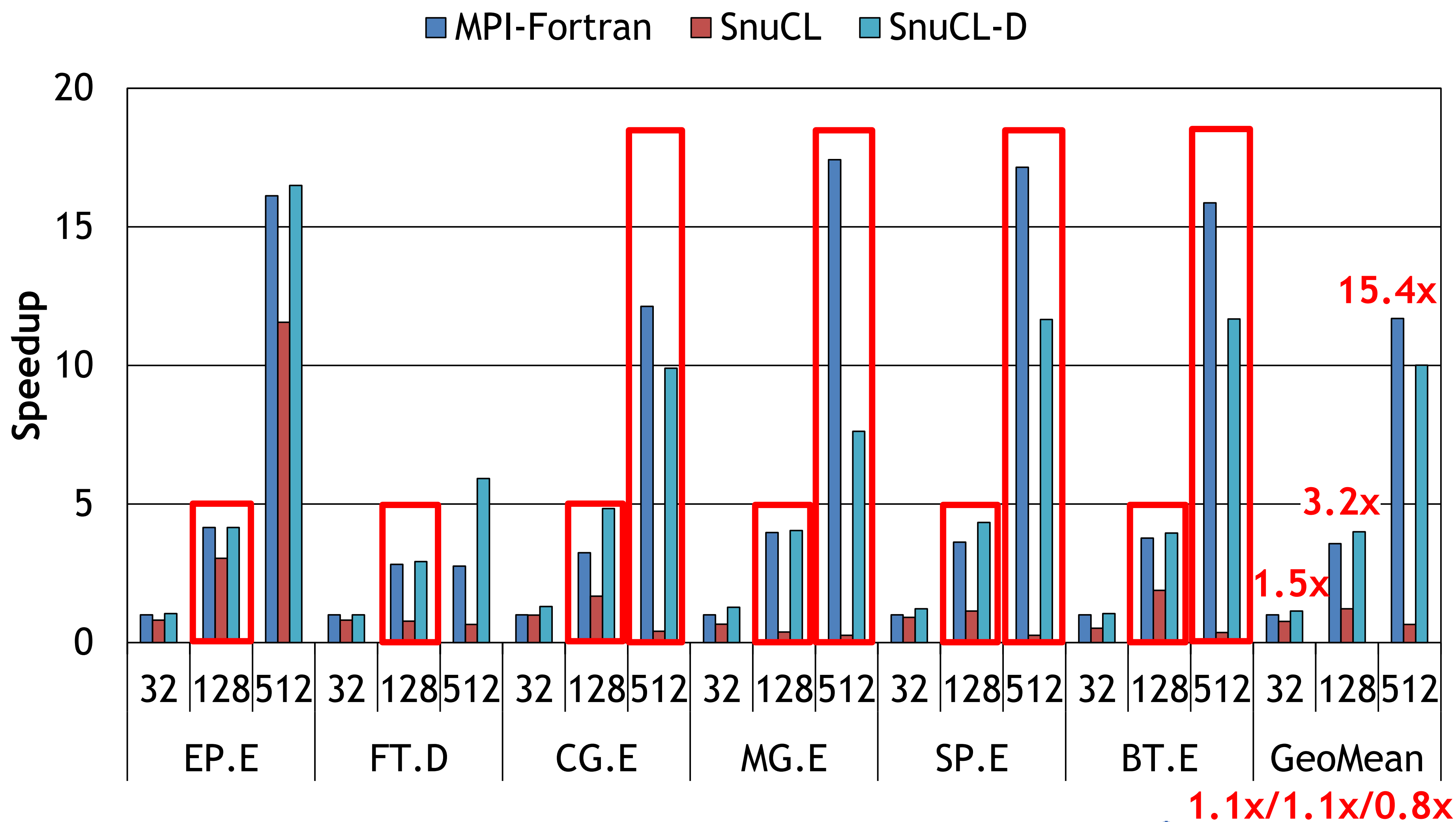


Reduced by queueing optimization

Performance



Performance



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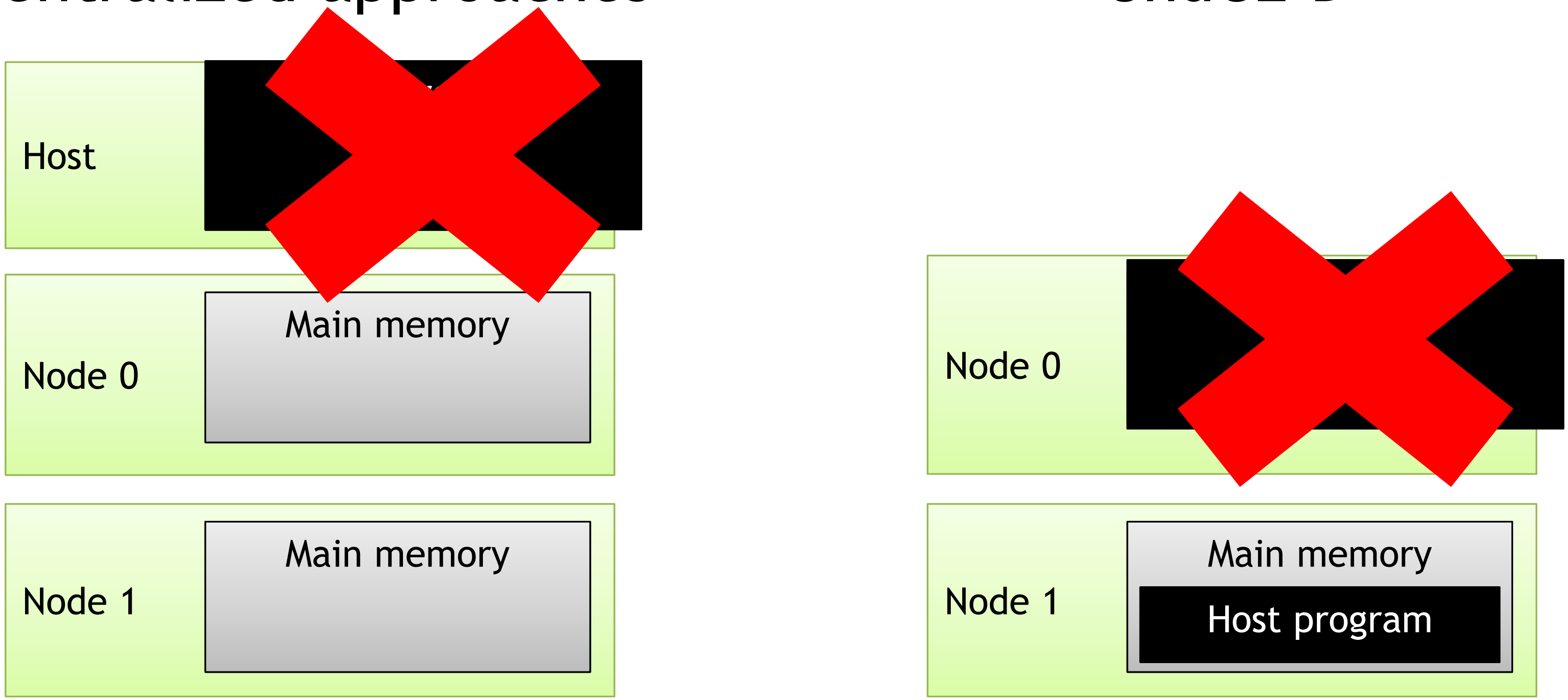
Limitation: Memory Footprint

Centralized approaches

SnuCL-D



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Conclusion

- SnuCL-D
  - A scalable and distributed OpenCL framework for clusters
  - OpenCL programs for multiple devices
    - Efficiently executed on a large-scale cluster
- Correctness Problems
  - Consistency problem and non-determinacy problem
- Three optimization techniques
  - Decentralization, new API function, and queueing optimization
- Available at http://snucl.snu.ac.kr
  - July 11, 2016

Thank you