AN ELASTIC MULTI-CORE ALLOCATION MECHANISM FOR DATABASE SYSTEMS

SIMONE DOMINICO [1], JORGE A. MEIRA [2], MARCO A. Z. ALVES [1], EDUARDO C. DE ALMEIDA [1]

FEDERAL UNIVERSITY OF PARANÁ, BRAZIL [1], UNIVERSITY OF LUXEMBOURG [2]

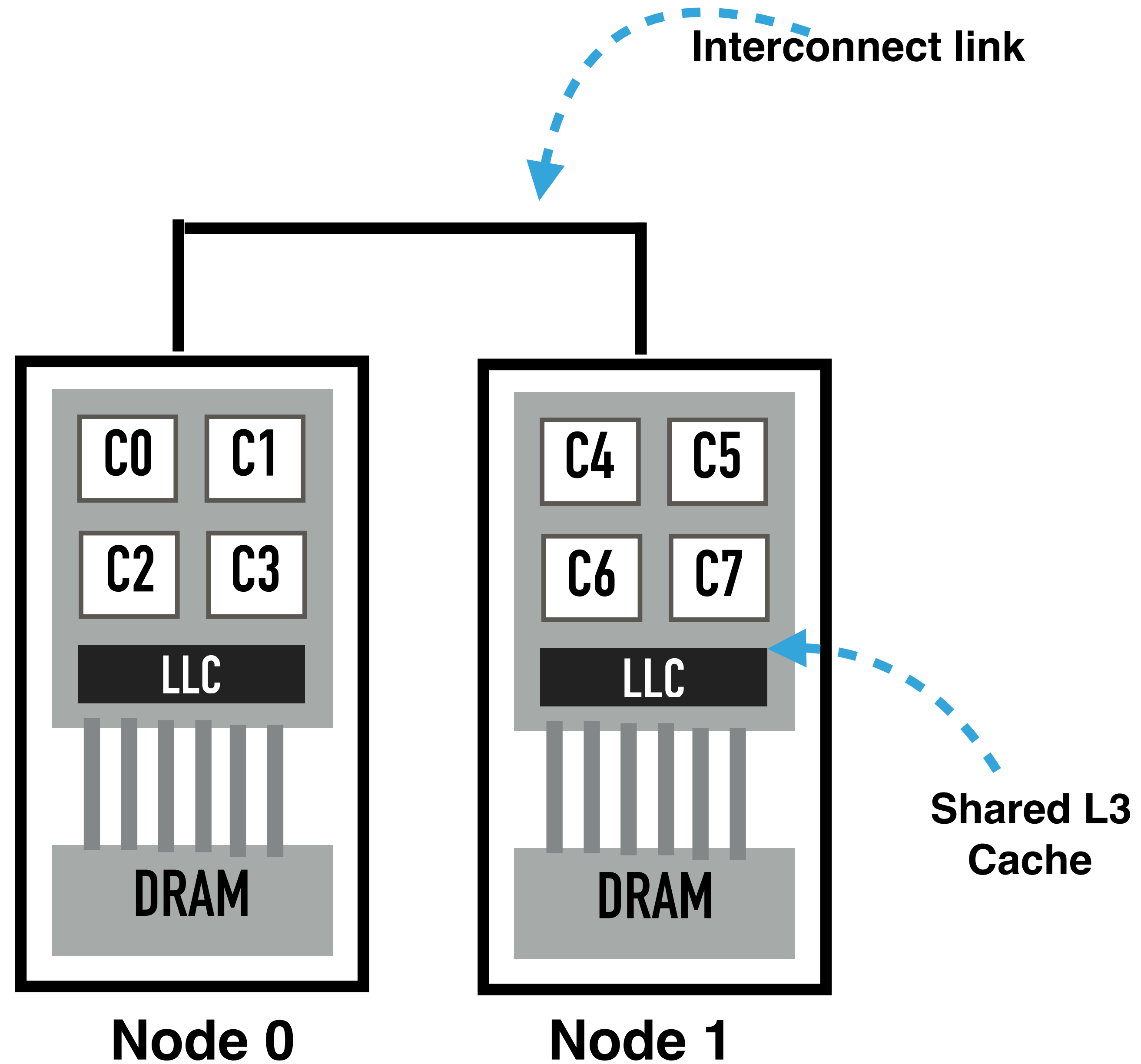
OUTLINE

- Introduction
- NUMA effect in OLAP
- PetriNet Multi-Core Allocation Mechanism
- Evaluation
- Conclusion

INTRODUCTION

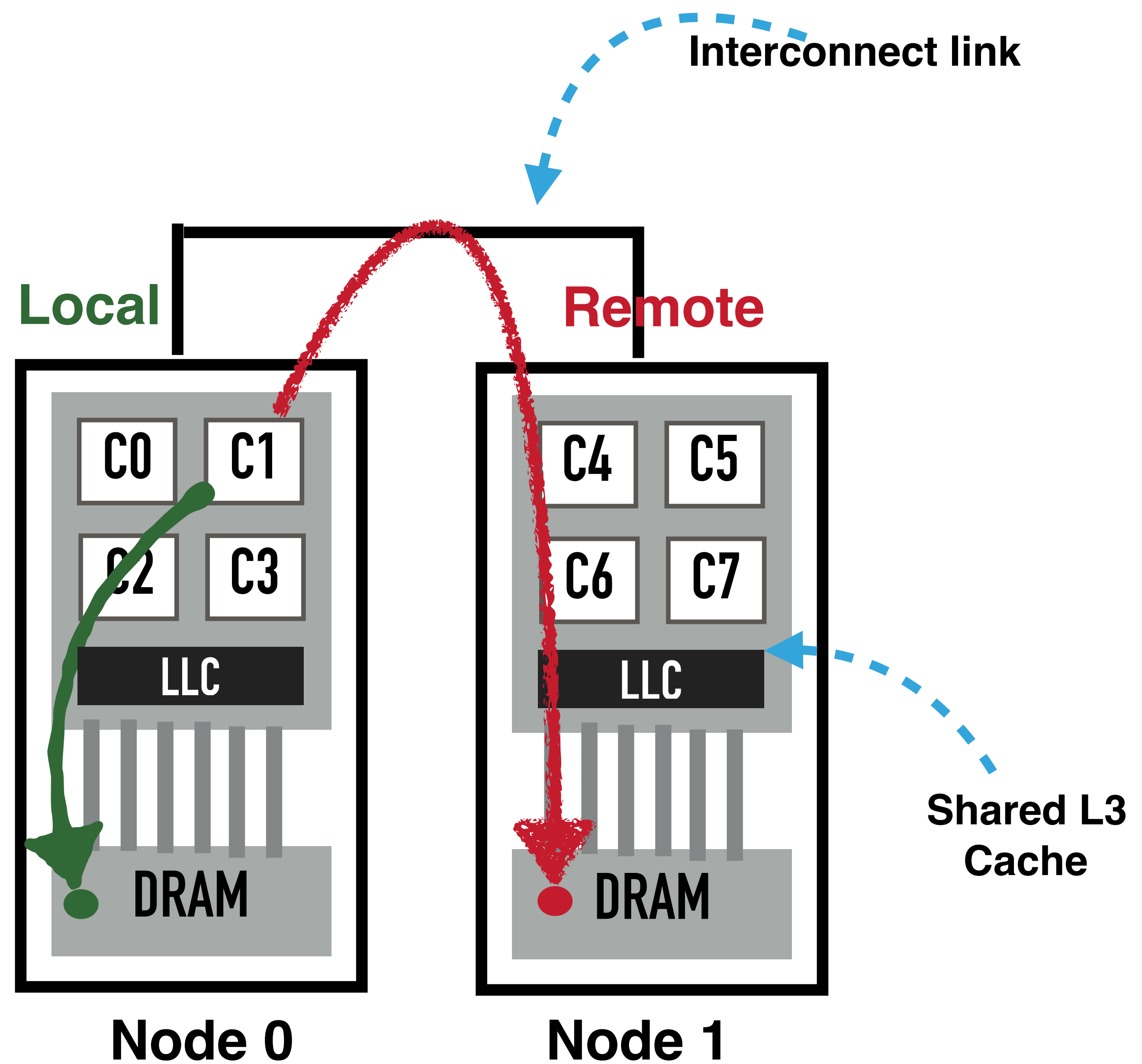
NON-UNIFORM MEMORY ACCESS (NUMA)

- Avoid memory contention in multi-core machines
- Node: Portion of memory and associated processor



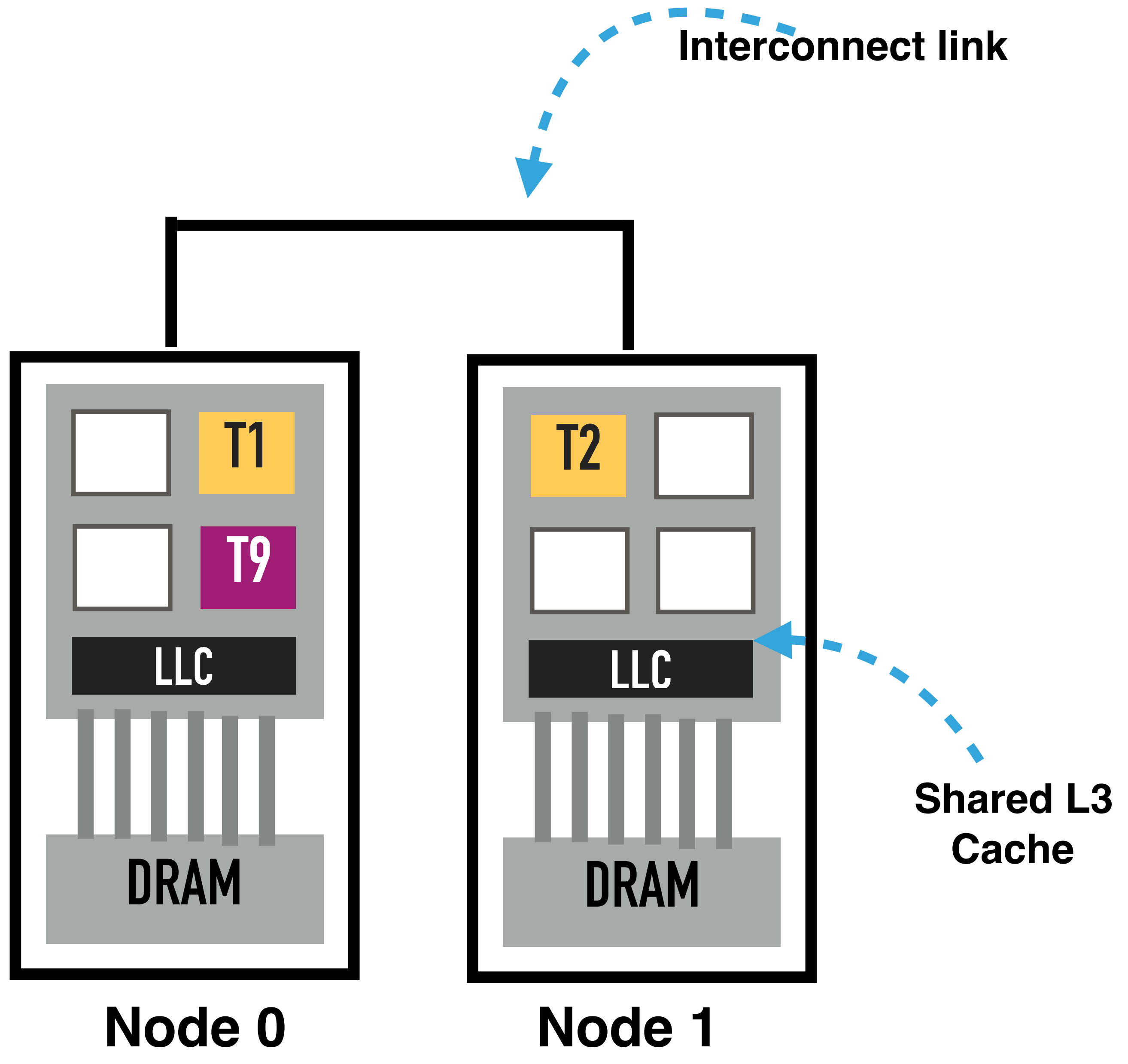
NON-UNIFORM MEMORY ACCESS (NUMA)

- Avoid memory contention in multi-core machines
- Node: Portion of memory and associated processor
- Fast local RAM and slow remote RAM



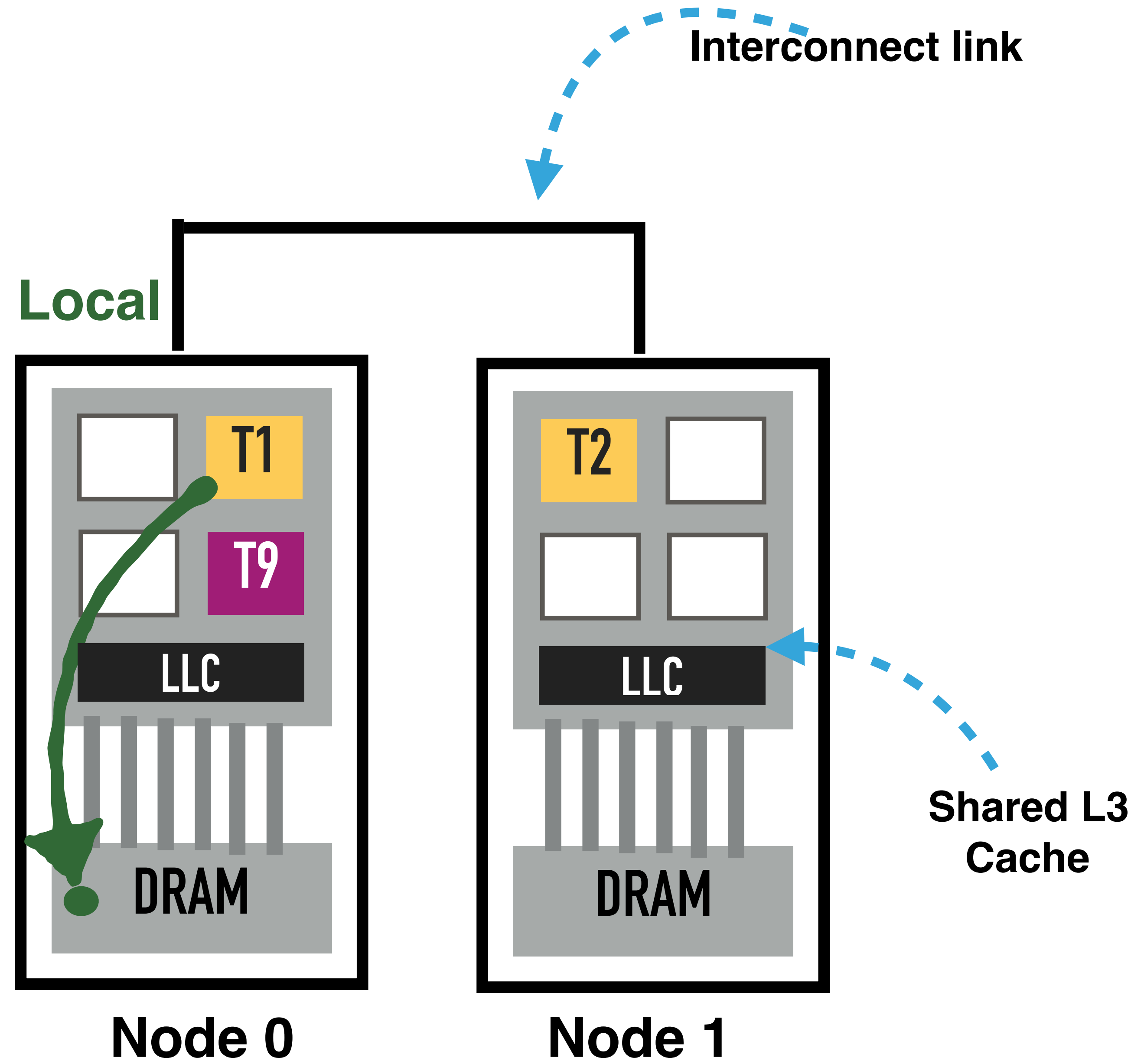
NON-UNIFORM MEMORY ACCESS (NUMA)

- Threads may run in any core over time



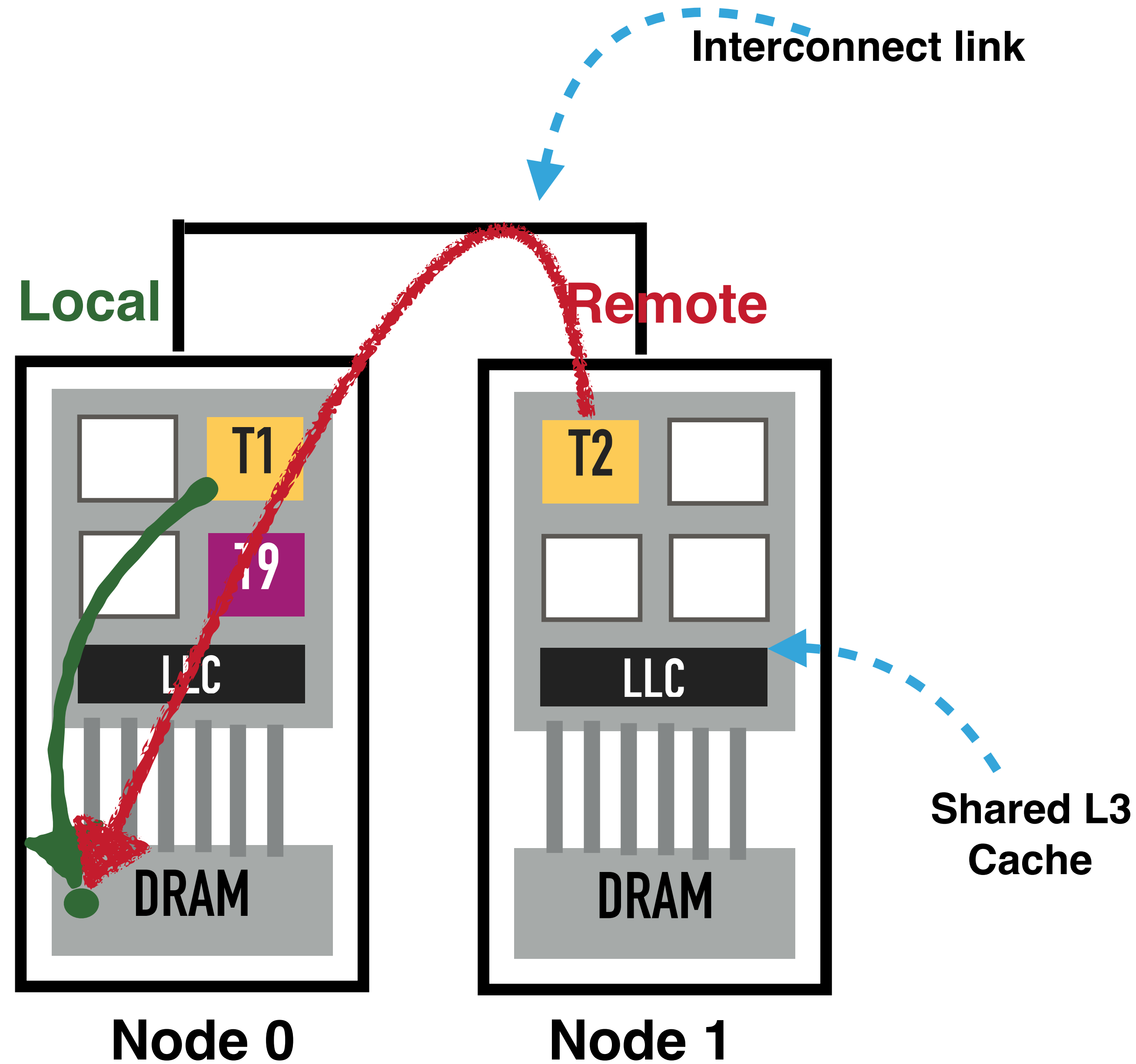
NON-UNIFORM MEMORY ACCESS (NUMA)

- Threads may run in any core over time
- Data is mapped at thread startup



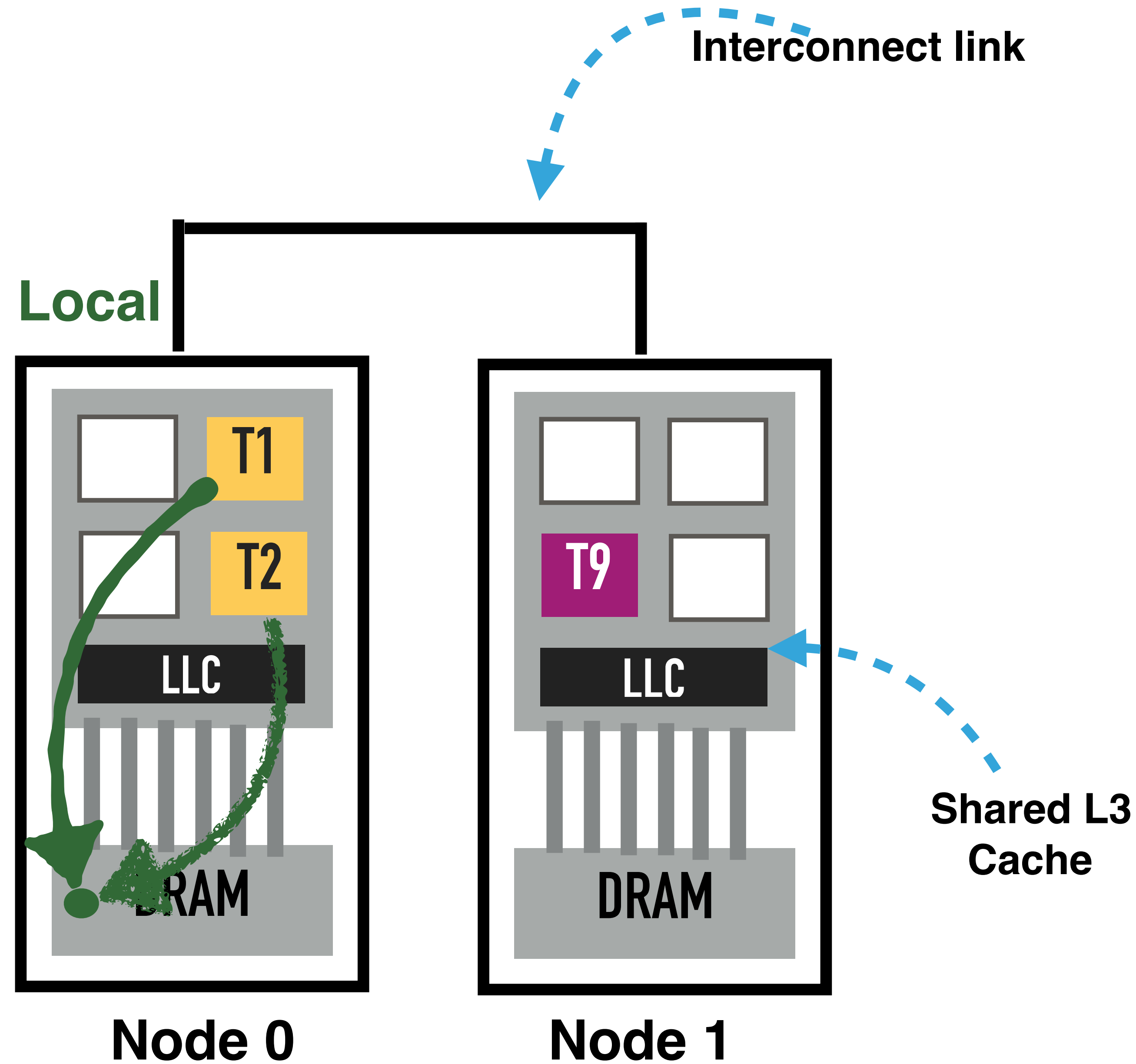
NON-UNIFORM MEMORY ACCESS (NUMA)

- Threads may run in any core over time
- Data is mapped at thread startup
- Remote access through the interconnection



NON-UNIFORM MEMORY ACCESS (NUMA)

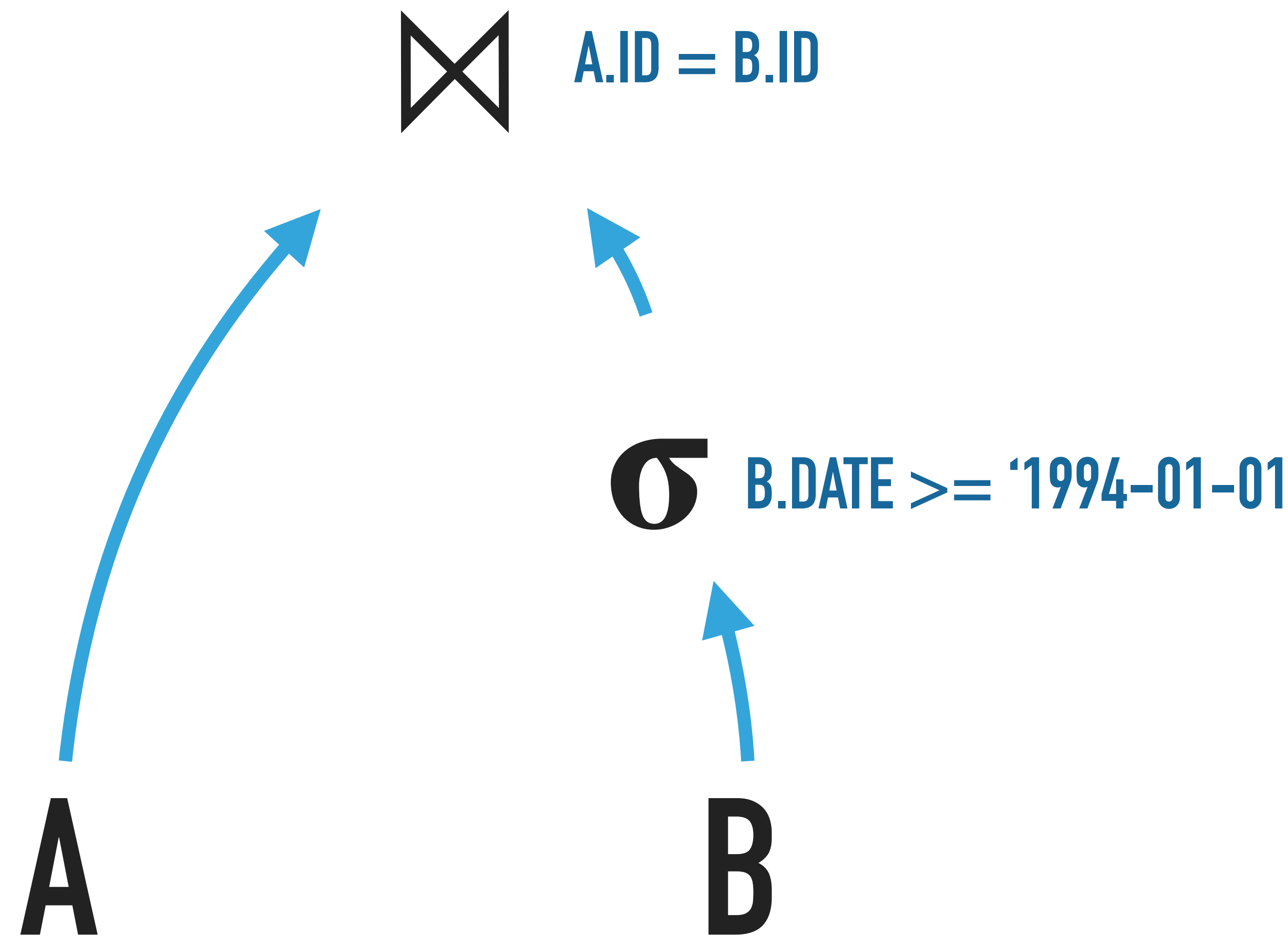
- Threads may run in any core over time
- Data is mapped at thread startup
- Remote access through the interconnection
- Migration: load balance, reduce intercon. usage



NUMA EFFECT IN OLAP

PARALLEL QUERY PROCESSING IN NUMA

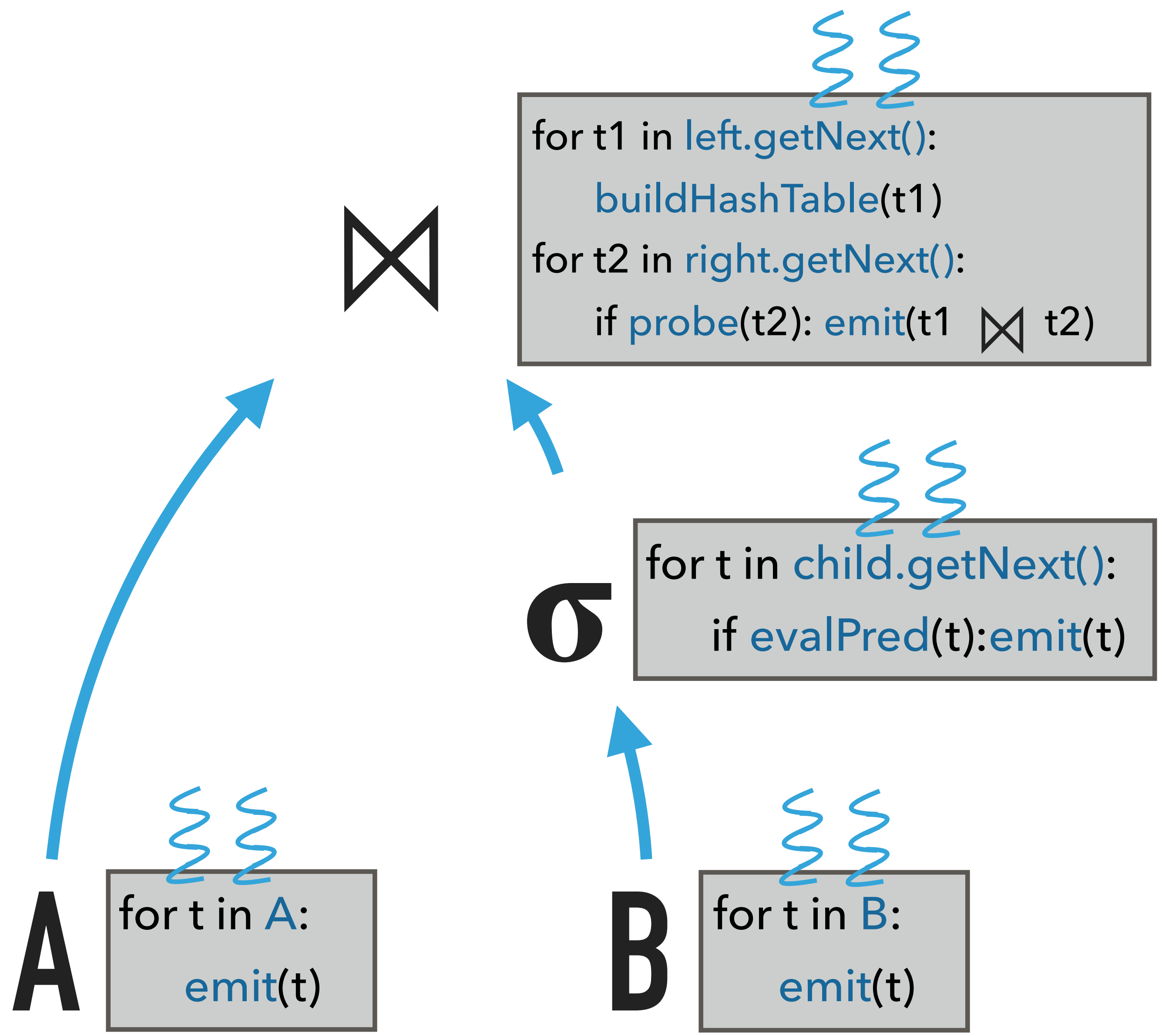
```
SELECT  *
 FROM   A, B
WHERE   A.ID = B.ID
  AND   B.DATE >= '1994-01-01'
```



PARALLEL QUERY PROCESSING IN NUMA

```
SELECT   *
  FROM   A, B
 WHERE   A.ID = B.ID
   AND   B.DATE >= '1994-01-01'
```

- Parallelism is baked in the query plan at planning time
- Batch work is assigned to threads statically (tuples or columns)
- Ex. VOLCANO and MONETDB

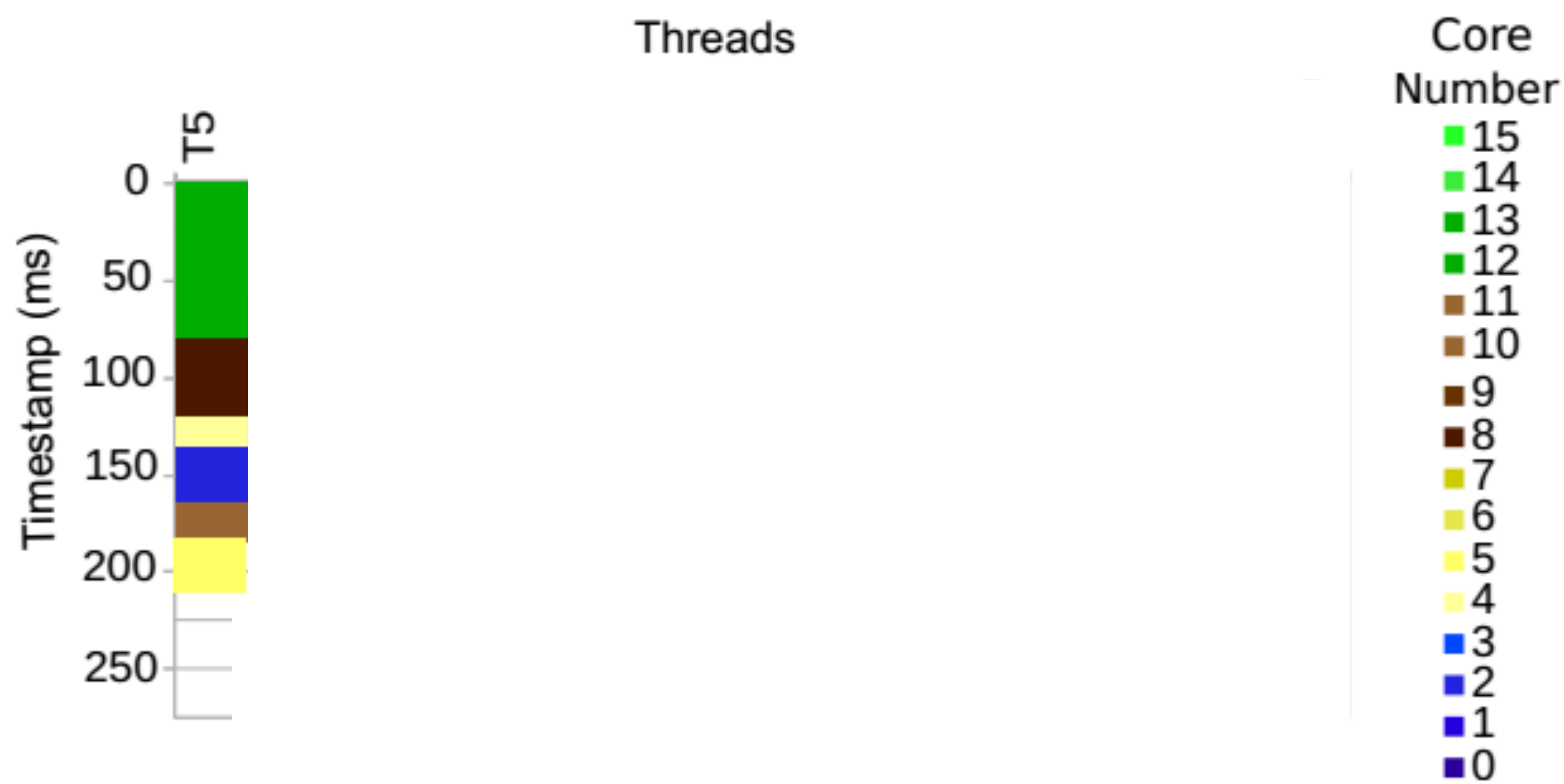


Encapsulation of parallelism in the volcano query processing system
G. Graefe
Sigmod, 1990

NUMA obliviousness through memory mapping
M. Gawadi, M. Kersten
Damon@Sigmod, 2015

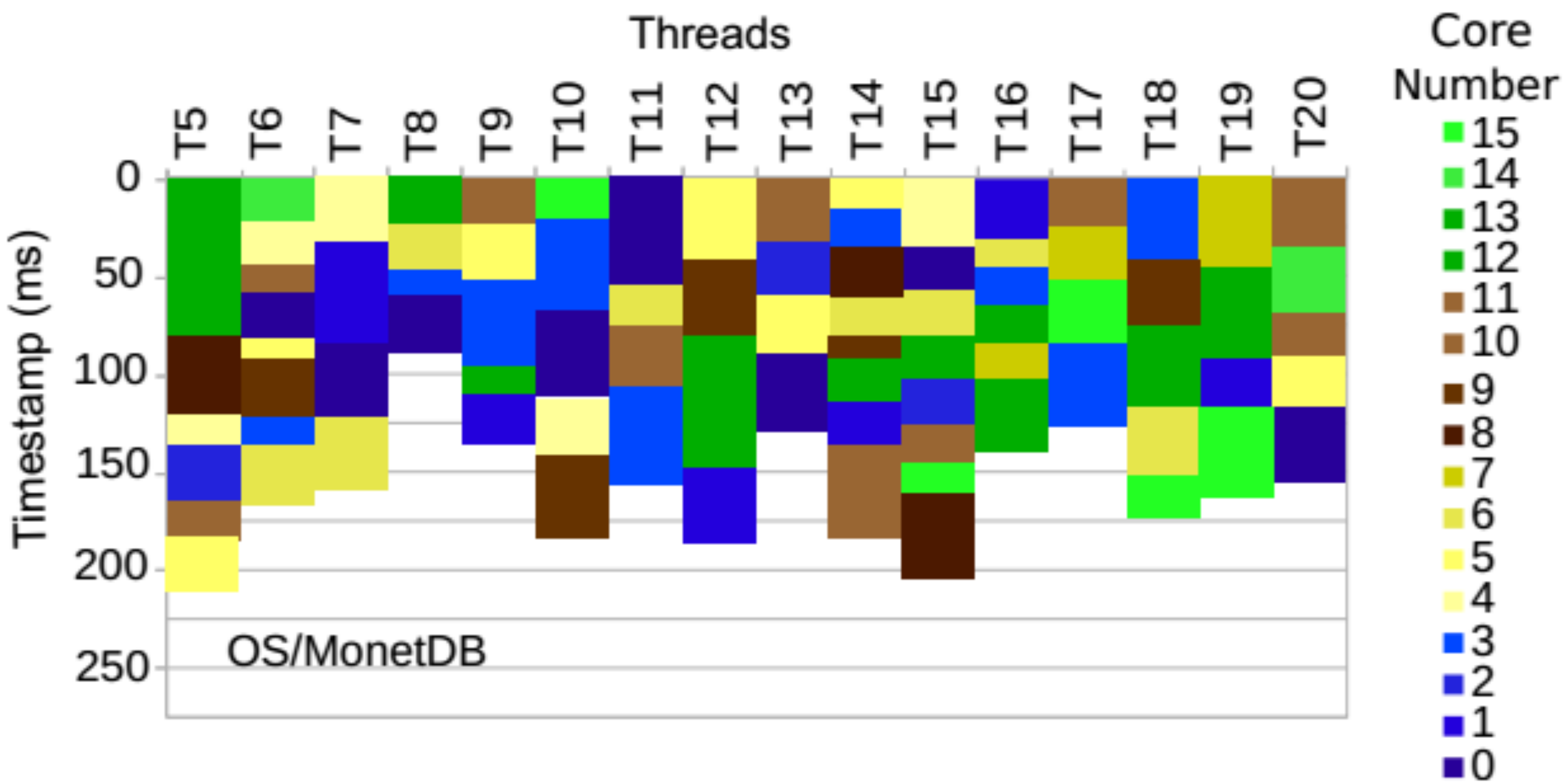
NOT NUMA-FRIENDLY PARALLELISM

- TPC-H Query 6 on 1GB database
- 4-node Quad-Core AMD Opteron 8000 Series (64Gb RAM/Node)
- MonetDB (v11.25.5)



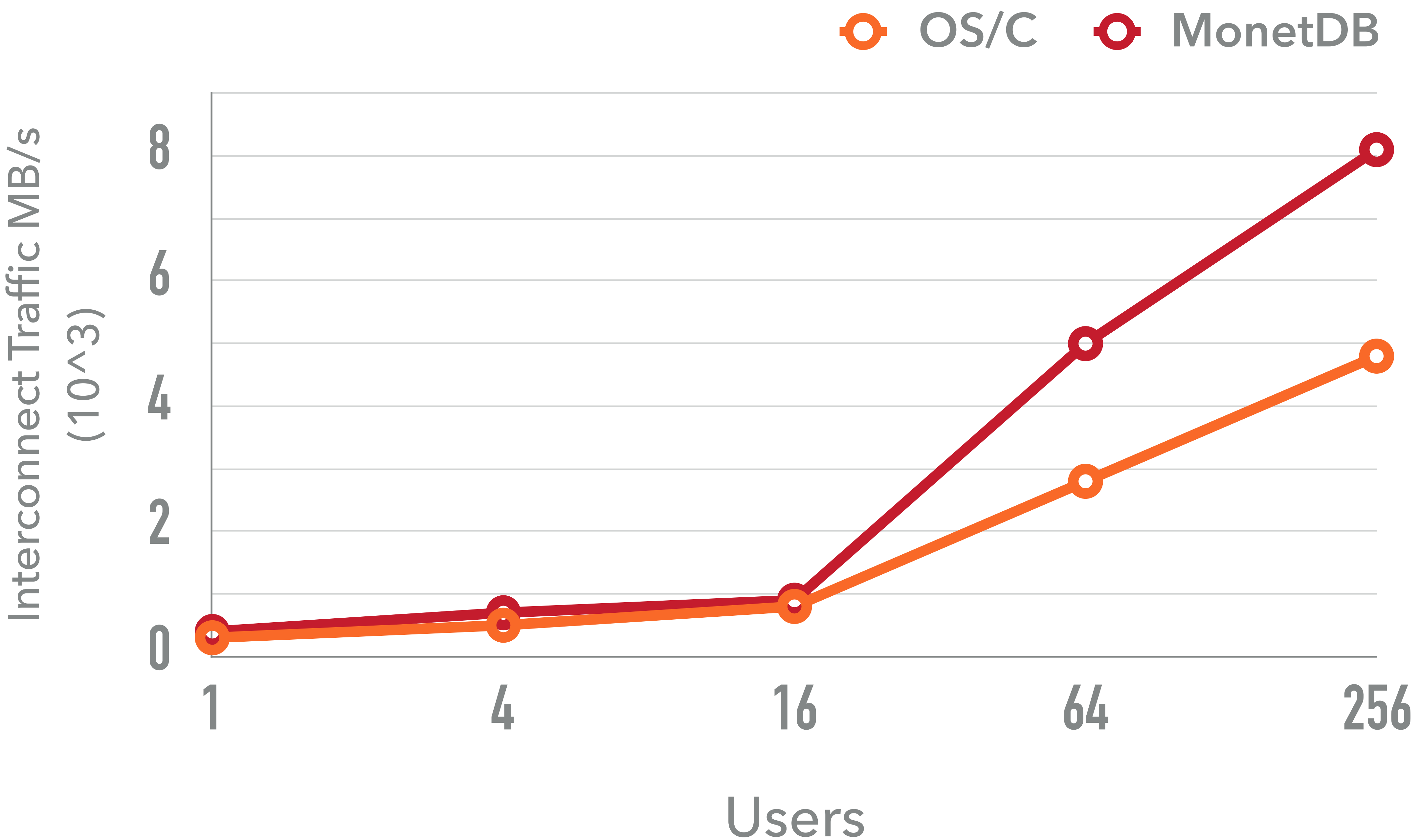
NOT NUMA-FRIENDLY PARALLELISM

- TPC-H Query 6 on 1GB database
- 4-node Quad-Core AMD Opteron 8000 Series (64Gb RAM/Node)
- MonetDB (v11.25.5)



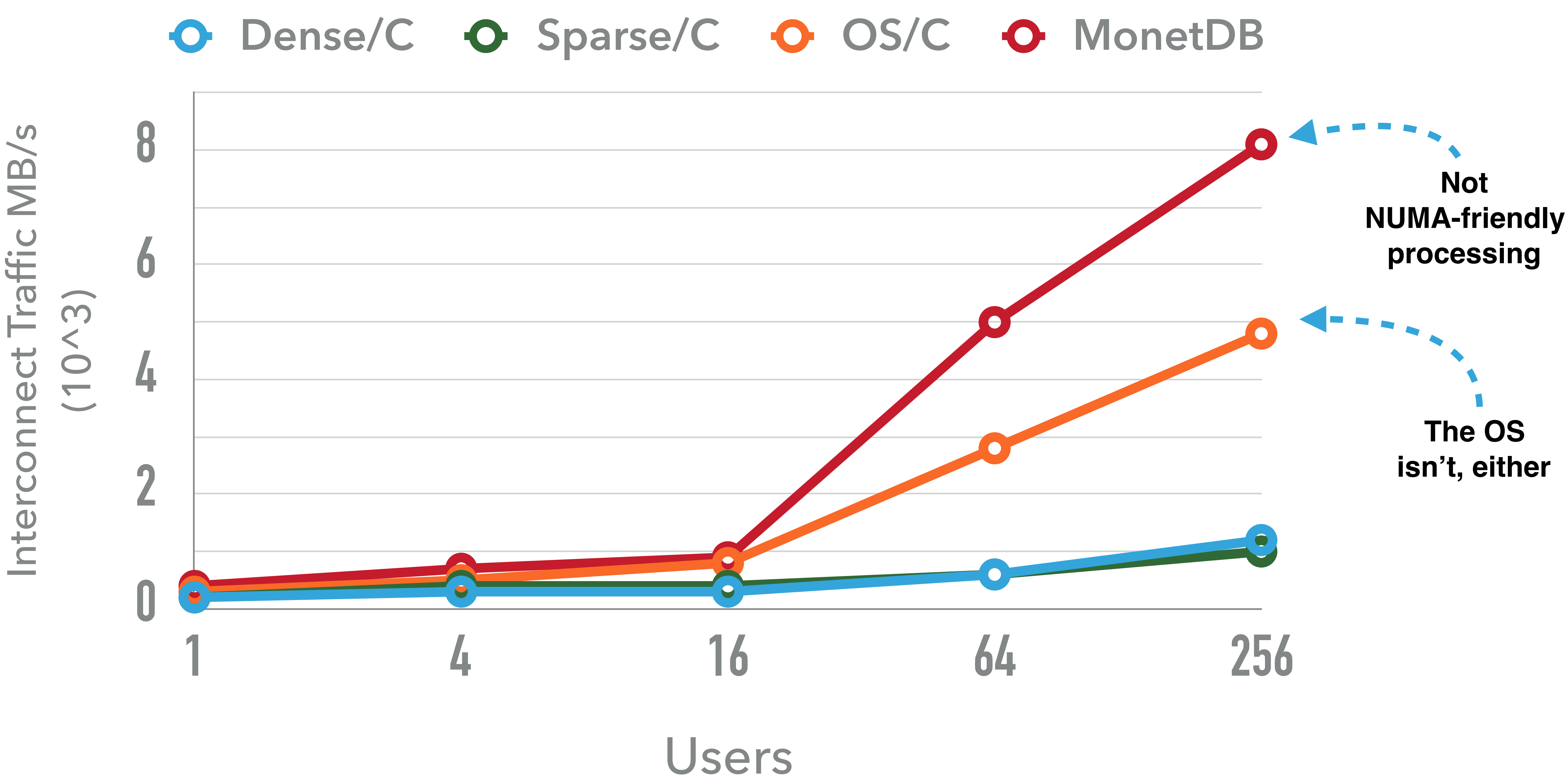
IMPACT OF REMOTE ACCESS

- TPC-H Q6: SQL vs. C language (raw performance)



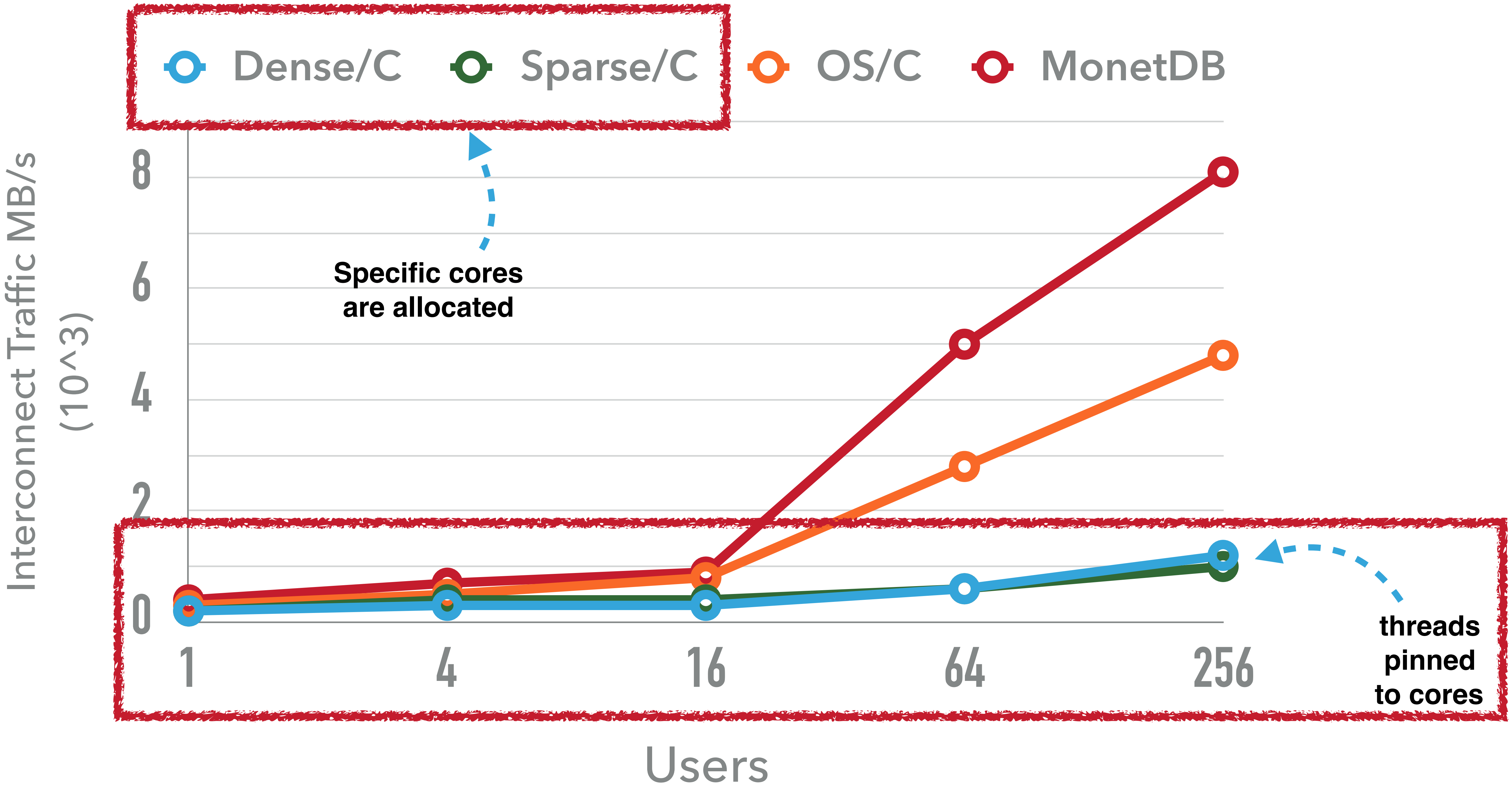
IMPACT OF REMOTE ACCESS

- TPC-H Q6: SQL vs. C language (raw performance)



IMPACT OF REMOTE ACCESS

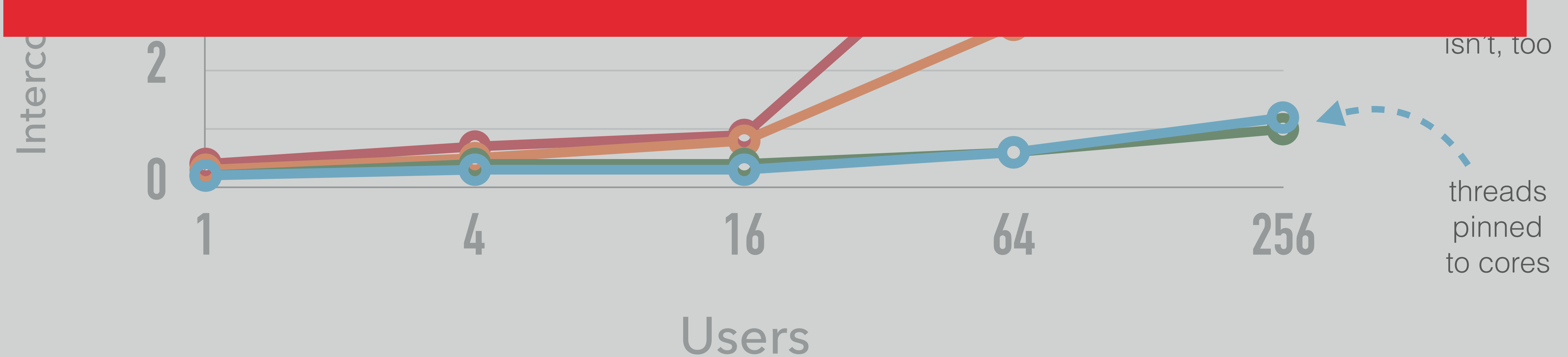
- TPC-H Q6: SQL vs. C language (raw performance)



IMPACT OF REMOTE ACCESS

- SQL query vs. C language (raw performance)

GOAL:
MITIGATE THE DATA MOVEMENT HANDING OUT TO THE OS THE LOCAL OPTIMUM NUMBER OF CORES IN SPECIFIC NODES



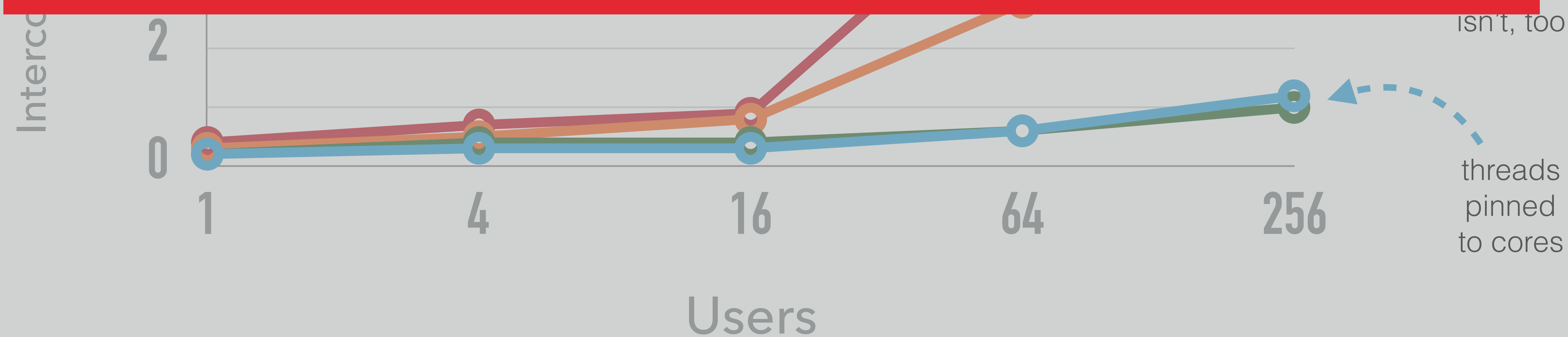
IMPACT OF REMOTE ACCESS

- SQL query vs. C language (raw performance)

CHALLENGES:

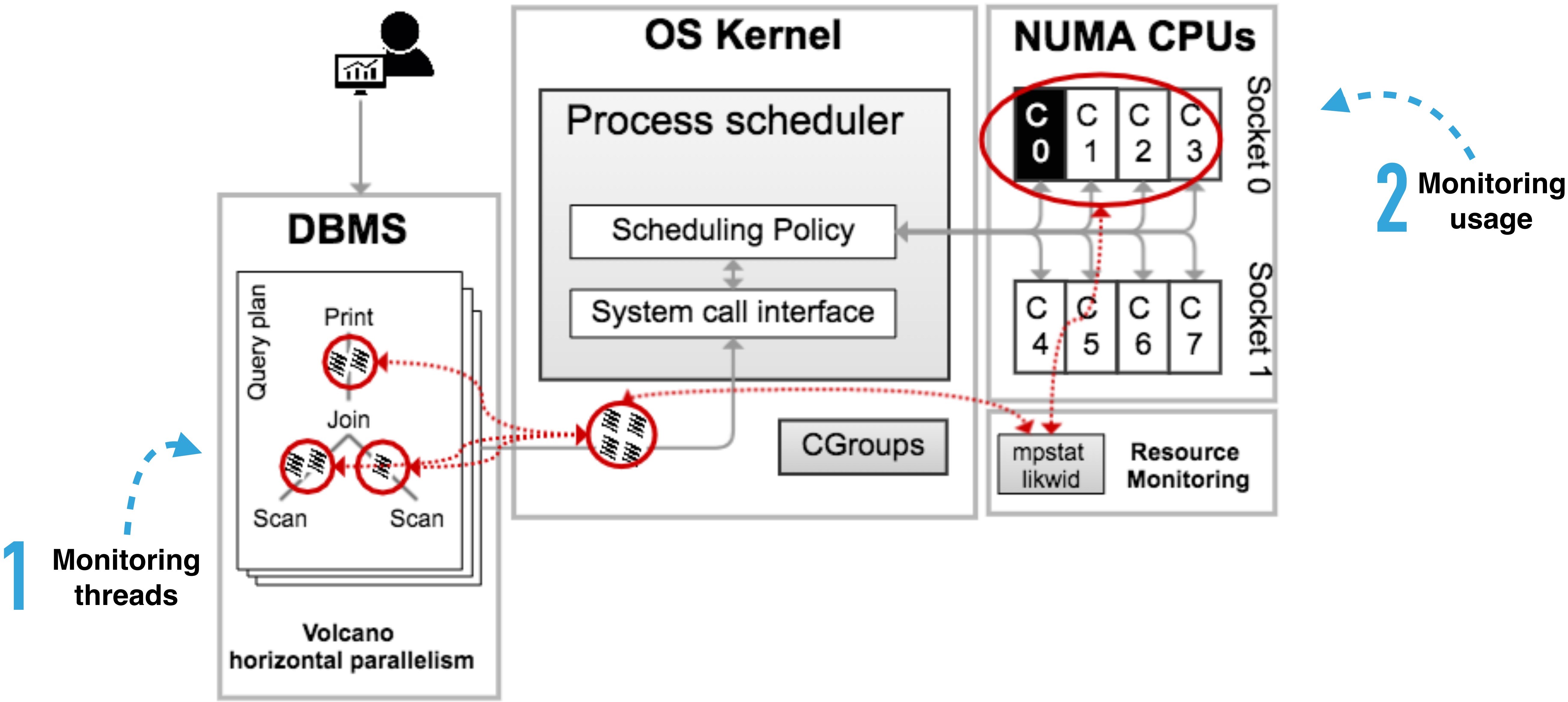
- LOCAL OPTIMUM NUMBER OF CORES
- CPU-CORE ALLOCATION

ndly

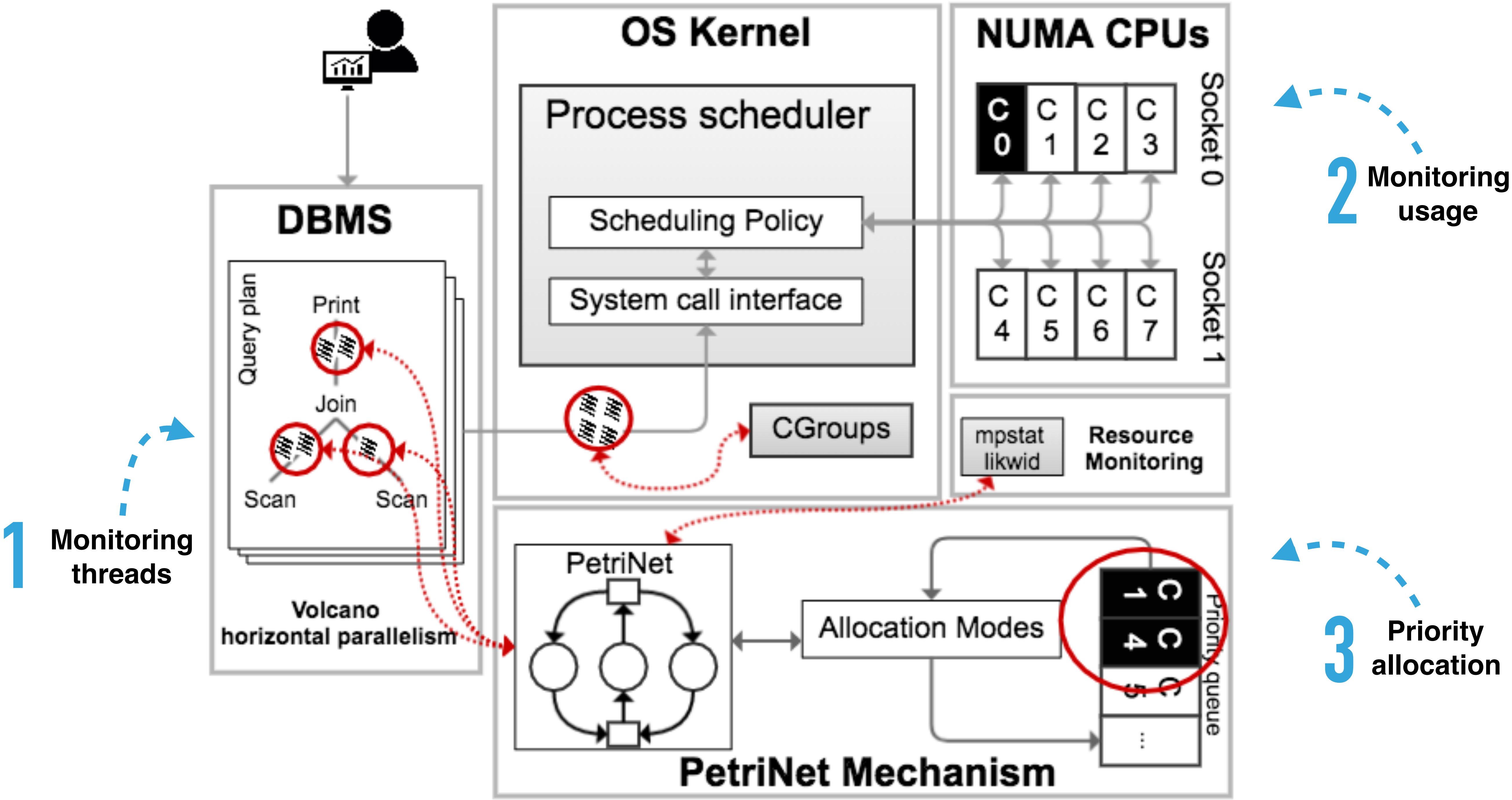


PETRINET MULTI-CORE ALLOCATION MECHANISM

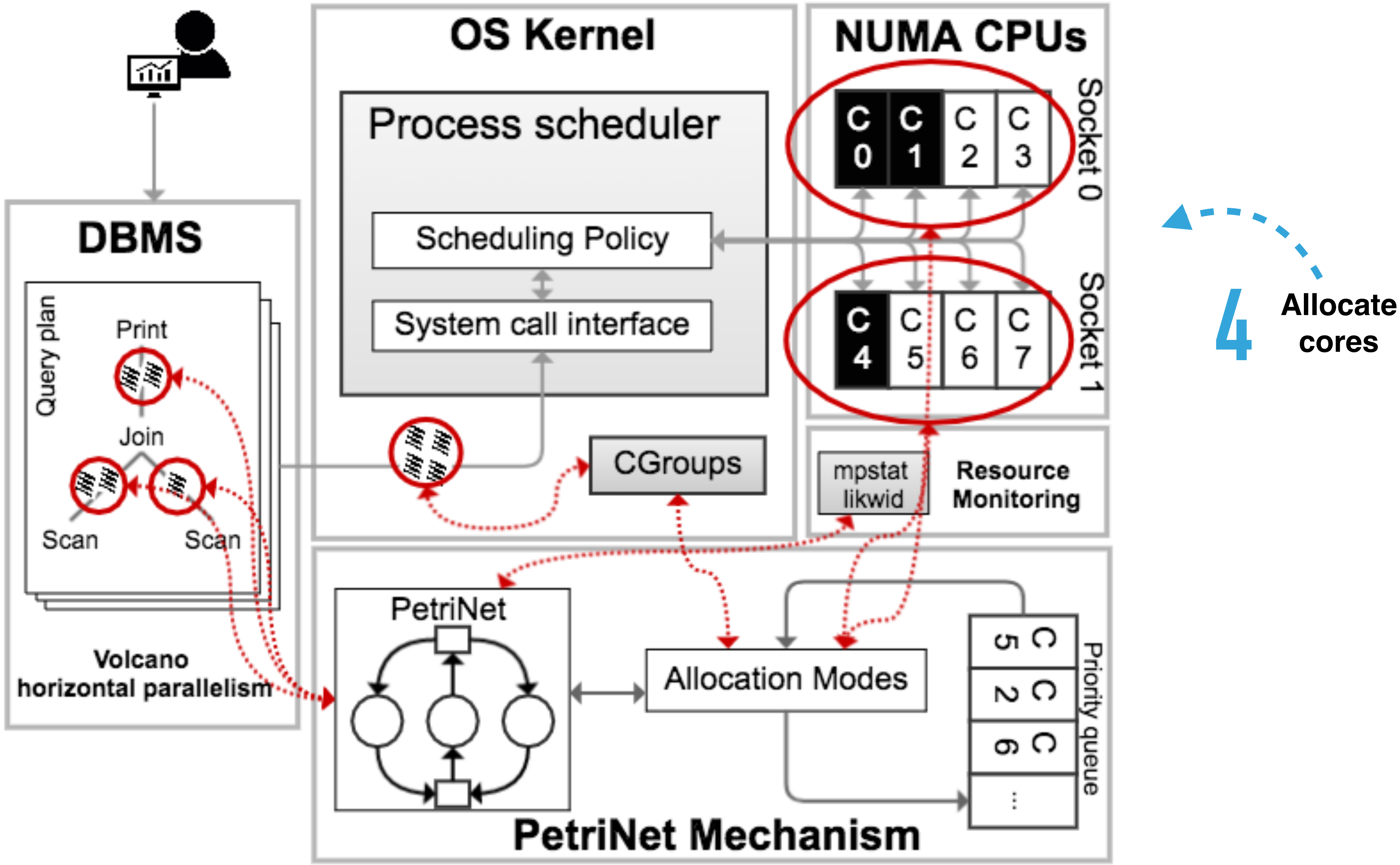
OVERVIEW OF OUR MULTI-CORE ALLOCATION MECHANISM



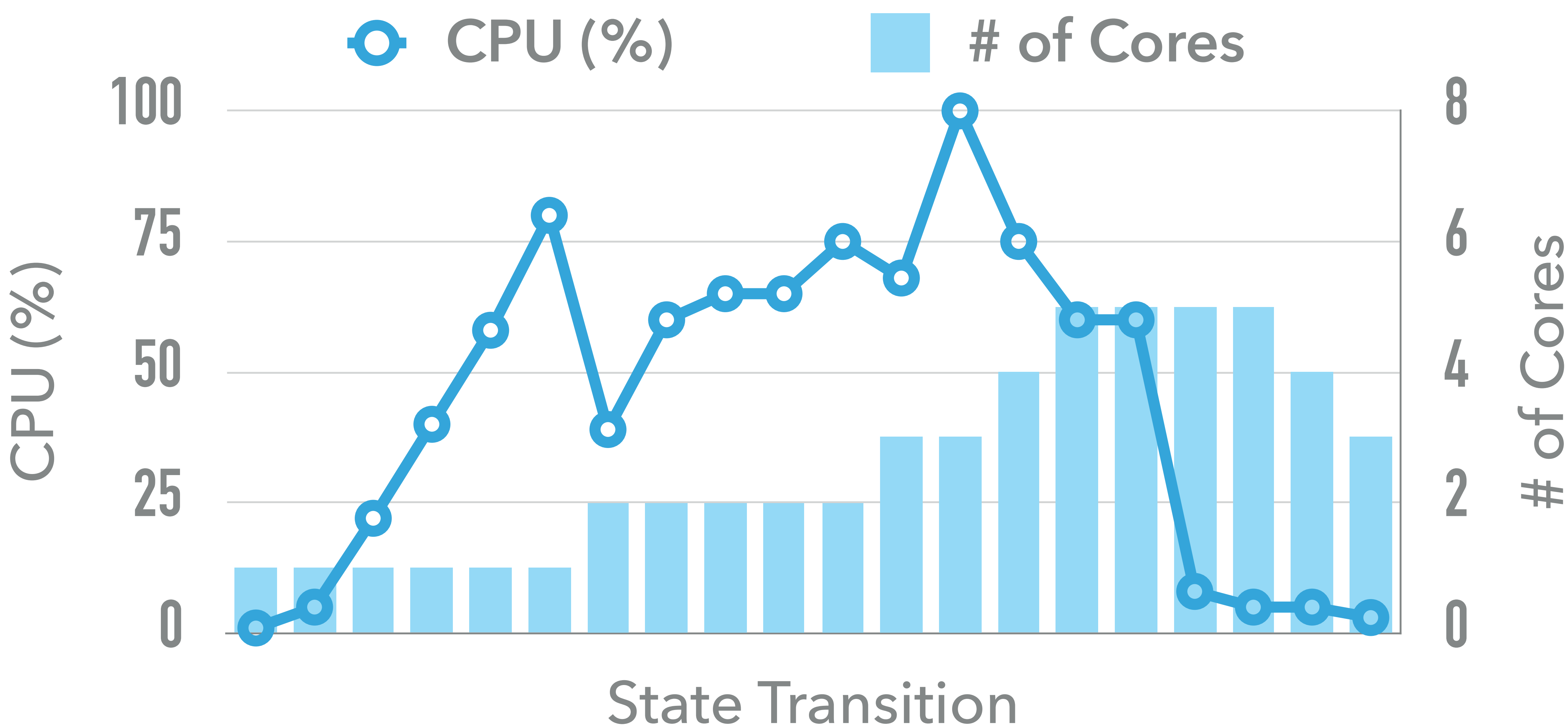
OVERVIEW OF OUR MULTI-CORE ALLOCATION MECHANISM



OVERVIEW OF OUR MULTI-CORE ALLOCATION MECHANISM

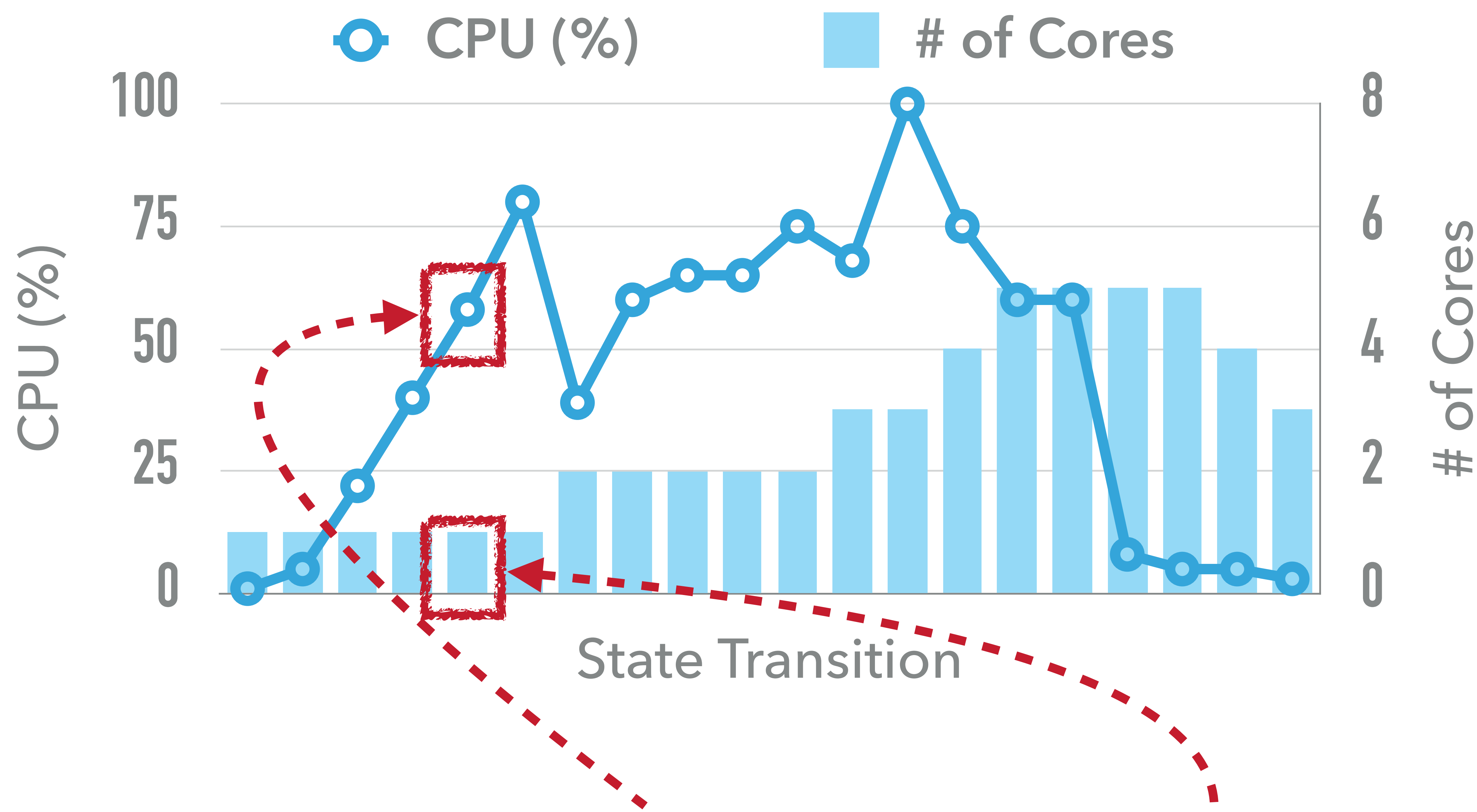


LOCAL OPTIMUM NUMBER OF CORES



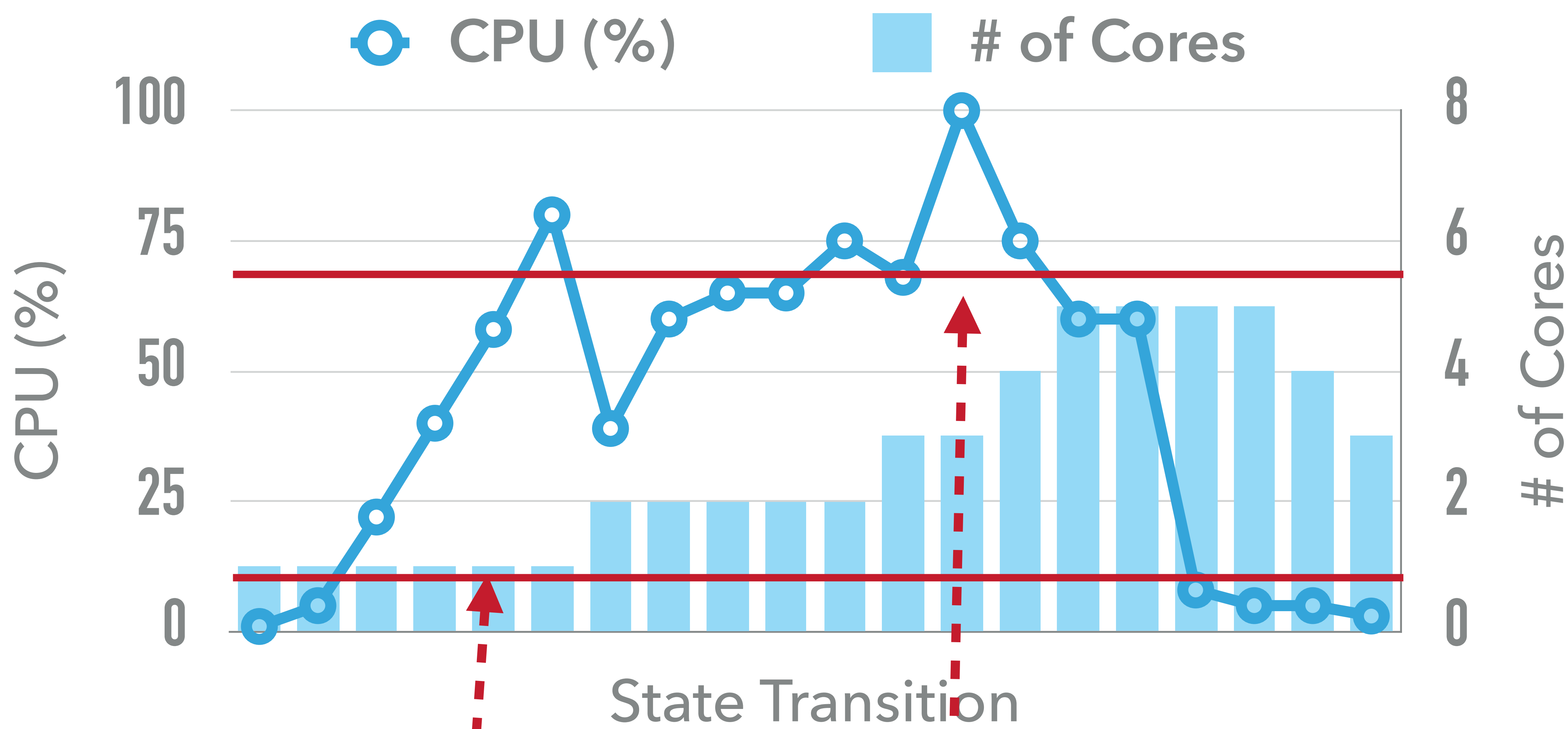
$$\forall\, w\ \exists\ n_{alloc} \mid (th_{min} < u < th_{max}) \land p(n_{alloc}) \geq p(n_{total})$$

LOCAL OPTIMUM NUMBER OF CORES



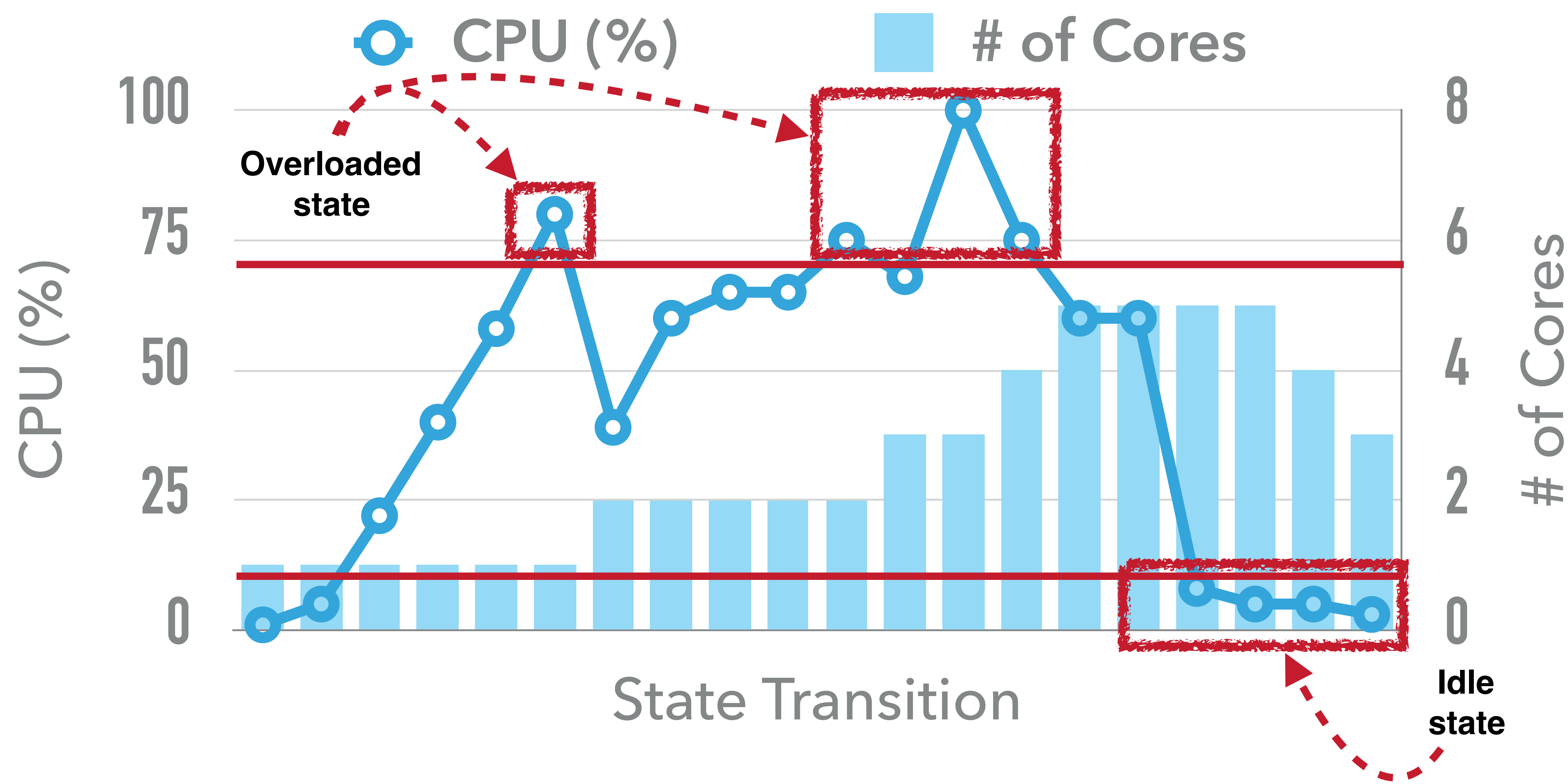
$$\forall\ w\ \exists\ n_{alloc} | (th_{min} < u < th_{max}) \land p(n_{alloc}) \geq p(n_{total})$$

LOCAL OPTIMUM NUMBER OF CORES



$$\forall\ w\ \exists\ n_{alloc} | (th_{min} < u < th_{max}) \wedge p(n_{alloc}) \geq p(n_{total})$$

LOCAL OPTIMUM NUMBER OF CORES

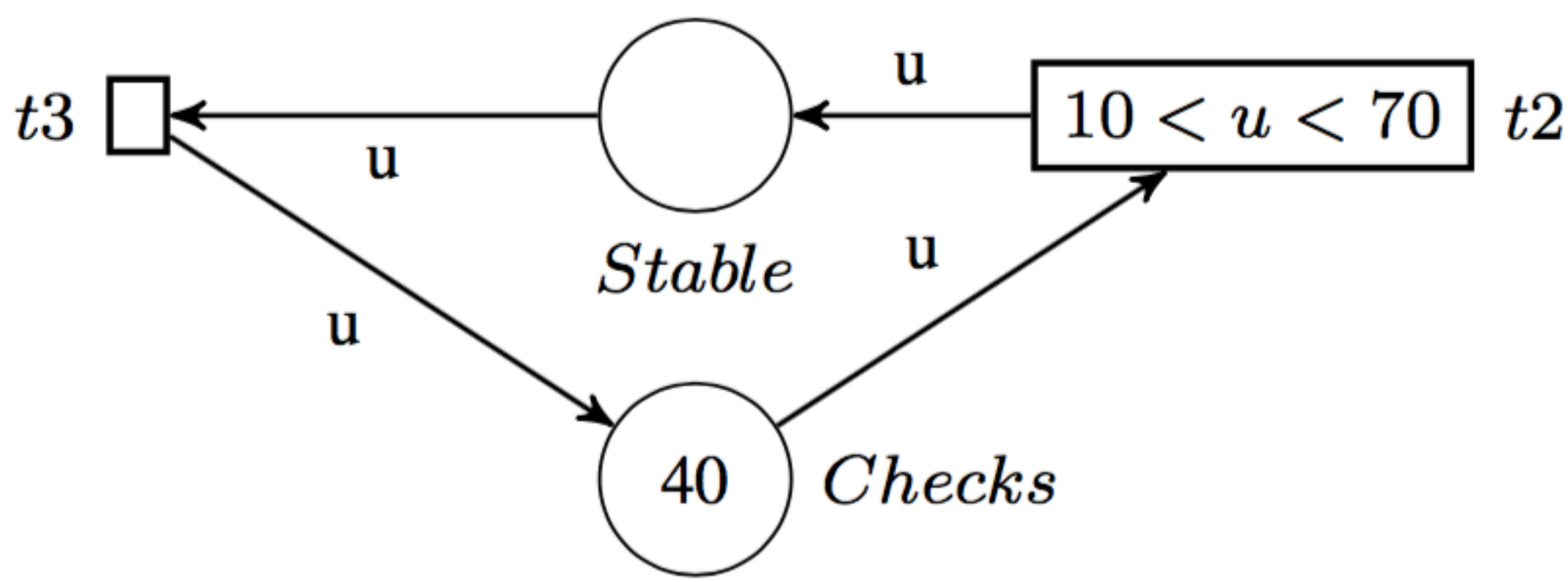


$$\forall\ w\ \exists\ n_{alloc} | (th_{min} < u < th_{max}) \wedge p(n_{alloc}) \geq p(n_{total})$$

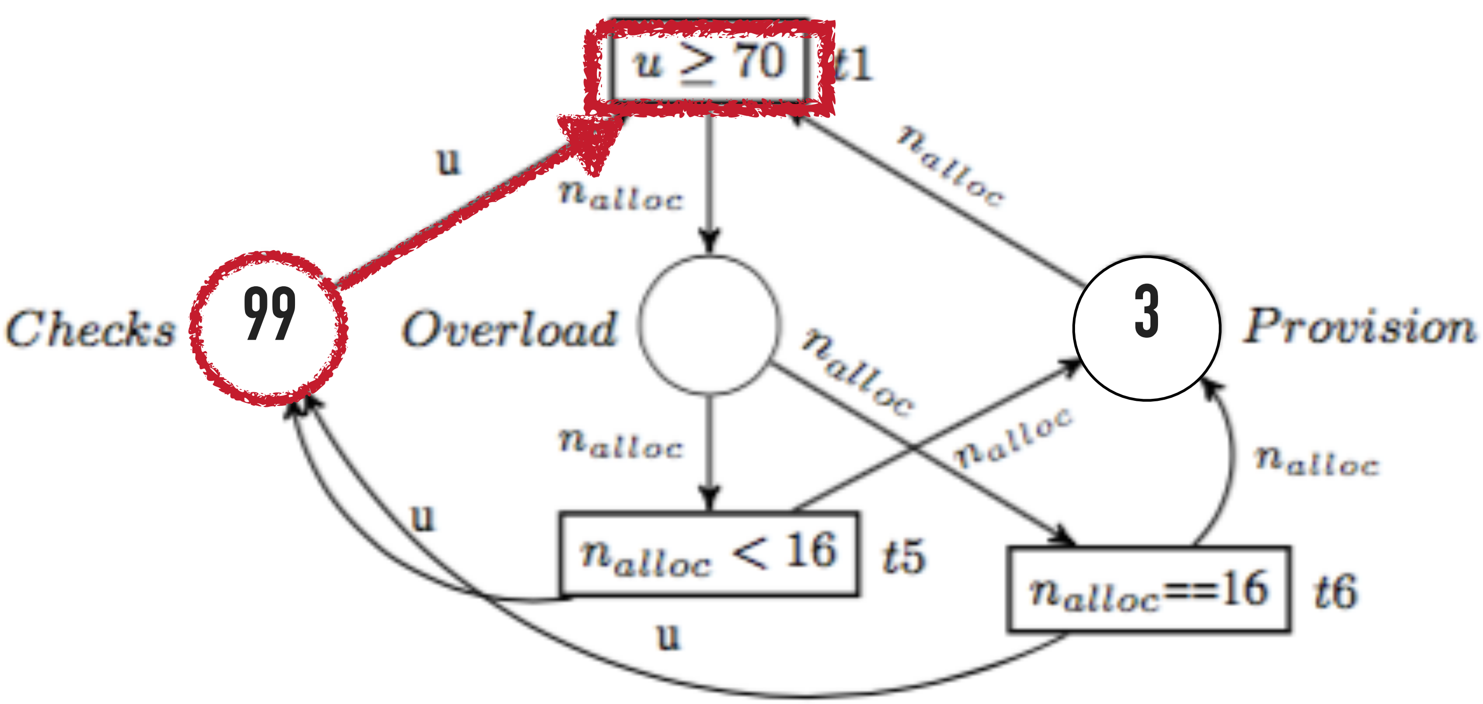
PETRINET MULTI-CORE ALLOCATION MECHANISM

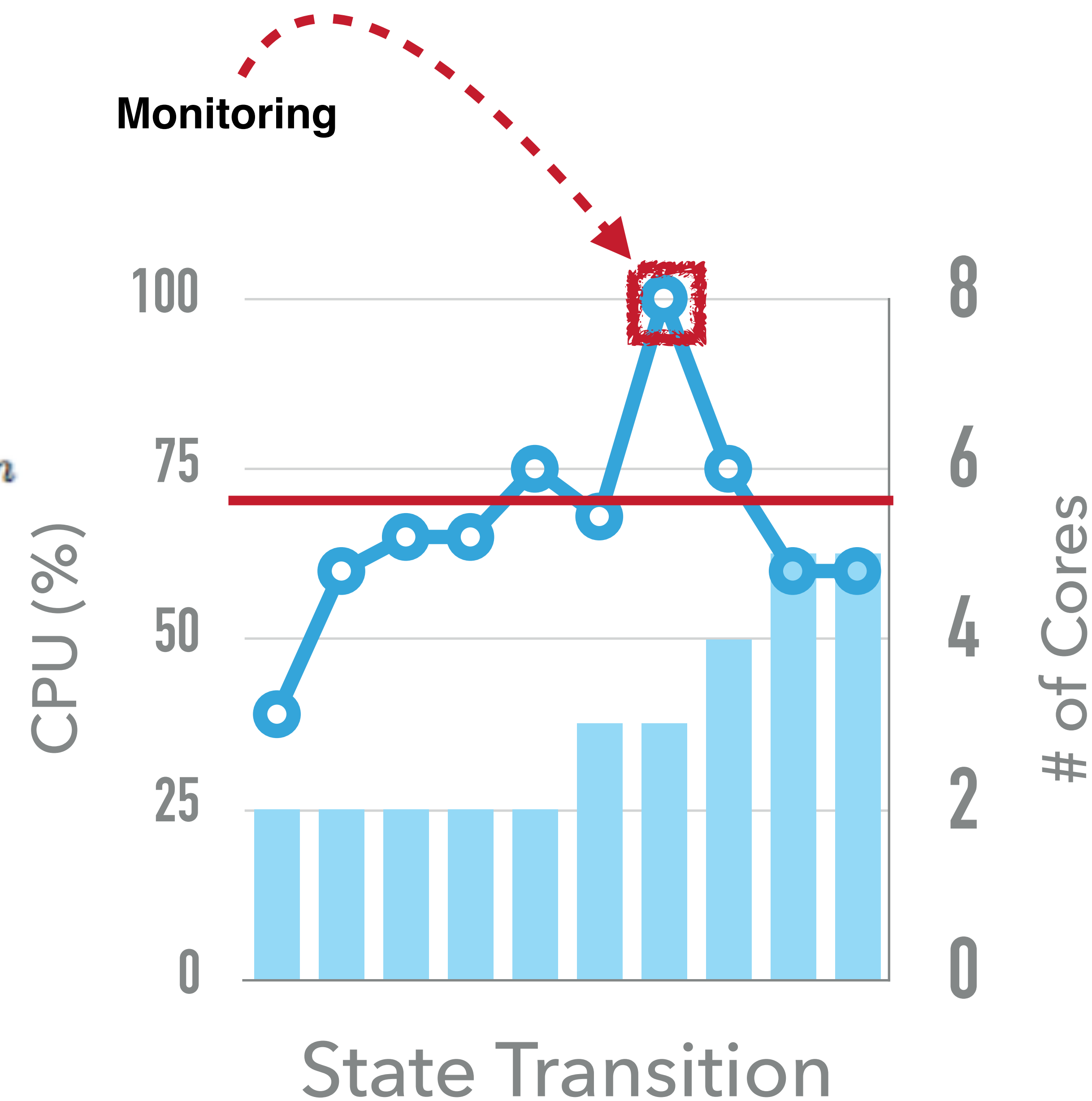
(DEFINITIONS)

- Places={Stable, Idle, Overload, Provision, Checks}
- Transitions={t0 , . . . , t7 }, (i.e., conditions)
- Arcs=<pi, tj > or <tj , pi>, (i.e., I/O functions)

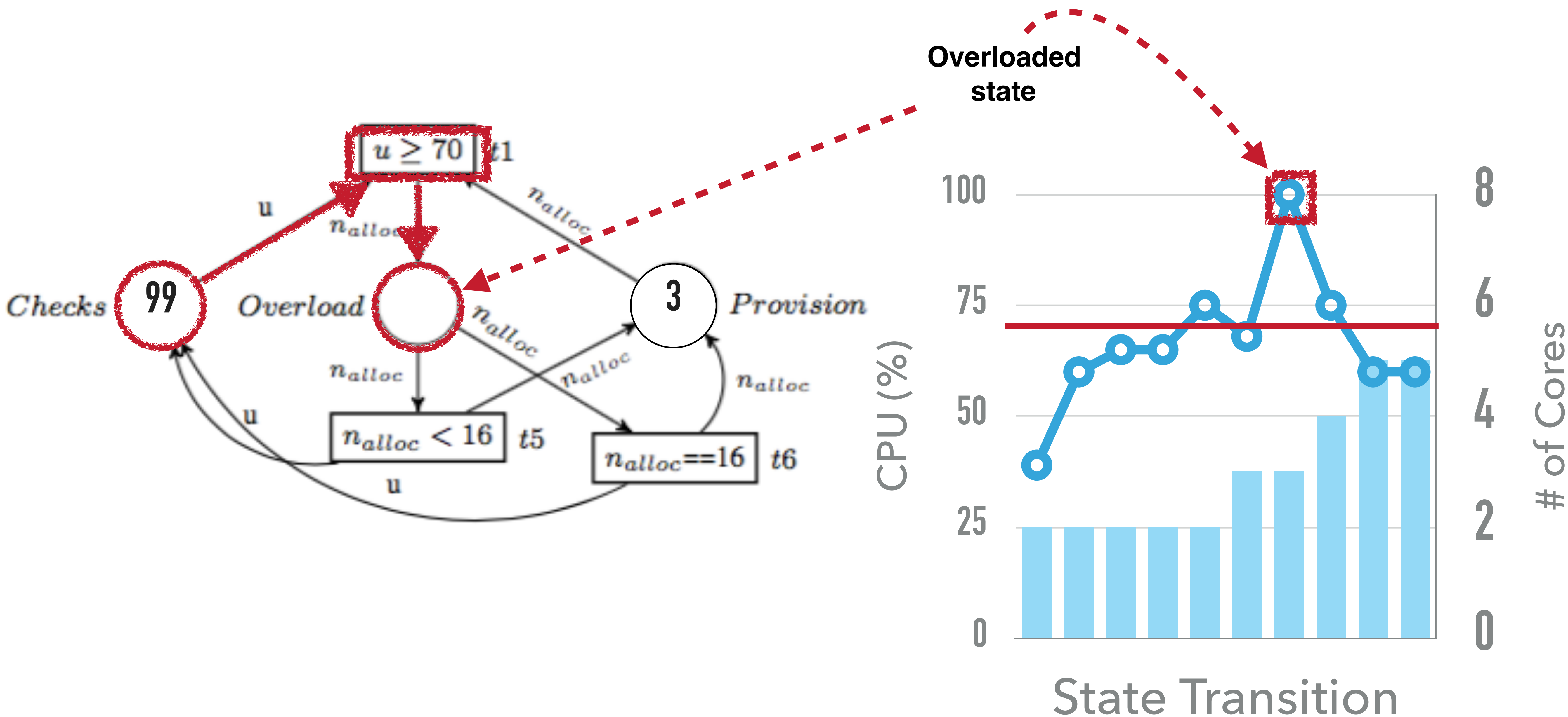


OVERLOADED STATE

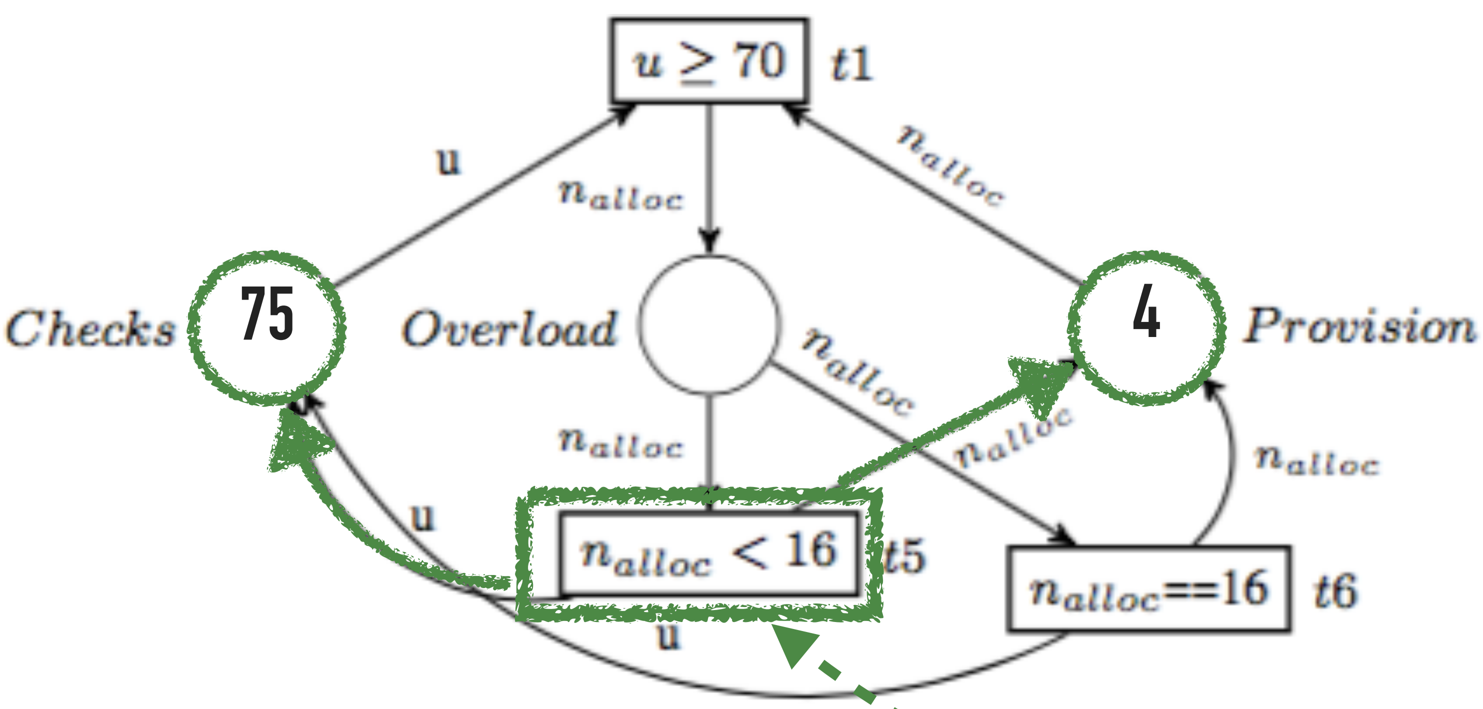


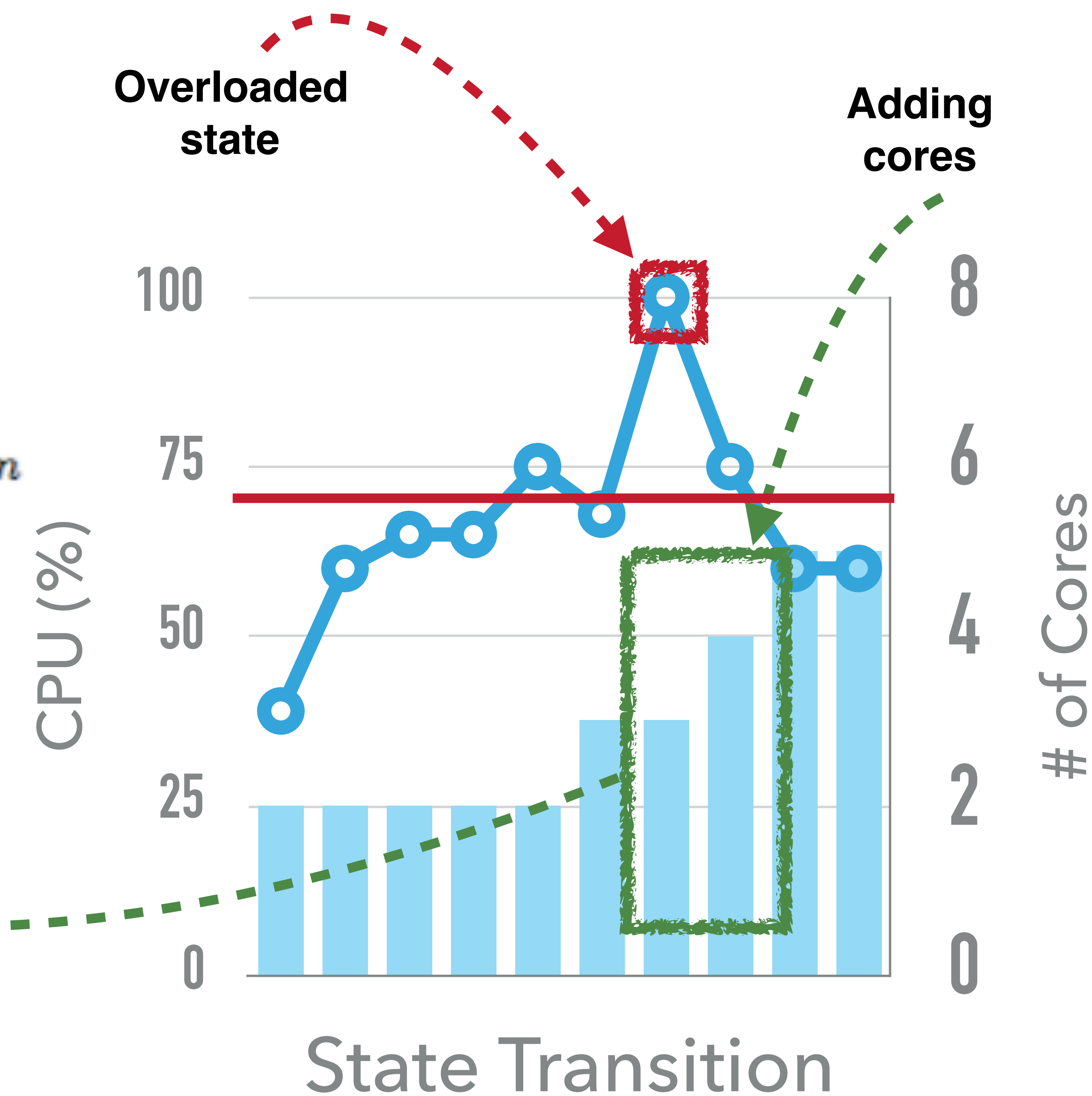


OVERLOADED STATE



OVERLOADED STATE

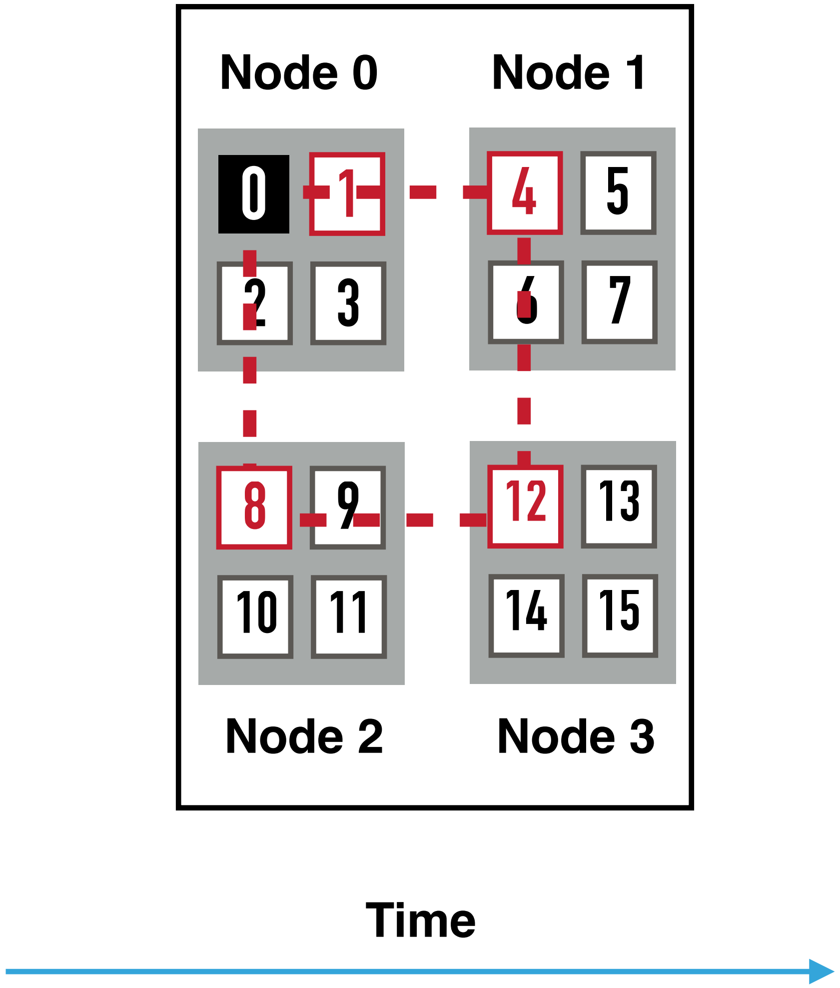




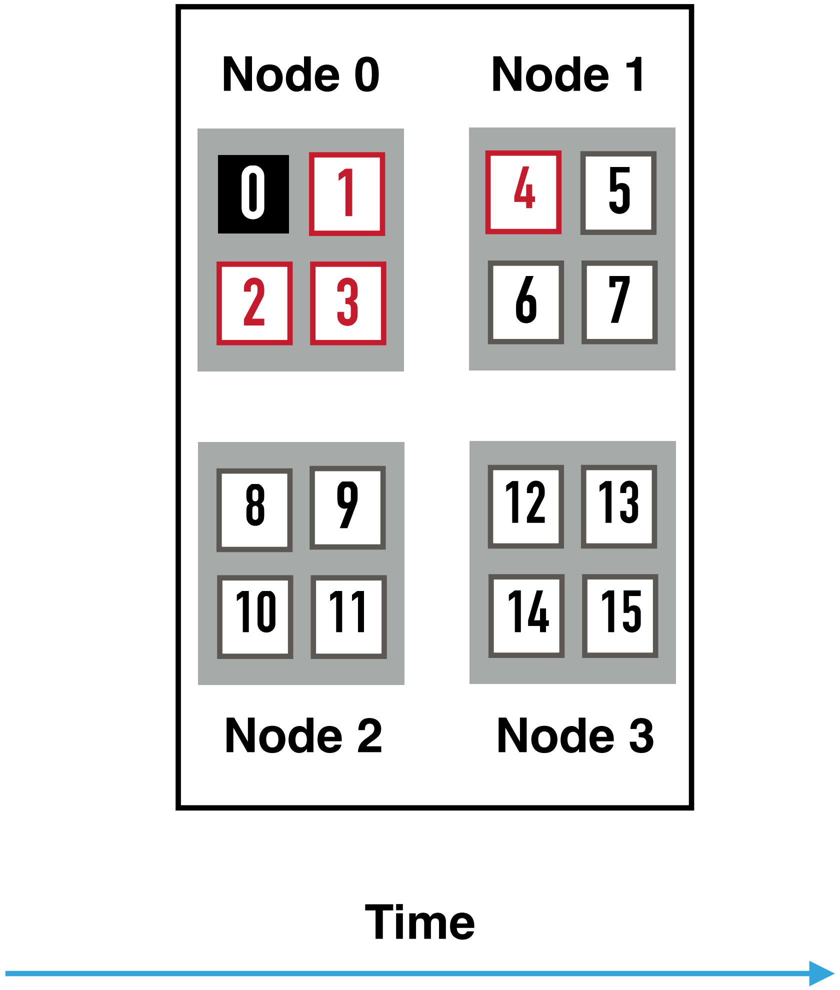
- Action: allocate cores

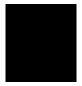
ALLOCATION MODES

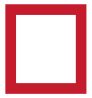
- Sparse



- Dense

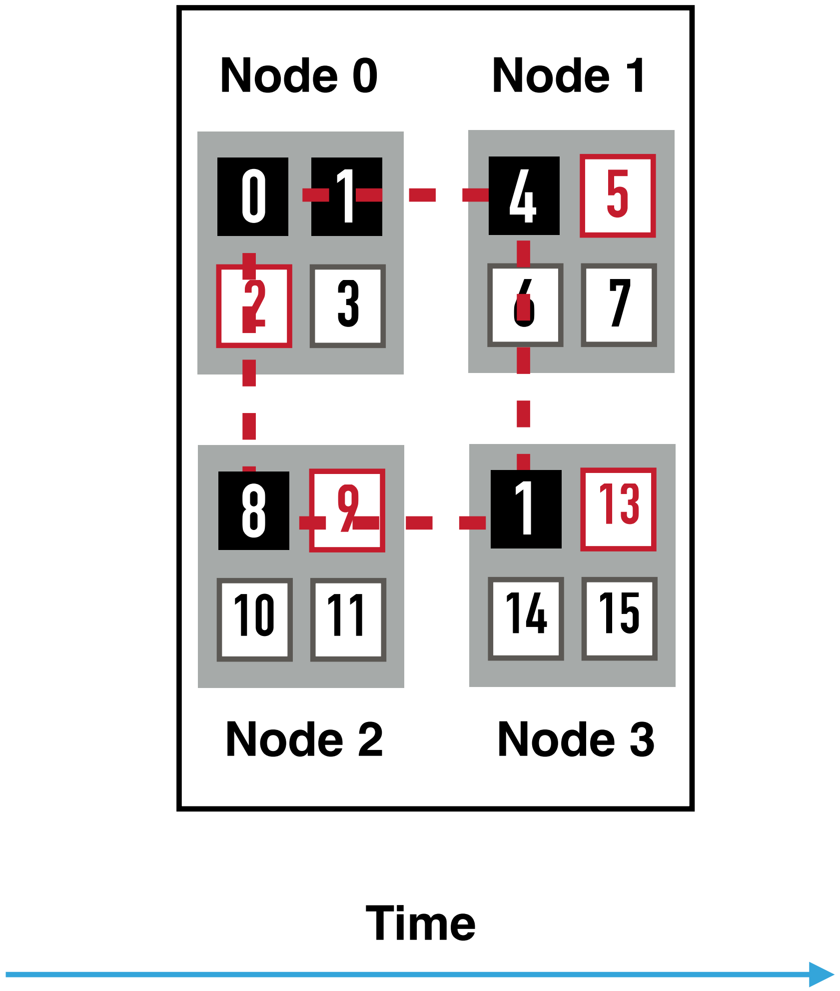



allocated

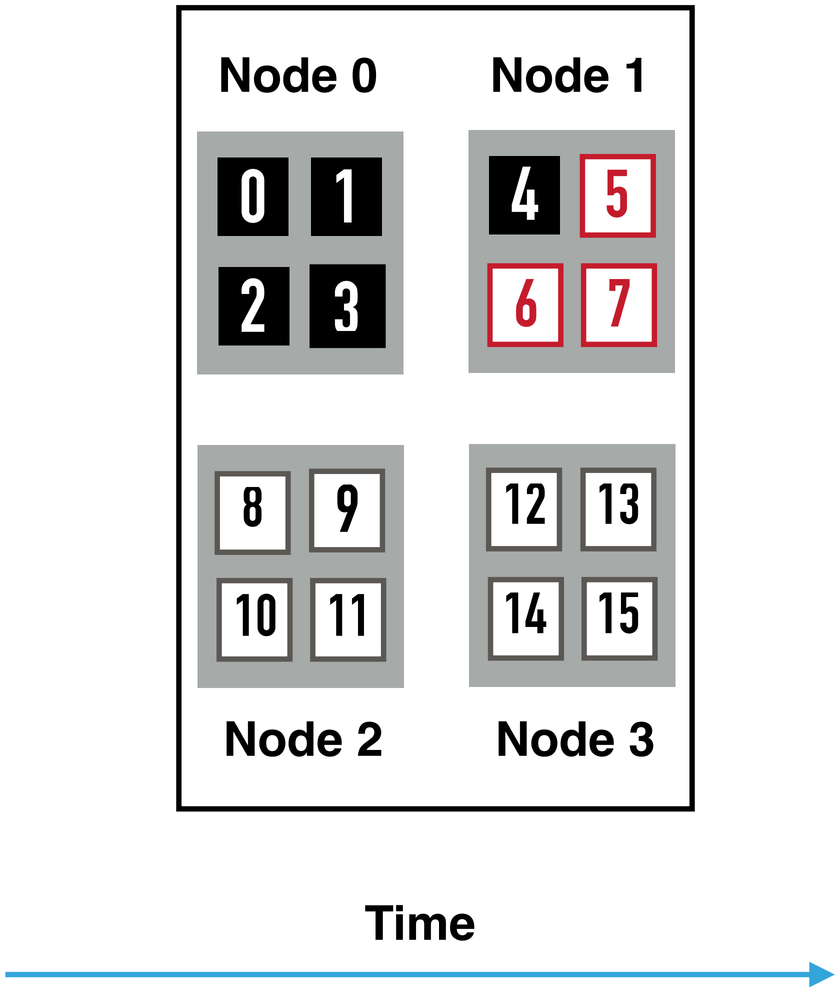

next to allocate

ALLOCATION MODES

- Sparse



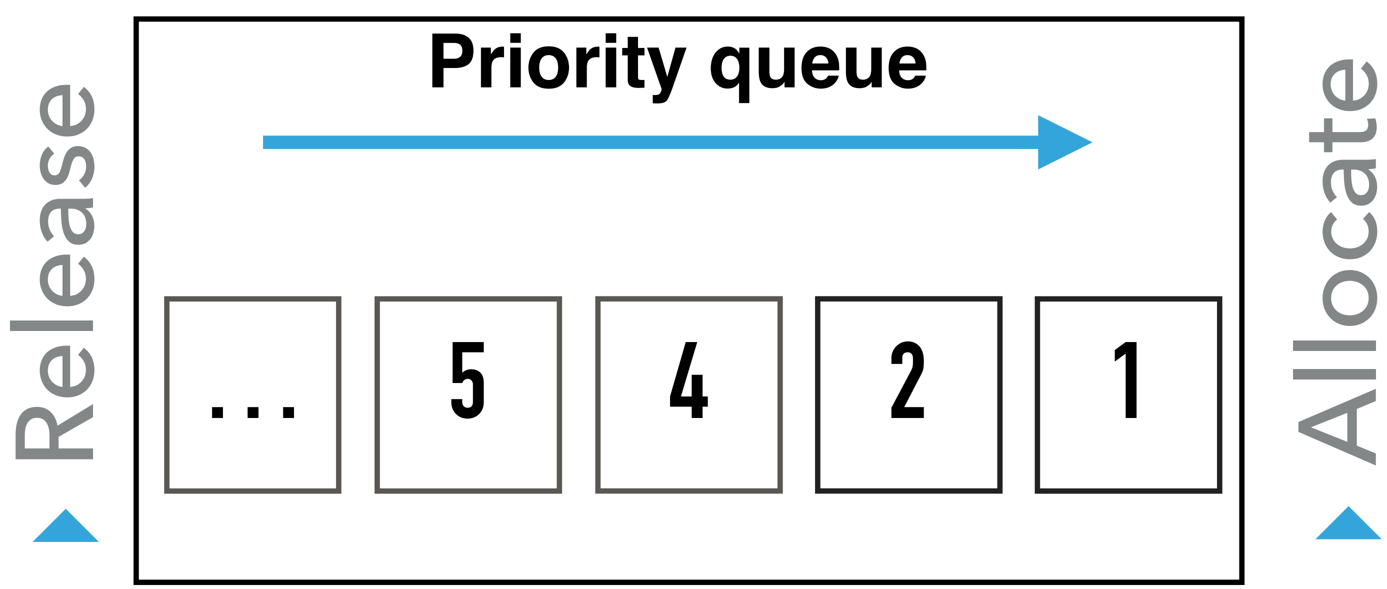
- Dense



allocated

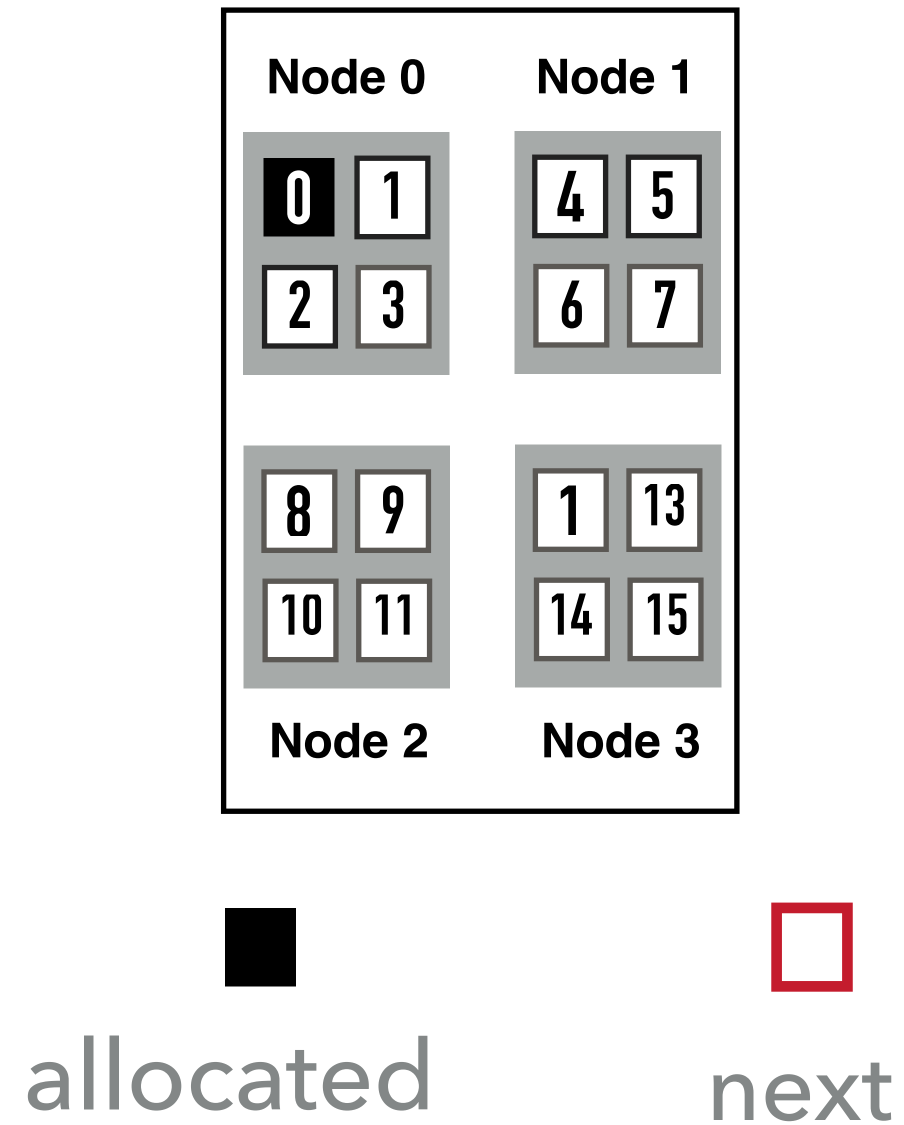
next to allocate

ADAPTIVE MODE

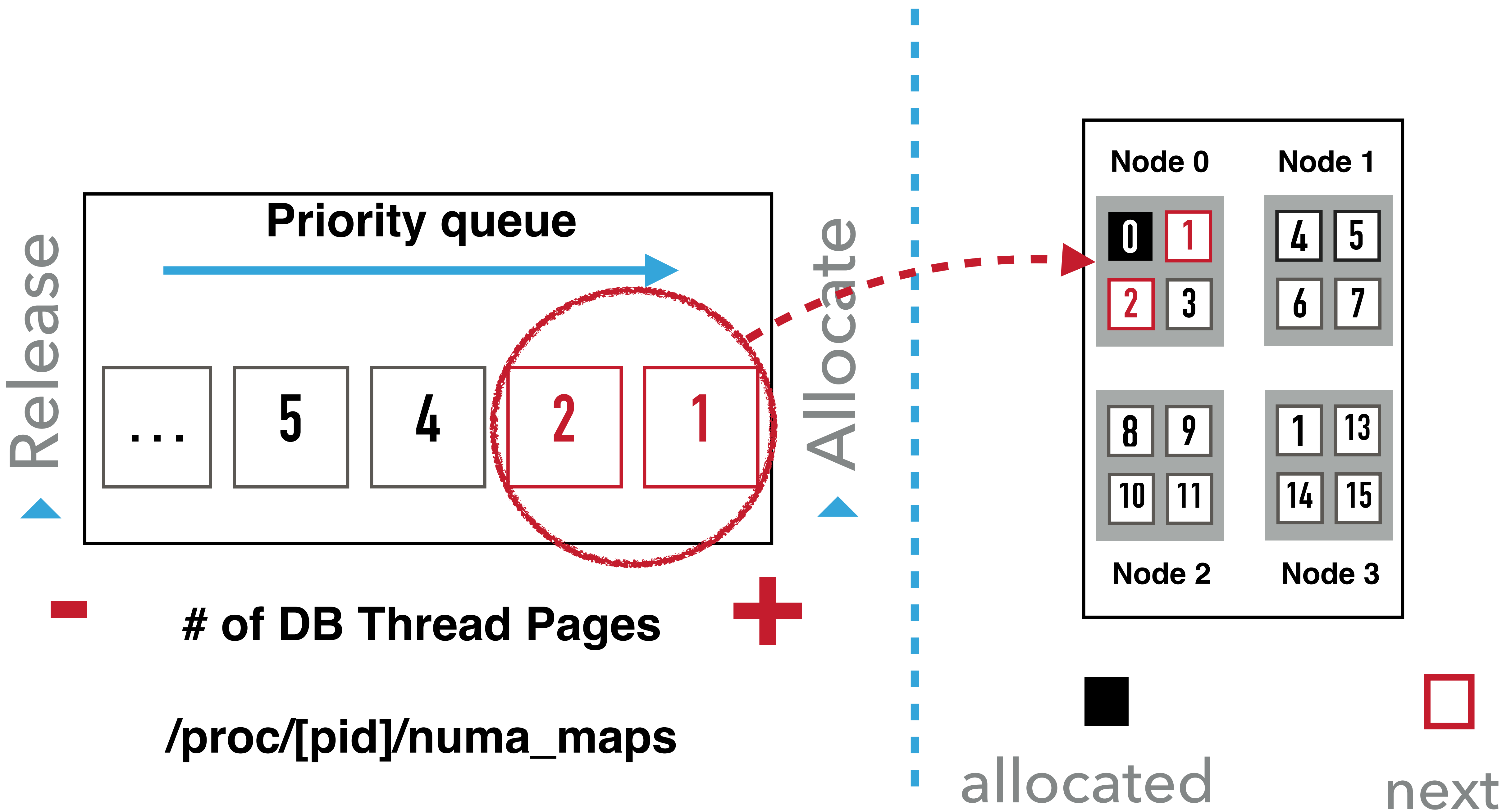


\- # of DB Thread Pages +

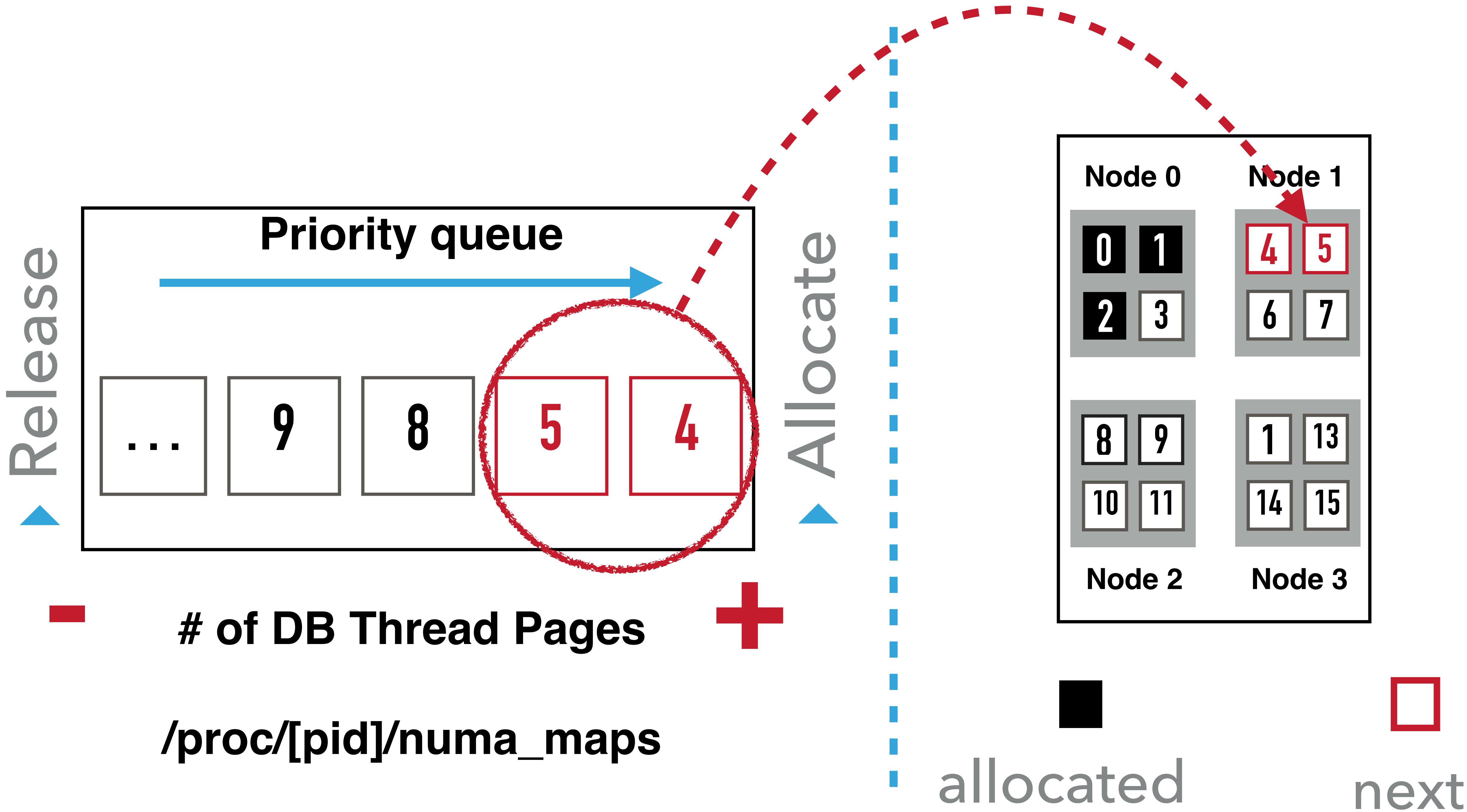
/proc/[pid]/numa_maps



ADAPTIVE MODE



ADAPTIVE MODE



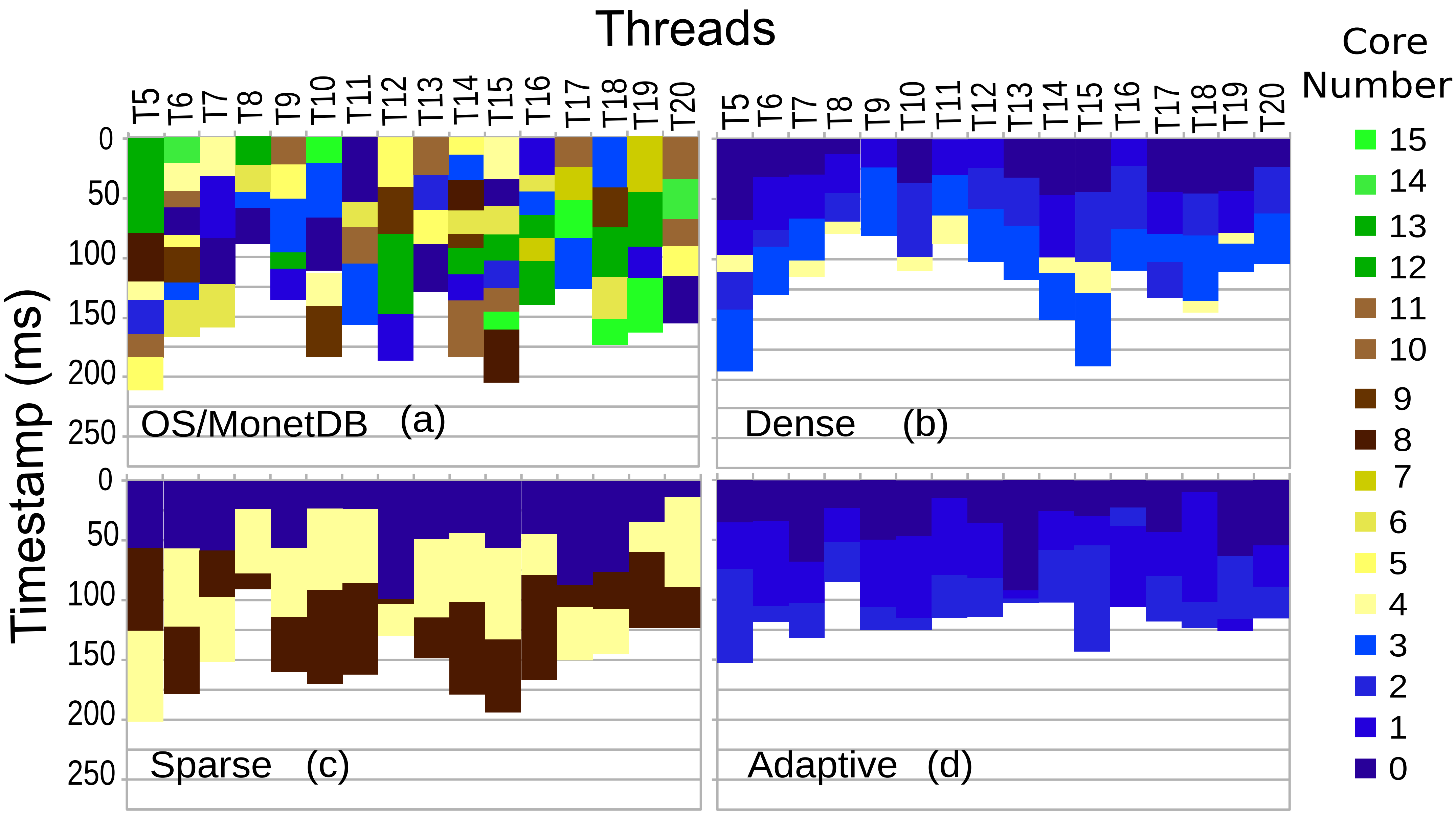
EXPERIMENTS

SETUP

- TPC-H 1GB and 100GB database up to 256 users
- 4-node Quad-Core AMD Opteron 8000 Series (64GB RAM/Node), Agr. Bandwidth 41.6 Gb/s, L3 (6MB)
- Debian Linux 8 “Jessie”
- Prototype in C language
- Database systems:
  - MonetDB (v11.25.5)
  - NUMA-Aware Microsoft SQL Server (v2017 Dev. RC2)

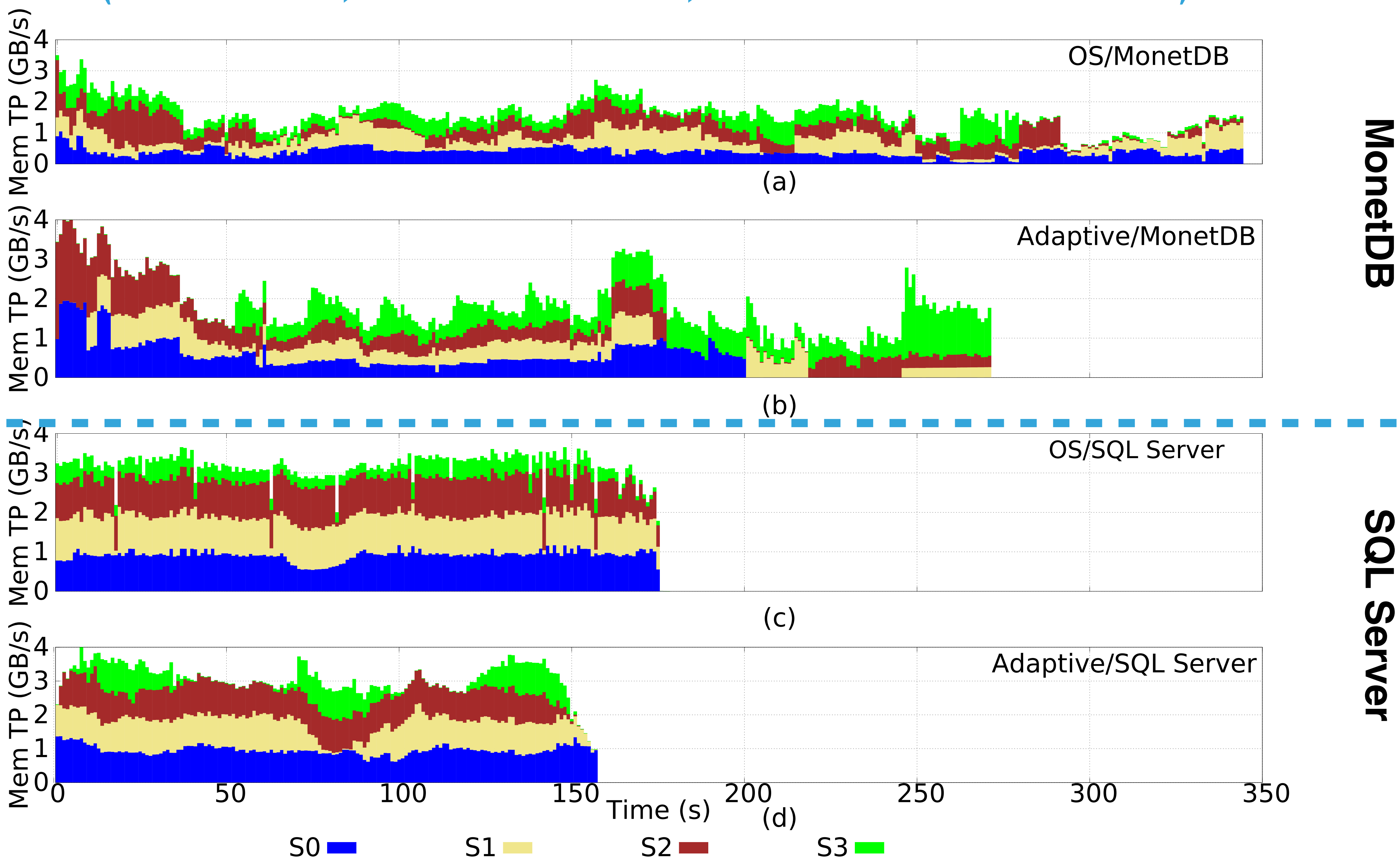
IMPACT OF THE MIGRATION OF THREADS

(TPC-H QUERY 6, 1 USER, 1 GB DATABASE, MONETDB)



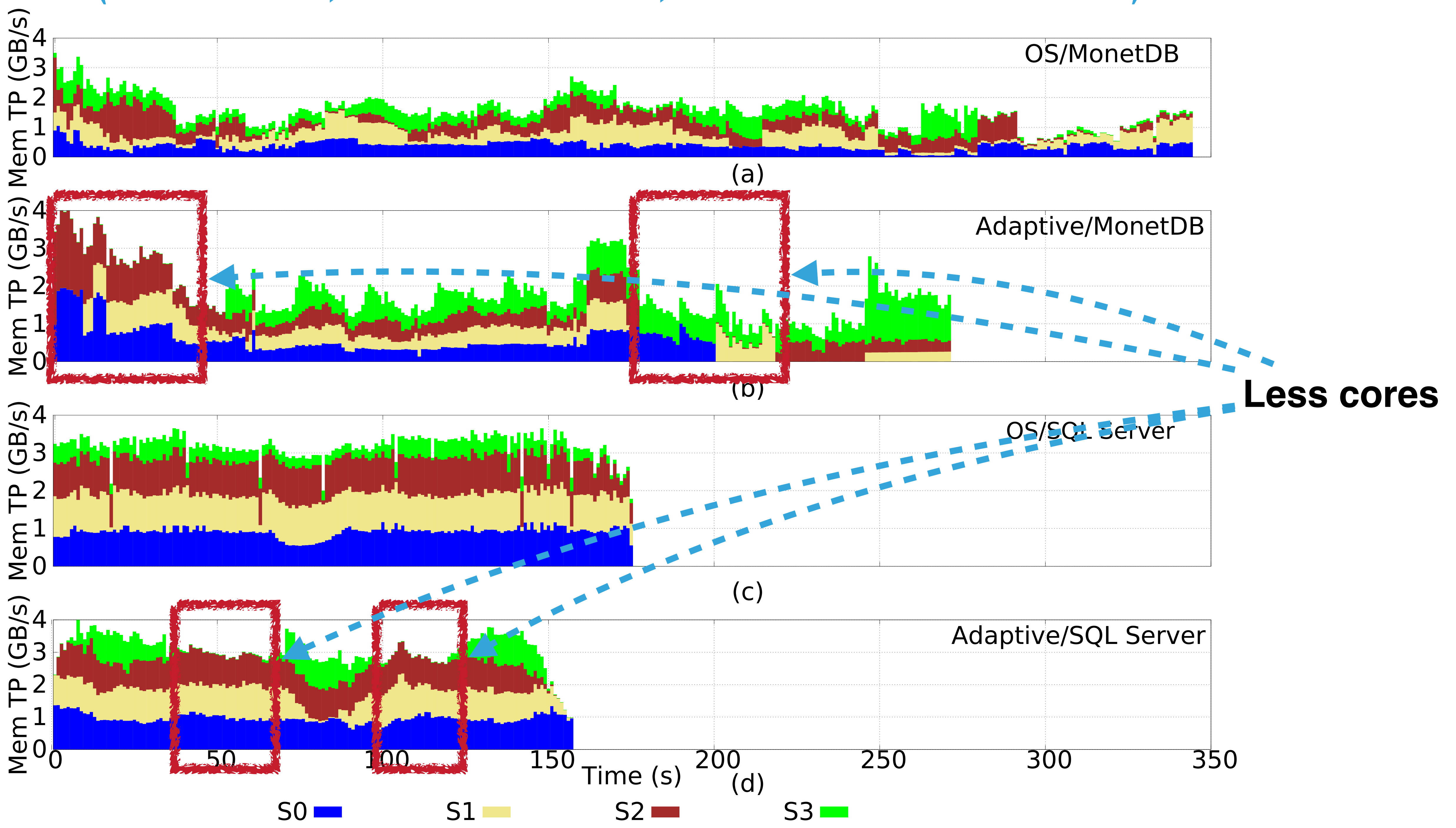
CONCURRENT EXECUTION OF TPC-H

(256 USERS, 1 GB DATABASE, MONETDB/SQLSERVER)



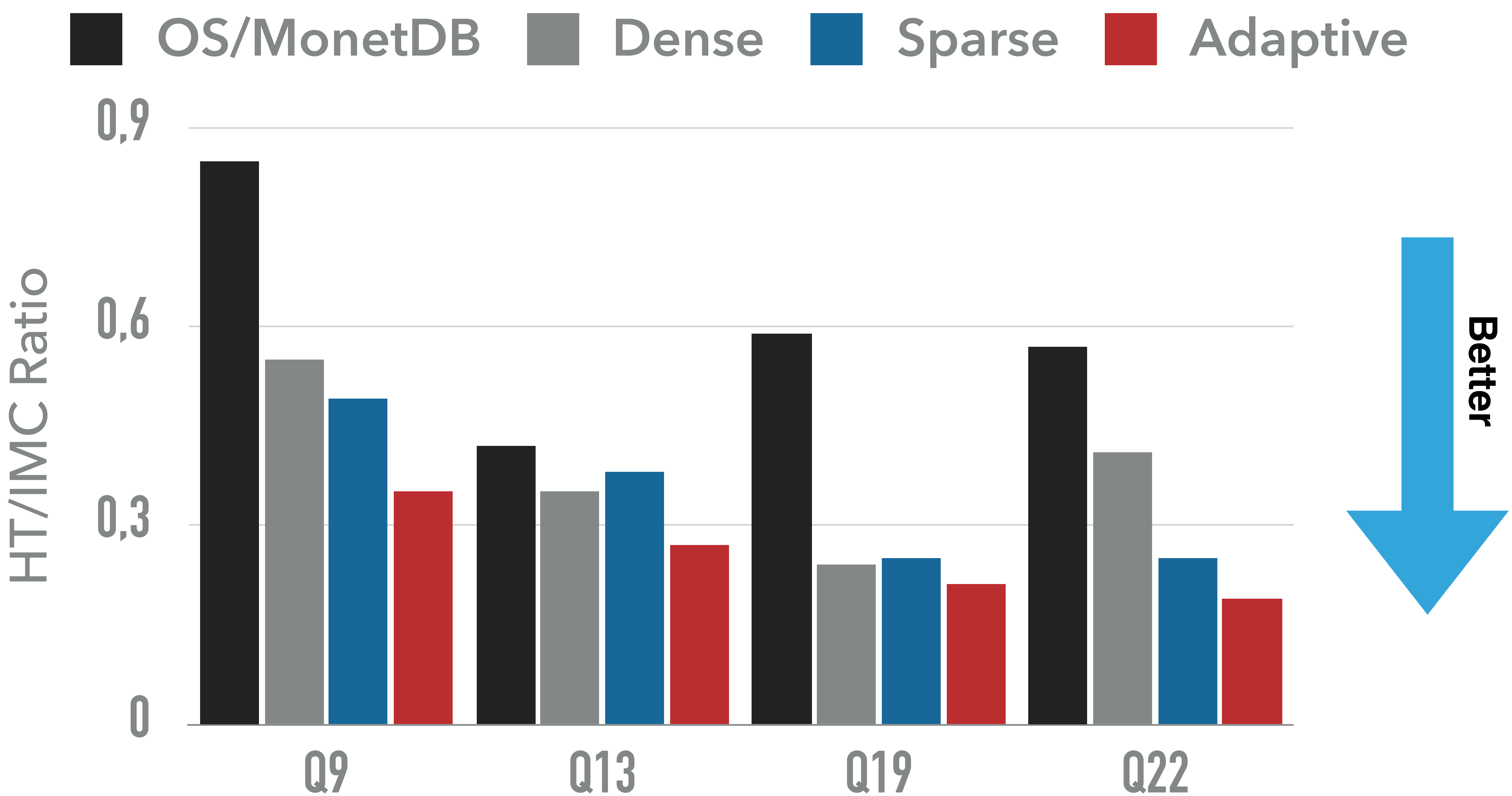
CONCURRENT EXECUTION OF TPC-H

(256 USERS, 1 GB DATABASE, MONETDB/SQLSERVER)



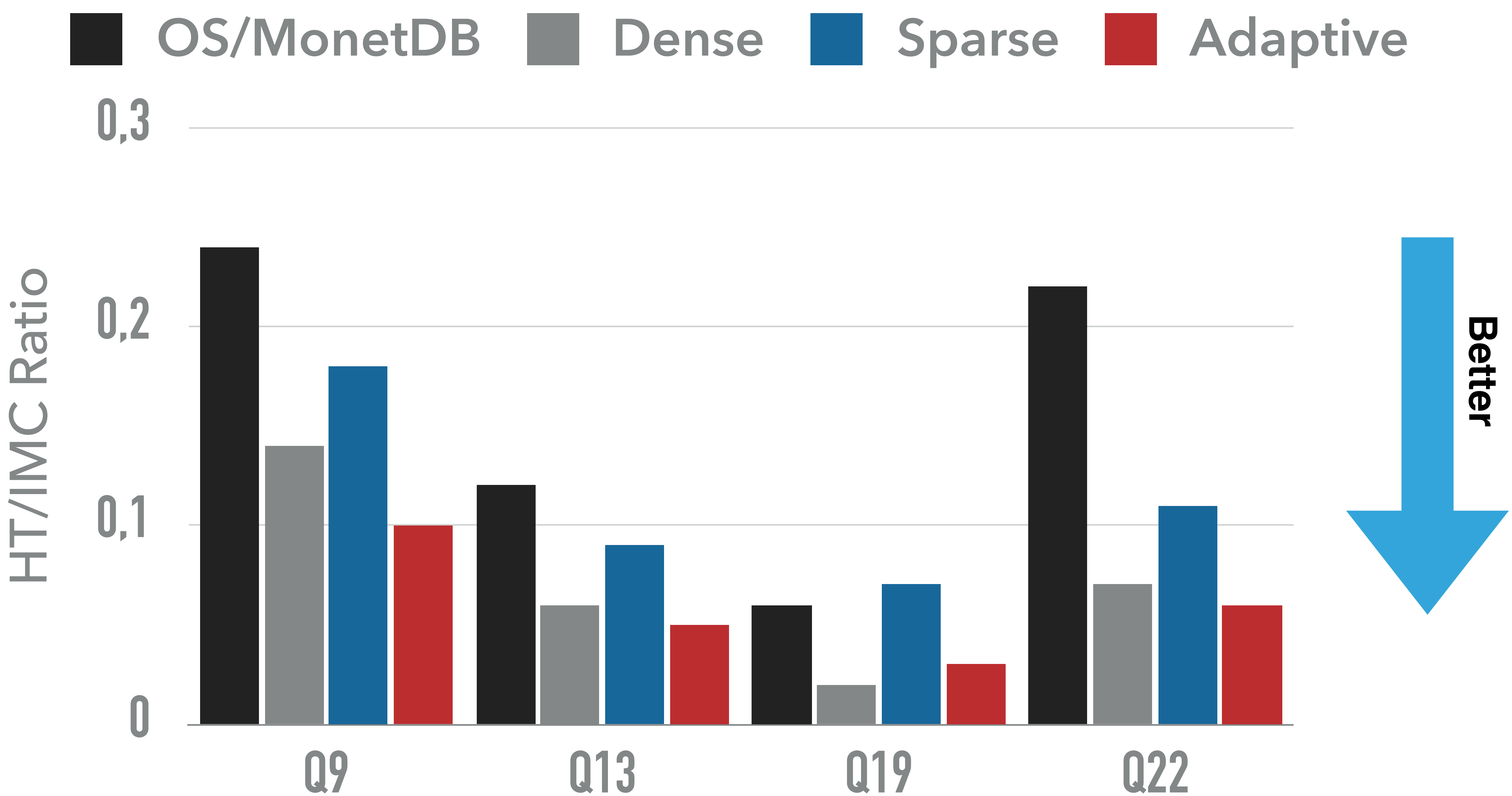
NUMA-FRIENDLINESS: INTERCONNECTION RATIO

(256 USERS, 1 GB DATABASE, MONETDB, TPC-H)



NUMA-FRIENDLINESS: INTERCONNECTION RATIO

(256 USERS, 1 GB DATABASE, SQL SERVER, TPC-H)



CONCLUSIONS

CONCLUSIONS

- Abstract model for the allocation of cores
- Thread scheduling works better with less cores (local optimum number of cores)
- Less thread migrations with less data movement: up to 3.87x of reduction on traffic ratio
- Up to 26% on energy savings

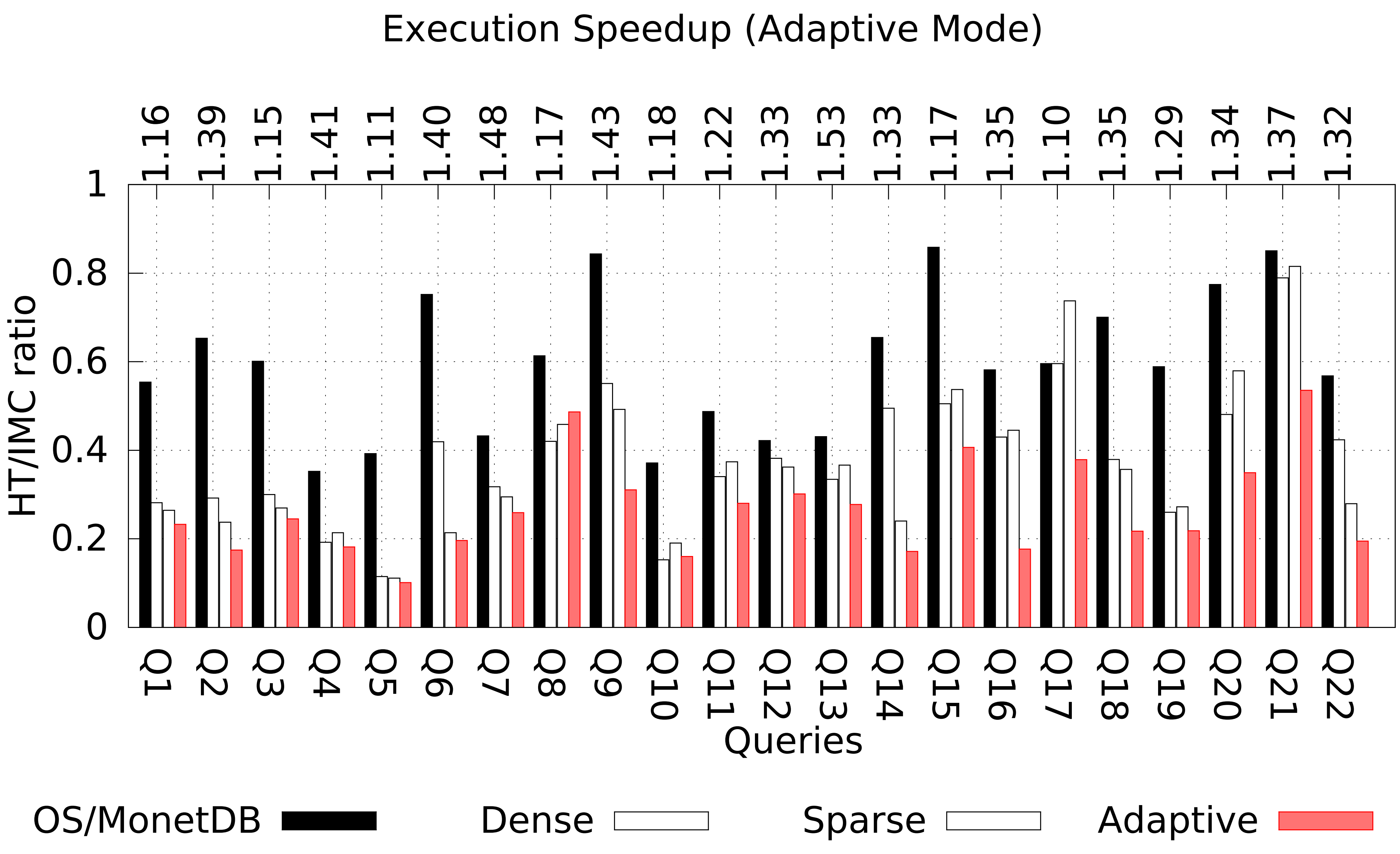
THANKS!

EDUARDO@INF.UFPR.BR

ACKNOWLEDGMENTS: FUNDAÇAO ARAUCARIA, CAPES, CNPQ AND FUNDO NACIONAL DE DESENVOLVIMENTO DA EDUCAÇÃO (FNDE).

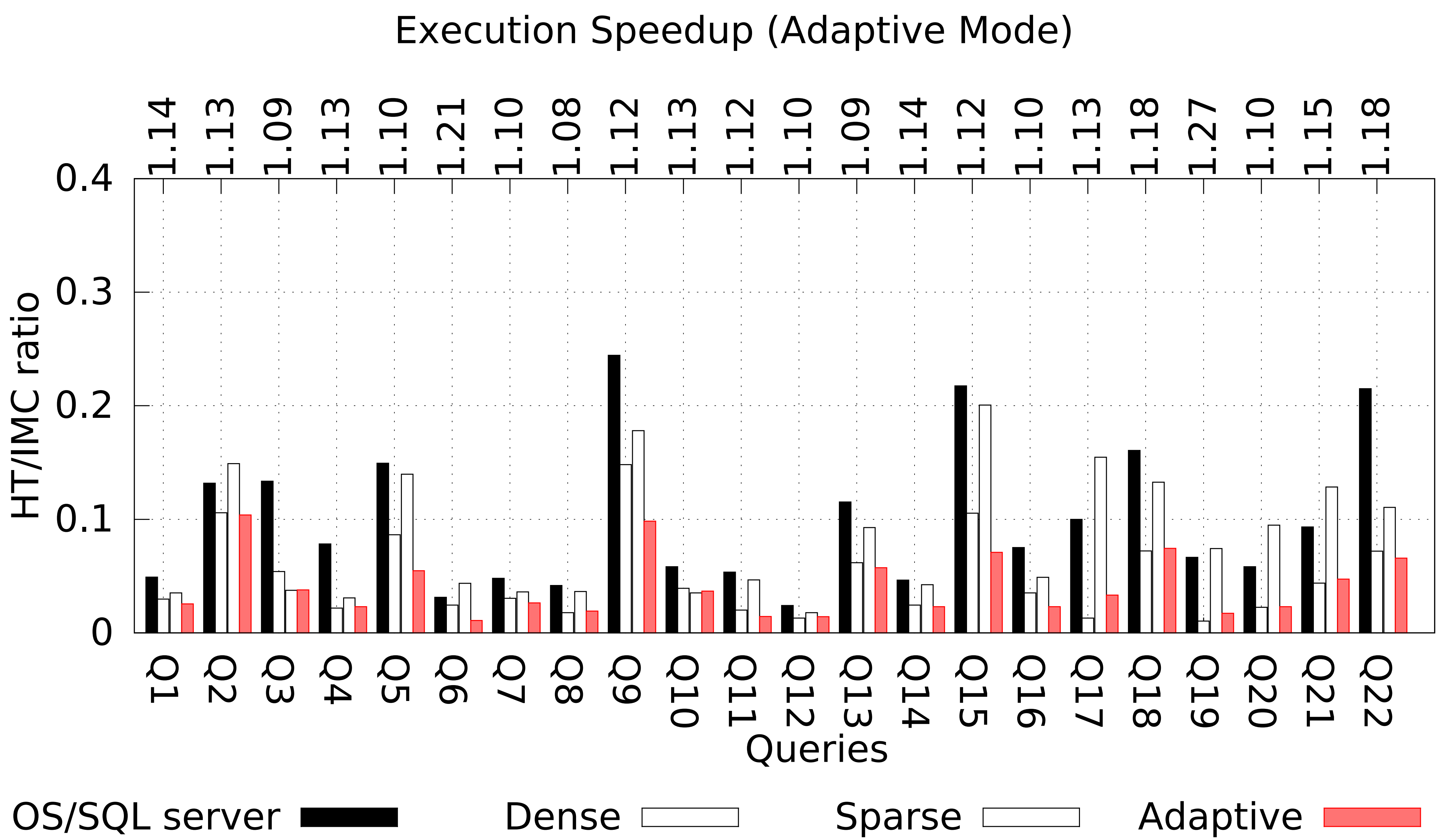
NUMA-FRIENDLINESS: INTERCONNECTION RATIO

(MONETDB, 256 USERS, 1 GB DATABASE, TPC-H)



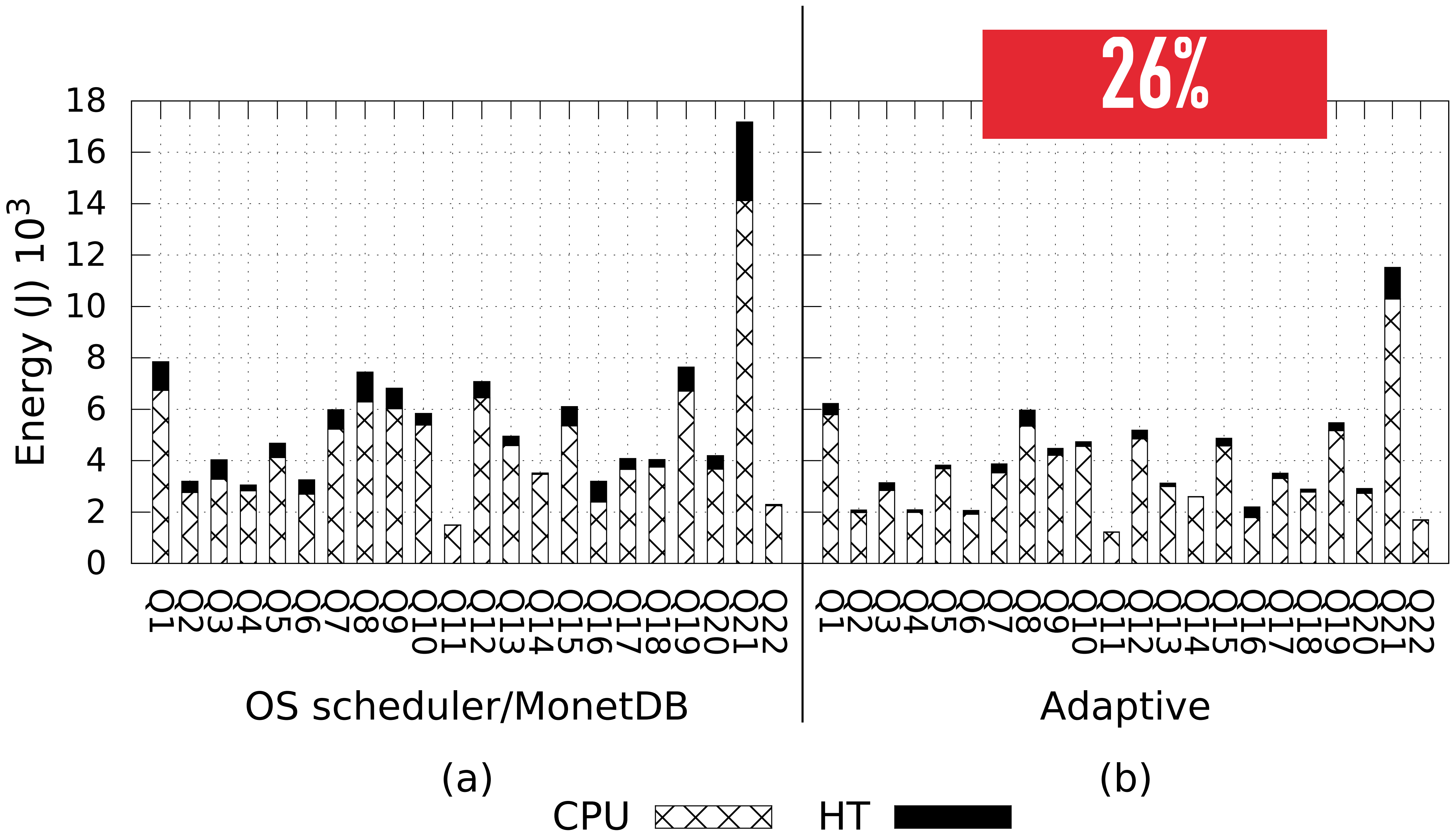
NUMA-FRIENDLINESS: INTERCONNECTION RATIO

(SQL SERVER, 256 USERS, 1 GB DATABASE, TPC-H)



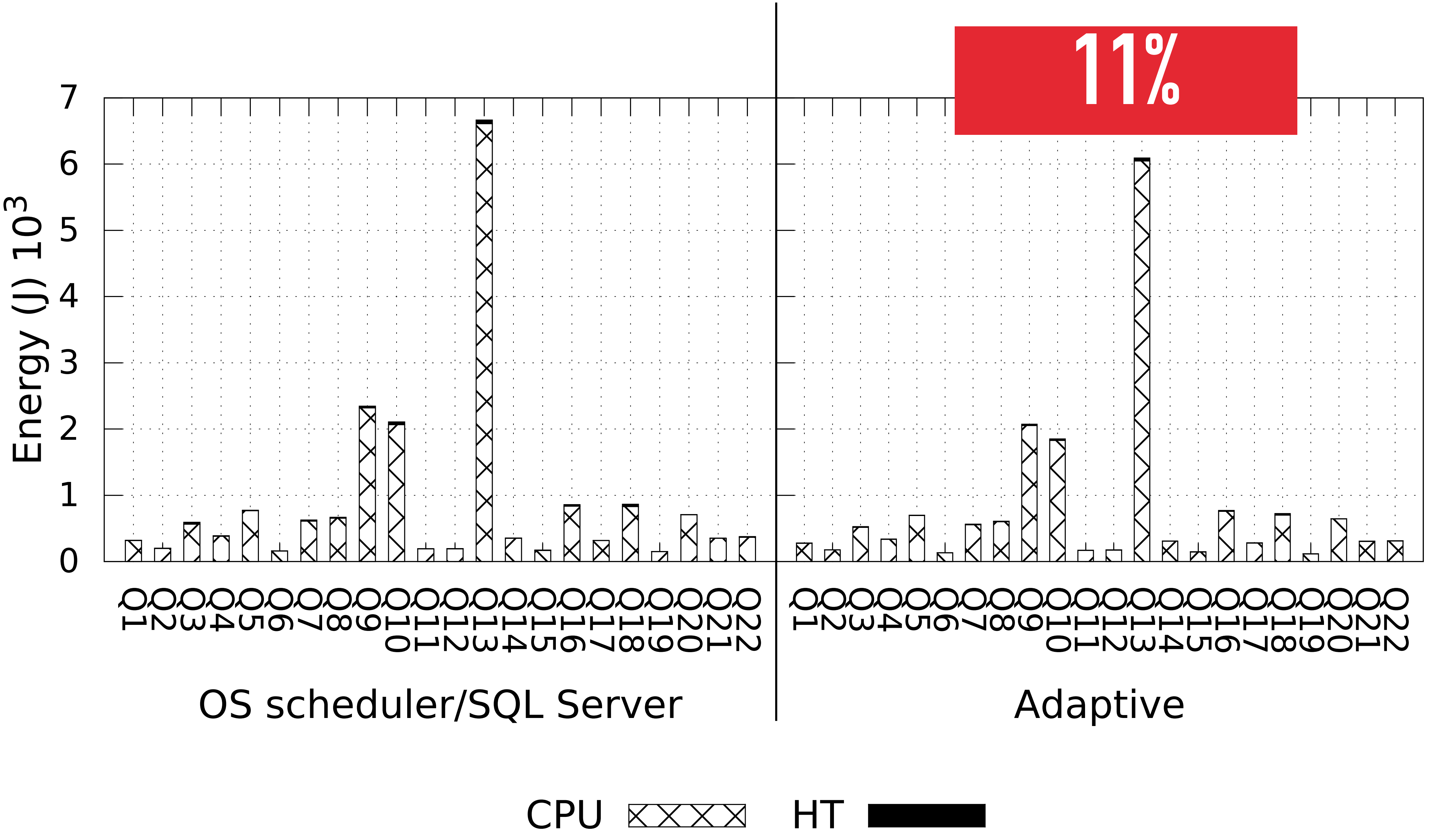
ENERGY SAVINGS

(MONETDB, 256 USERS, 1 GB DATABASE, TPC-H)



ENERGY SAVINGS

(SQL SERVER, 256 USERS, 1 GB DATABASE, TPC-H)



PETRINET MULTI-CORE ALLOCATION MECHANISM

(DEFINITION: LOCAL OPTIMUM NUMBER OF CORES)

$$\forall\ w\ \exists\ n_{alloc} | (th_{min} < u < th_{max}) \wedge p(n_{alloc}) \geq p(n_{total})$$

- w is the current workload of the database threads
- n_{alloc} is the number of allocated CPU cores ($n_{alloc} \leq n_{total}$)

PETRINET MULTI-CORE ALLOCATION MECHANISM

(DEFINITION: LOCAL OPTIMUM NUMBER OF CORES)

$$\forall\ w\ \exists\ n_{alloc} | (th_{min} < u < th_{max}) \land p(n_{alloc}) \geq p(n_{total})$$

- u is the average resource usage of database threads between minimum and maximum *thresholds*
- ntotal is the number of available CPU cores
- p(x) is the performance function, where x assumes the number of CPU cores nalloc or ntotal