A Compiler Framework for Optimizing Dynamic Parallelism on GPUs

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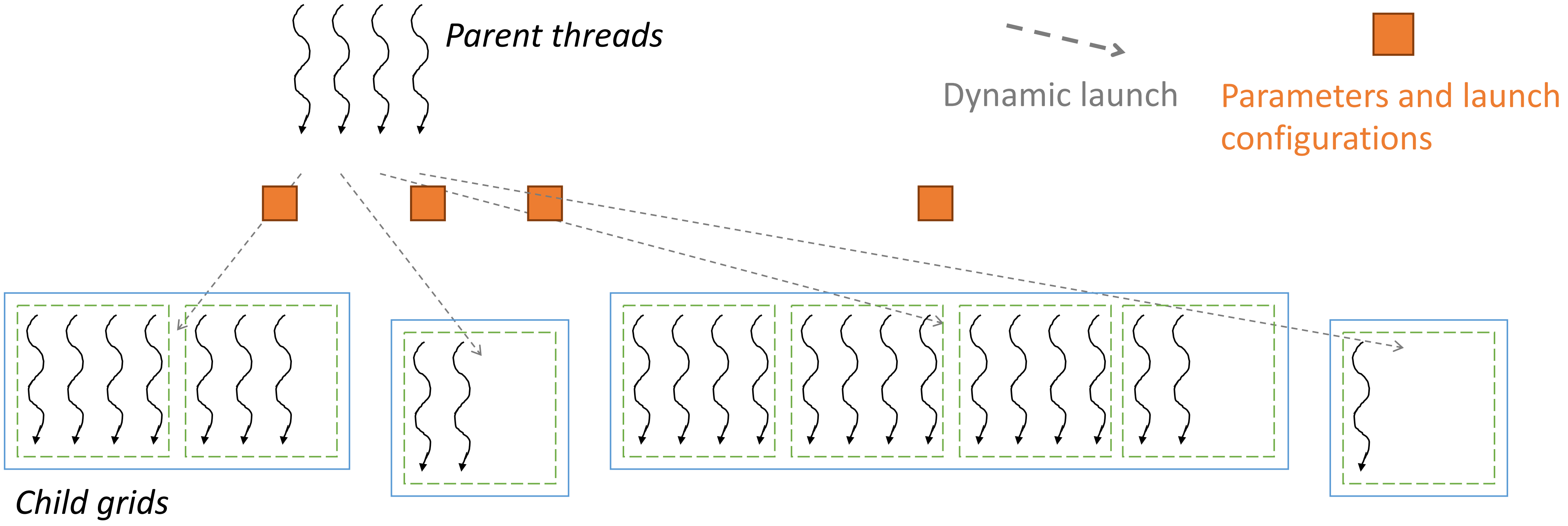
Dynamic Parallelism on GPUs

- **Dynamic parallelism** enables executing GPU threads to launch other grids of threads



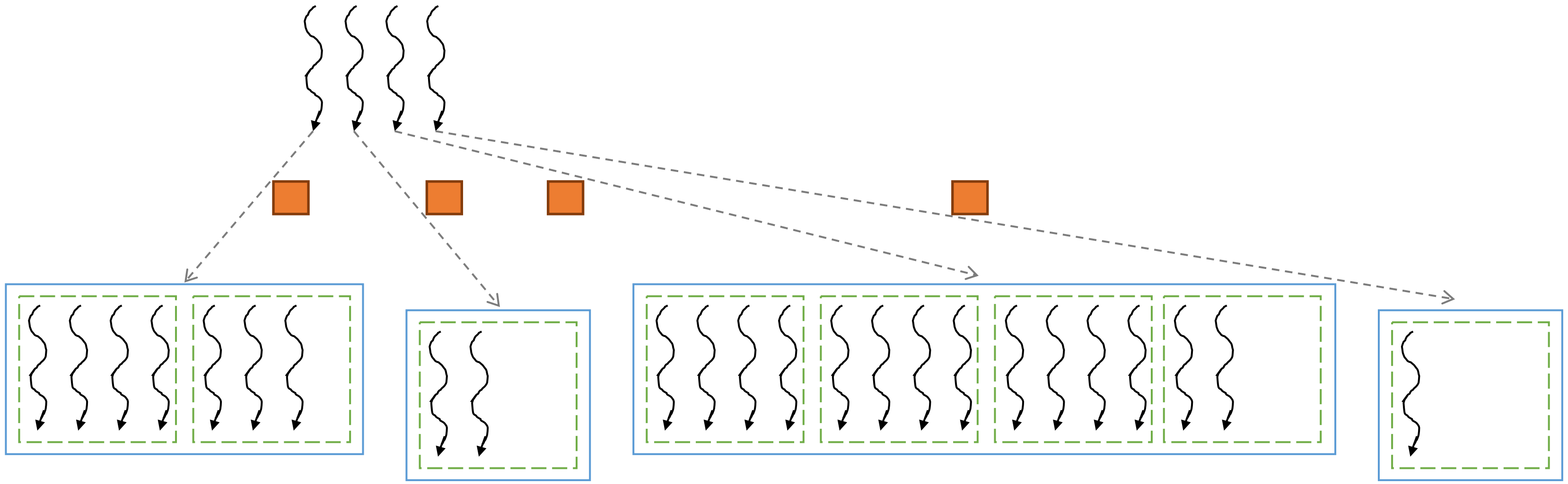
- Useful for implementing computations with **nested parallelism**

Dynamic Parallelism Overhead

- Using dynamic parallelism may cause many small grids to be launched
- Launching many small grids causes **performance degradation** due to:
  - **Congestion**
    - Limited number of grids can execute simultaneously (others need to wait)
  - **Hardware underutilization**
    - If grids are small, their may not be enough threads launched to fully utilize hardware resources
- Solution: launch **fewer grids** of **larger sizes**

Prior Work: Aggregation

- Aggregation is an optimization where:
  - Multiple child grids are consolidated into a single aggregated grid
  - One parent thread launches the aggregated grid on behalf of the rest



- I. El Hajj, J. Gomez-Luna, C. Li, L.-W. Chang, D. Milojicic, and W.-m. ´ Hwu, “KLAP: Kernel launch aggregation and promotion for optimizing dynamic parallelism,” in Microarchitecture (MICRO), 2016 49th Annual IEEE/ACM International Symposium on. IEEE, 2016, pp. 1–12
- D. Li, H. Wu, and M. Becchi, “Exploiting dynamic parallelism to efficiently support irregular nested loops on GPUs,” in Proceedings of the 2015 International Workshop on Code Optimisation for Multi and Many Cores. ACM, 2015, p. 5.
- Li, D., Wu, H., & Becchi, M., “Nested parallelism on GPU: Exploring parallelization templates for irregular loops and recursive computations,” in Parallel Processing (ICPP), 2015 44th International Conference on. IEEE, 2015, pp. 979– 988.
- H. Wu, D. Li, and M. Becchi, “Compiler-assisted workload consolidation for efficient dynamic parallelism on GPU,” arXiv preprint arXiv:1606.08150, 2016.

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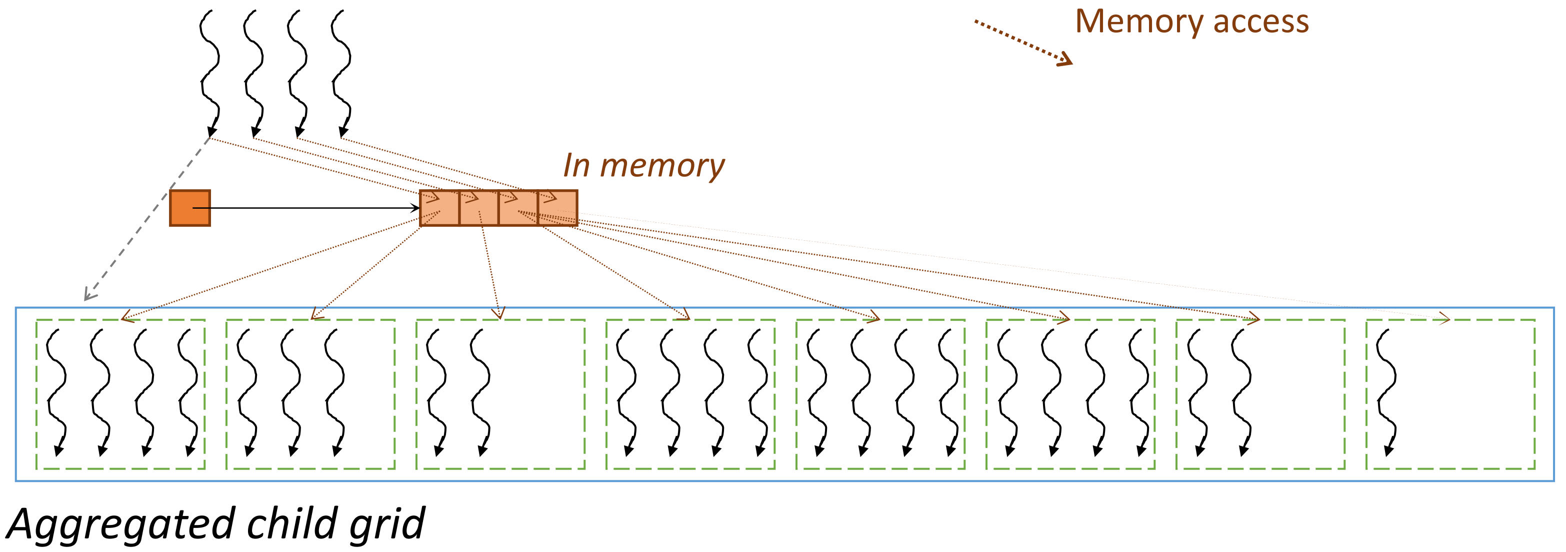


+ Reduces congestion by reducing the number of launched grids

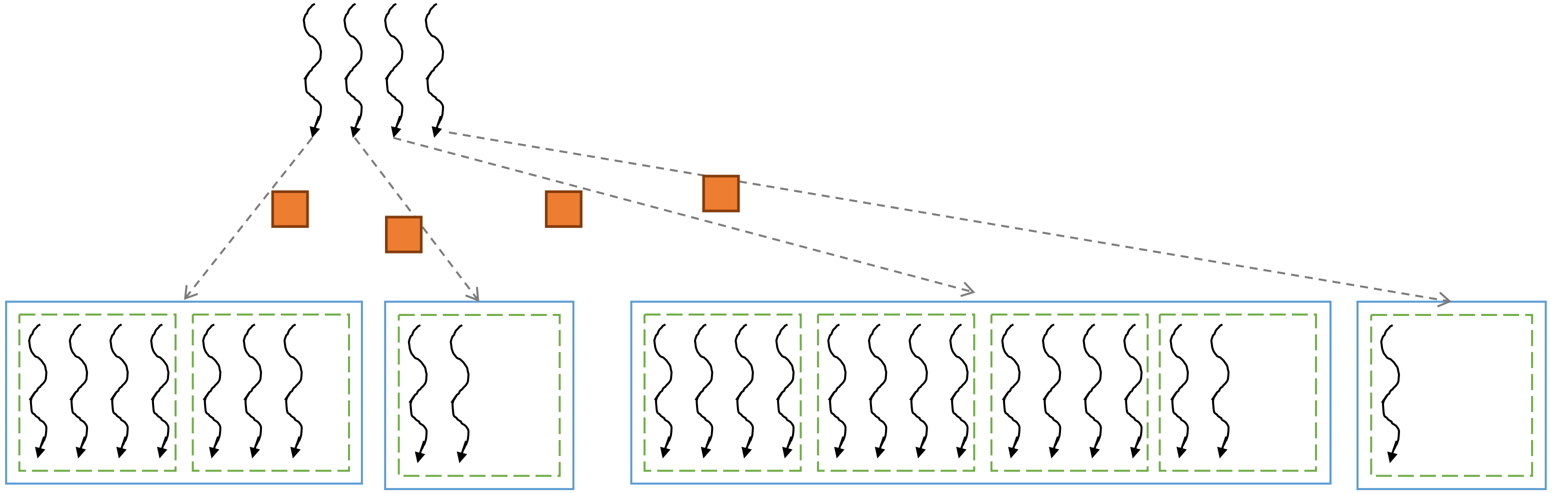
+ Improves utilization because aggregated child grids have more threads then original ones

Contributions

- **Thresholding** (as a compiler optimization)
  - Prior work relies on programmers to apply it manually
- **Coarsening** of child thread blocks
  - Prior work on compiler-based coarsening not specialized for dynamic parallelism
- **Aggregation** of child grids at multi-block granularity
  - Prior work only compiler-based aggregation only considers warp, block, and grid granularity
- One **compiler framework** that combined the three optimizations

Thresholding

- Thresholding is an optimization where:
  - A grid is launched dynamically only if the number of child threads exceeds a certain threshold
  - Otherwise, work is executed sequentially by the parent thread



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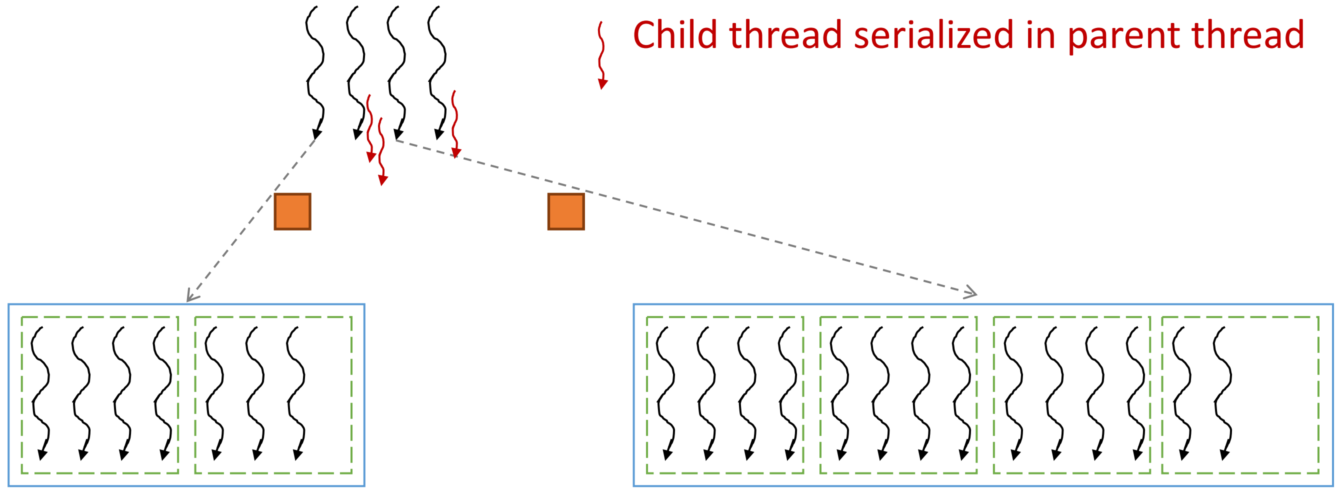
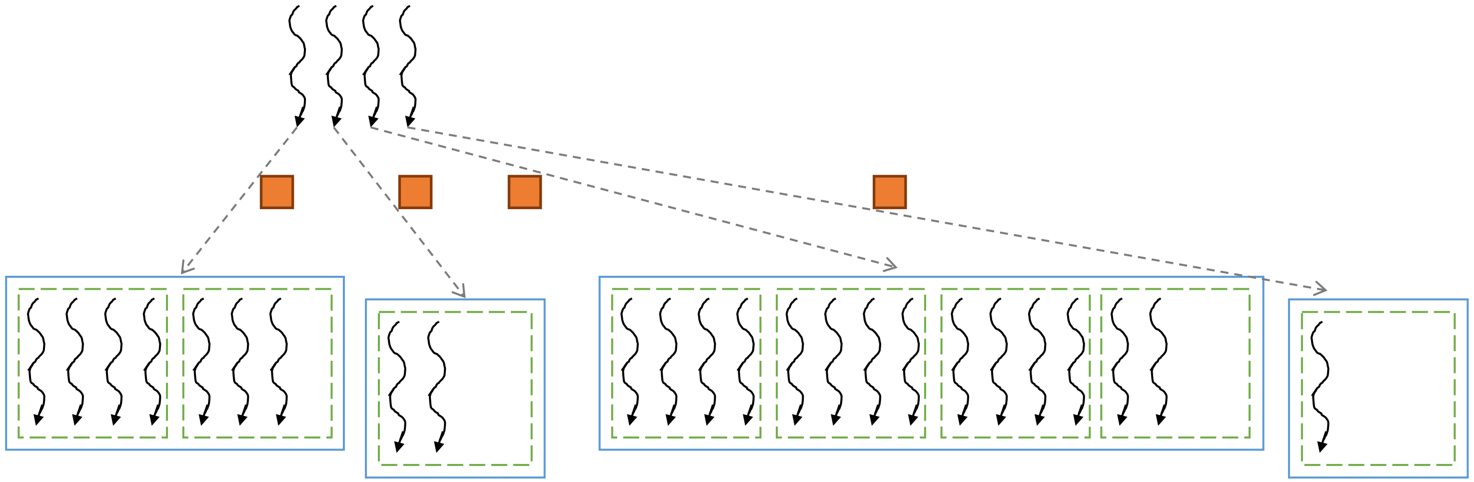


+ Reduces congestion by reducing the number of launched grids

+ Improves utilization by only allowing grids with many threads to be launched

Coarsening

- Coarsening is a transformation where:
  - The work of multiple child blocks is assigned to a single child block



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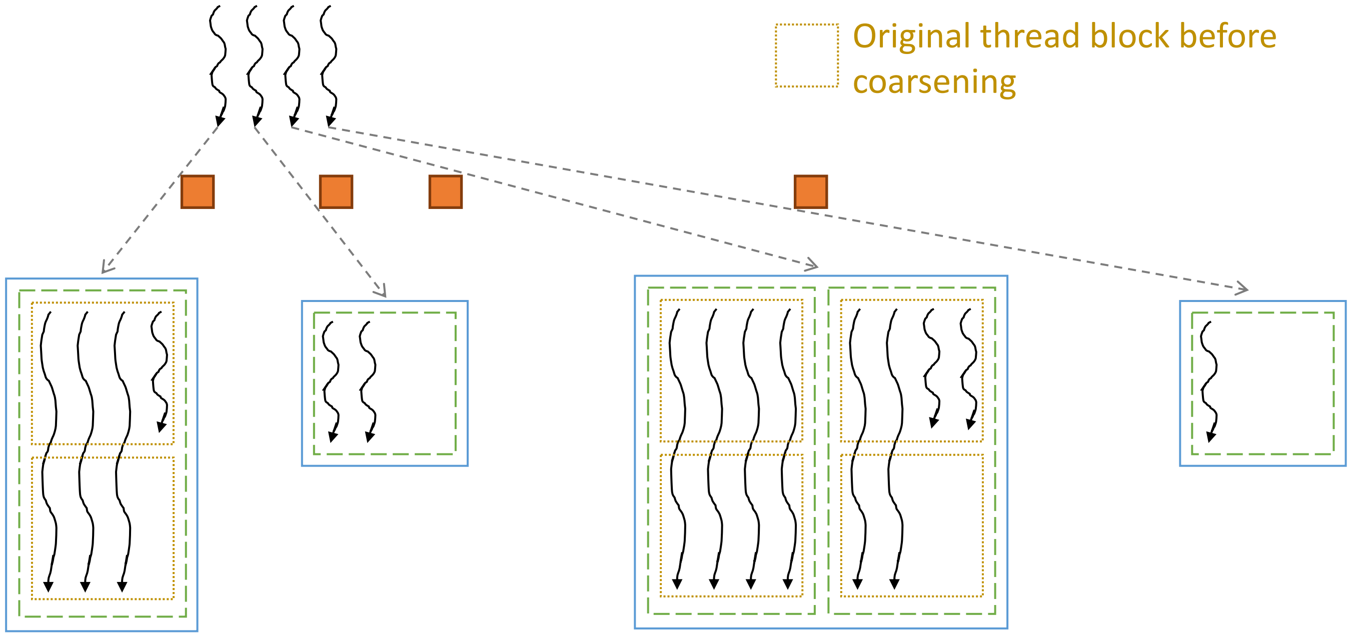
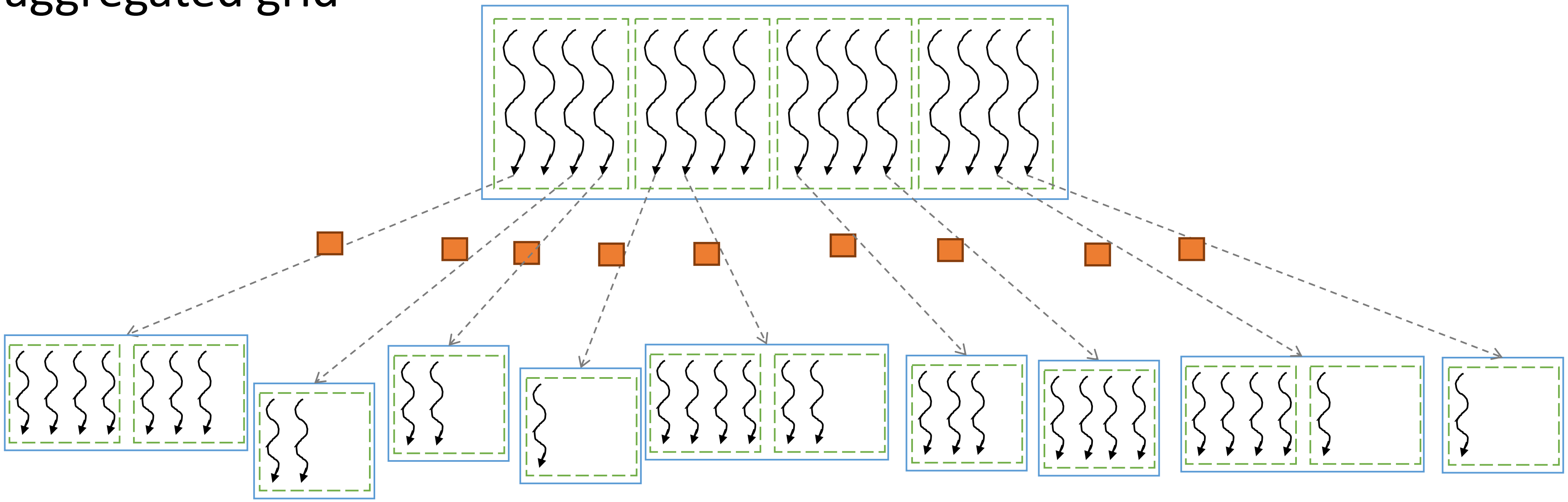


Coarsened child grids

+ When applied before aggregation, amortizes the cost of disaggregation (incurred once per child blocks)

Multi-block Granularity Aggregation

- Multi-block granularity aggregation is an optimization where:
  - The child grids of multiple parent blocks are consolidated into a single aggregated grid



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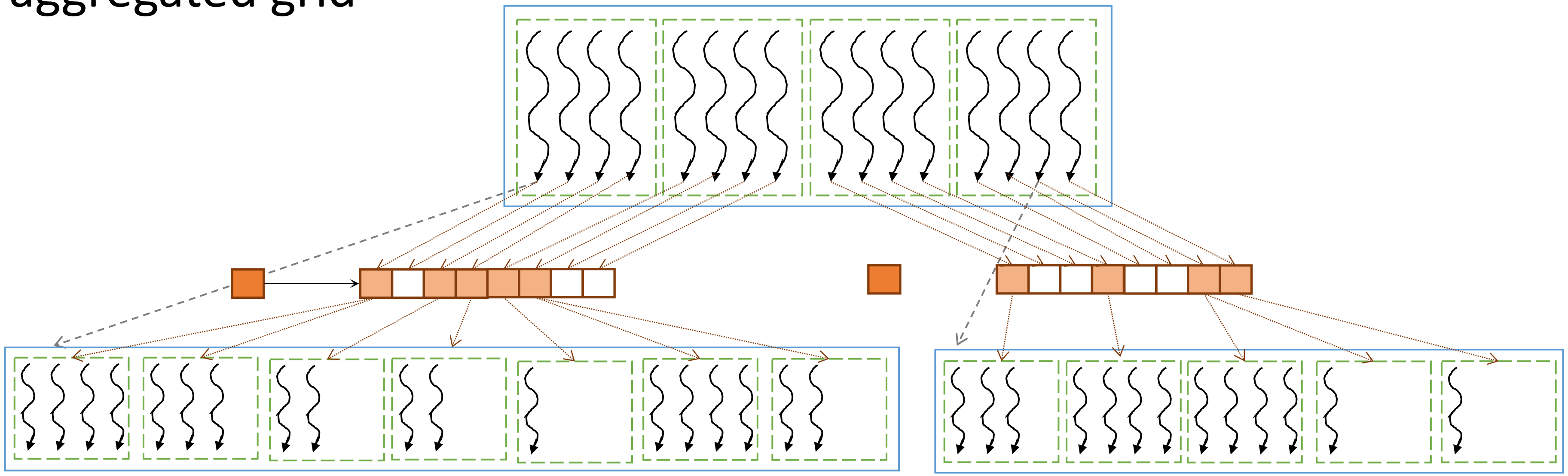
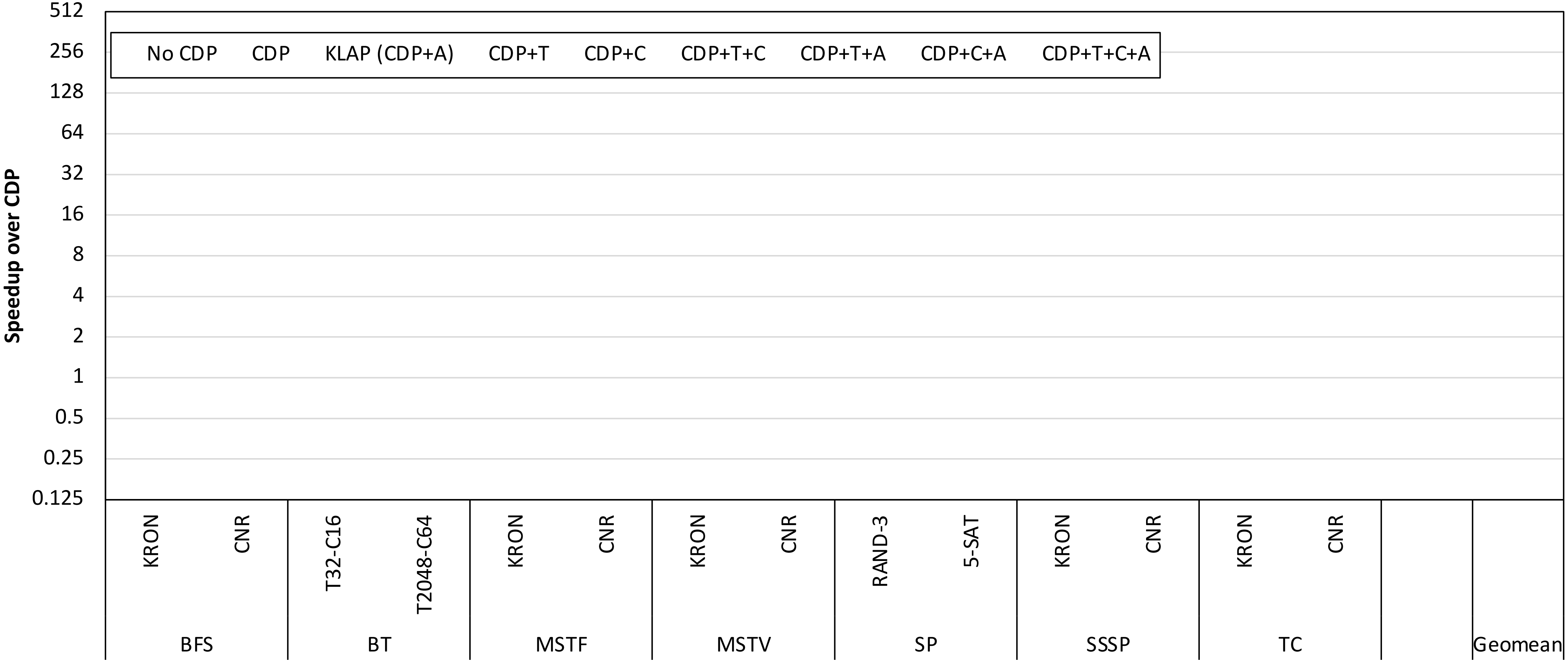


+ Compared to block granularity, launches fewer and larger grids

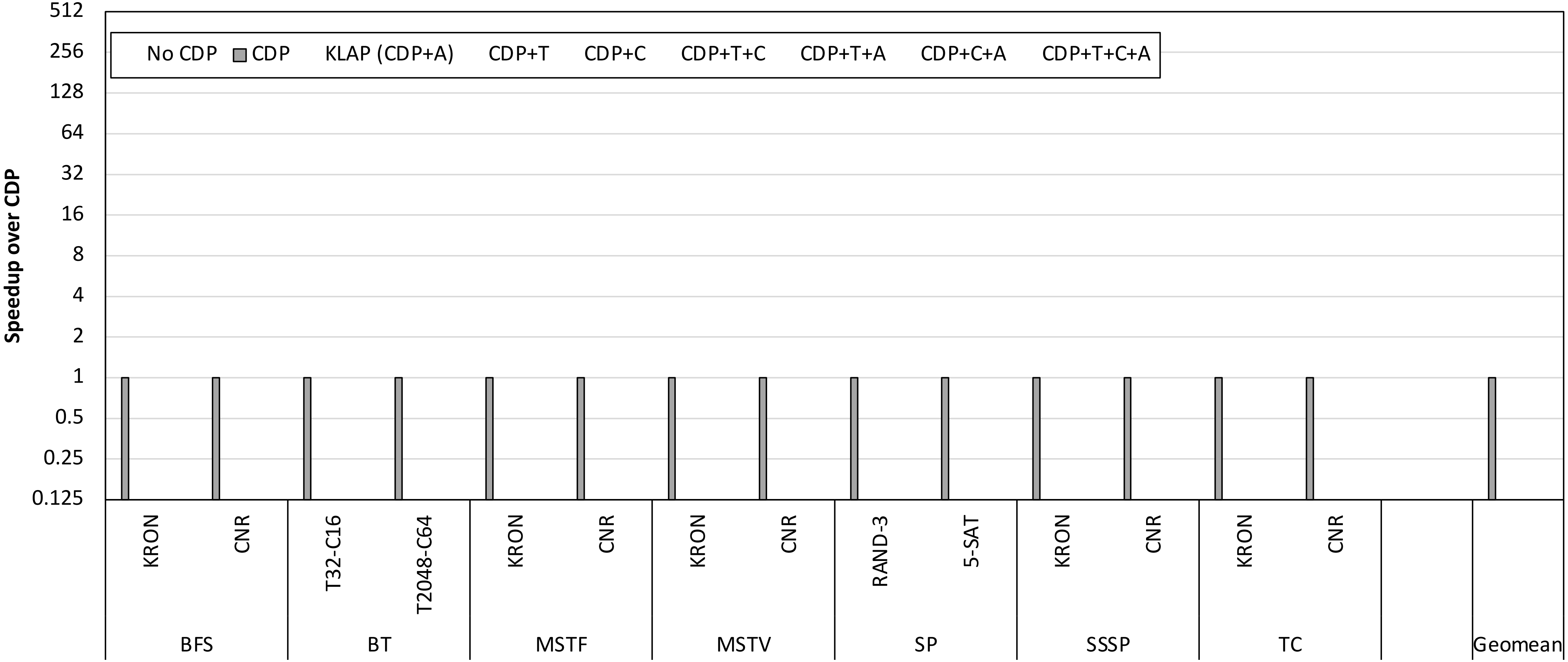
+ Compared to grid granularity, launches child grids more eagerly

Overall Speedup



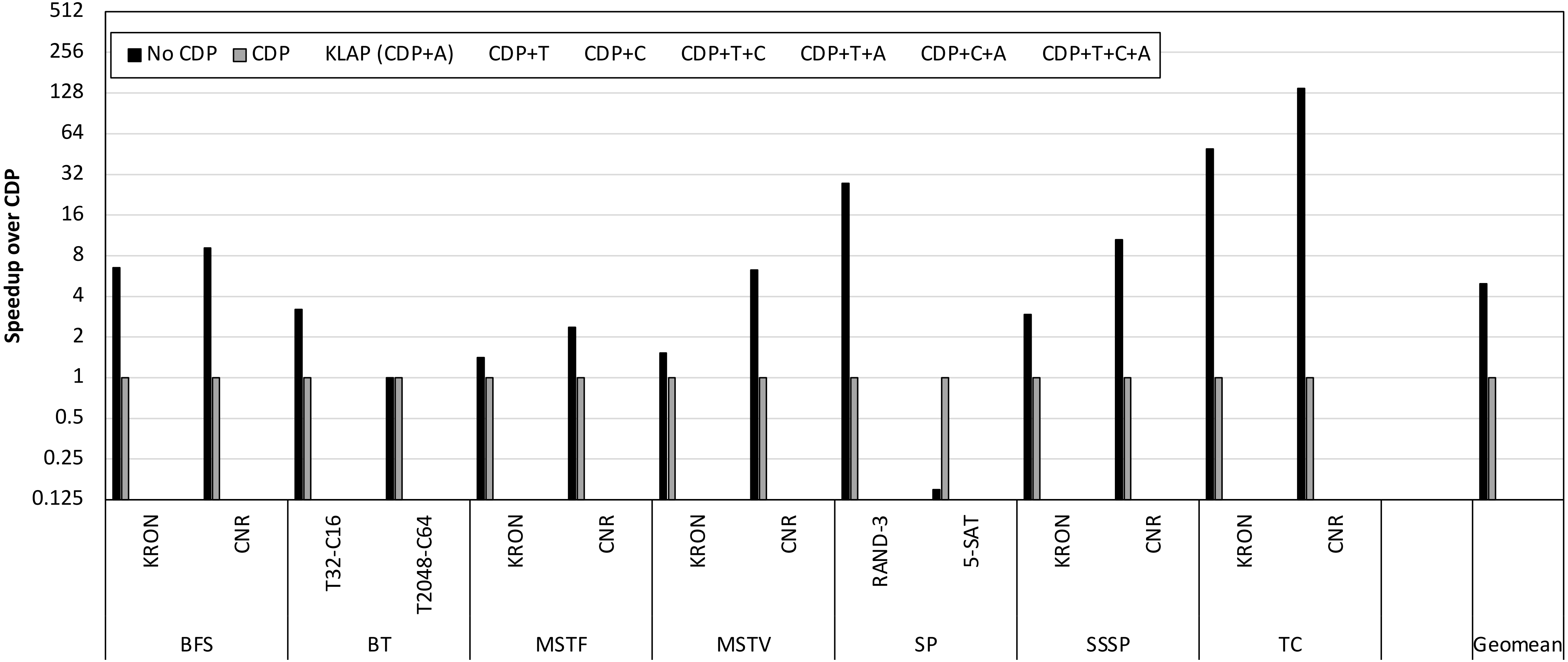
We evaluate all combinations of optimizations for 7 benchmarks with 2 datasets each

Overall Speedup



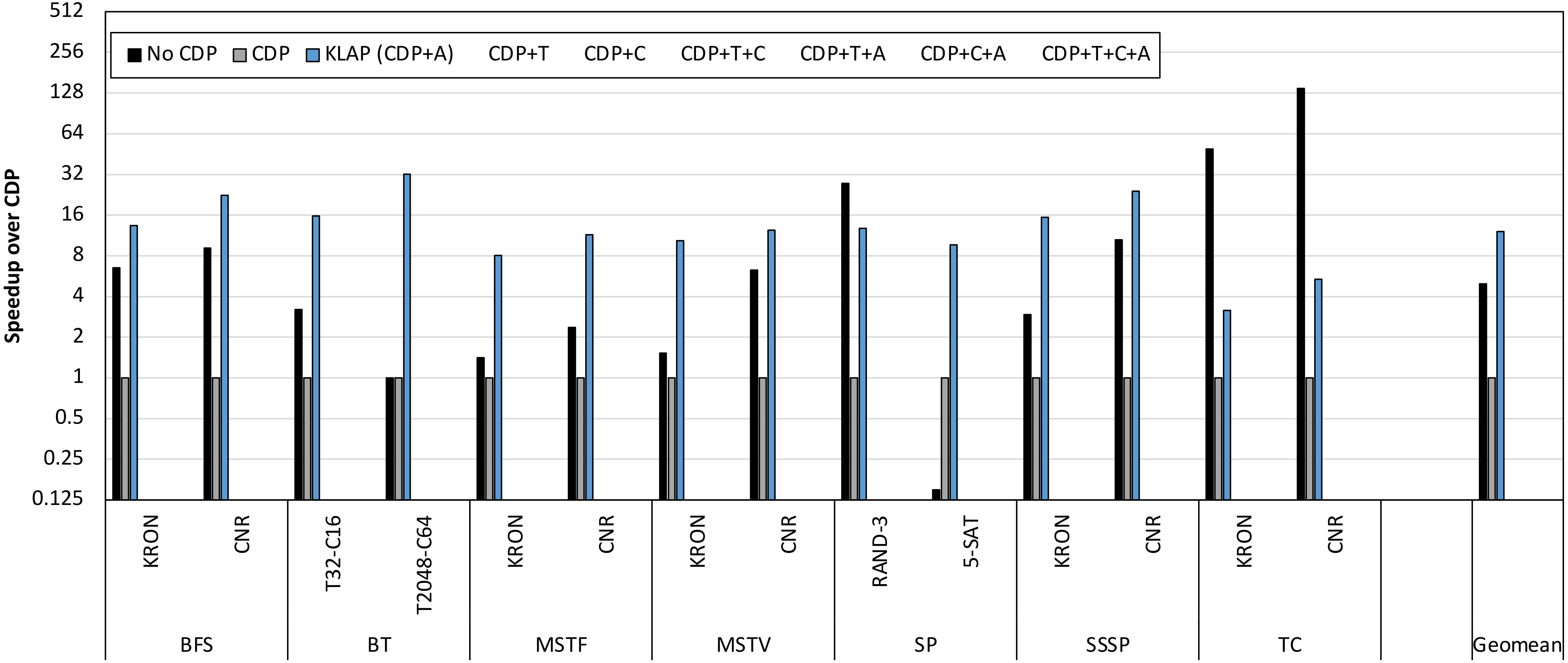
We report speedup (higher is better) over the baseline that uses **CUDA dynamic parallelism (CDP)**

Overall Speedup



<u>Observation #1:</u> Not using CDP performs better than **naïve CDP** (same observation as prior work).

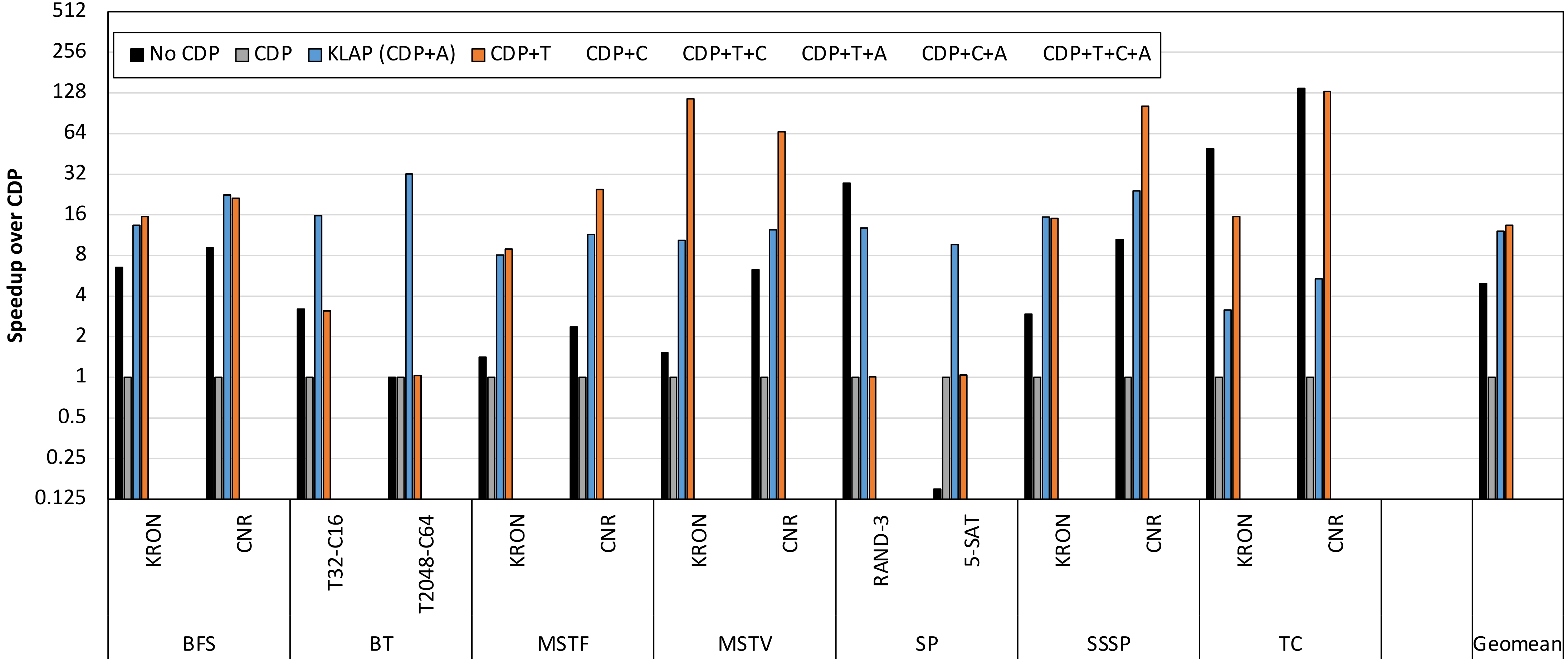
Overall Speedup



<u>Observation #2:</u> **Aggregation** improves performance of **naïve CDP** (same observation as prior work).

KLAP(CDP+A) is 12.1× faster than **CDP** on average (geomean).

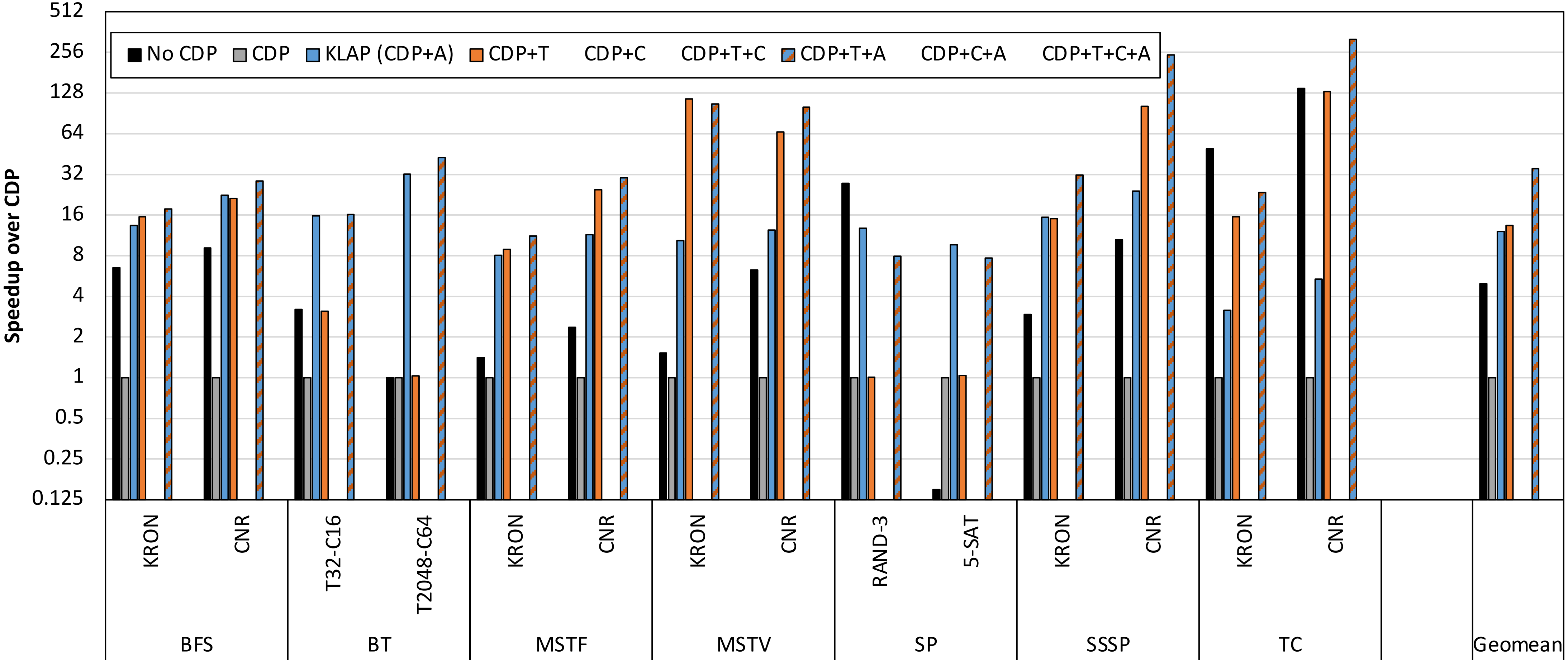
Overall Speedup



Observation #3: Thresholding alone improves the performance over CDP.

CDP+T is 13.4× faster than CDP on average (geomean).

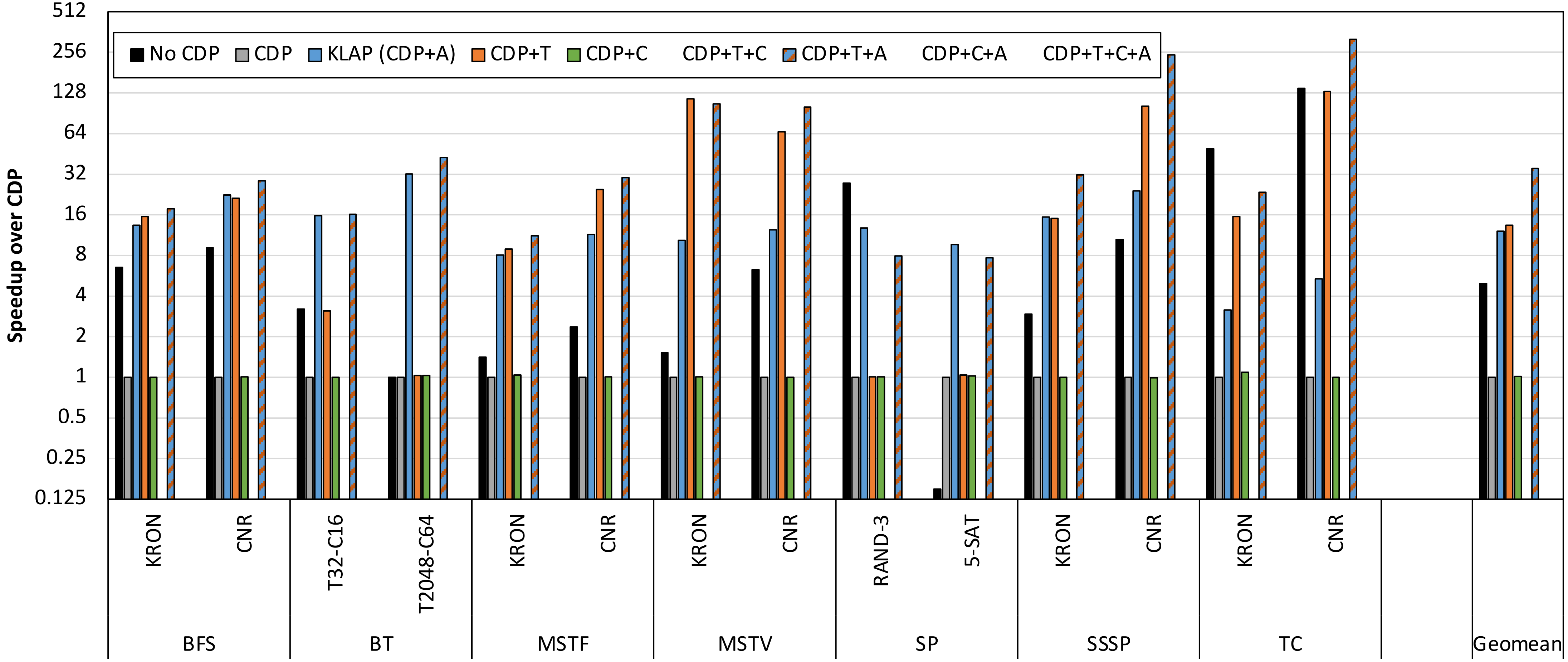
Overall Speedup



Observation #4: Thresholding and Aggregation together improve the performance over CDP even more.

Despite both targeting the same source of inefficiency, one optimization does not obviate the other.

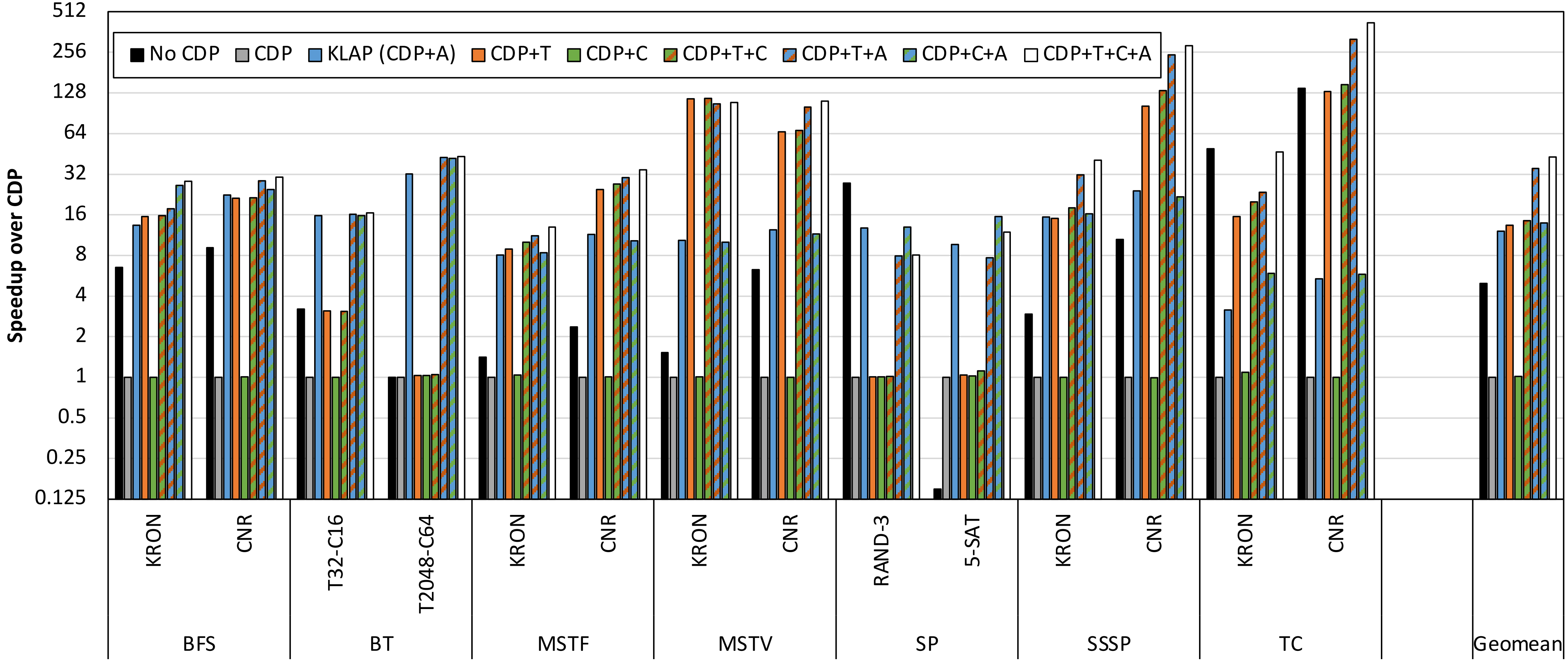
Overall Speedup



Observation #5: Coarsening alone does not improve performance substantially over CDP.

CDP+C is 1.01× faster than CDP.

Overall Speedup



<u>Observation #6:</u> **Coarsening** does improve performance when combined with the other optimizations.

Recall: main benefit was amortizing overhead of aggregation. **CDP+T+C+A** is 1.22× faster than **CDP+T+A**.

Summary

- We present a **compiler framework** for optimizing the use of dynamic parallelism on GPUs in applications with nested parallelism
- The framework includes **three key optimizations**:
  - Thresholding
  - Coarsening
  - Aggregation
- Our evaluation shows that our compiler framework **substantially improves performance of applications with nested parallelism** that use dynamic parallelism
  - 43.0× faster than CDP.
  - 8.7× faster than No CDP
  - 3.6× faster than prior aggregation work (KLAP)

Thank you!

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