Triton Join: Efficiently Scaling to a Large Join State on GPUs with Fast Interconnects

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German Research Center for Artificial Intelligence

BIFOLD

Goal

*Scale GPU-accelerated joins to **a large join state**.*

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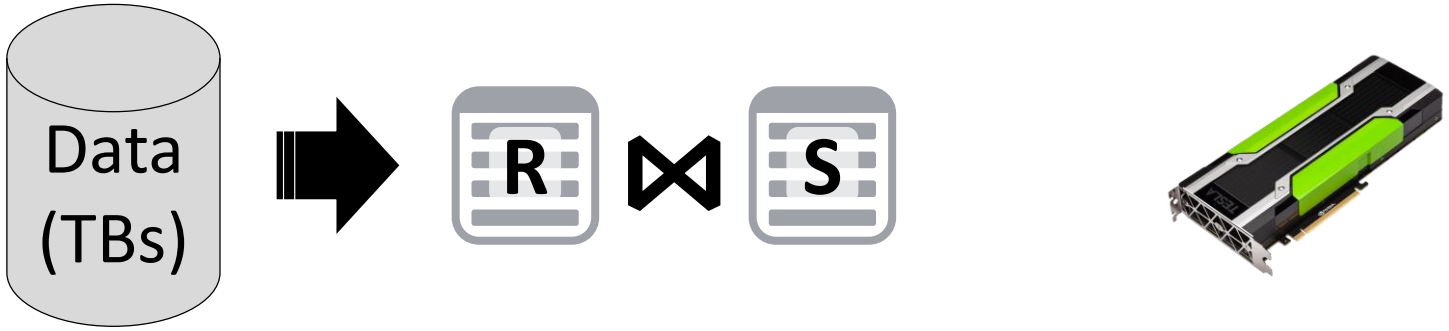
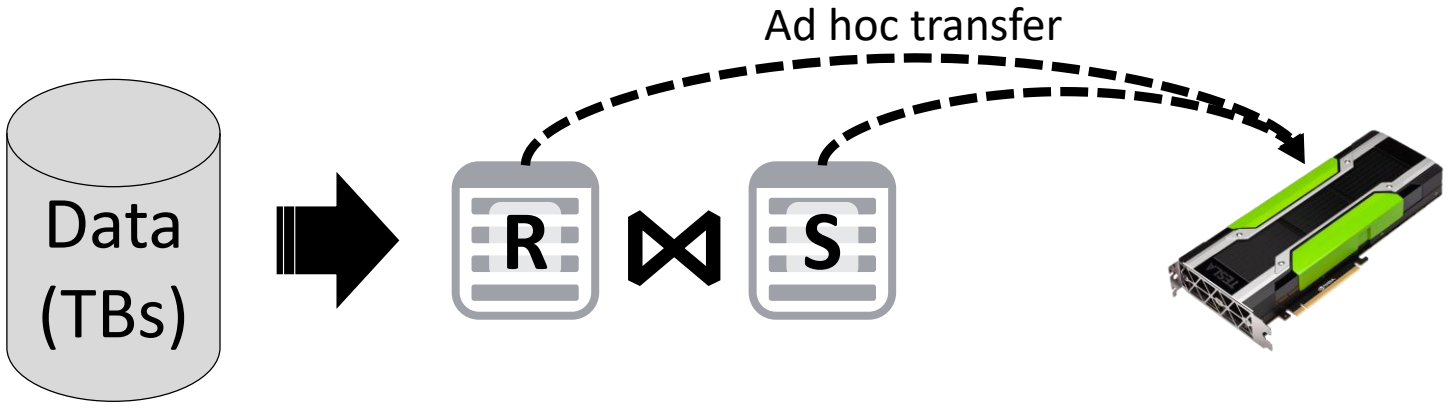


Research Problem

*Scale GPU-accelerated joins to **a large join state**.*



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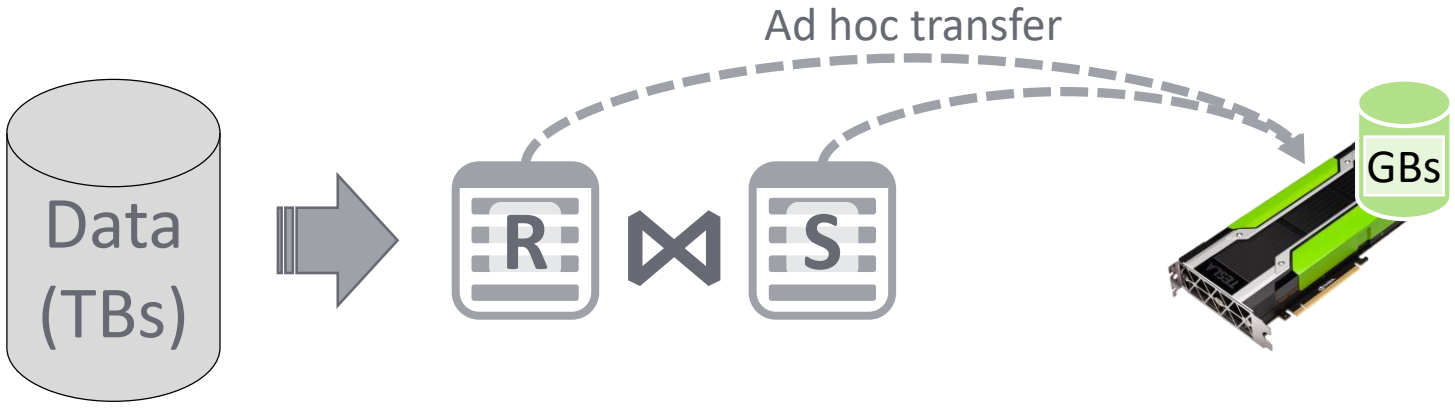

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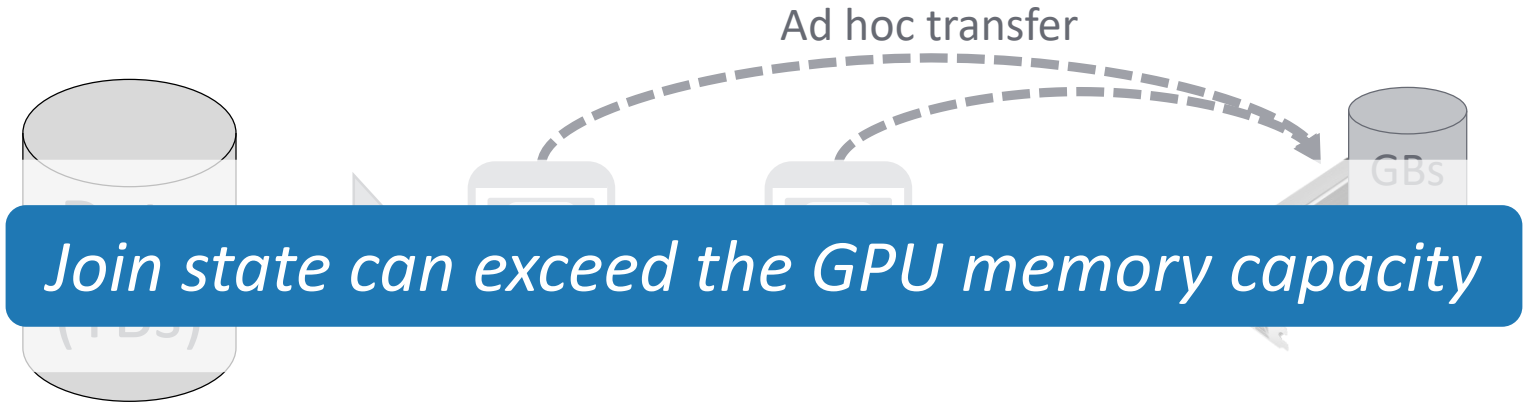


State-of-the-Art Premise

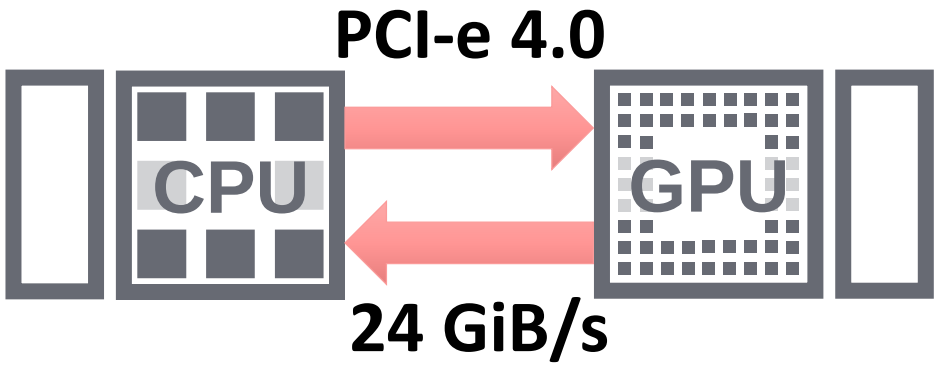
Memory capacity

Interconnect bandwidth

State-of-the-Art Premise

Memory capacity

Interconnect bandwidth



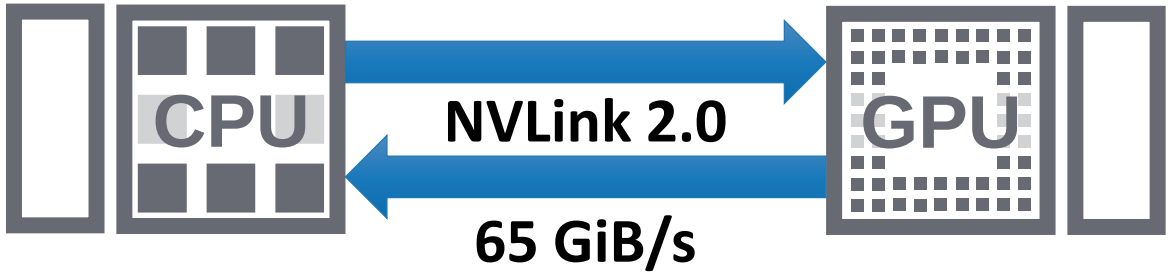
State-of-the-Art Premise

Memory capacity

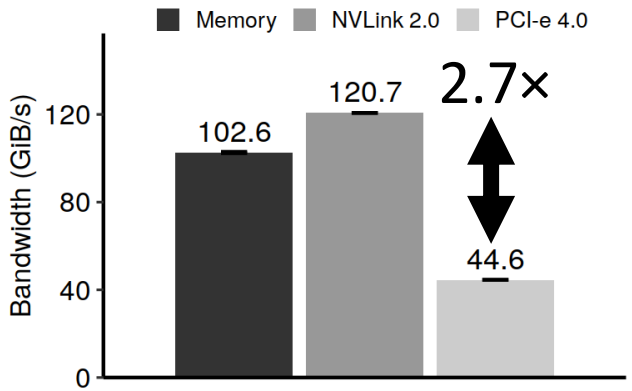
Interconnect bandwidth

Data Transfer Bottleneck

Game Changer: Fast Interconnects



Game Changer: Fast Interconnects



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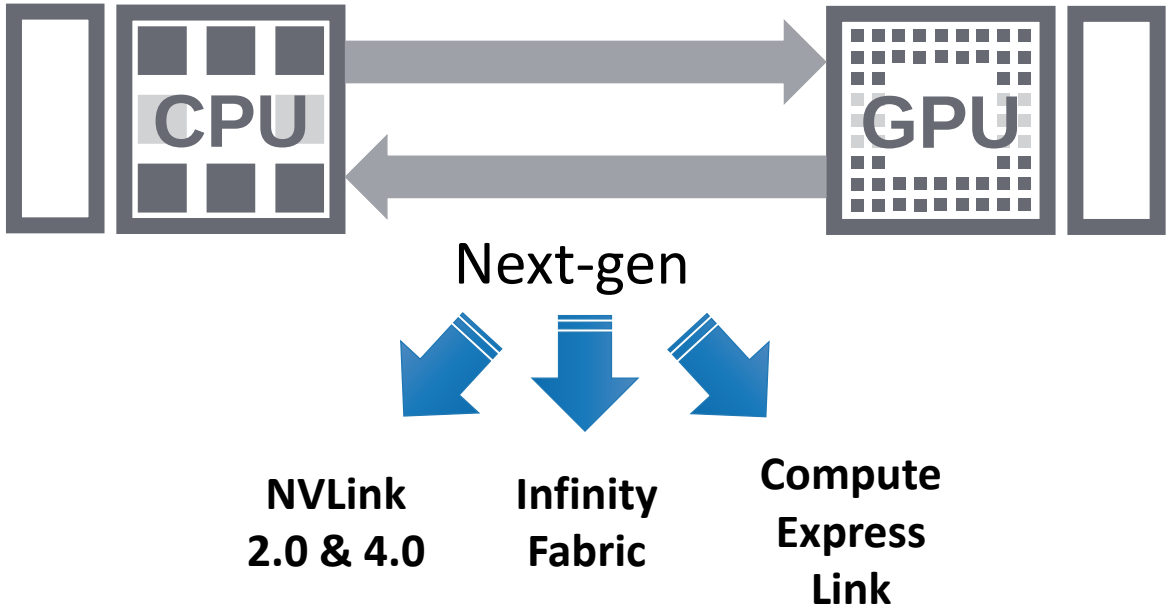
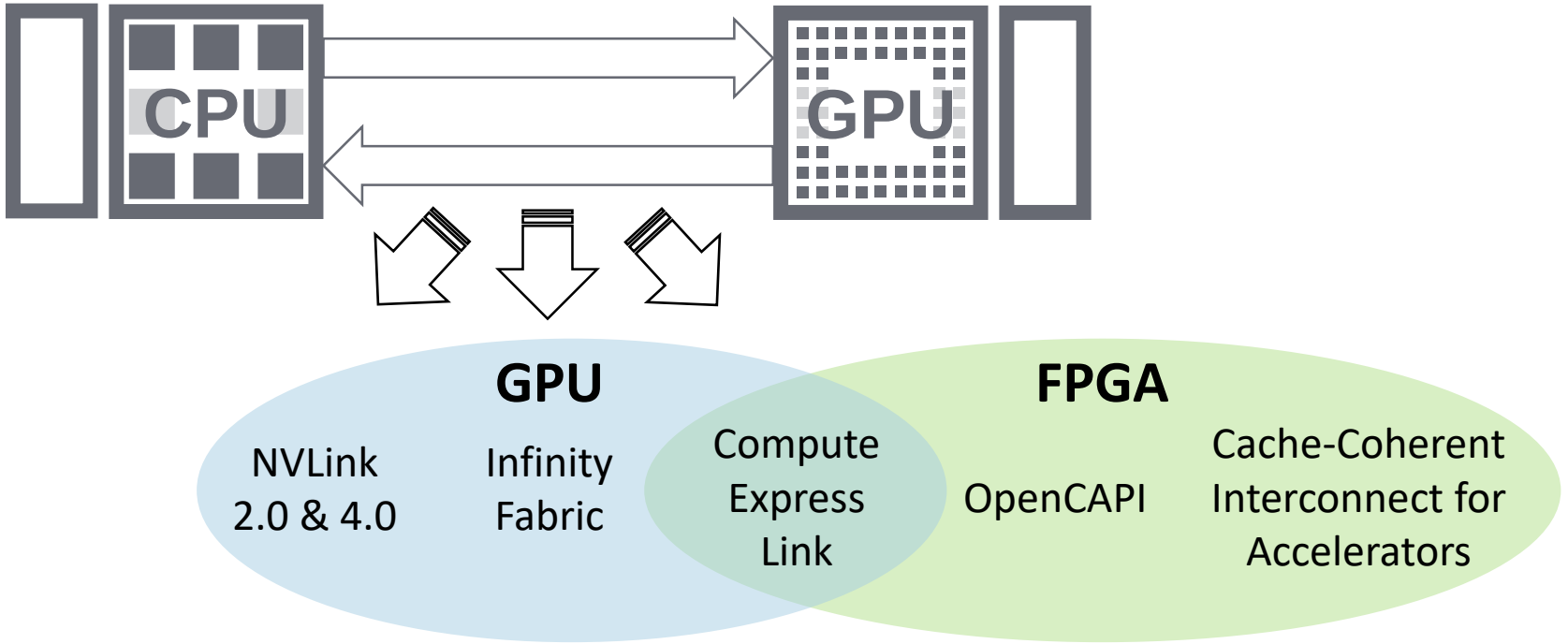


Game Changer: Fast Interconnects



Contributions

- Revisit GPU Hash Joins
- Identify Hardware Bottlenecks
- Out-of-core Radix Partitioning
- Triton Join Algorithm

Agenda

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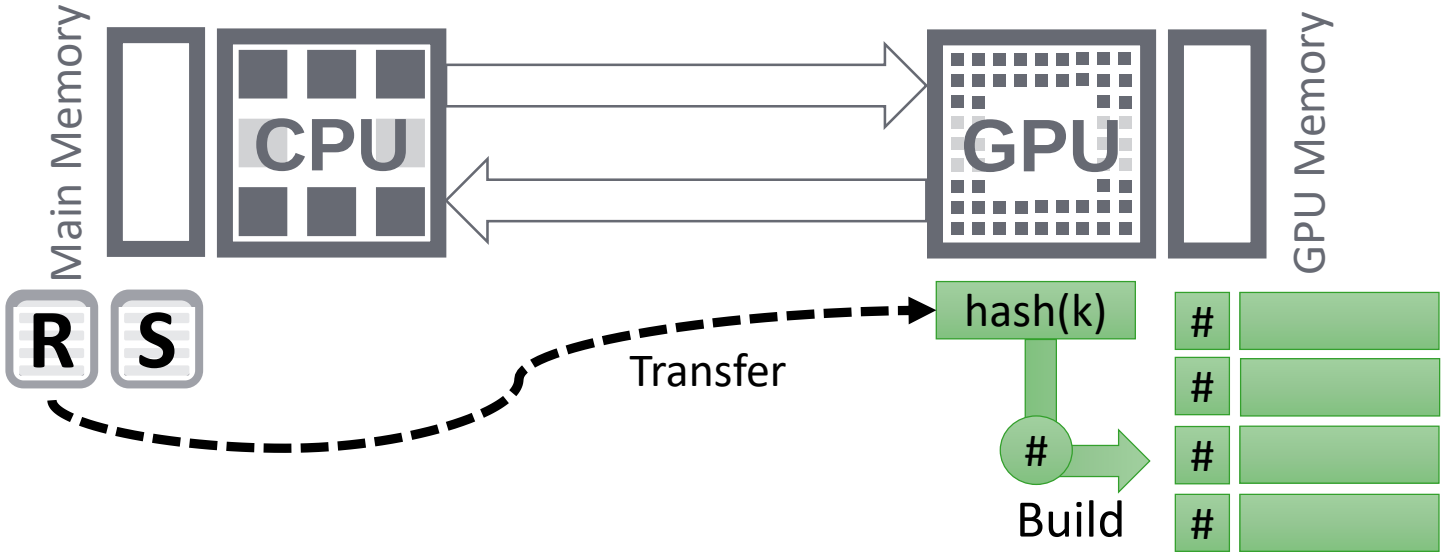
- Identify Hardware Bottlenecks
- Out-of-core Radix Partitioning
- Triton Join Algorithm

Approach 1: Hash Table in GPU Memory



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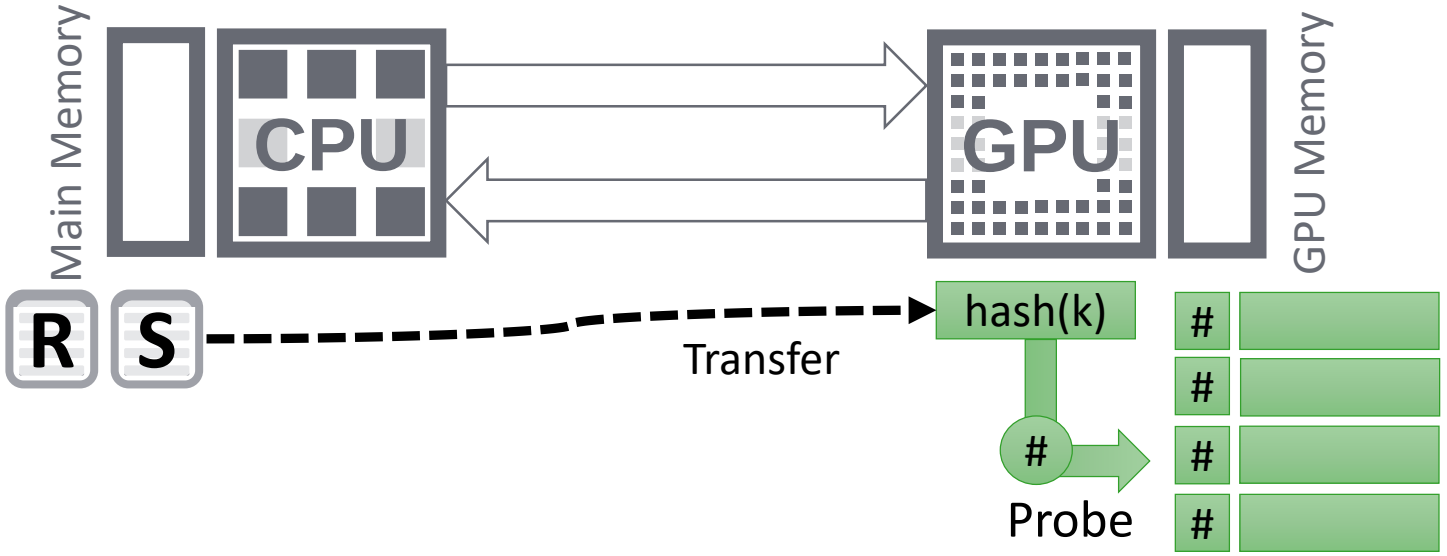

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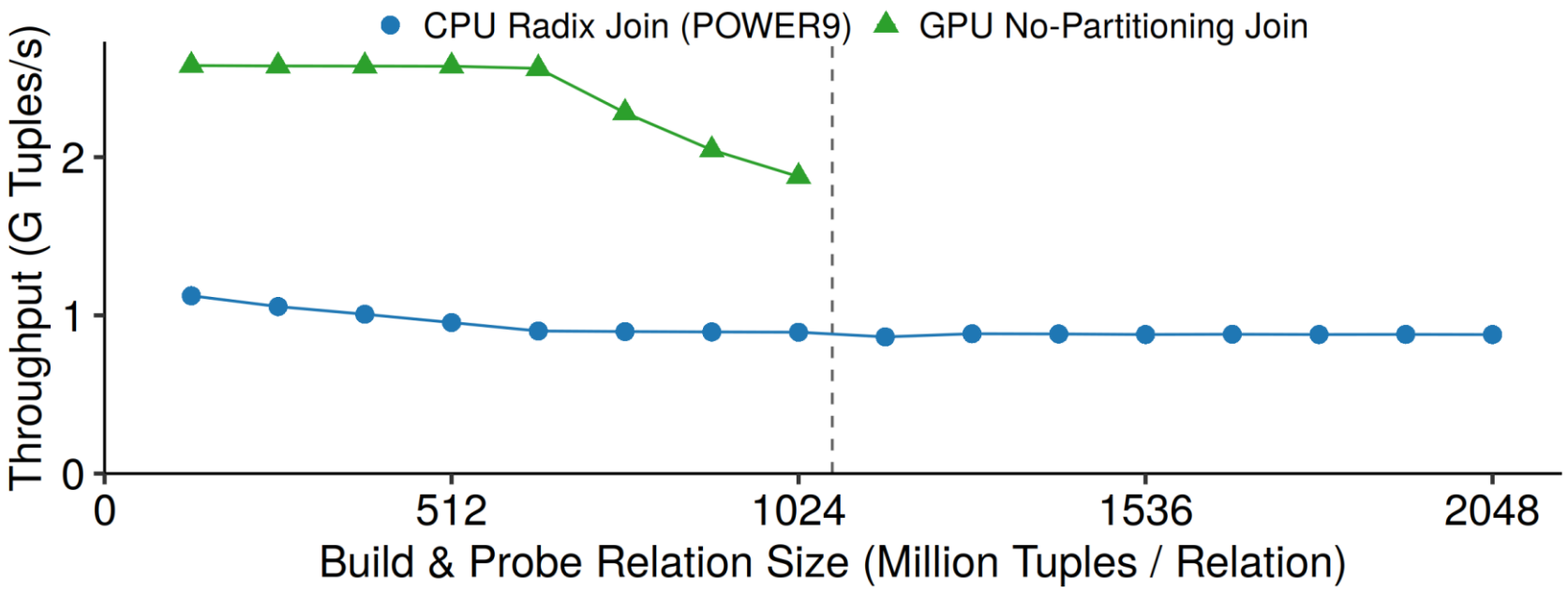
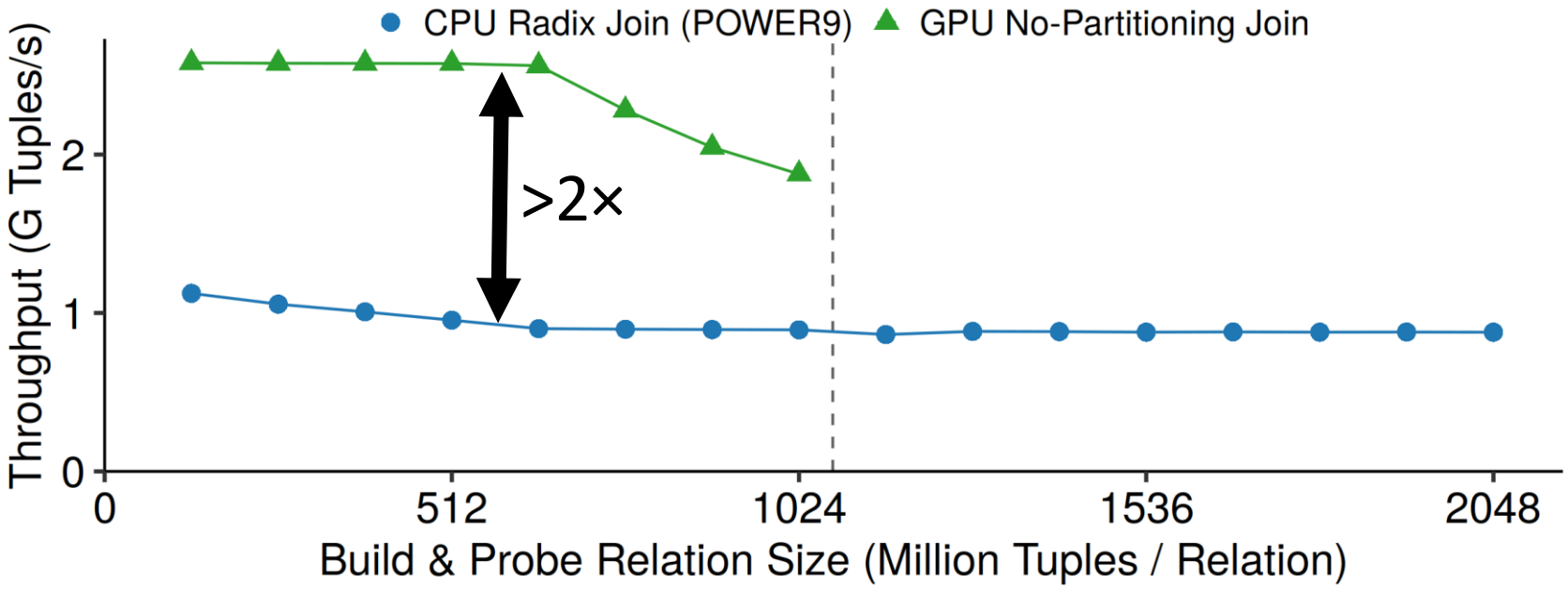
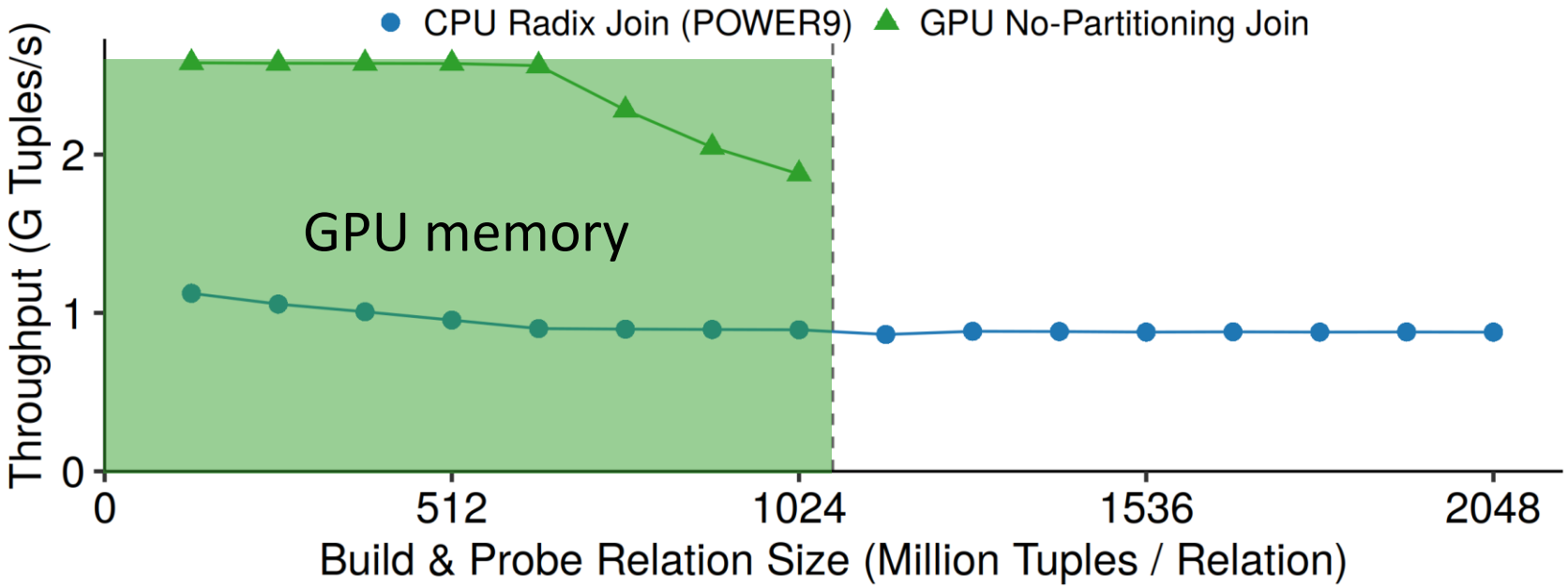


Data:	30 GiB ⋈ 30 GiB
CPU:	IBM POWER9 with 16 cores
GPU:	Nvidia V100 with NVLink 2.0

Challenge 1

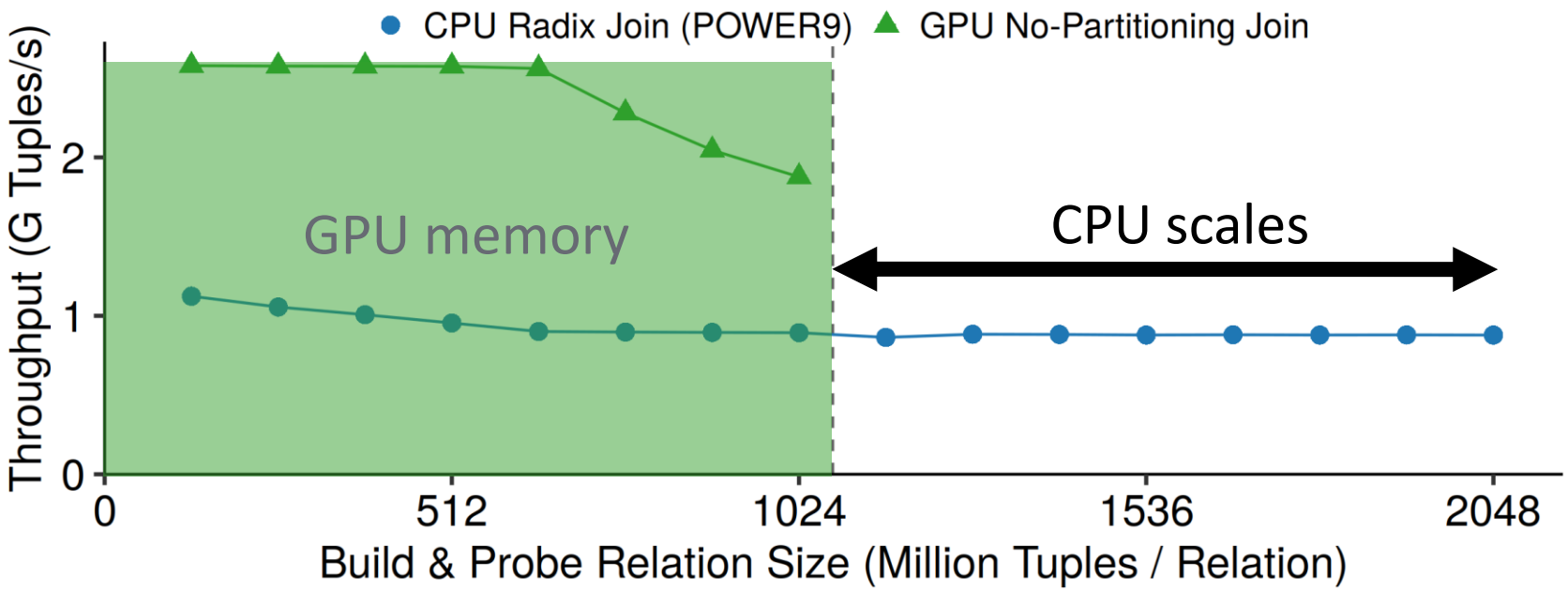

CPU Radix Join (POWER9)
GPU No-Partitioning Join
Throughput (G Tuples/s)
0
1
2
>2×
0
512
1024
1536
2048
Build & Probe Relation Size (Million Tuples / Relation)

Challenge 1



- Join state has limited size

Challenge 1



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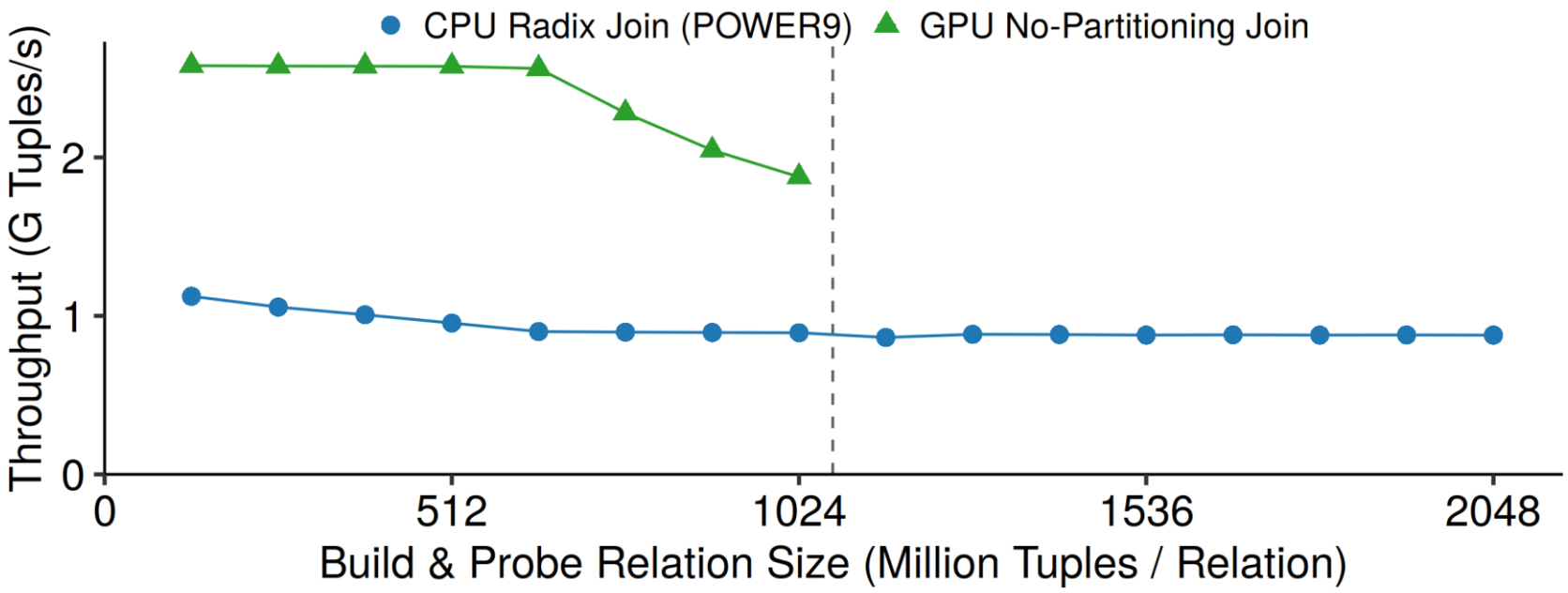
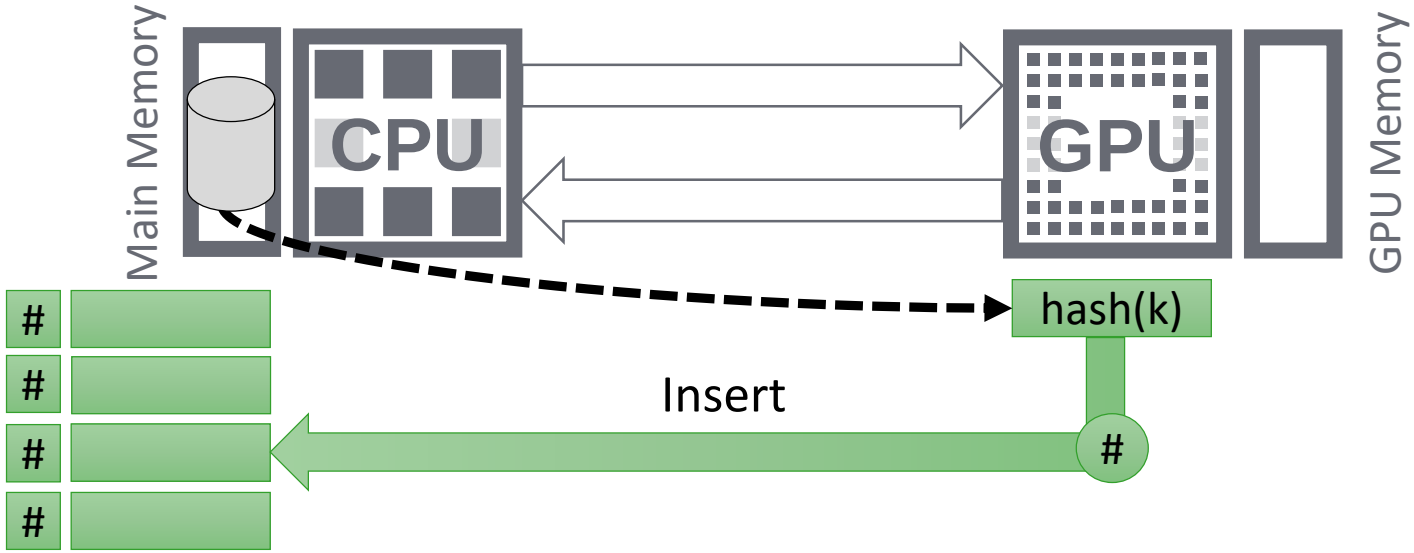
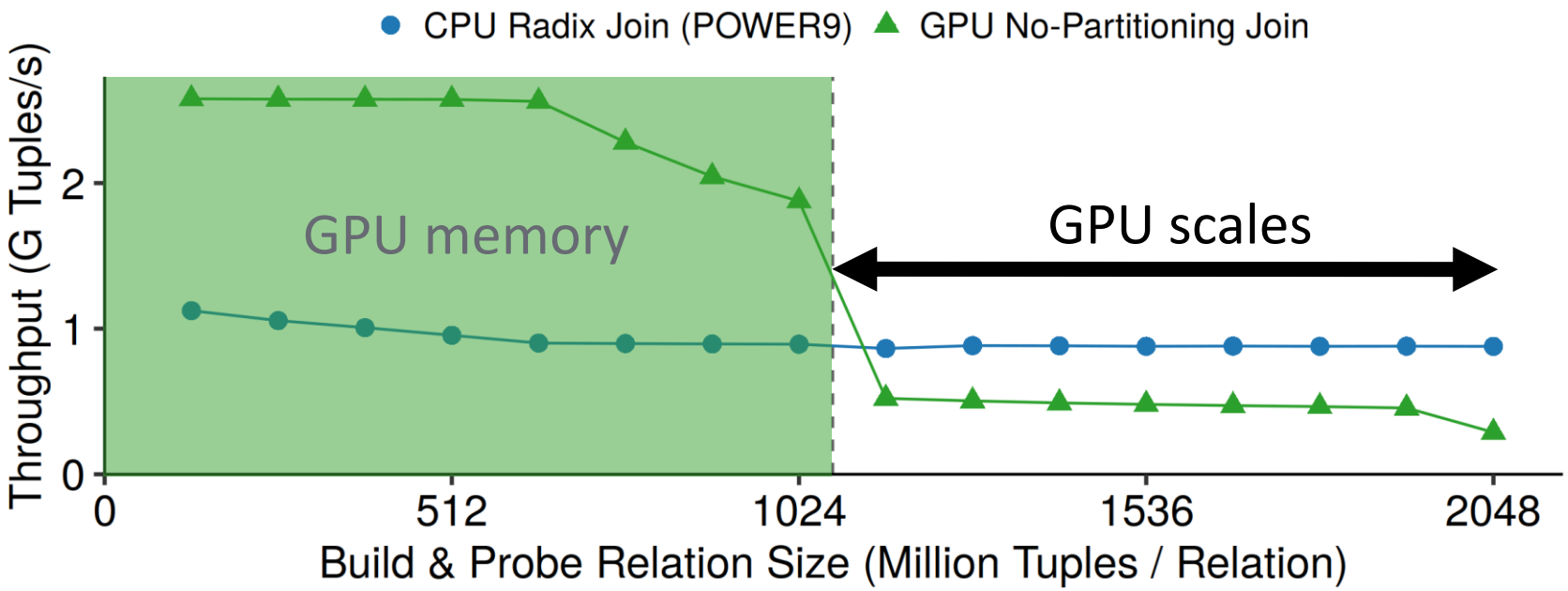


GPU hash join does not scale to a large join state

Approach 2: Spill Hash Table

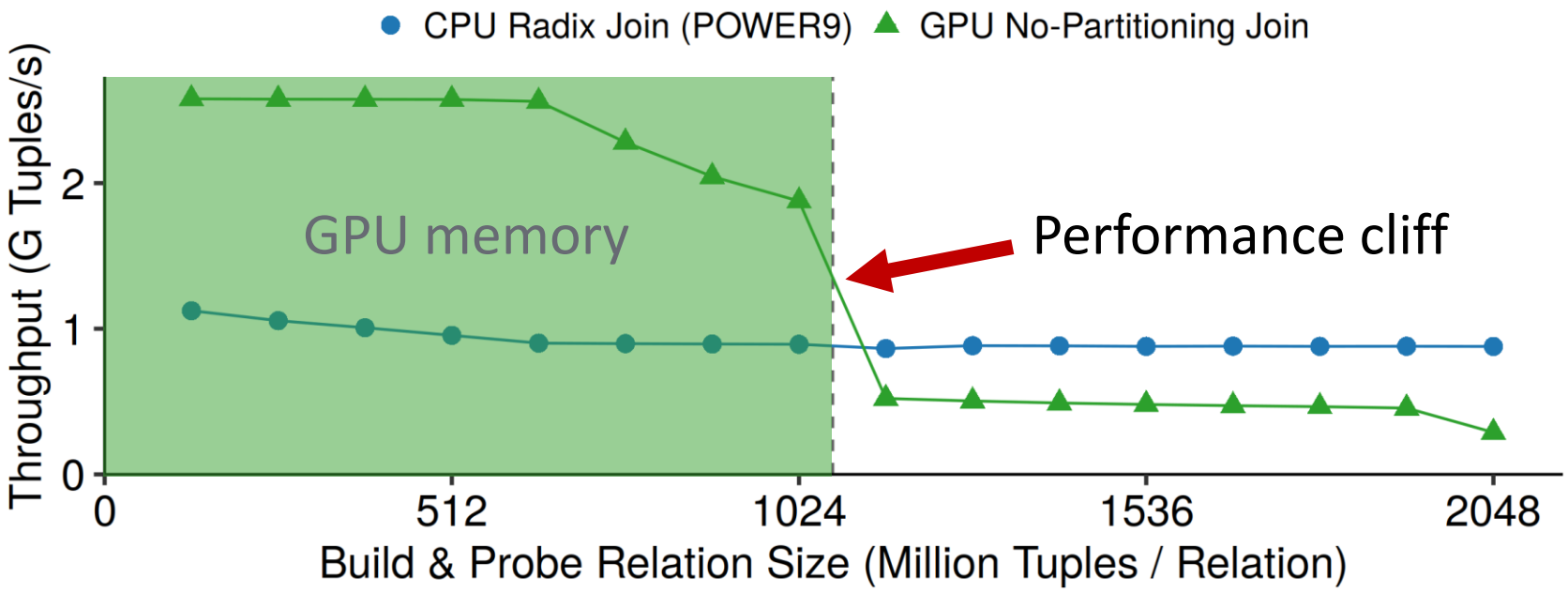


Challenge 2



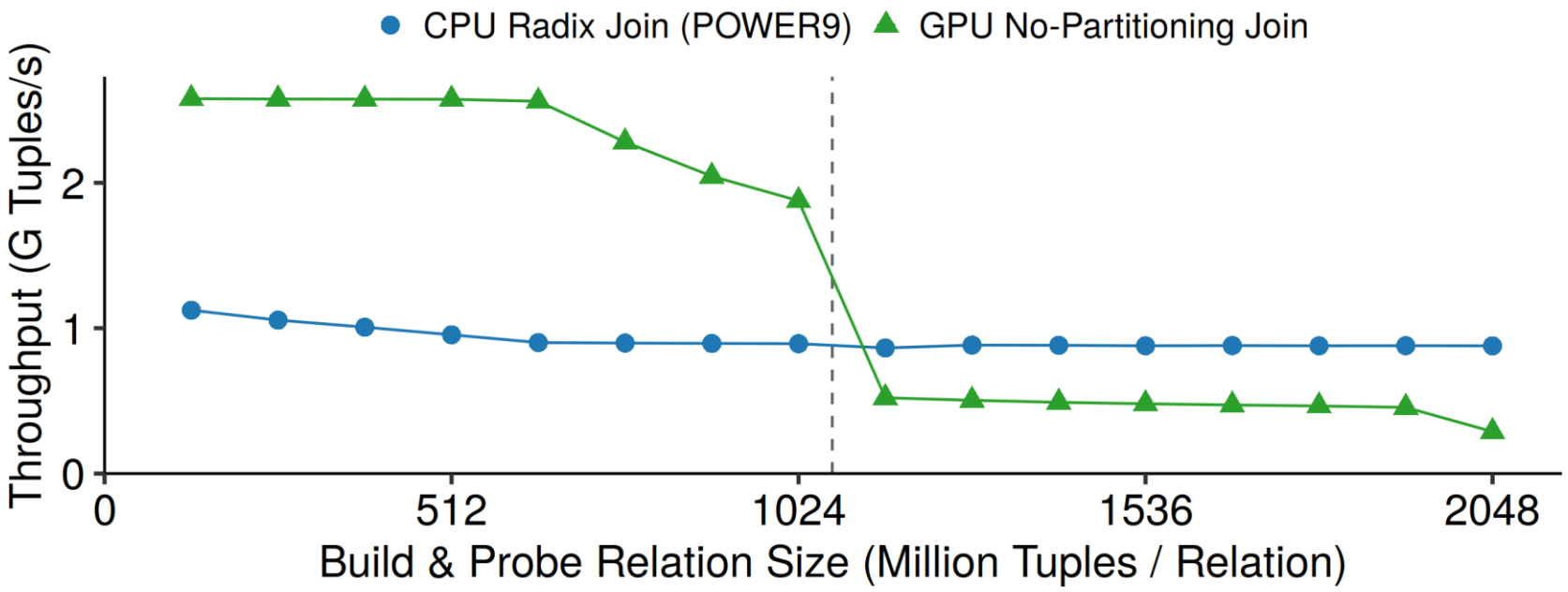
- Scalable ✓

Challenge 2



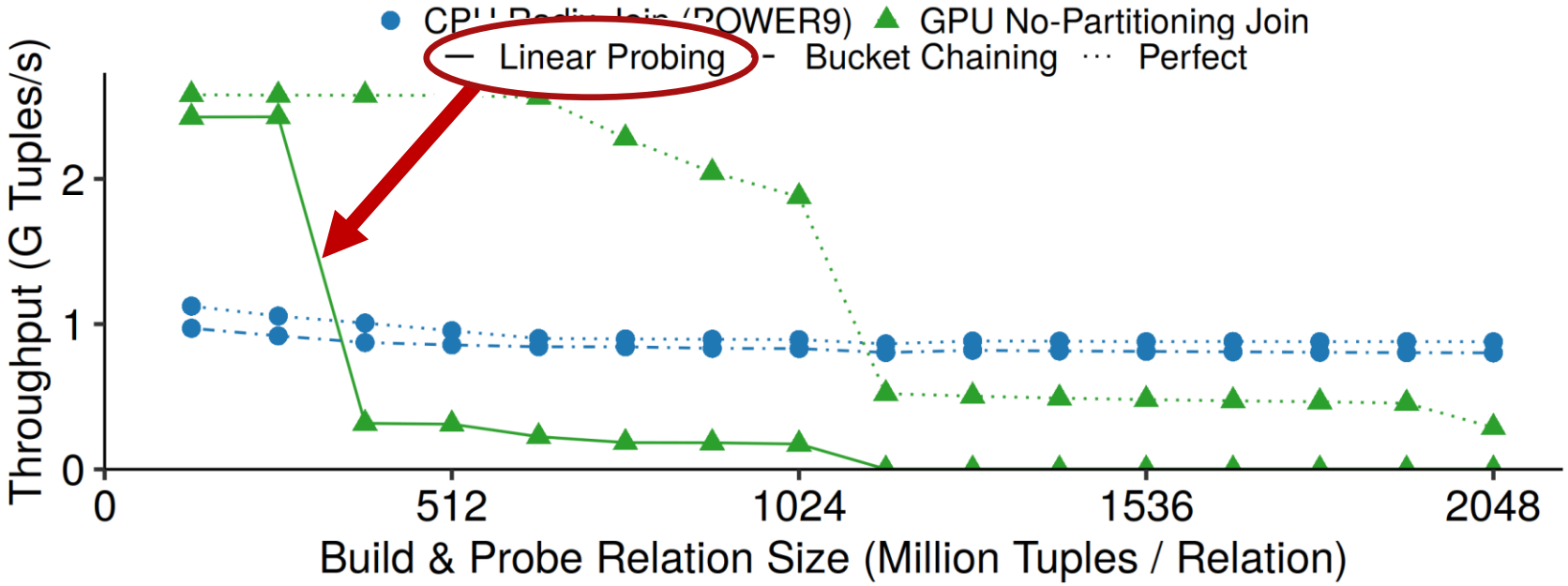
- Scalable ✓
- But: Performance cliff for large hash tables

Challenge 2



Spilling hash table does not lead to robust performance

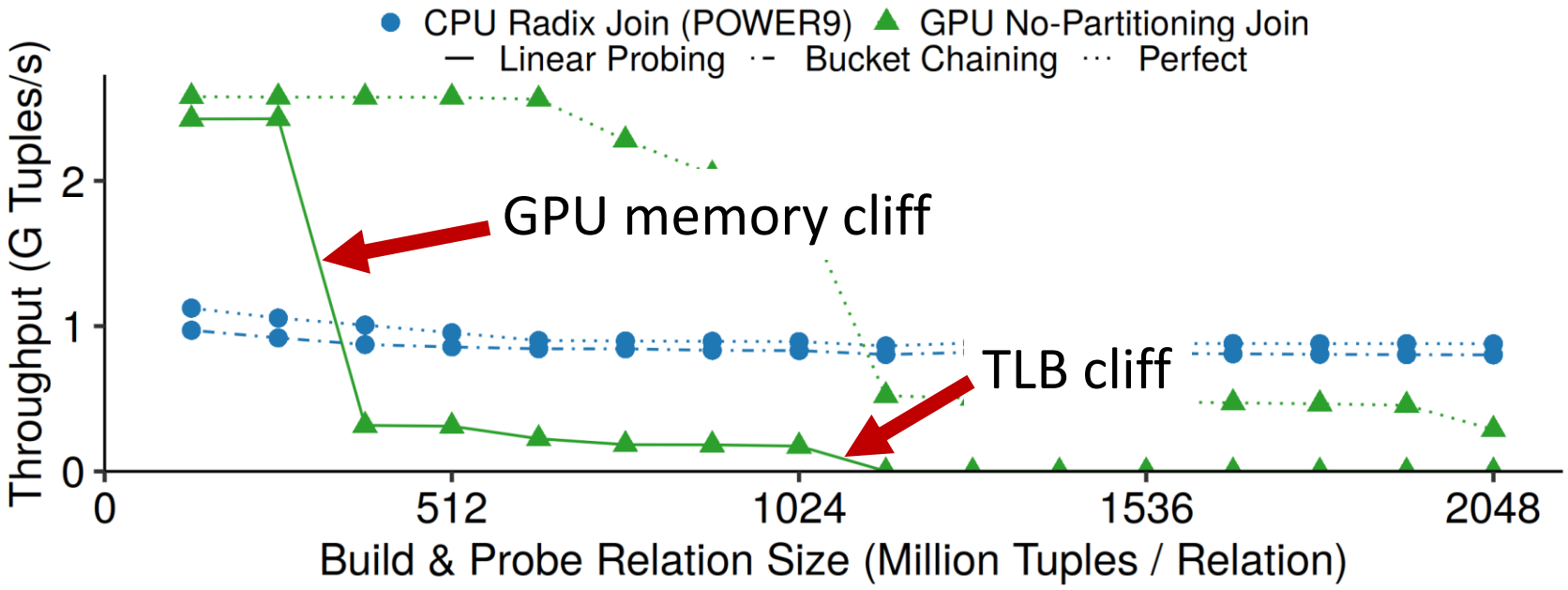
Challenge 2



- Linear probing instead of perfect hashing

  → 2× hash table size

Challenge 2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GPU No-Partitioning Join
Linear Probing
Bucket Chaining
Perfect
Throughput (G Tuples/s)
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2
GPU memory cliff
TLB cliff
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1024
1536
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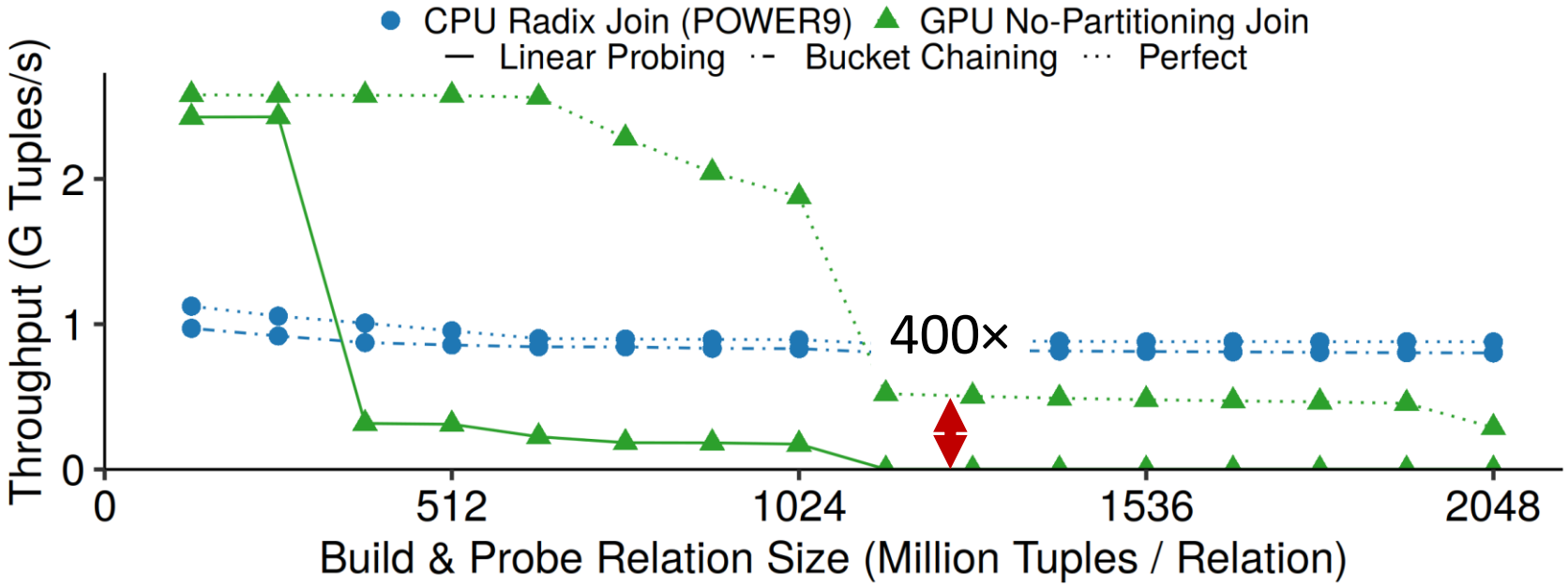
Build & Probe Relation Size (Million Tuples / Relation)

Challenge 2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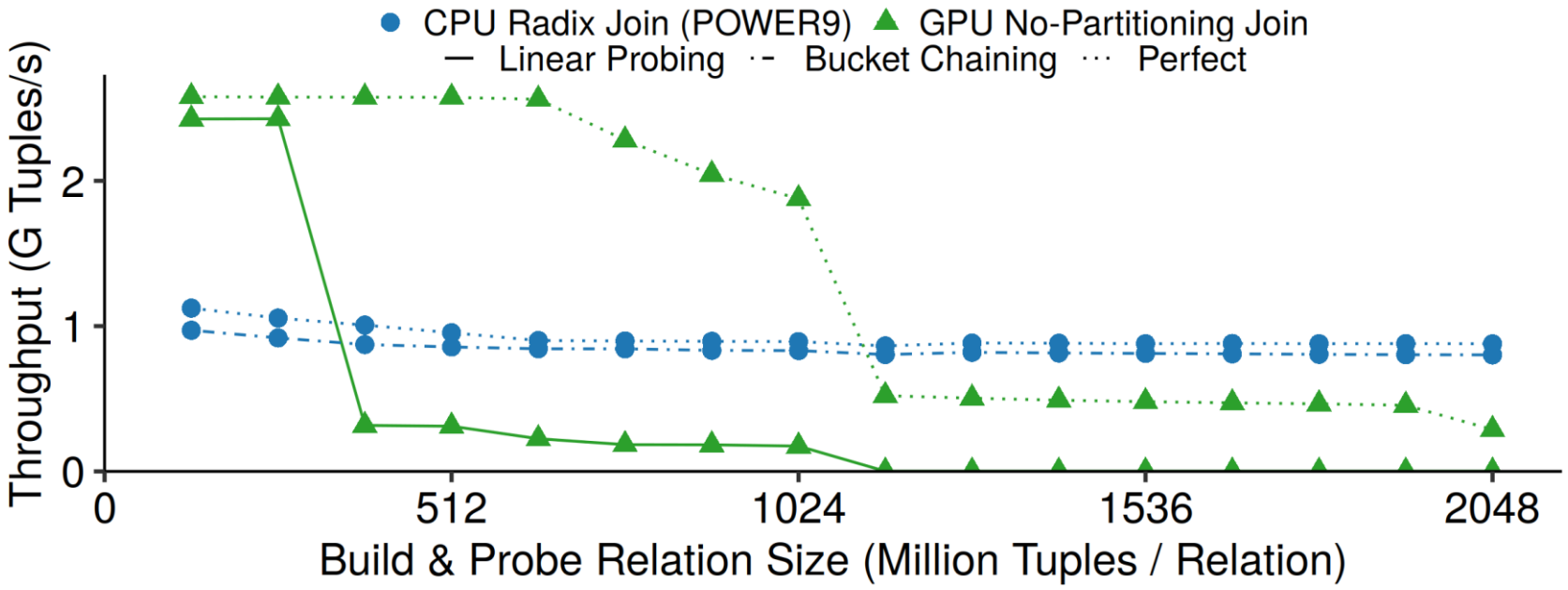
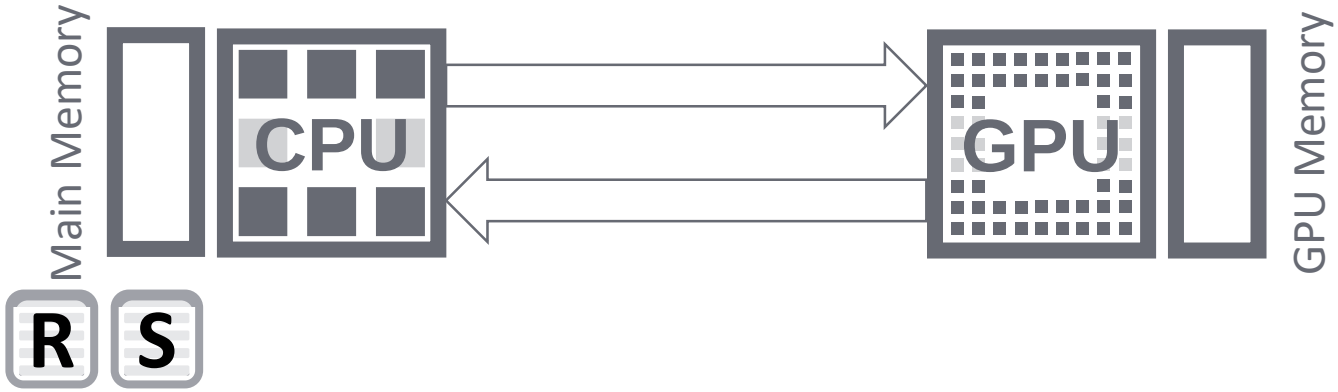


GPU TLB misses cause a slow down for large hash tables

Approach 3: Partition Data using CPU



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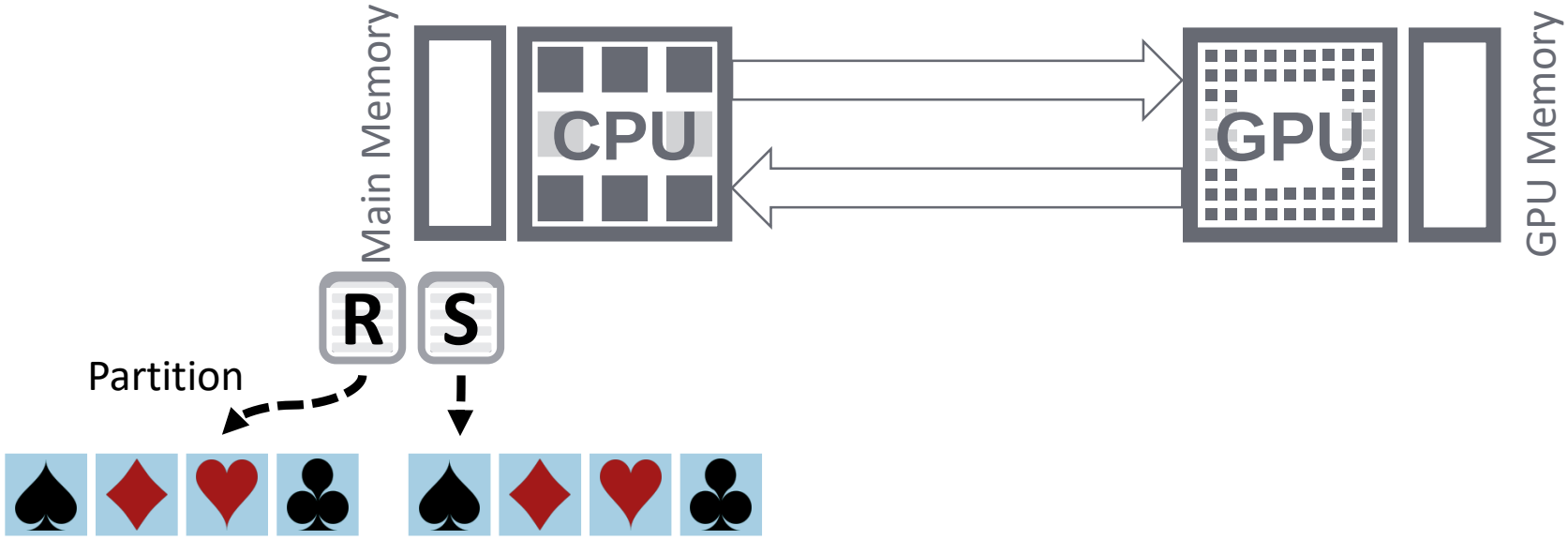

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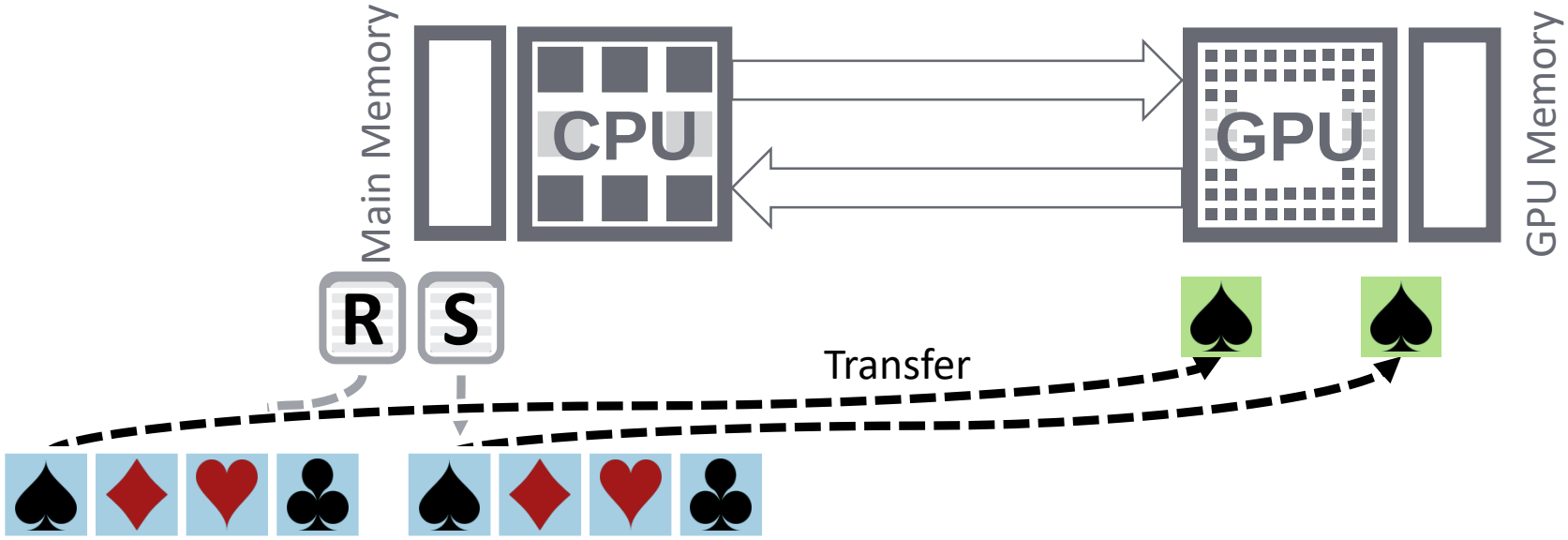

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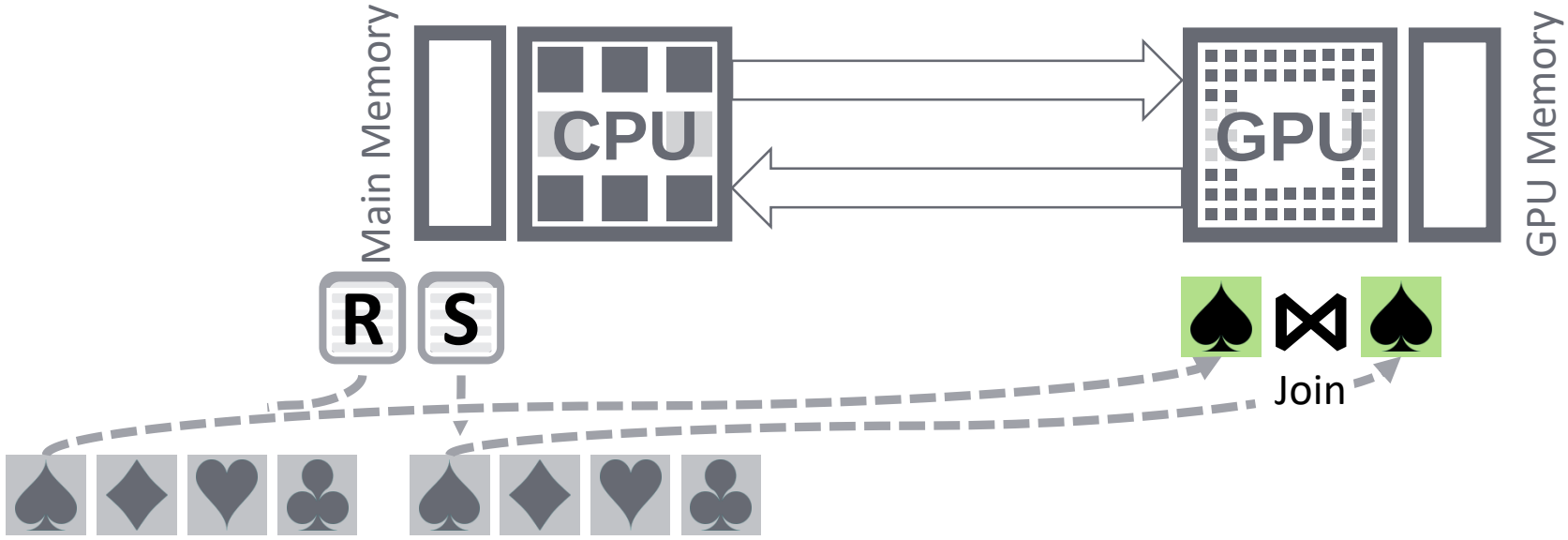

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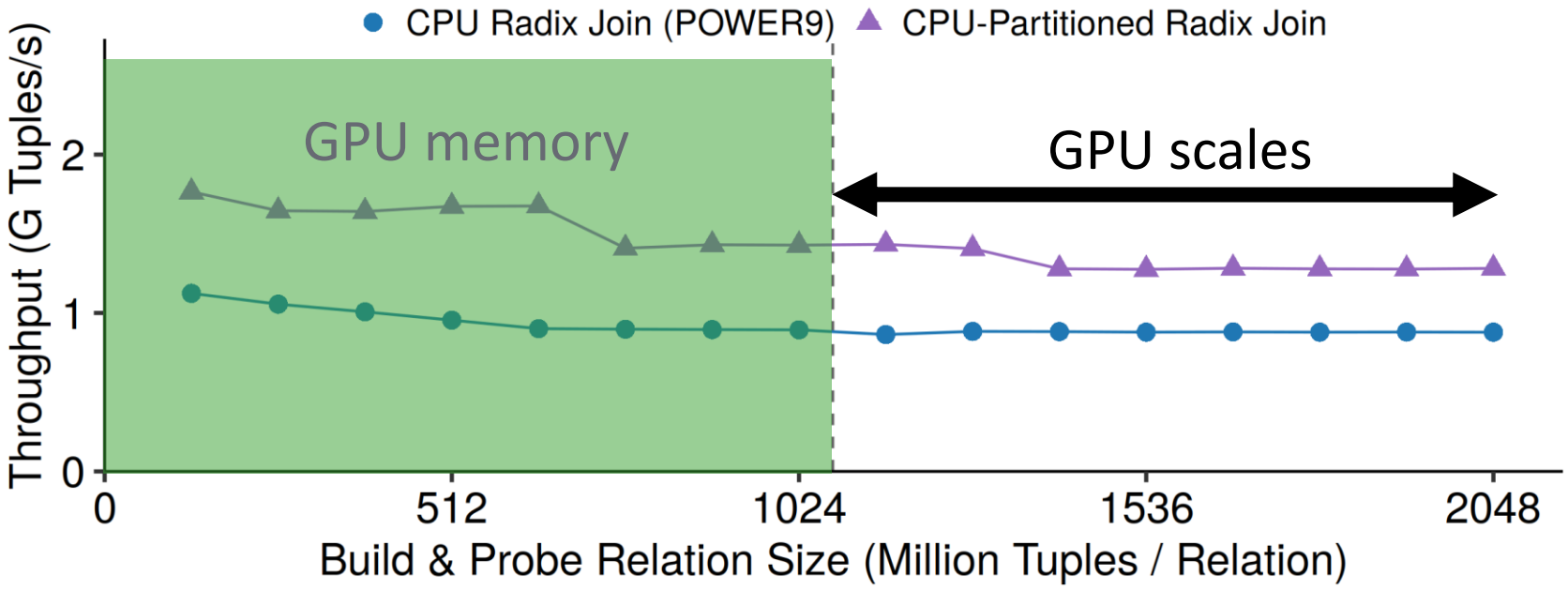
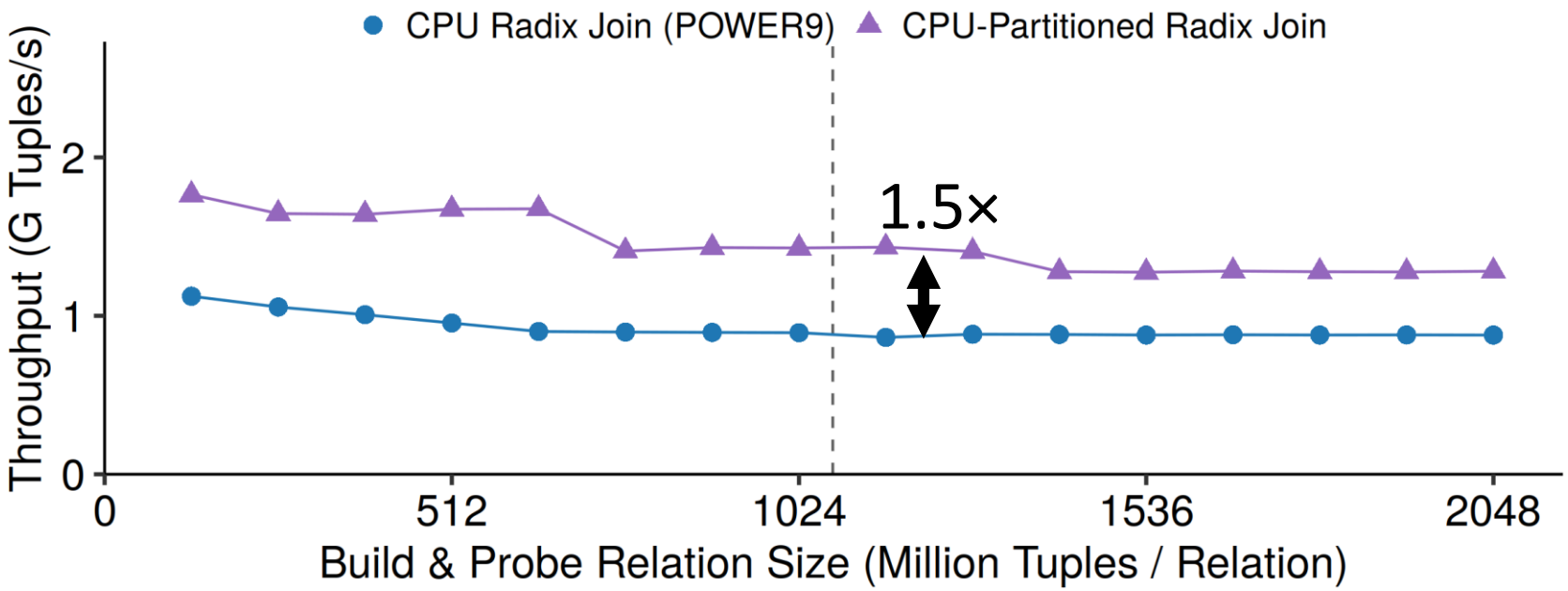


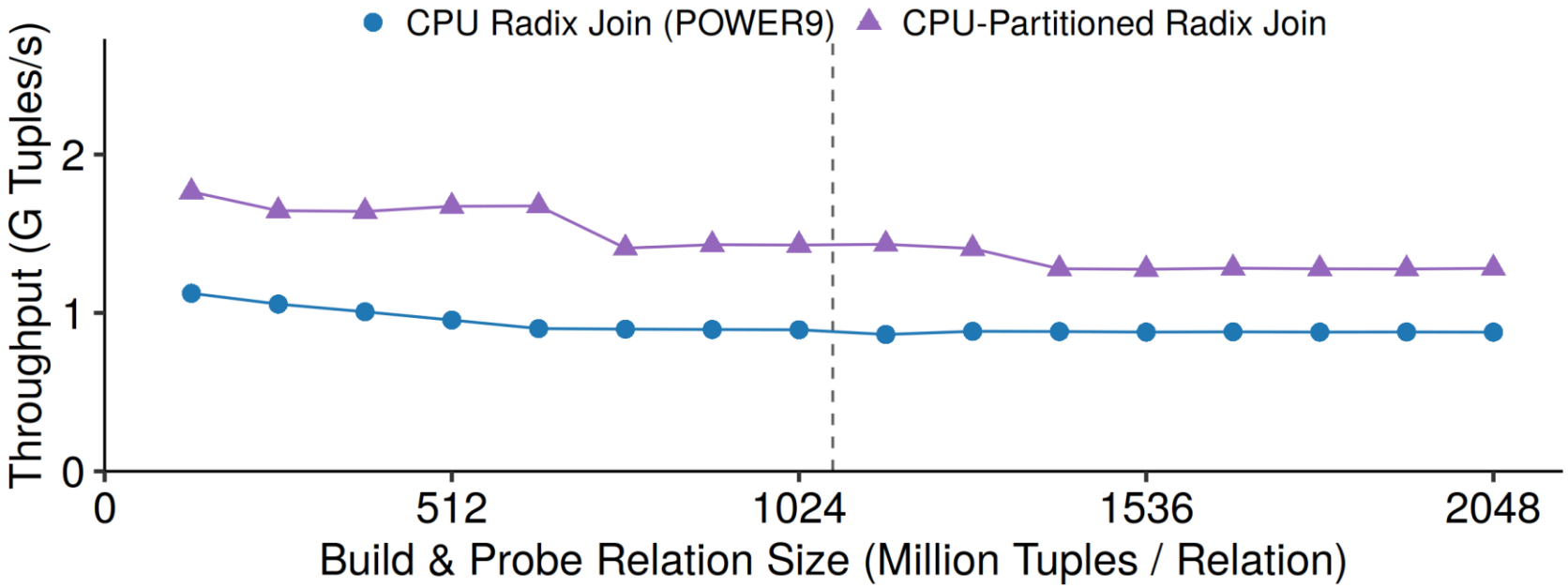
- Scalable ✓

Challenge 3



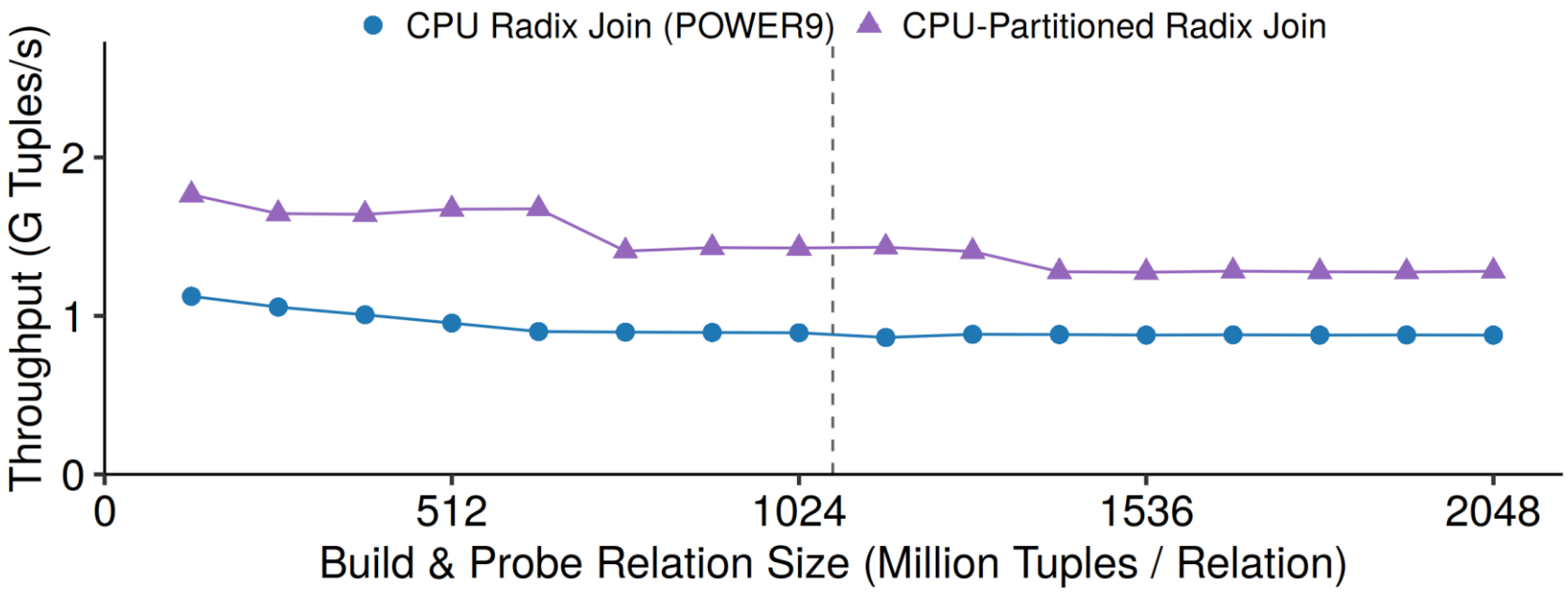
- Scalable ✓
- Robust ✓

Challenge 3



- Scalable ✓
- Robust ✓
- But: Requires a fast CPU and a fast GPU

Challenge 3



CPU-partitioned radix join is not resource-efficient

Challenge Summary

*Higher interconnect bandwidth is **necessary,***
***but not sufficient** to achieve high scalability.*

Key Insight

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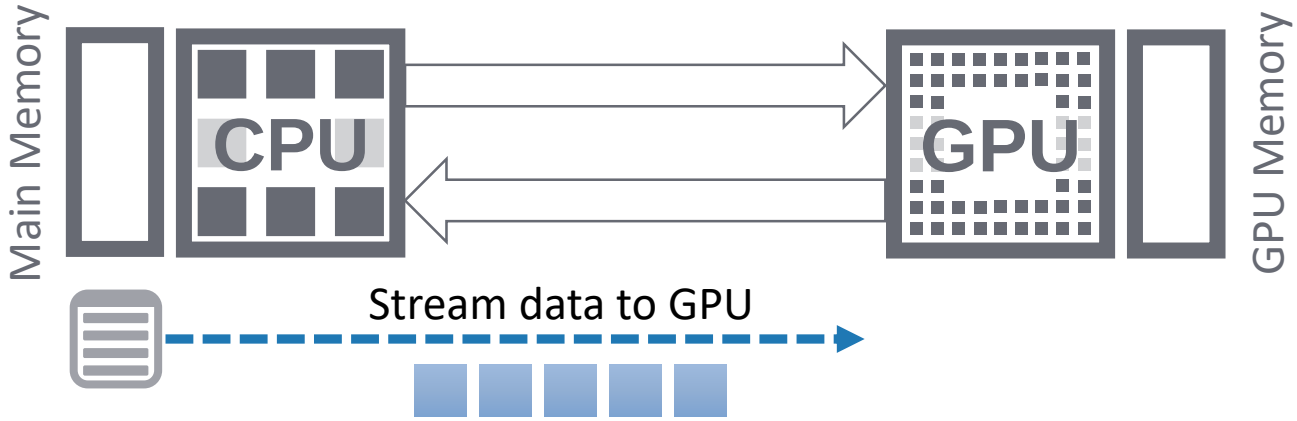

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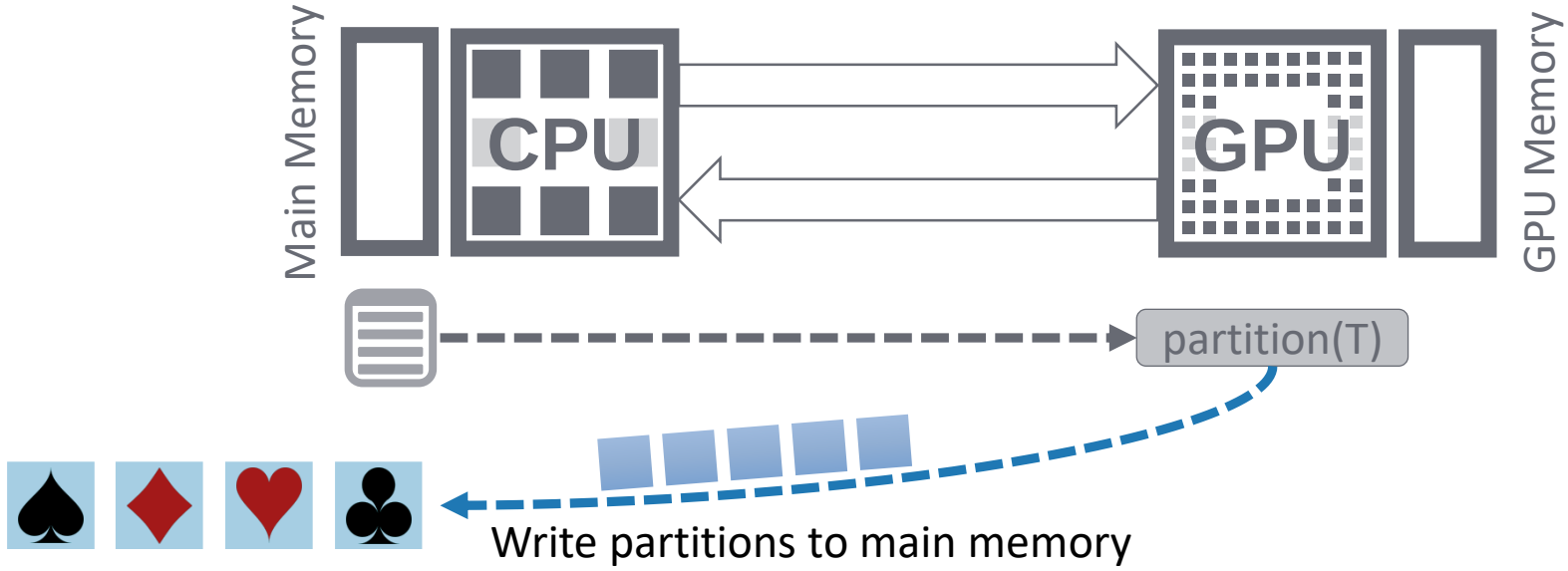
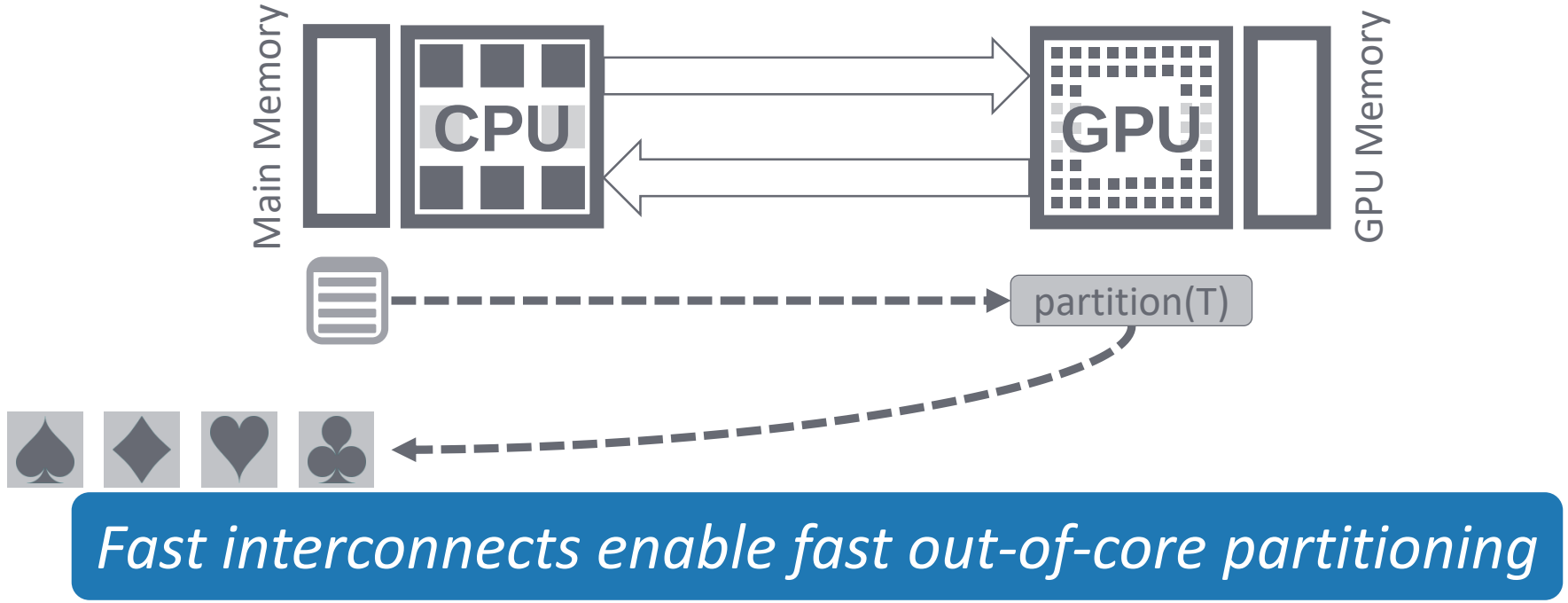
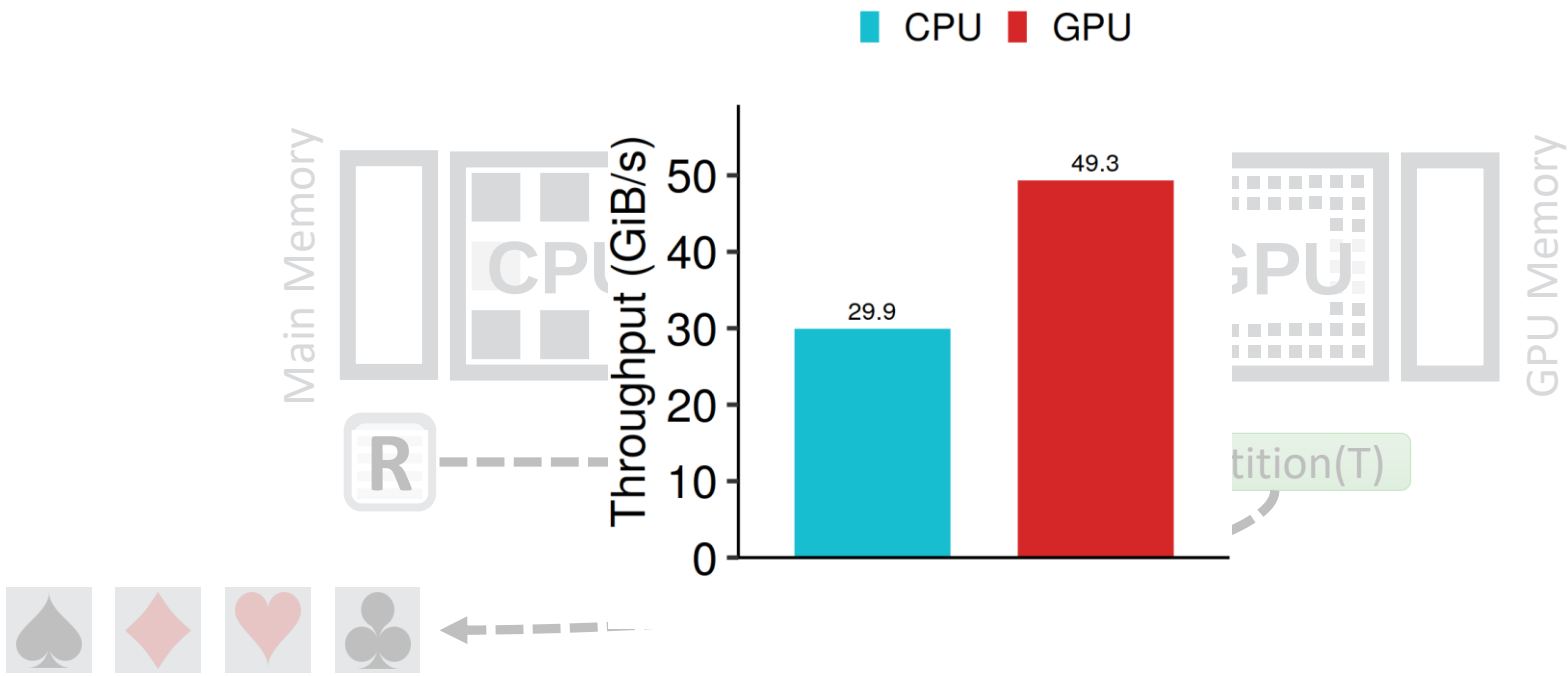

Main Memory
CPU
GPU
GPU Memory
partition(T)
Write partitions to main memory

Key Insight



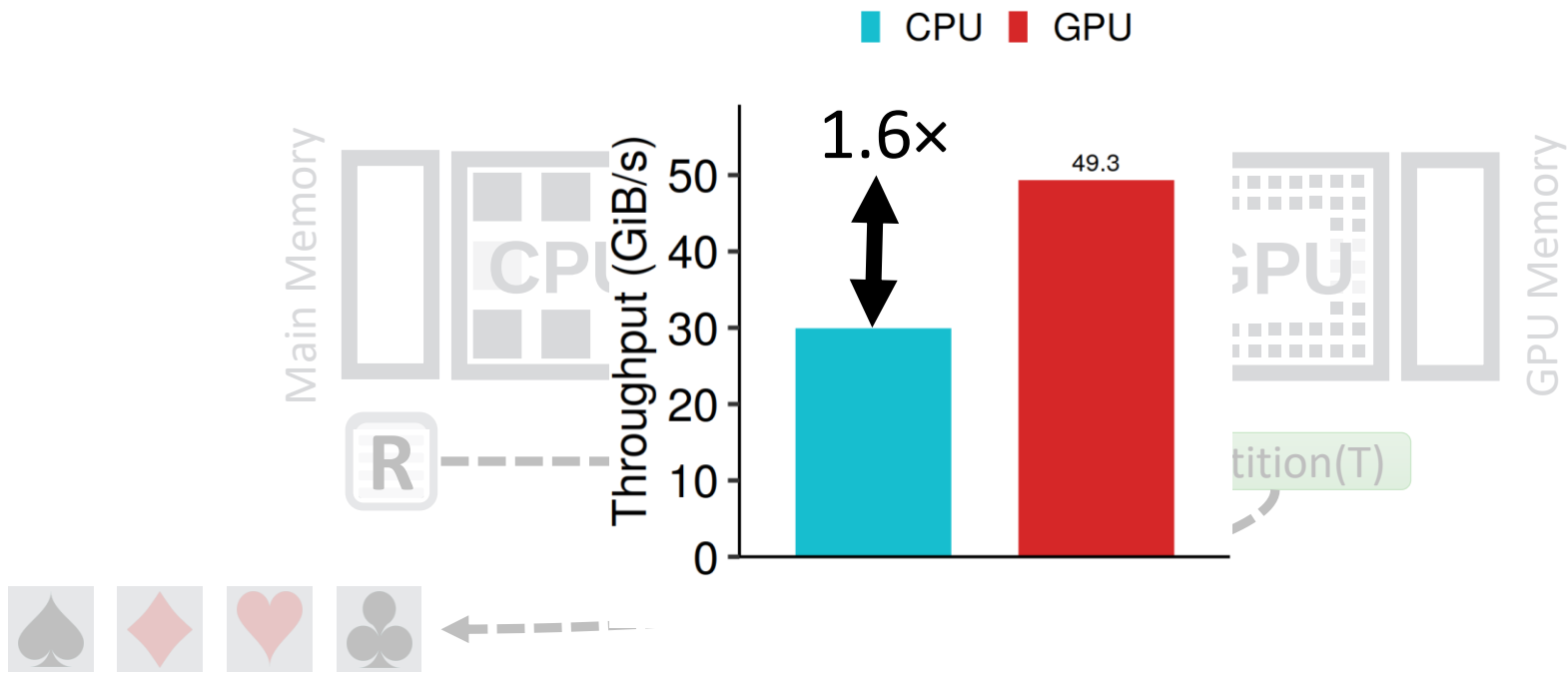
Fast interconnects enable fast out-of-core partitioning

Key Insight

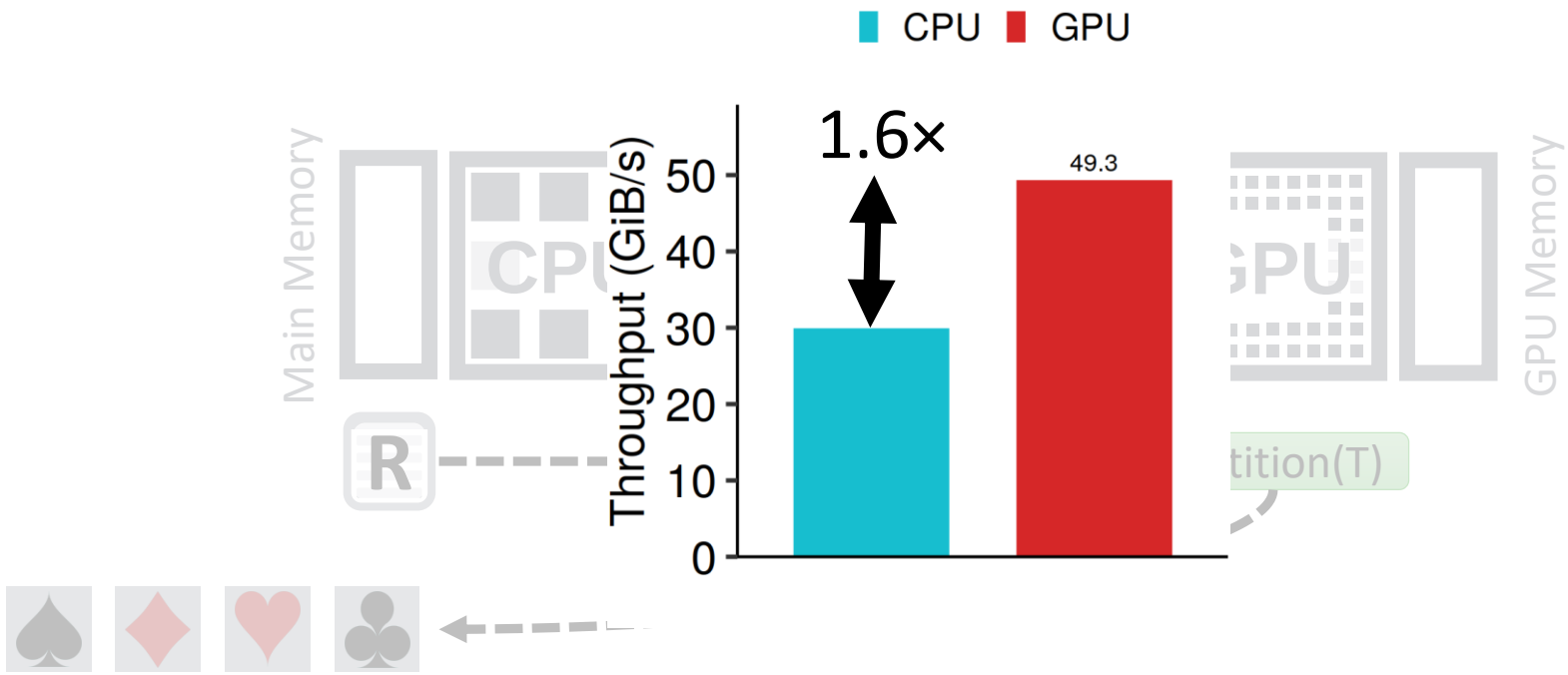


Data: 15 GiB
Fanout: 512 partitions

Key Insight


CPU
GPU
Throughput (GiB/s)
0
10
20
30
40
50
1.6×
49.3
Main Memory
GPU Memory
R
tition(T)

Key Insight



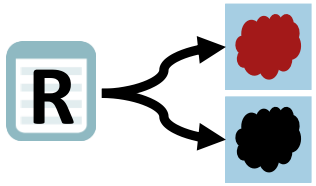
GPU with fast interconnect outperforms CPU

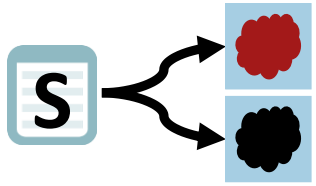
The Triton Join

The Triton Join

The Triton Join

Out-of-core
radix partitioning

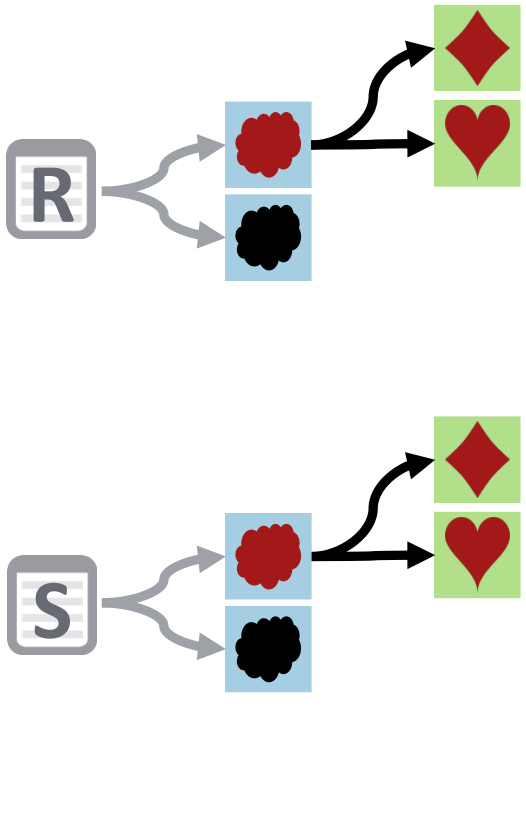




1st Pass
GPU Partitioning

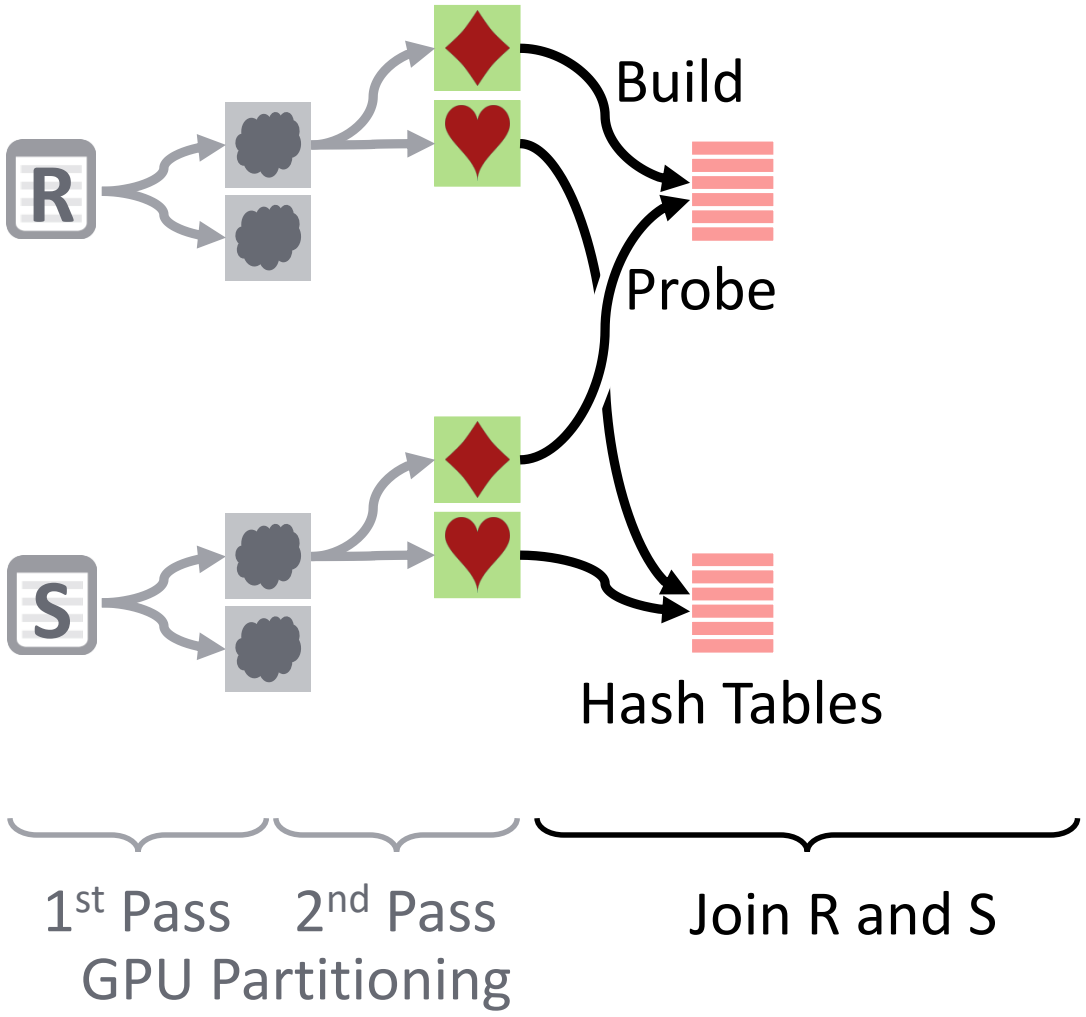
The Triton Join

Out-of-core radix partitioning



The Triton Join

Out-of-core radix partitioning



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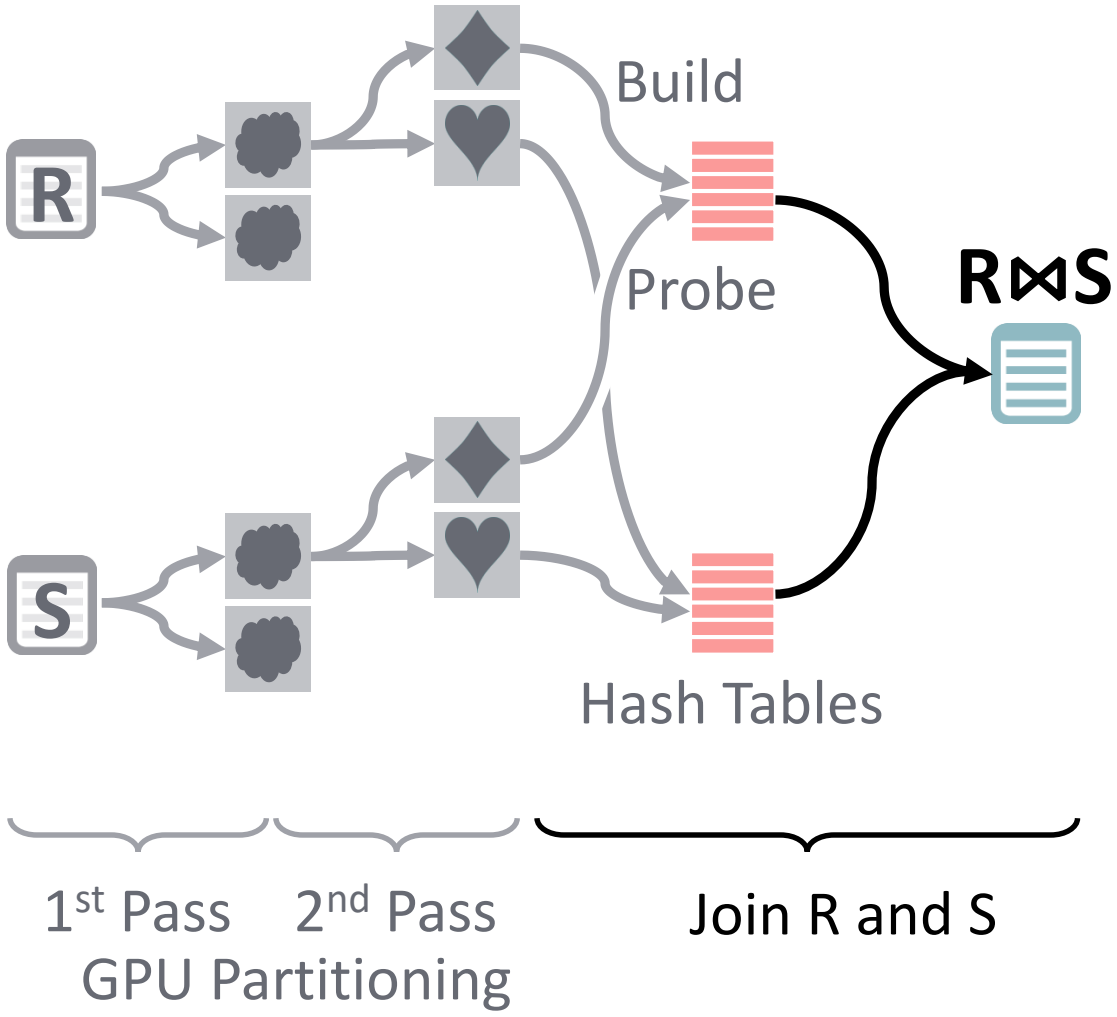
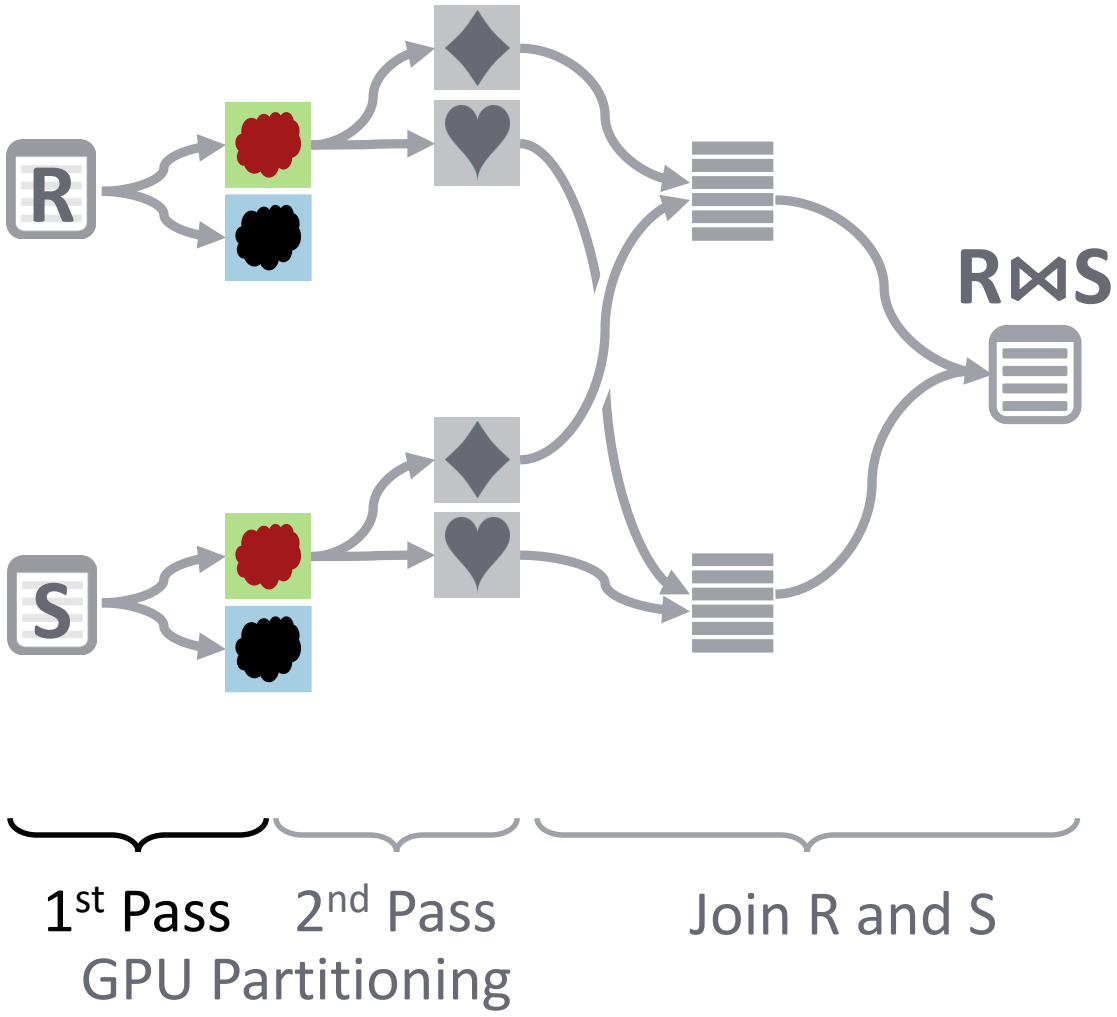


The Triton Join

Out-of-core radix partitioning

Caching partitions in GPU memory



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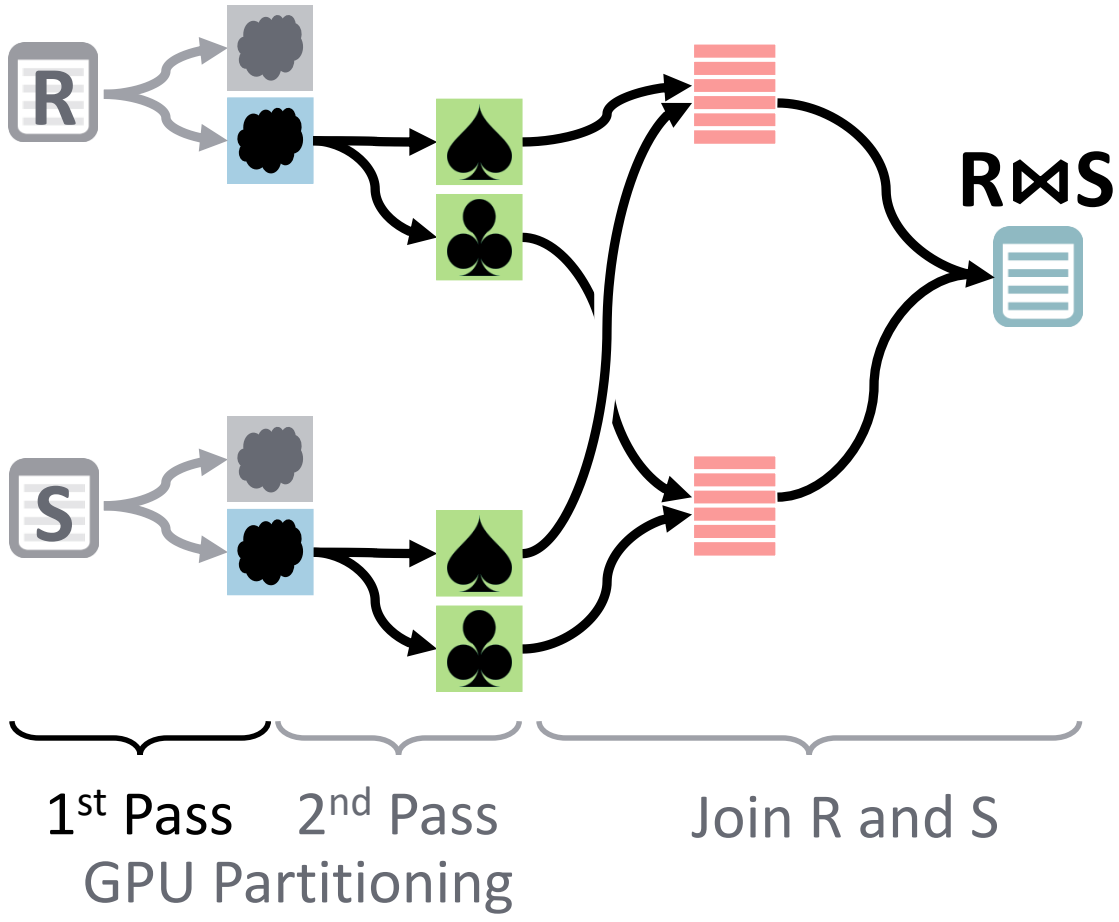

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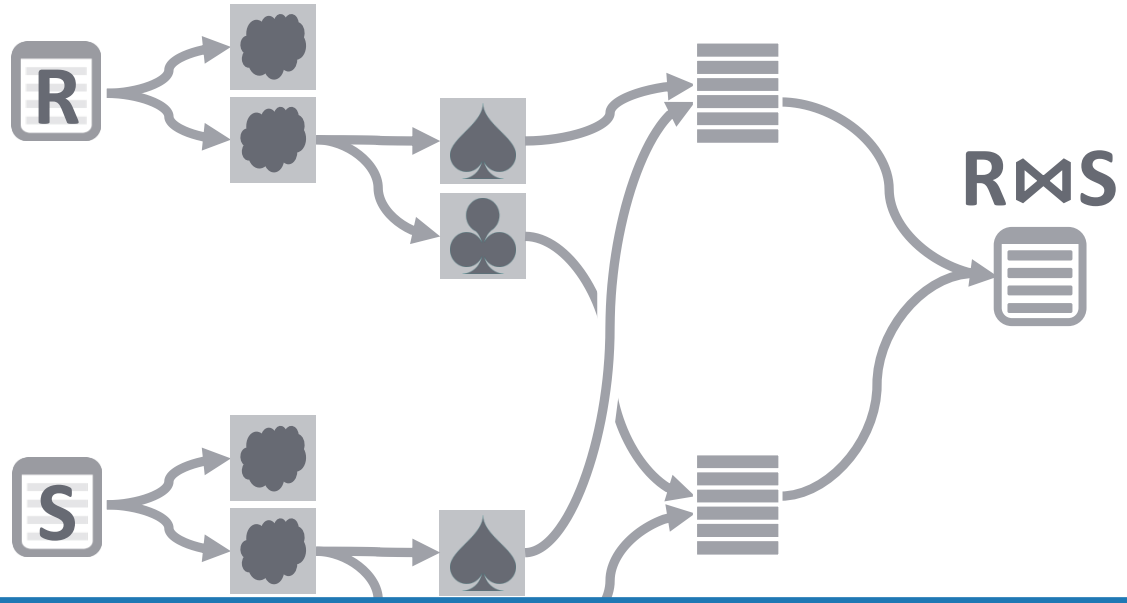
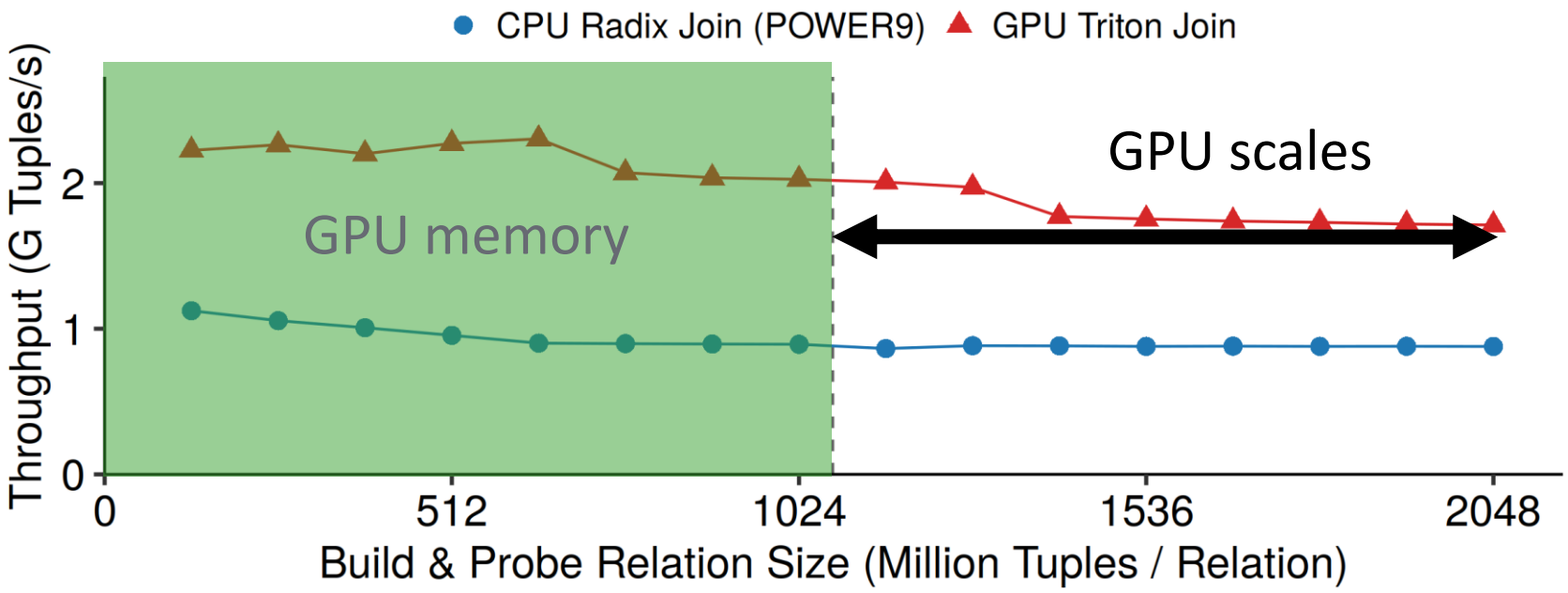
Caching partitions in GPU memory



Triton join is new hierarchical hybrid hash join for GPUs

Evaluation: Scalability



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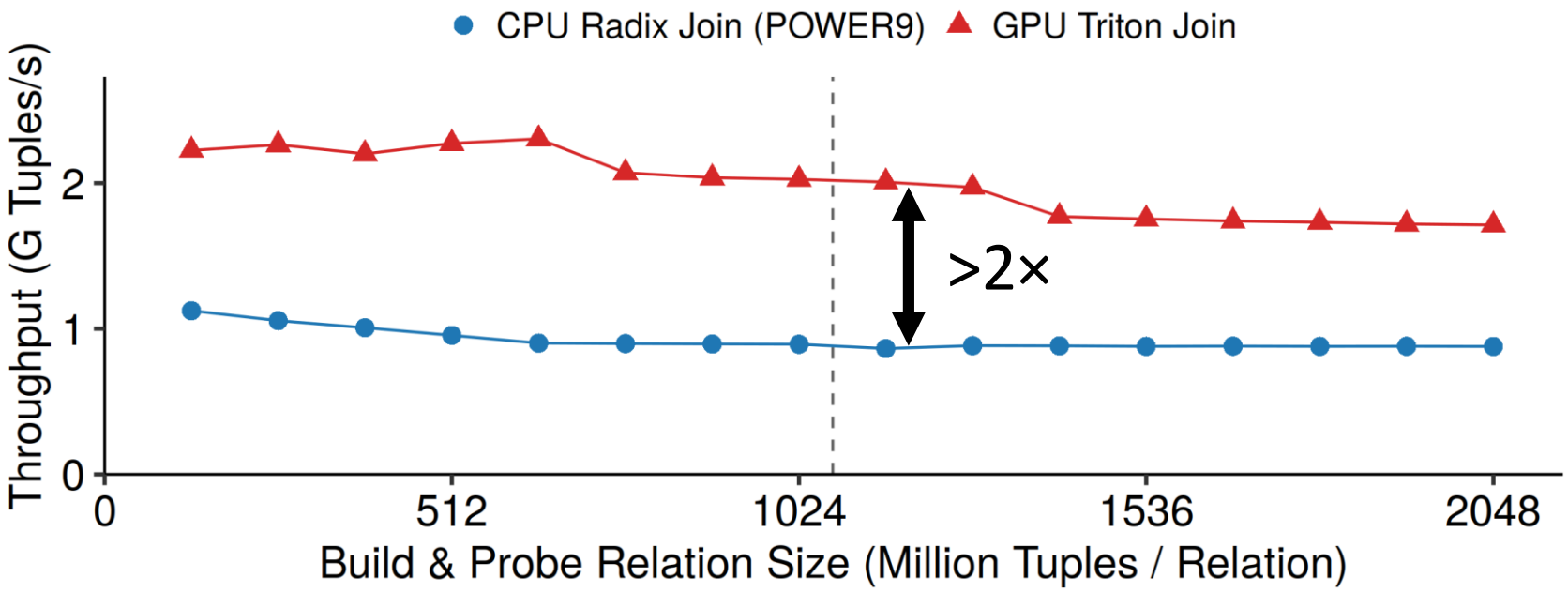

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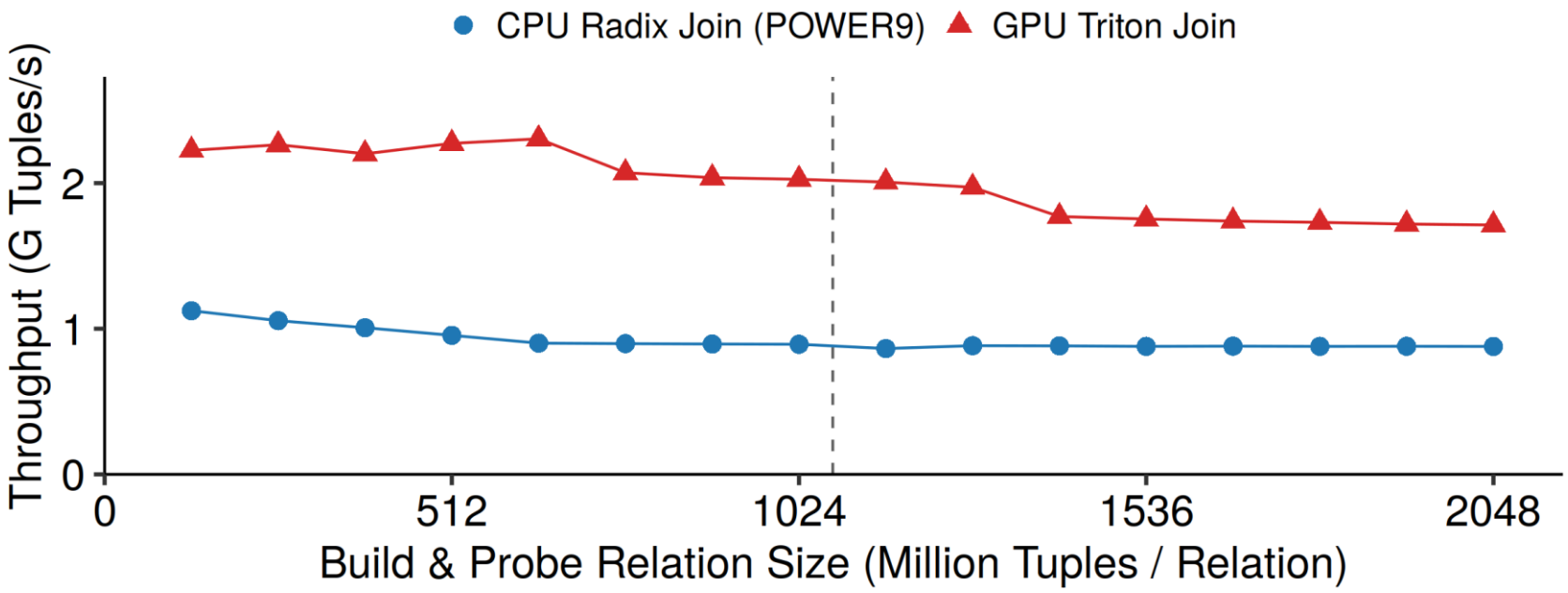
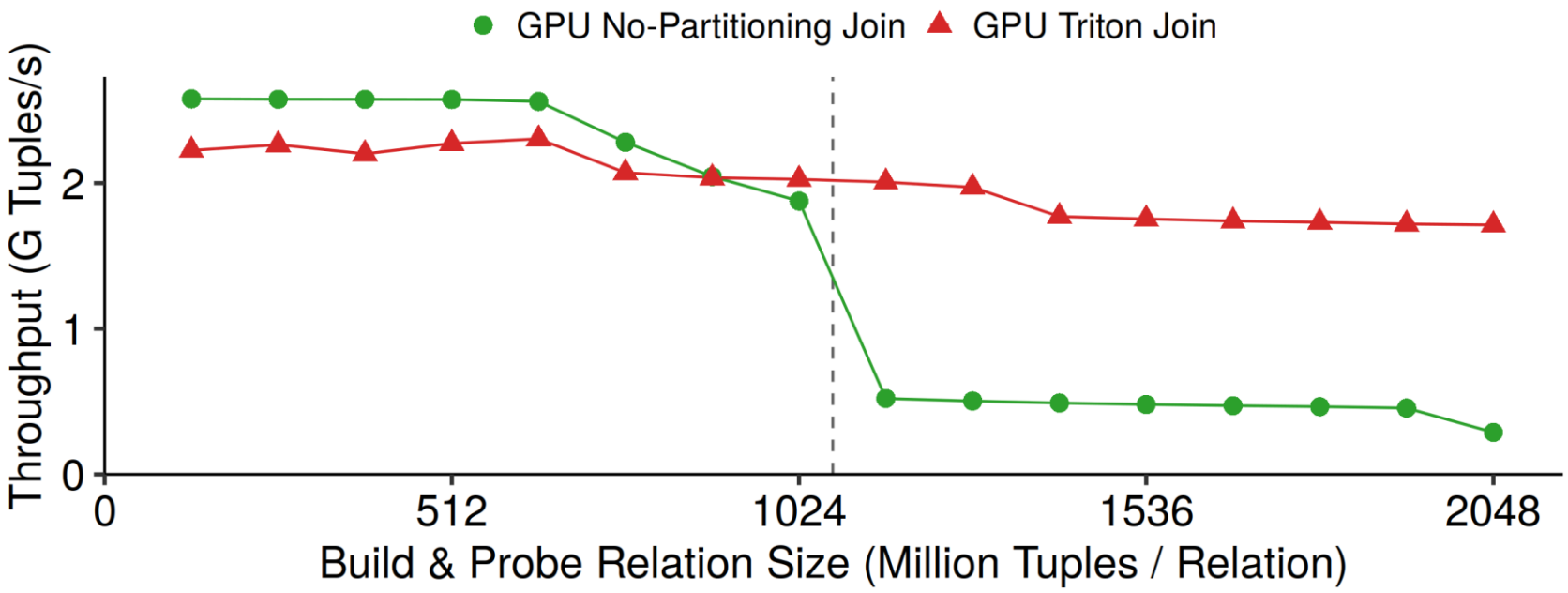
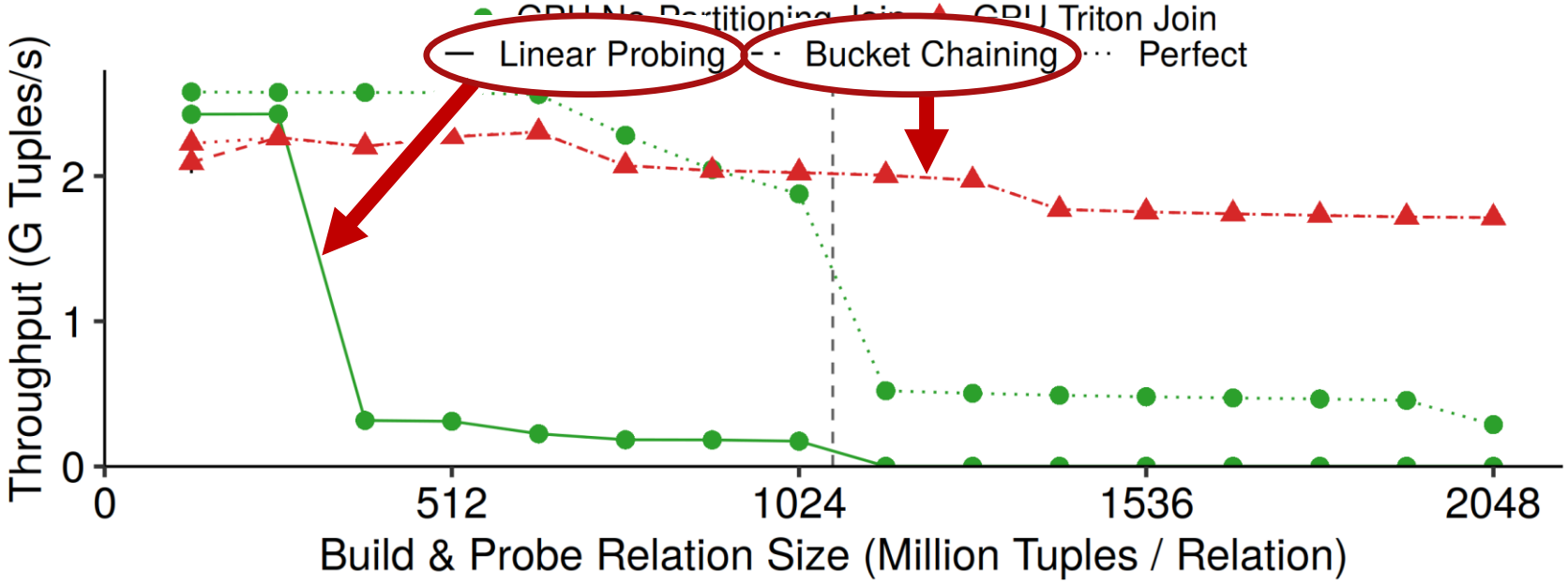


Triton join scales to a large join state

Evaluation: Robustness



Evaluation: Robustness



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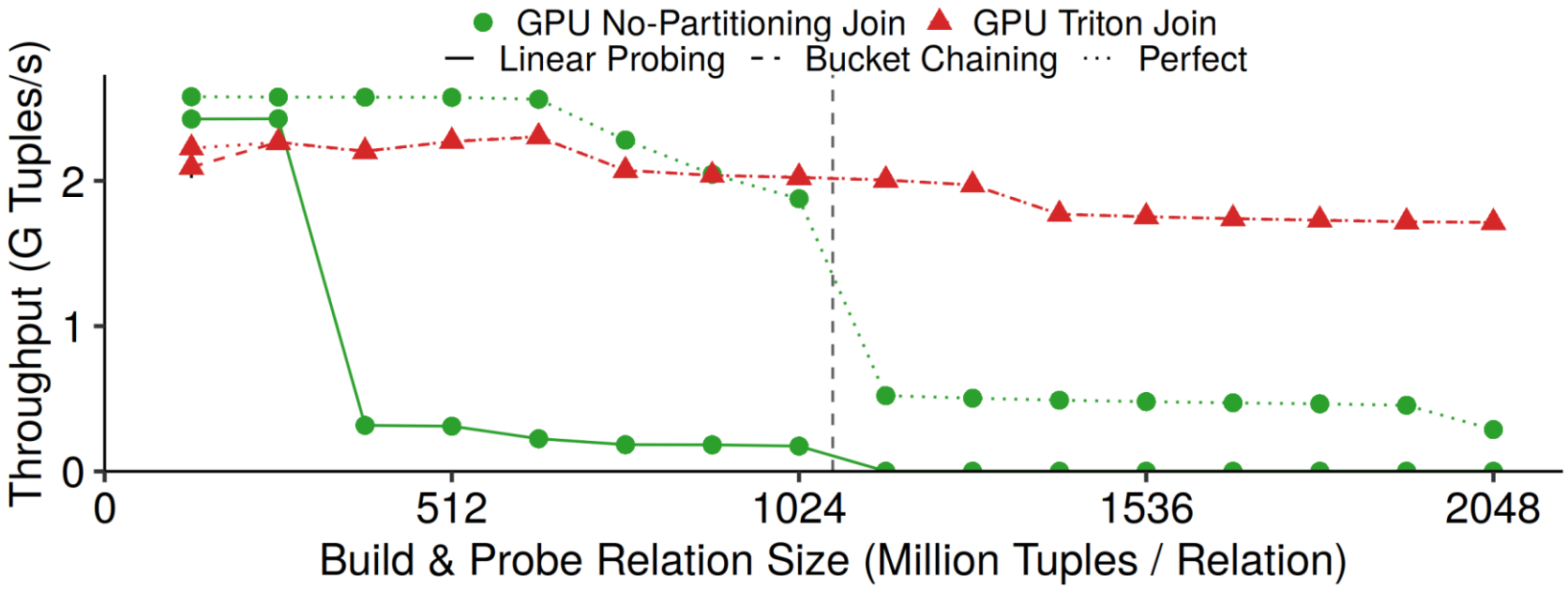
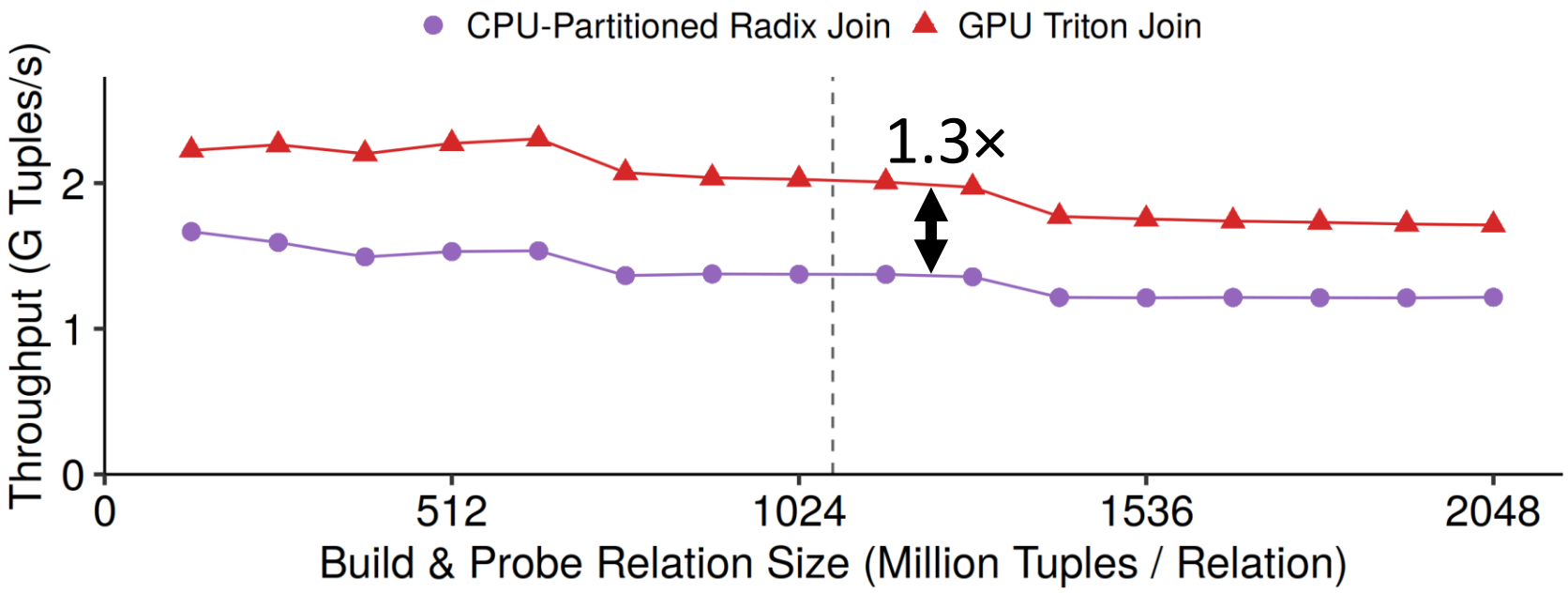
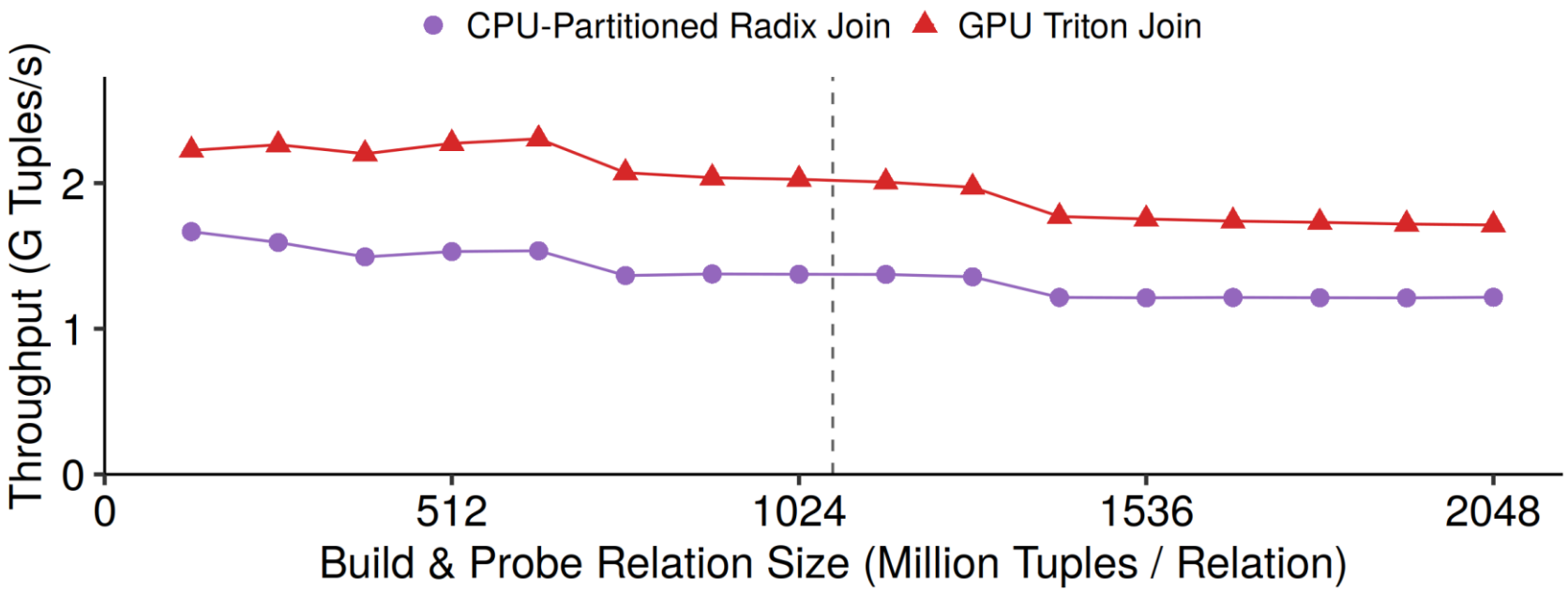


Performance of Triton join degrades gracefully

Evaluation: Resource-Efficiency

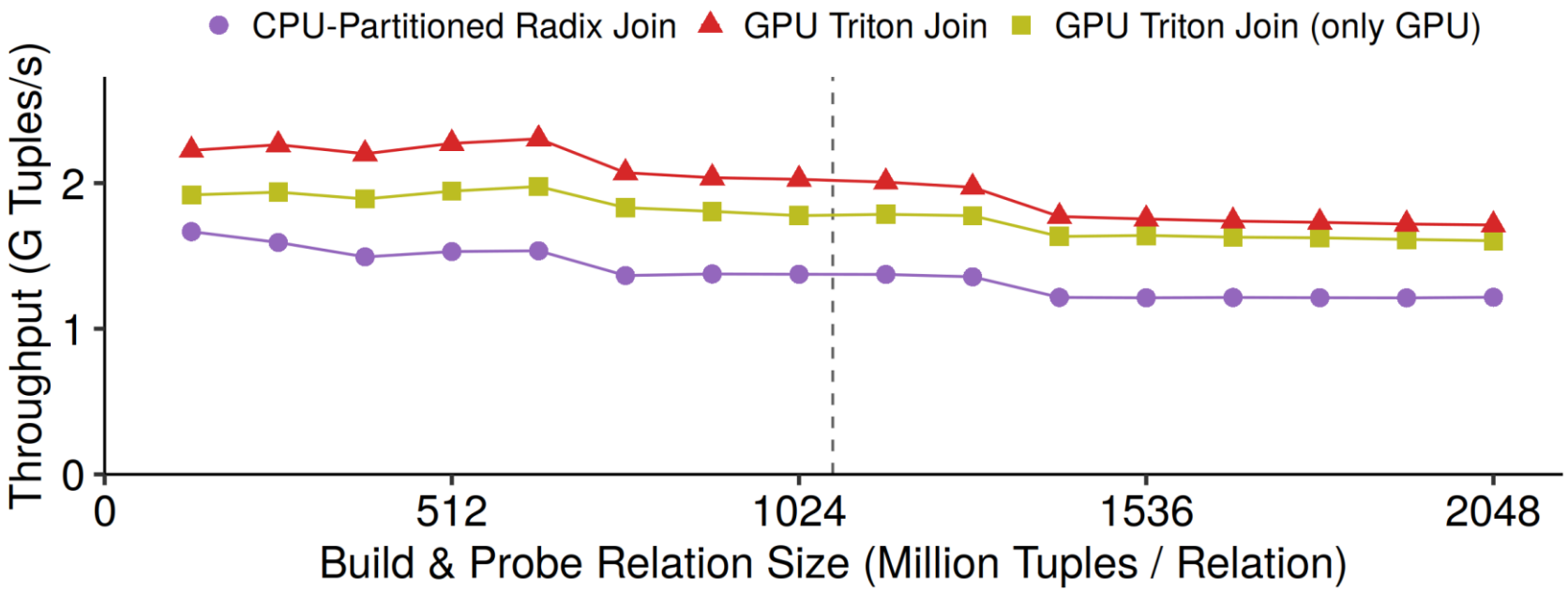


Evaluation: Resource-Efficiency



- CPU-Partitioned Radix Join: CPU + GPU
- GPU Triton Join: GPU only*

Evaluation: Resource-Efficiency



- CPU-Partitioned Radix Join: CPU + GPU
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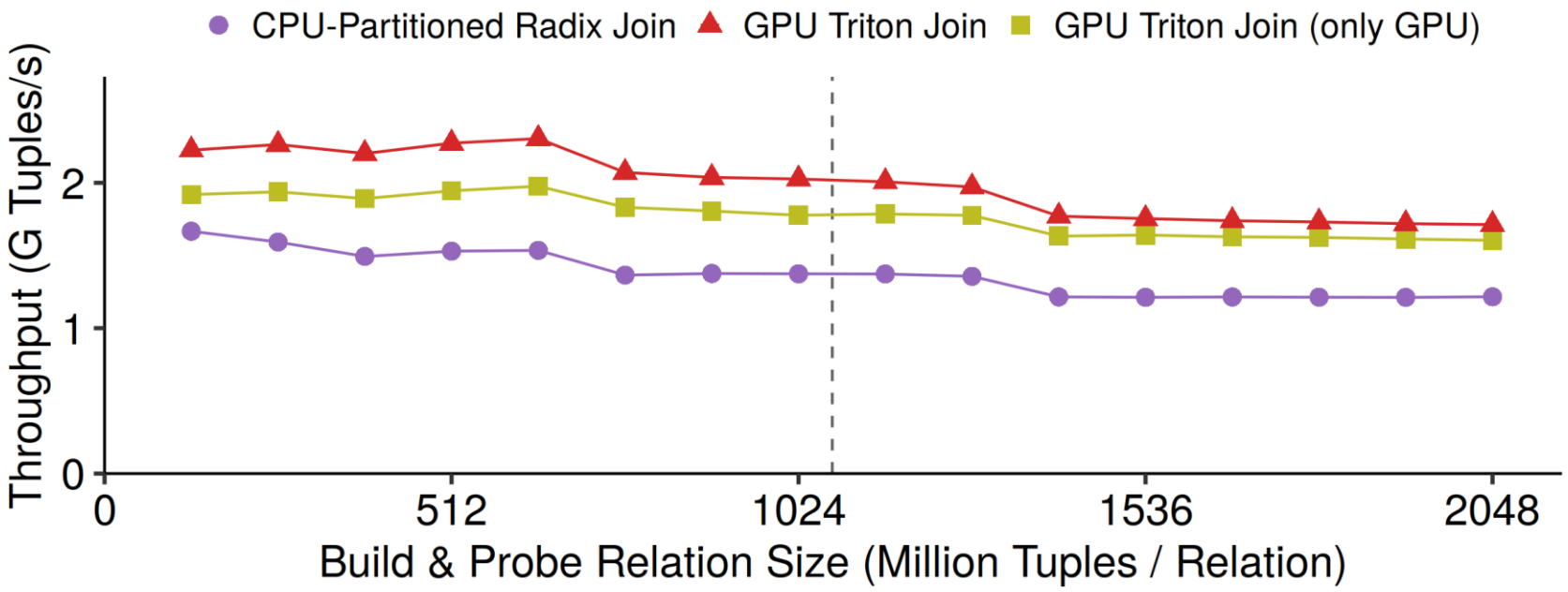
Evaluation: Resource-Efficiency



Triton join efficiently processes joins end-to-end on GPU

Conclusion

Our Triton join exploits fast interconnects to:

- **Scale** to a large **join state**
- **Robustly spill** state to main memory
- **Efficiently** process the join using **the GPU**

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github.com/TU-Berlin-DIMA/fast-interconnects