Efficient Memory Disaggregation with Infiniswap

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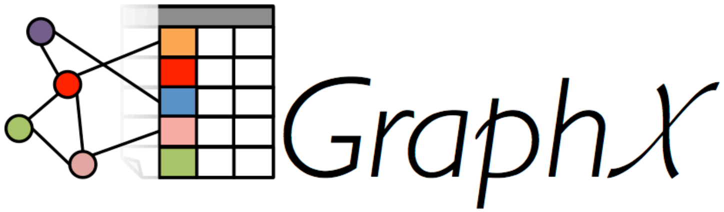
MICHIGAN

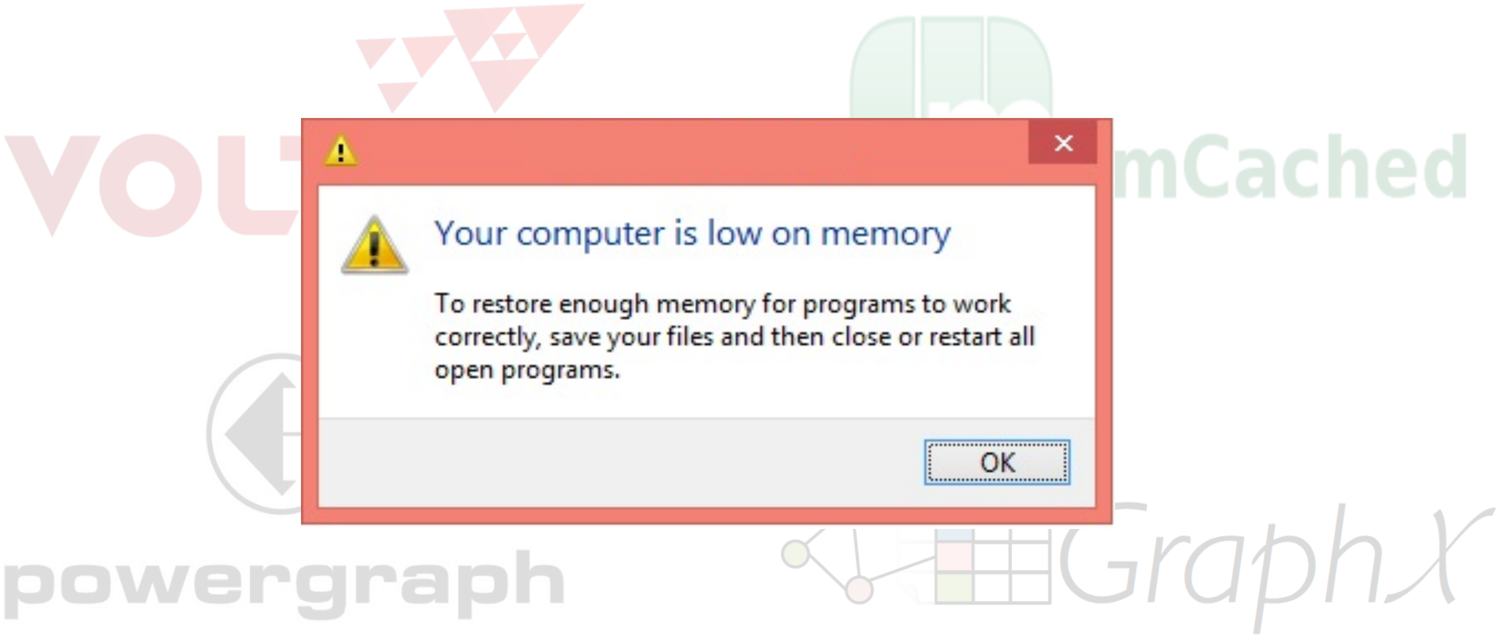
Agenda

- **Motivation and related work**
- Design and system overview
- Implementation and evaluation
- Future work and conclusion

Memory-intensive applications



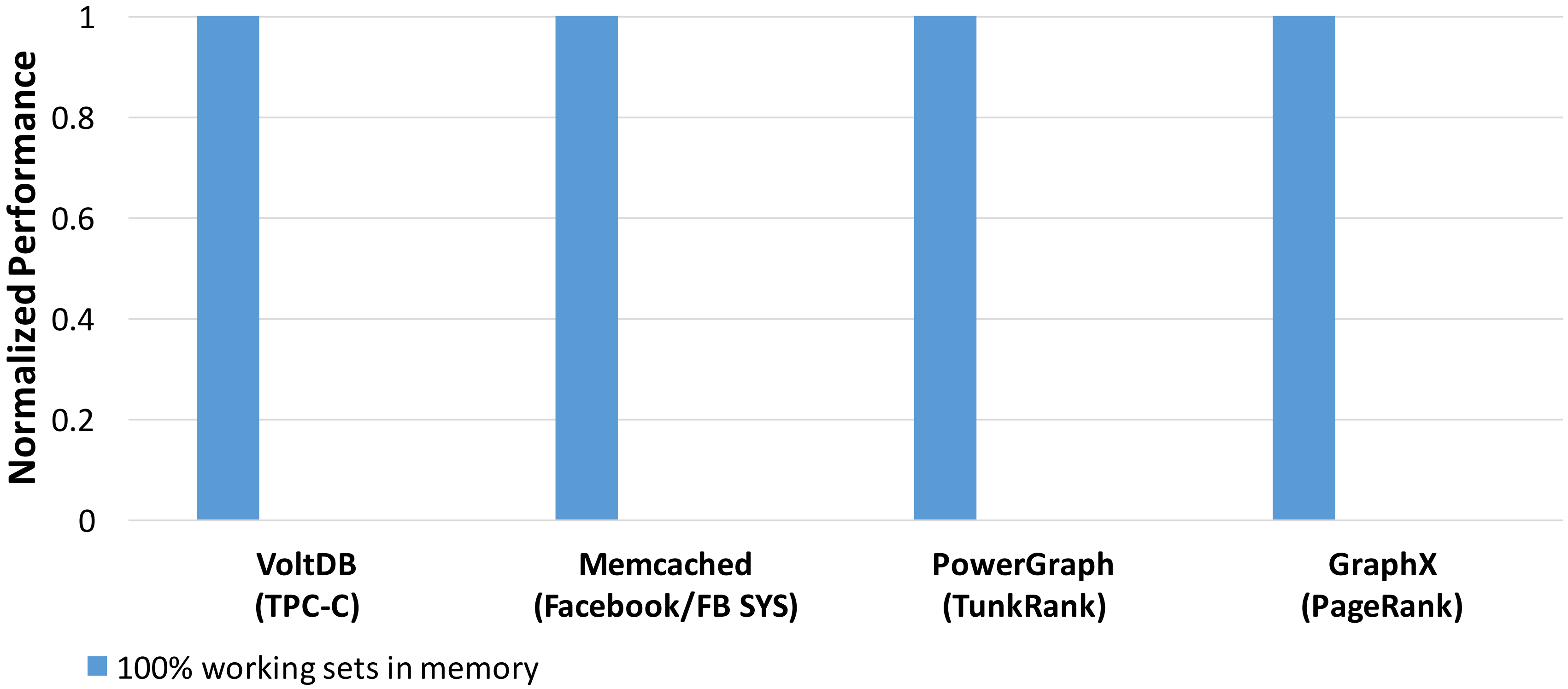
Memory-intensive applications



Your computer is low on memory

To restore enough memory for programs to work correctly, save your files and then close or restart all open programs.

Performance degradation



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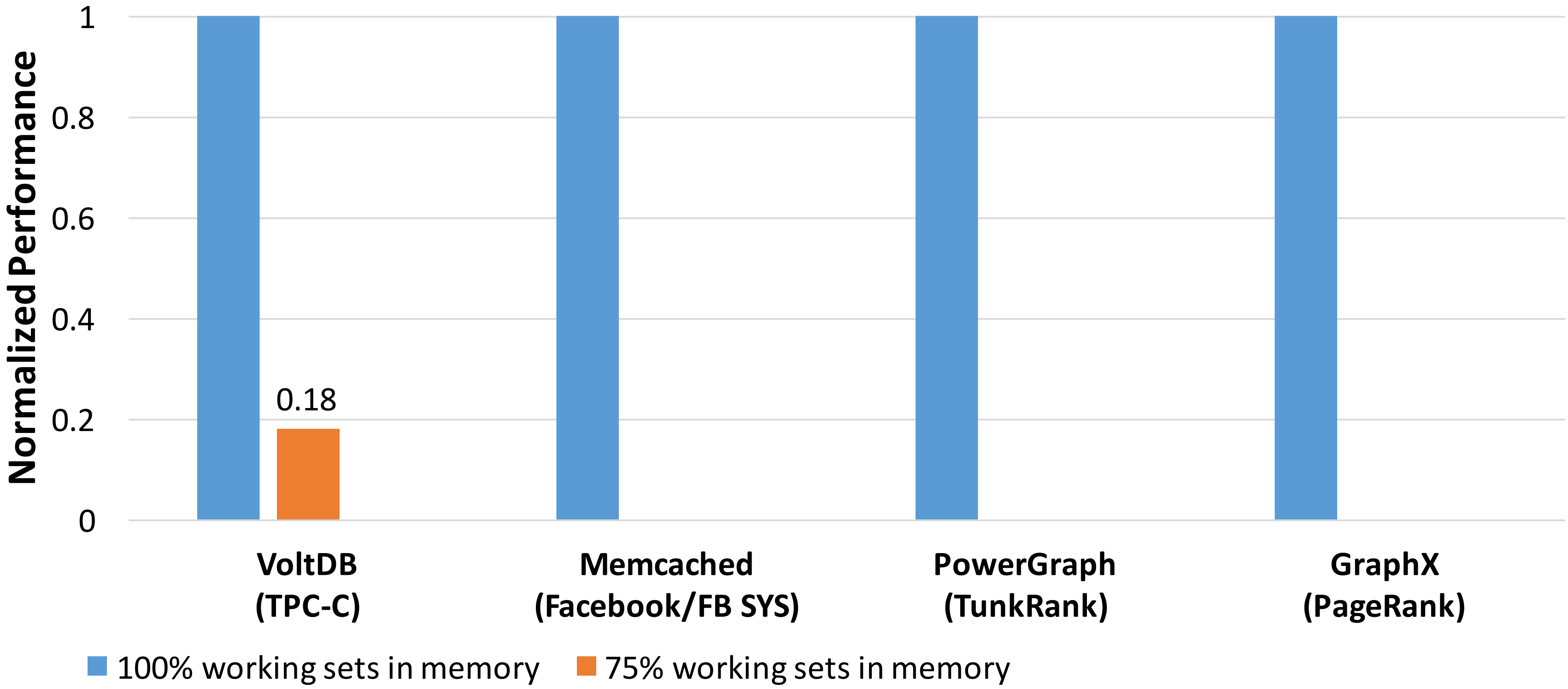

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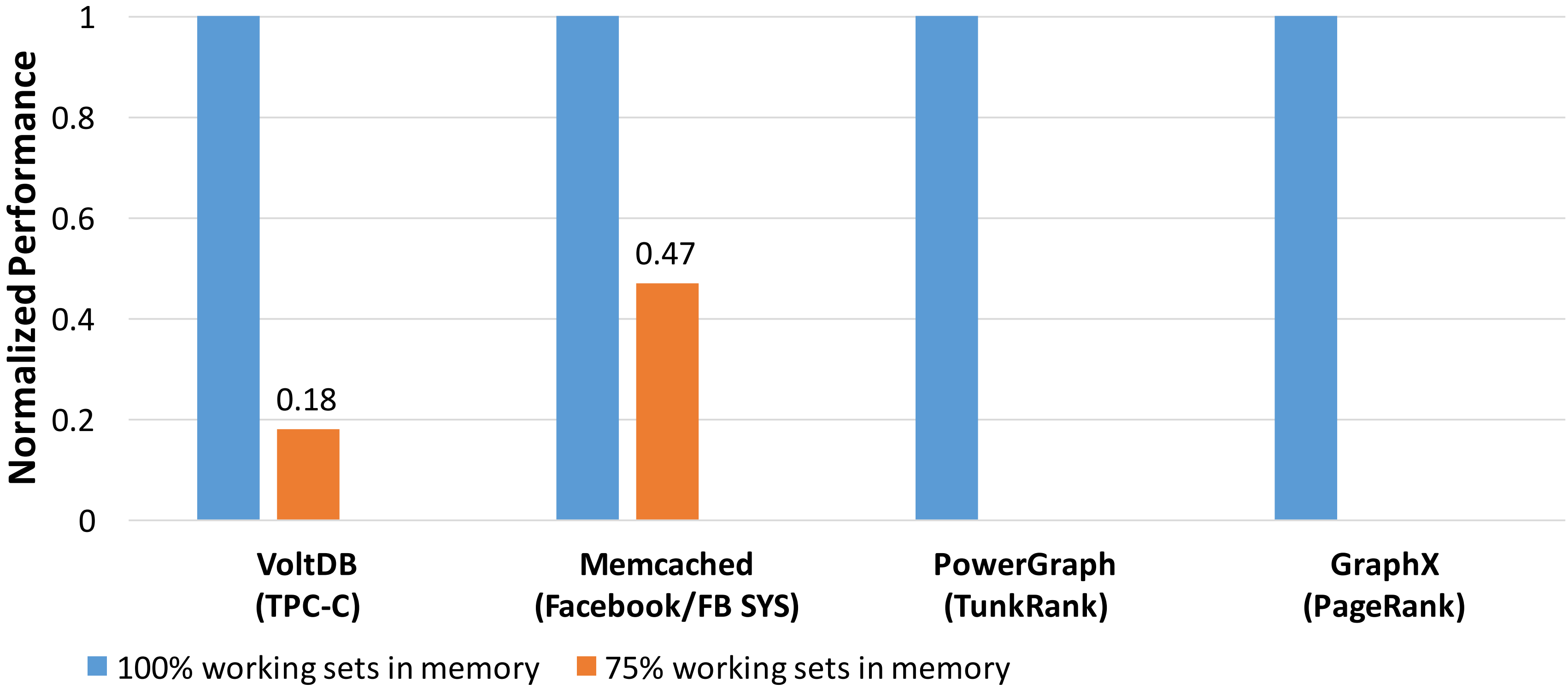

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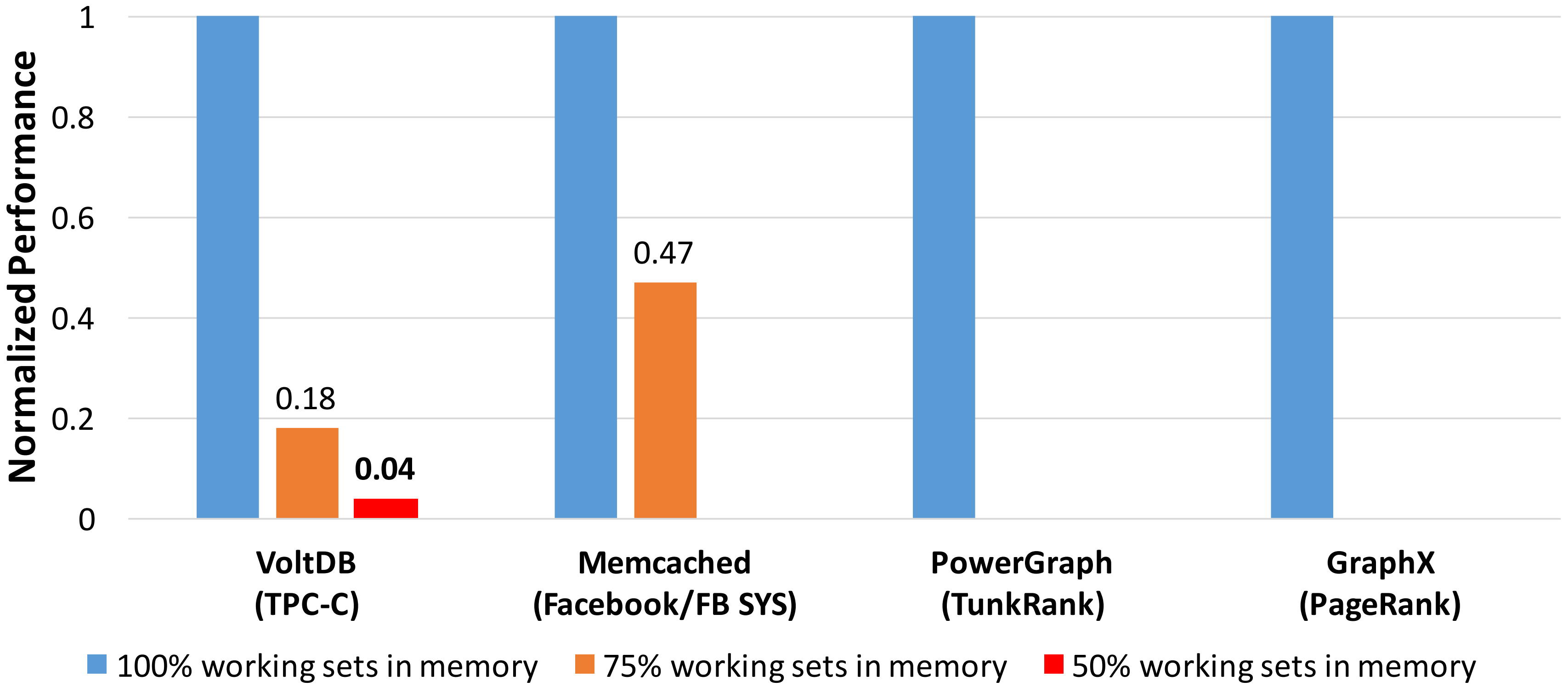

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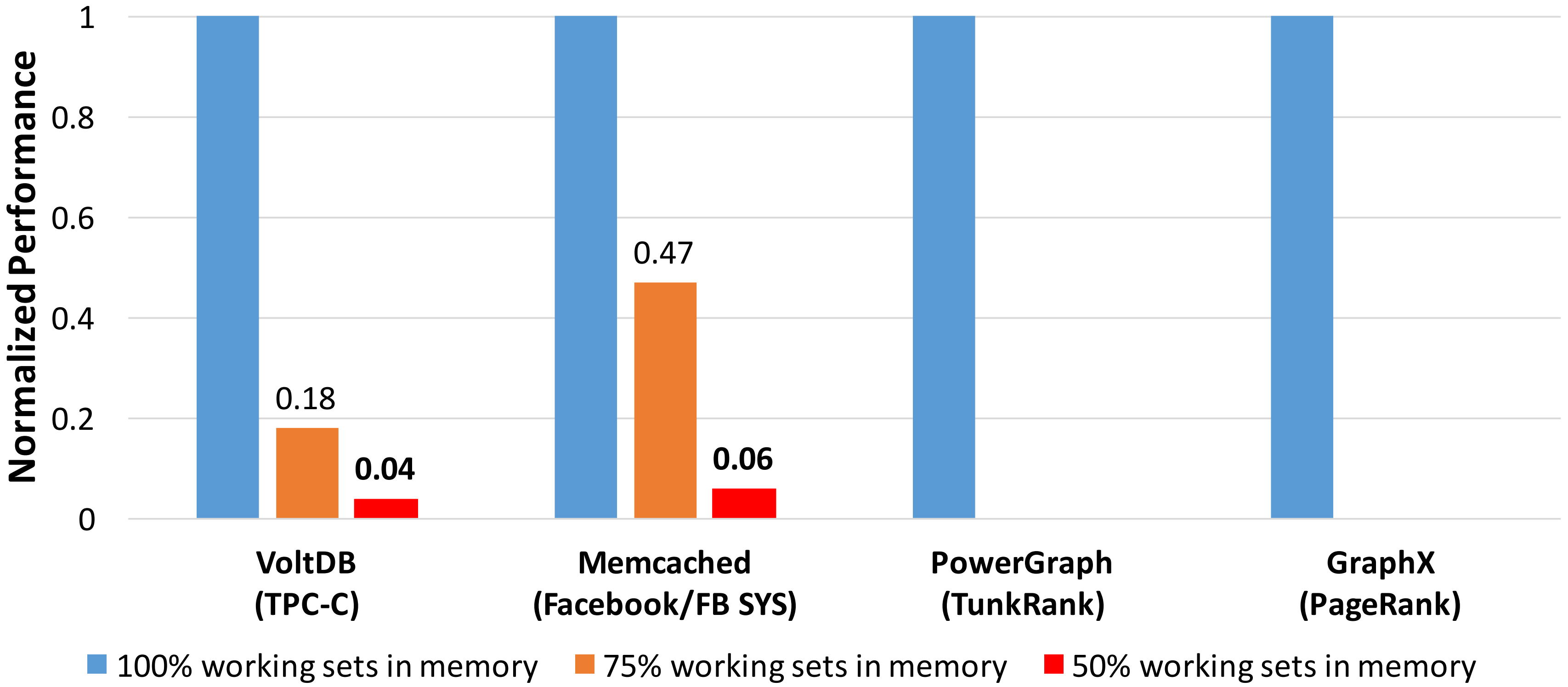

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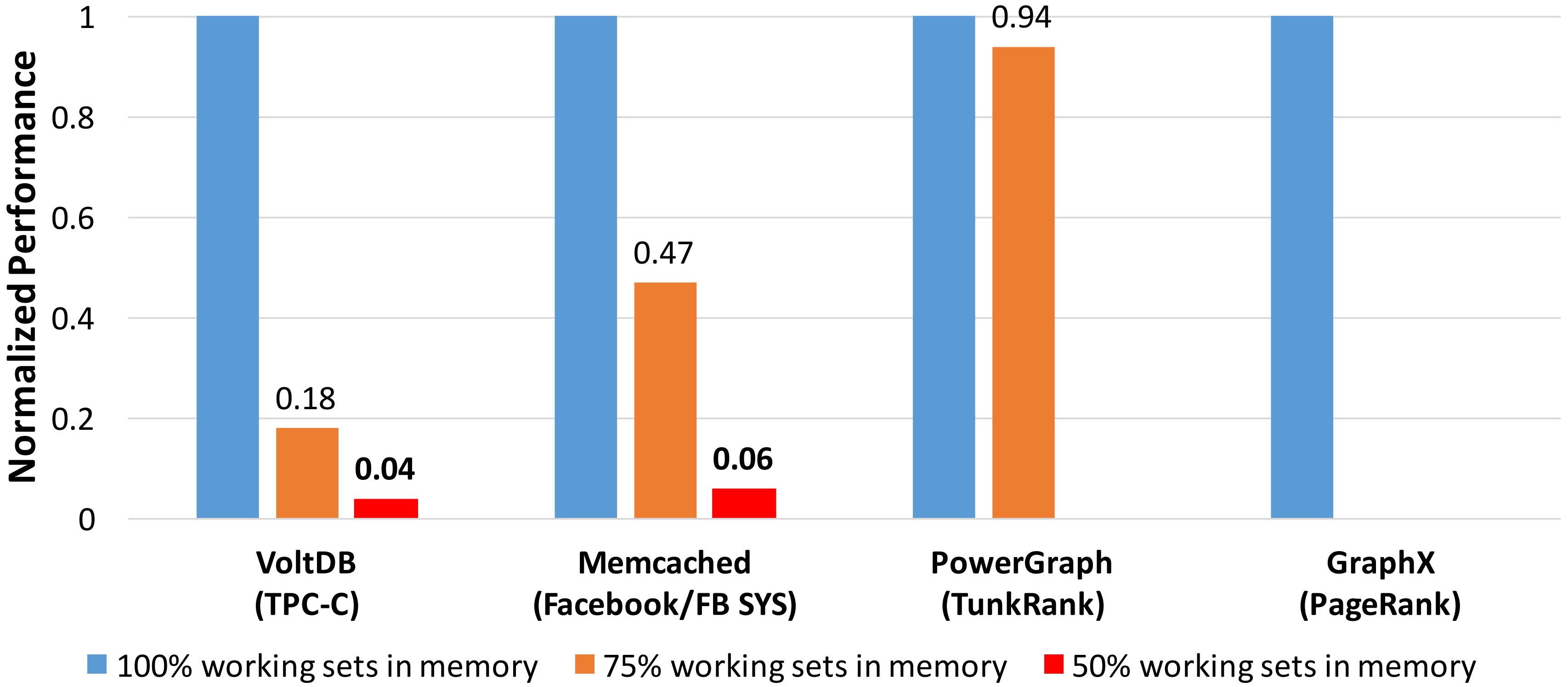

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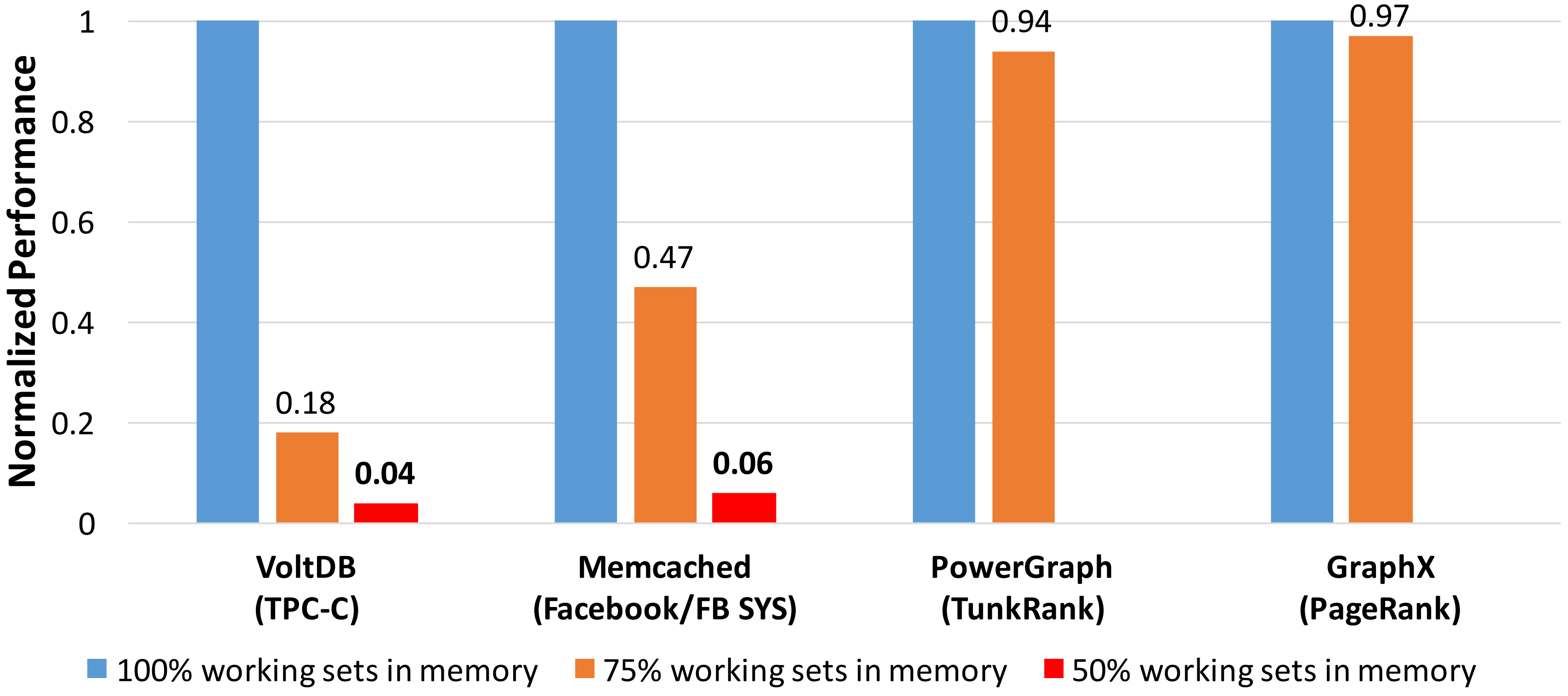

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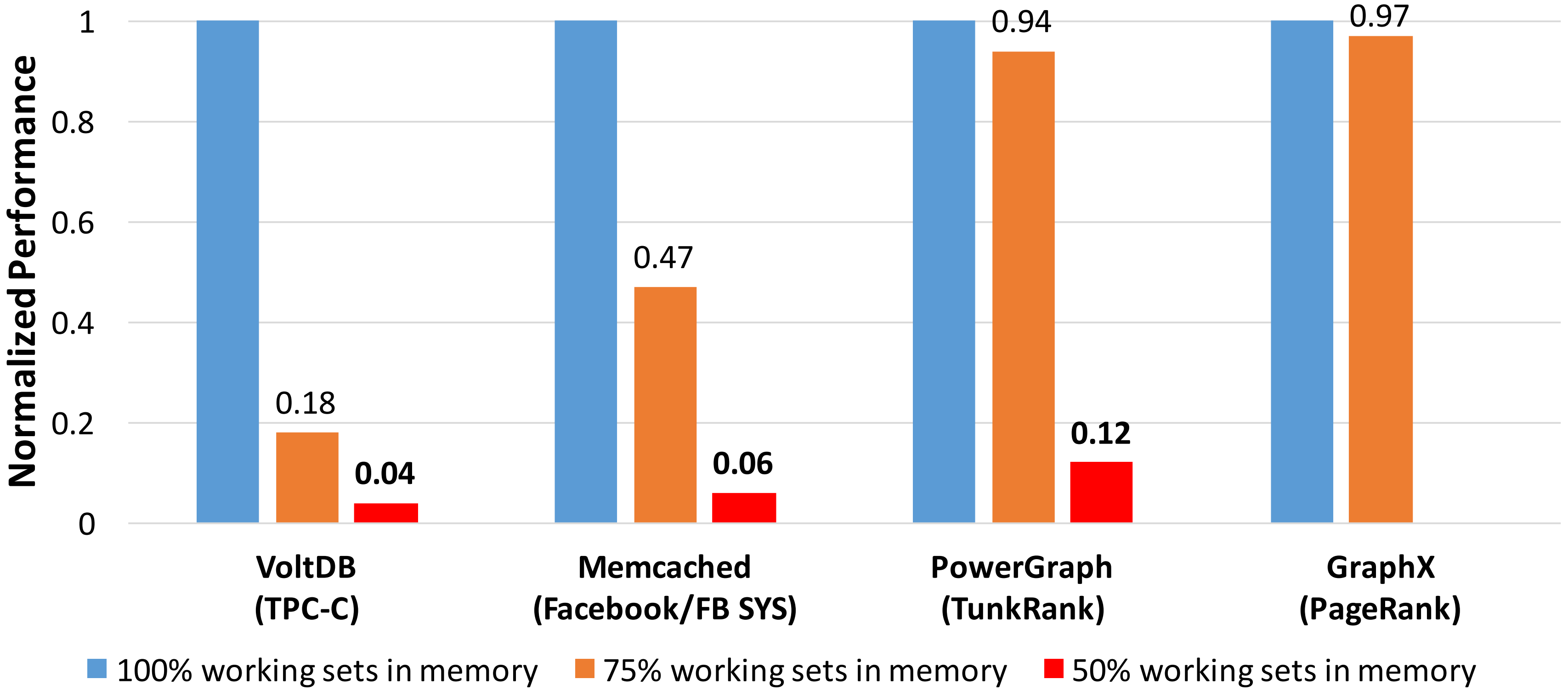

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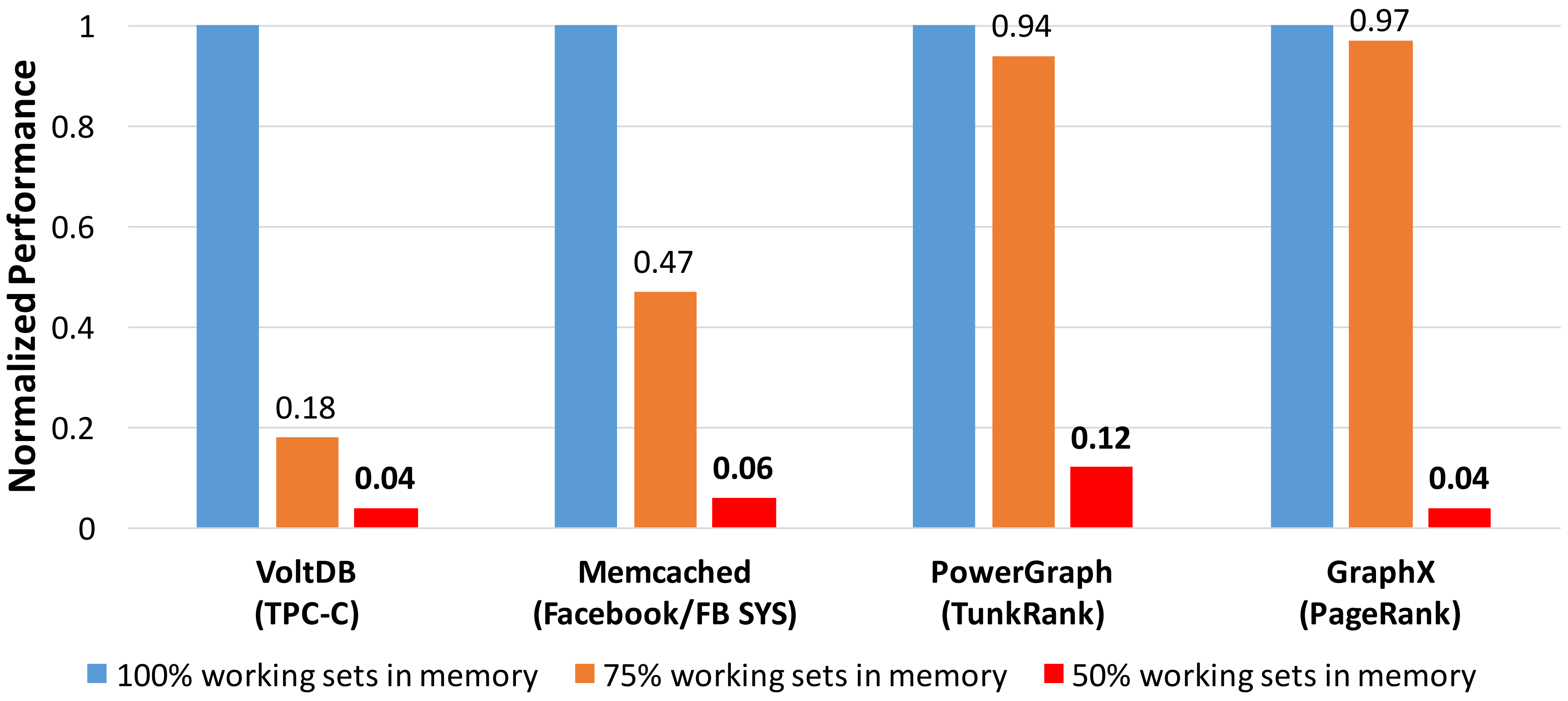

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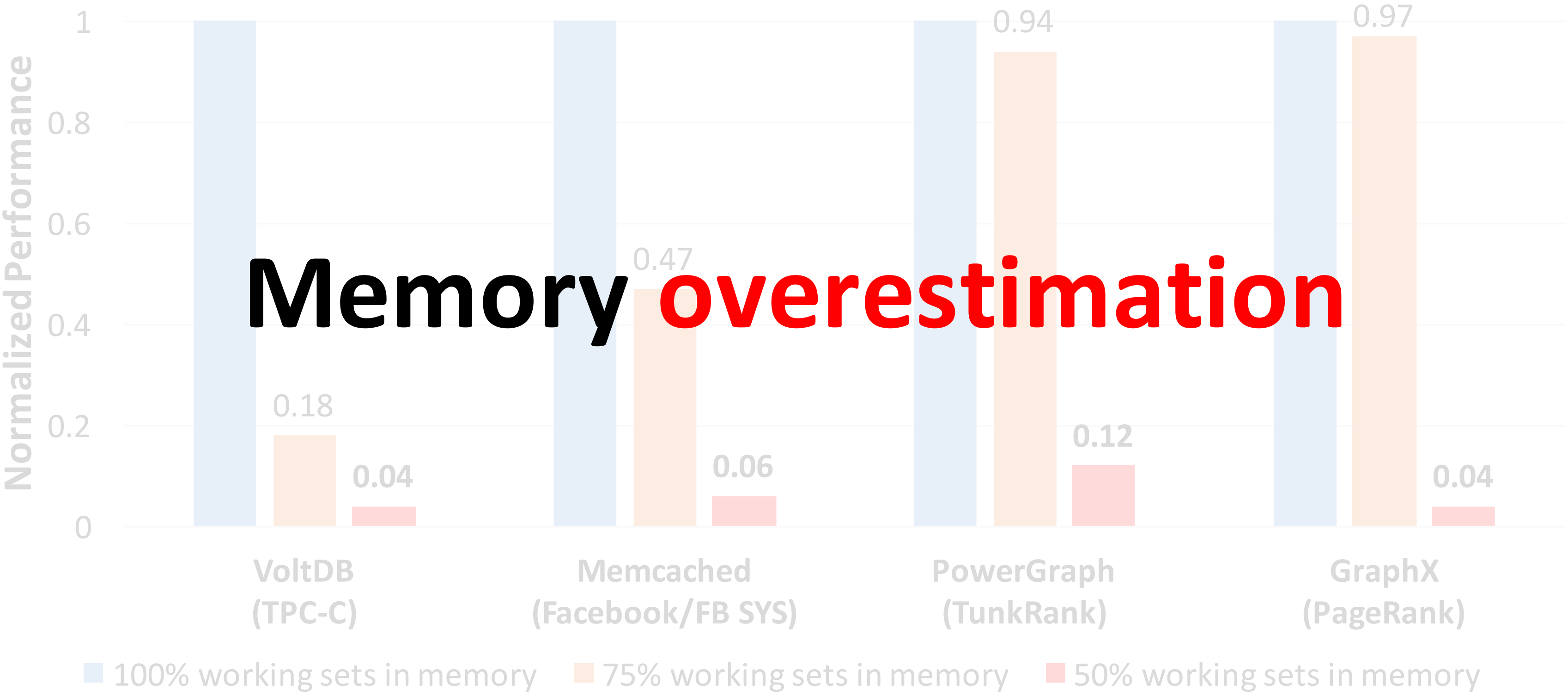
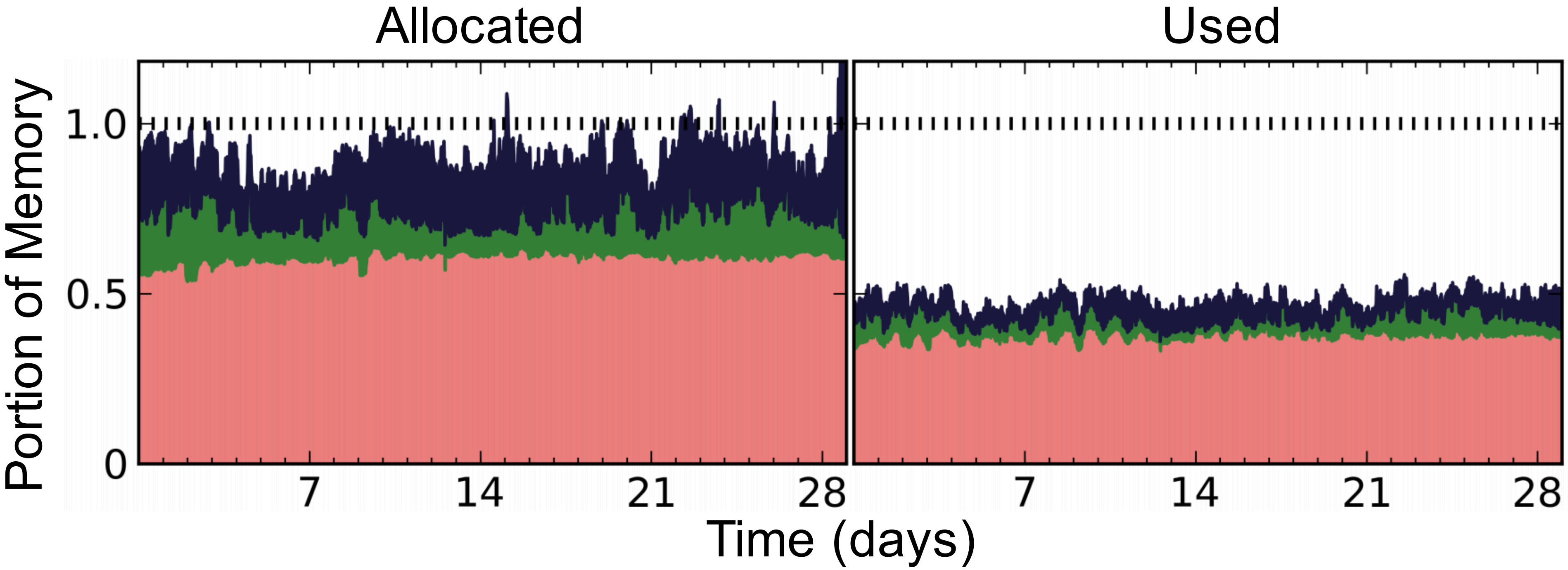


Memory overestimation

Memory underutilization

- Google Cluster Analysis[1]



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Memory underutilization

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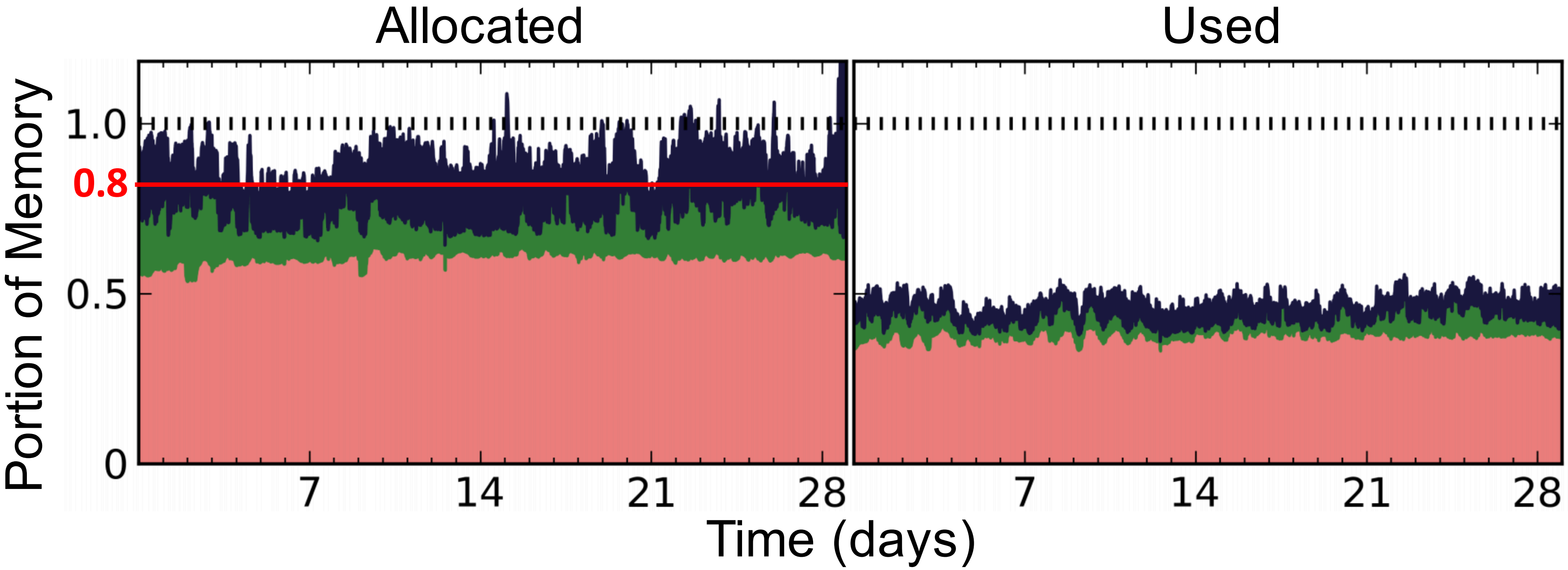

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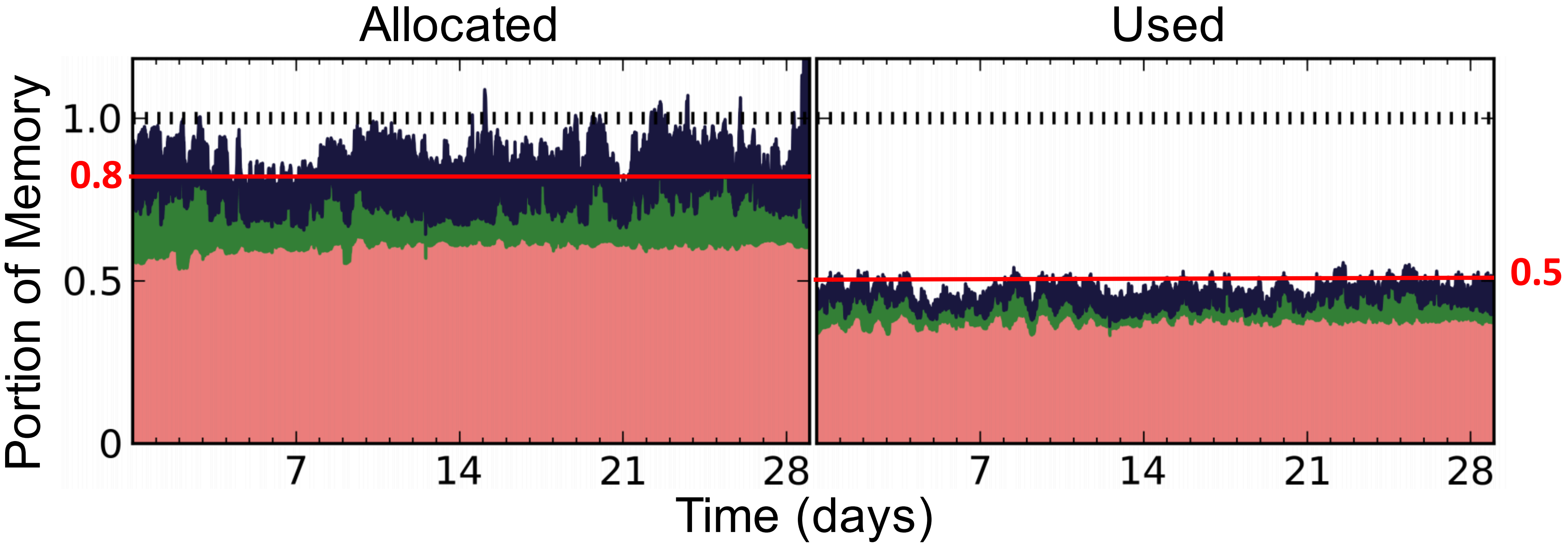

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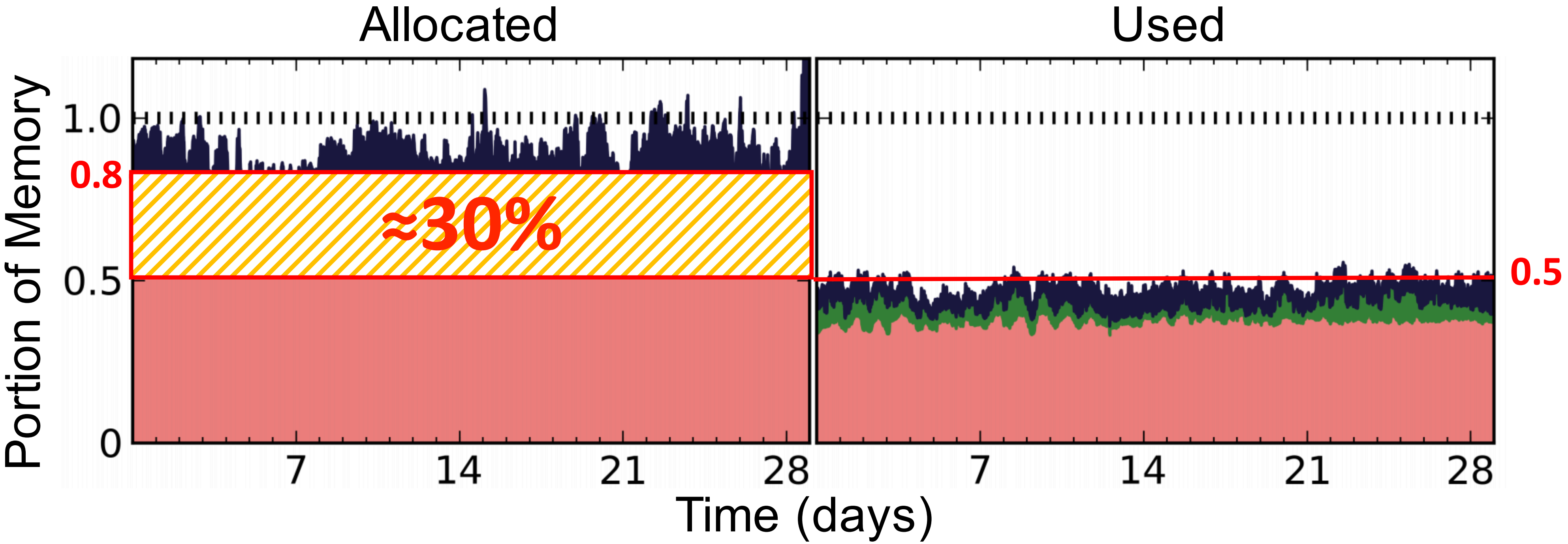

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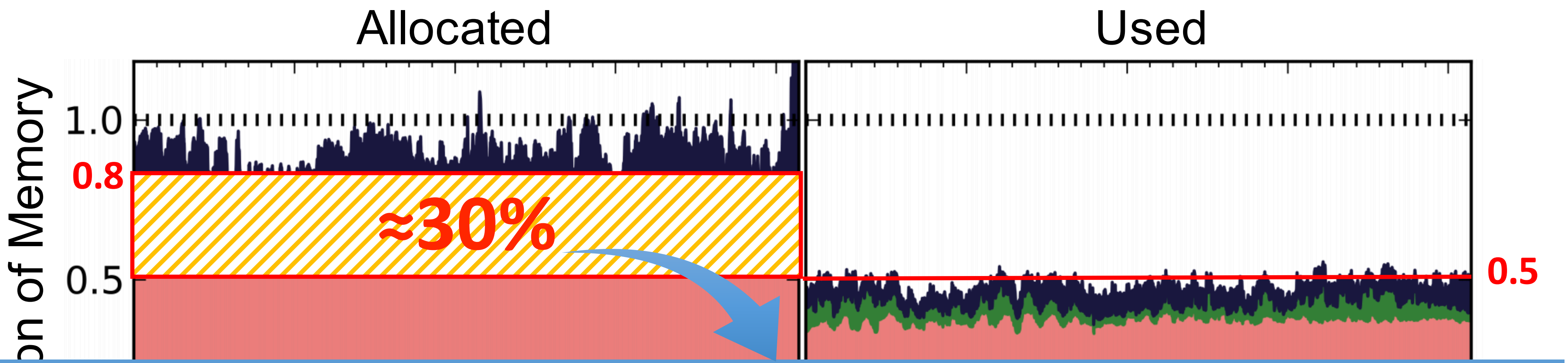

Can we utilize this memory?

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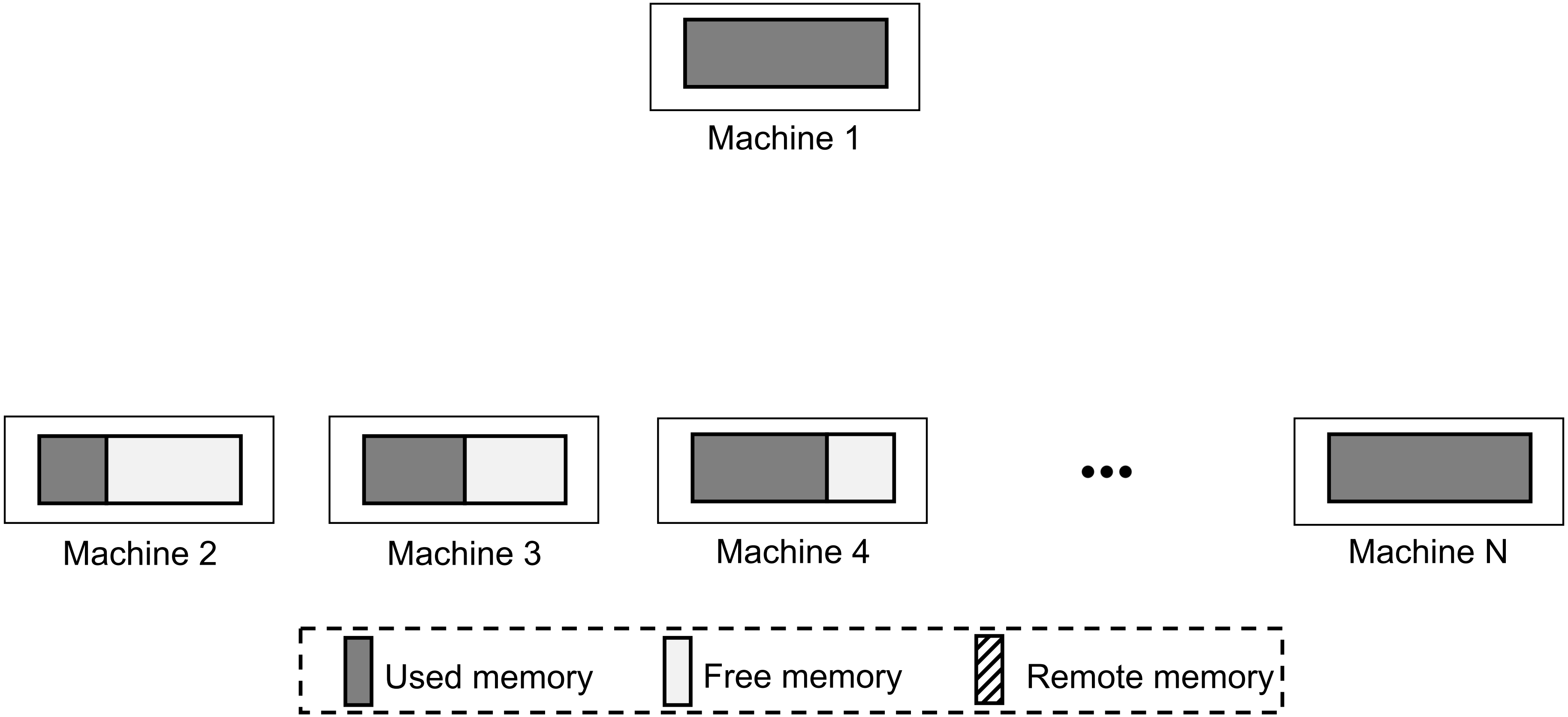


Machine 1

Machine 2

Machine 3

Machine 4

•••

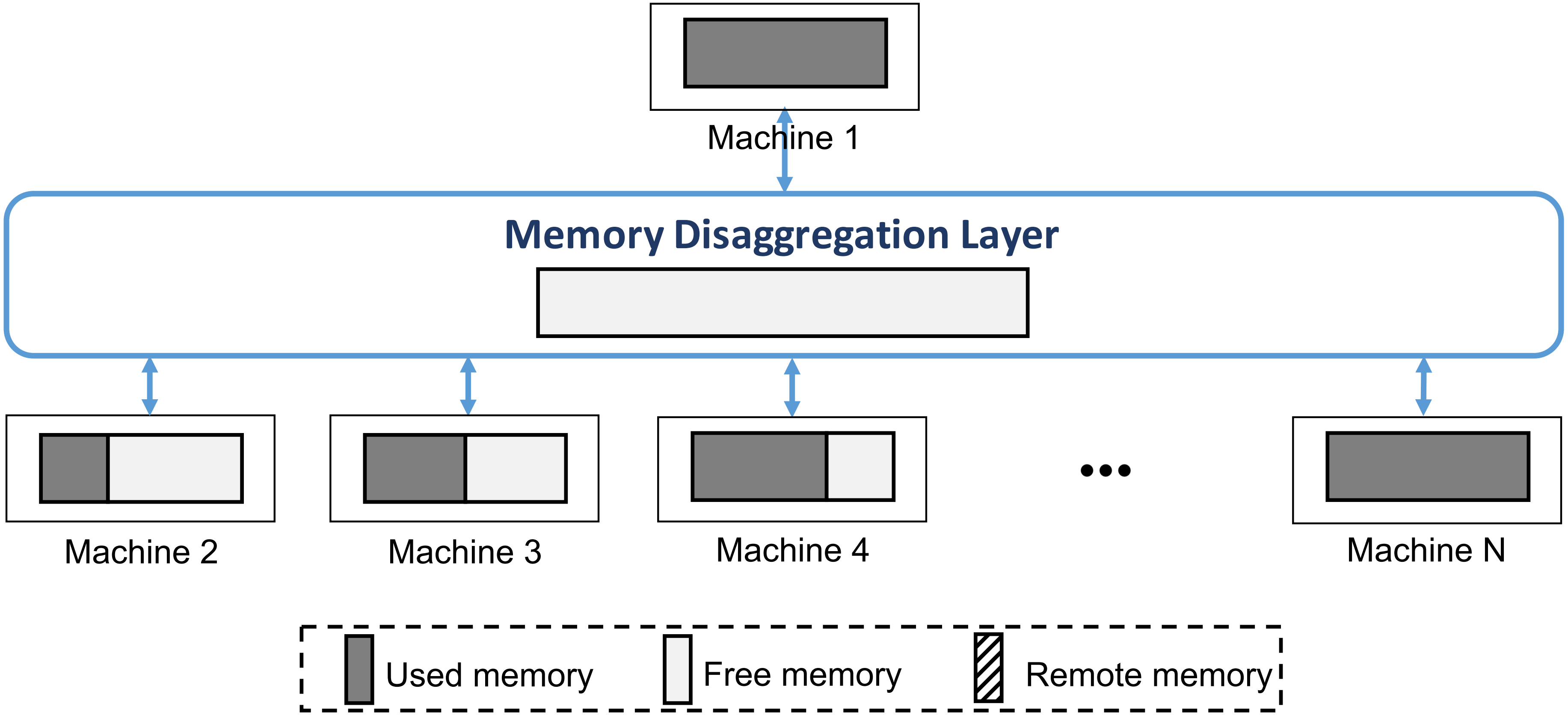
Machine N

Used memory

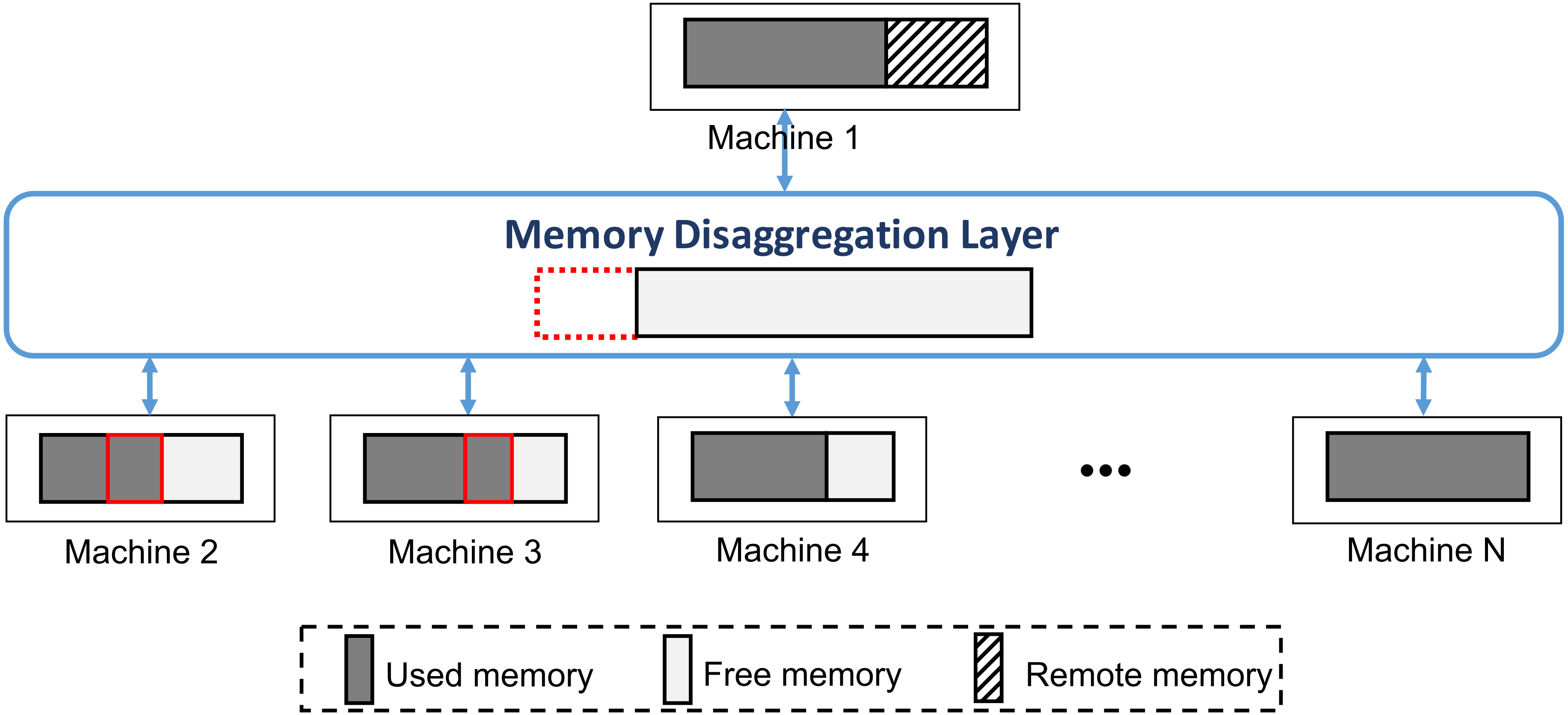
Free memory

Remote memory

Disaggregate free memory



Disaggregate free memory



What are the challenges?

- Minimize deployment overhead
  - No hardware design
  - No application modification
- Tolerate failures
  - e.g. network disconnection, machine crash
- Manage remote memory at scale

Recent work on memory disaggregation

	No HW design	No app modification	Fault-tolerance	Scalability
Memory Blade[ISCA'09]	✗	✓	✓	✓
HPBD[CLUSTER'05] / **NBDX**[1]	✓	✓	✗	✗
RDMA key-value service (e.g. HERD[SIGCOMM'14], FaRM[NSDI'14])	✓	✗	✓	✓
Intel Rack Scale Architecture (RSA)[2]	✗	✓	✓	✓
Infiniswap	✓	✓	✓	✓

[1] https://github.com/accelio/NBDX
[2] http://www.intel.com/content/www/us/en/architecture-and-technology/rack-scale-design-overview.html

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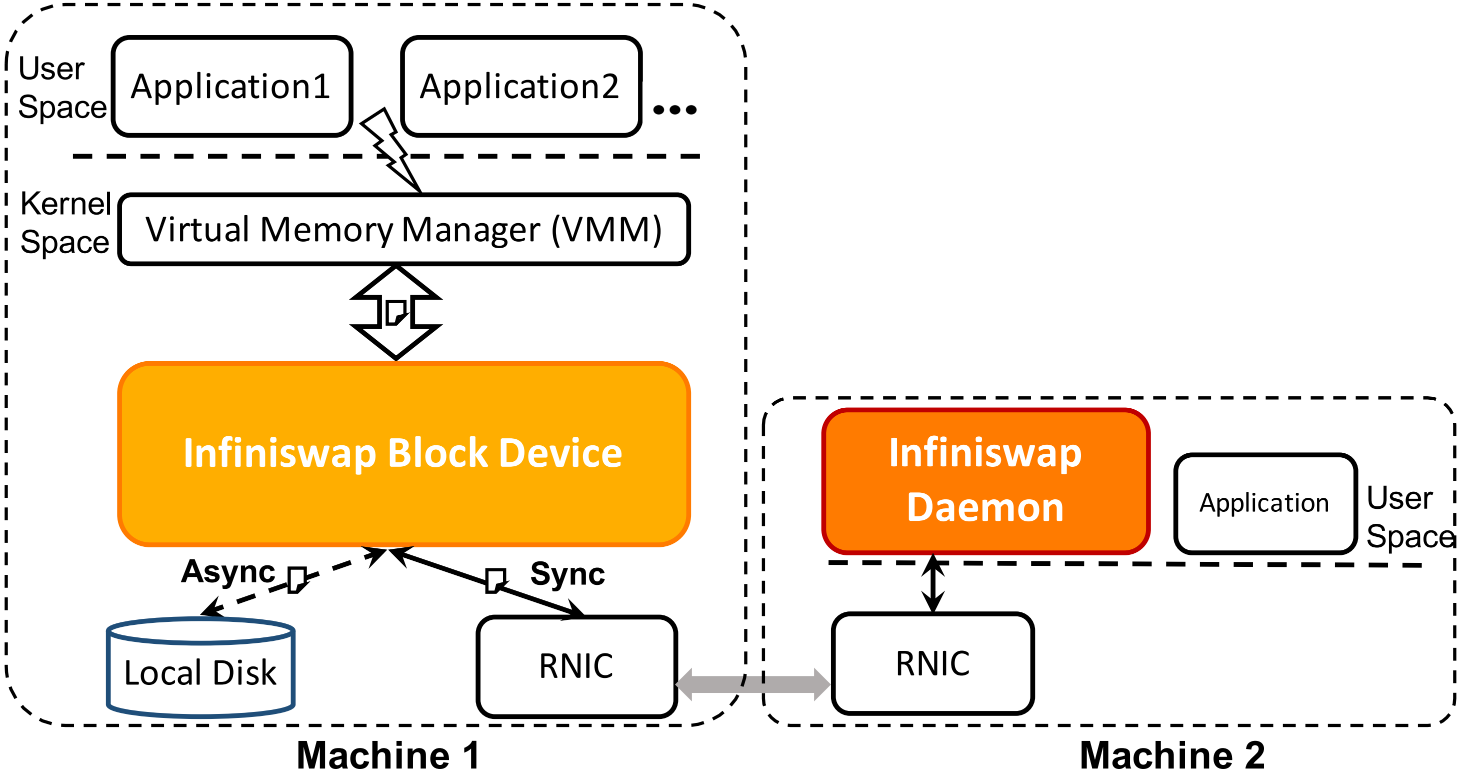
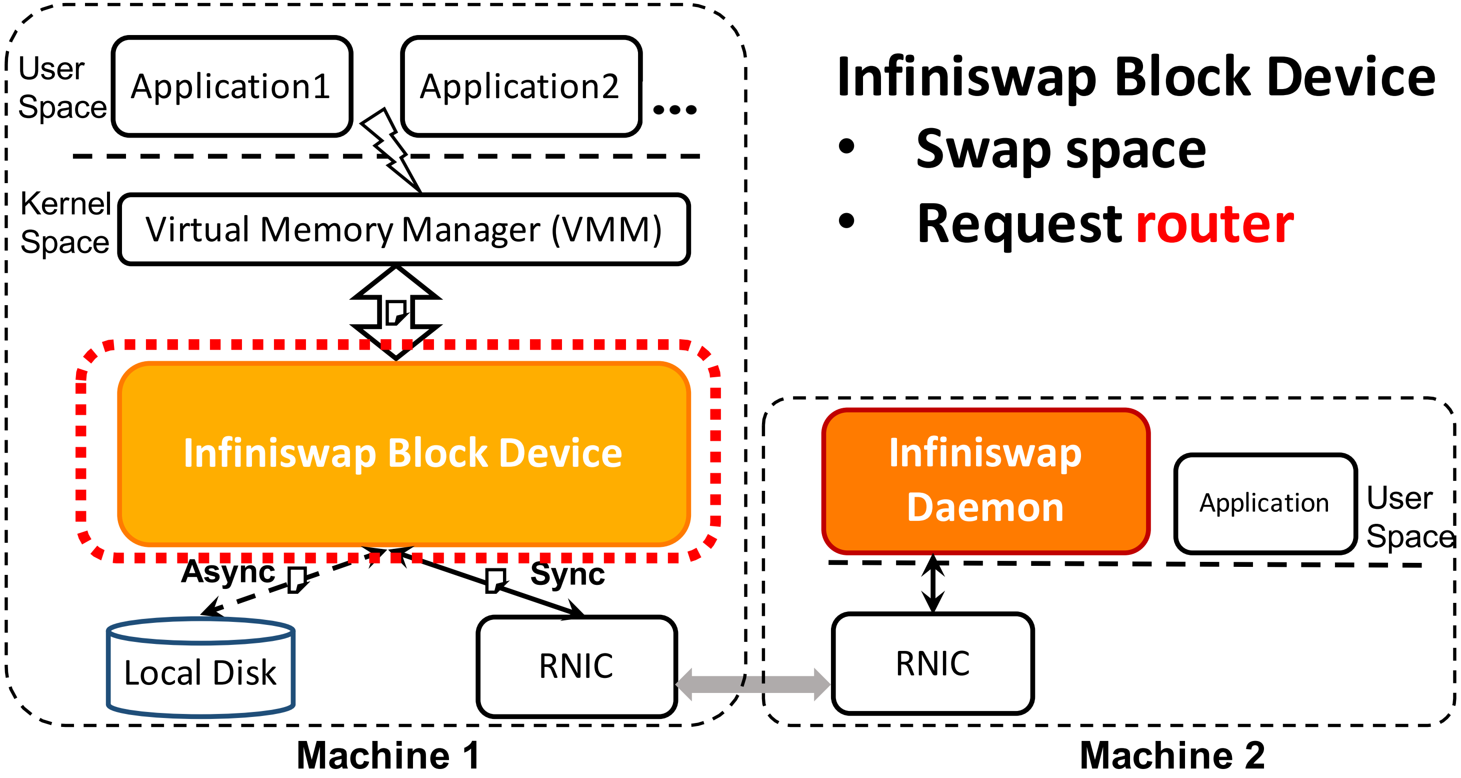
System Overview



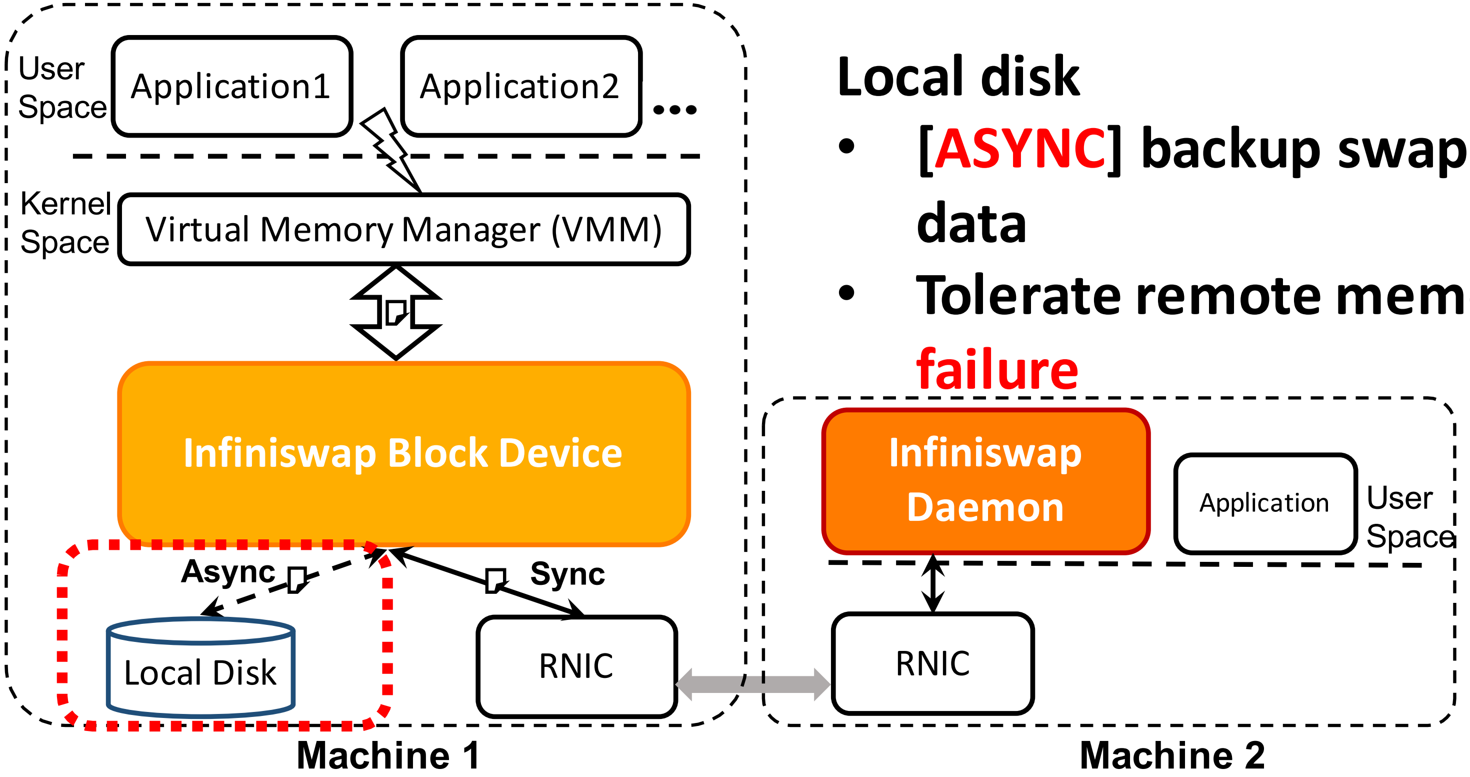
System Overview



Infiniswap Block Device

- **Swap space**
- **Request router**

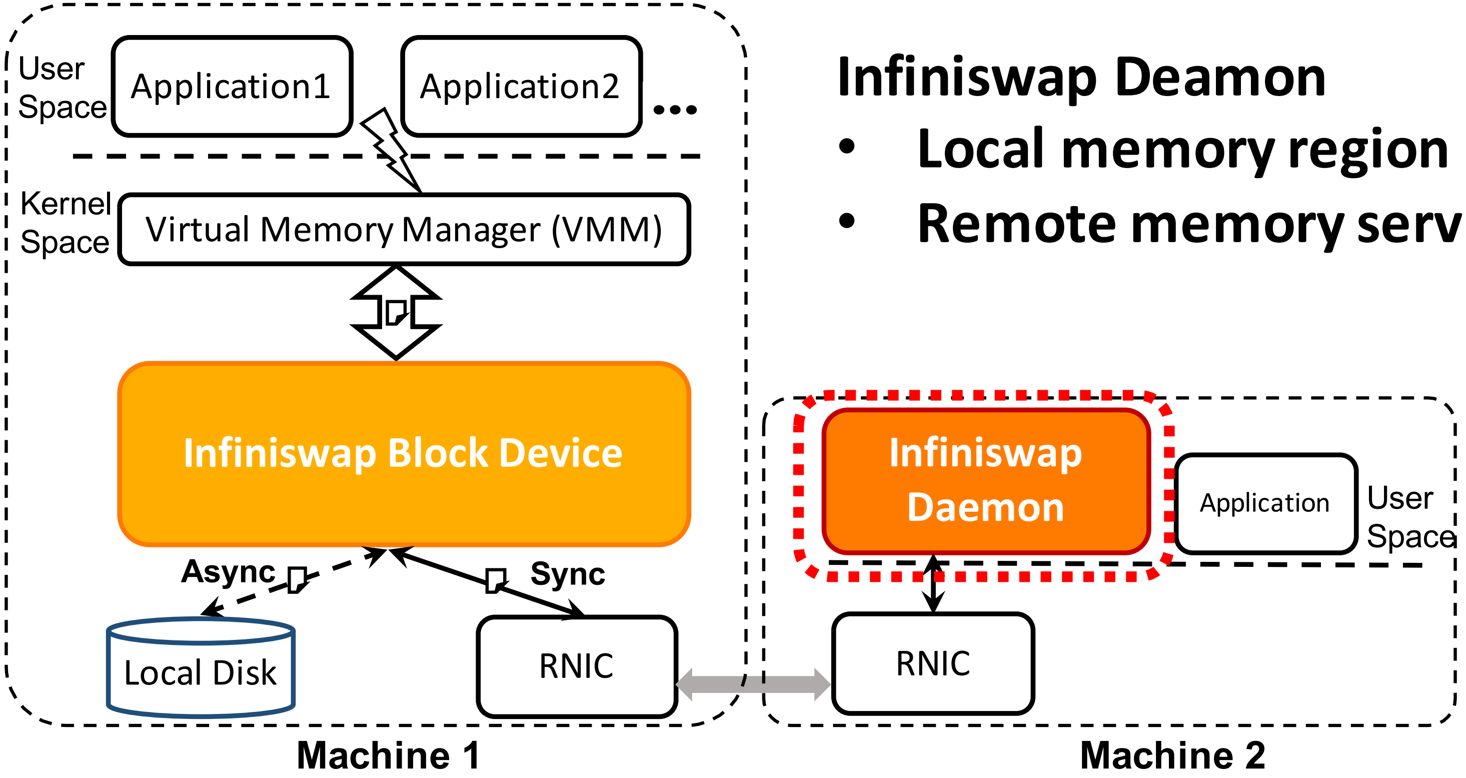
System Overview



Local disk

- **[ASYNC] backup swapped-out data**
- **Tolerate remote memory failure**

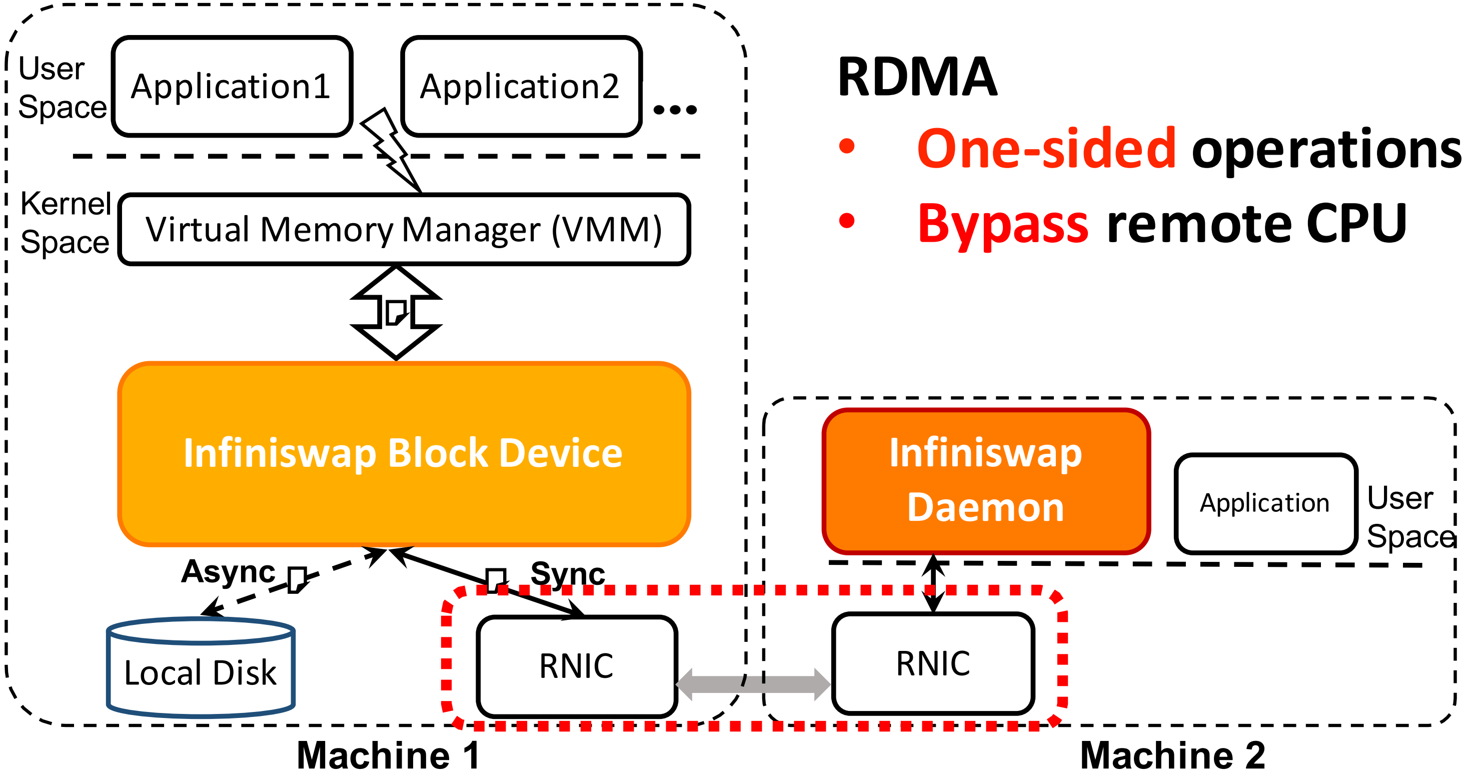
System Overview



Infiniswap Deamon

- **Local memory region**
- **Remote memory service**

System Overview



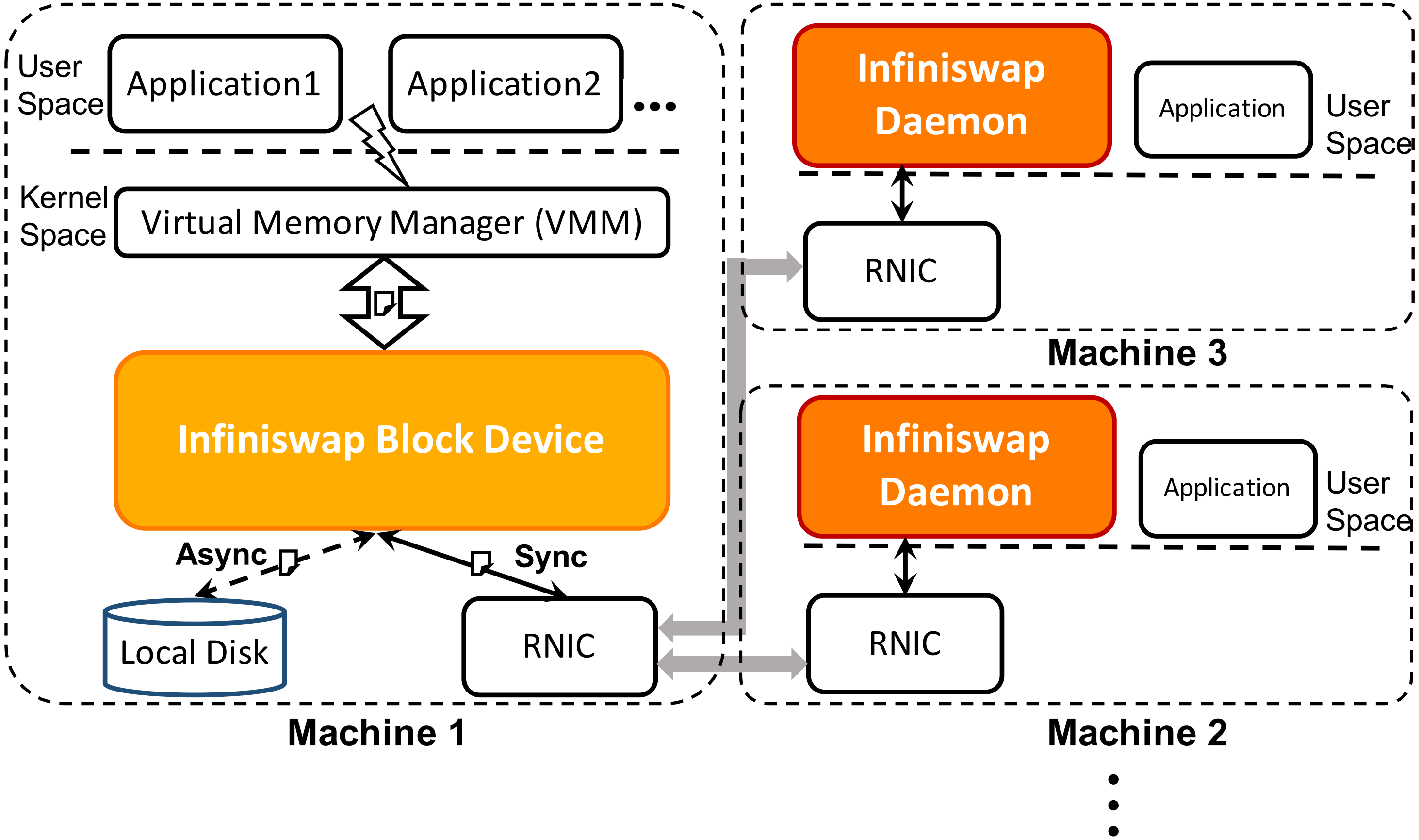
RDMA

- **One-sided operations**
- **Bypass remote CPU**

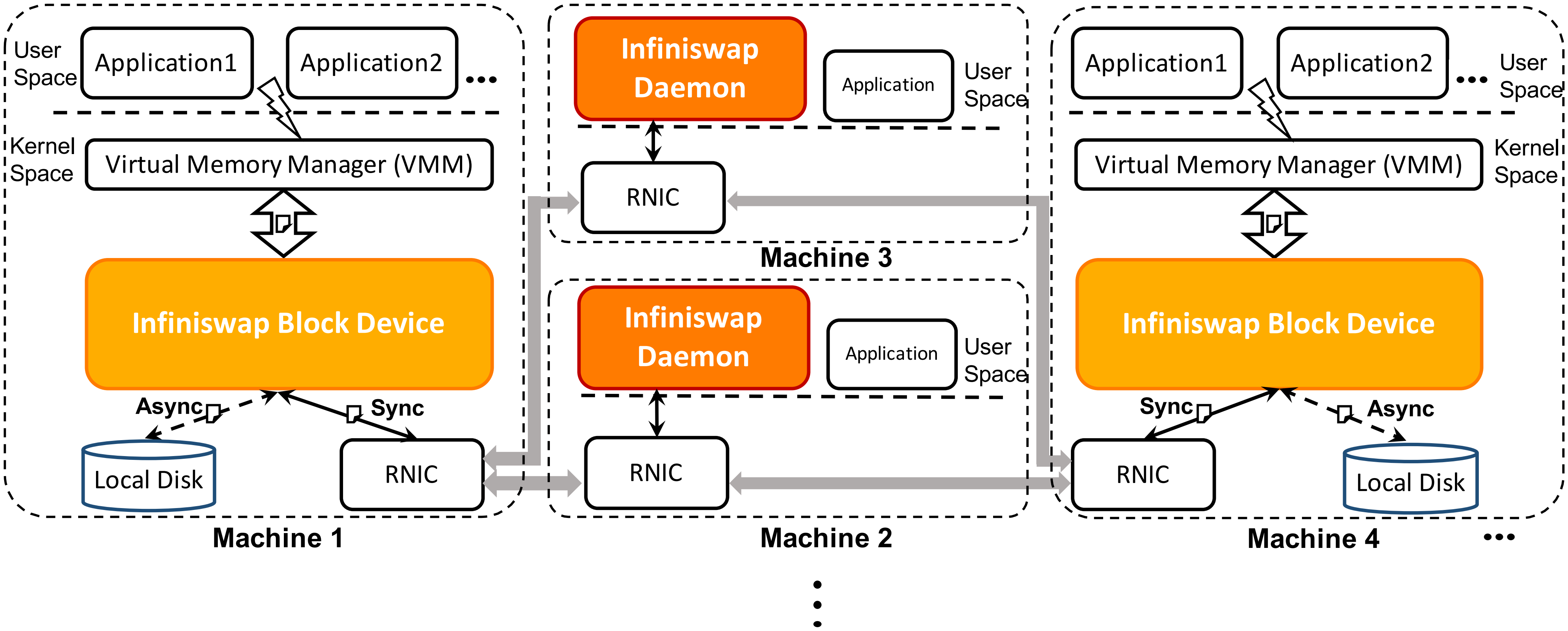
How to meet the design objectives?

Objectives	Ideas
No hardware design	Remote paging
No application modification	
Fault-tolerance	Local backup disk

One-to-many


User Space
Application1
Application2
...
Kernel Space
Virtual Memory Manager (VMM)
Infiniswap Block Device
Async
Sync
Local Disk
RNIC
Machine 1
Infiniswap Daemon
Application
User Space
RNIC
Machine 3
Infiniswap Daemon
Application
User Space
RNIC
Machine 2

Many-to-many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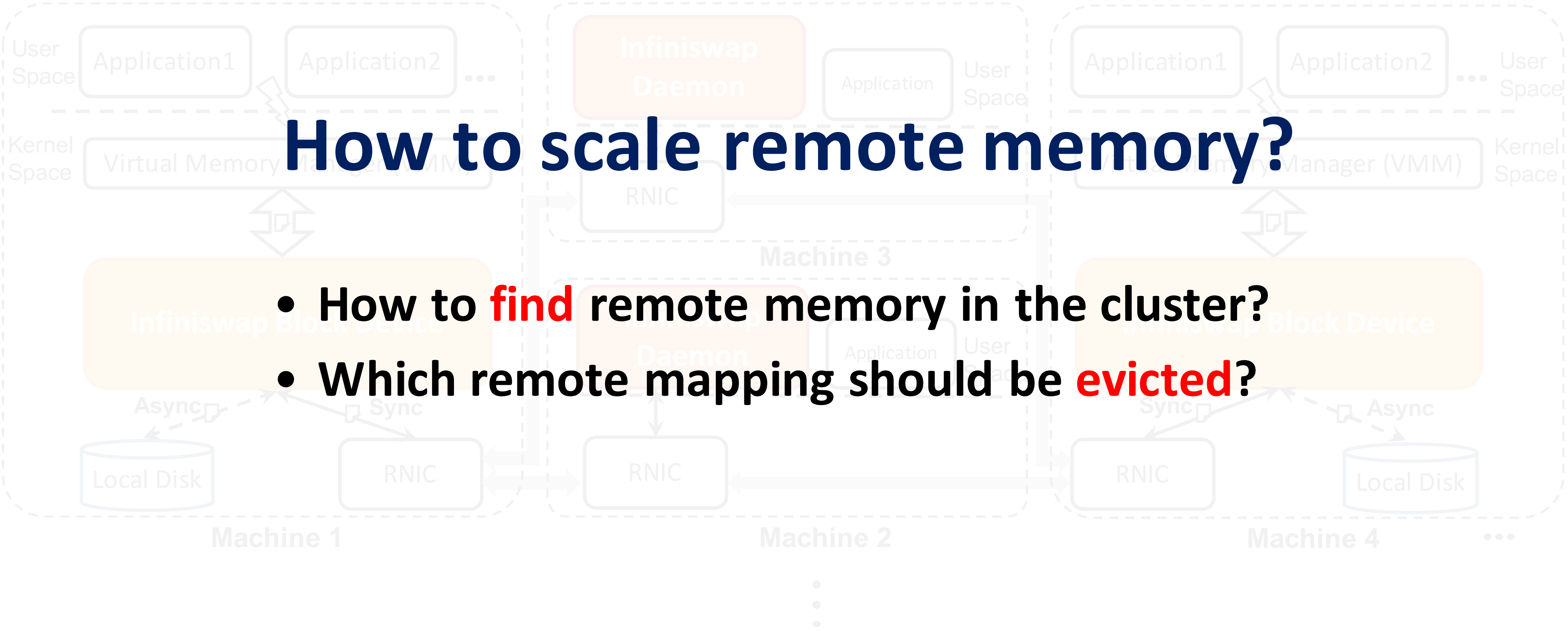
Many-to-many



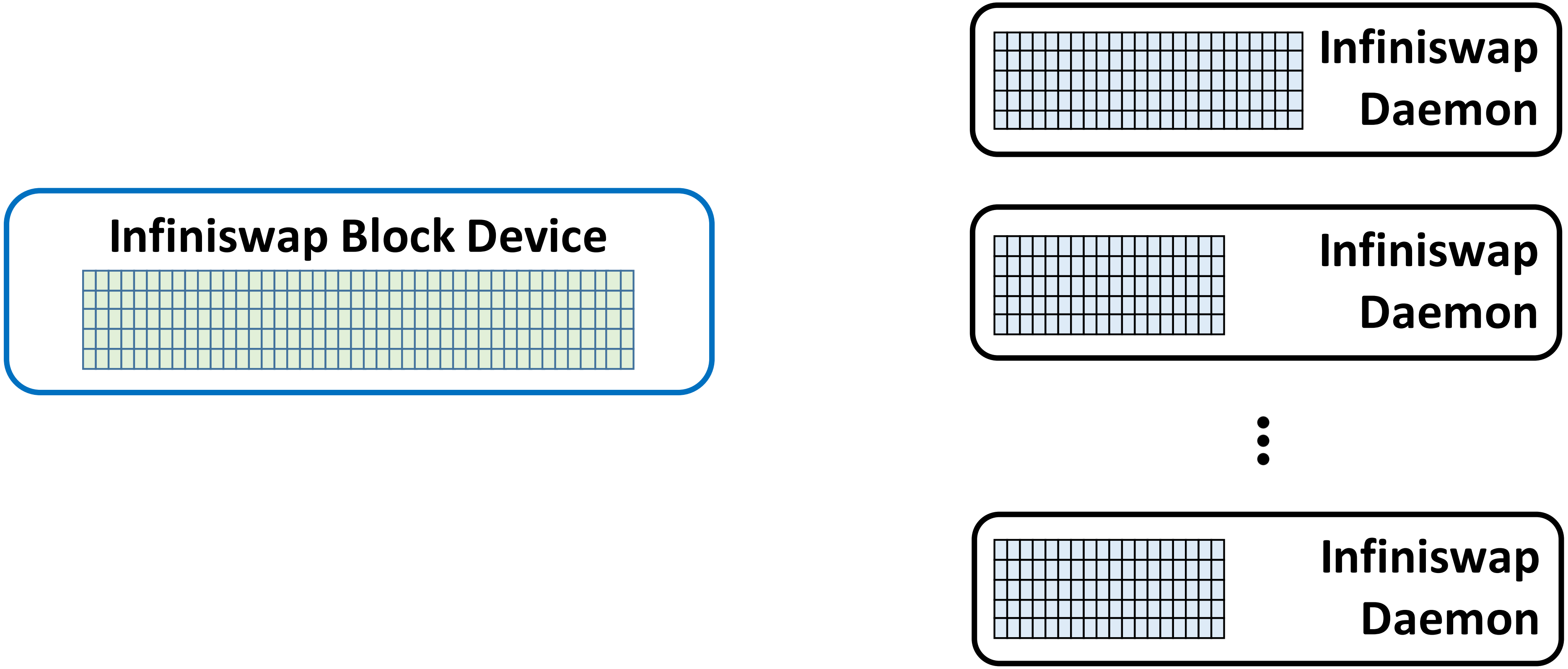
How to scale remote memory?

- How to **find** remote memory in the cluster?
- Which remote mapping should be **evicted**?

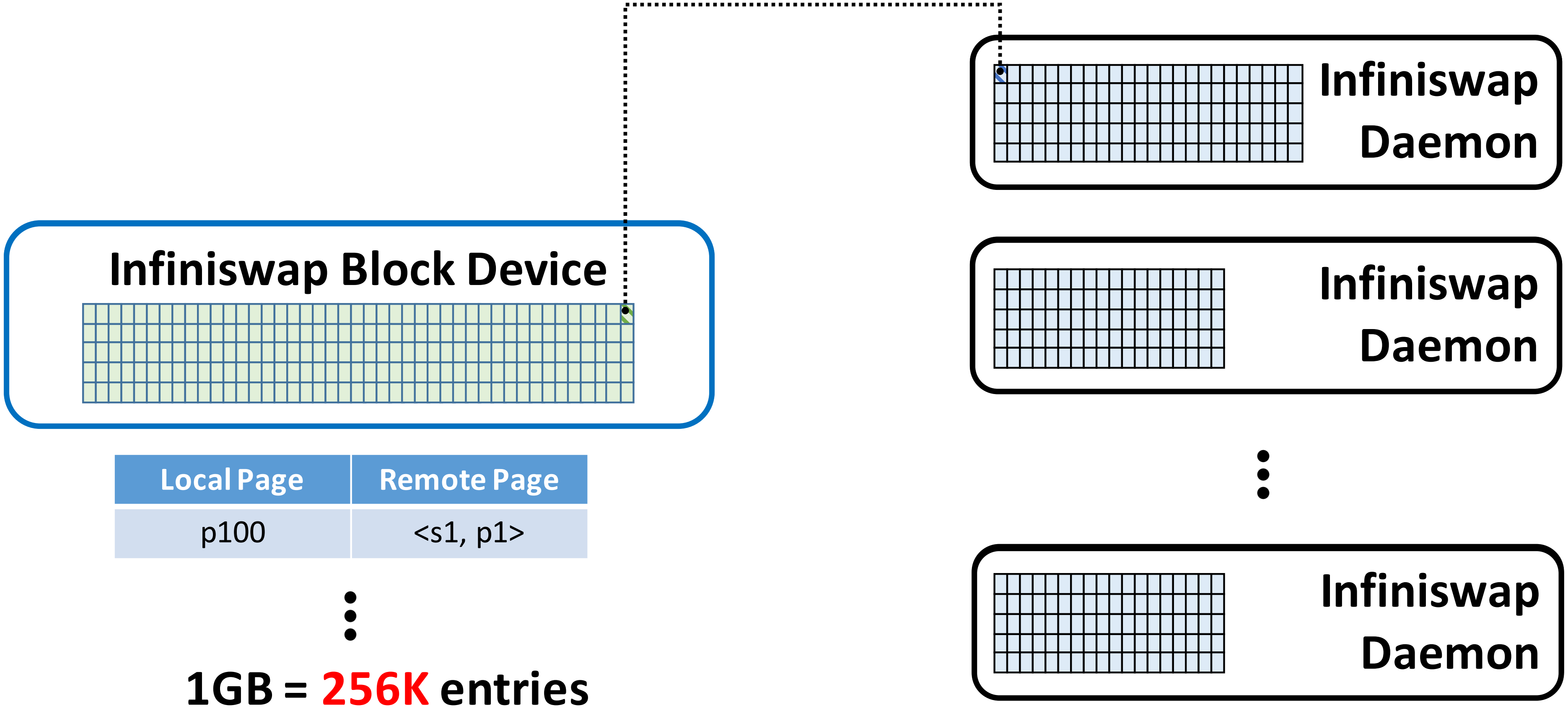
How to meet the design objectives?

Objectives	Ideas
No hardware design	Remote paging
No application modification	
Fault-tolerance	Local backup disk
Scalability	**Decentralized** remote memory management

Management unit: memory page?



Management unit: memory page?



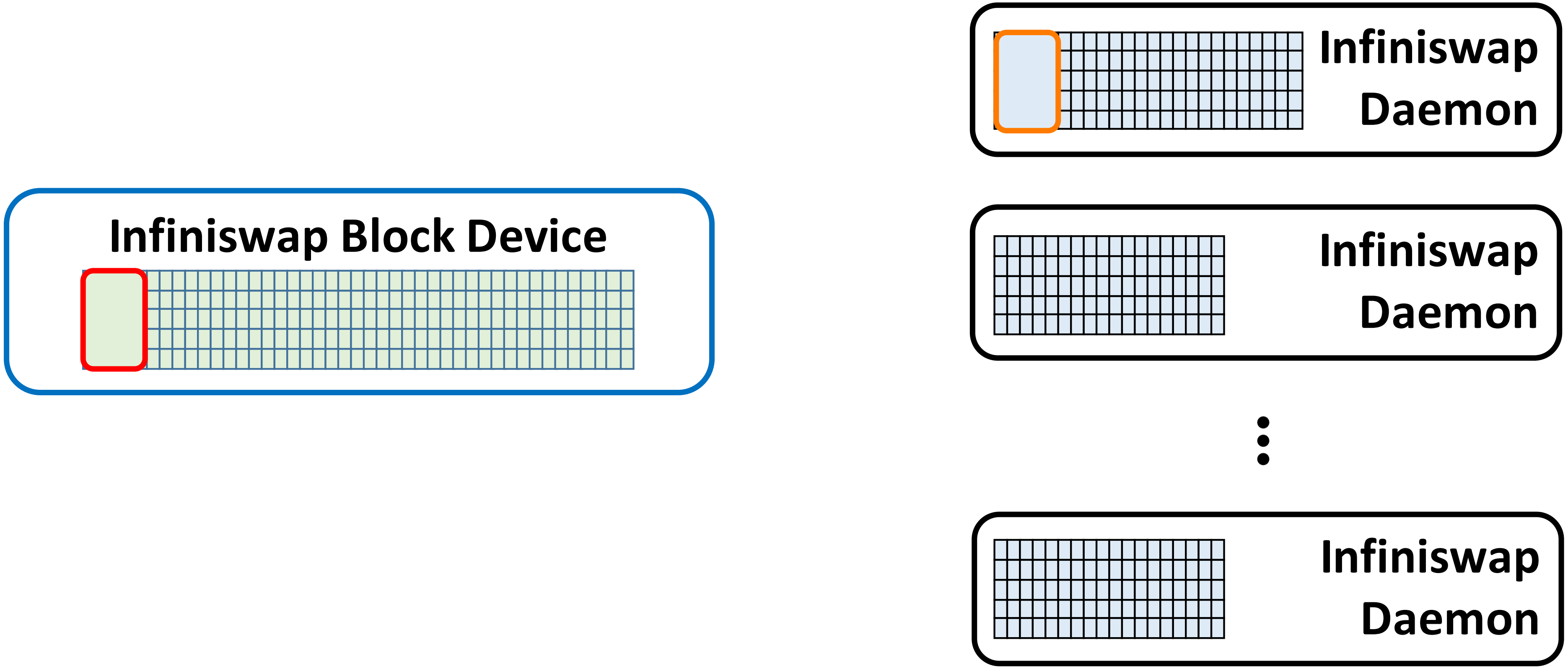
Local Page	Remote Page
p100	<s1, p1>

⋮

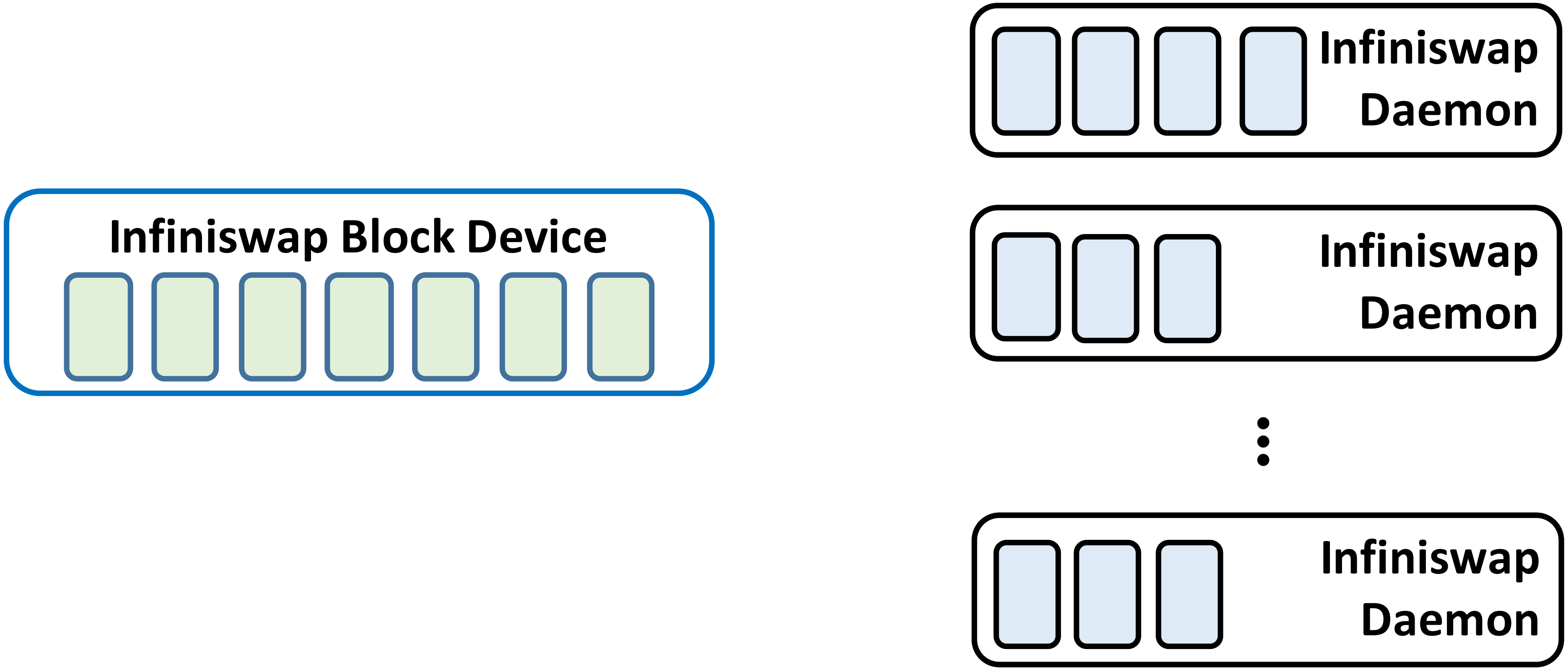
1GB = 256K entries

1GB = 256K RTTs

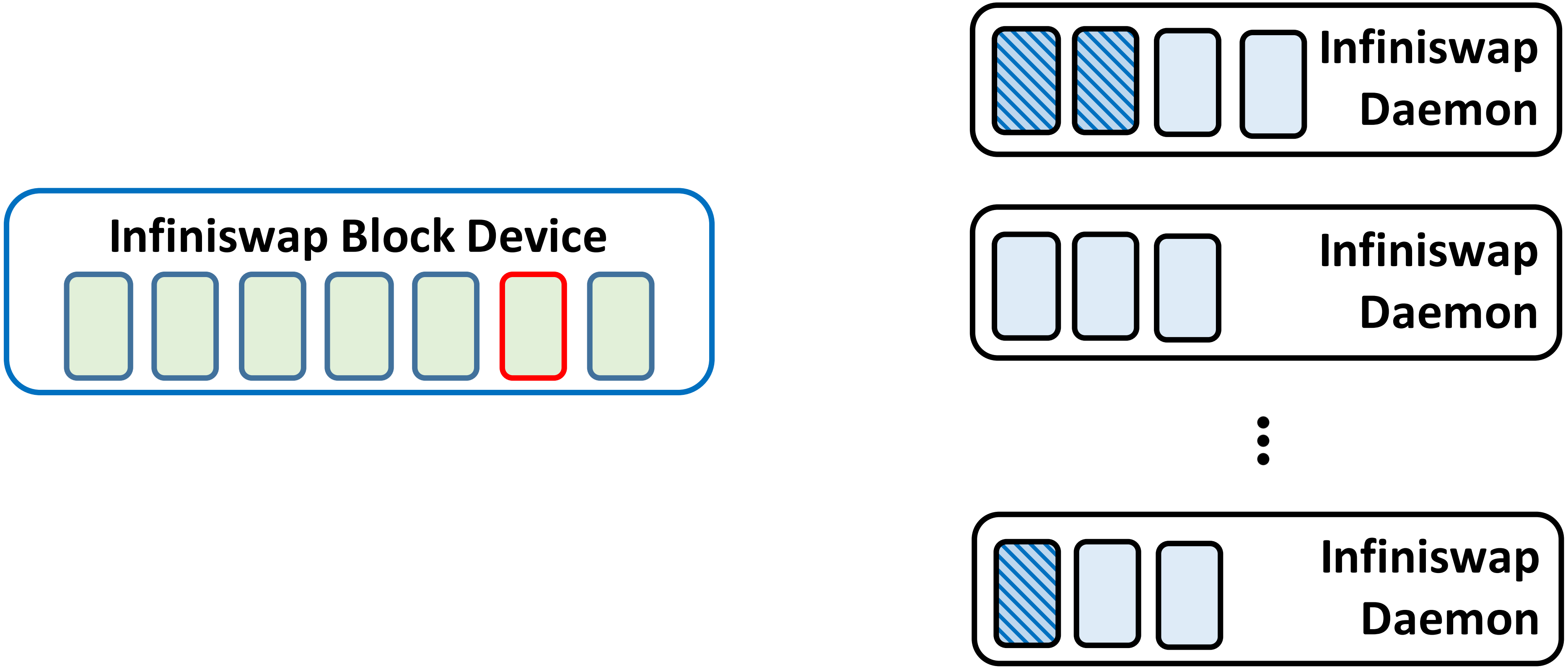
Management unit: memory slab!



Management unit: memory slab!



Which remote machine should be selected?



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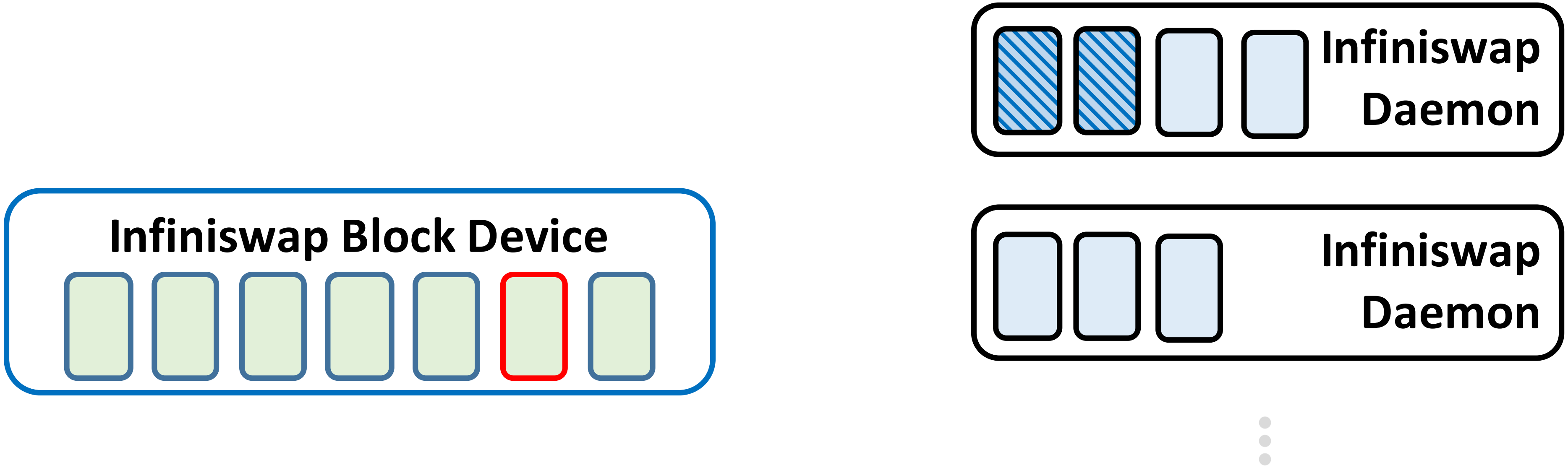
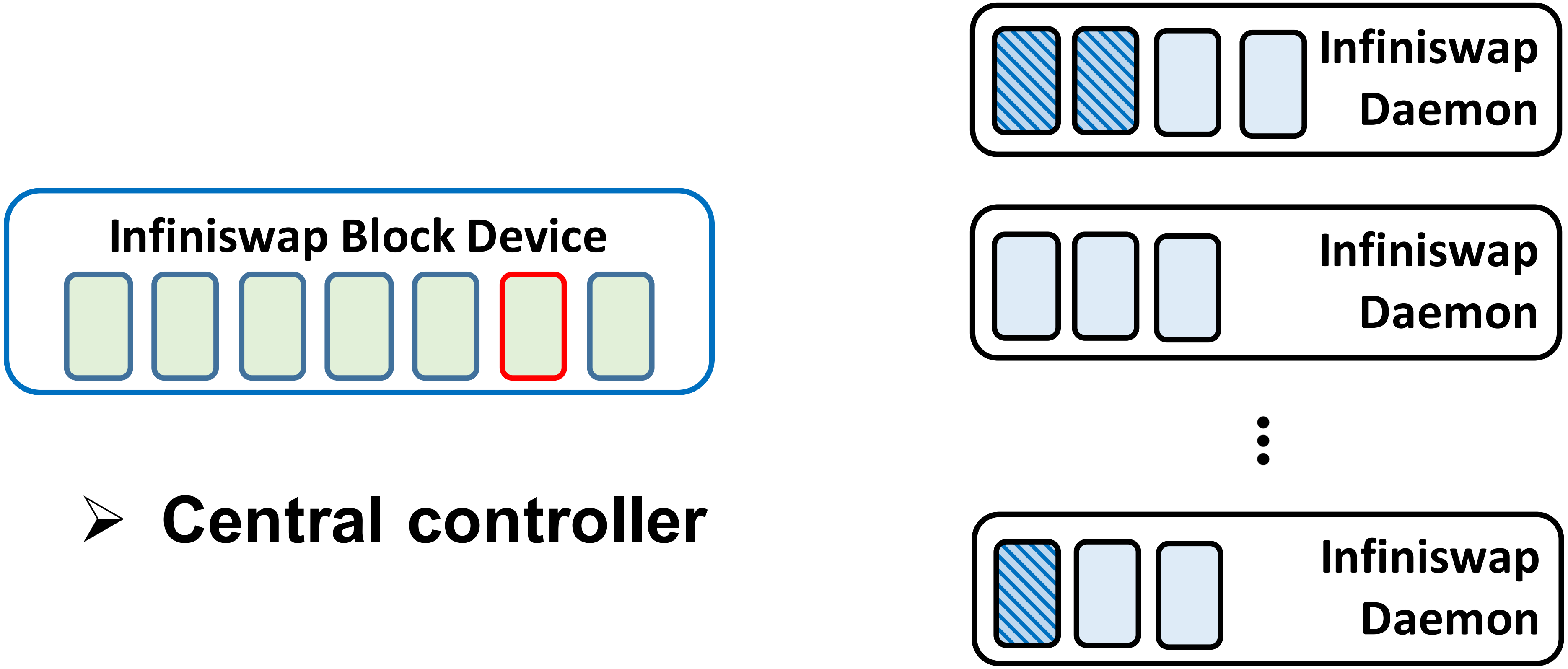


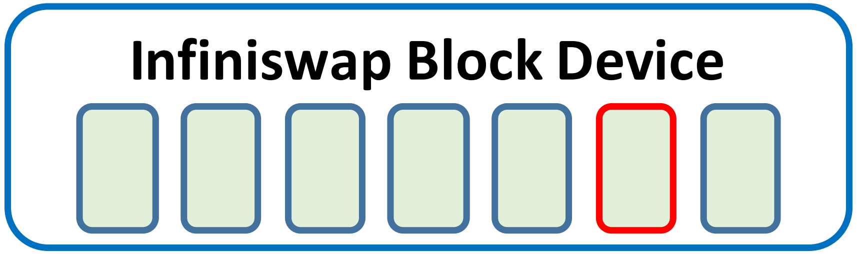
Goal: balance memory utilization

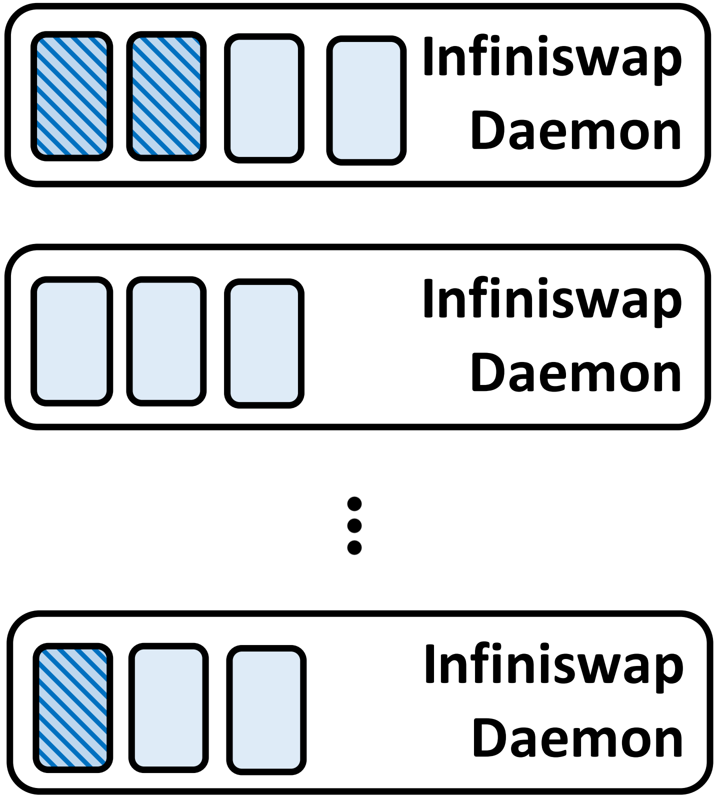
Which remote machine should be selected?



- Central controller

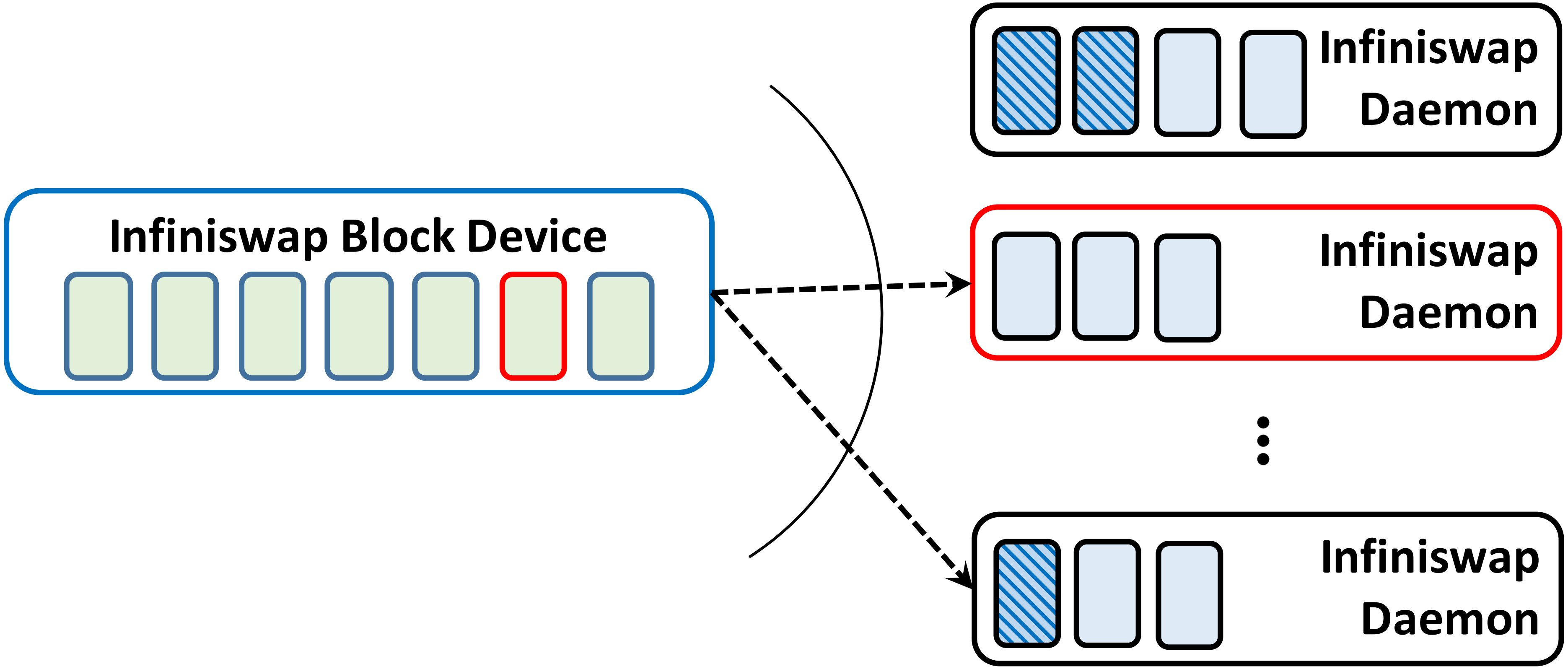
Which remote machine should be selected?





- ~~Central controller~~
- Decentralized approach

Power of two choices[1]



[1] Mitzenmacher, Michael. "The power of two choices in randomized load balancing.", Ph.D. thesis, U.C. Berkeley, 1996

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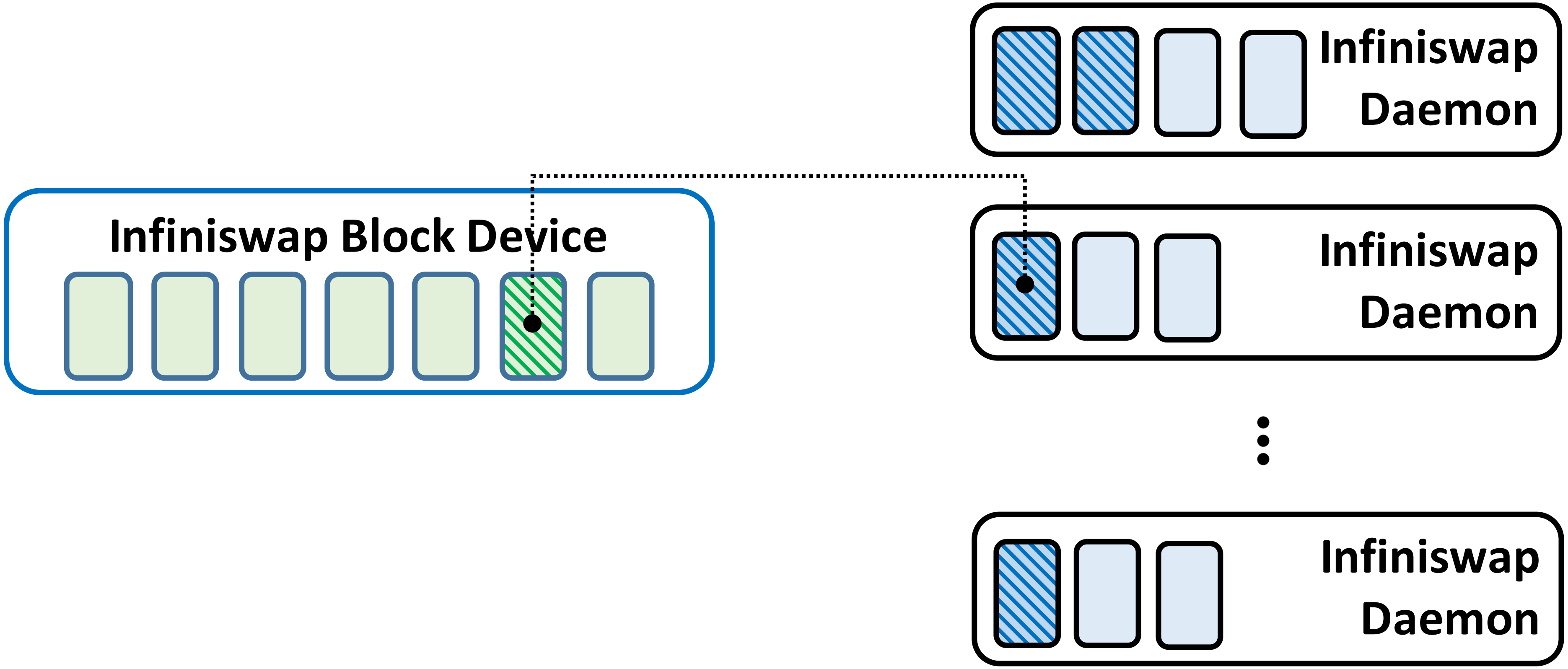

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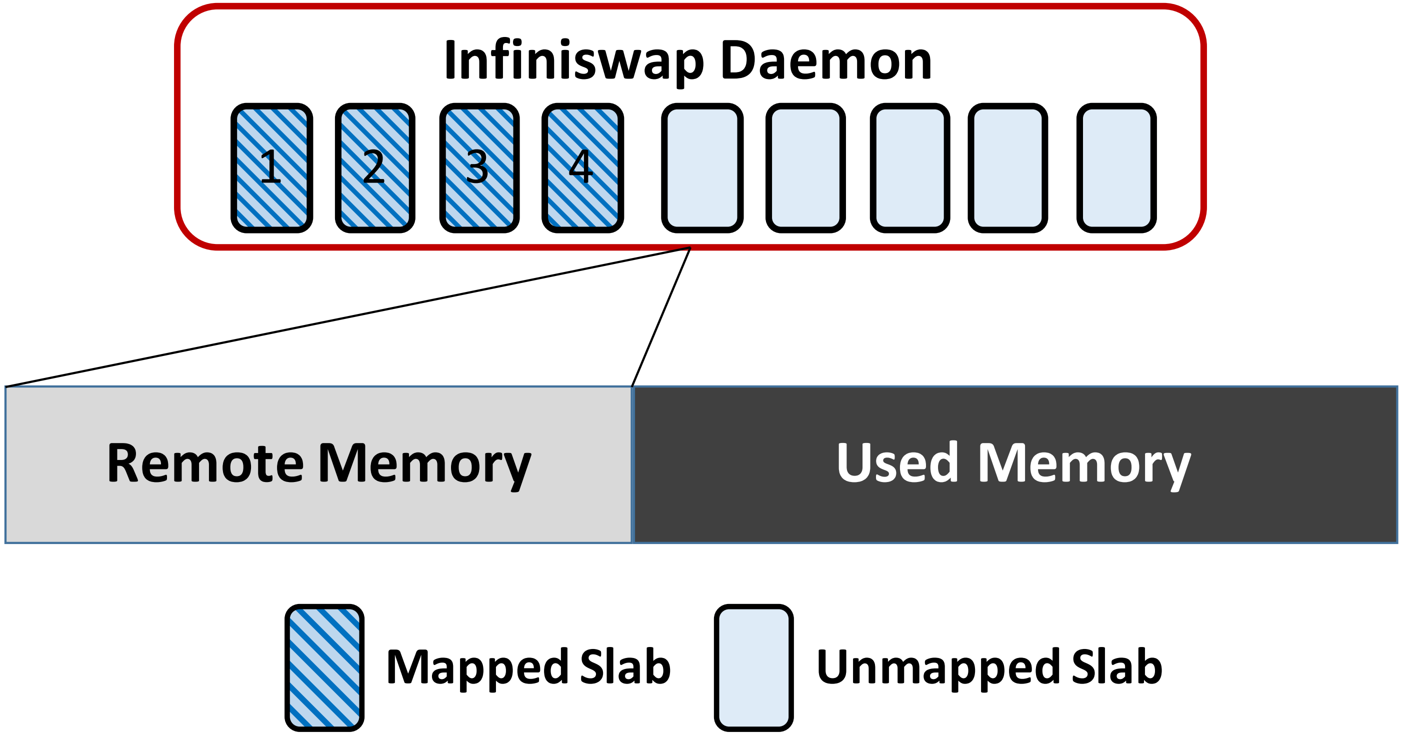
Slab eviction



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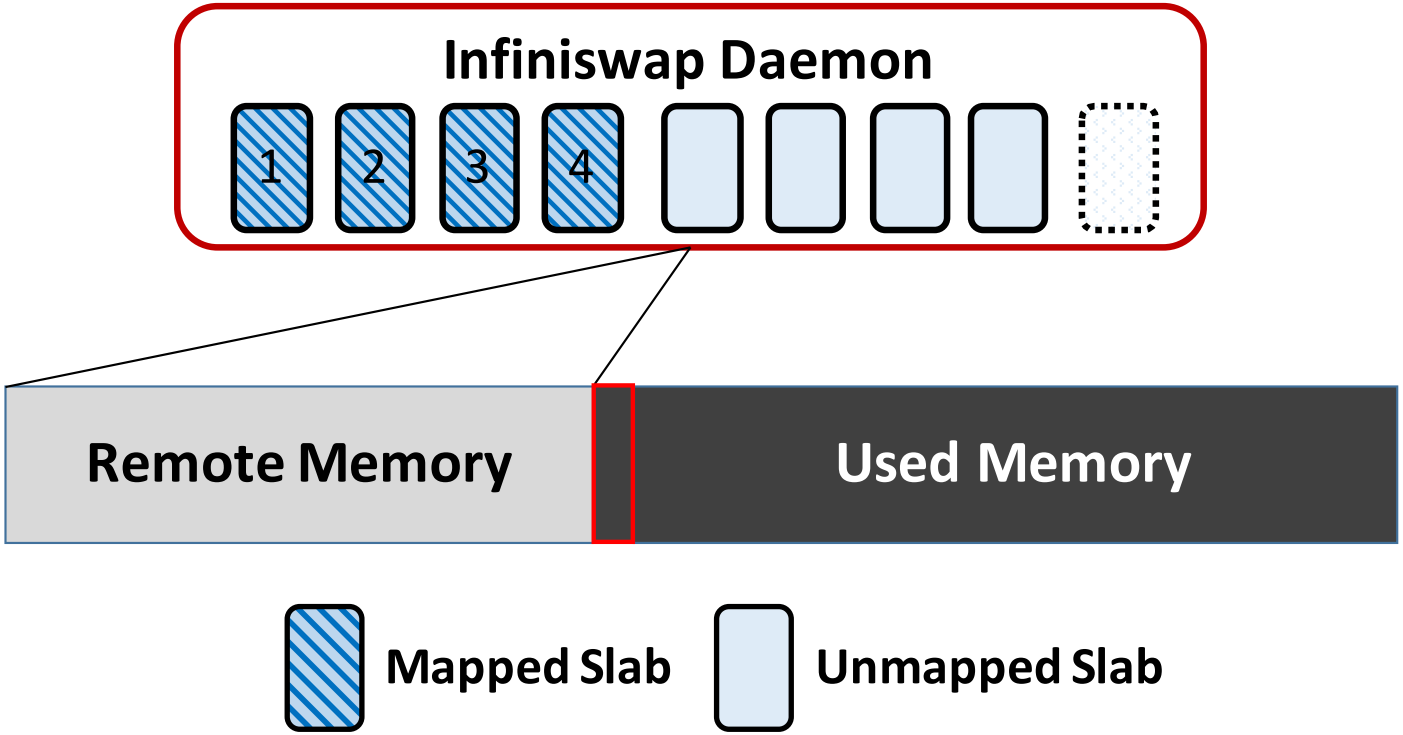

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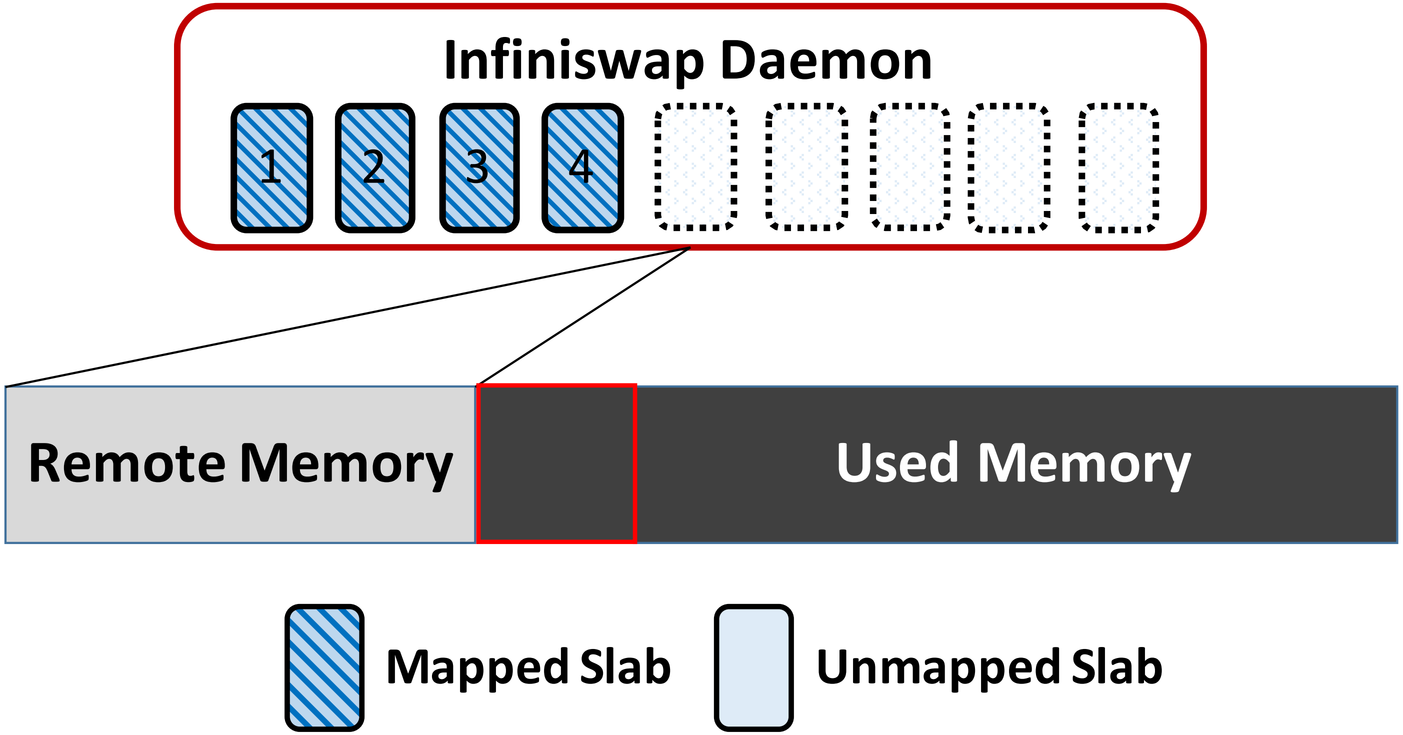

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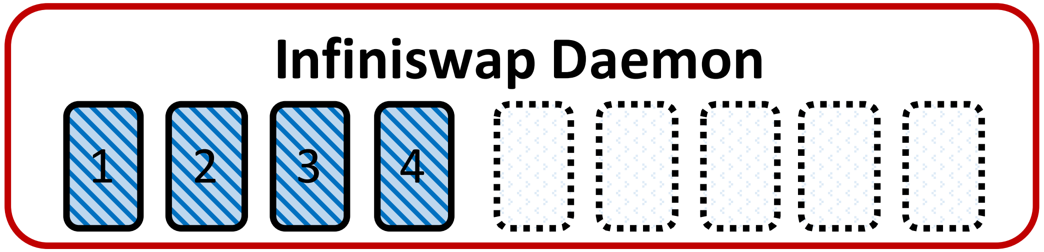
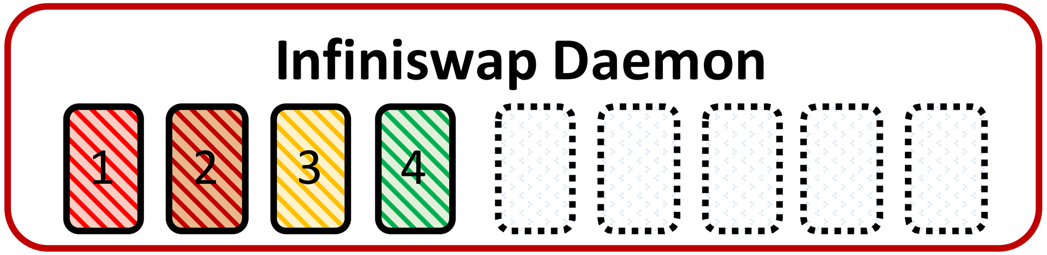


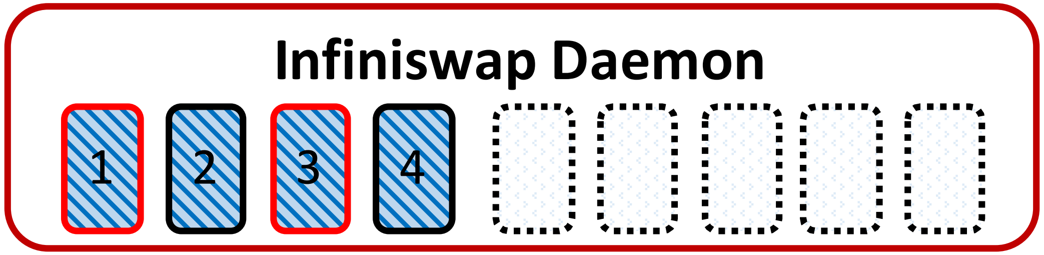
Daemon: Does not know the swap activities

Which slab should be evicted?



Daemon: Too expensive to query all the slabs

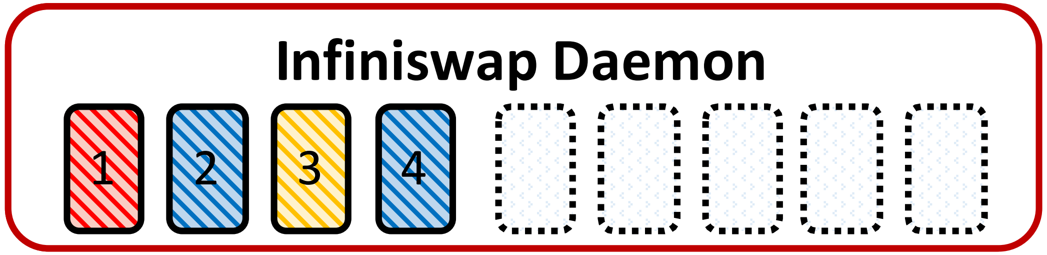
Power of multiple choices[1]



Select E least-active slabs from E+E’ random slabs

[1] Park, Gahyun. "A generalization of multiple choice balls-into-bins.” PODC’11

Power of multiple choices[1]



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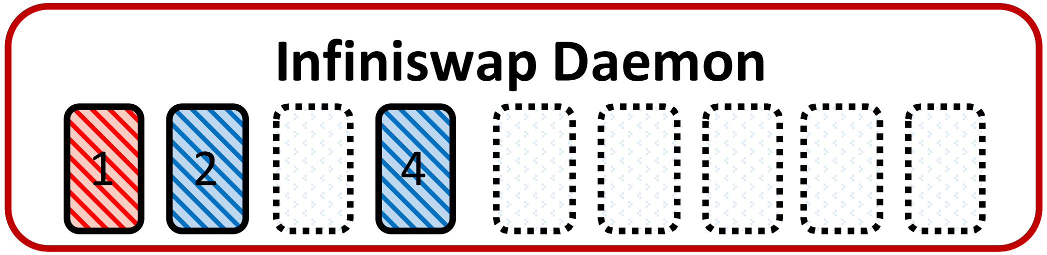

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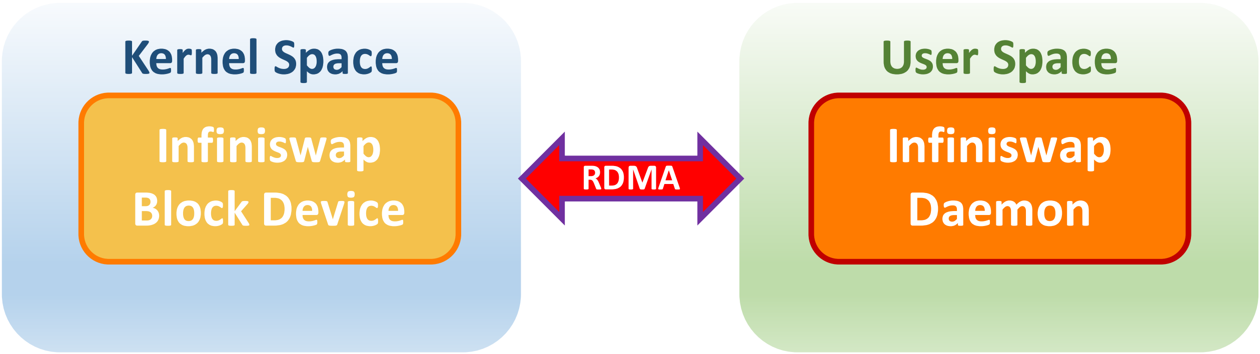
Implementation



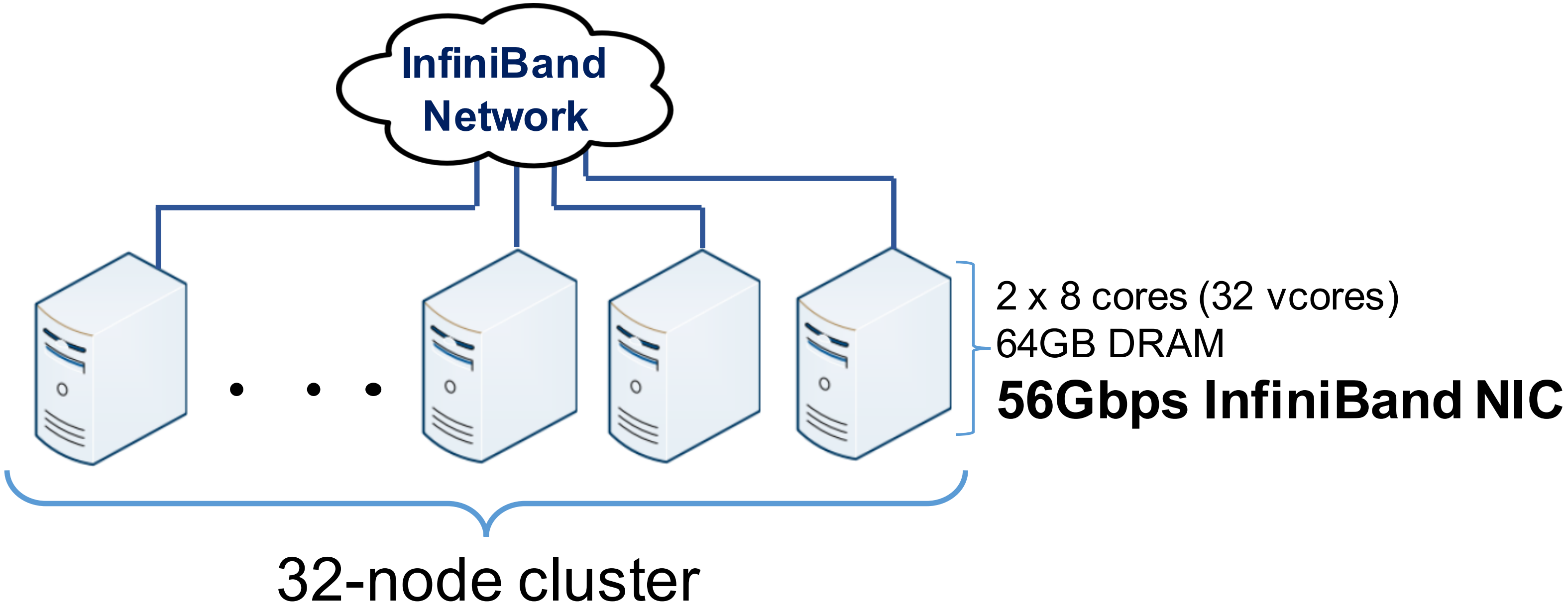
- Connection Management
  - **One** RDMA connection per active block device - daemon pair
- Control Plane
  - **SEND, RECV**
- Data Plane
  - **One-sided RDMA READ, WRITE**

What are we expecting from Infiniswap?

- **Application performance**
- **Cluster memory utilization**
- Network usage
- Eviction overhead
- Fault-tolerance overhead
- Performance as a block device

⋮

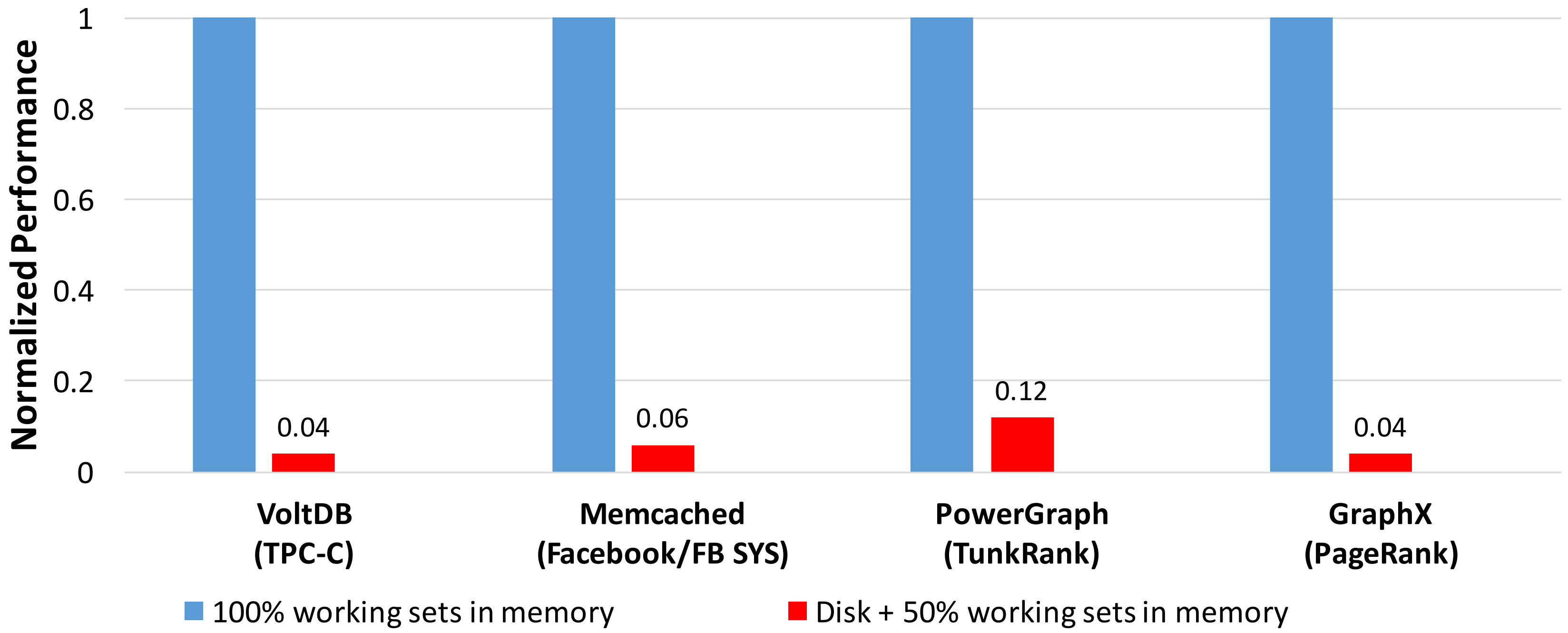
Evaluation



VOLTDB memCached powergraph GraphX

Application performance

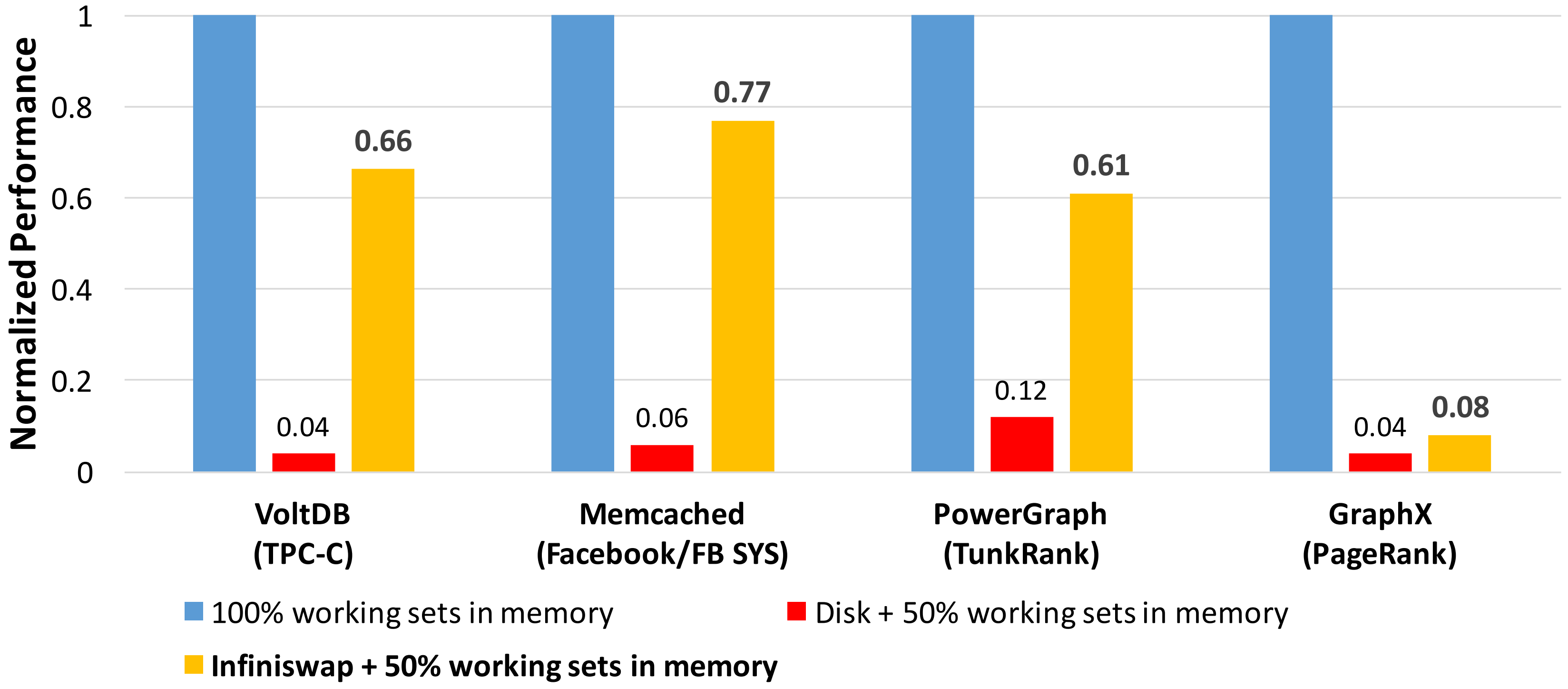
- 50% working sets in memory



- Application performance is improved by 2-16x

Application performance

- 50% working sets in memory



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Application performance

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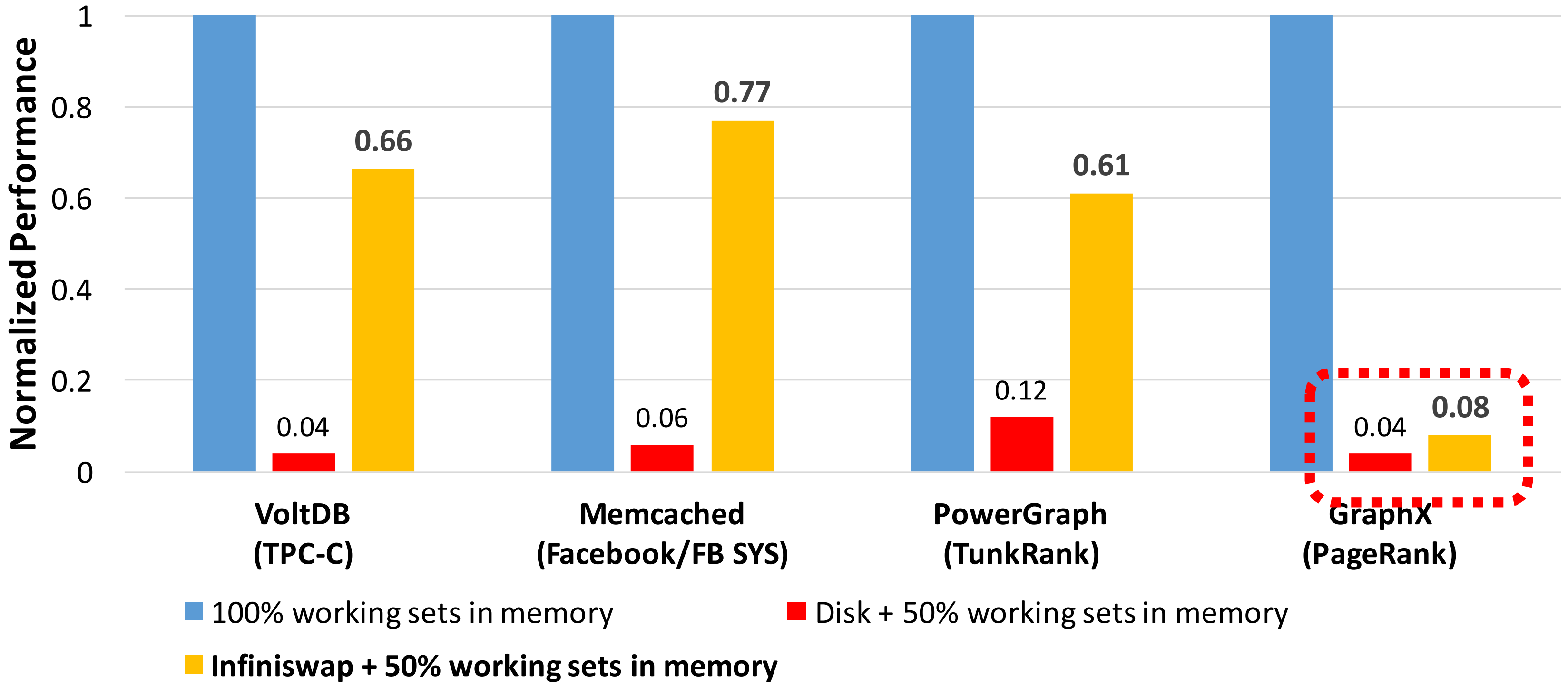
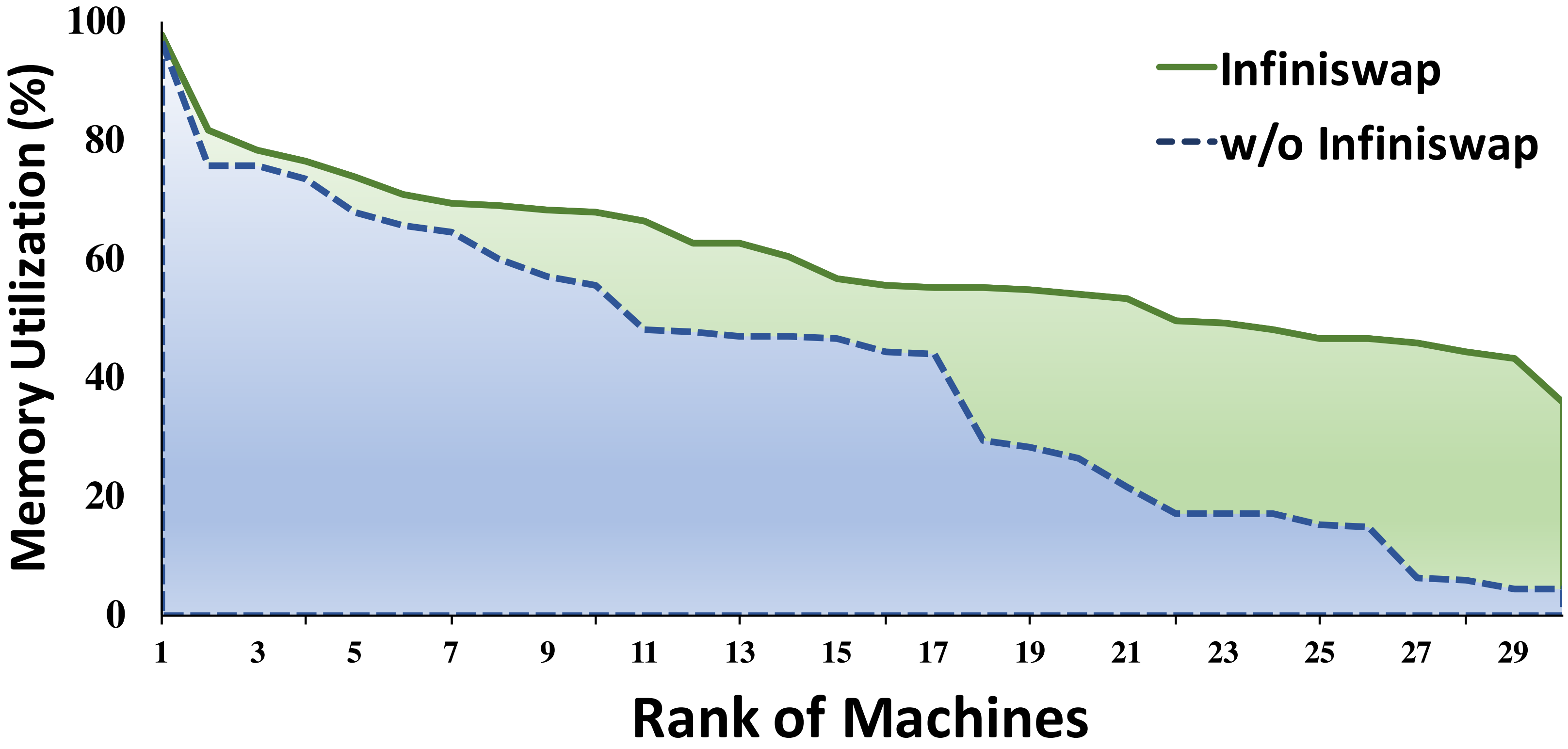


- Application performance is improved by 2-16x

Cluster memory utilization

- 90 containers (applications), mixing all applications and memory constraints.



- Cluster memory utilization is improved from **40.8%** to **60%** (1.47x)

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Limitations and future work

- **Trade-off in fault-tolerance**
  - Local disk is the bottleneck
  - Multiple remote replicas
    - Fault-tolerance vs. space-efficiency
- **Performance isolation among applications**
  - W/o limitation on each application's usage
  - W/o mapping between remote memory and applications

Conclusion

- **Infiniswap: remote paging over RDMA**
  - Application performance
  - Cluster memory utilization
- **Efficient, practical memory disaggregation**
  - No hardware design
  - No application modification
  - **Fault-tolerance**
  - **Scalability**

Source code is coming soon!

https://github.com/Infiniswap/infiniswap.git

Thank You !