Unleashing dynamic task scheduling at rack-scale

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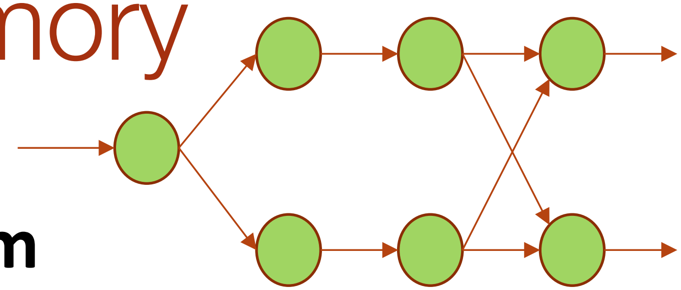
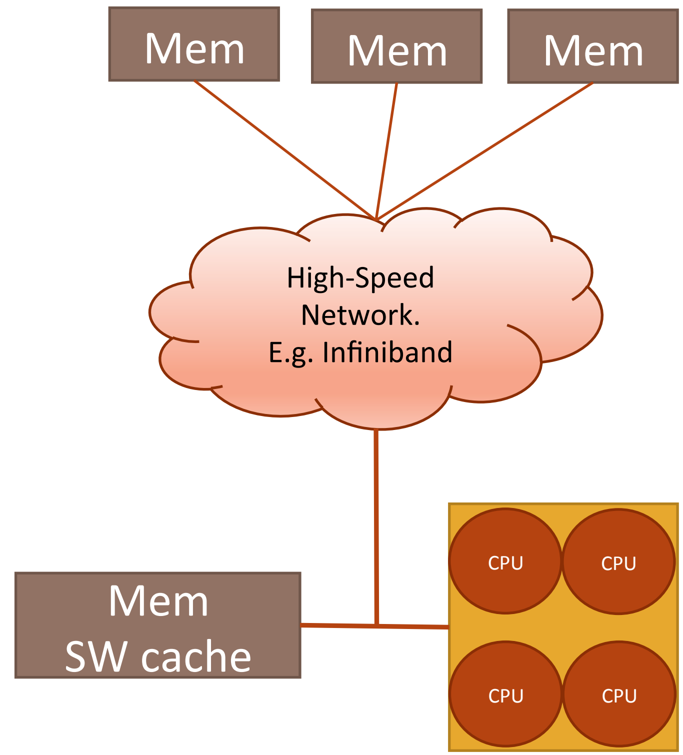
Task based programming on distributed shared memory



- **Can we scale a task based system at cluster scale?**
- **… on a Software DSM ?!**
  - **→ Yes, If we co-design scheduling & caching**

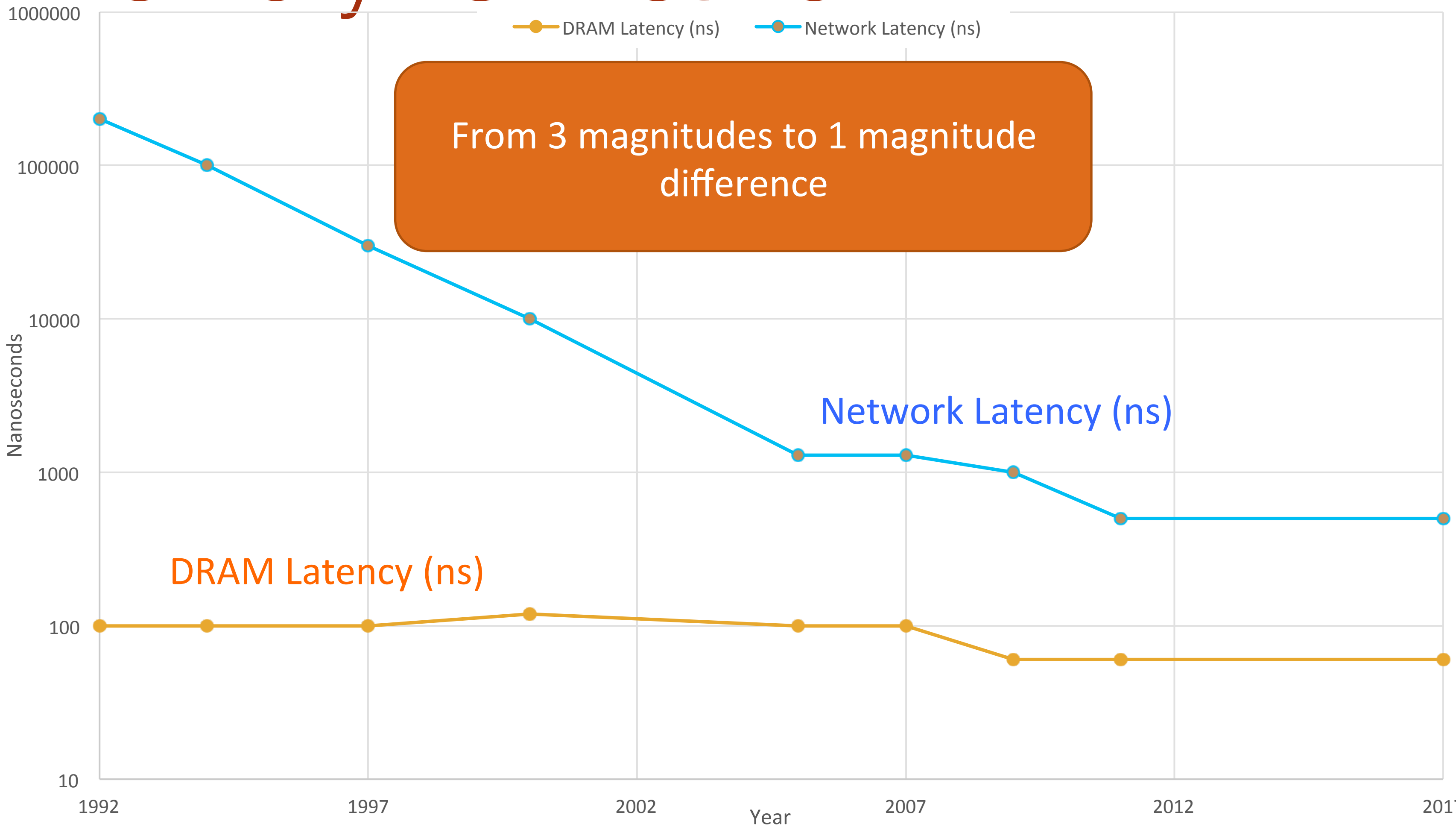


Early results: Running tasks on remote memory at >90% of native execution on local memory

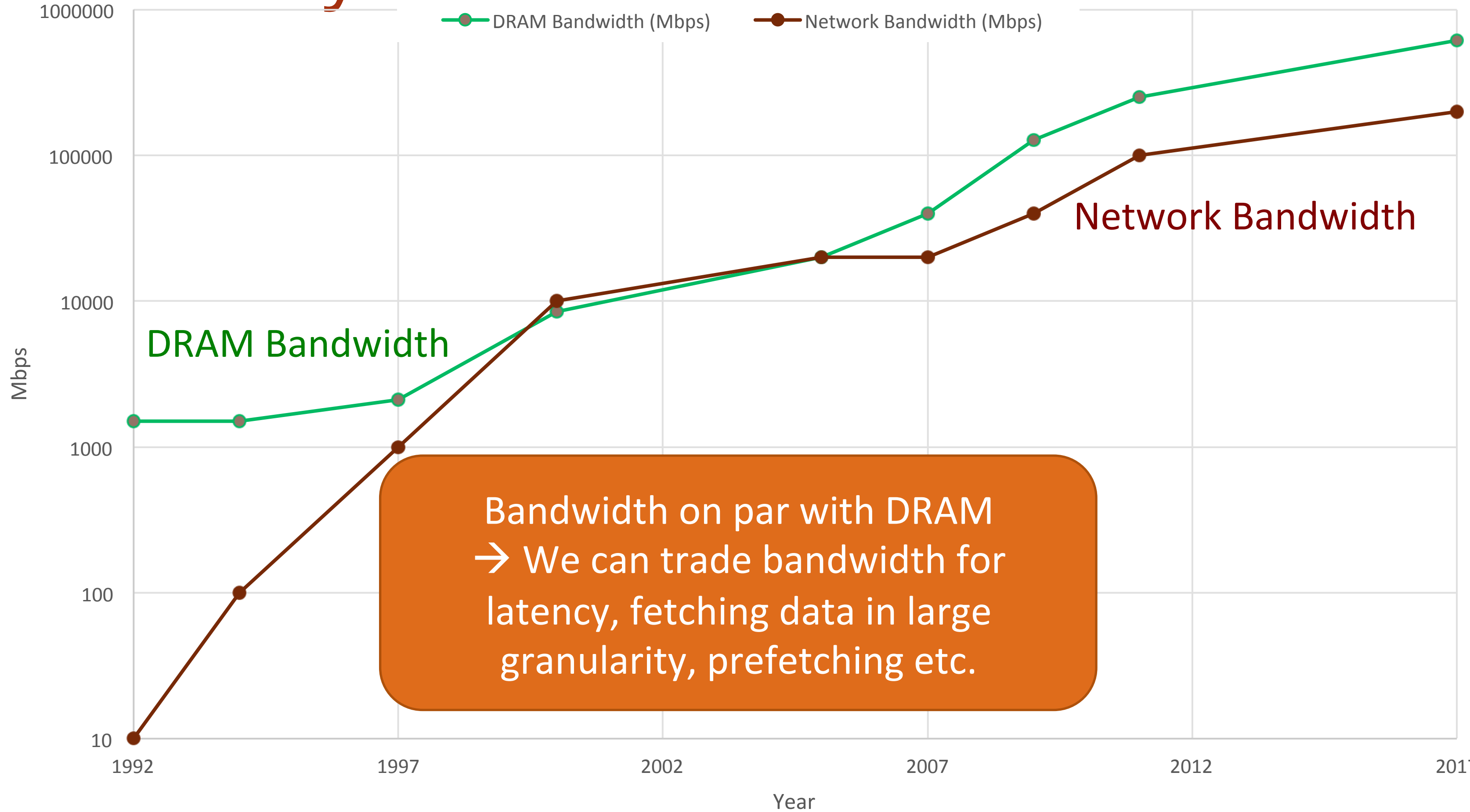
Distributed Shared Memory

- Coherent Distributed Shared Memory (DSM) gives us:
  - Transparent Caching (takes advantage of *any* locality)
    - Even if locality is tiny, its benefit is a function of latency!
    - Avoids hybrid SM (intranode)-MP (internode) programming
  - Freedom from data distribution
    - Demand fetching, prefetching can largely hide bad distribution
  - Natural and familiar synchronization constructs (locks)
  - Extend memory beyond one node
- But isn't this quite costly?
  - Yes – Used to be, but times have changed
    - Latency only one magnitude worse than DRAM
    - …And bandwidth is on par with DRAM

Trends: Latency
Memory vs. Network



Trends: Bandwidth Memory vs. Network



Bandwidth on par with DRAM
→ We can trade bandwidth for latency, fetching data in large granularity, prefetching etc.

ARGO DSM (www.argodsm.com)

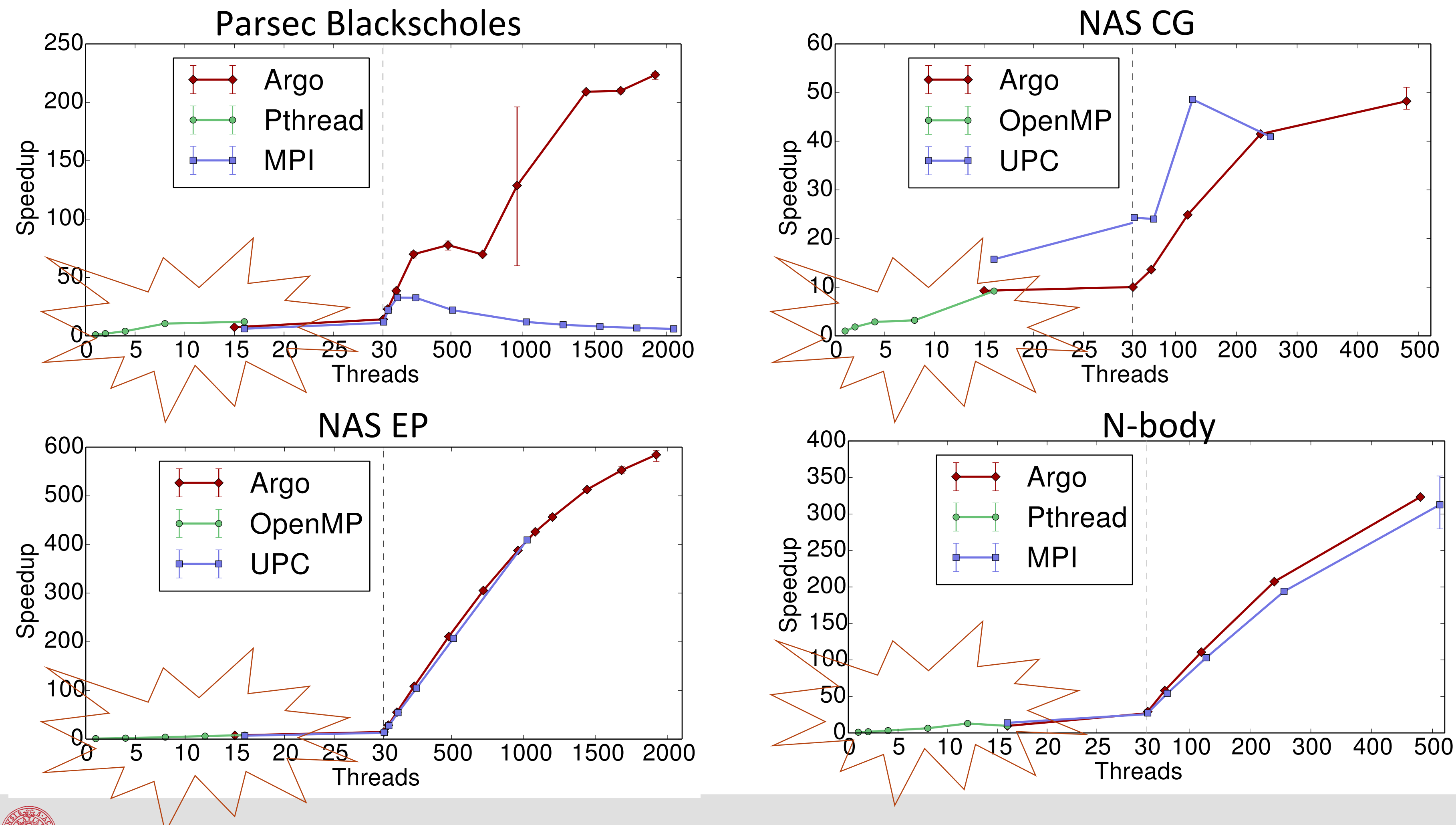
- A DSM based on current trends [HPDC'15]:
  - User-space implementation
  - Page-based DSM (uses virtual memory faults for misses)
  - MPI is the "network layer" (but only need RDMA)
  - Runs
    - Pthreads – Data race free programs
    - OpenMP - Manually ported (Minor modifications)
    - Compile and link with ArgoDSM library → MPI program that implements DSM

ARGO DSM (www.argodsm.com)

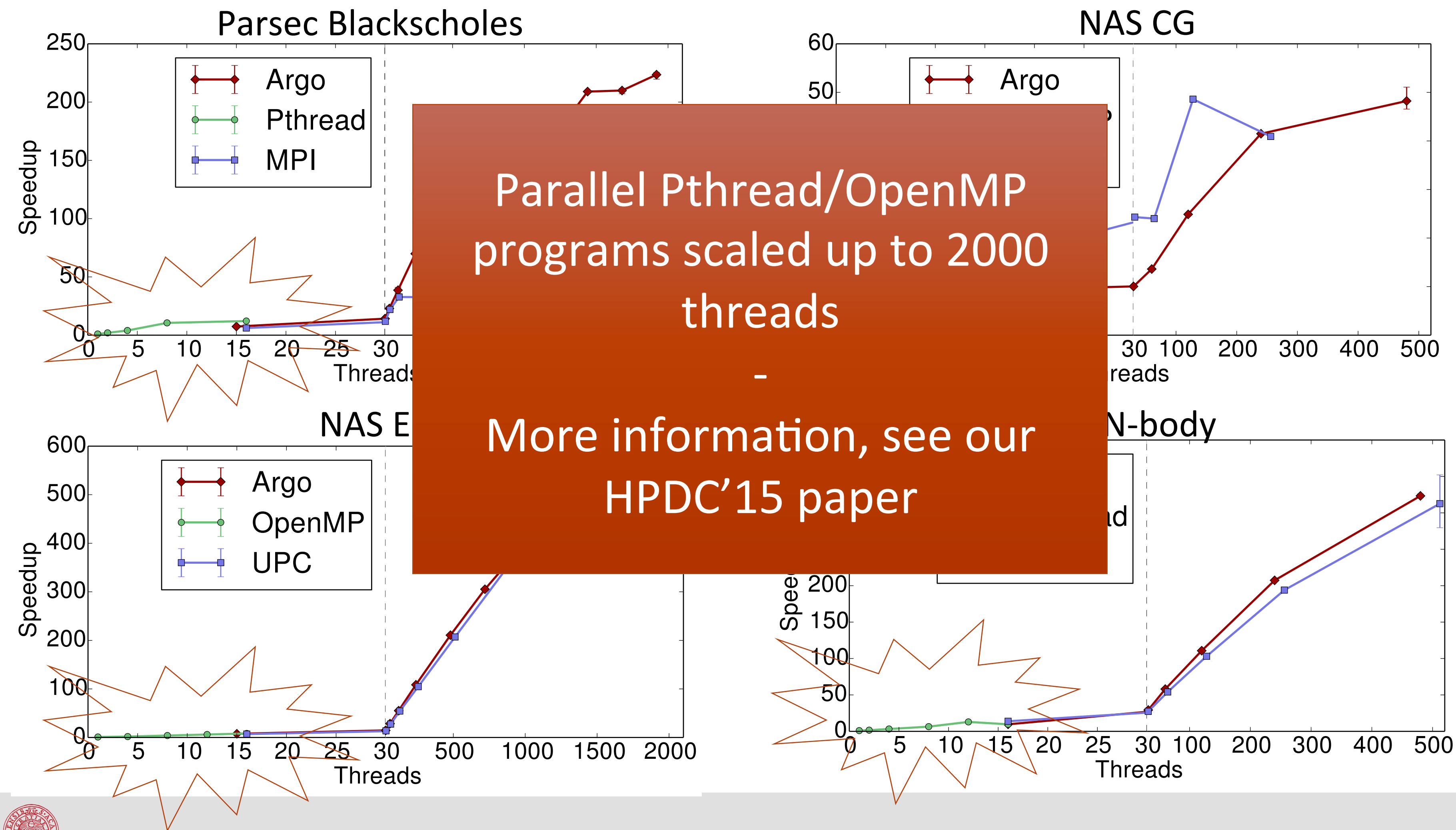
- Under the hood [HPDC'15]
  - SC for DRF (Sequential Consistency for Data Race Free)
    - Full relaxation of memory ordering between synchronization
  - Builds on very simple, completely distributed coherence (VIPS) [PACT'15, ISCA'13]
  - Queue Delegation Locking primitives [IEEE TPDS'18]

- Take decisions locally & Trade bandwidth for latency

Benchmark scaling
Pthread / OpenMP on ArgoDSM



Benchmark scaling
Pthread / OpenMP on ArgoDSM



Parallel Pthread/OpenMP programs scaled up to 2000 threads

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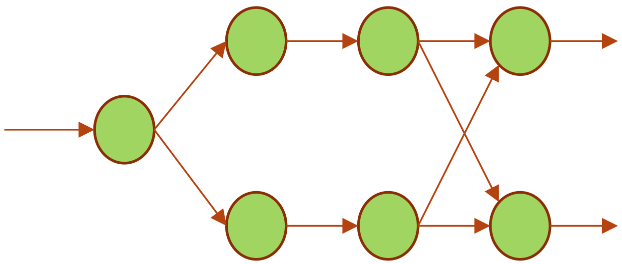
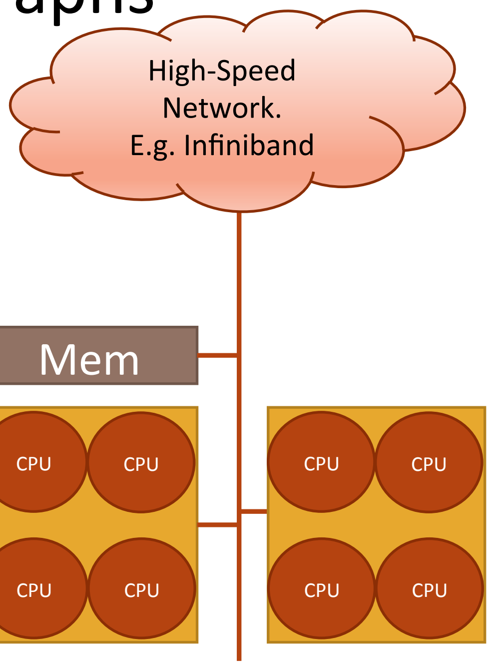
More information, see our HPDC'15 paper

Task based programming



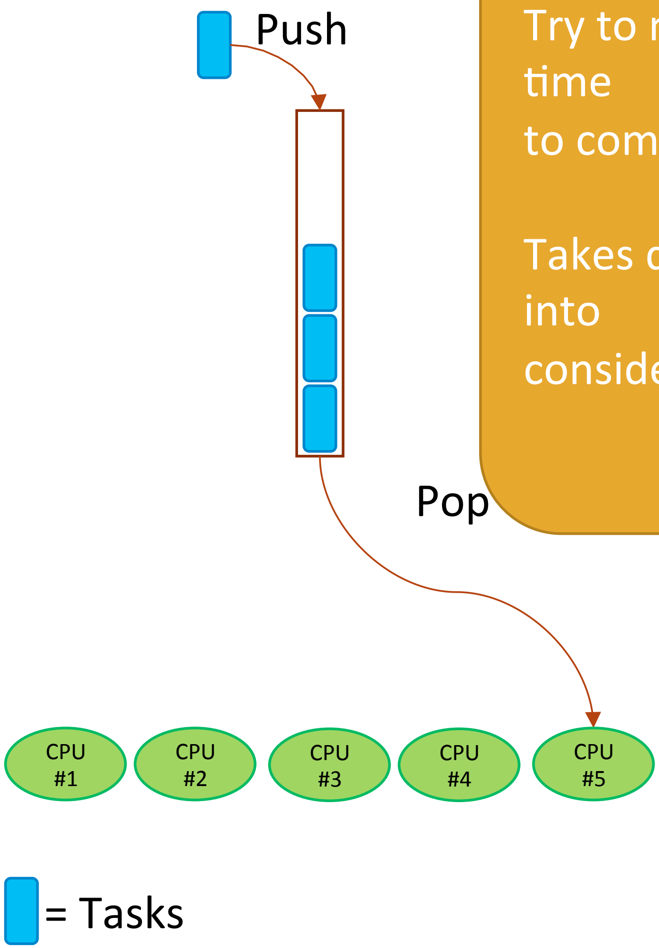
- Parallel programming model
  - **StarPU**, OmpSs, OpenMP, etc
- Express parallelism in terms of task-graphs
  - Can target heterogeneous systems
    - Our use case only runs on CPUs
  - High performance
    - Use kernels from BLAS libraries
- Challenge: How to do scheduling?
  - Eager
  - Data aware
  - Custom…

Couple with ArgoDSM for cluster awareness!



Task schedulers

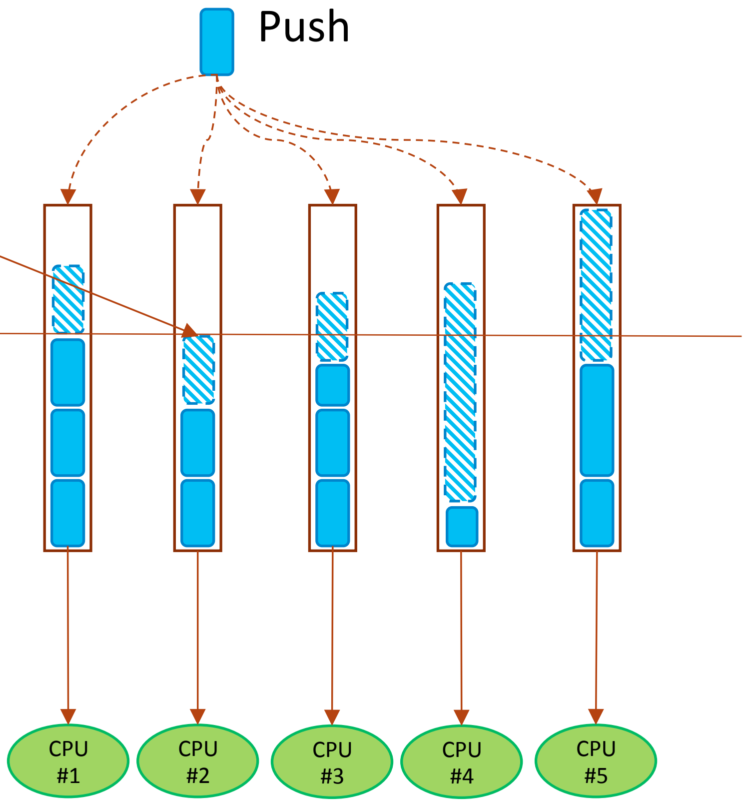
Eager Scheduling



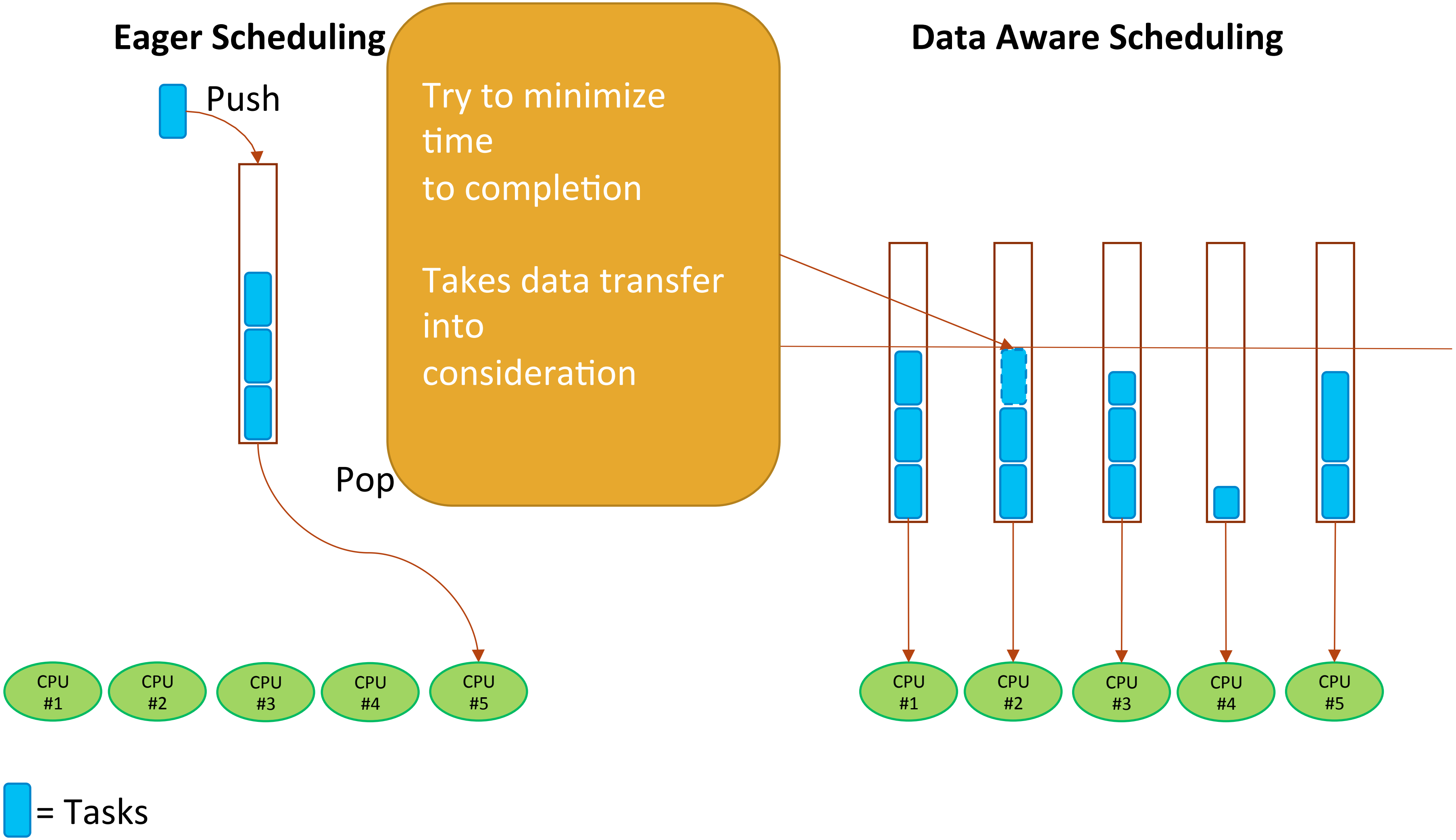
Try to minimize time to completion

Takes data transfer into consideration

Data Aware Scheduling



Task schedulers



Try to minimize time
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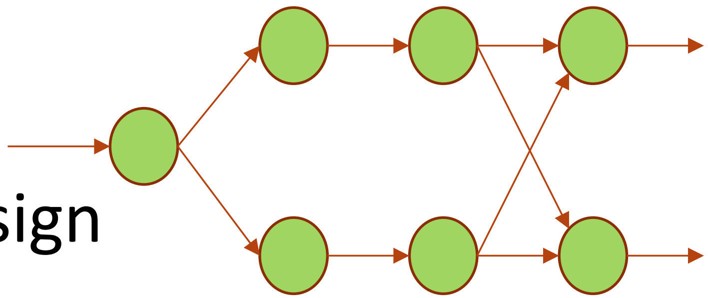
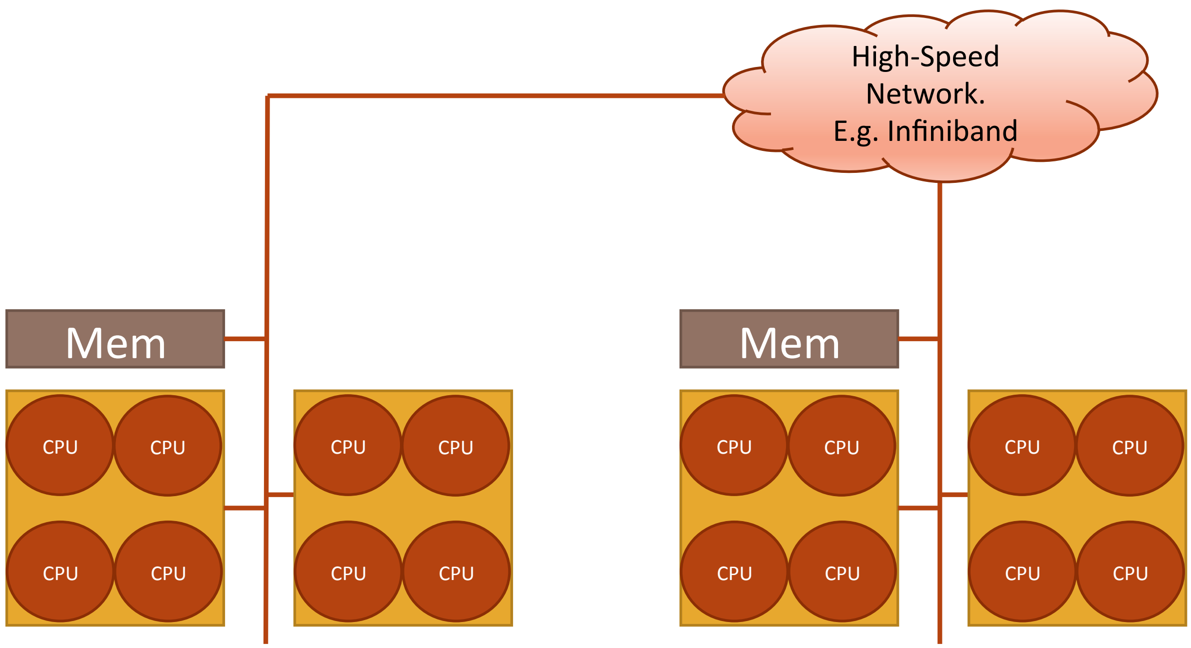
The perfect fit ArgoDSM+Tasks



- Tasks over ArgoDSM Co-design
  - ArgoDSM can
    - Handle caching of remote data making it appear as local



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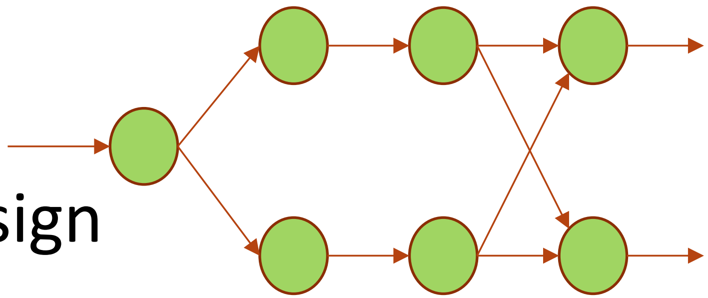

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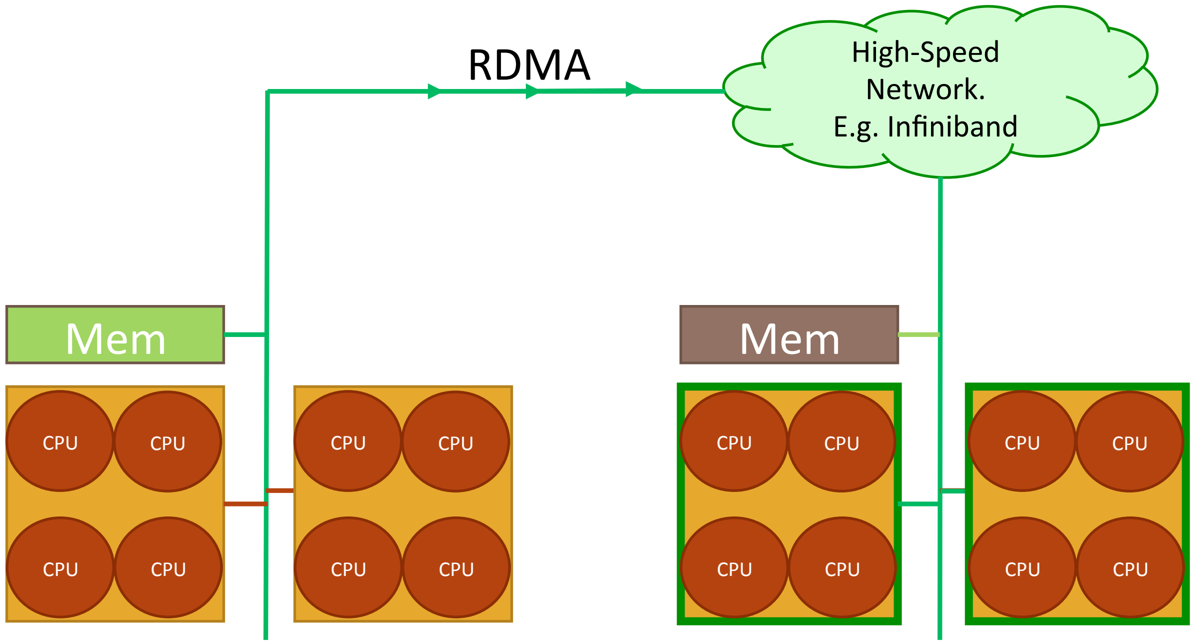
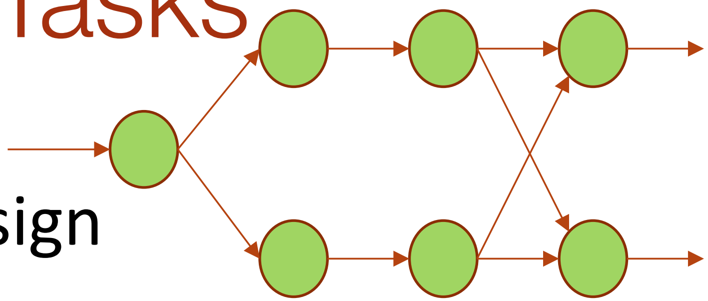
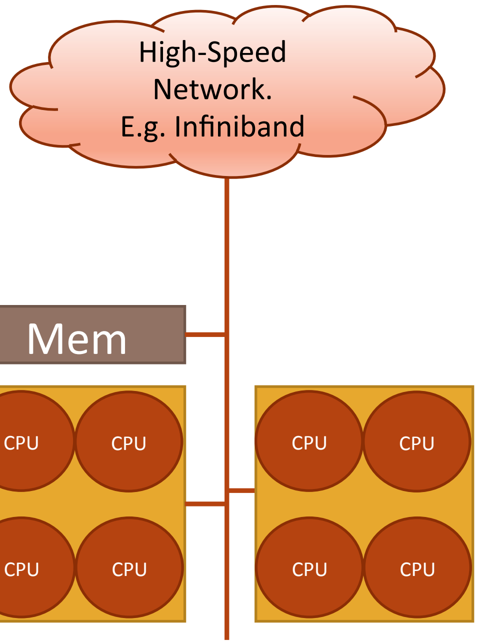


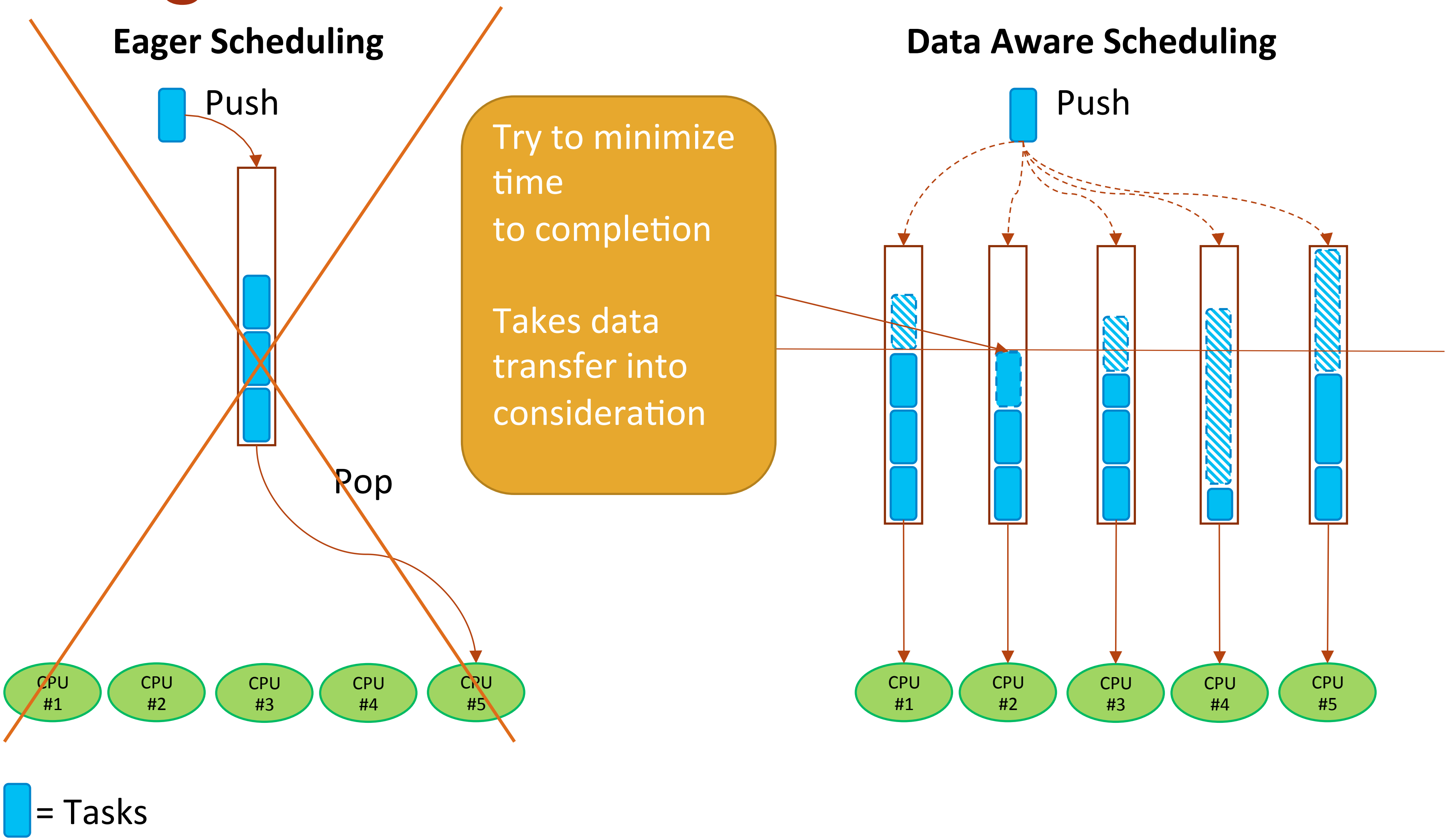
The perfect fit
Cluster level DSM+Tasks



- Tasks over ArgoDSM Co-design
  - ArgoDSM can
    - Handle caching of remote data making it appear as local
    - Exploit task information
      - Prefetch data ahead of time
      - Prevent eviction of useful data
  - StarPU: performance models
    - ➔ ArgoDSM (cluster) locality!



ArgoDSM aware scheduler



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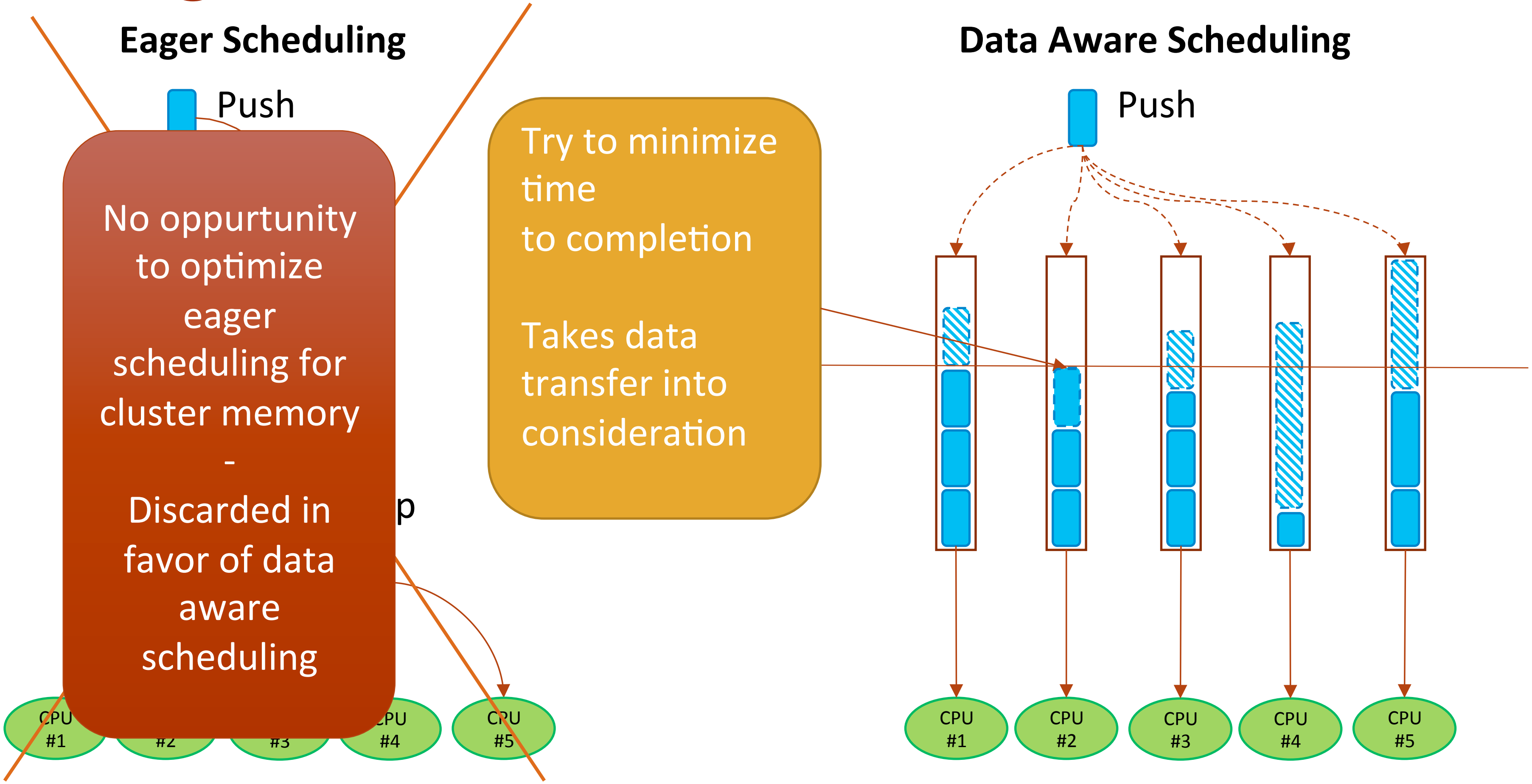
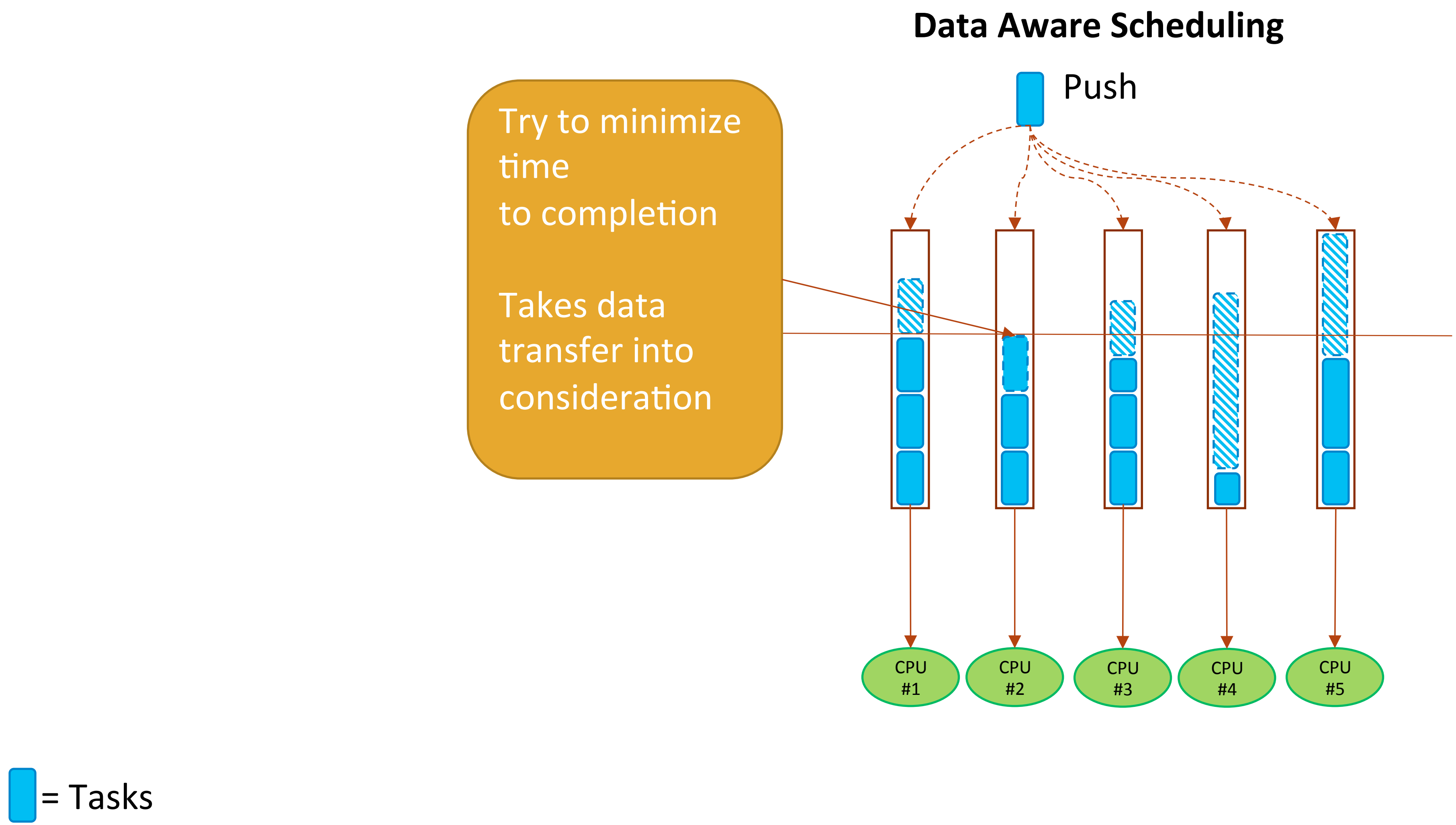


= Tasks

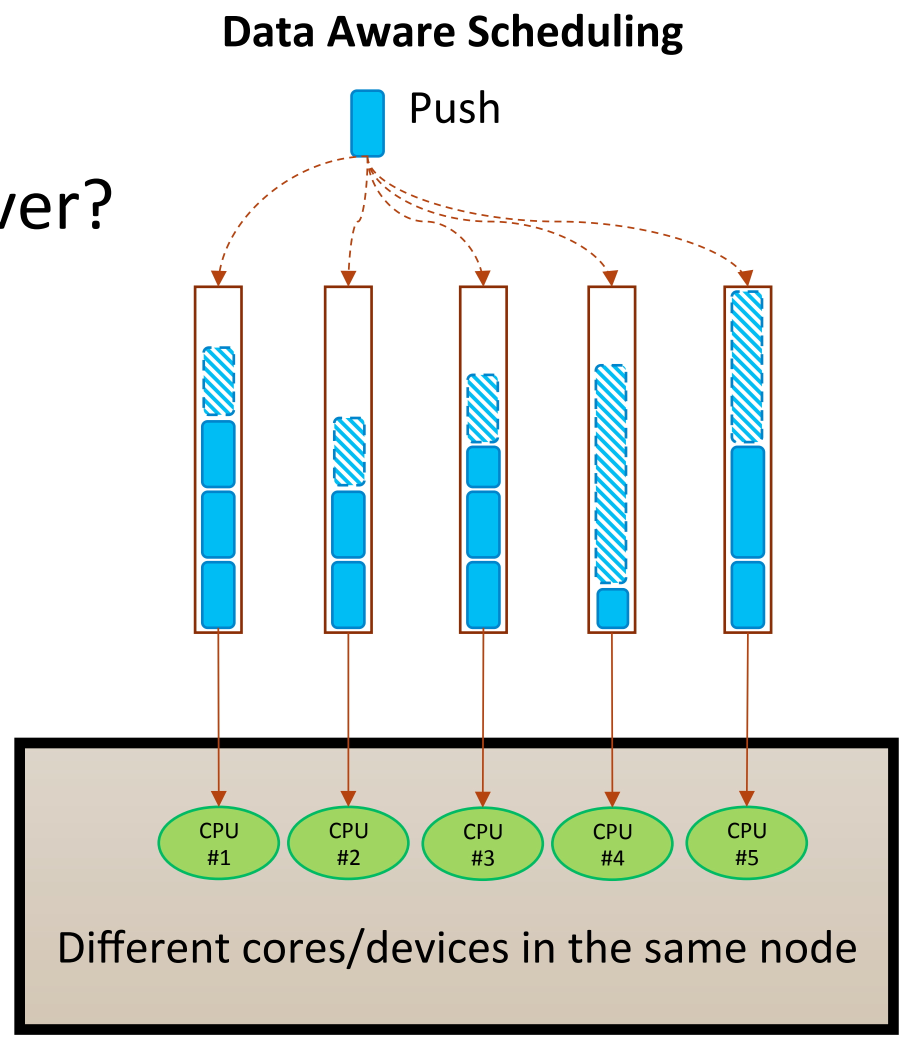
ArgoDSM aware scheduler



ArgoDSM aware scheduler
Data Aware

ArgoDSM aware scheduler
Data Aware

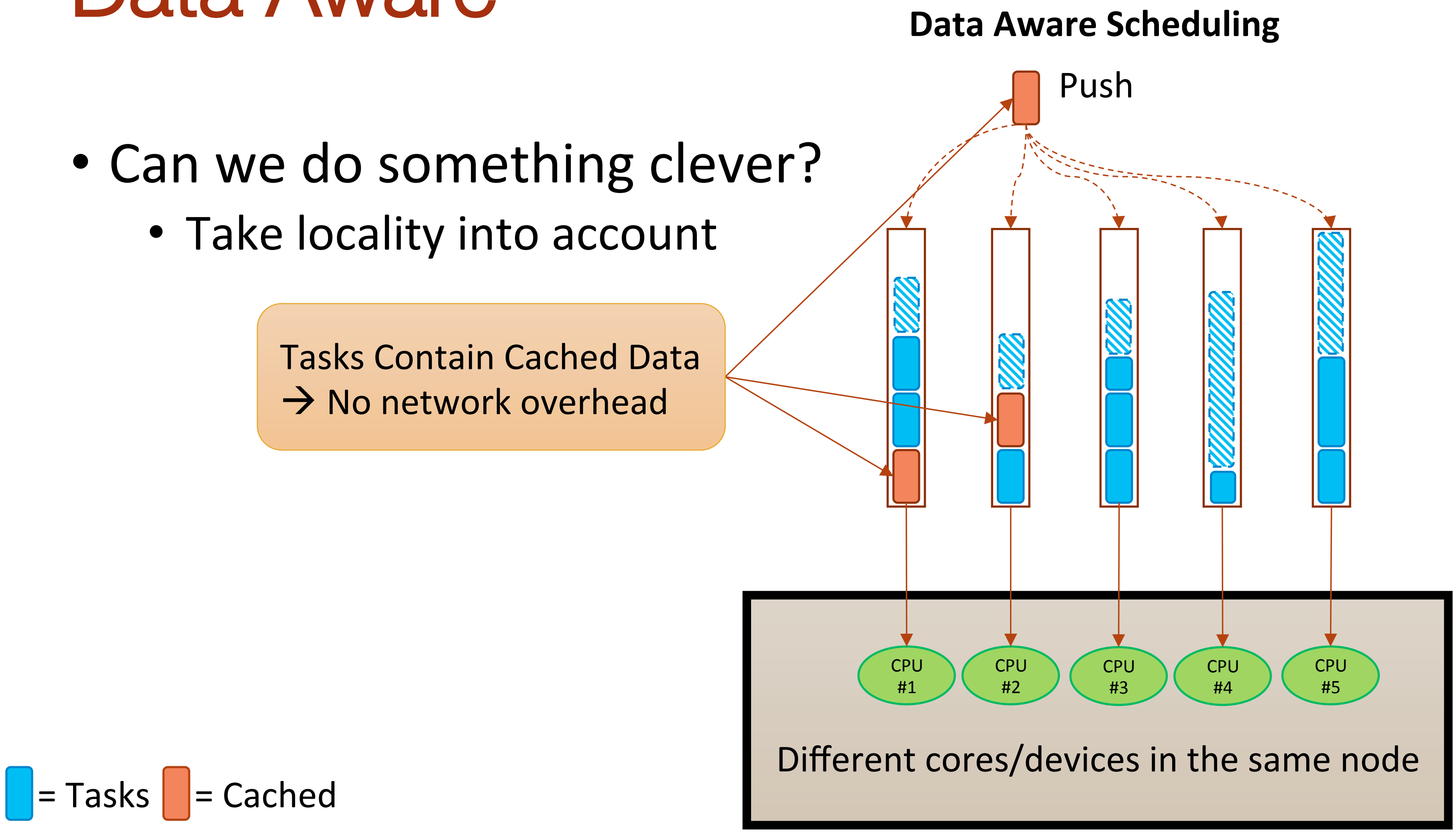
- Can we do something clever?



= Tasks

ArgoDSM aware scheduler
Data Aware

- Can we do something clever?
  - Take locality into account



ArgoDSM aware scheduler
Data Aware

- Can we do something clever?
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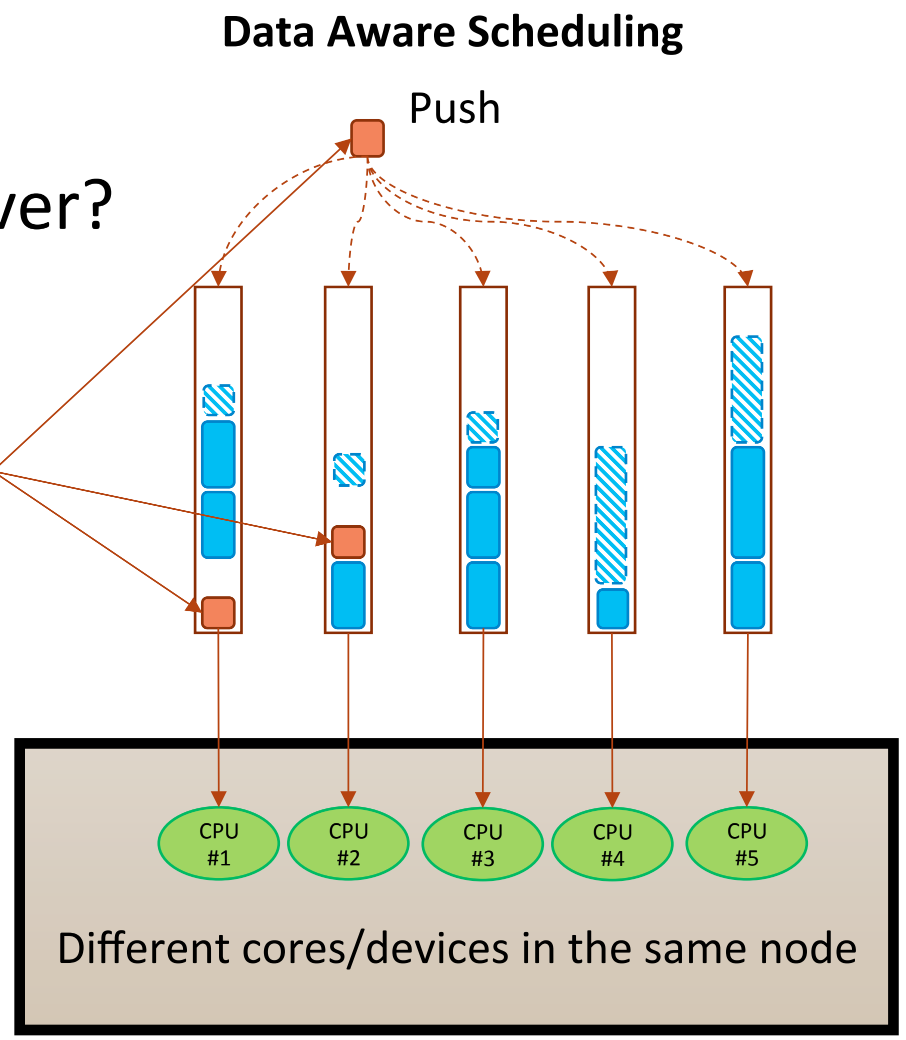
Tasks Contain Cached Data
→ No network overhead



= Tasks = Cached

ArgoDSM aware scheduler
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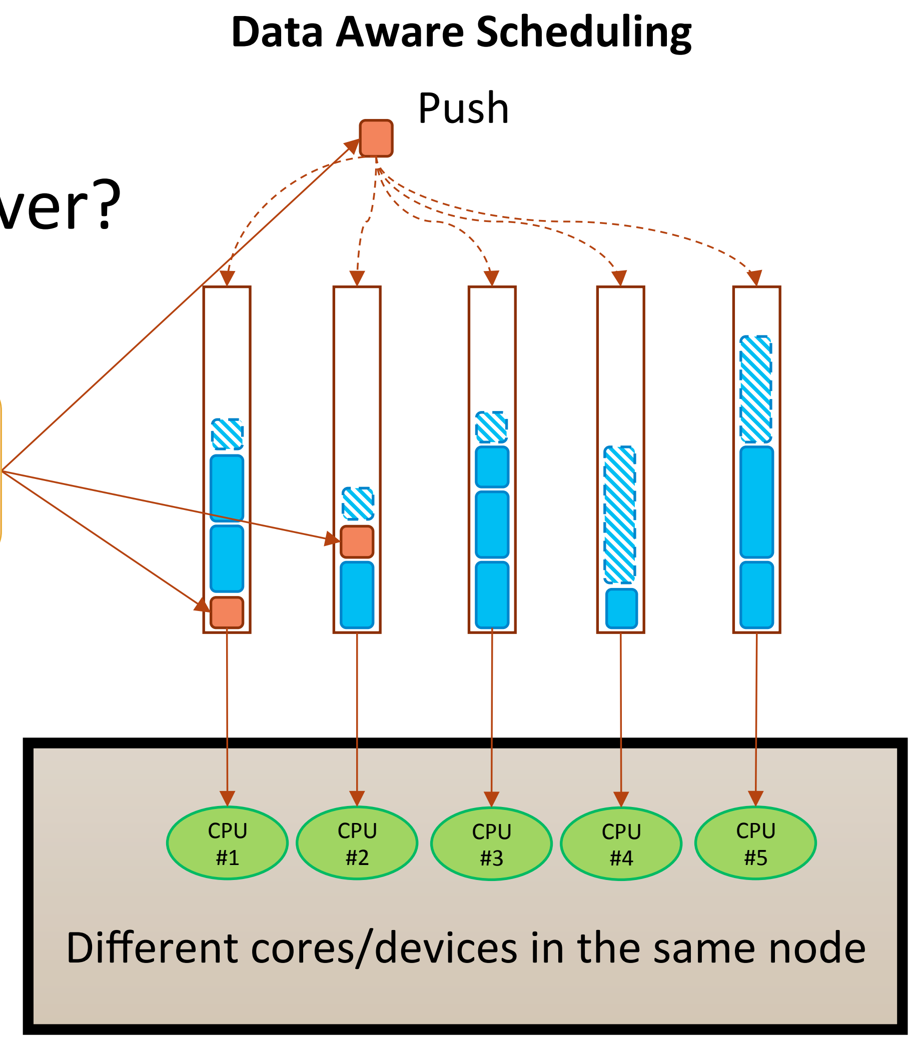

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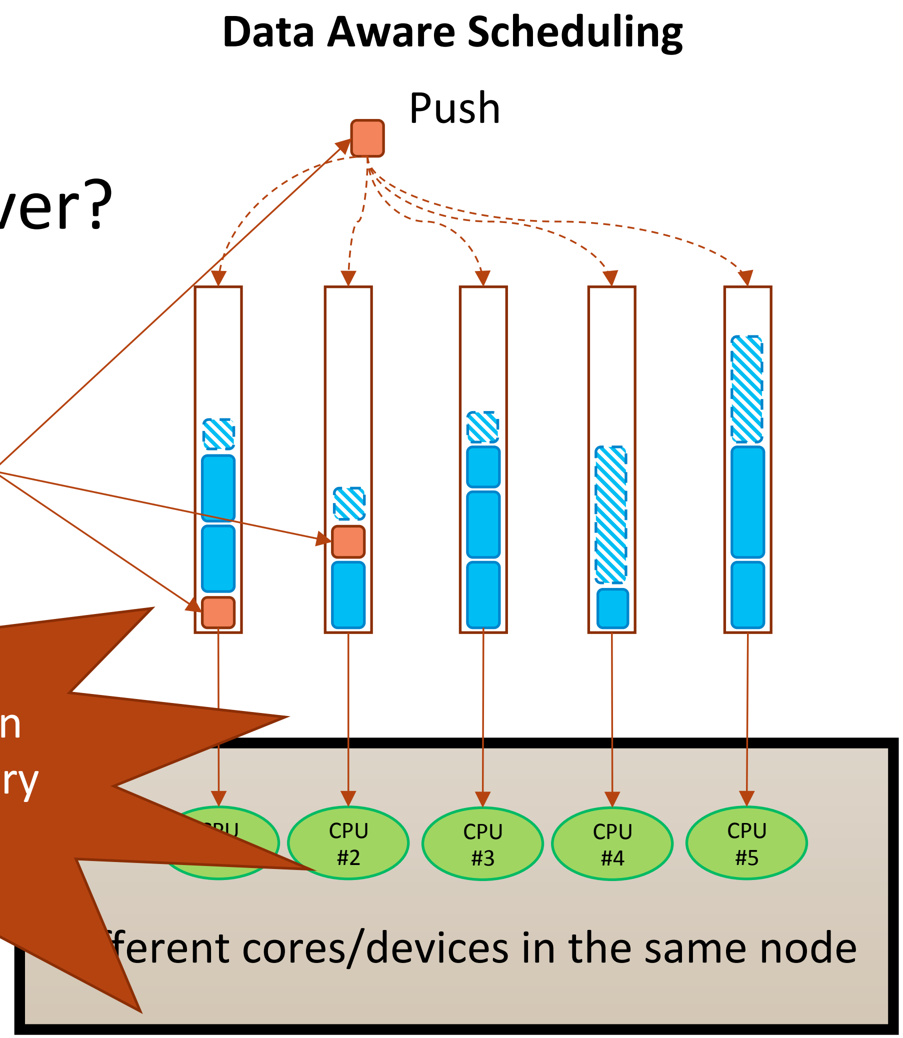


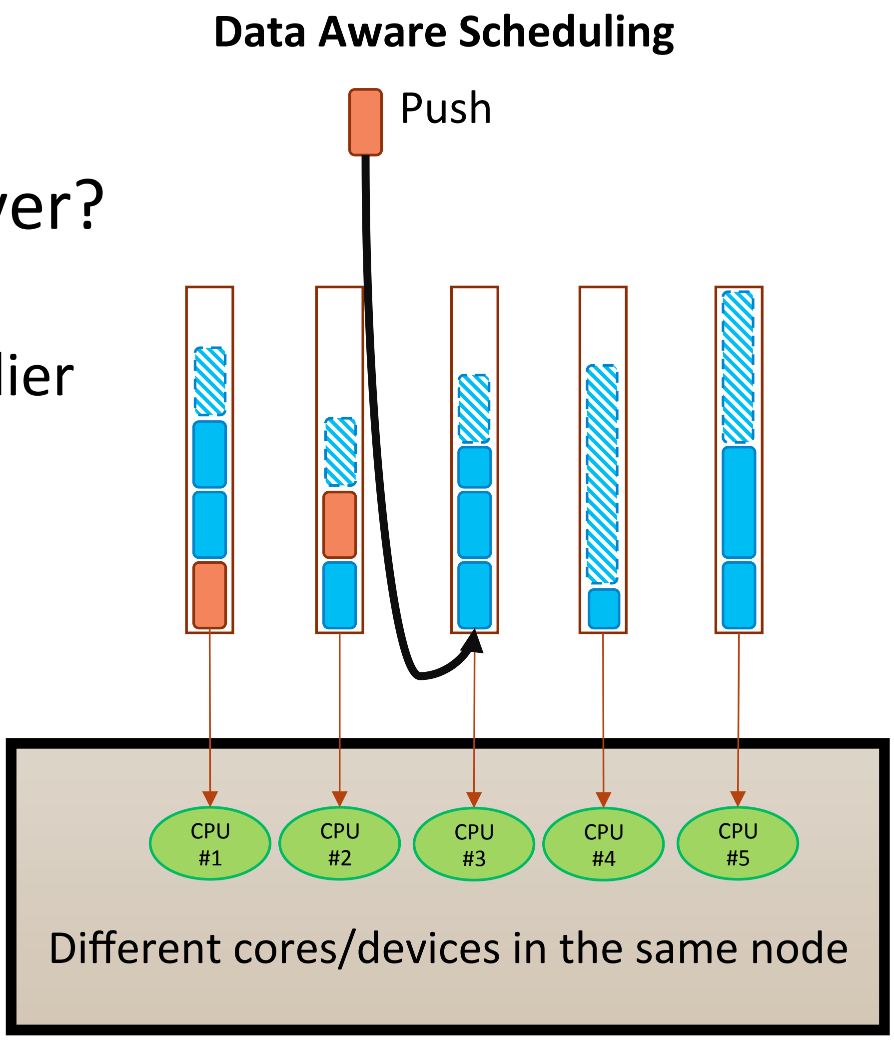
Better runtime prediction
adapted to cluster memory
→ Higher performance

= Tasks = Cached

ArgoDSM aware scheduler
Local First

ArgoDSM aware scheduler
Local First

- Can we do something clever?
  - Take locality into account
  - Schedule cached tasks earlier



= Tasks = Cached

ArgoDSM aware scheduler
Local First

Data Aware Scheduling

Push

- Can we do something clever?
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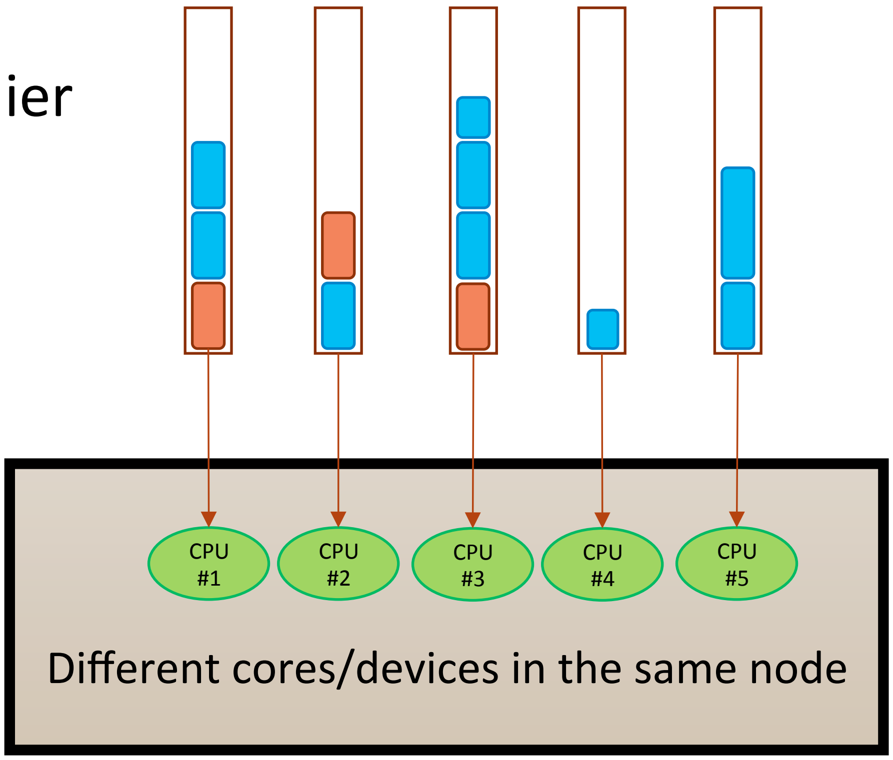
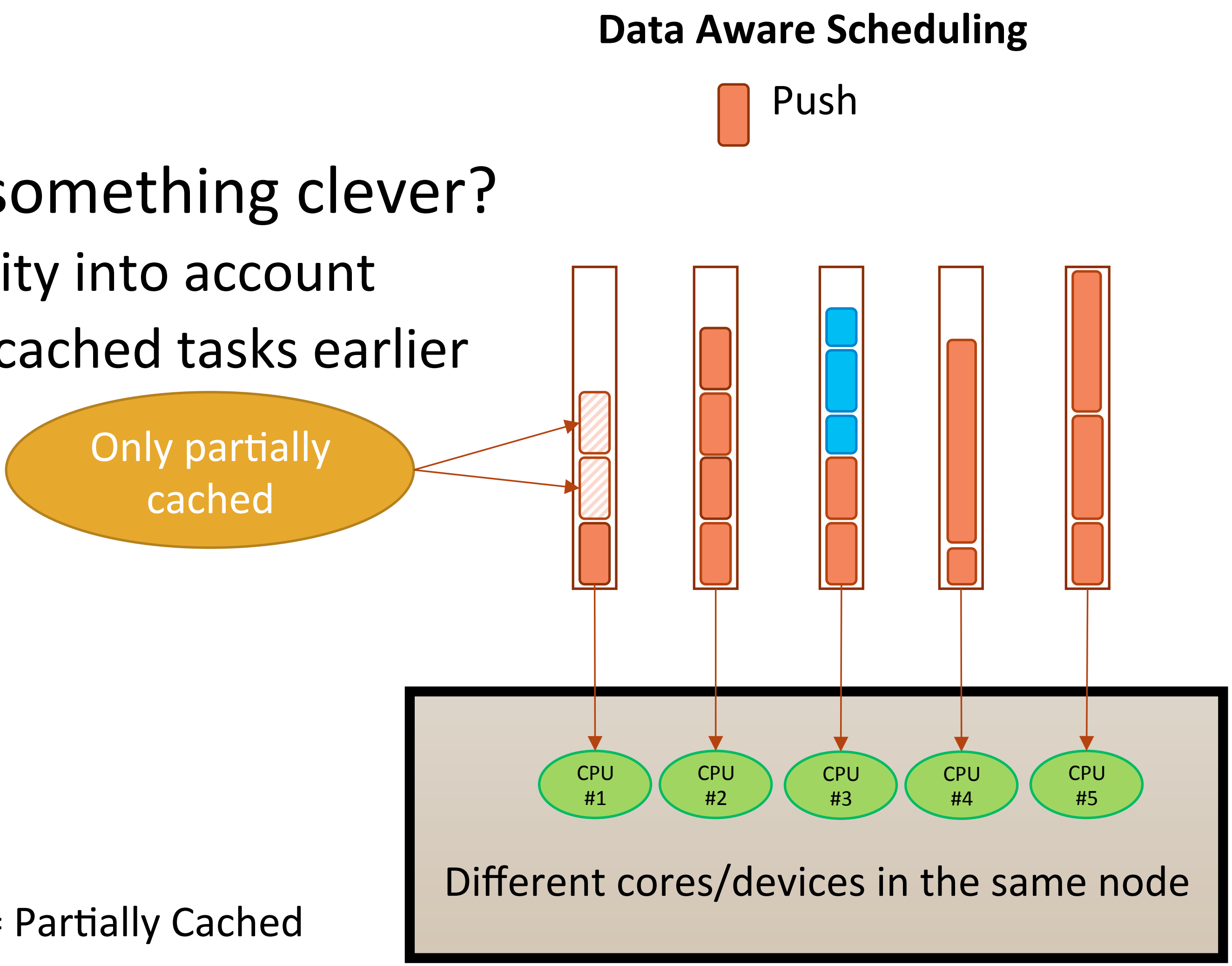


= Tasks = Cached

ArgoDSM aware scheduler
Sorted Insert

ArgoDSM aware scheduler
Sorted

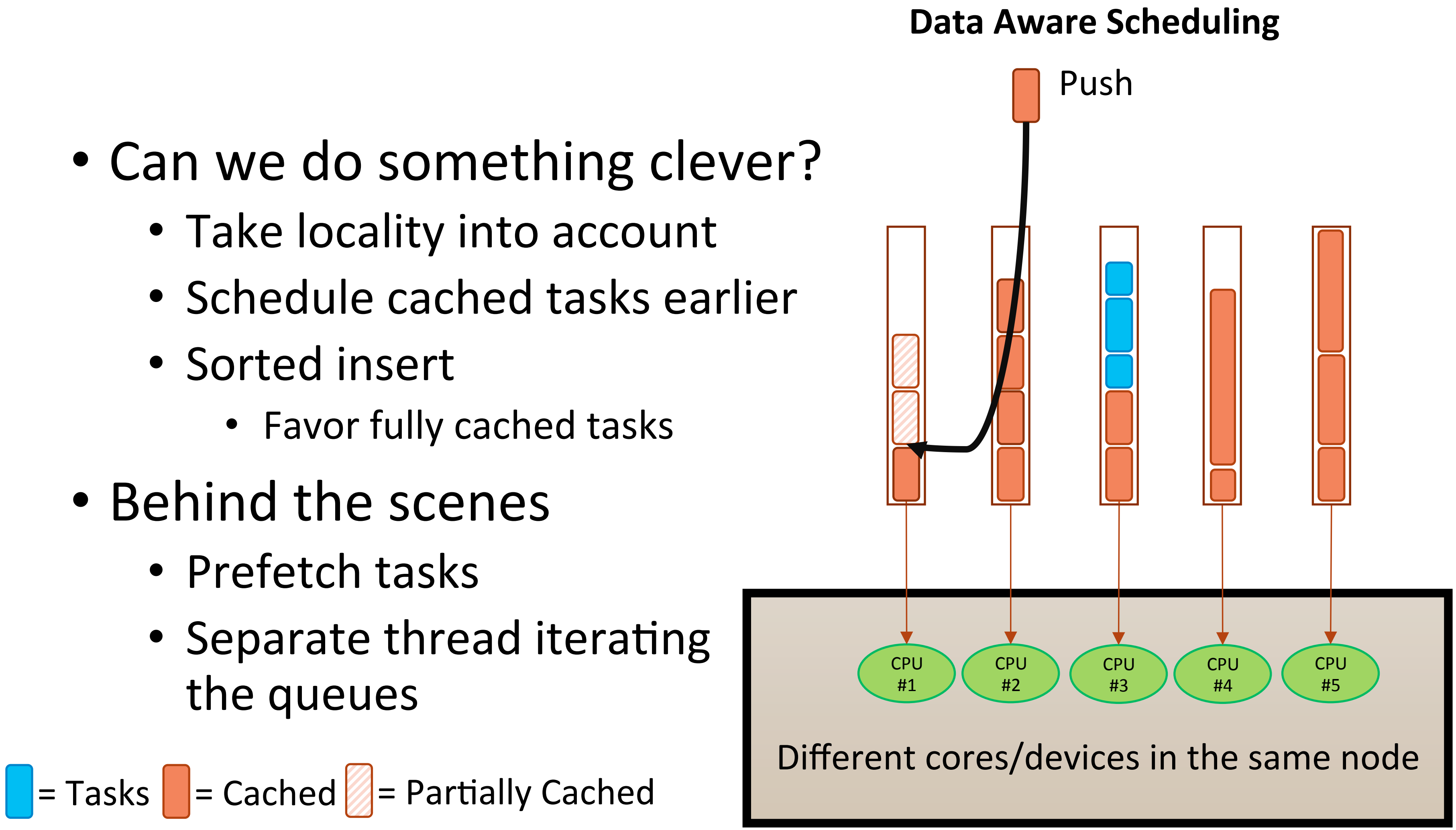
- Can we do something clever?
  - Take locality into account
  - Schedule cached tasks earlier



= Tasks = Cached = Partially Cached

ArgoDSM aware scheduler

- Can we do something clever?
  - Take locality into account
  - Schedule cached tasks earlier
  - Sorted insert
    - Favor fully cached tasks
- Behind the scenes
  - Prefetch tasks
  - Separate thread iterating the queues



ArgoDSM aware scheduler

Data Aware Scheduling

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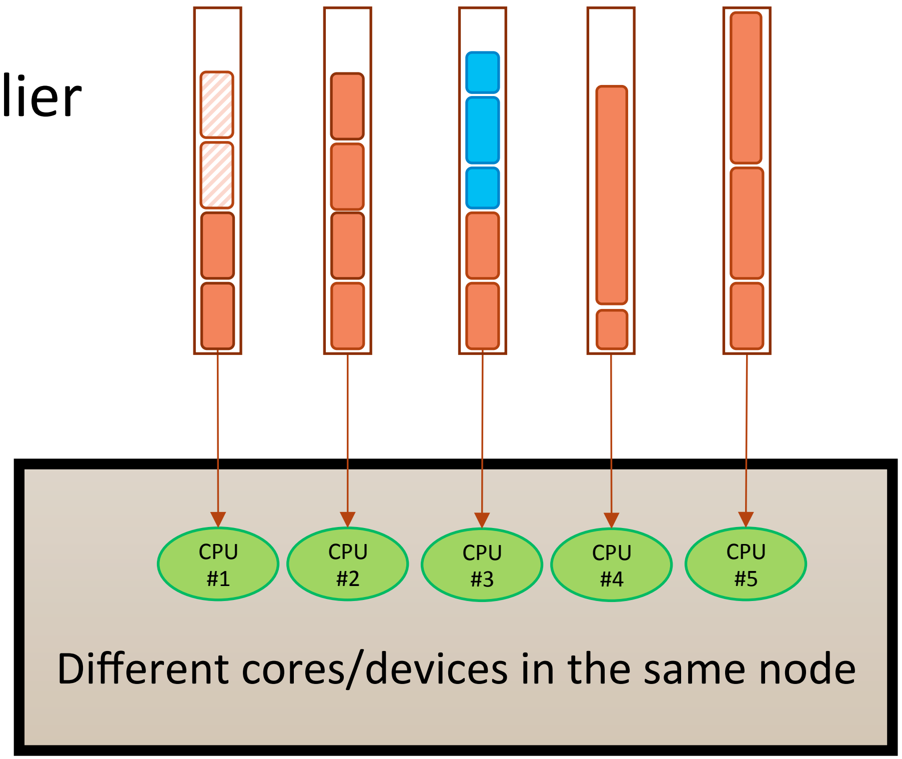
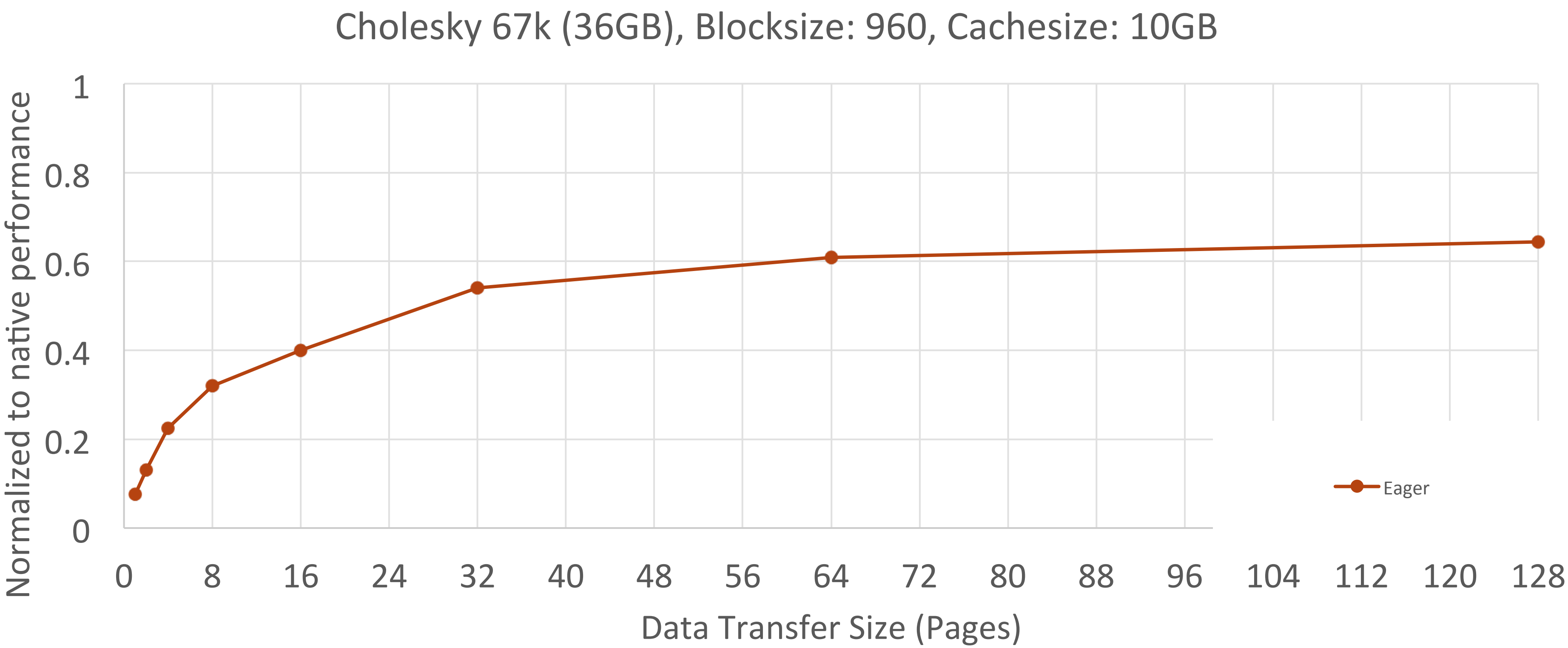


= Tasks = Cached = Partially Cached

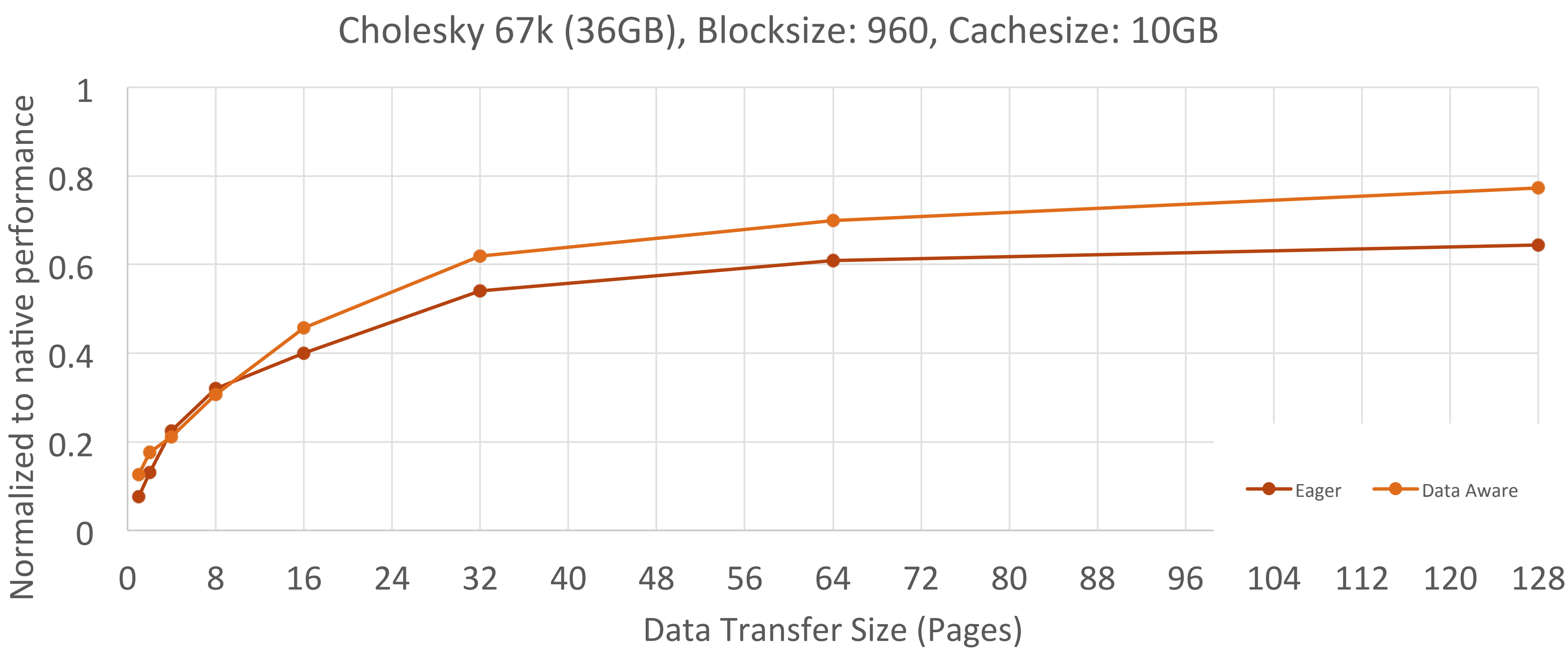
Cholesky

- Coarse grain data transfer make use of BW better
  - 1800 pages per task buffer
  - >32 pages data transfer unit to get performance



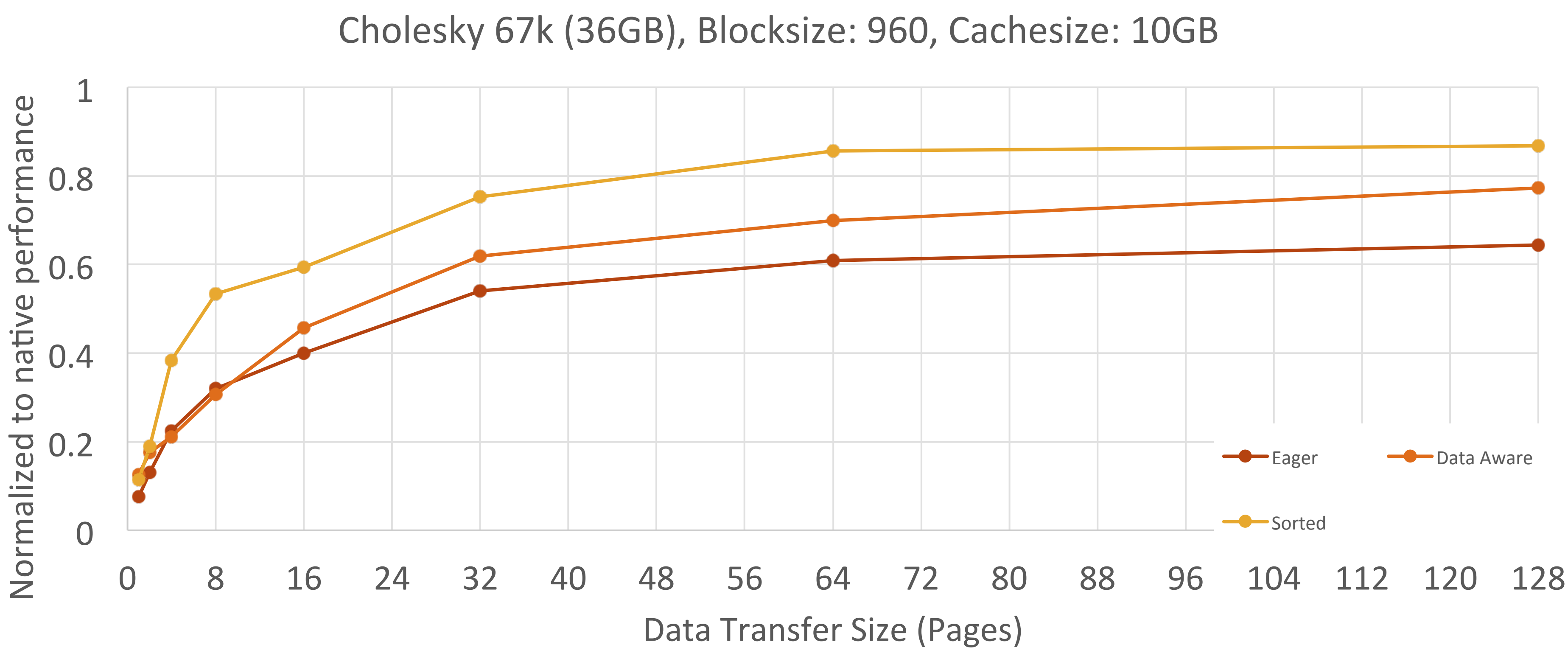
Cholesky

- Data aware – increases performance by 10%



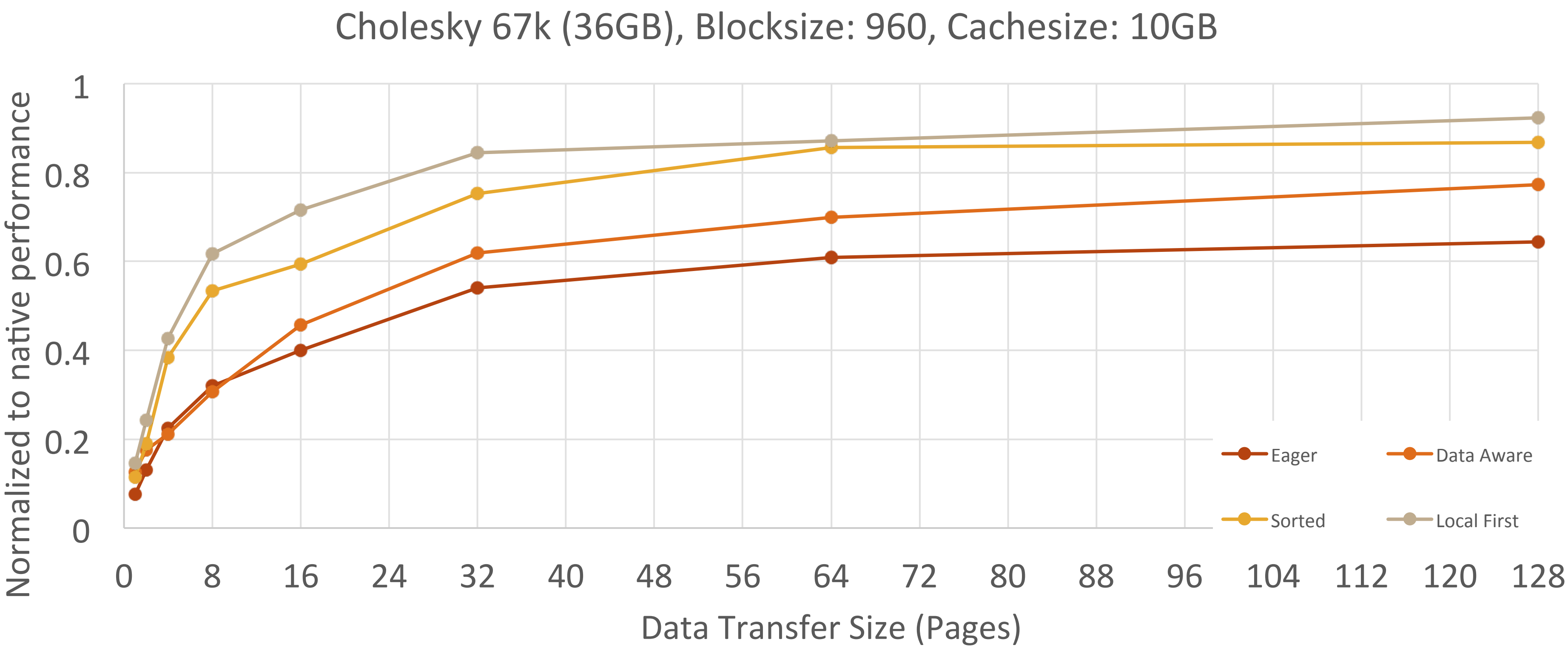
Cholesky

- *Sorted* - Inserts tasks based on how much is cached
  - Increase performance another ~10%



Cholesky

- *Local First* - Any cached task is always placed first
  - Small chance of data evicted when executed
  - Increases performance up 90%+ of performance



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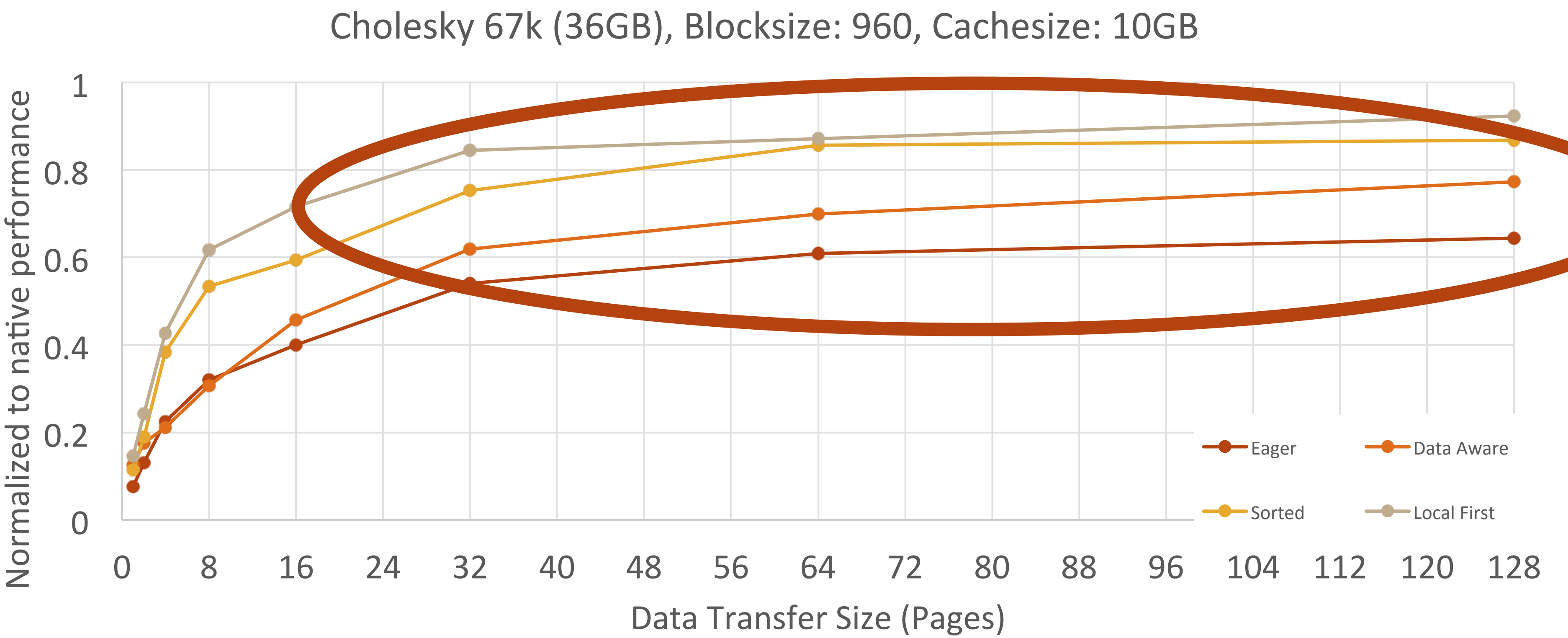
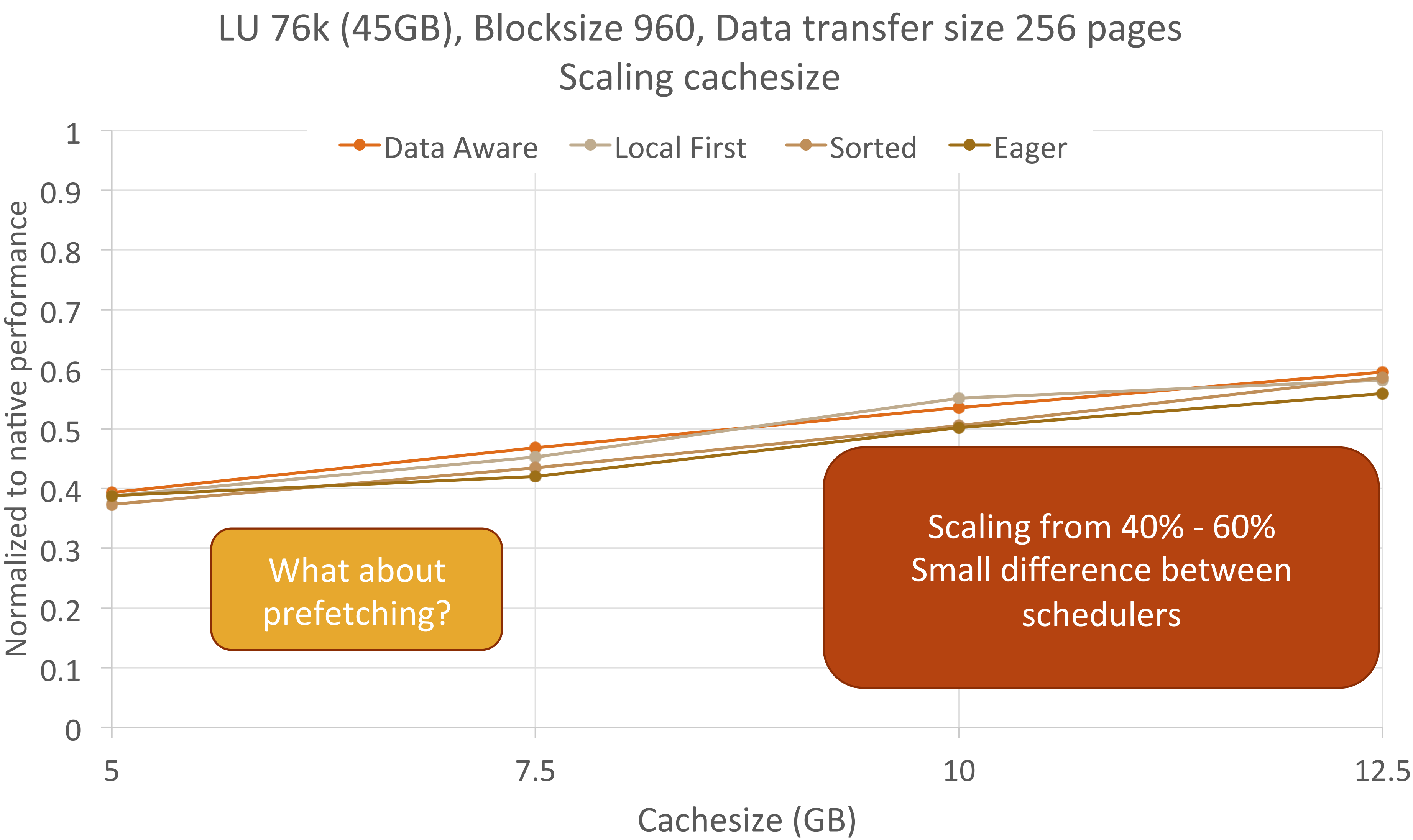
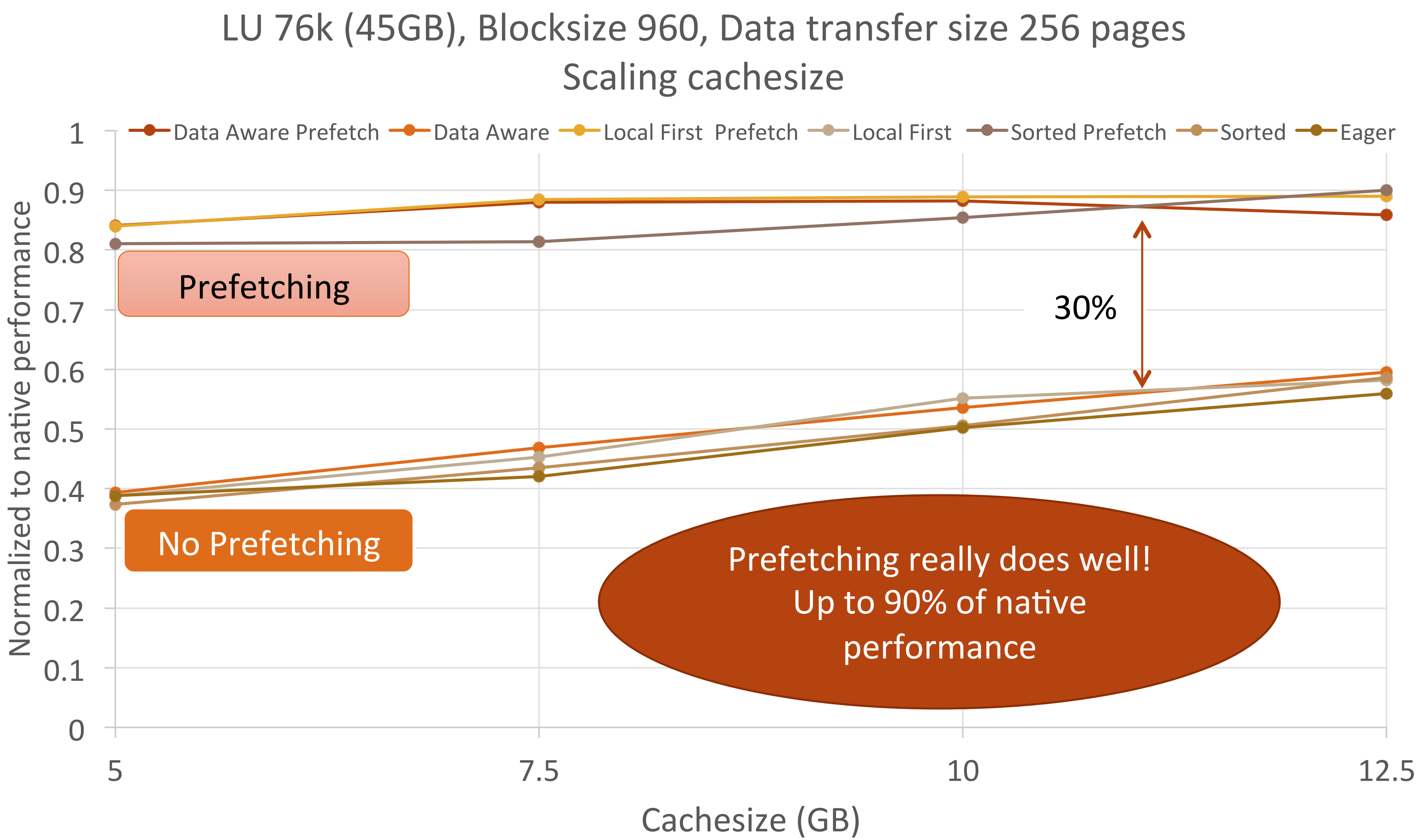


LU


LU 76k (45GB), Blocksize 960, Data transfer size 256 pages
Scaling cachesize
Data Aware
Local First
Sorted
Eager
Normalized to native performance
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5
7.5
10
12.5
Cachesize (GB)
What about prefetching?
Scaling from 40% - 60%
Small difference between schedulers

LU


LU 76k (45GB), Blocksize 960, Data transfer size 256 pages
Scaling cachesize
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0
5
7.5
10
12.5
Cachesize (GB)
Prefetching
No Prefetching
30%
Prefetching really does well!
Up to 90% of native
performance

The next step – Scale computation

- Using our method we have 2 degrees of freedom
  - Move data or tasks (EPEEC – Horizon 2020)
- Optimize at cluster level
  - How to divide up work?
    - Cluster global work queues?
    - Open question: When do we synchronize?
  - Give the scheduler locality information to improve scheduling
  - Give the DSM task information
    - Similar to this talk, memory is the important part

Conclusions

- Task-based systems are a great fit for DSMs

Conclusions

- DSMs are a great fit for a Task based systems
  - ArgoDSM can make use of efficient caching and prefetching based on scheduler information
  - Scheduling policies can make use of DSM information to schedule for locality
- As advertised:
  - Up to 90%+ of native performance operating on remote memory using a co-design of scheduler and DSM caching techniques

Thank you!
Questions?

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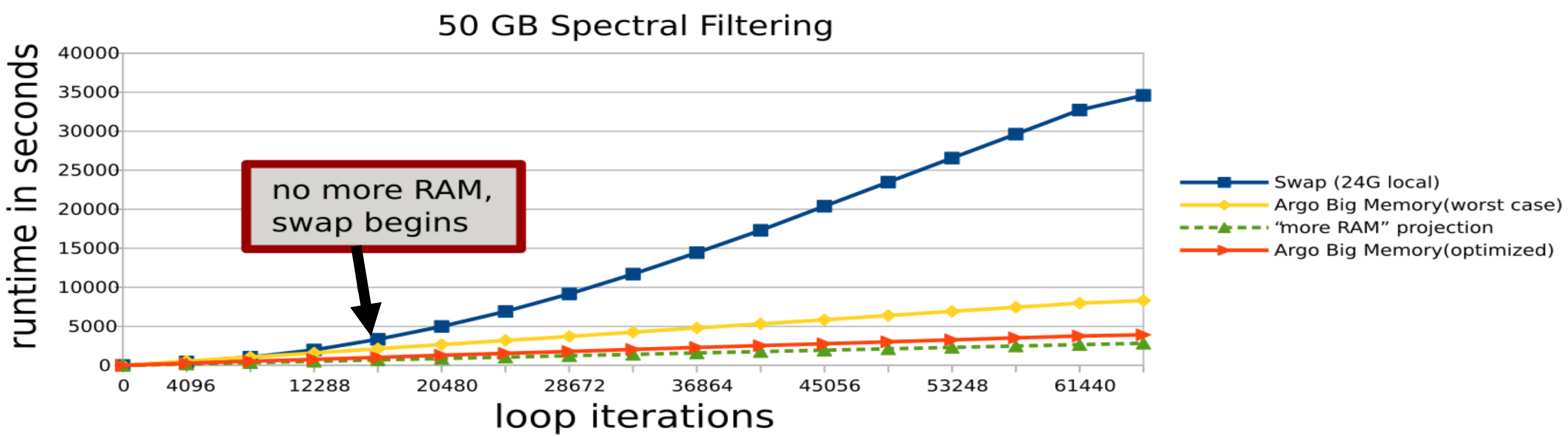
www.argodsm.com

Resources and References

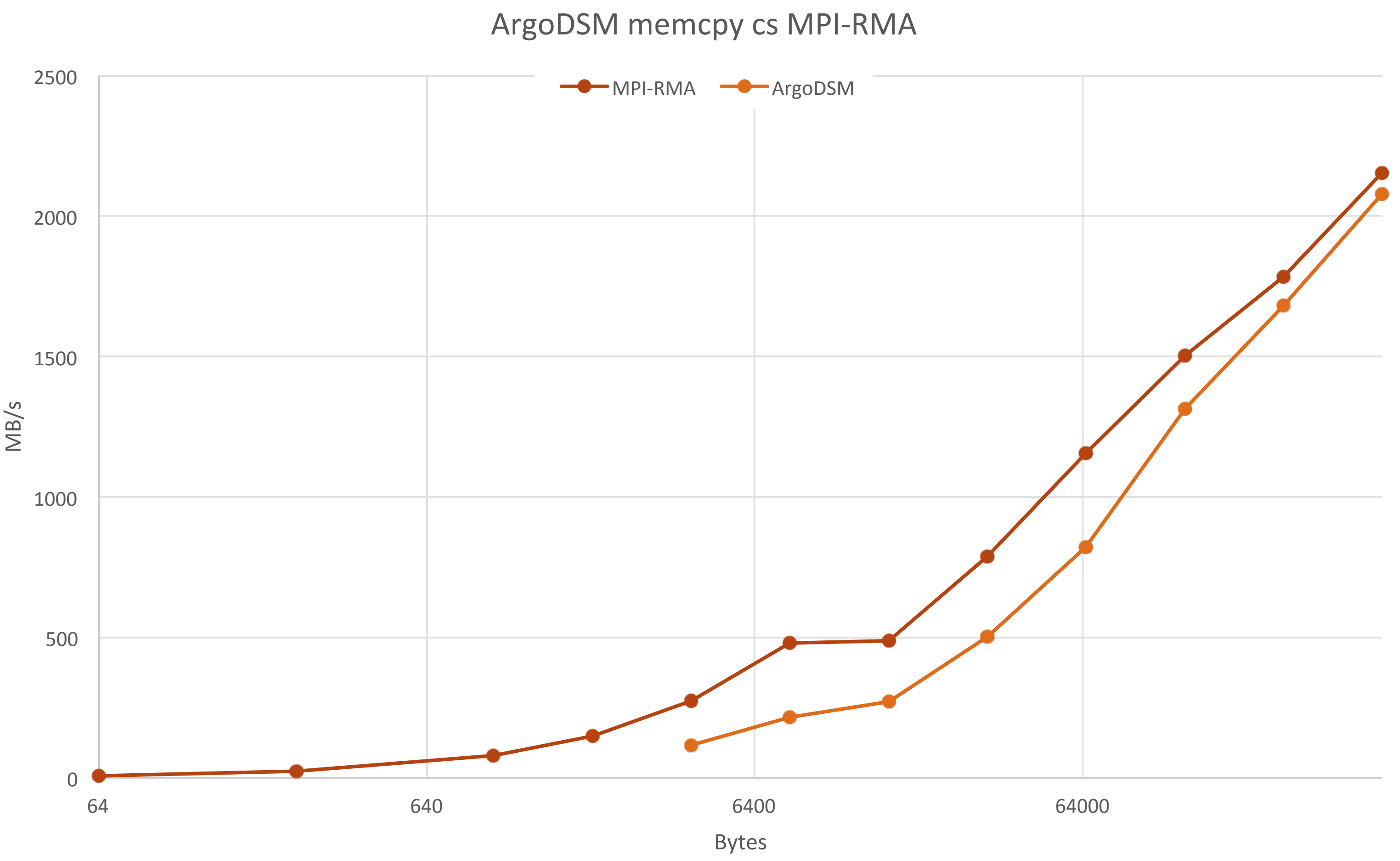
- ArgoDSM
    - Project site (and the HPDC'15 paper)
        - http://www.it.uu.se/research/project/argo
    - *http://www.argodsm.com*
    - https://dl.acm.org/citation.cfm?id=2749250
- VIPS Coherence
    - https://dl.acm.org/citation.cfm?doid=2370816.2370853
    - http://ieeexplore.ieee.org/document/6398353/?reload=true
- Queue-Delegation Locking
    - http://www.it.uu.se/research/group/languages/software/qd_lock_lib
- StarPU
    - http://starpu.gforge.inria.fr

Extra Slides – Scaling ONLY MEMORY Python example

- Python-based spectral filter application from meteorology (very large data set using SciPy)
  - 8 Nodes for memory, one node for compute
  - Outperforms swap



Extra Slides - Bandwidth



Extra Slides – HW Specs

- Compute per node
  - Two Intel Xeon E5 2630 v4, 2.20Ghz (10 cores, 20 threads)
- Network
  - Infiniband FDR
    - Latency 0.7us
    - Bandwidth 56GB/s

Extra Slide - Eviction Policies

- Eviction Policy - Direct Mapped, Random, ’least recently mapped’=FIFO