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## Motivation

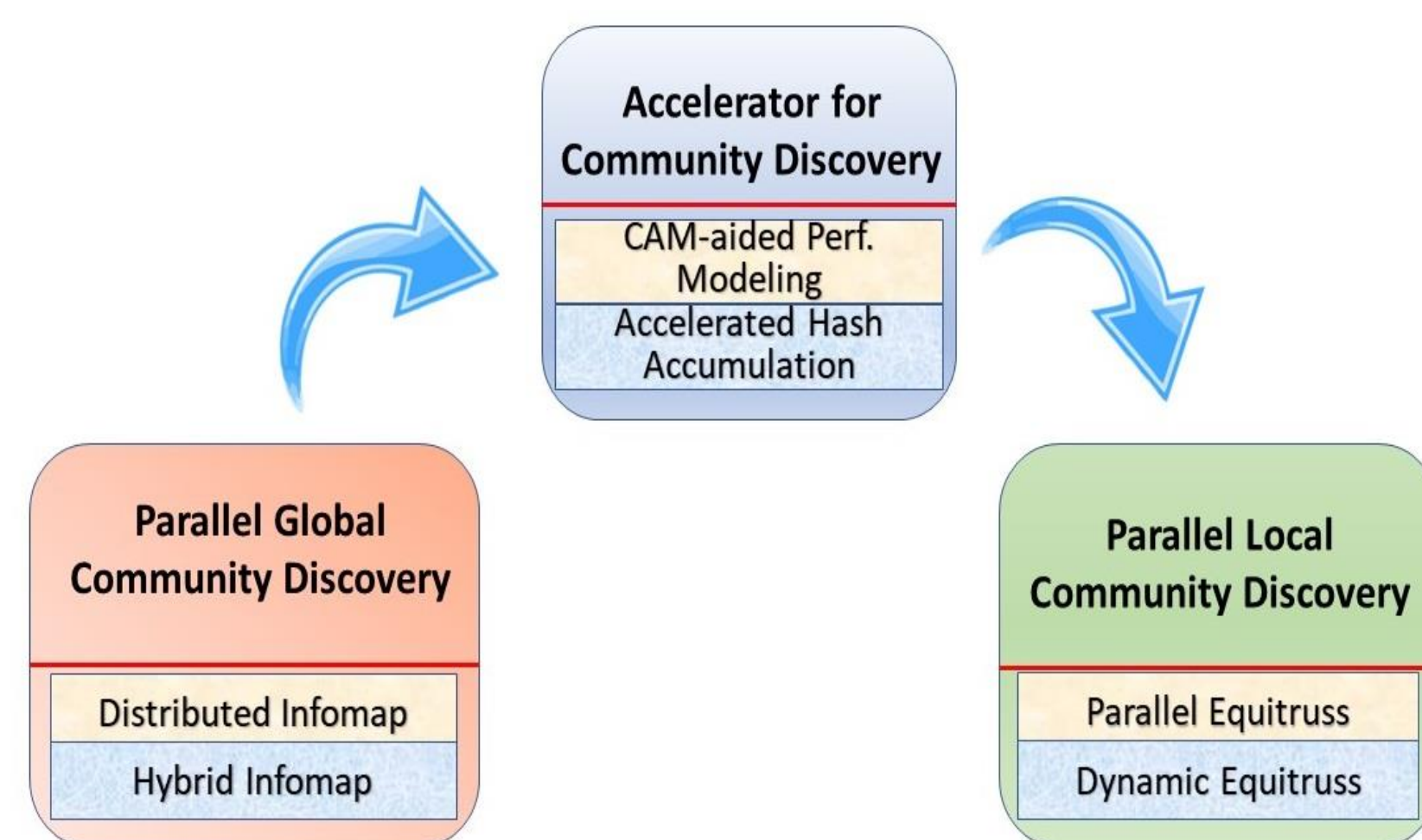
Community discovery, a prominent graph application with usages in social, professional network analysis, health, bioinformatics and metagenomics, etc.



**Limitations:** State-of-the-art techniques suffer from inadequate scalability, poor performance, and methodological inaccuracy

**Our Approach:** Software-hardware co-design for high-performance, scalable, highly accurate parallel community discovery

## Research Scope



- Hybrid-memory parallel global community discovery using information-theoretic approach
- Accelerator design for fast community discovery, and
- k-truss-oriented parallel algorithm design for local community discovery

## Research Tools

- Frameworks:** MPI, OpenMP, CUDA-C
- Platforms:** NERSC Perlmutter, NERSC Cori, LONI



NERSC Perlmutter



NERSC Cori



Louisiana Optical Network Infrastructure

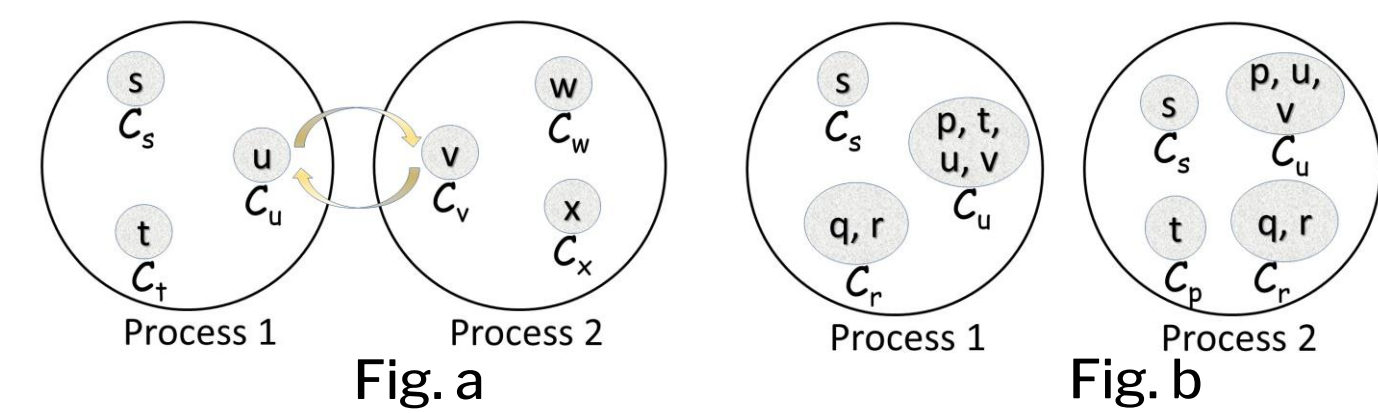
- Language:** C++
- Distributed Architecture:** CPU, GPU
- Profiling Tools:** Vtune, OSU benchmark
- Dataset:** SNAP Networks
- Micro-architecture Simulator:** ZSim, Pin

## Parallel Global Community Discovery<sup>[1,2]</sup>

### Distributed Infomap

#### Distributed Challenges:

- Vertex bouncing problem (Fig. a)
- Inconsistent update ordering (Fig. b)
- Inactive vertices
- Distributed workload imbalance



Figures: a) Shows the effect of vertex bouncing due to group of vertices having strong affinity, b) Incorrect communities after synchronization due to incorrect ordering

#### Solution Heuristics:

- MPI for distributed computing
- Numeric ordering for vertex bouncing
- Priority-based assignment for inconsistency
- Maintaining and disregarding inactive vertices
- Metis partitioner for workload balancing

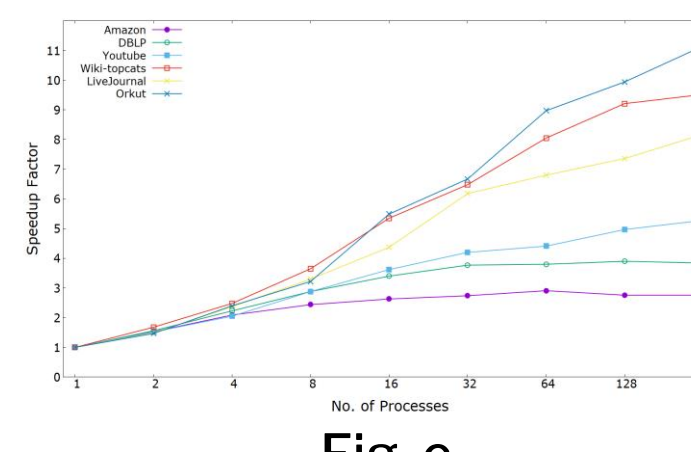


Fig. c

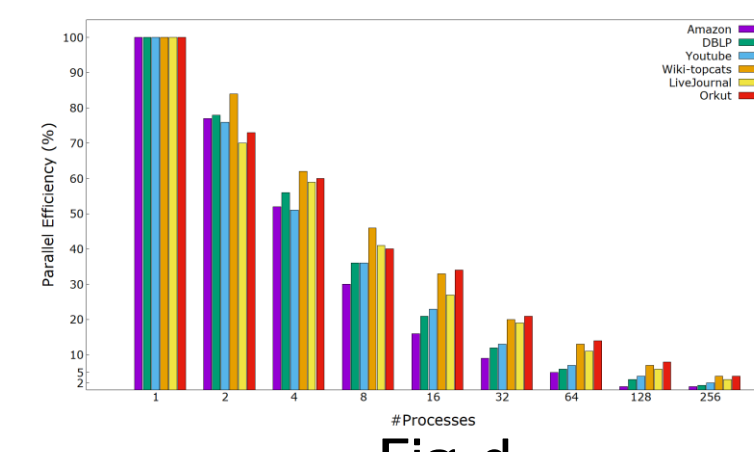


Fig. d

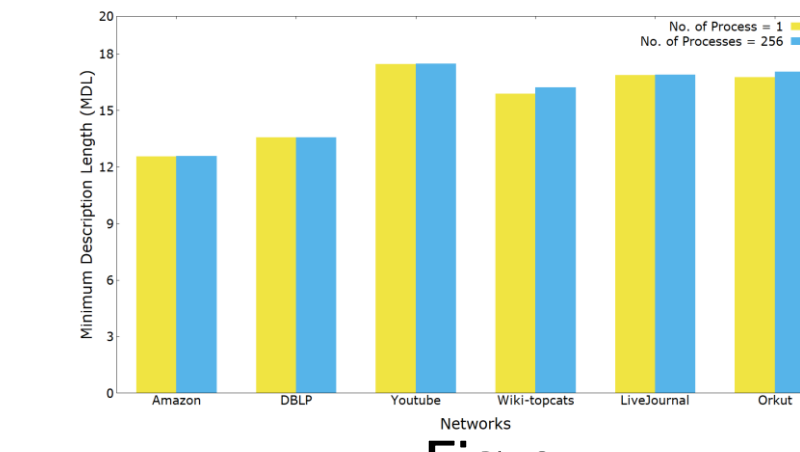


Fig. e

Figures c-e: The plots demonstrate the speedup (strong scalability) of the distributed Infomap (fig. c), the parallel efficiency of the algorithm (fig. d), and the accuracy of the converged solution in terms of Minimum Description Length (MDL) (fig. e)

### Hybrid Infomap

#### Observations:

- Kernel breakdown shows (Fig. f) FindBestCommunity kernel needs to be further optimized
- Adopt OpenMP parallelism
- Use cache-friendly data-structure

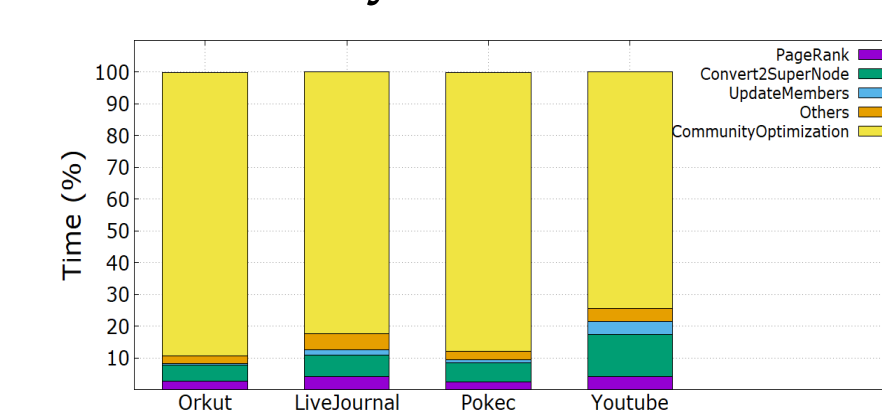


Figure f: Compute kernel breakdown of the distributed Infomap

#### Kernel Runtime Analysis:

- Cache optimized *unordered\_map* data structure demonstrate better performance over regular *map*
- The biggest performance boost (Fig. g) obtained from multithreaded kernel

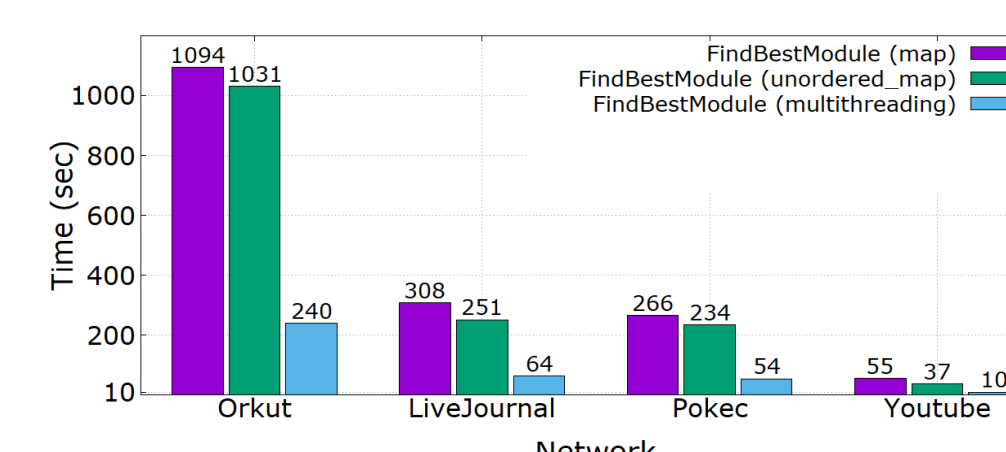


Figure g: Runtime effect of optimizations on dominant kernel

#### Optimized Hybrid Infomap Design:

- Delivers 25X speedup, accuracy maintained
- Scales to 1280 processing cores (Fig. i)

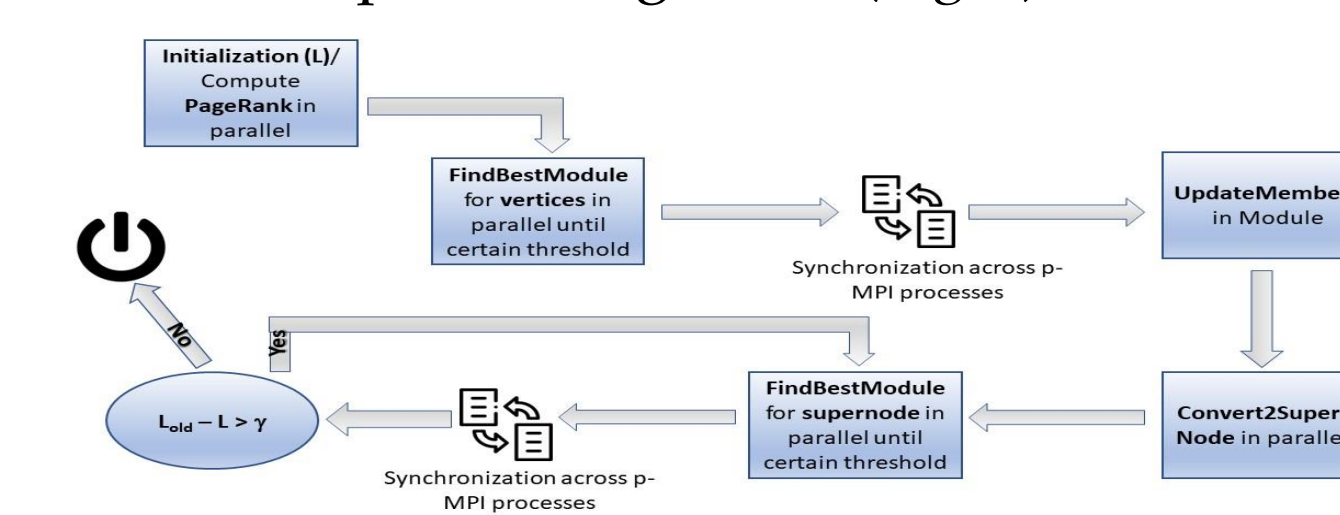


Figure h: HyPC-Map workflow

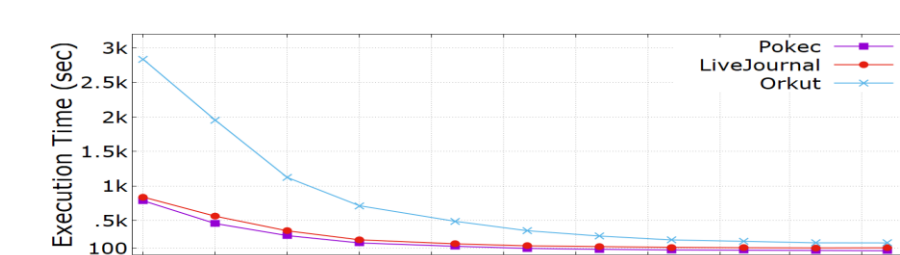


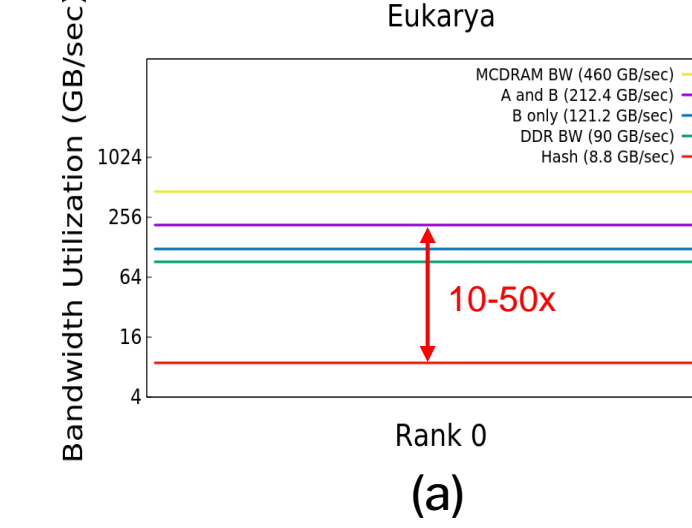
Figure i: Strong scalability (runtime)

## Accelerator-aided Community Discovery<sup>[3]</sup>

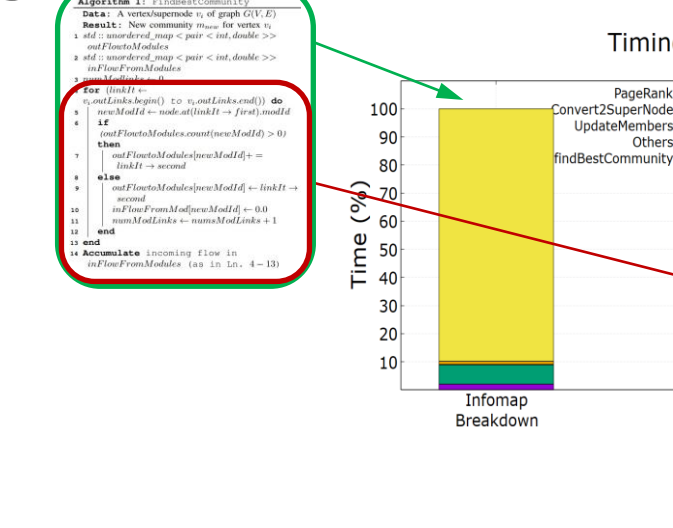
### Performance Modeling for Software-Hardware Co-design

#### Case Studies:

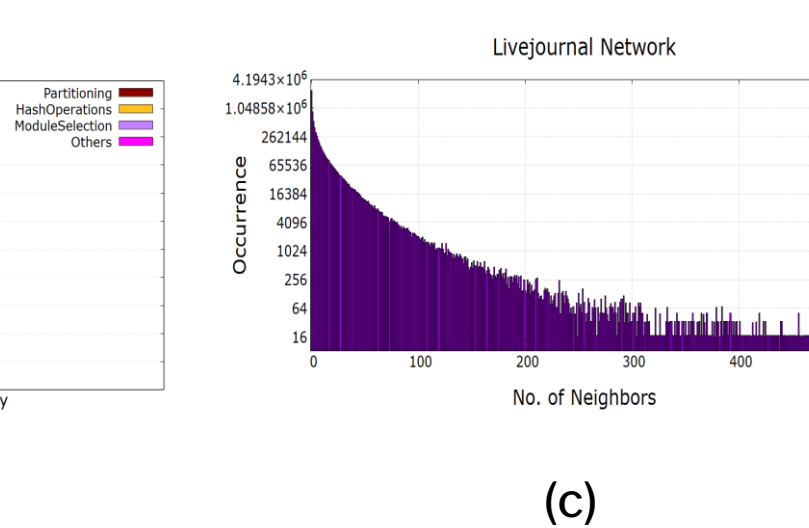
- Two community detection applications: *HipMCL*, and *HyPC-Map*
- Performance profiling and Modeling shows large gap between achievable and operational performance
- Performance limiting factor in both applications: *Software hash accumulation*



(a)



(b)



(c)

Figures a-c: (a) Performance gap between software hash (red) and streaming bandwidth (purple and blue) in *HipMCL* illustrates the potential impact (10-50X) for HW CAM support, (b) Timing breakdown shows impact of latency bound software hash in HyPC-Map, (c) Real-world networks exhibiting power-law degree distribution.

### Fast HyPC-Map with Accelerator for Sparse Hash Accumulation (ASA)

#### 3 main computation phases:

- Hardware accumulation
- Hardware CAM gather
- Software sort and merge

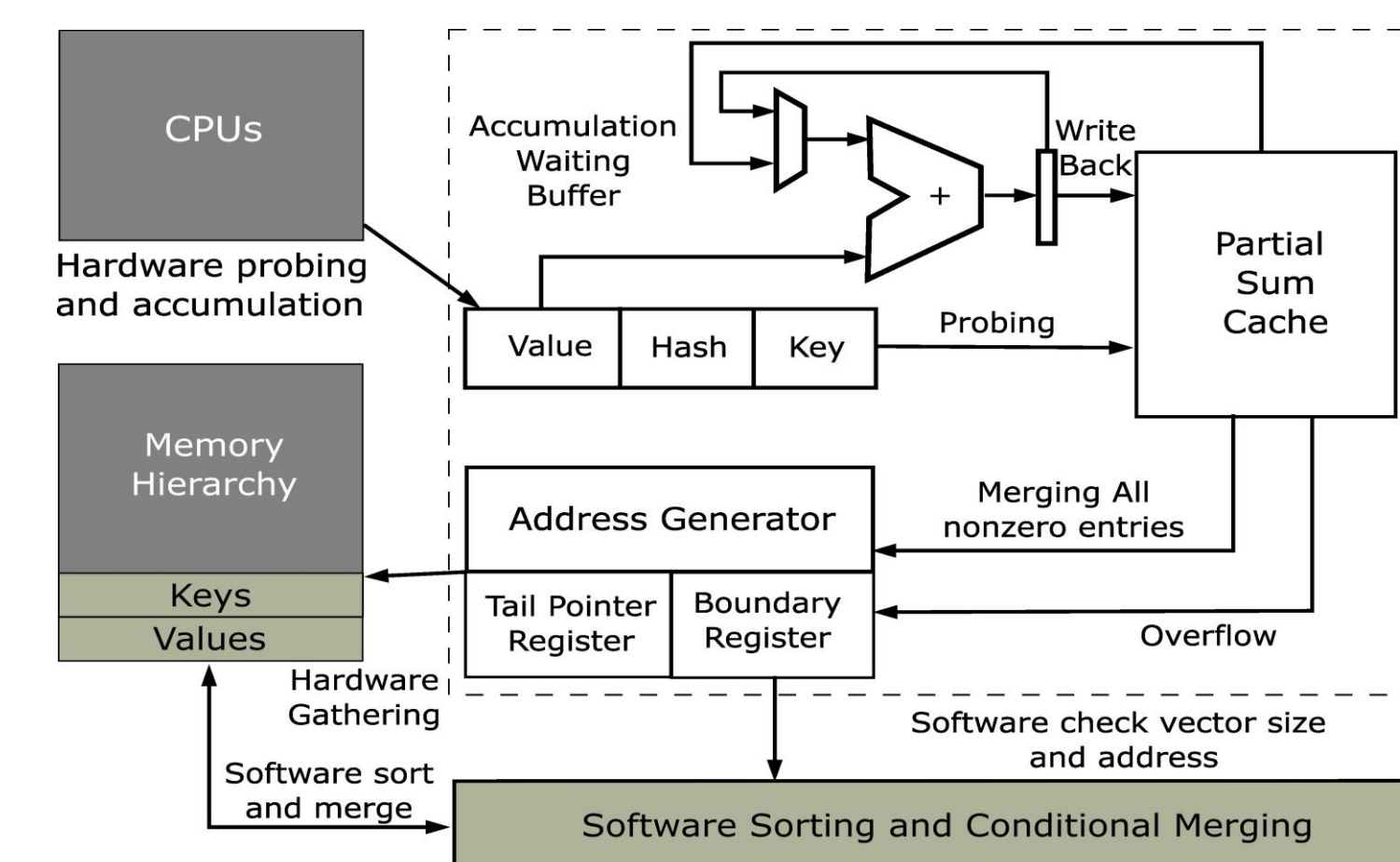
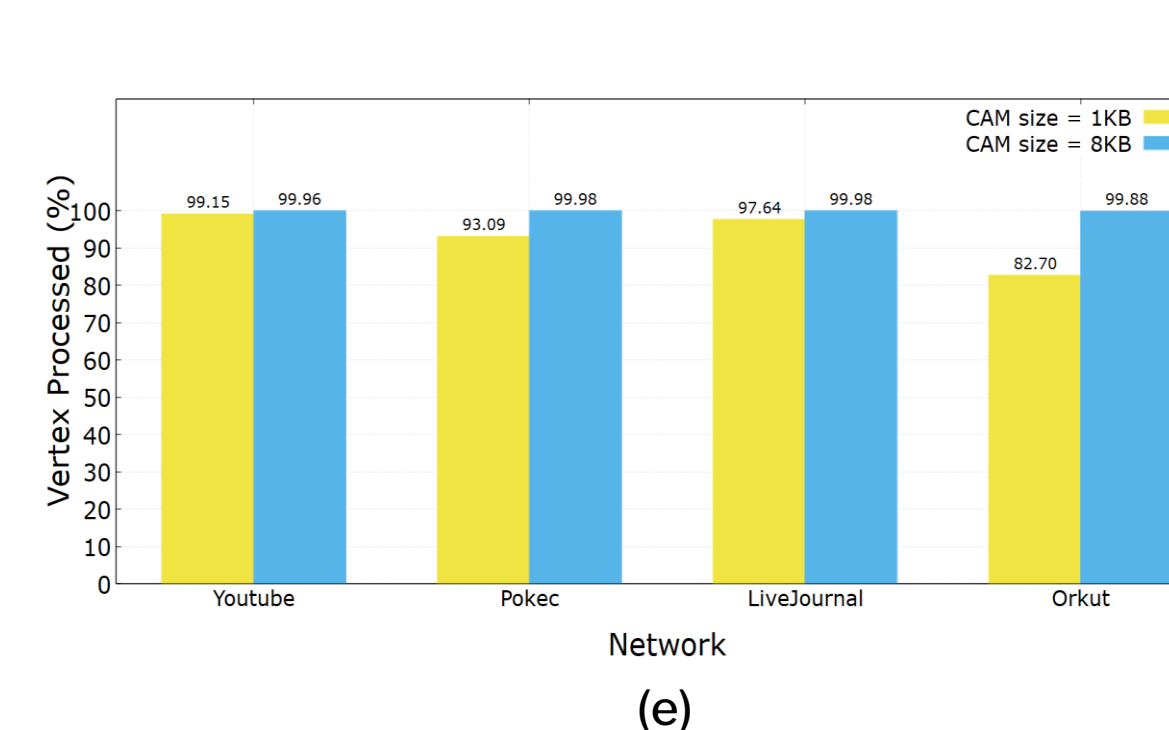
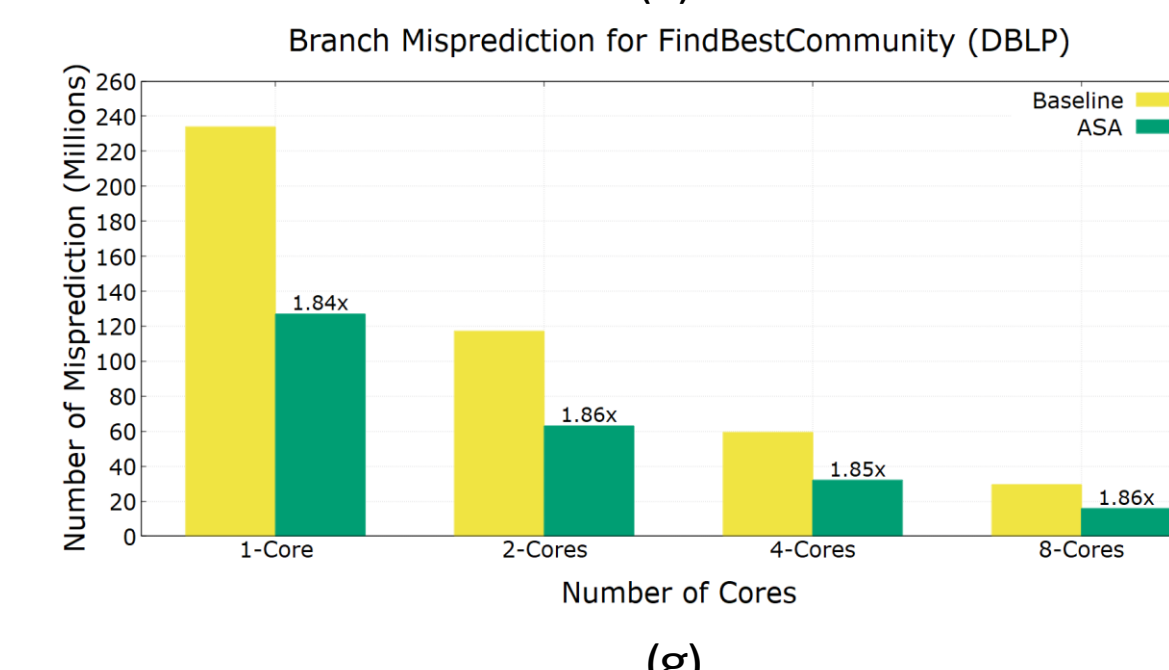


Figure d: Block diagram of the generalized ASA microarchitecture. Details of different modules of the architecture and their functionalities are described in Chao et al. [4].

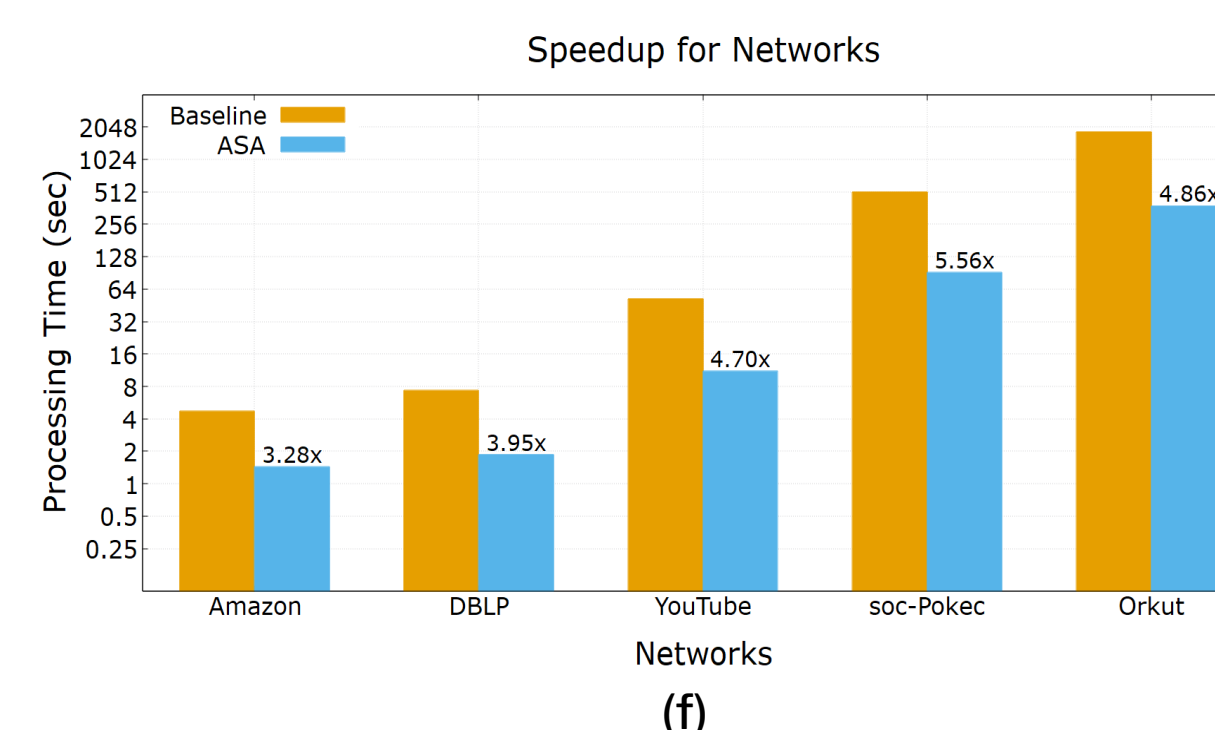


(e)

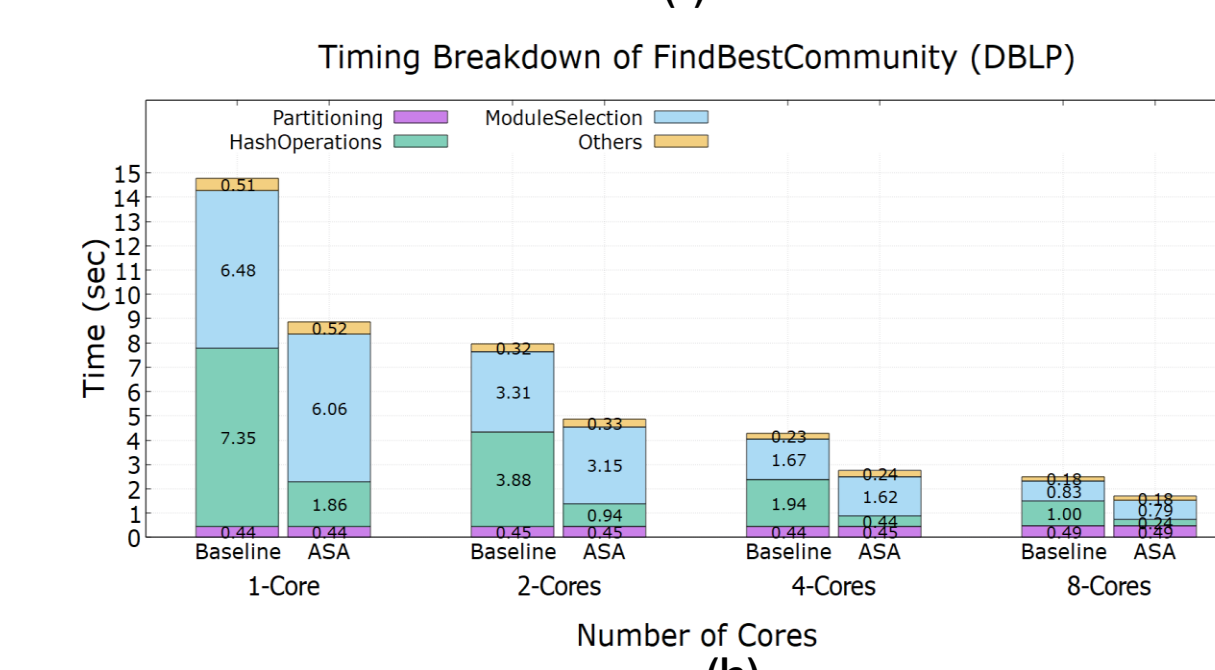


(f)

Figures e-h: (e) Limited capacity core-local Content Addressable Memory (CAM) can cover 99% of the vertices of power-law graphs, (f) ASA demonstrating up to 5.56x speedup over baseline, (g) ASA exhibiting 47% reduction in branch misprediction, and (h) strong scalability across varying number of cores



(g)



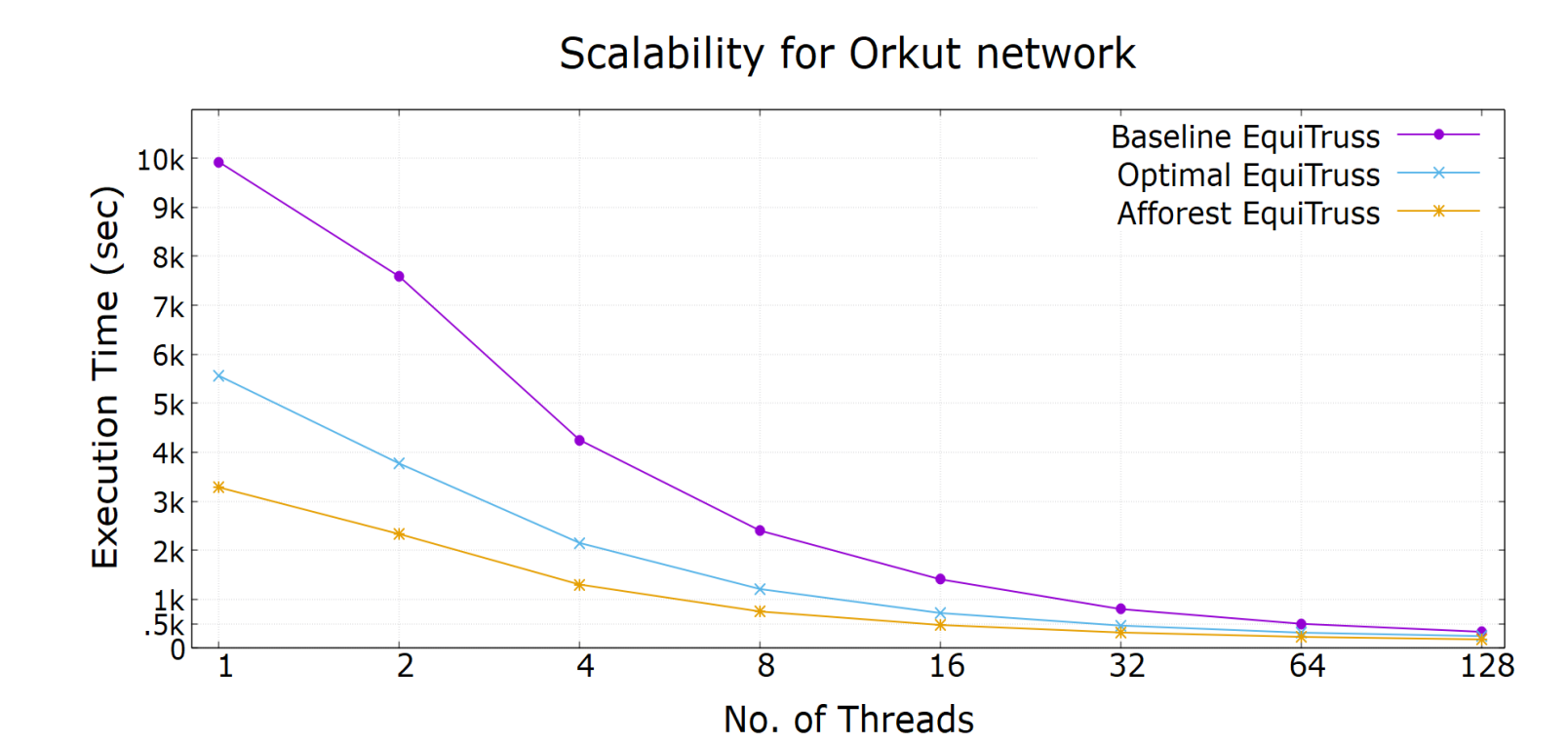
(h)

## Parallel Local Community Search

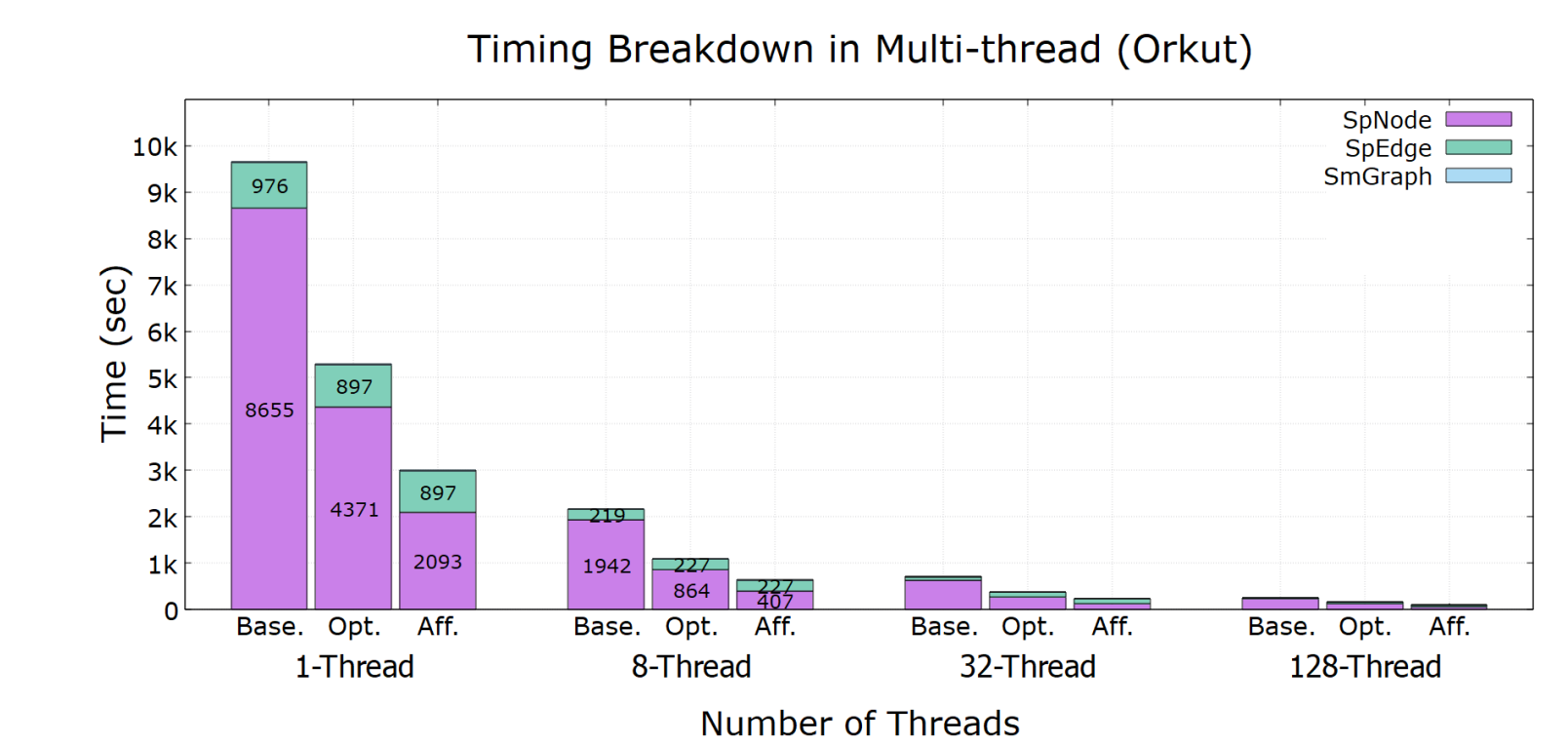
**Specification:** Real-world applications often demand community of a query entity

**Limitations:** Lack of scalable algorithms, methodological inefficiency

**Our Approach:** A k-truss-based scalable local community search, **parallel EquiTruss**, using higher order graph motif (k-triangle connectivity) as building block



Strong scalability for our parallel **EquiTruss** in 3 different optimization phases for Orkut social network.



Timing breakdown of major compute kernels for parallel **EquiTruss** and reduction of execution time for different number of threads

## ACKNOWLEDGMENTS

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- Collaborators:** John Shalf, Cy Chan, Maximilian Bremmer, and Doru Thom Popovici, Computer Architecture group (CAG), Berkeley Lab (LBNL)

## SCHOLARLY ARTICLES

- HyPC-Map: A Hybrid Parallel Community Detection Algorithm Using Information-Theoretic Approach, MAM Faysal, S Arifuzzaman, C Chan, M Bremer, D Popovici, J Shalf, 2021 IEEE High Performance Extreme Computing Conference (HPEC), 1-8
- Distributed community detection in large networks using an information-theoretic approach, MAM Faysal, S Arifuzzaman, 2019 IEEE International Conference on Big Data (Big Data), 4773-4782
- Md Abdul Motaheb Faysal, Maximilian Bremmer, Shaikh Arifuzzaman, Doru Popovici, John Shalf and Cy Chan, "Fast Community Detection in Graphs with Infomap Method using Accelerated Sparse Accumulation", [Just Accepted] ASHES 2023 IPDPSW
- C. Zhang, M. Bremer, C. Chan, J. Shalf, and X. Guo, "Asa: Accelerating sparse accumulation in column-wise spgmm," ACM Trans. Archit. Code Optim., May 2022, just Accepted. [Online]. Available: <https://doi.org/10.1145/3543068>

