GraphP: Reducing Communication for PIM-based Graph Processing with Efficient Data Partition

Mingxing Zhang, **Youwei Zhuo (equal contribution)**,
Chao Wang, Mingyu Gao, Yongwei Wu, Kang Chen,
Christos Kozyrakis, Xuehai Qian

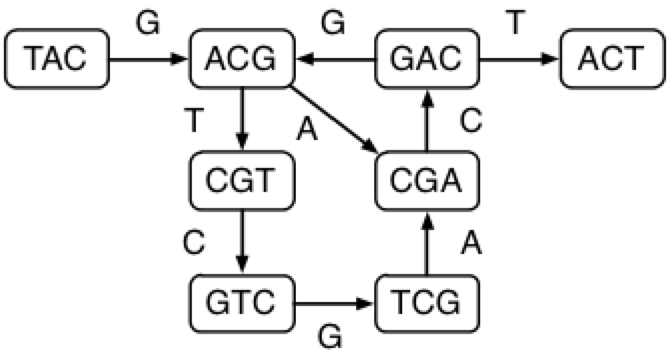
Tsinghua University
University of Southern California
Stanford University

Outline

- **Motivation**
  - Graph applications
  - Processing-In-Memory
  - The drawbacks of the current solution
- GraphP
- Evaluation

Graph Applications

- Social network analytics
- Recommendation system
- Bioinformatics
- …



Challenges

- High bandwidth requirement
  - Small amount of computation per vertex
  - Data movement overhead

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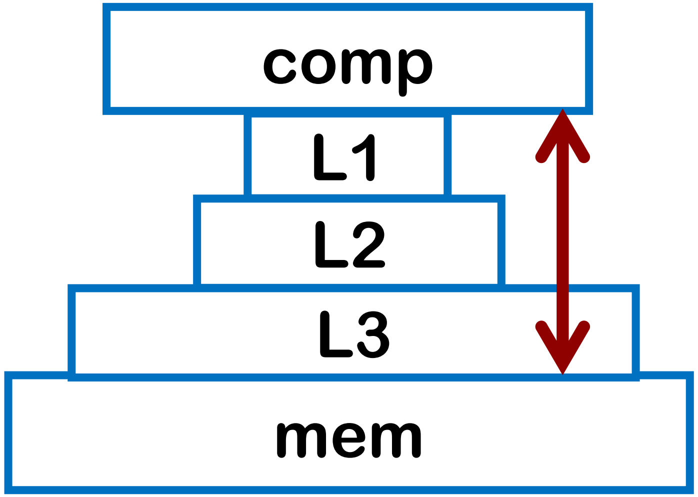

PIM: Processing-In-Memory

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- **Advantage**: High memory bandwidth

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- **Example**: Hybrid Memory Cubes (HMC)

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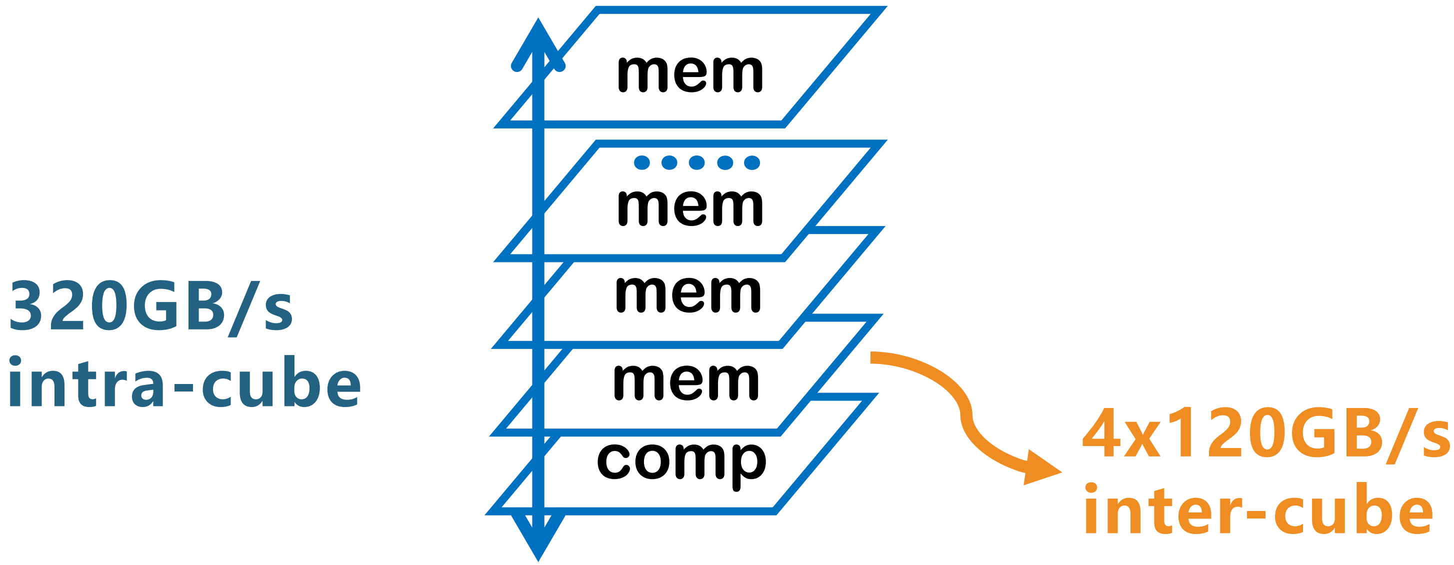

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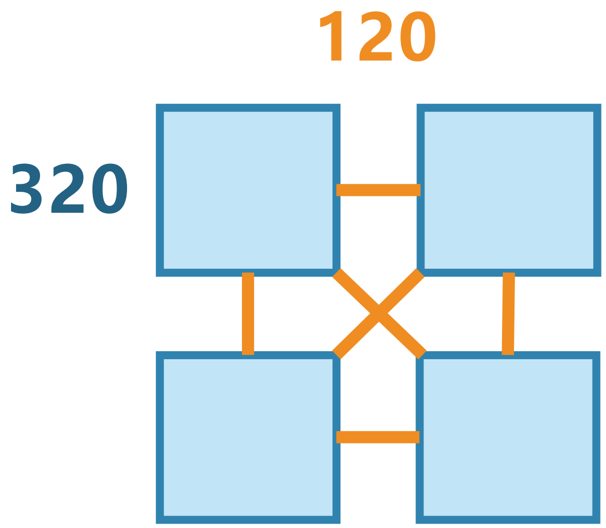
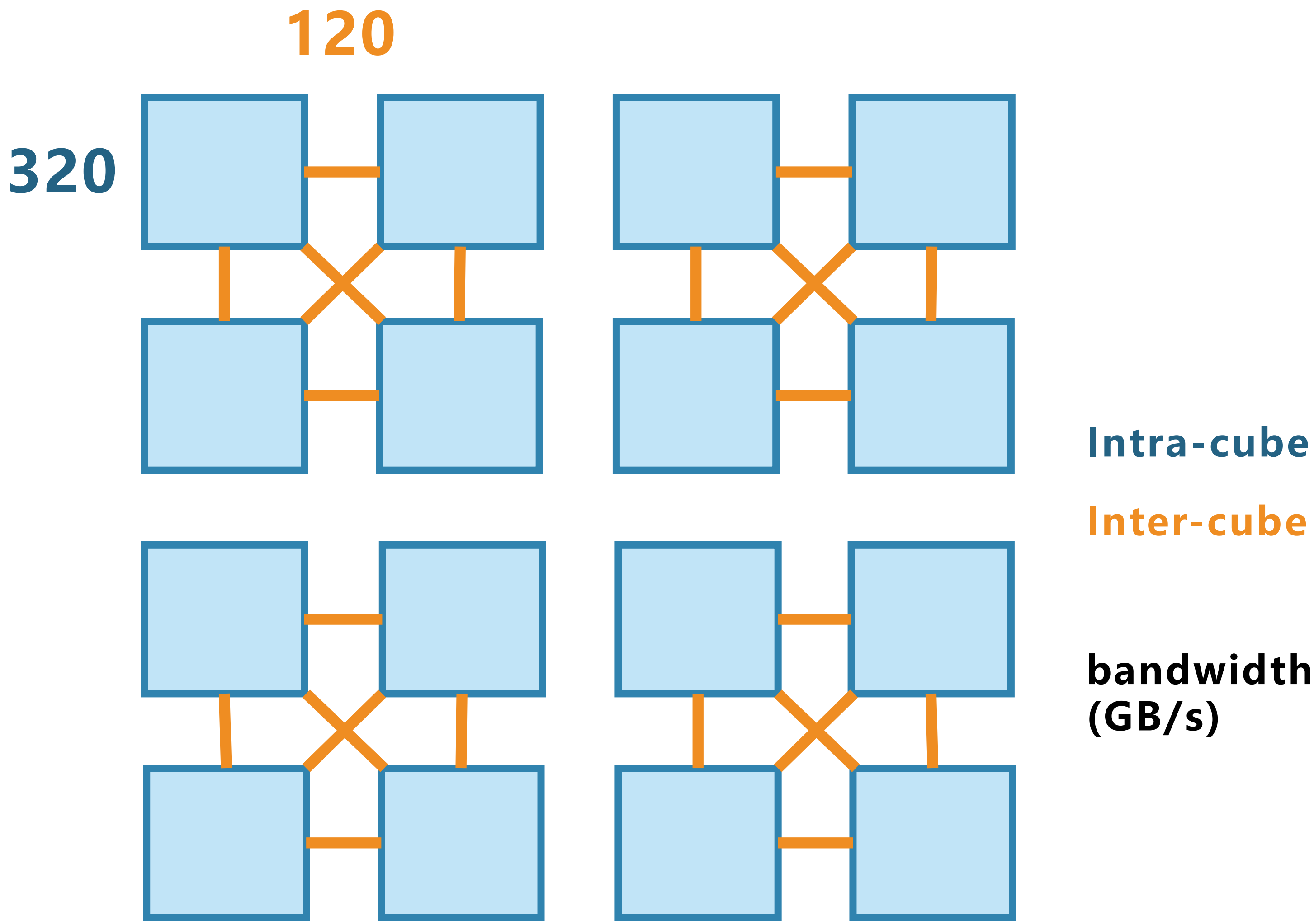


Intra-cube

Inter-cube

bandwidth (GB/s)

HMC: Hybrid Memory Cubes



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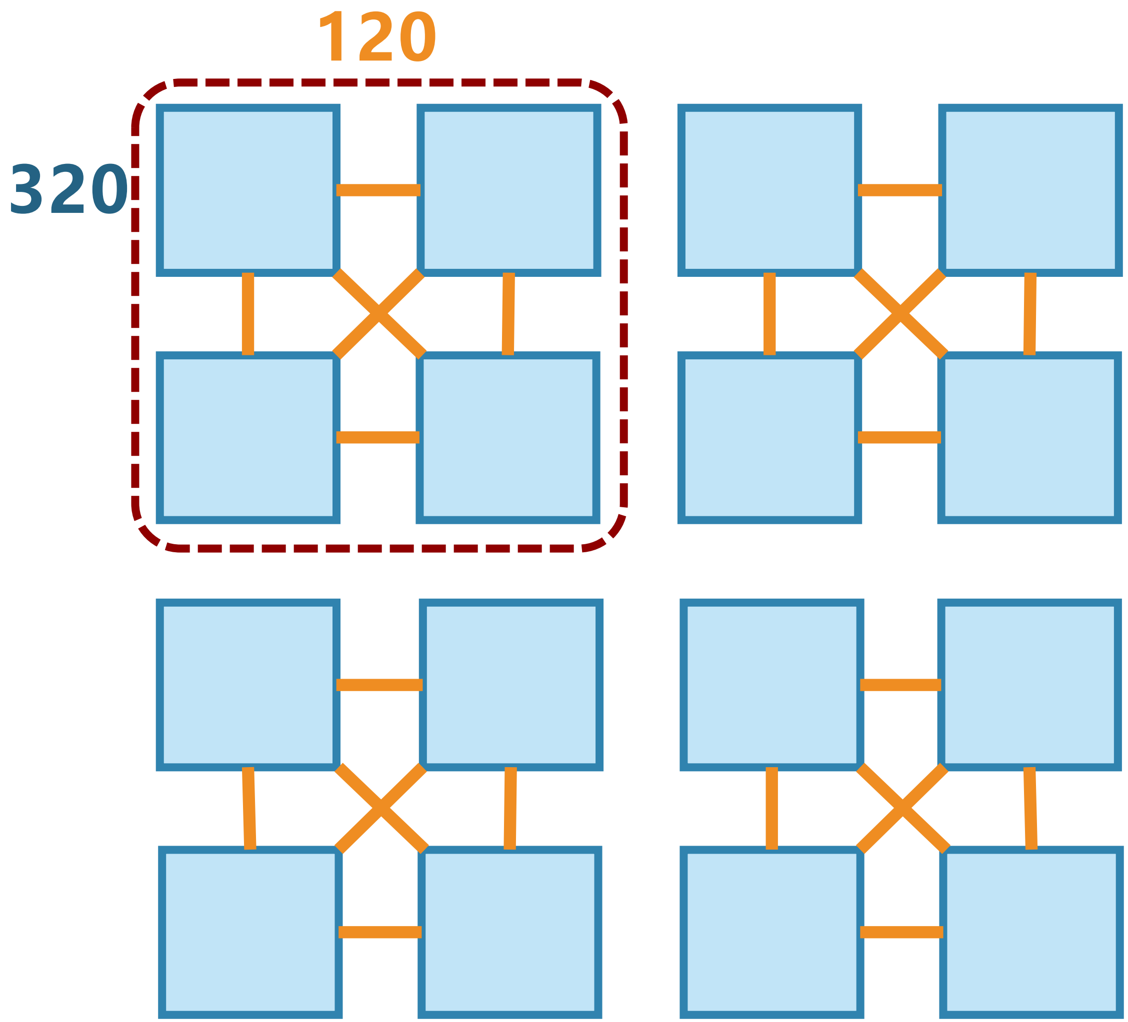

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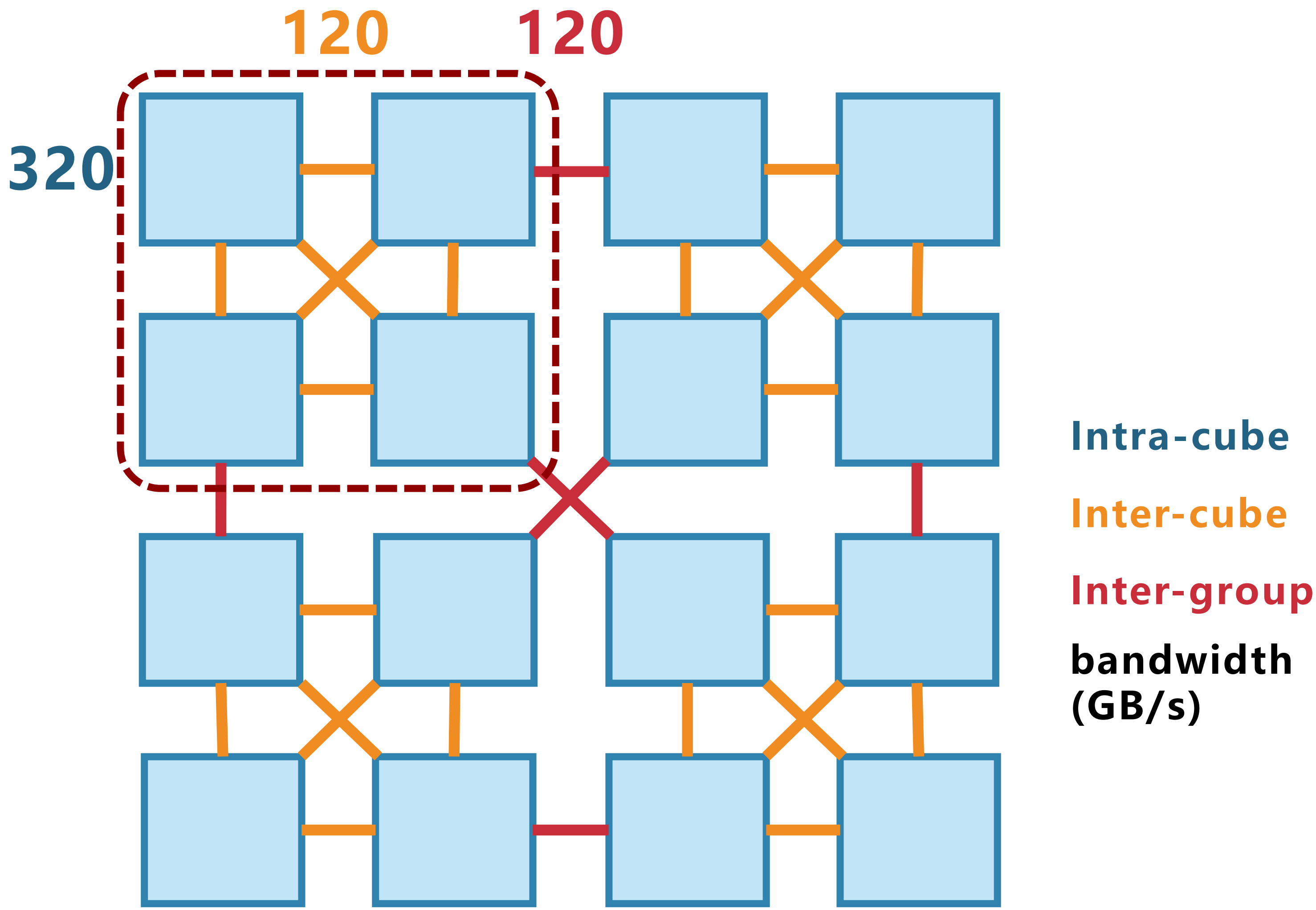

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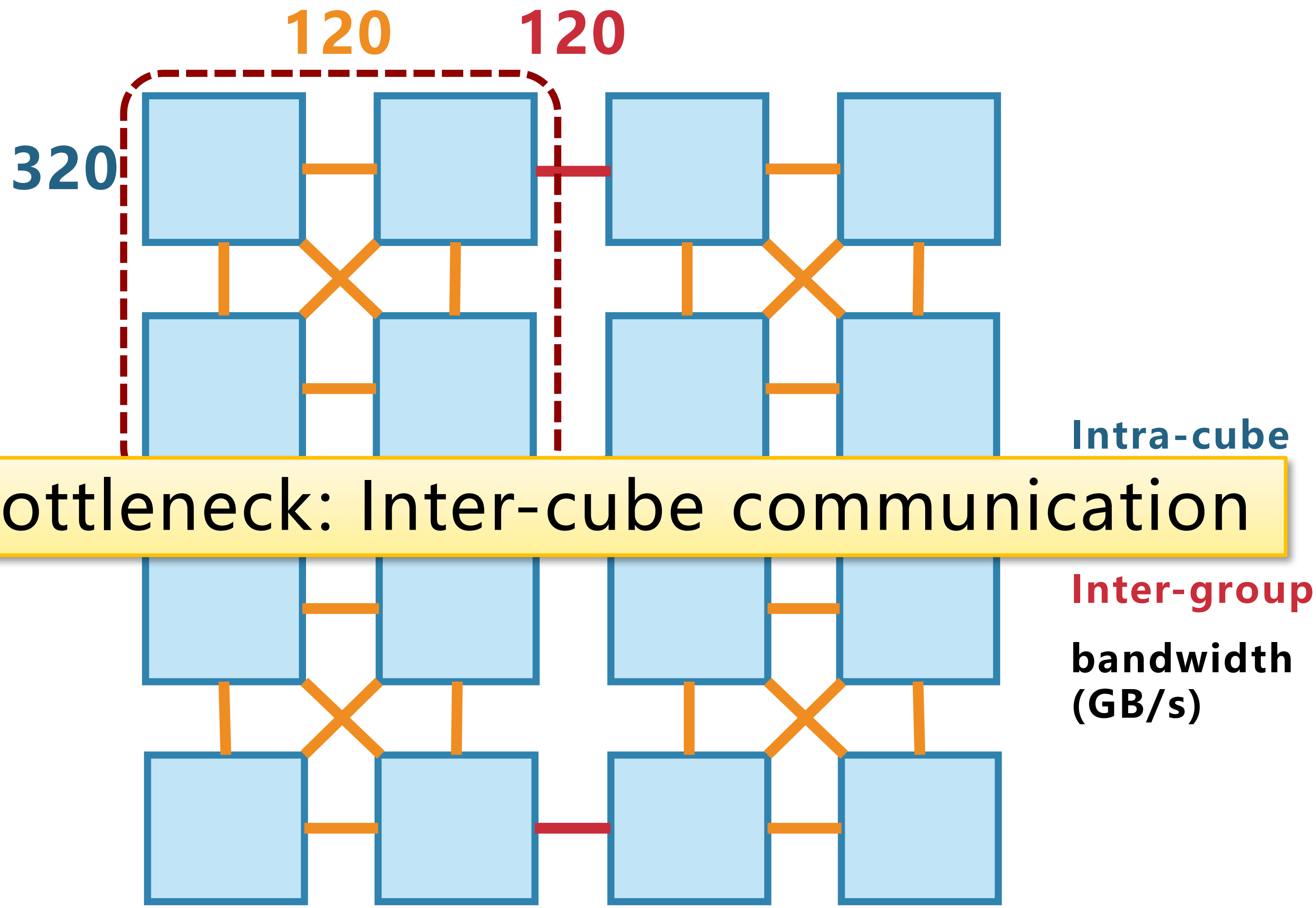

Bottleneck: Inter-cube communication

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Current Solution: Tesseract

- First PIM-based graph processing architecture

Ahn, J., Hong, S., Yoo, S., Mutlu, O., & Choi, K. A scalable processing-in-memory accelerator for parallel graph processing. In *2015 ACM/IEEE 42nd Annual International Symposium on Computer Architecture (ISCA)*.

Current Solution: Tesseract

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- **Programming model**
  - Vertex program

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- **Partition**
  - Based on vertex program

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PageRank in Vertex Program

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for (v: vertices) {
    update = 0.85 * v.rank / v.out_degree;
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for (v: vertices) {
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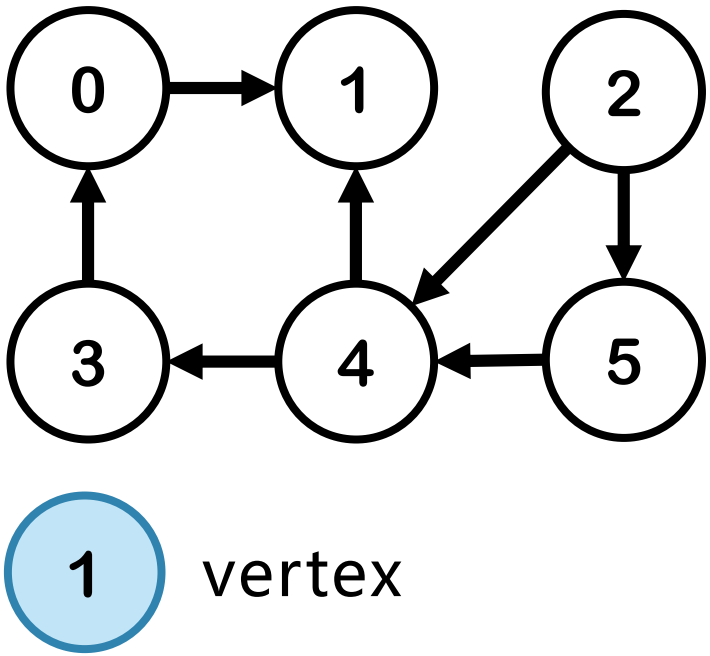
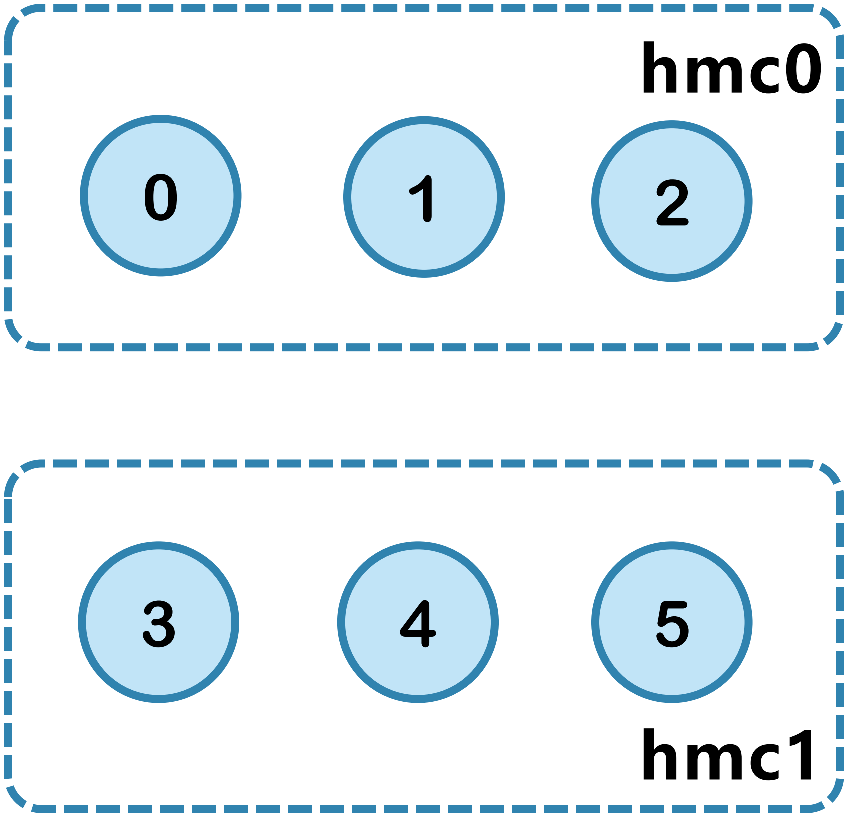
Graph Partition





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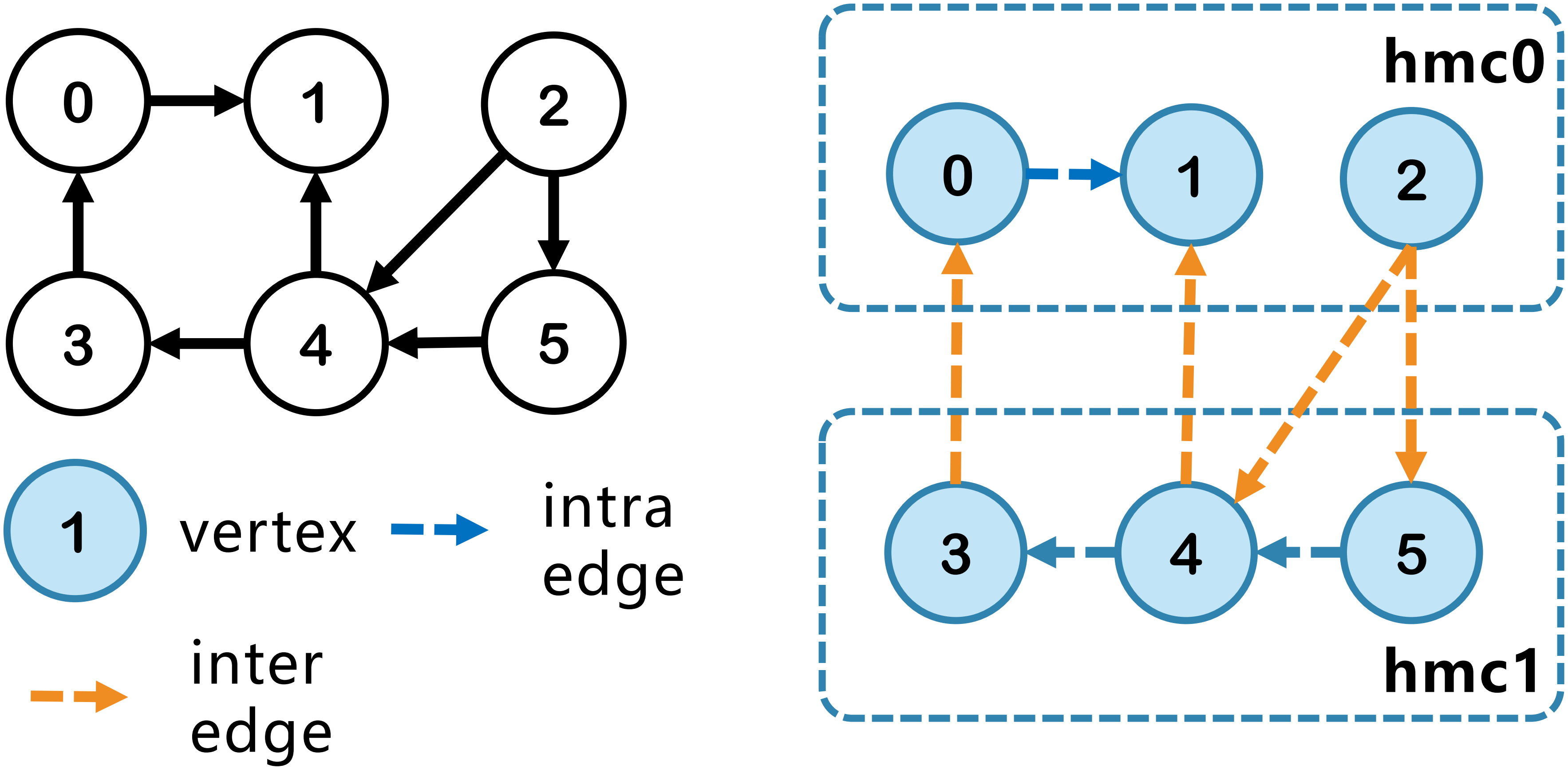

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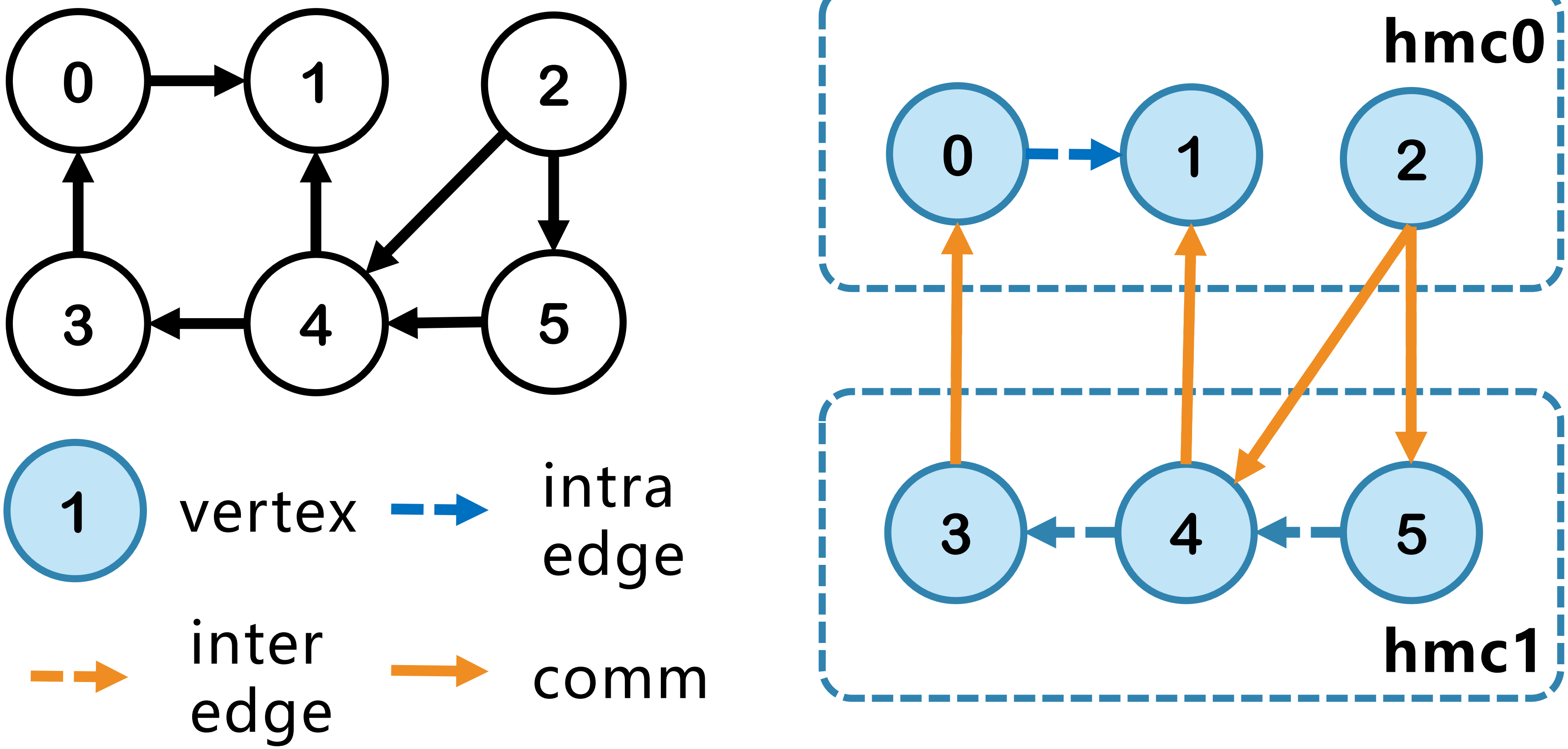


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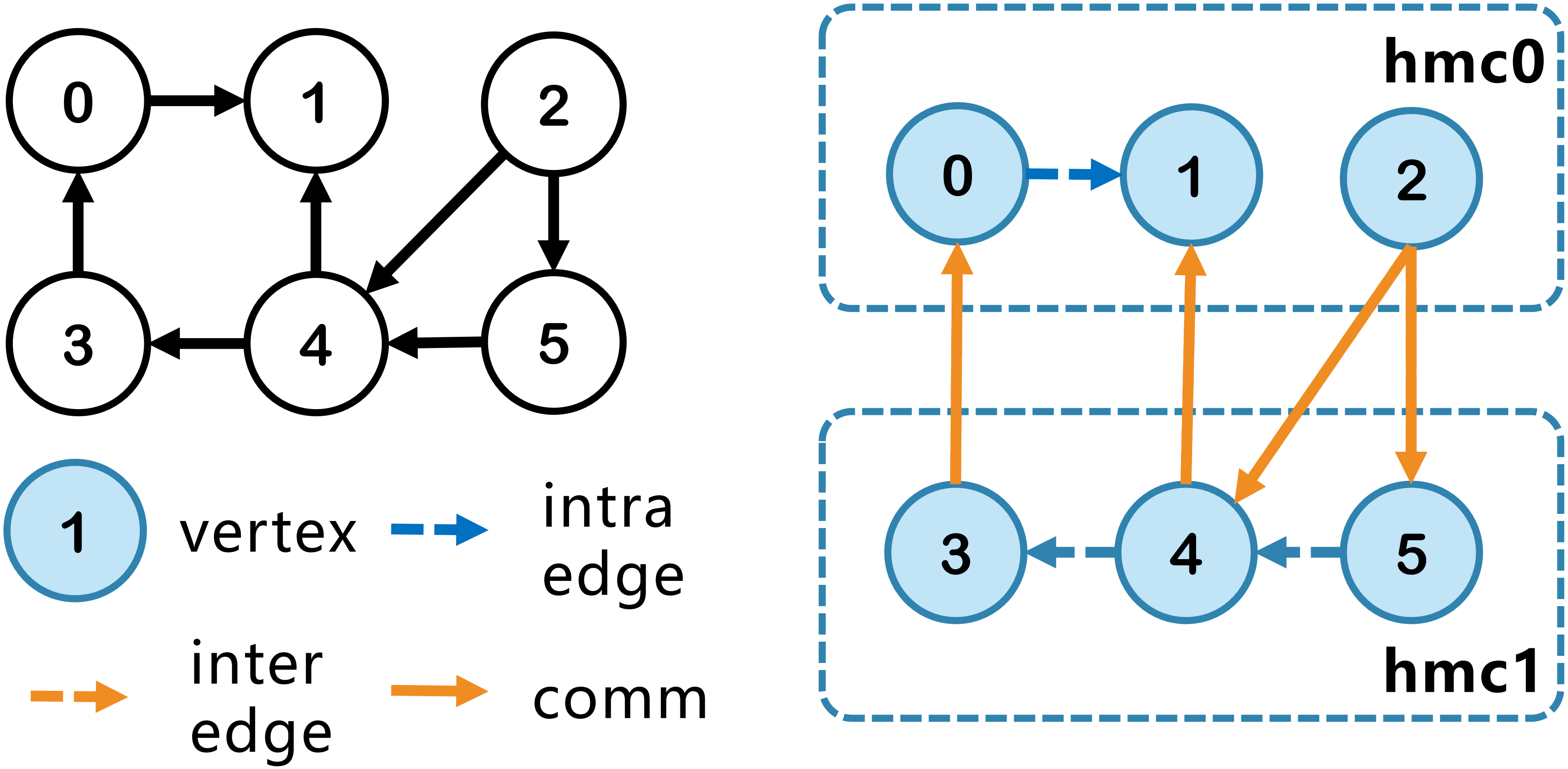
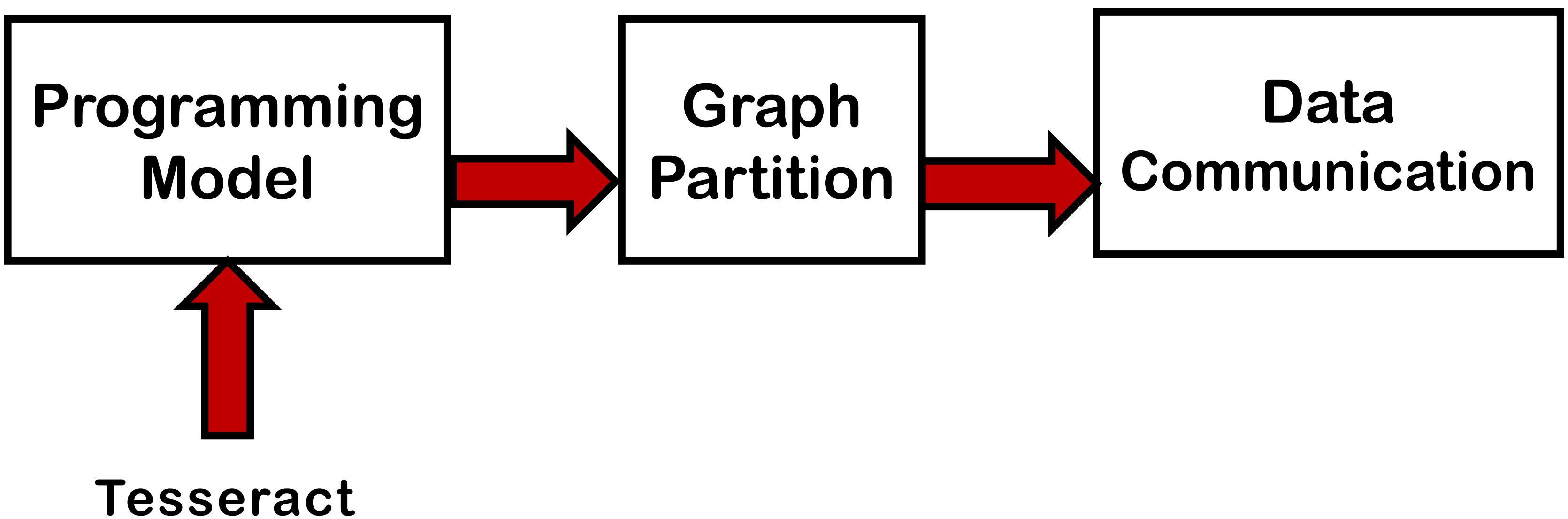
Graph Partition



communication = # of cross-cube edges

Drawback of Tesseract

- Excessive data communication
- Why?



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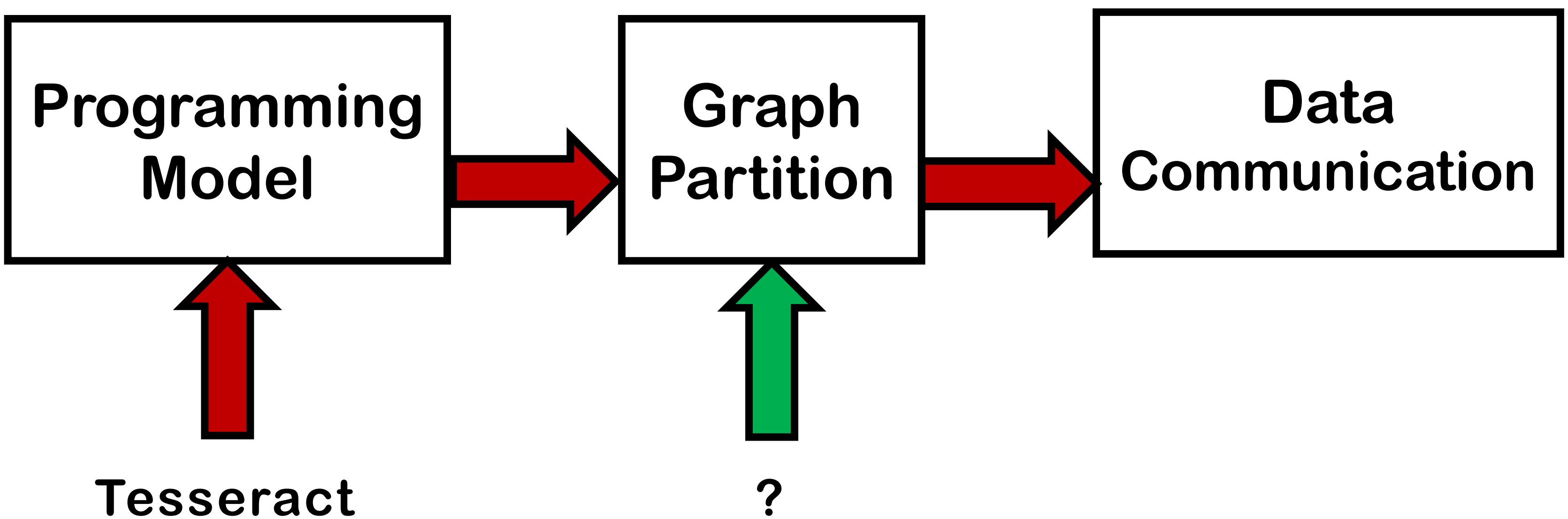

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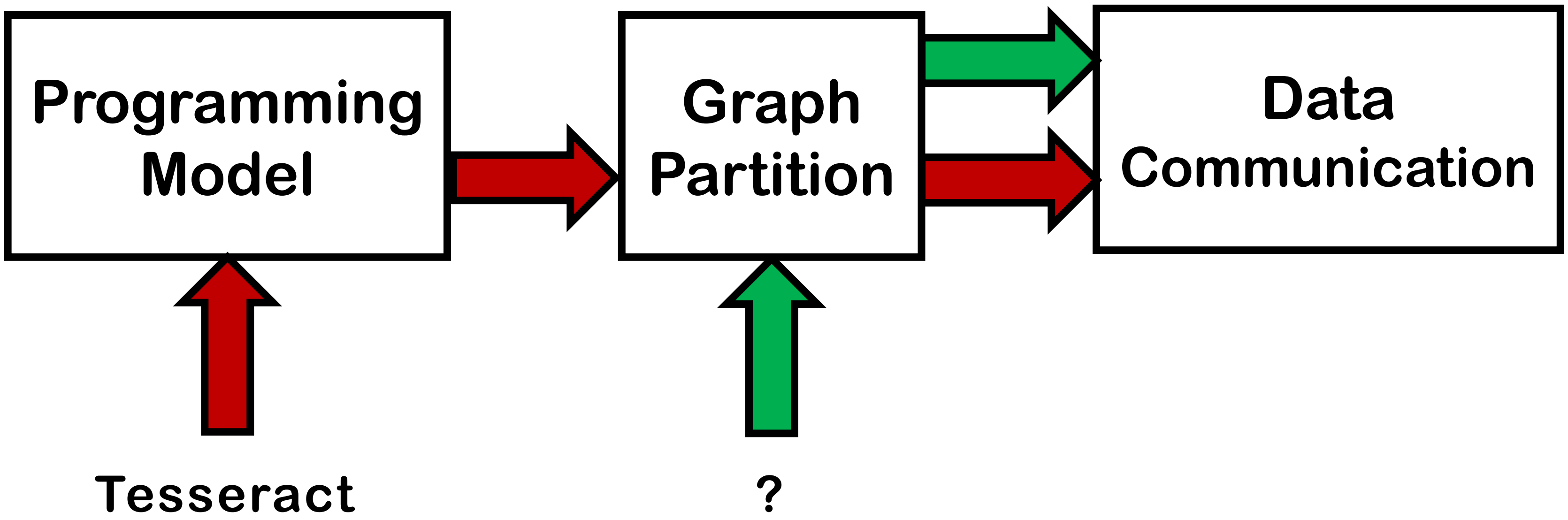

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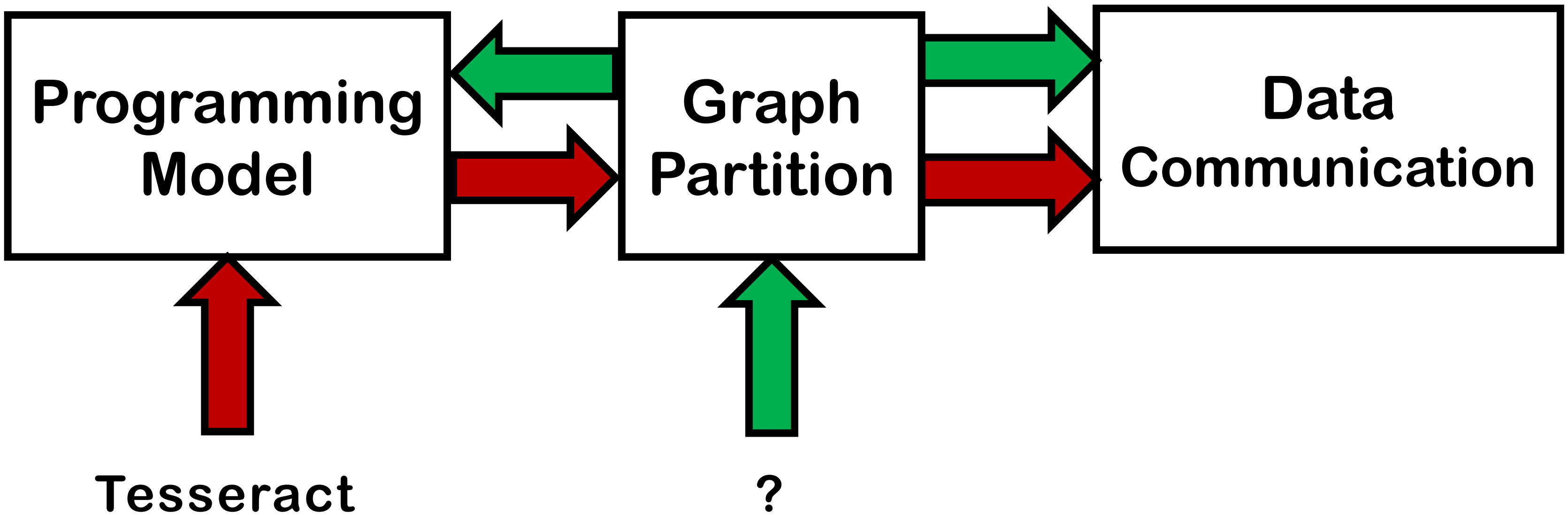

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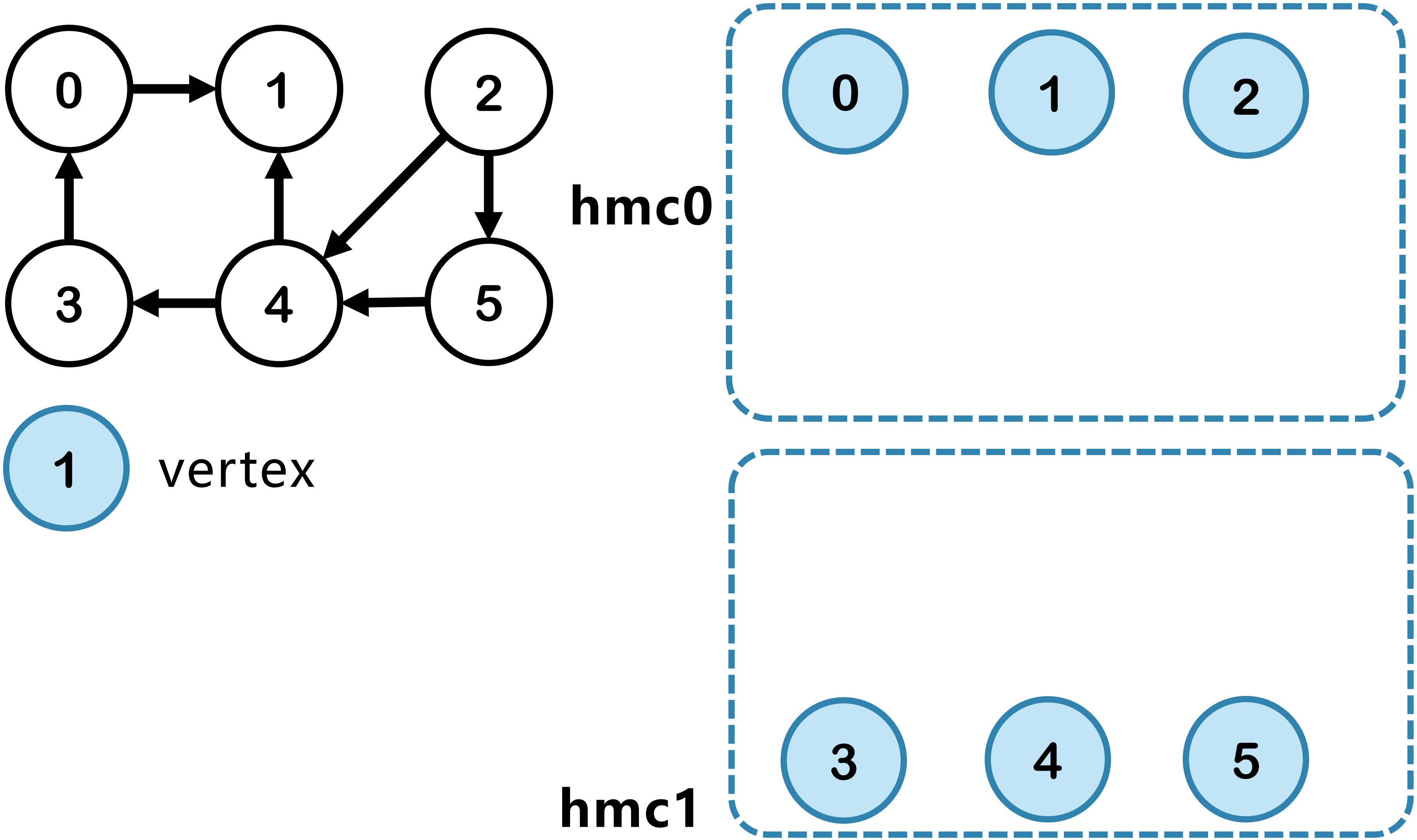
GraphP

- **Consider graph partition first.**
- **Graph Partition**
  - Source-Cut
- **Programming model**
  - Two-phase vertex program
- Reduces inter-cube communication

Source-Cut Partition



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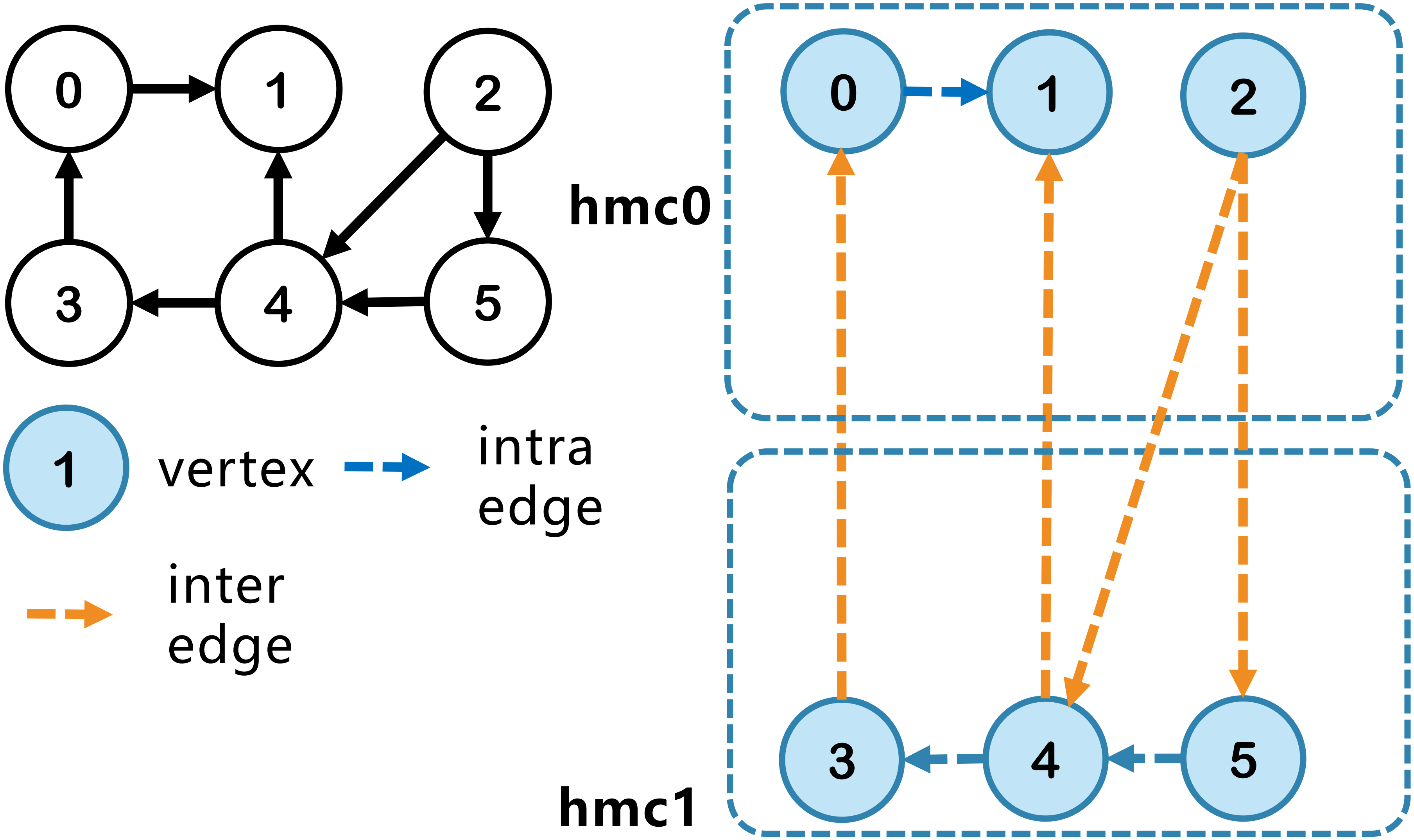

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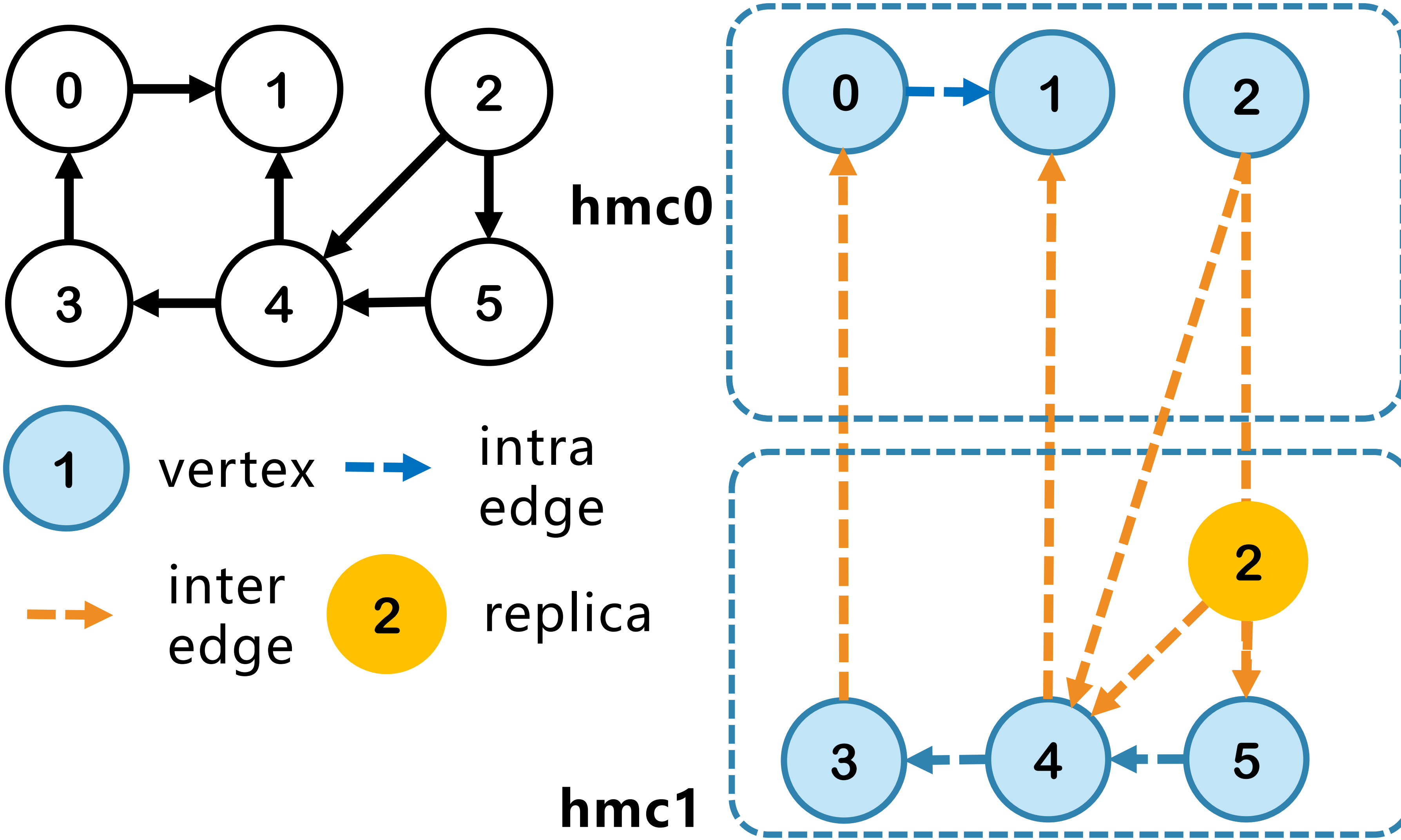

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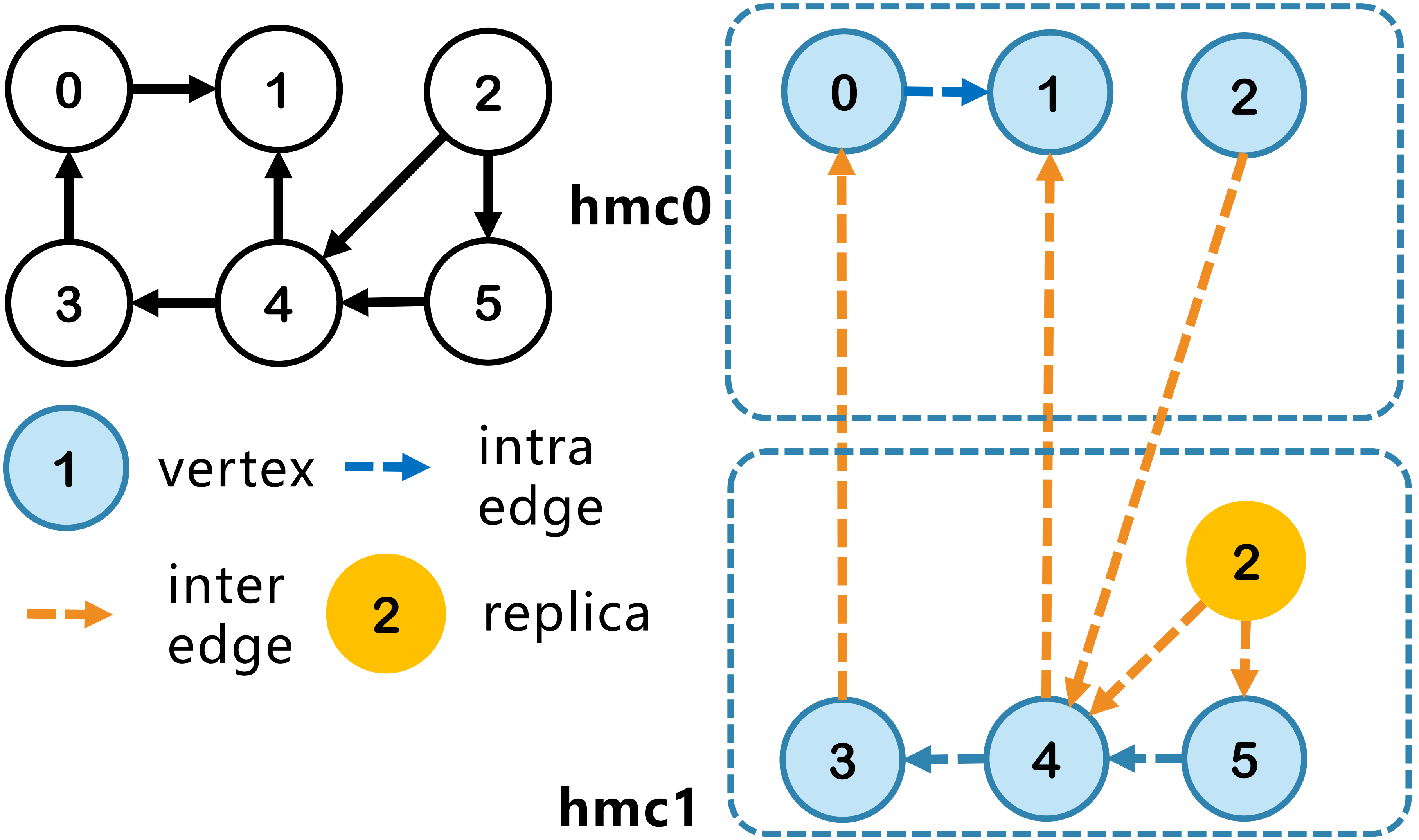

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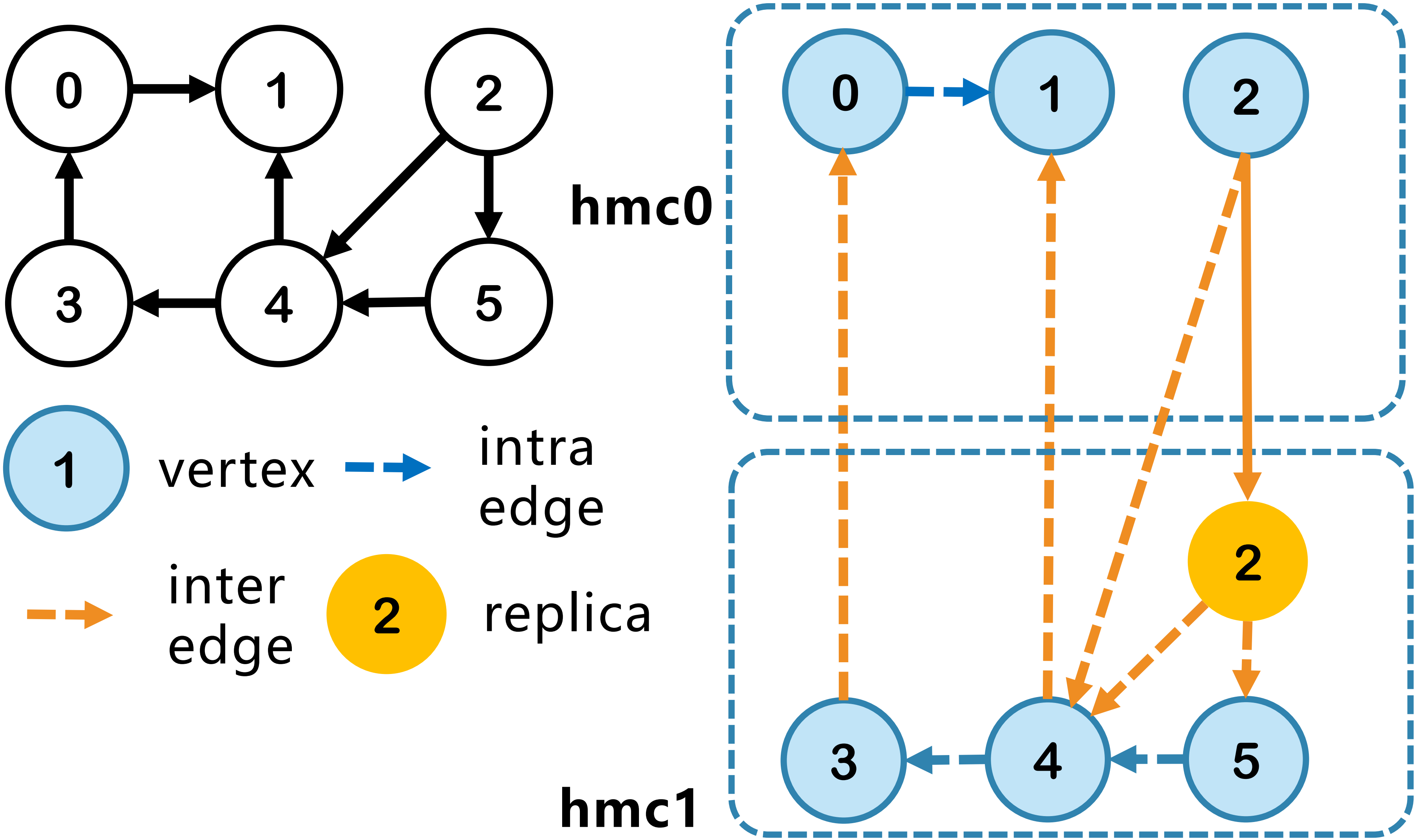

Two-Phase Vertex Program

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```
//apply updates from previous iterations
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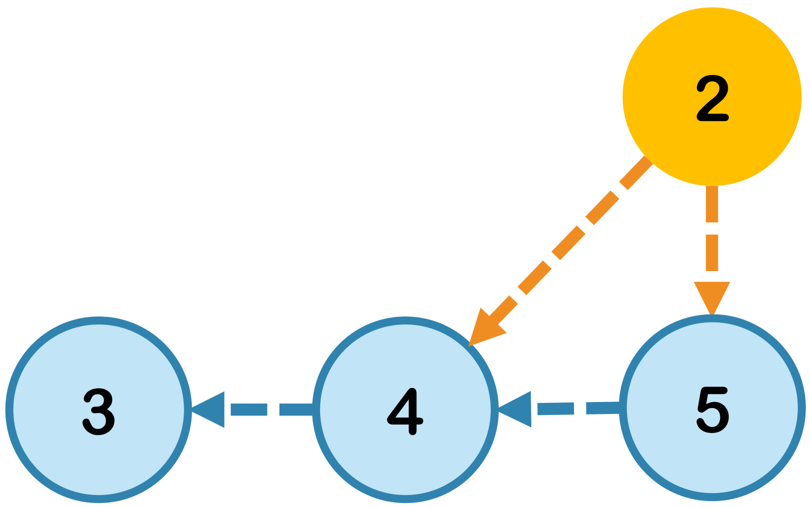

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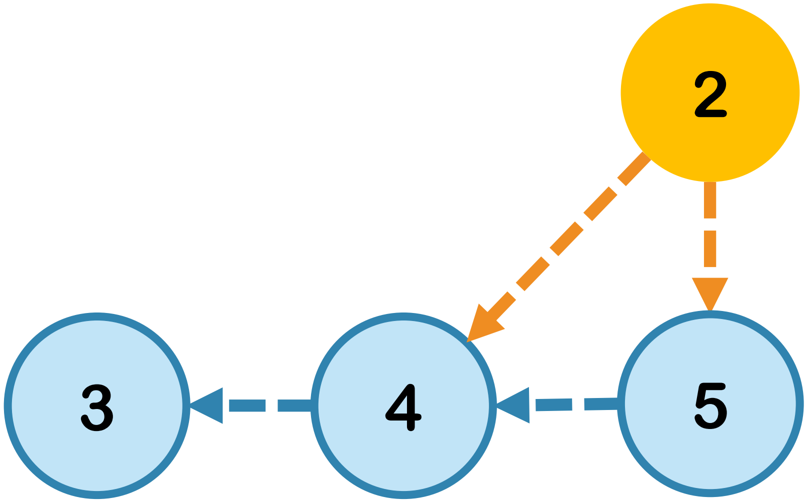

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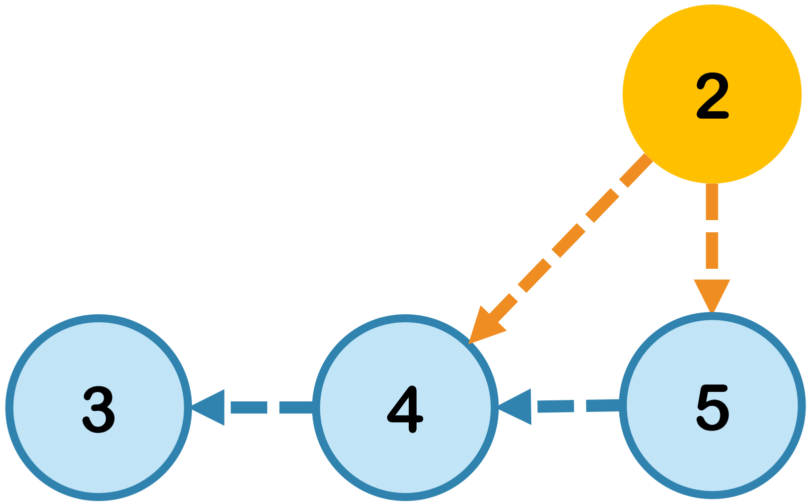

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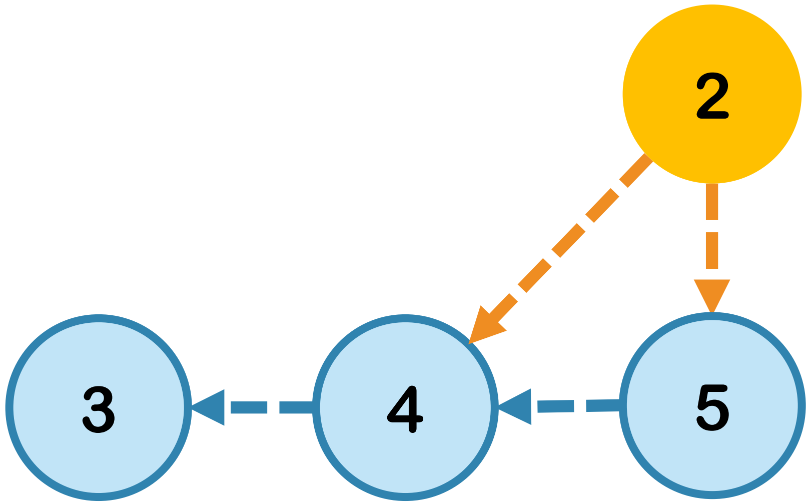

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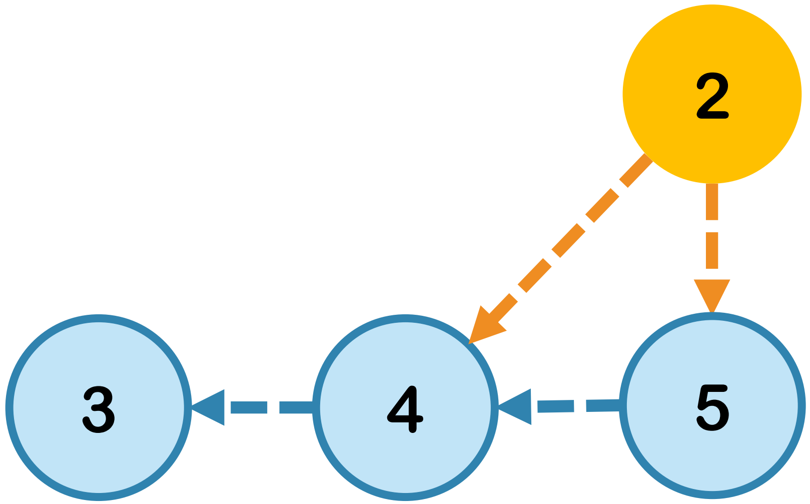

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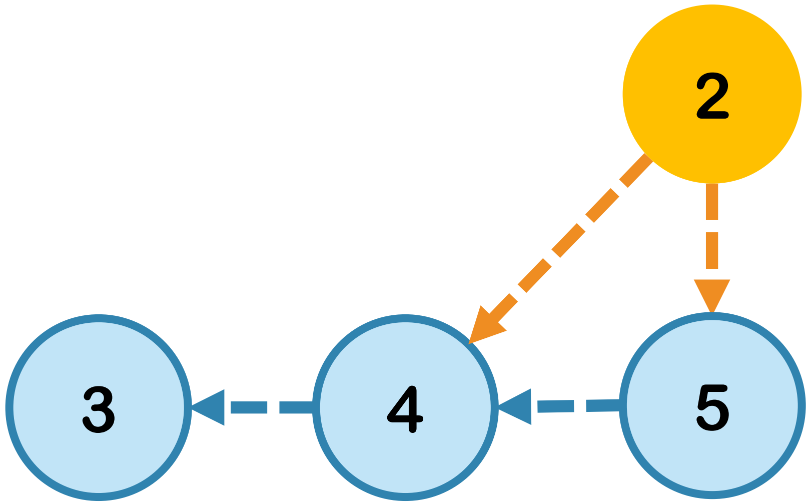

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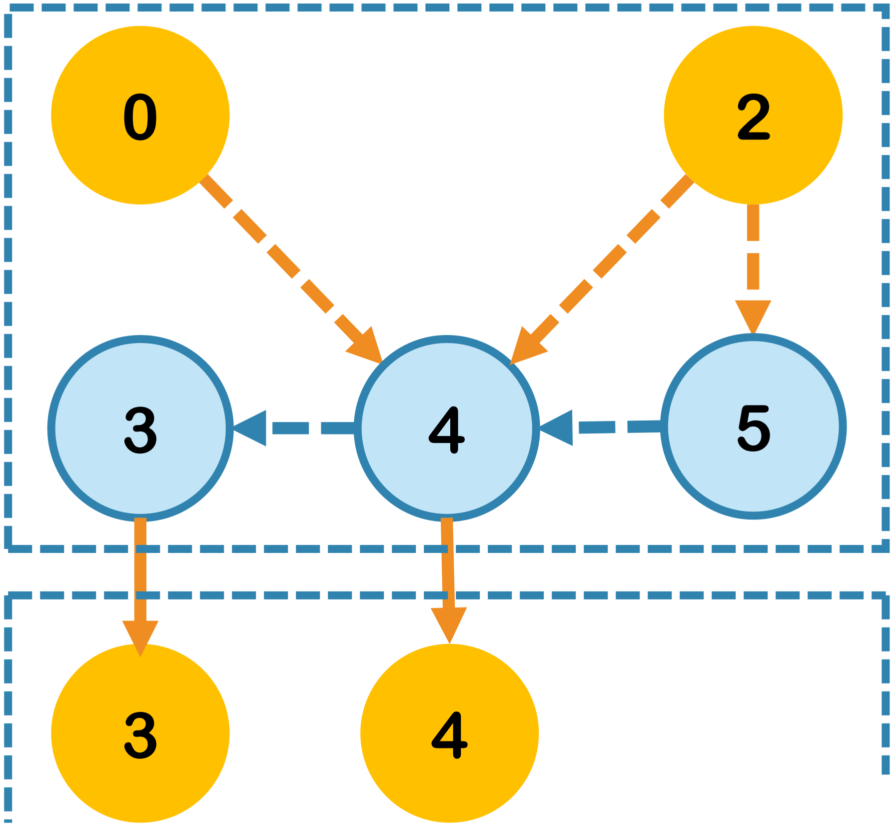
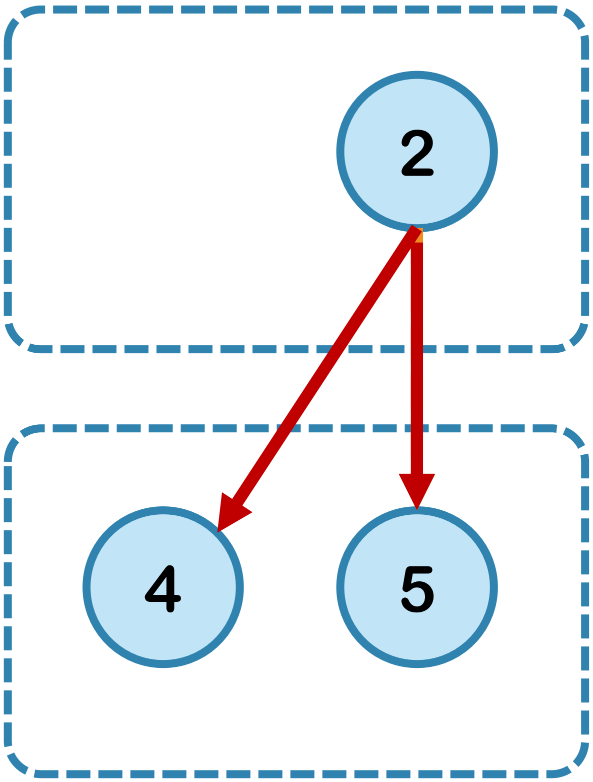


Benefits

- **Strictly less** data communication
- Enables architecture optimizations

Less Communication



Tesseract **GraphP**

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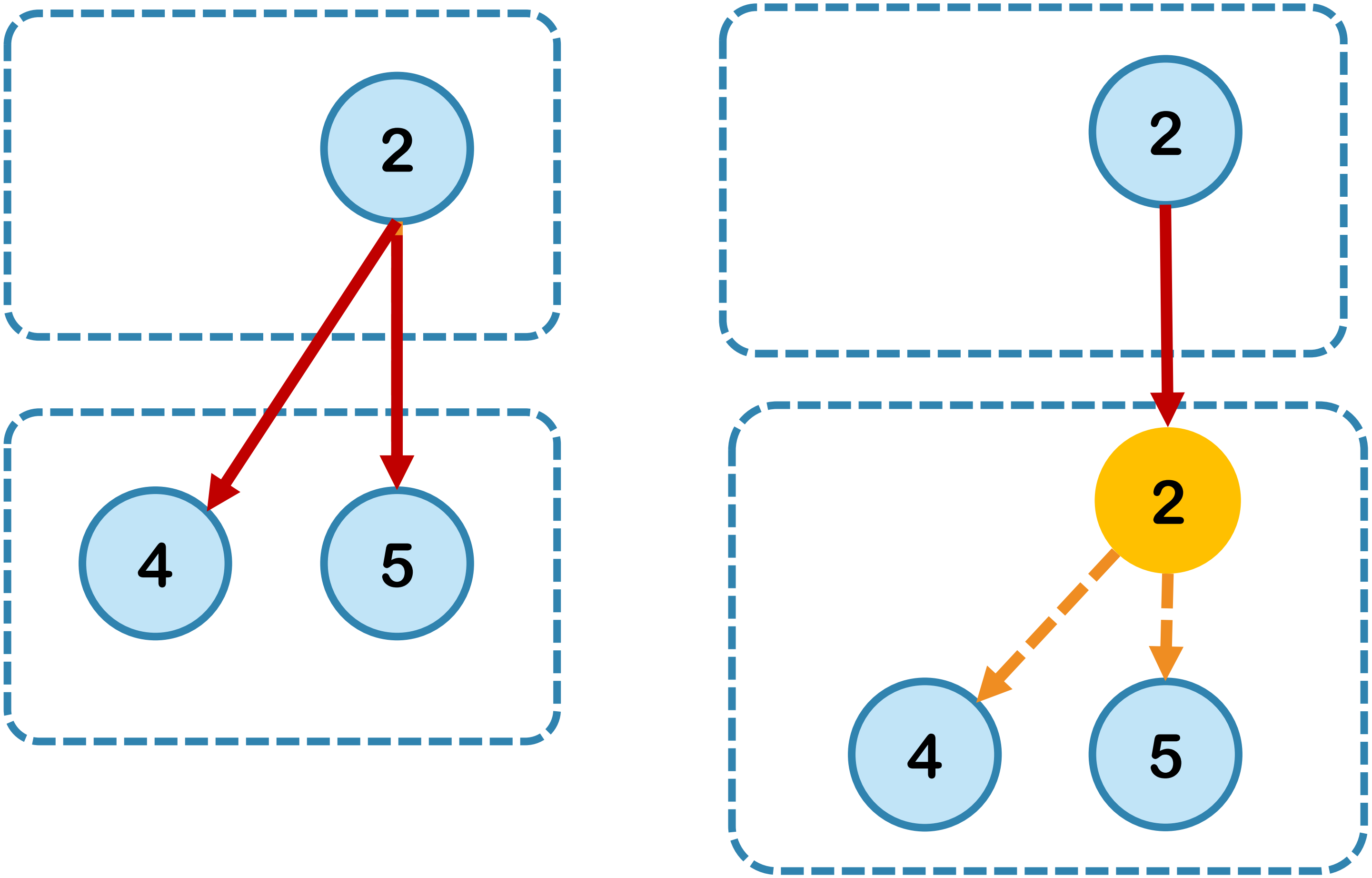

Tesseract **GraphP**

Broadcast Optimization

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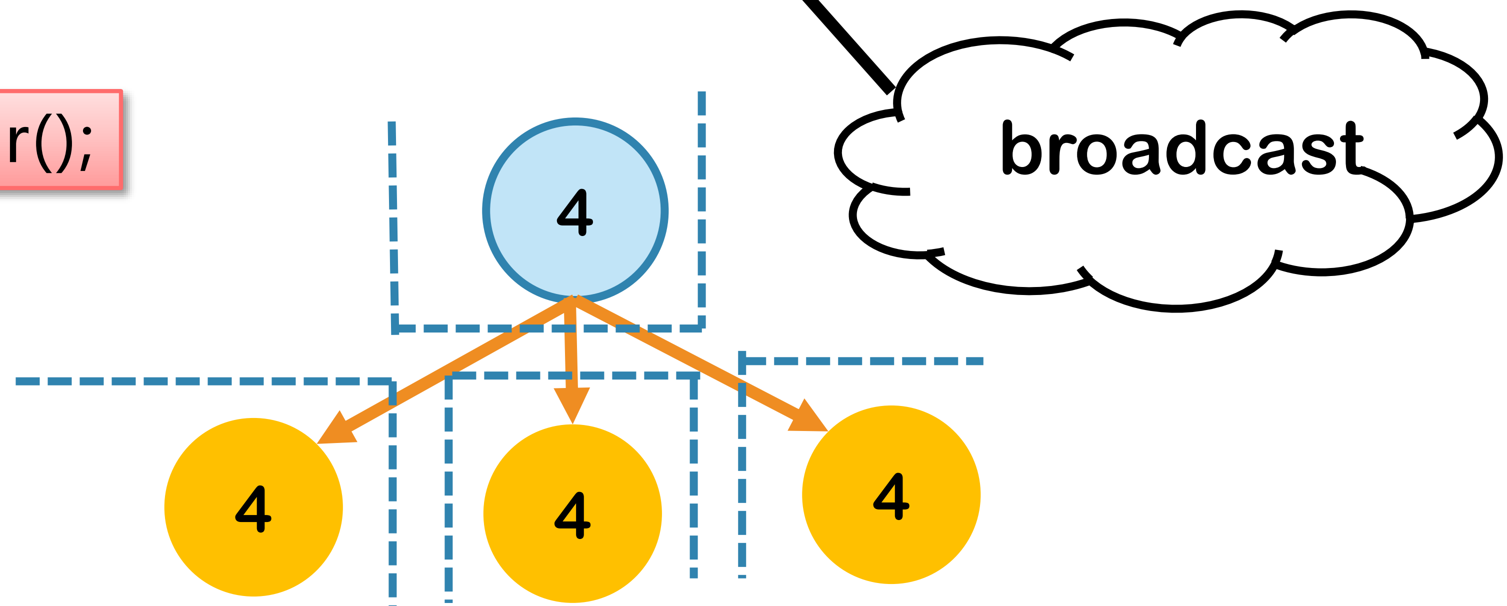
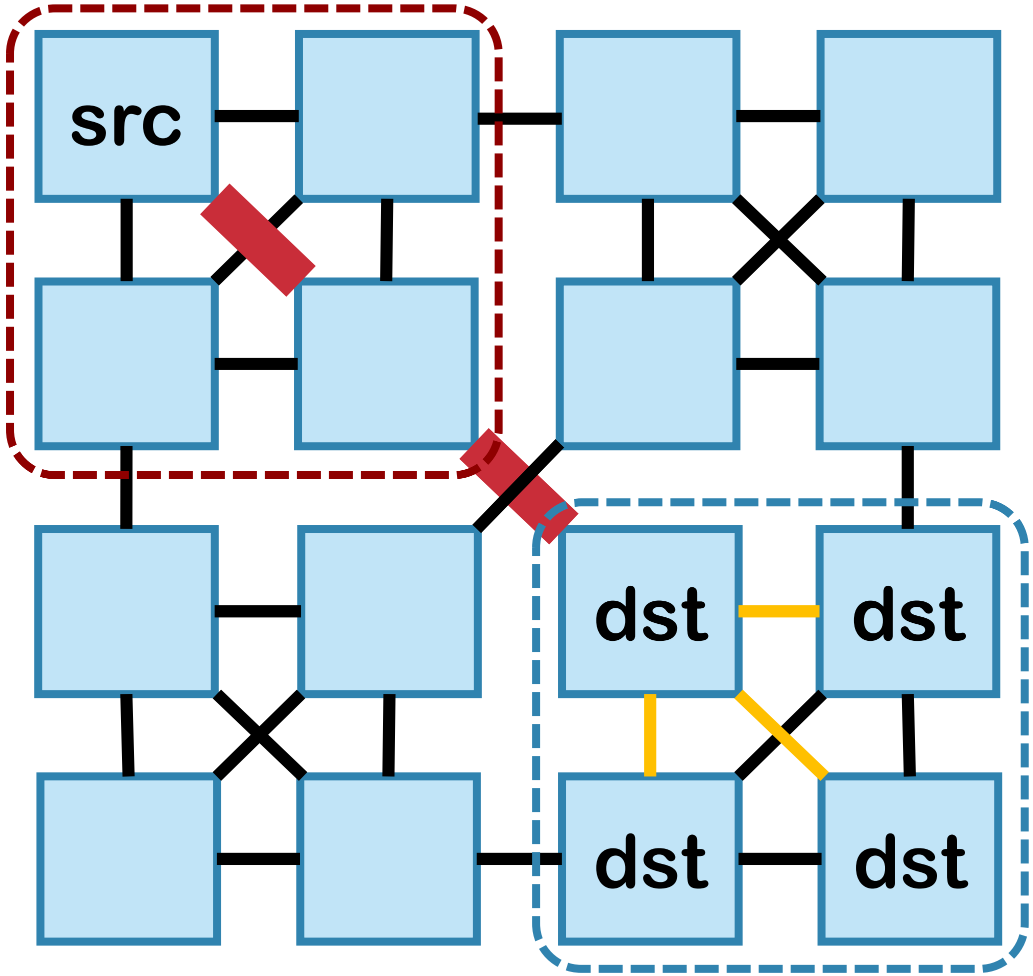


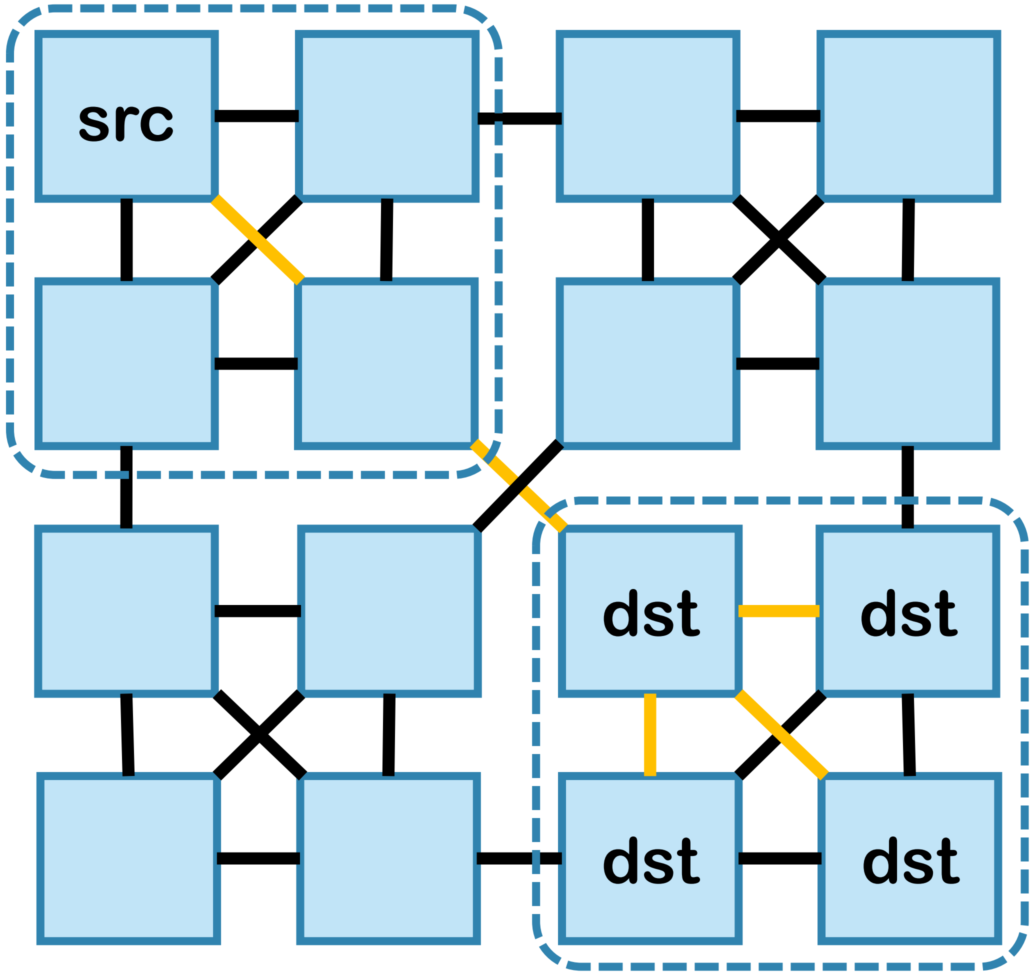
Naïve Broadcast

- 15 point to point messages



Hierarchical communication

- 3 intergroup messages



Other Optimizations

- Computation/communication overlap
- Leveraging low-power state of SerDes

Please see the paper for more details

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- **Evaluation**

Evaluation Methodology

- Simulation Infrastructure
  - zSim with HMC support
  - ORION for NOC Energy modeling
- Configurations
  - Same as Tesseract
  - 16 HMCs
  - Interconnection: Dragonfly and Mesh2D
  - 512 CPUs
    - Single-issue in-order cores
    - Frequency: 1GHz

Workloads

- 4 graph algorithms
- 5 real-world graphs

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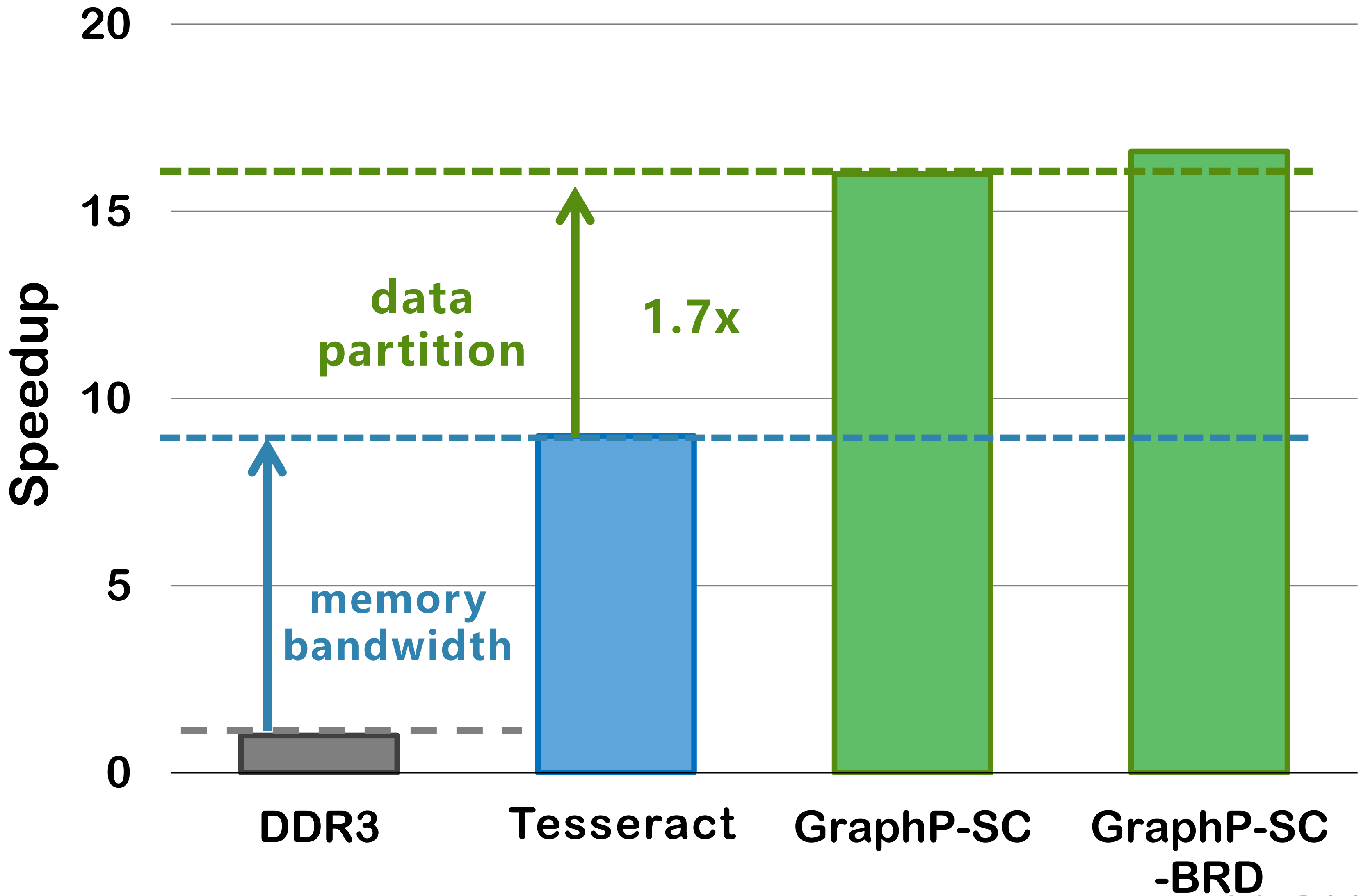
- 4 graph algorithms
  - Breadth First Search
  - Single Source Shortest Path
  - Weakly Connected Component
  - PageRank
- 5 real-world graphs
  - Wiki-Vote (WV)
  - ego-Twitter (TT)
  - Soc-Slashdot0902 (SD)
  - Amazon0302 (AZ)
  - ljournal-2008 (LJ)

Performance

Performance



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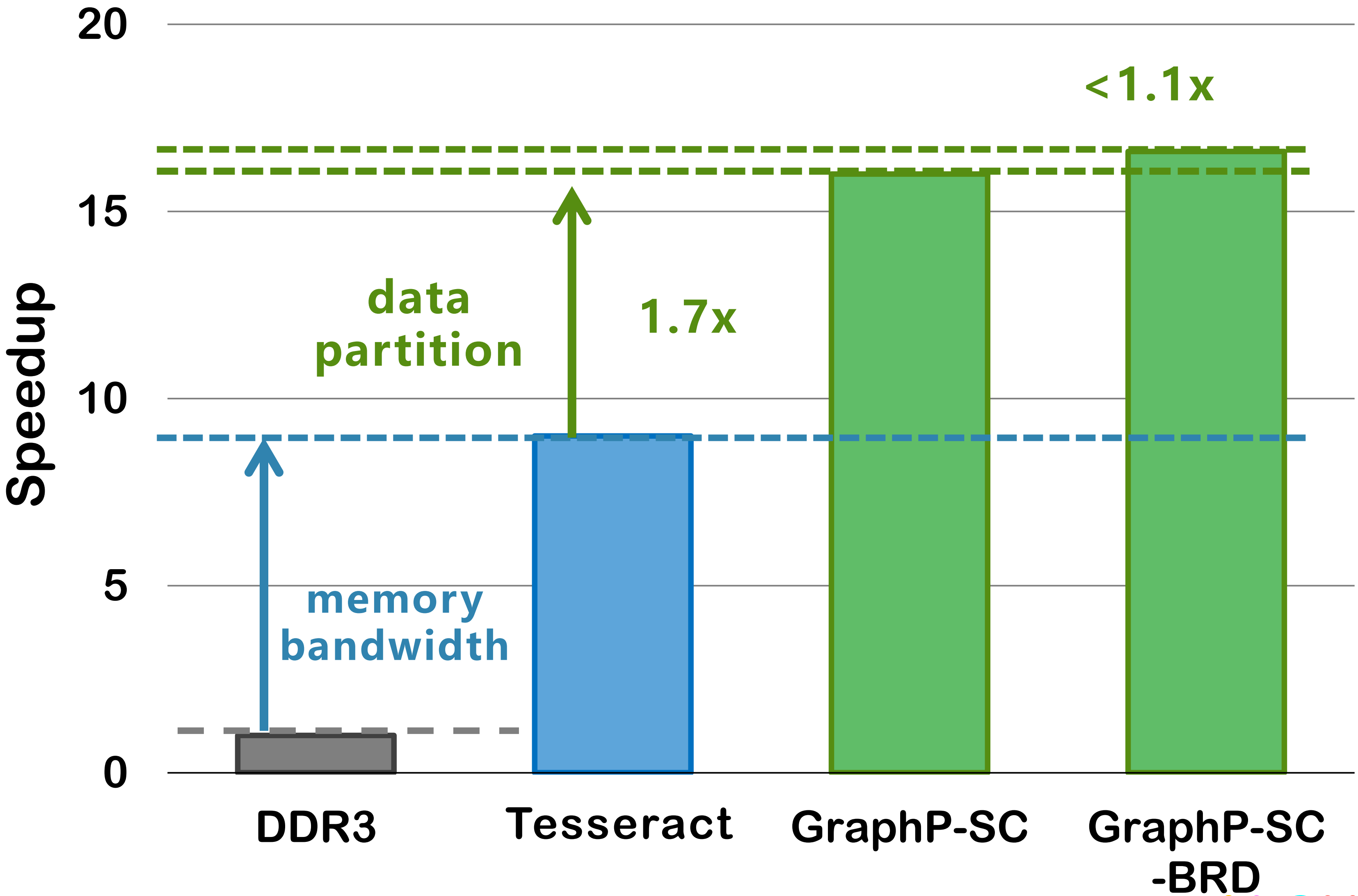
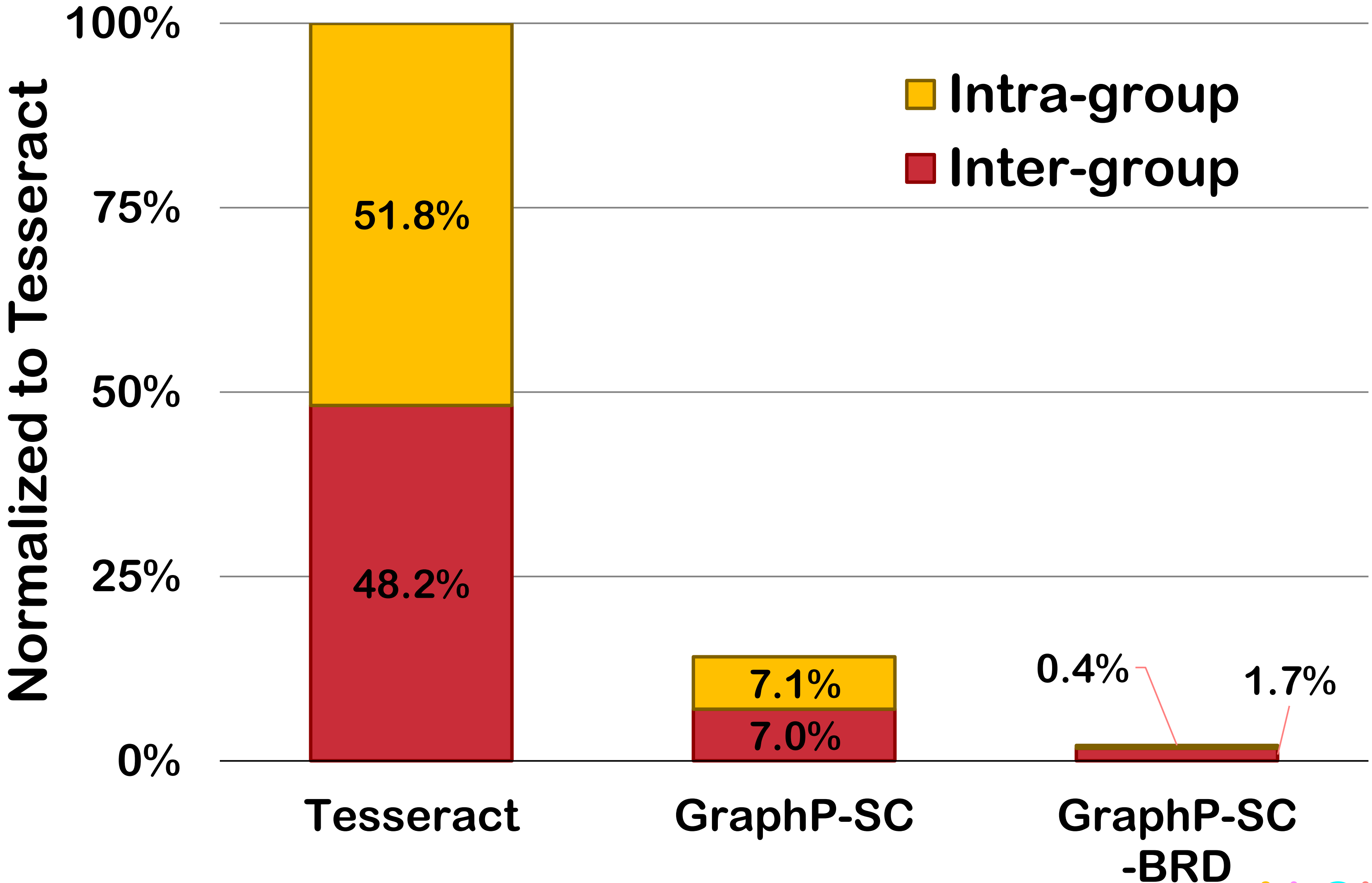
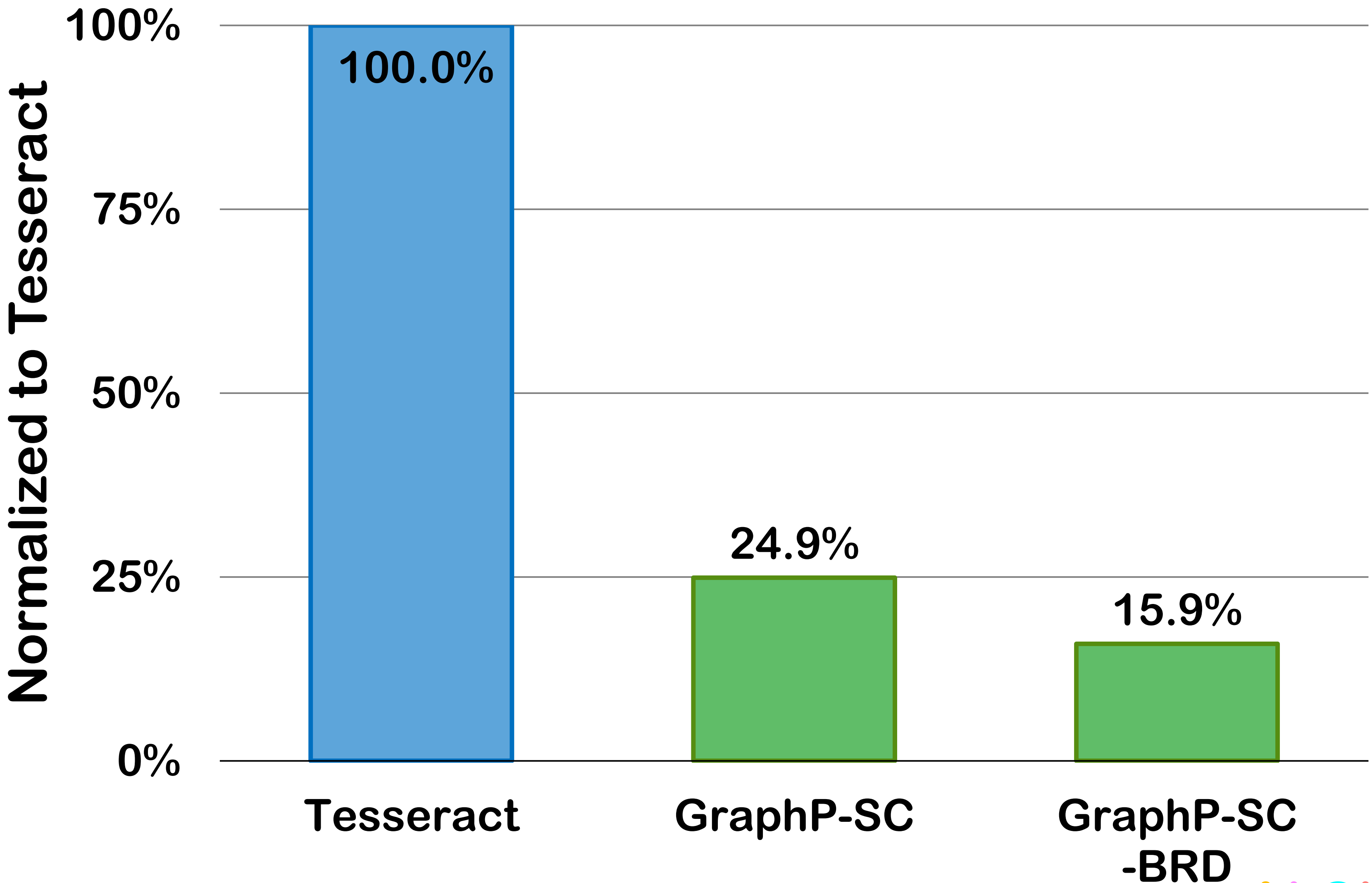


Communication Amount



Energy consumption



Other results

- Bandwidth utilization
- Scalability
- Replication overhead

Please see the paper for more details

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  - Enable additional architecture optimizations
- GraphP drastically reduces inter-cube communication and improves energy efficiency.

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Workload Size & Capacity

- 128 GB (16 * 8GB)
- ~16 billion edges
- ~400 million edges (SNAP)
- ~7 billion edges (WebGraph)

https://snap.stanford.edu/data/
http://law.di.unimi.it/datasets.php

Two-phase vertex program

- Equivalent Expressiveness as vertex programs