WALM: WORKLOAD-AWARE LIVE MIGRATION OF VIRTUAL MACHINES

SCS 4224 FINAL YEAR PROJECT IN COMPUTER SCIENCE

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A Workload-Aware Live Migration mechanism to reduce the total migration time related to LAN- based VM migrations by choosing the most optimal migration method for a given VM workload dynamically.

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1. BACKGROUND

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Live Migration of VMs

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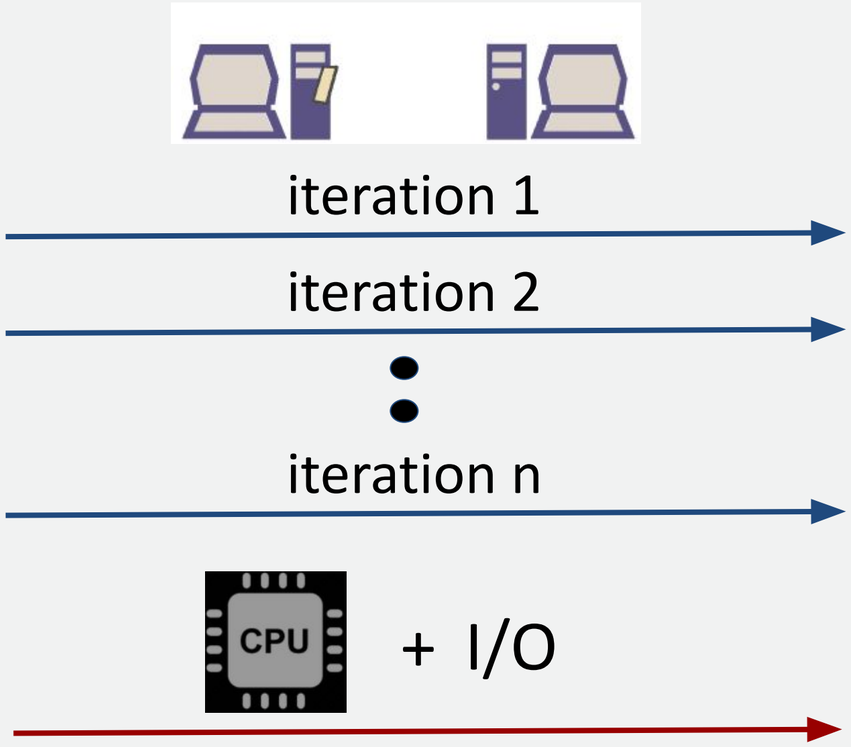
Migration Methods

- Pre-copy Migration



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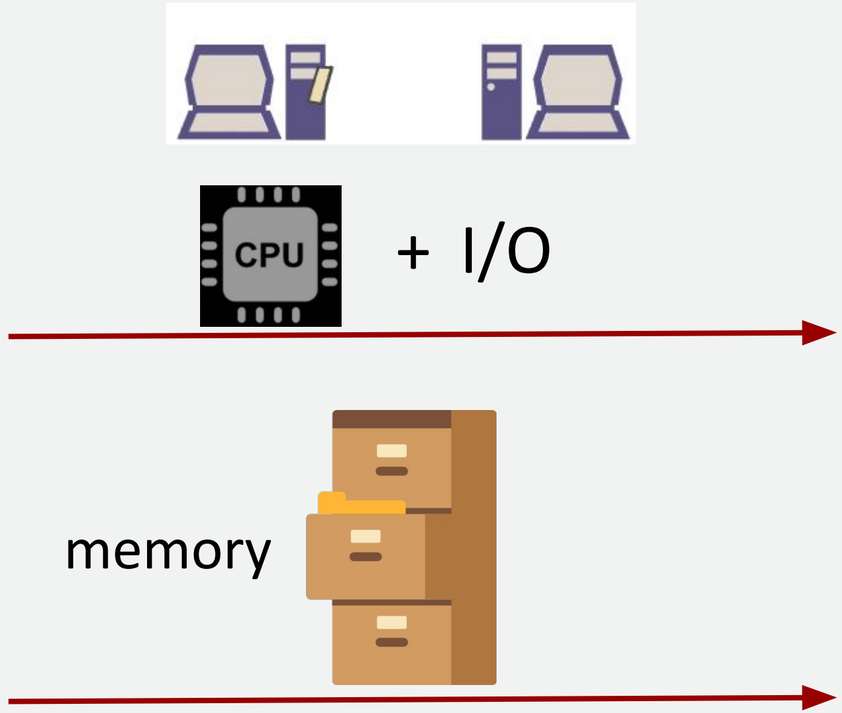
Migration Methods

- Post-copy Migration



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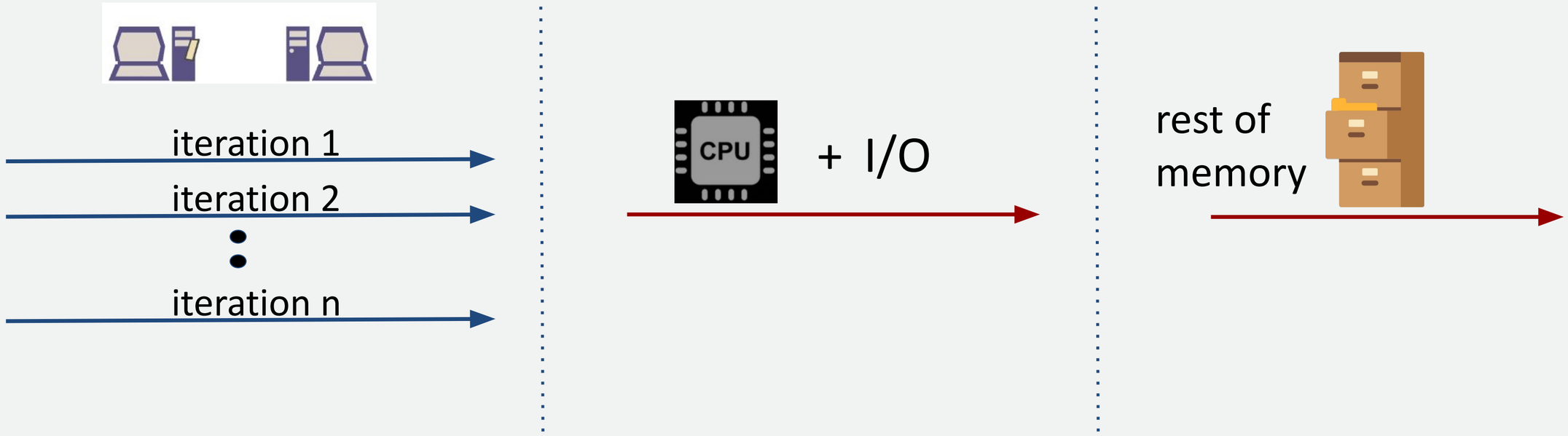
- **Hybrid Migration**



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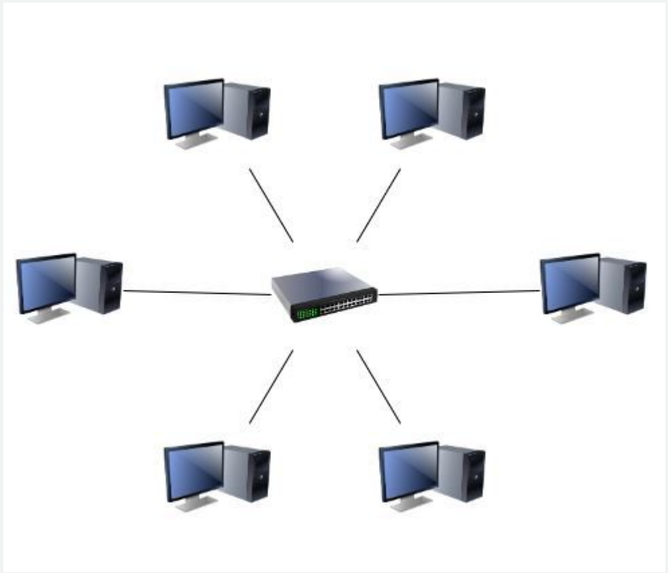
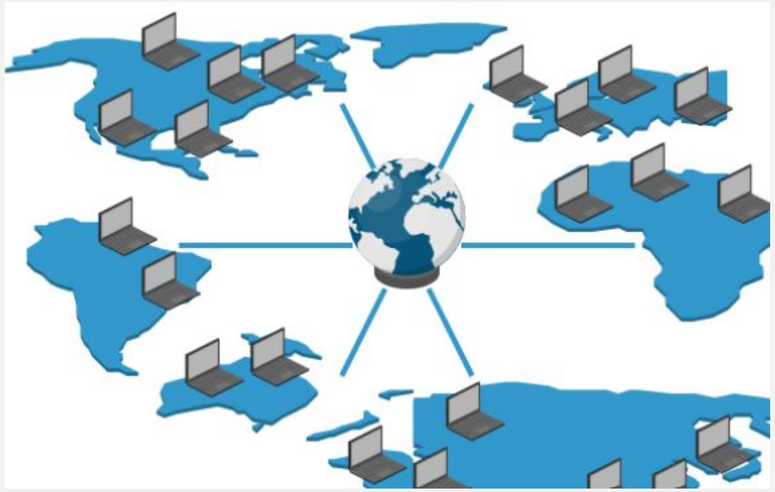
- LAN Migration



- WAN Migration



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- Performance Metrics
  - Downtime
  - Total Migration Time
  - Bandwidth Utilization
  - Performance Degradation

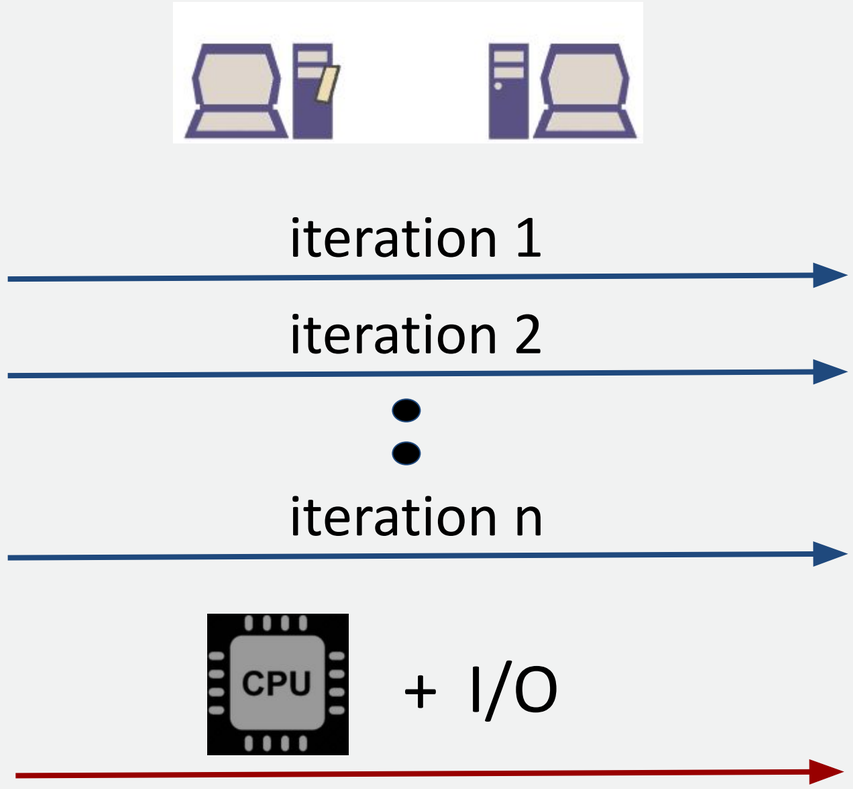
2. PROBLEM STATEMENT

WALM

Different migration techniques perform differently for different kinds of VM workloads.

CPU intensive	Memory intensive	Network intensive
		
Pre-copy	Post-copy	Hybrid

- **Pre-copy Migration**



"...even moderately write-intensive workloads can reduce precopy's effectiveness during migration"

- Hines, M. R., Deshpande, U. & Gopalan, K. (2009), 'Post-copy live migration of virtual machines', ACM SIGOPS operating systems review 43(3), 14–26.

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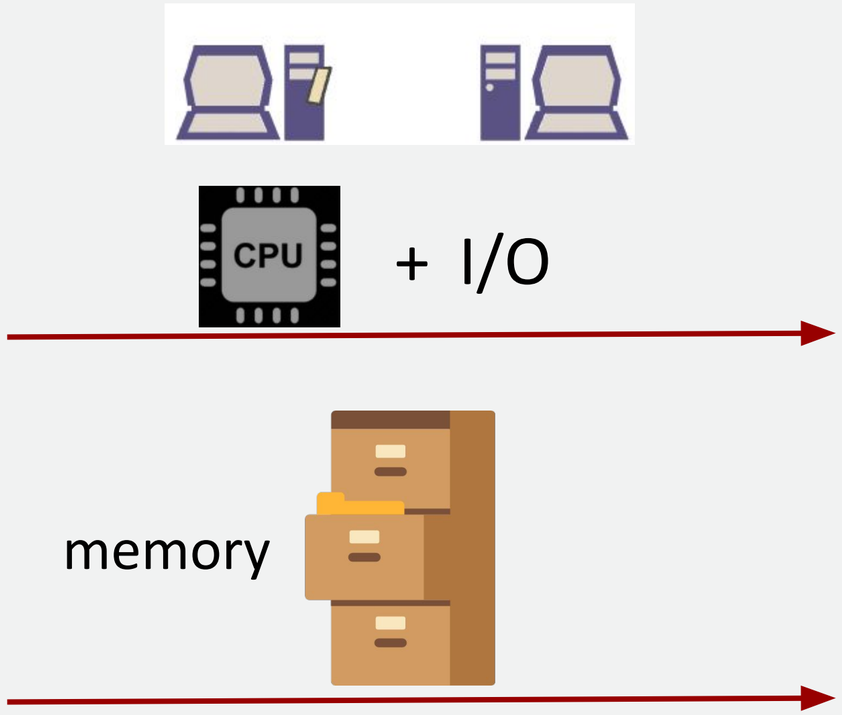
- **Post-copy Migration**



“... post-copy doesn’t perform well with read intensive loads. A read intensive VM will lead to an increase in the number of page faults ”

- Sahni, S. and Varma, V., 2012, October. A hybrid approach to live migration of virtual machines. In 2012 IEEE international conference on cloud computing in emerging markets (CCEM) (pp. 1-5). IEEE.

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3. RELATED WORK

SOLive (Fernando et al., IEEE INFOCOM 2020-IEEE conference on computer communications, 2020)

- **Aims to minimize the total migration time.**
- **Considers different VM workloads.**
  - **CPU Intensive**
  - **Network Intensive**
  - **Memory Intensive**
- **Dynamically categorizes VMs.**

SOLive (Fernando et al., IEEE INFOCOM 2020-IEEE conference on computer communications, 2020)

- **Aims to minimize the total migration time.**
- **Considers different VM workloads.**
  - **CPU Intensive**
  - **Network Intensive**
  - **Memory Intensive**
- **Dynamically categorizes VMs.**

- **Choose the most optimal migration method according to the VM workload types.**
- **Automatic selection of migration method based on VM workload type.**

AdaMig (Li et al., Proceedings of the 17th ACM SIGPLAN/SIGOPS International Conference on Virtual Execution Environments, 2021)

- **Adaptive Live Migration.**
- **Prioritizing pre-copy.**
- **Halts inefficient migration and dynamically switches to another method.**
- **"Migration Speed < Page Dirtying Rate"**
  - **CPU Throttling**
  - **Compression**

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- **Adaptive Live Migration.**
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- **Halts inefficient migration and dynamically switches to another method.**
- **"Migration Speed < Page Dirtying Rate"**
  - **CPU Throttling**
  - **Compression**

- **No priority among the migration methods.**
- **Consider general workloads which can be demanding or non-demanding.**

Intelligent Hybrid Migration (Li et al., Future Generation Computer Systems, 95:126–139, 2019)

- **Aims to shorten the postcopy duration.**
- **Monitors dirty pages at each pre-copy iteration.**
- **"Pages dirtied >= Pages sent"**
  - **Monitor dirty pages for a few iterations to identify a local minima**
  - **Switch to post-copy**

Intelligent Hybrid Migration (Li et al., Future Generation Computer Systems, 95:126–139, 2019)

- **Aims to shorten the postcopy duration.**
- **Monitors dirty pages at each pre-copy iteration.**
- **"Pages dirtied >= Pages sent"**
  - **Monitor dirty pages for a few iterations to identify a local minima**
  - **Switch to post-copy**

- **Monitors pages dirtied at successive iterations.**
- **Doesn’t focus on shortening the post-copy duration.**

RESEARCH GAP

- Less focus on how the type of VM workload impacts the migration process.
- Less focus on dynamically changing migration aspects.
- Less focus on seamless and automatic migration technique selection.

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MOTIVATION

- **Migrating VMs with minimal migration duration.**
- **Decrease performance degradation.**

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4. INTRODUCTION

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WALM

Workload-aware Live Migration dynamically detects the nature of the workload running in the VM and migrates it by choosing the most efficient migrating method out of live migration techniques (namely pre-copy, post-copy and hybrid approaches).

WALM aims to reduce the total migration time related to LAN-based VM migrations

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RESEARCH QUESTIONS

1. **How can workload characteristics be effectively analyzed and classified to determine the most suitable migration method for a given virtual machine?**

2. What are the performance implications of different migration methods (pre-copy, post-copy, hybrid) in workload-aware live migration?

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SCOPE

IN SCOPE

- Workload analysis.
- Analyzing migration methods with respect to different workloads.
- Developing an algorithm for workload-aware live migration.

OUT SCOPE

- WAN migrations.
- Multi-tier VM applications.
- Multiple VM migrations.

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5. EMPIRICAL STUDY

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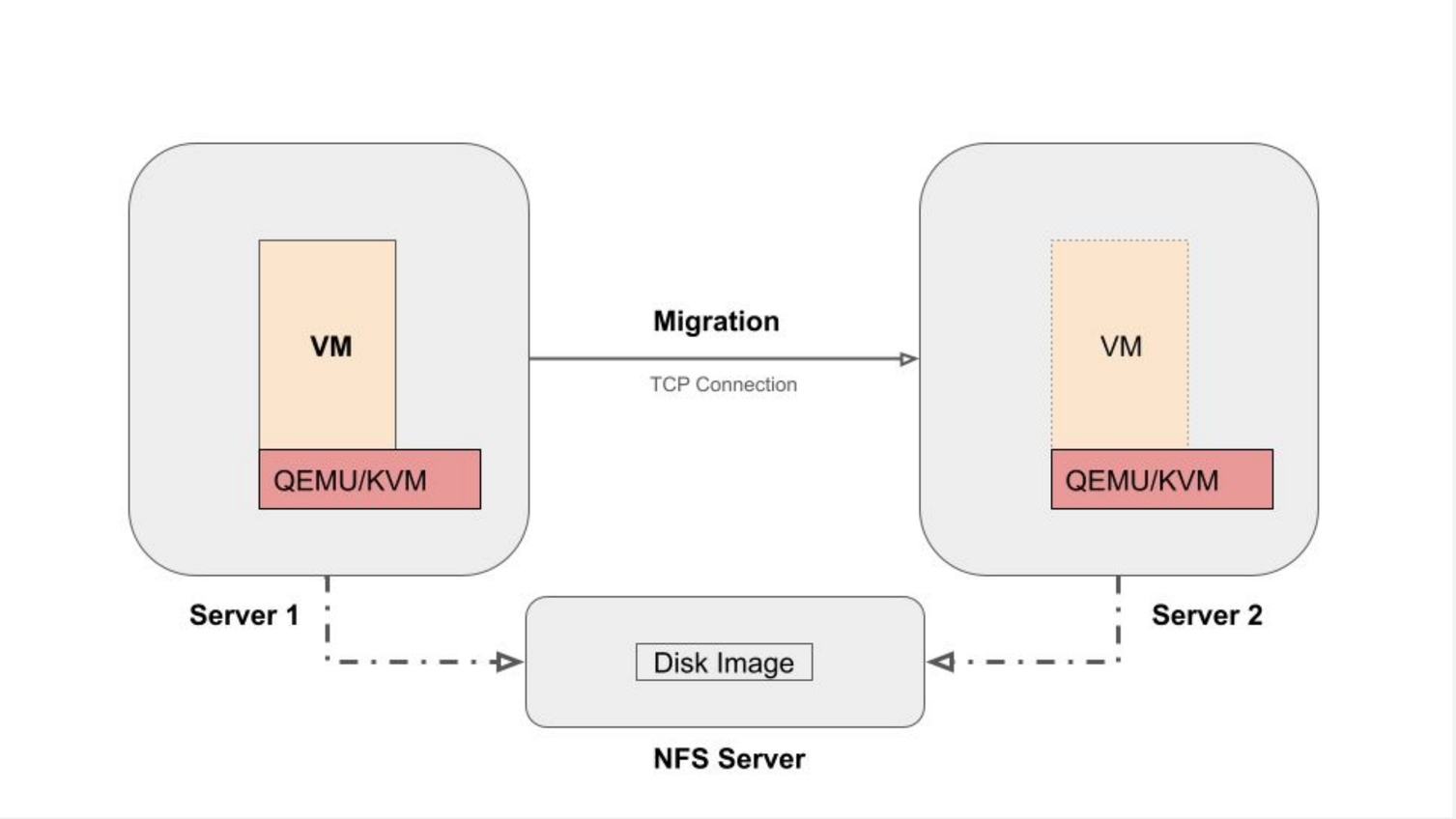
Testbed Architecture



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VM WORKLOADS

Memory-intensive Workloads
Working Set (WS)

CPU-intensive Workloads
Sysbench
Quicksort

Network-intensive Workloads
iPerf

Multiple-intensive Workloads
Yahoo! Cloud Serving Benchmark (YCSB)
Memcached

6. DESIGN

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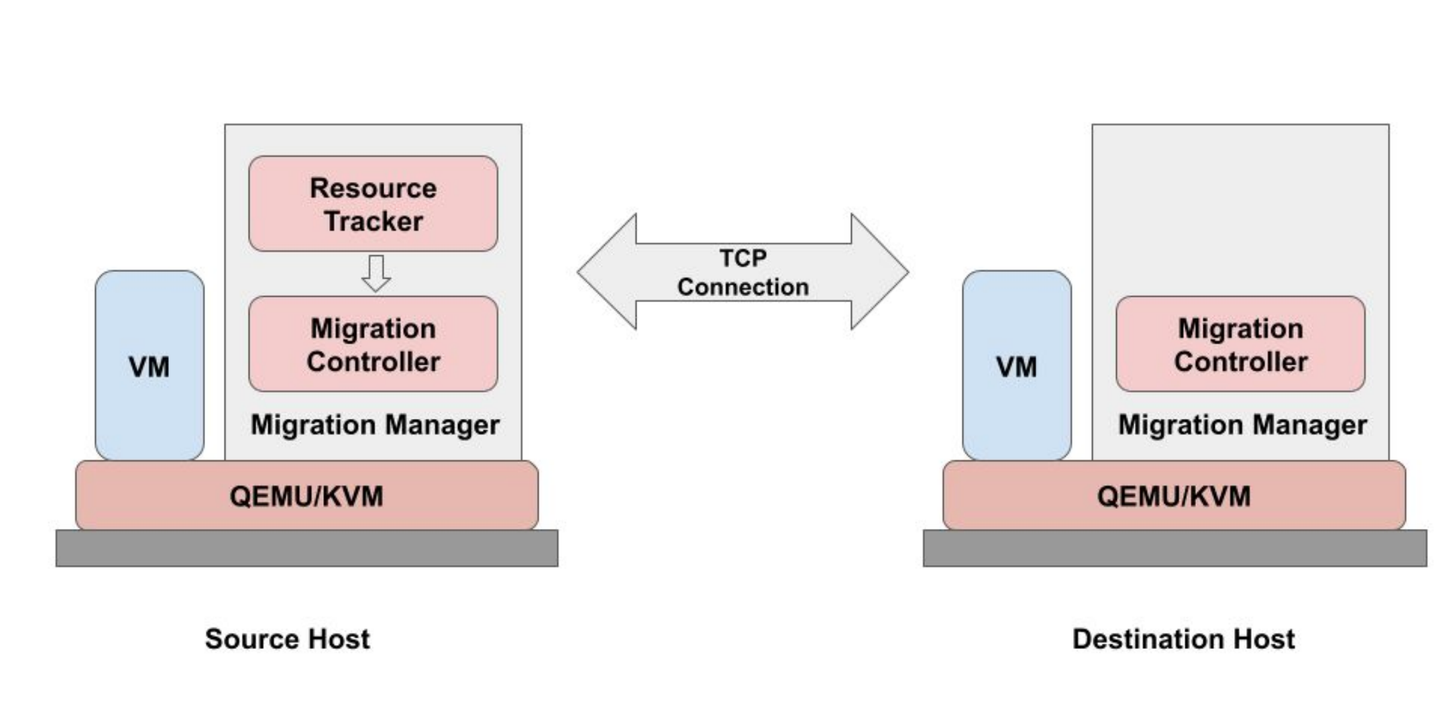
ARCHITECTURE



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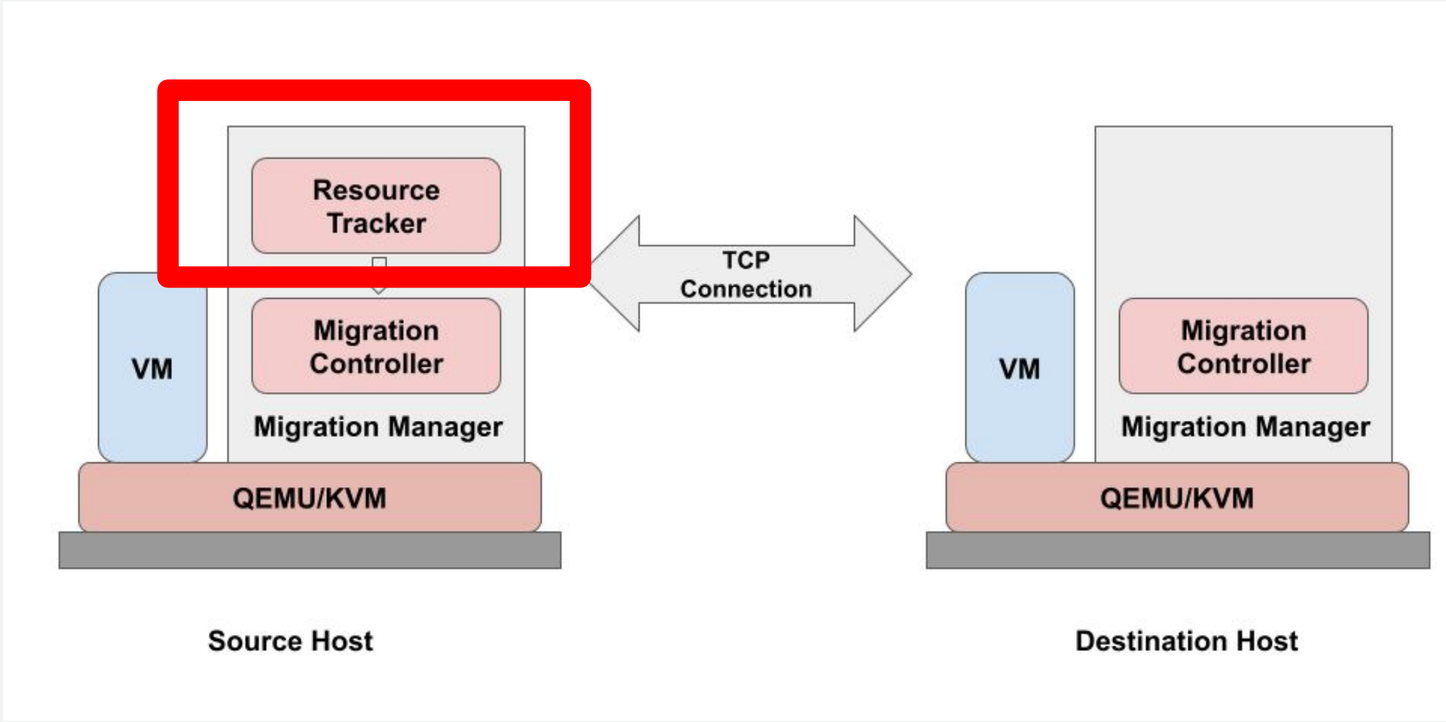

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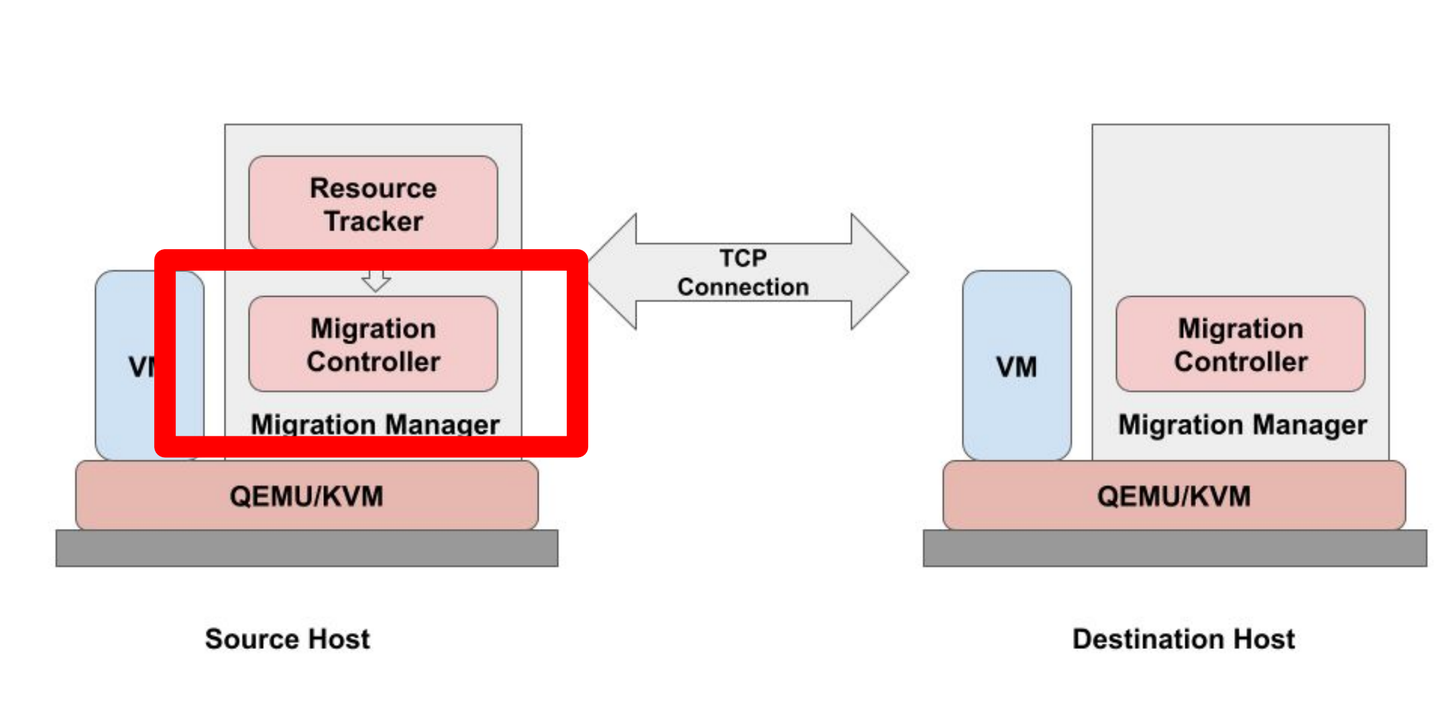

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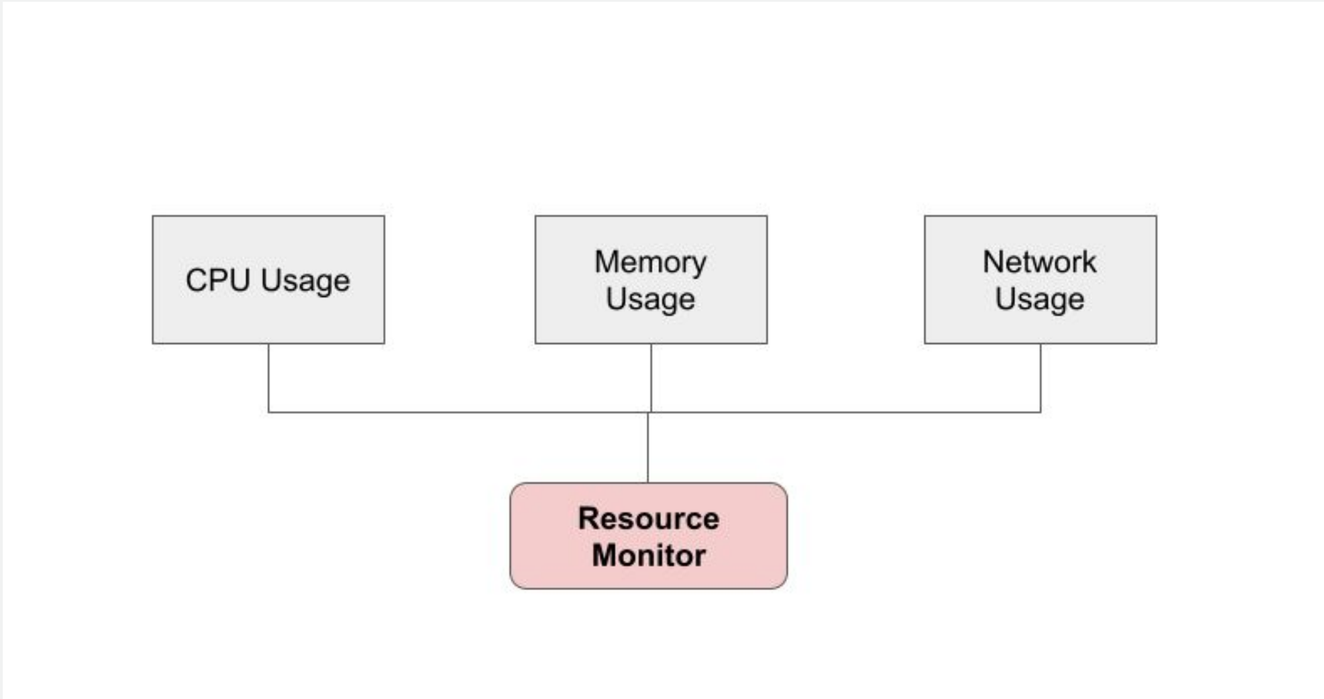
Architecture Ctd.

Resource Monitor

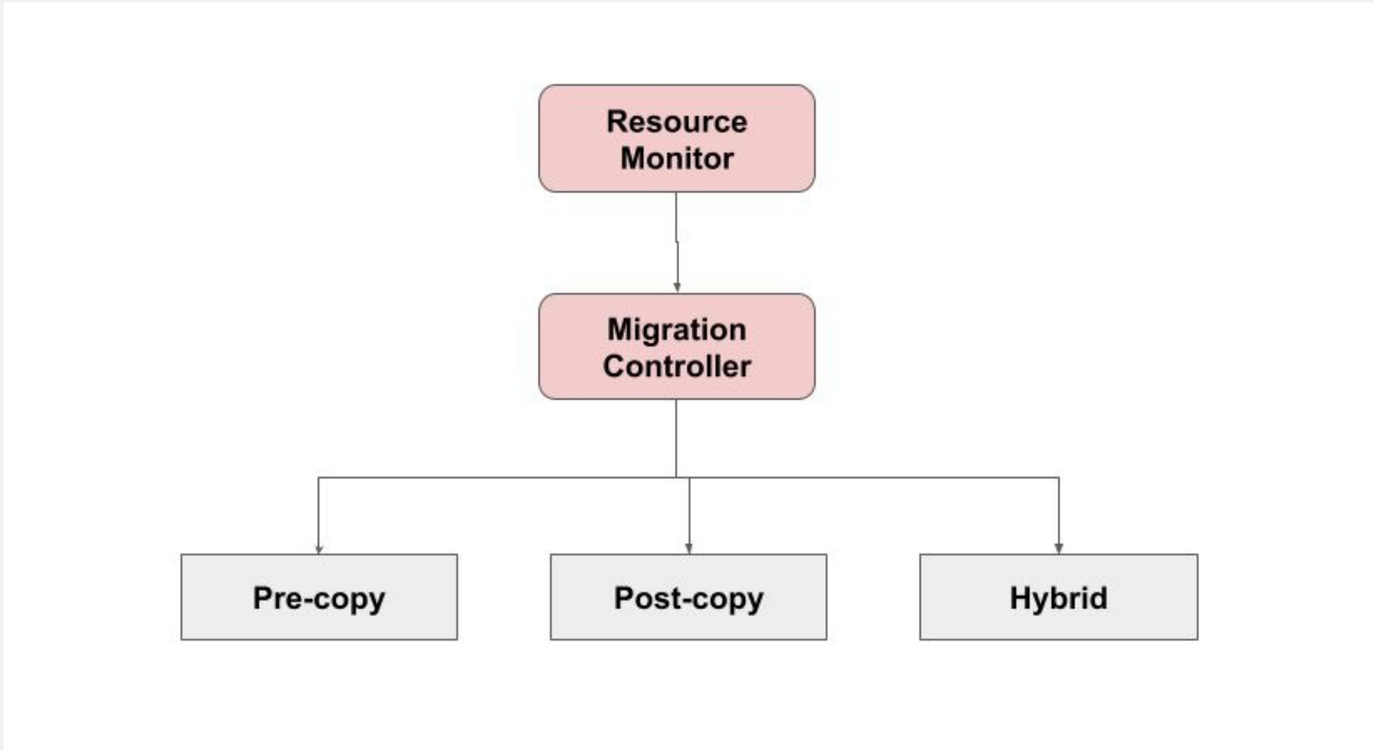


Capturing Resource Usage with Resource Monitor

- CPU usage - Linux *top* command
- Network usage - *ifconfig* utility by observing the tap interface connected to the VM.
- Page-dirtying rate - *calc-dirty-rate* command in QEMU

Architecture Ctd.

Migration Controller



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INTELLIGENT HYBRID MIGRATION

Determines the optimal point to switch from pre-copy to post-copy depending on the memory pages dirtied at each iteration.

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Intelligent Hybrid Migration Ctd.

Traditional Hybrid Migration

- Switches from pre-copy to post-copy in a fixed number of iterations.
- Not ideal for memory intensive workloads.

Intelligent Hybrid Migration Ctd.

- Observes the pattern of dirty memory pages.

How to identify non-converging behaviour in pre-copy?

Condition 1:

Dirty pages in current iteration > Dirty pages in previous iteration?

Condition 2:

Difference between the number of dirty pages in current and previous iteration is less than a threshold?

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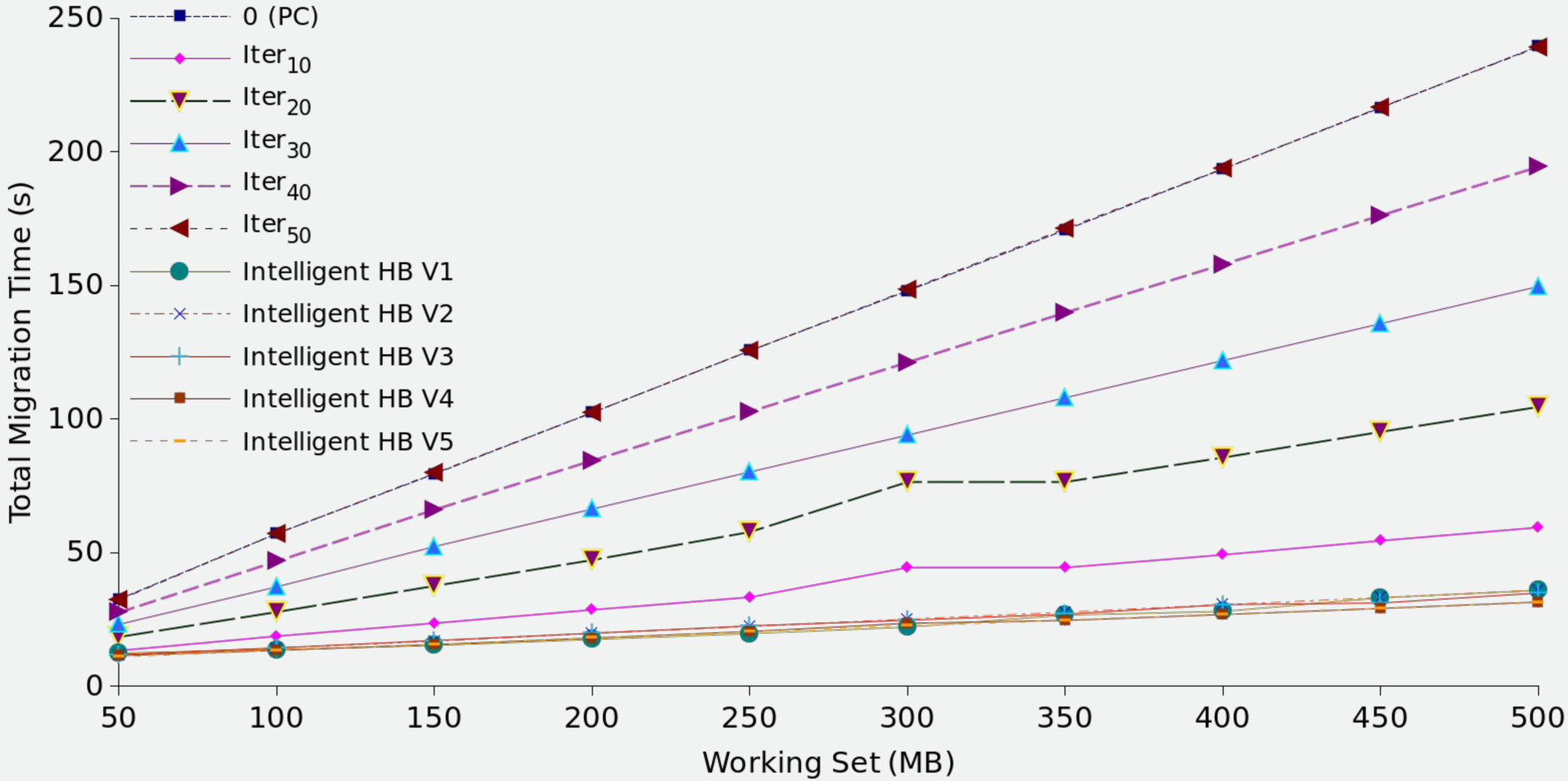
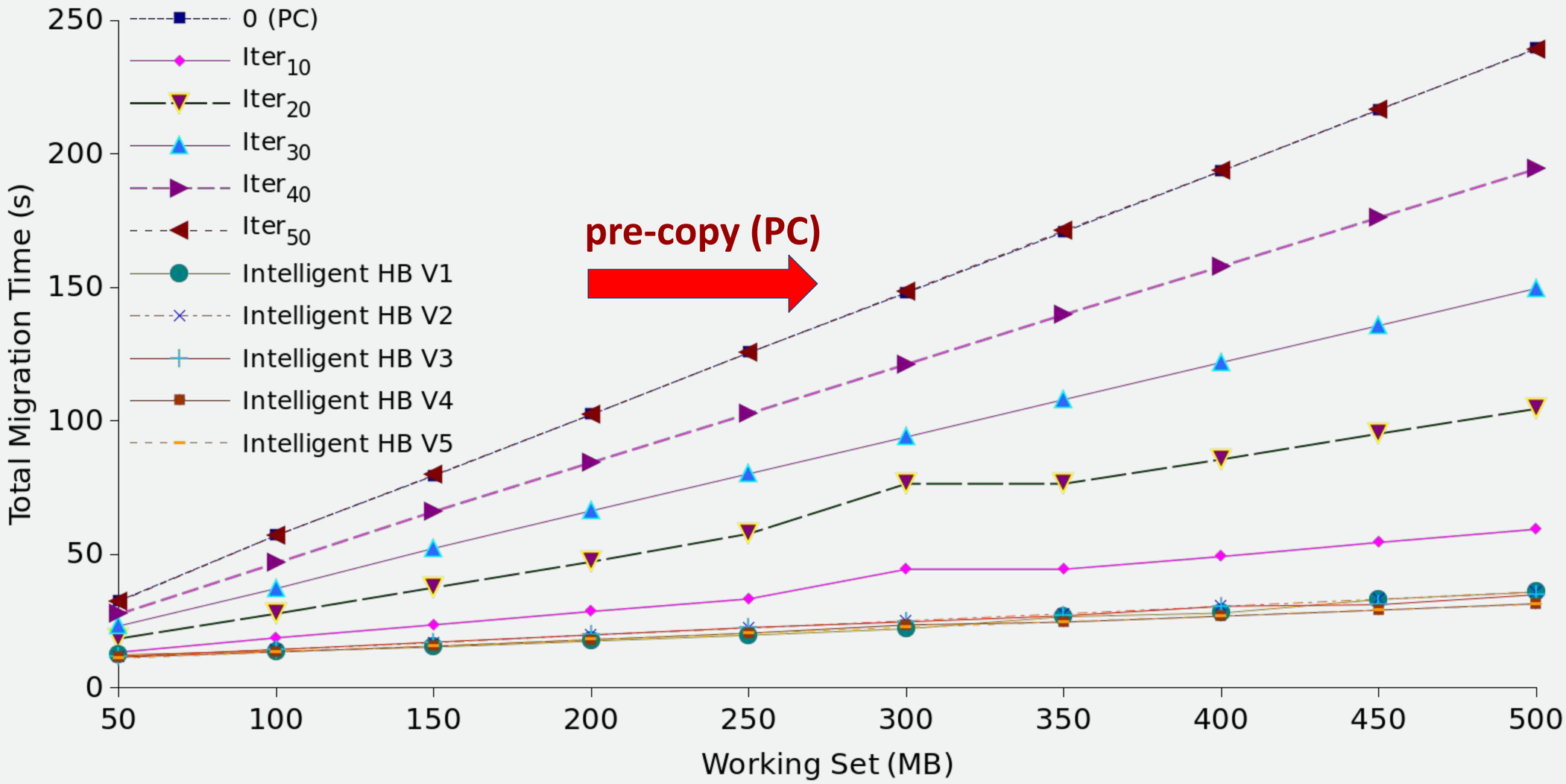


Intelligent Hybrid Migration Ctd.



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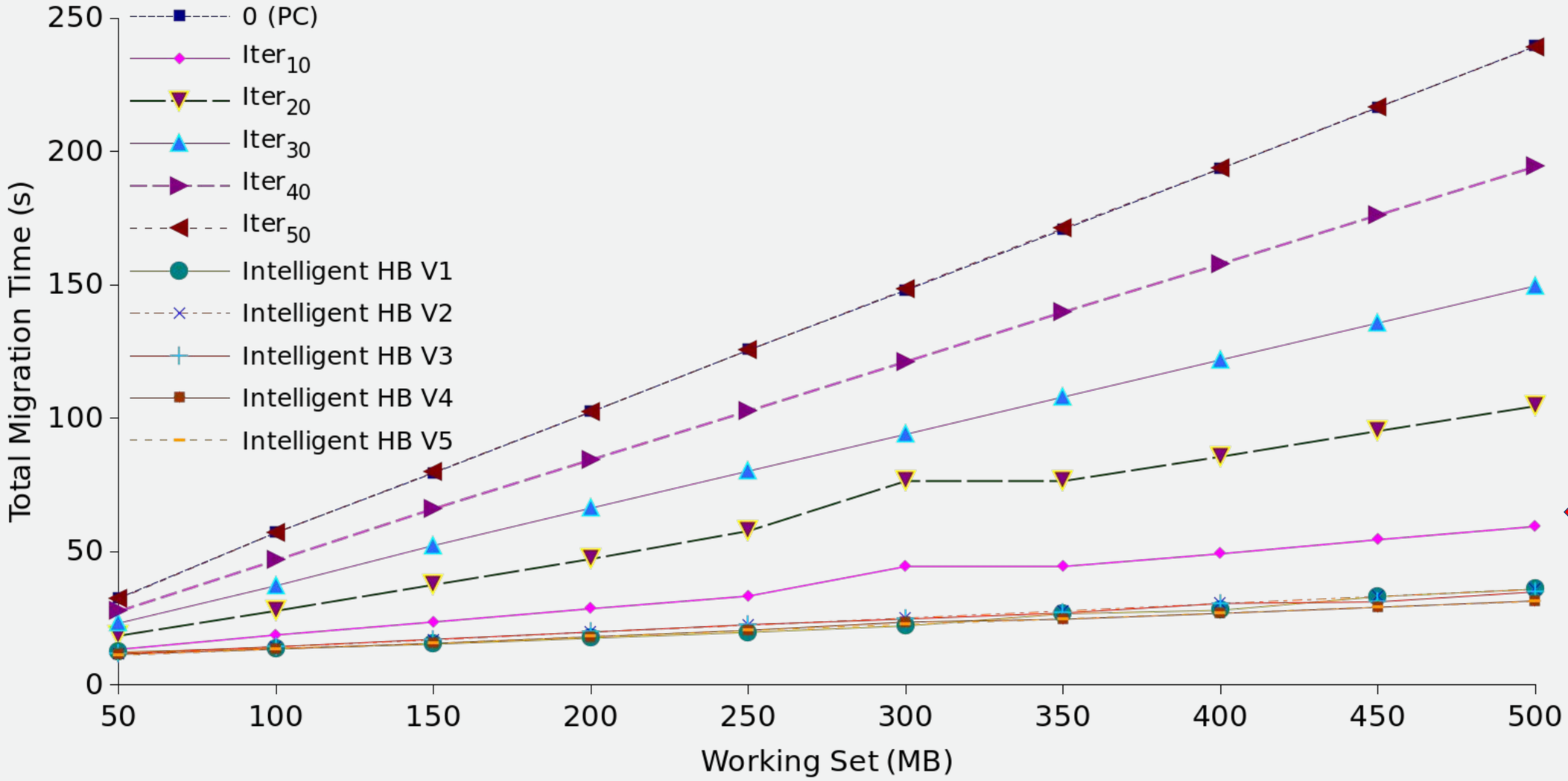

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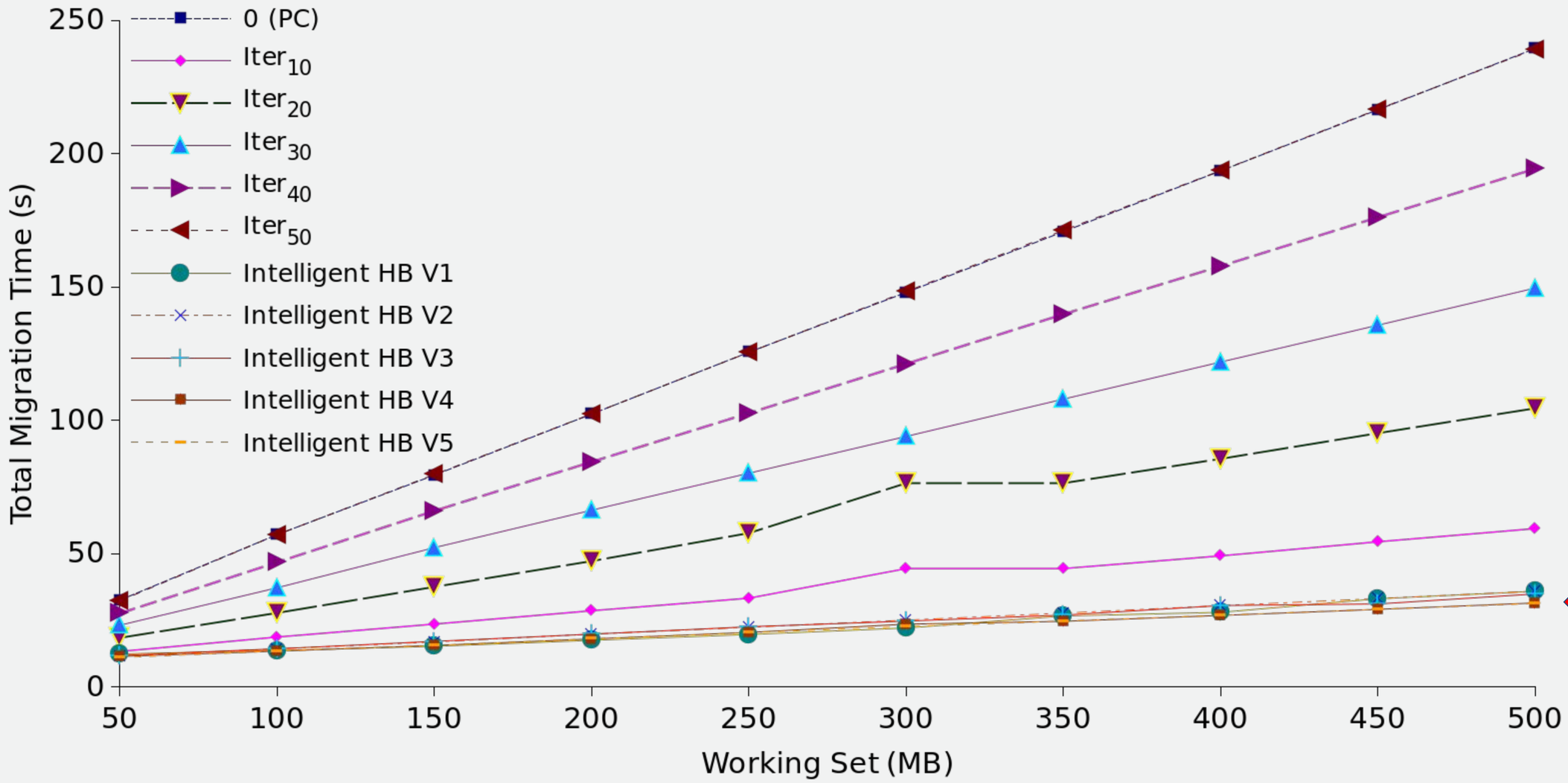
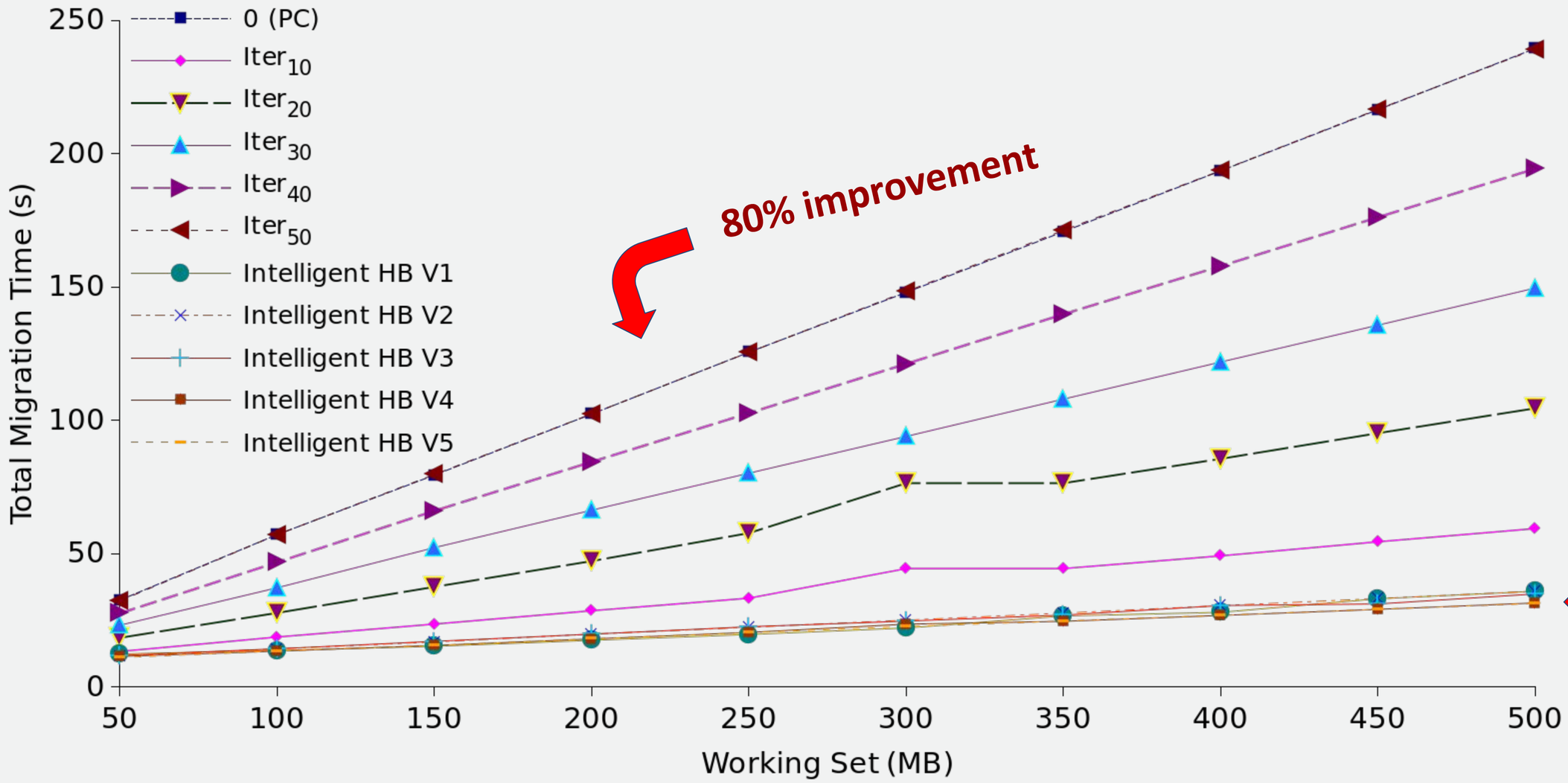


Intelligent Hybrid

Intelligent Hybrid Migration Ctd.



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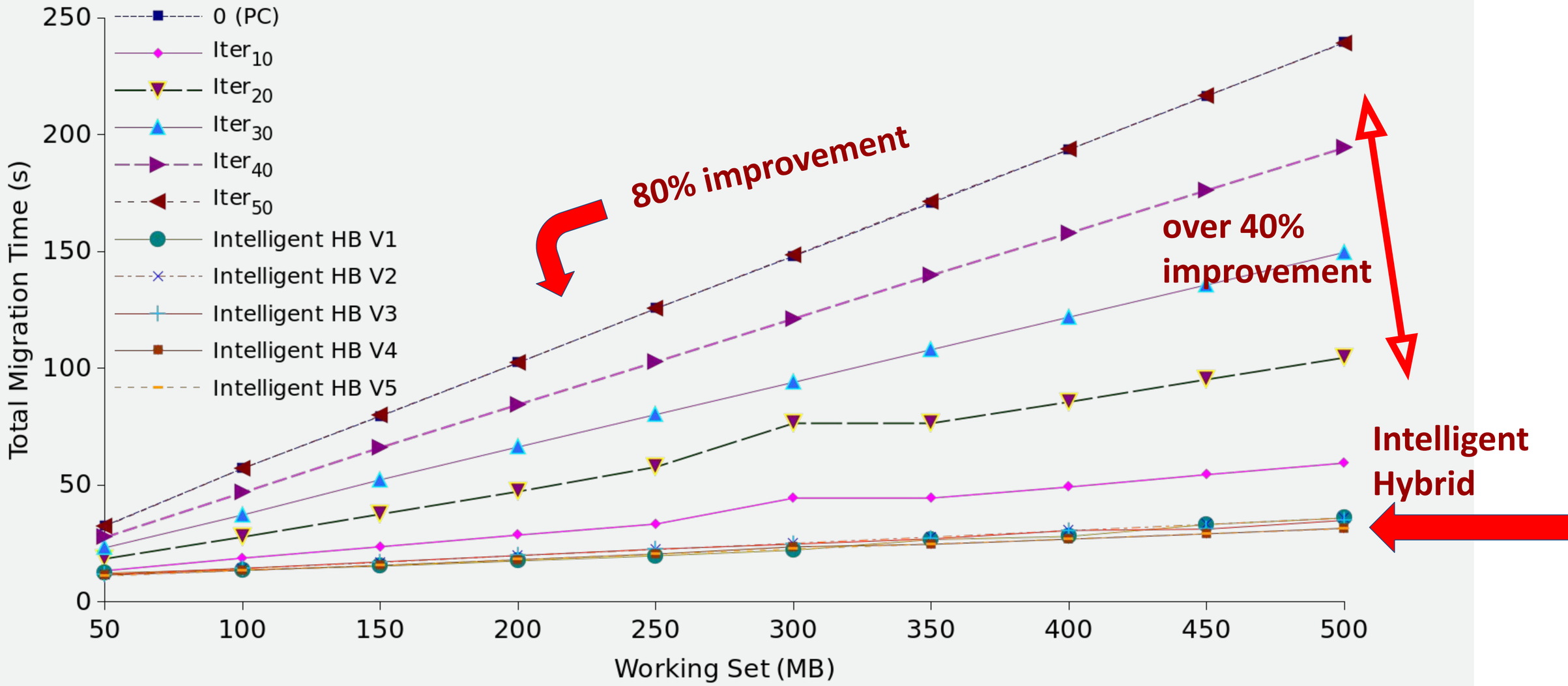

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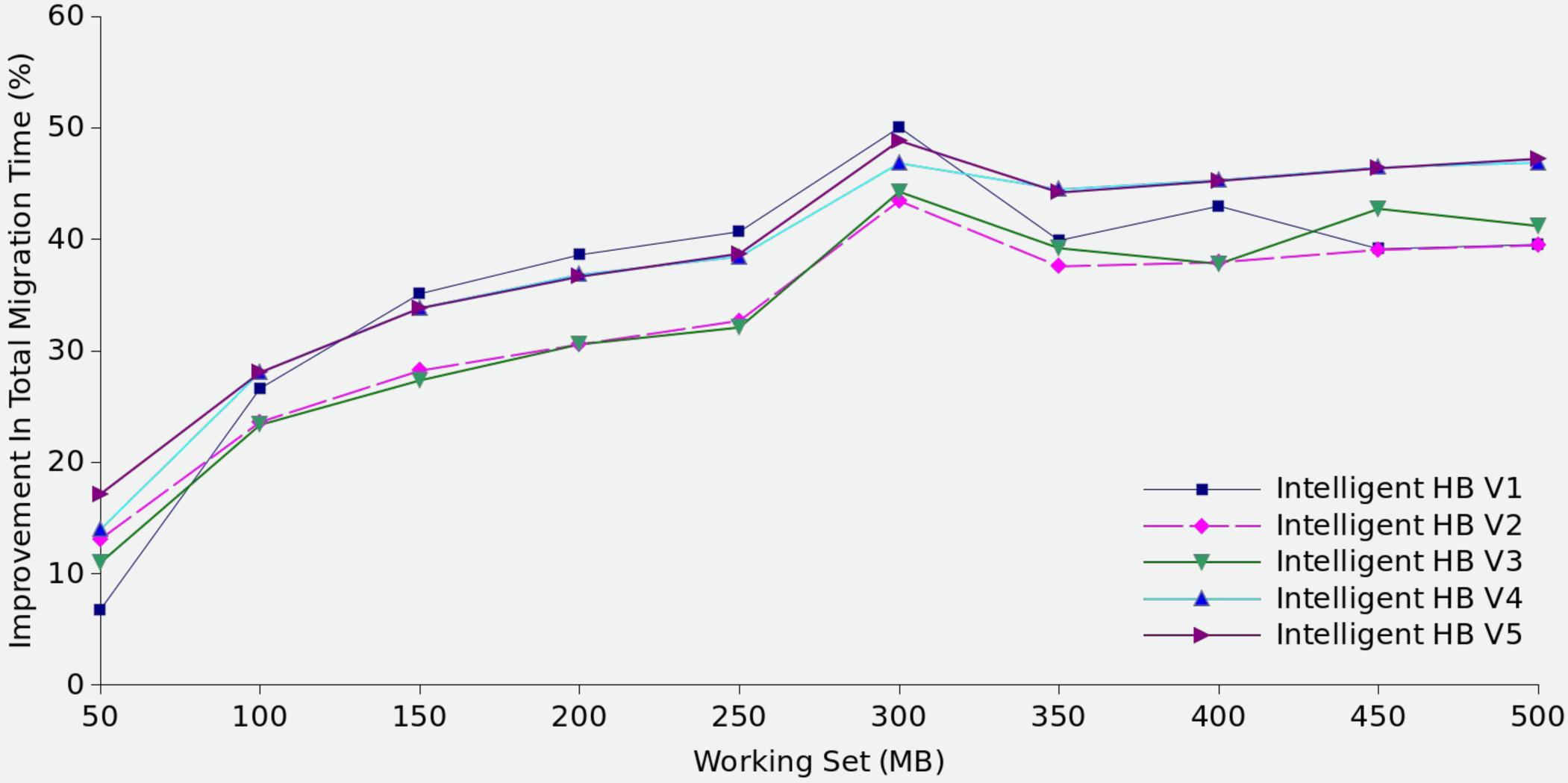

PERFORMANCE IMPACT OF VM WORKLOAD

Impact of VM workload on its migration

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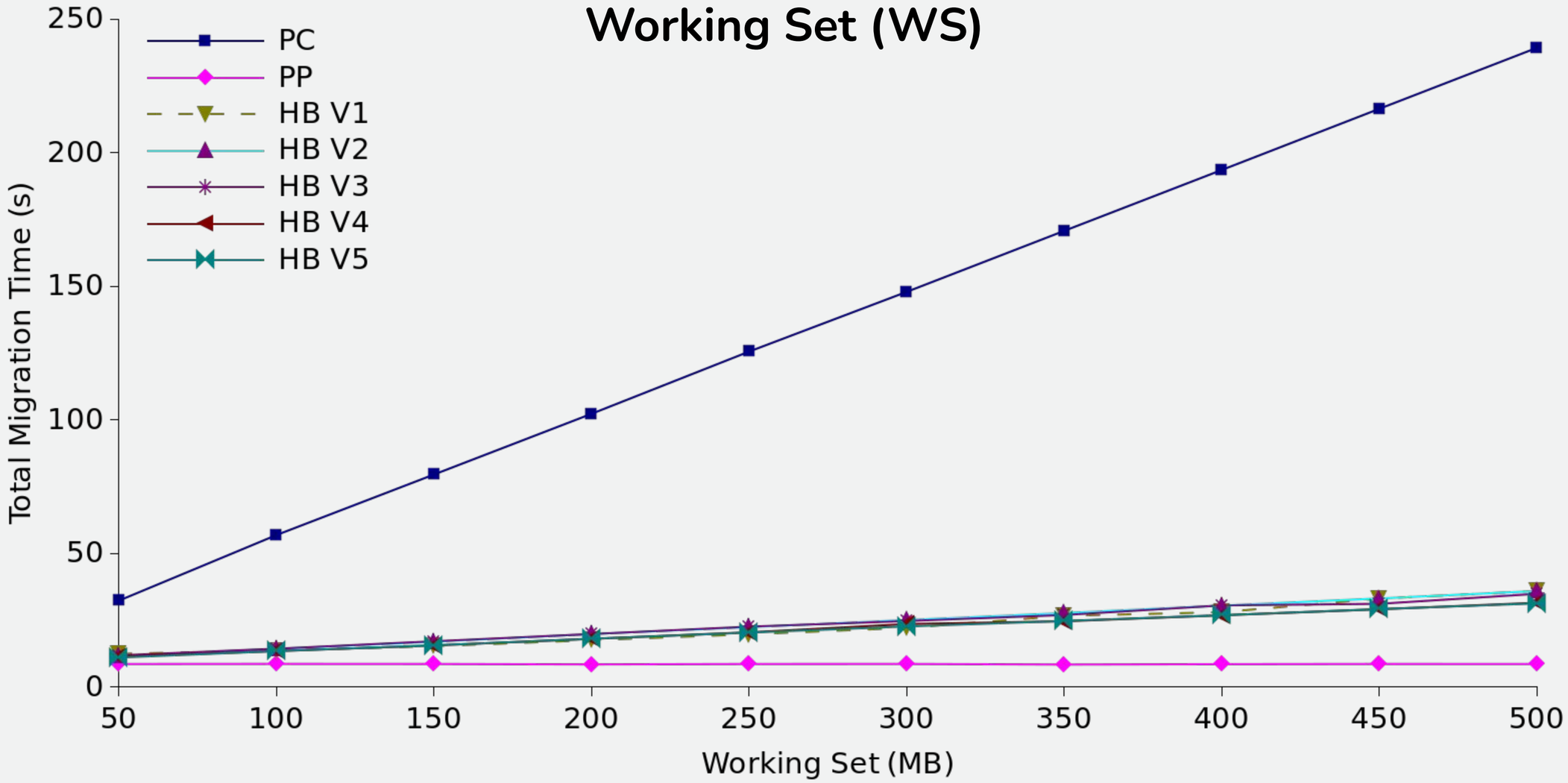
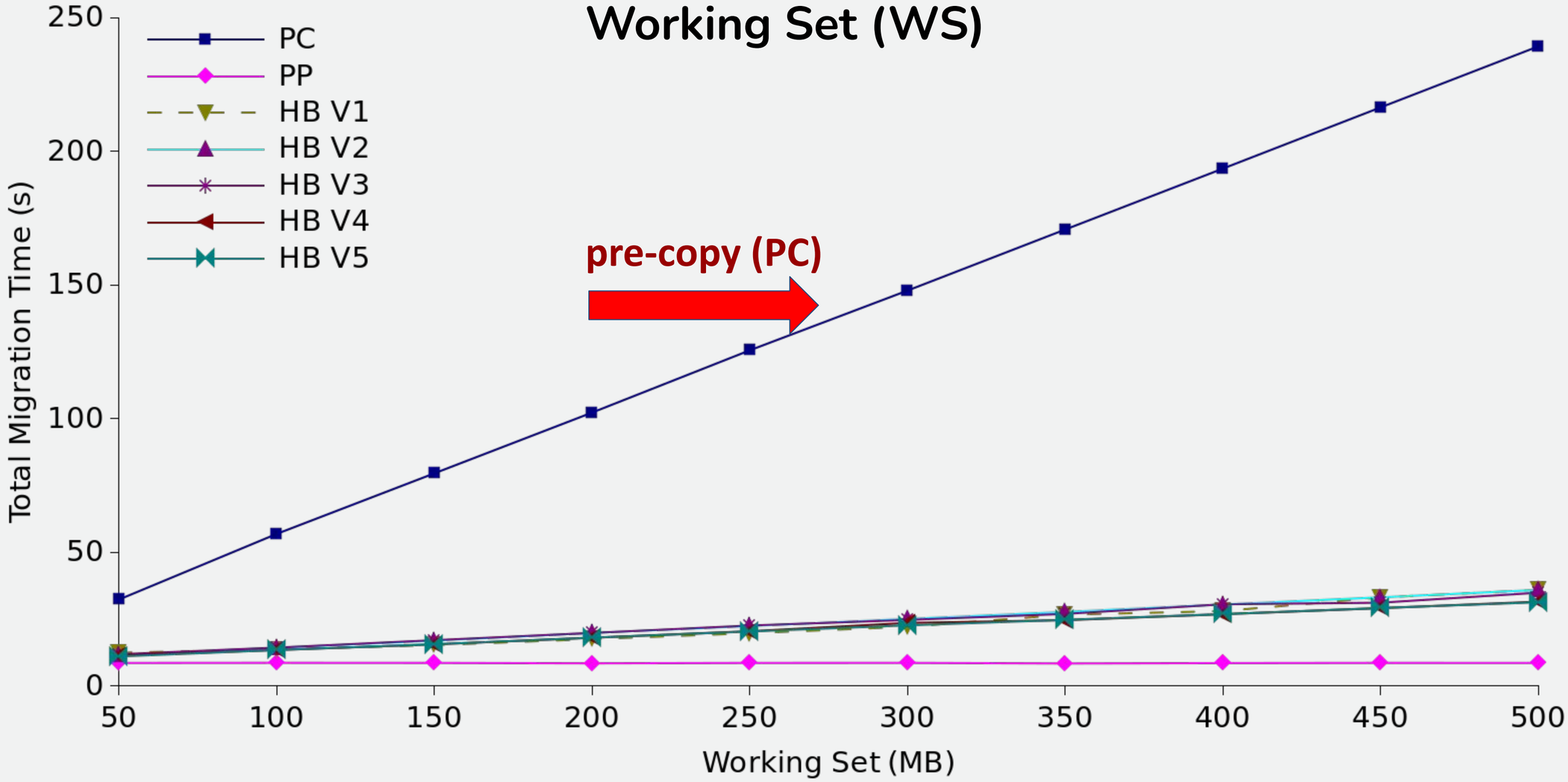
Performance Impact Of A Memory-intensive Workload



Pre-copy (PC) Post-copy (PP) Hybrid (HB)

Performance Impact Of A Memory-intensive Workload



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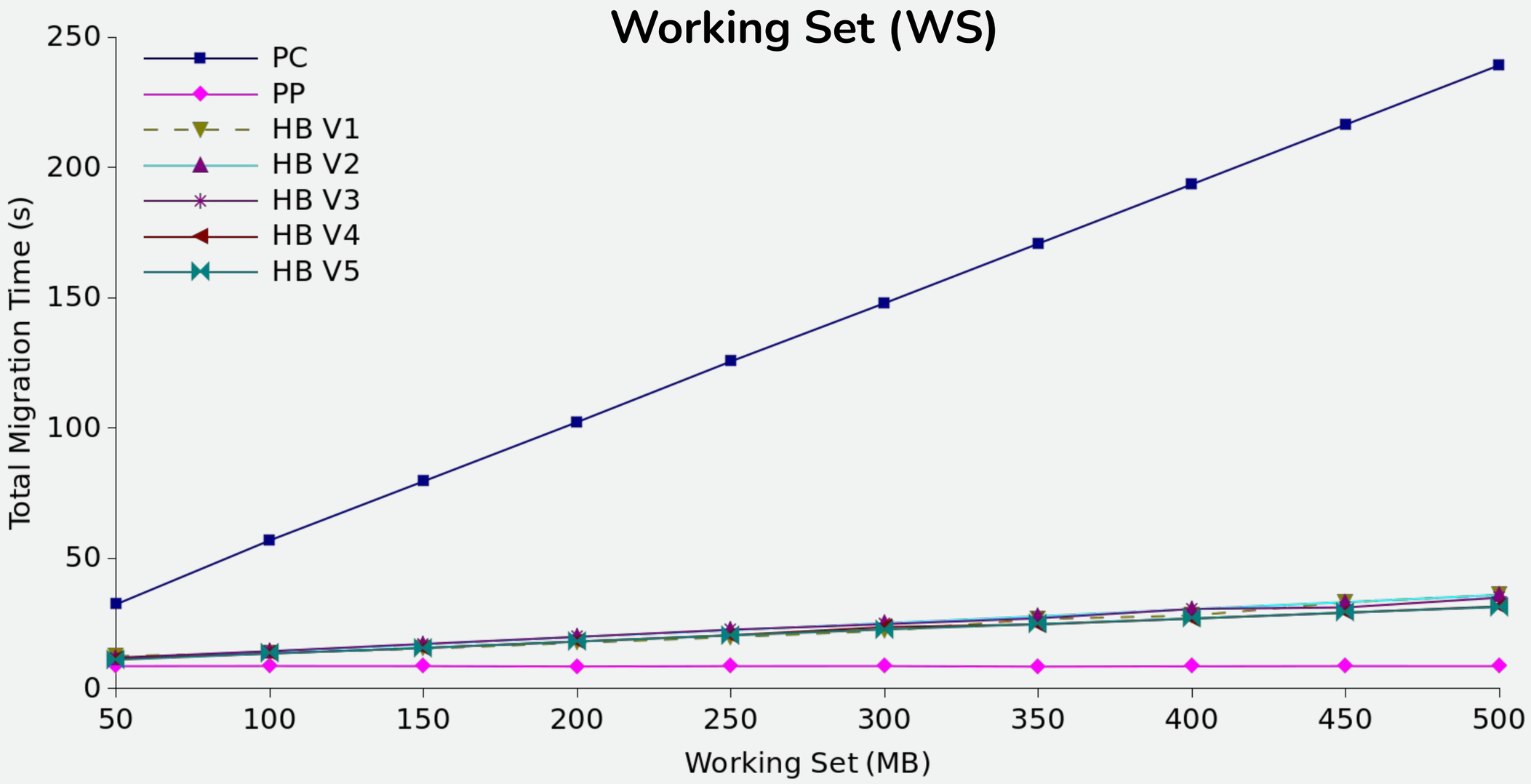
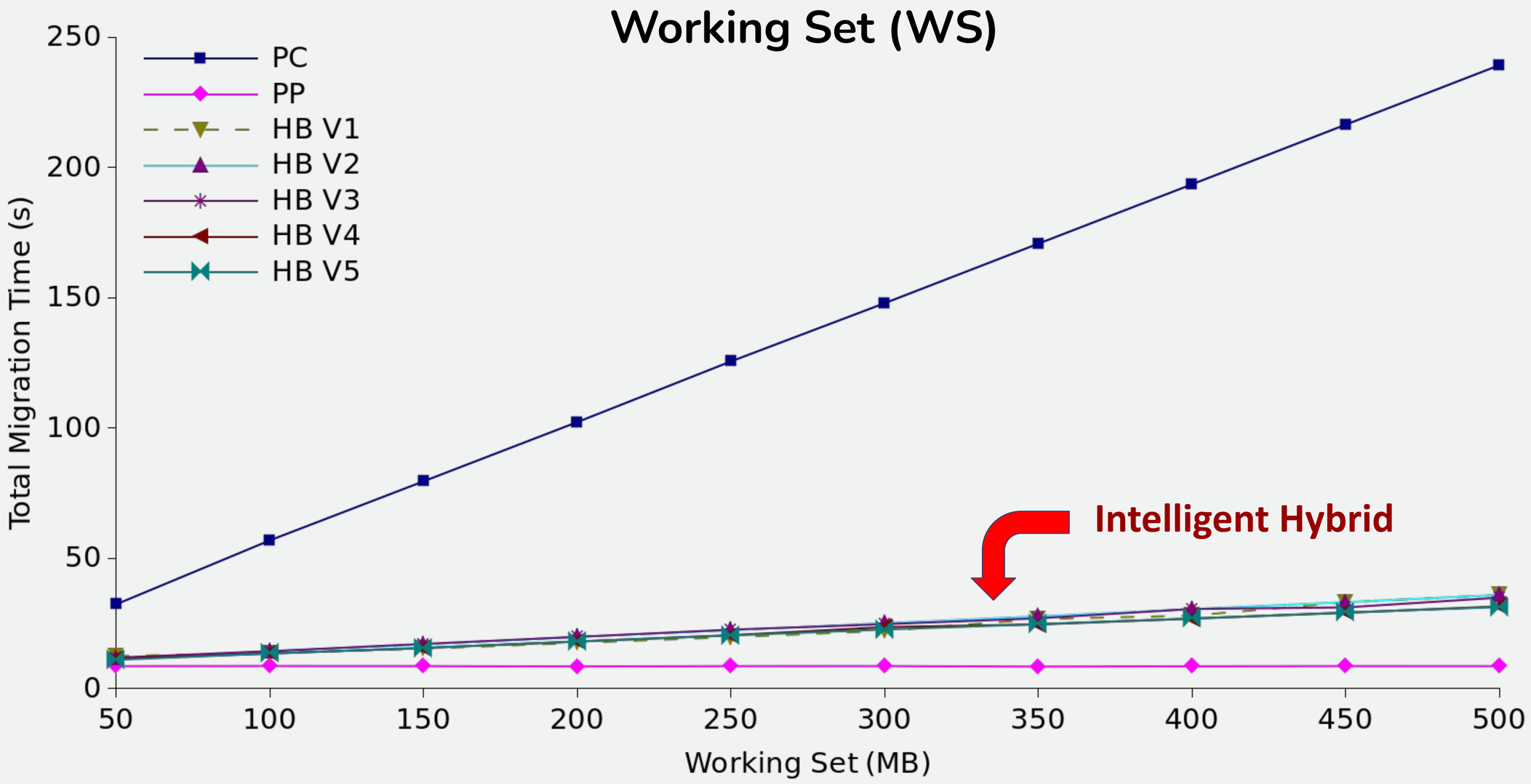


post-copy (P

Pre-copy (PC) Post-copy (PP) Hybrid (HB)

Performance Impact Of A Memory-intensive Workload



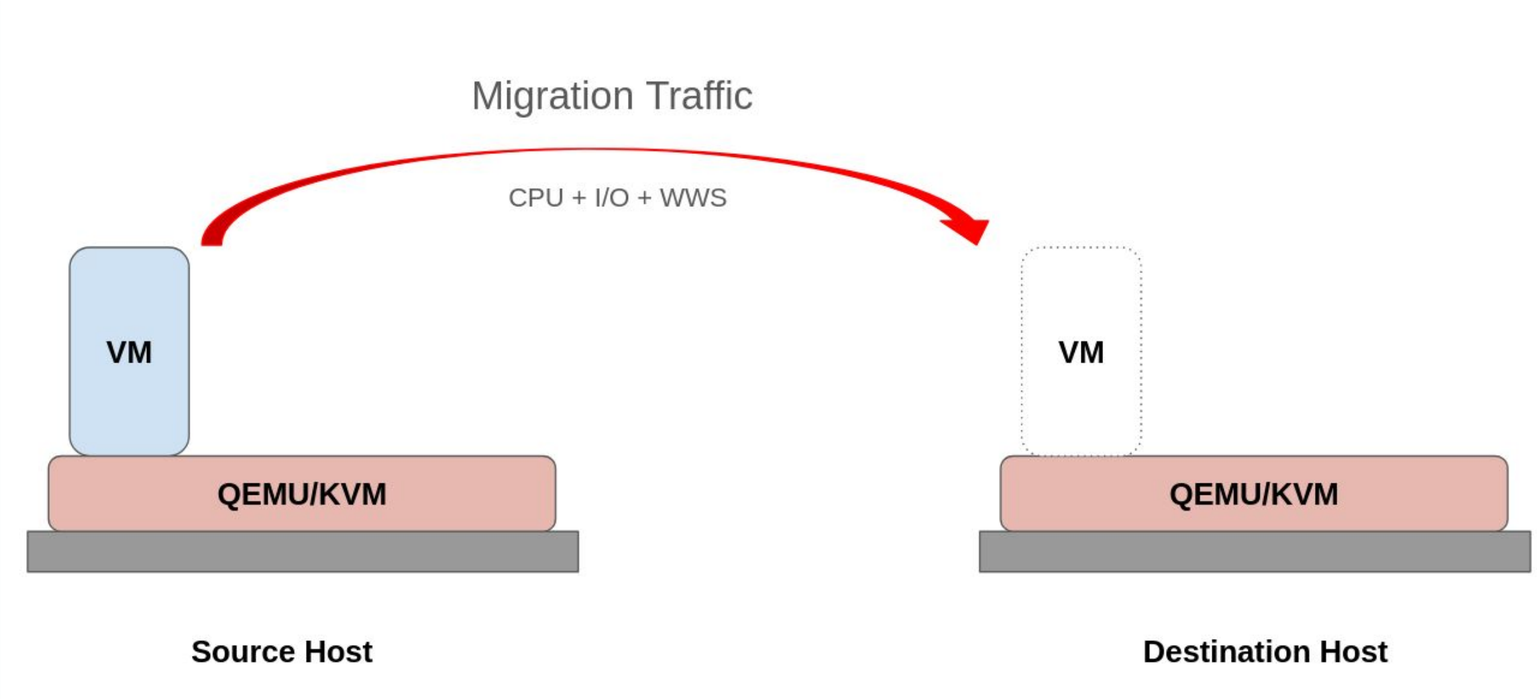
Pre-copy (PC) Post-copy (PP) Hybrid (HB)

Performance Impact Of A Network-intensive Workload

Pre-copy (PC) Post-copy (PP) Hybrid (HB)

Performance Impact Of A Network-intensive Workload

iPerf - Pre-copy Migration



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Performance Impact Of A Network-intensive Workload

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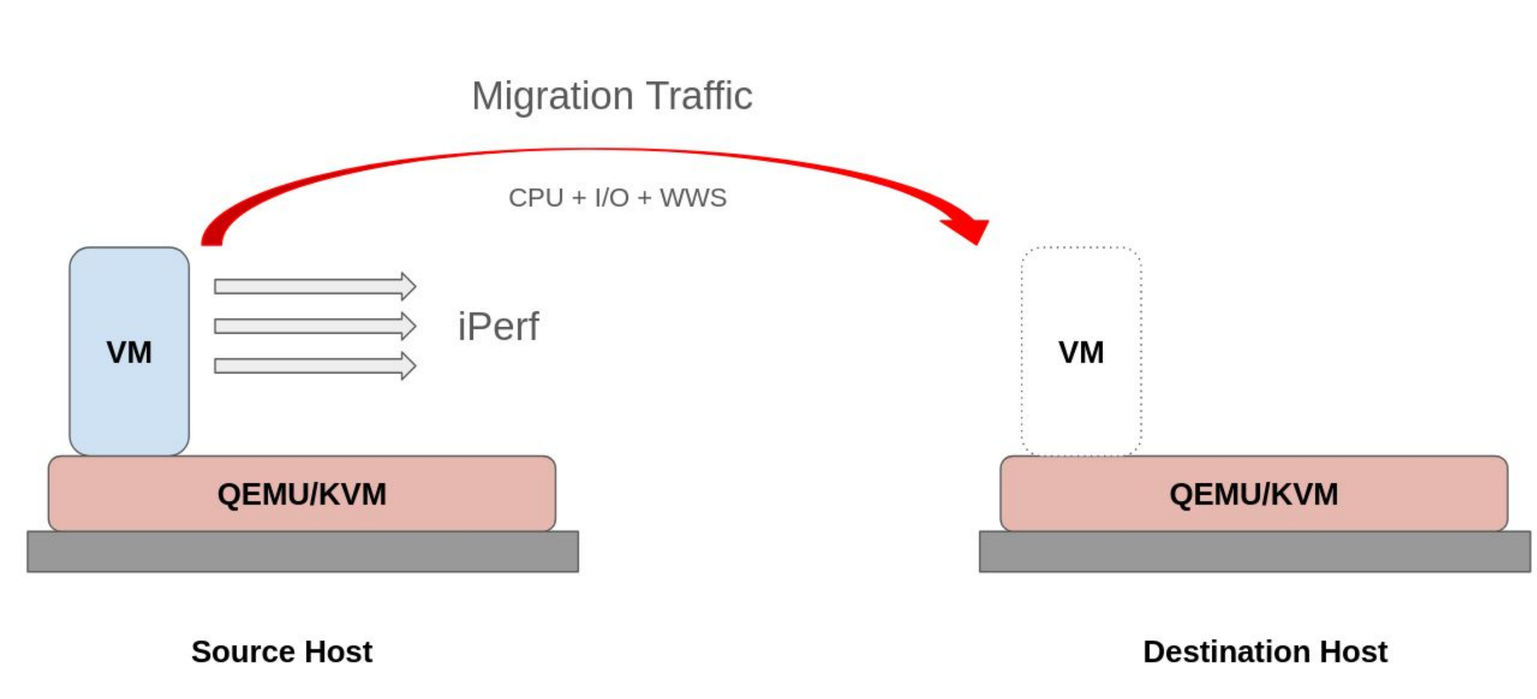

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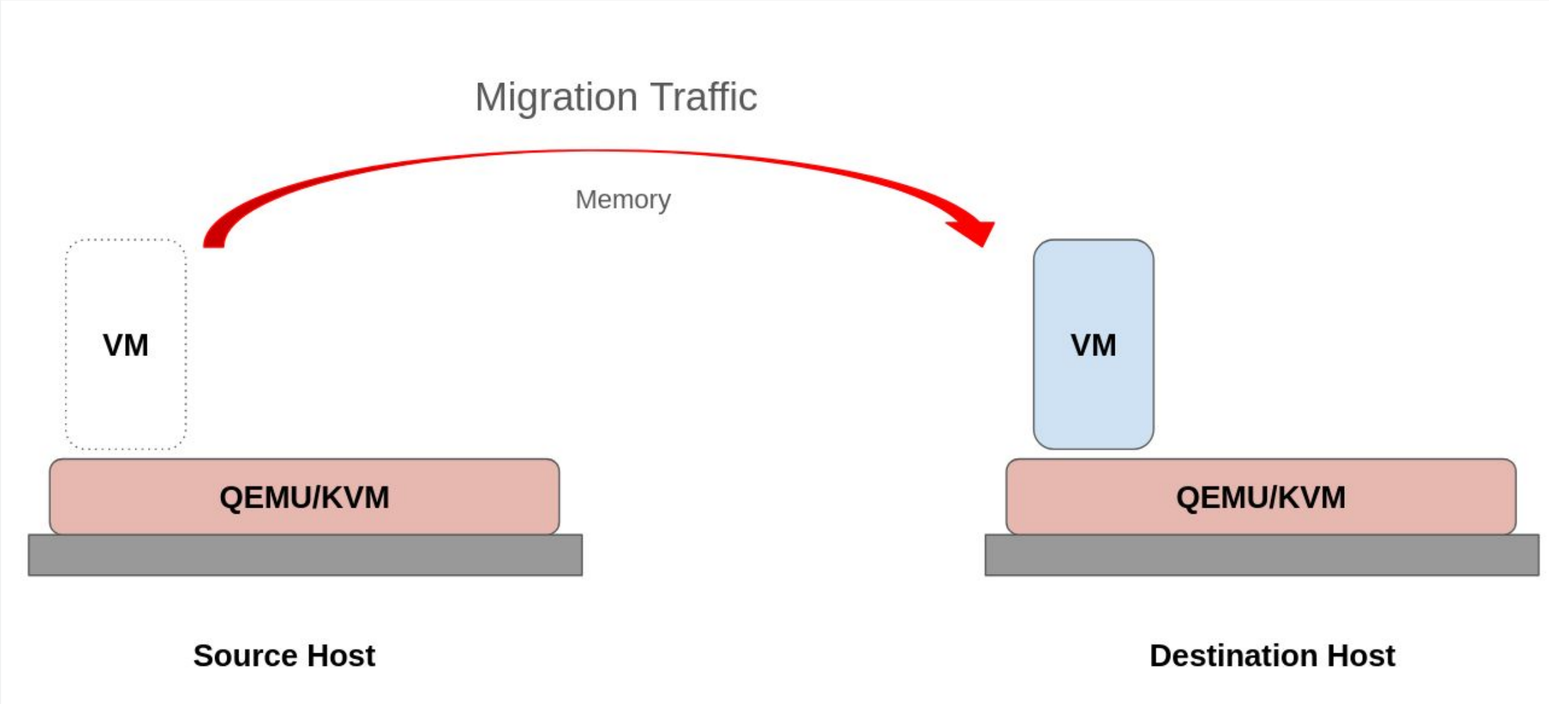
Performance Impact Of A Network-intensive Workload

- iPerf - Post-copy Migration



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Performance Impact Of A Network-intensive Workload

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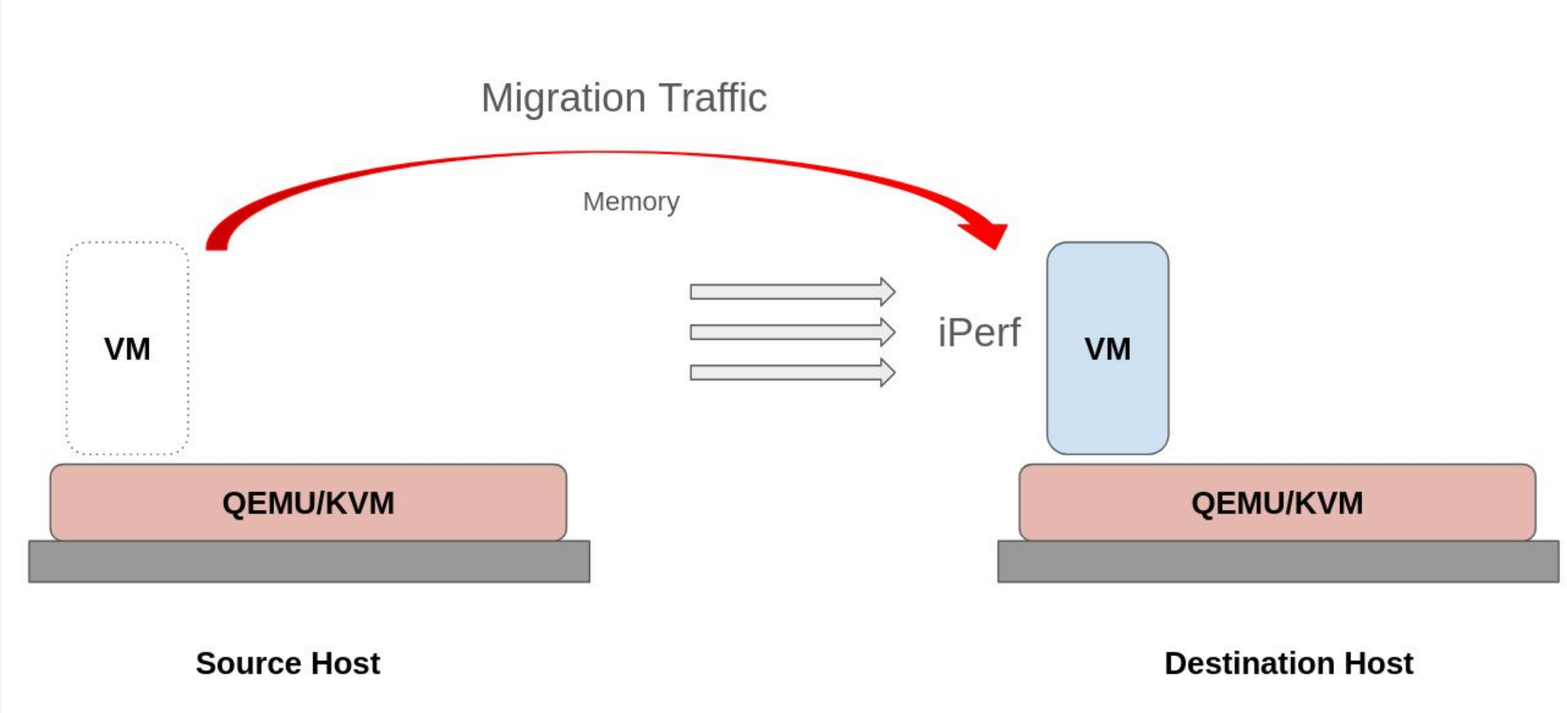

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7. IMPLEMENTATION

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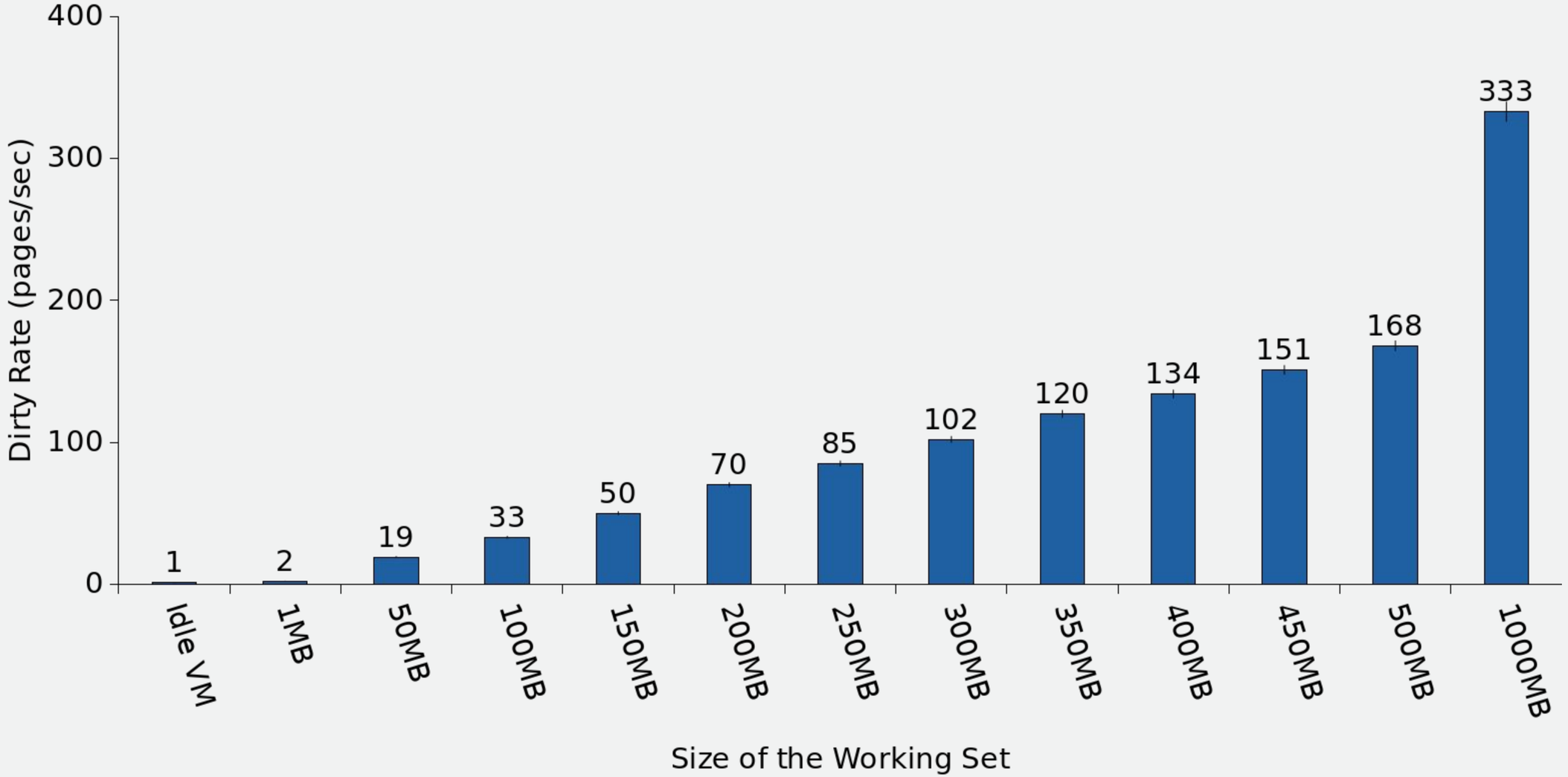
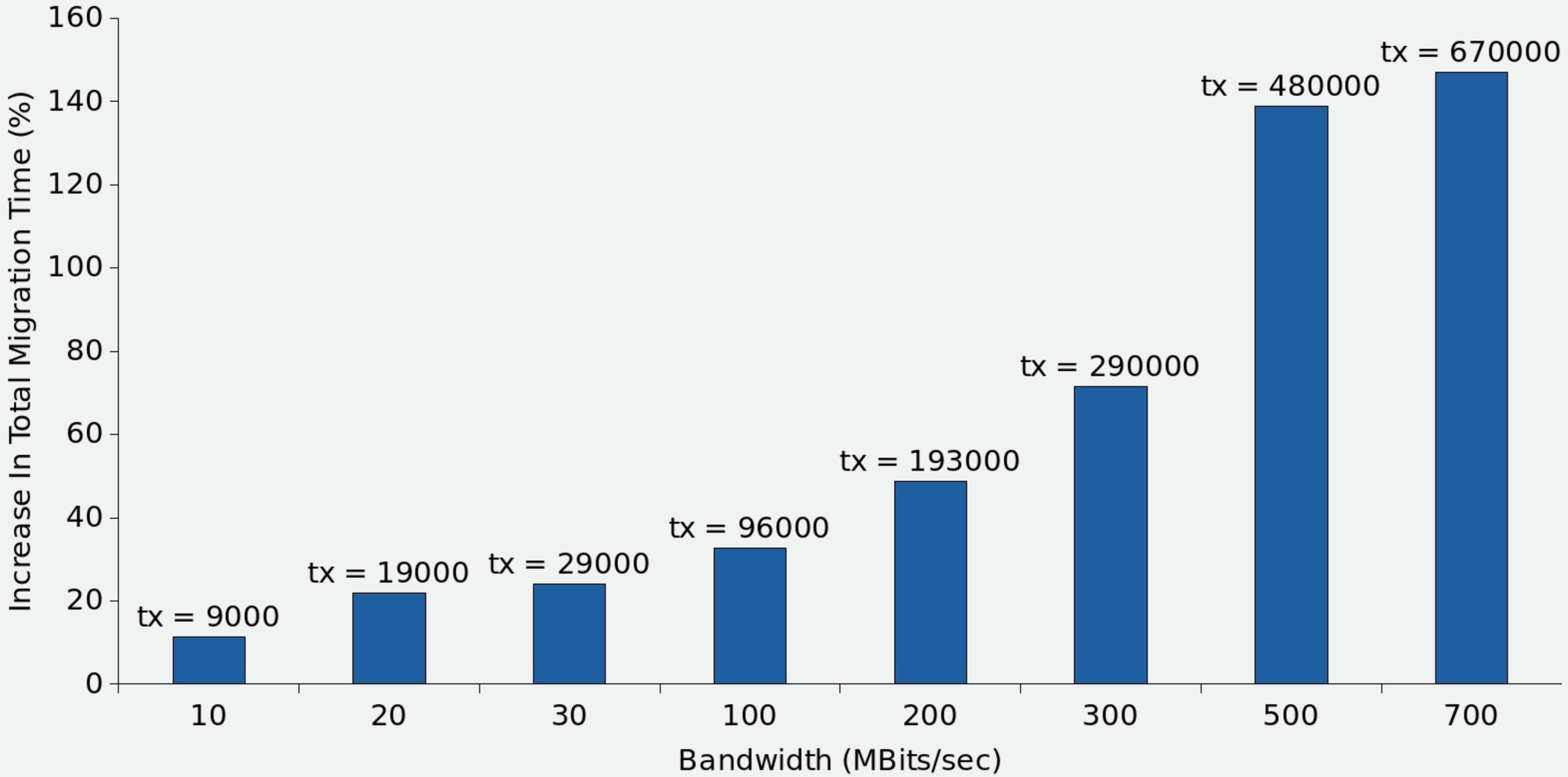
How do we identify if a workload is memory intensive or not?

Identifying Thresholds

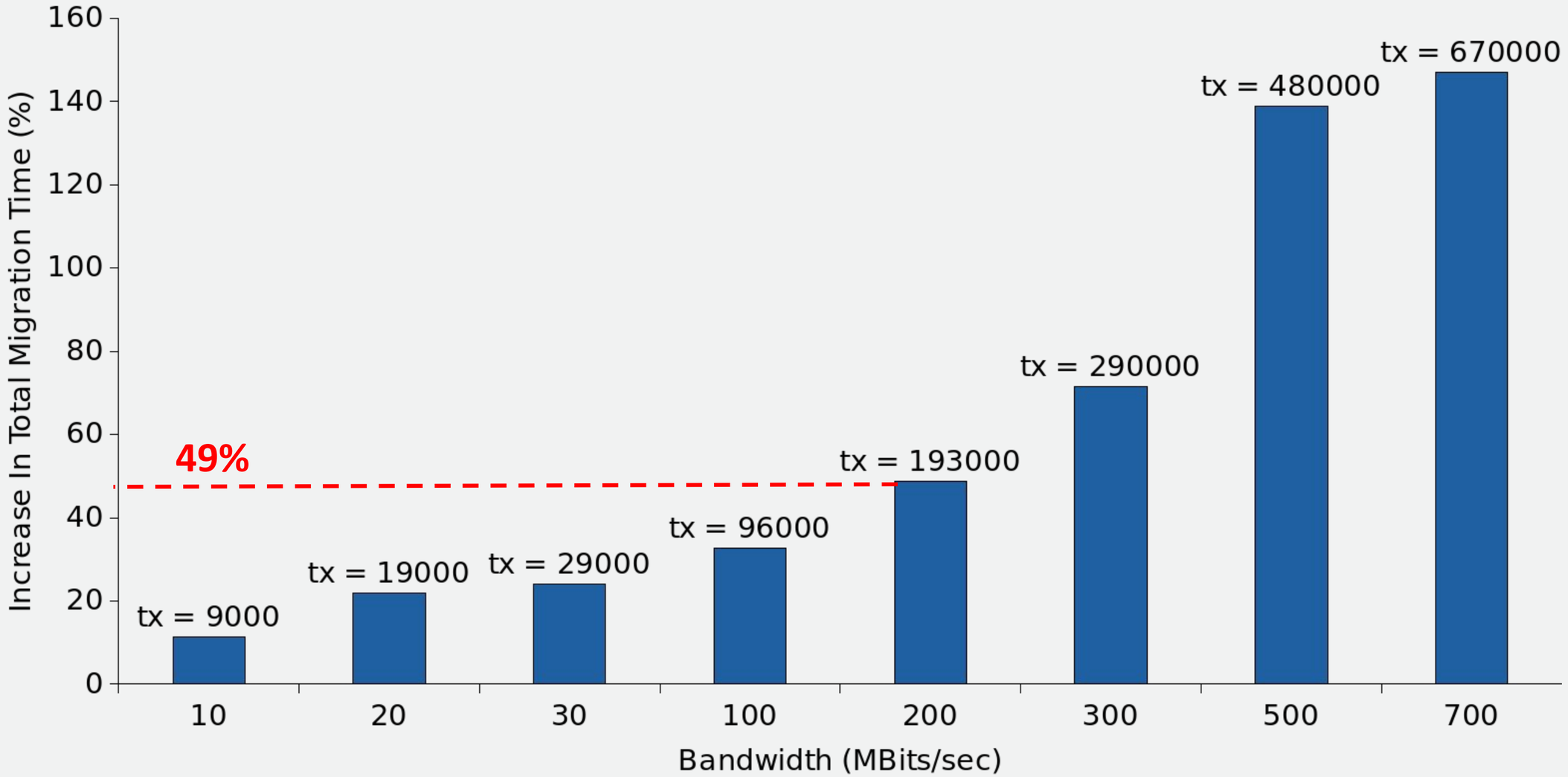


How do we identify if a workload is network intensive or not?

Identifying Thresholds



Identifying Thresholds



WALM ALGORITHM

```
If workload is memory-intensive
        post-copy()
else If workload is network-intensive
        If it is mostly incoming traffic
                pre-copy()
        else
                post-copy()
else
        hybrid()
```

8. EVALUATION

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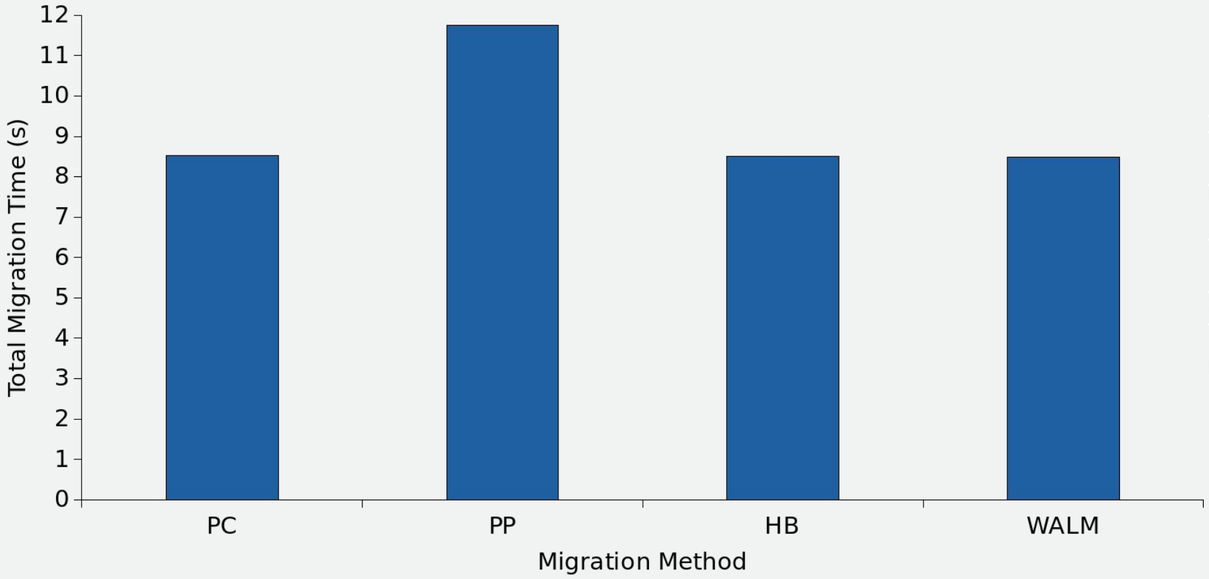
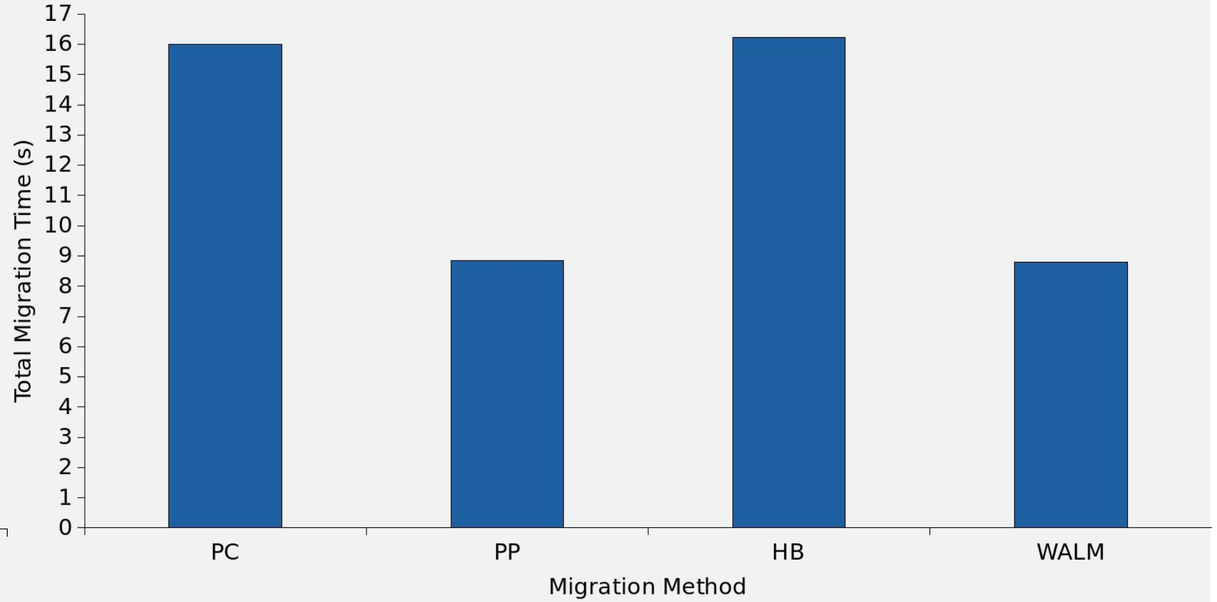
Evaluation With Network-intensive Workloads

- iPerf (Network, CPU)



Incoming Traffic

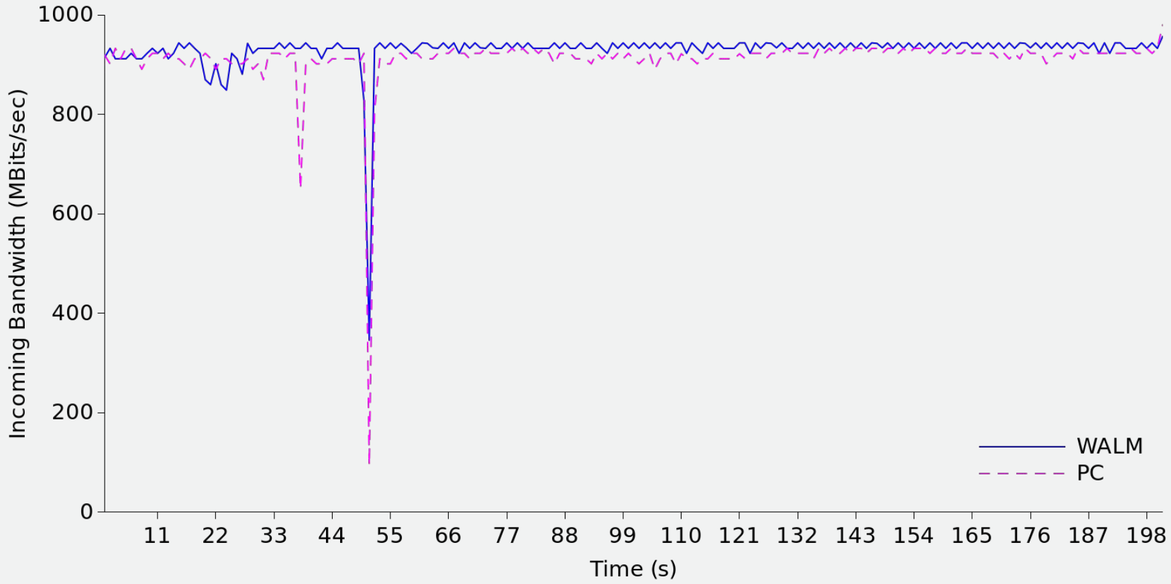


Outgoing Traffic

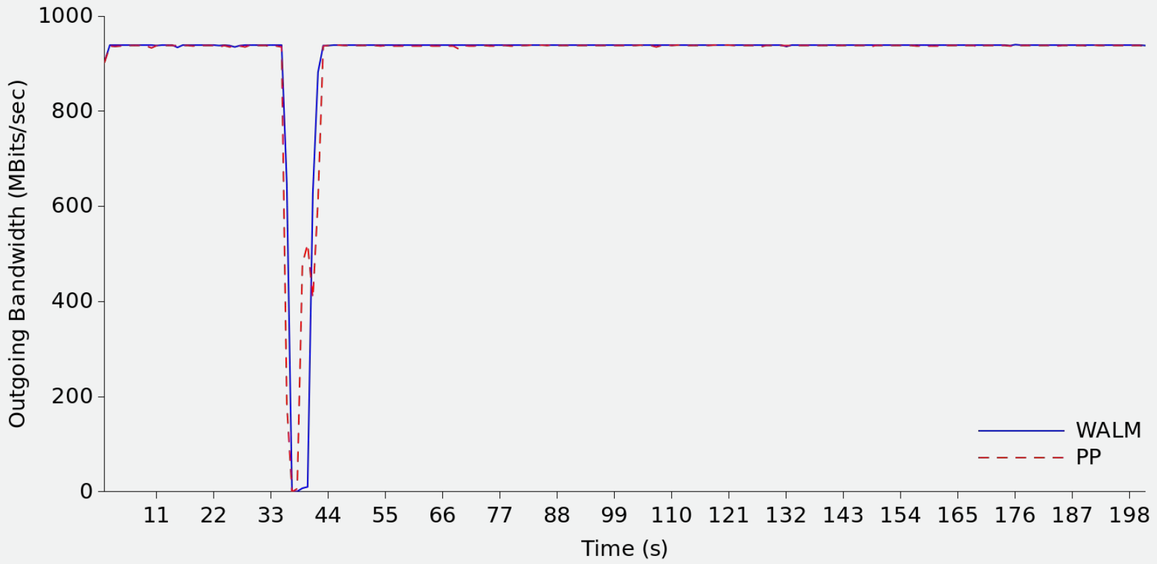
Pre-copy (PC) **Post-copy (PP)** **Hybrid (HB)** **WALM**

Evaluation With Network-intensive Workloads

- iPerf (Network, CPU)



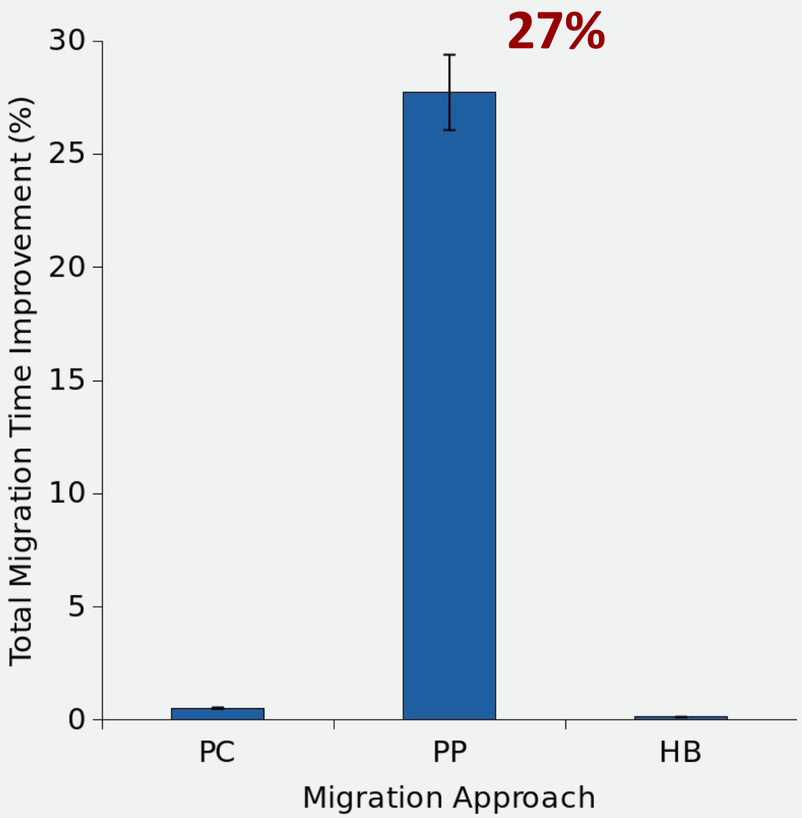
Incoming Traffic



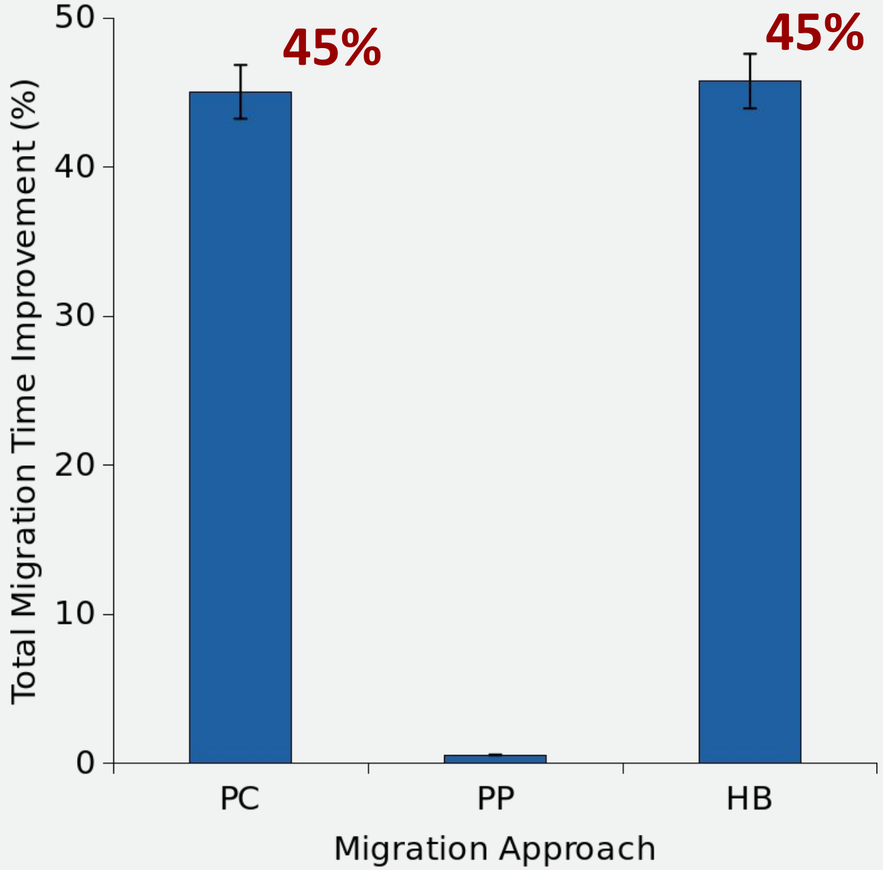
Outgoing Traffic

Evaluation With Network-intensive Workloads

- iPerf (Network, CPU)



Incoming Traffic

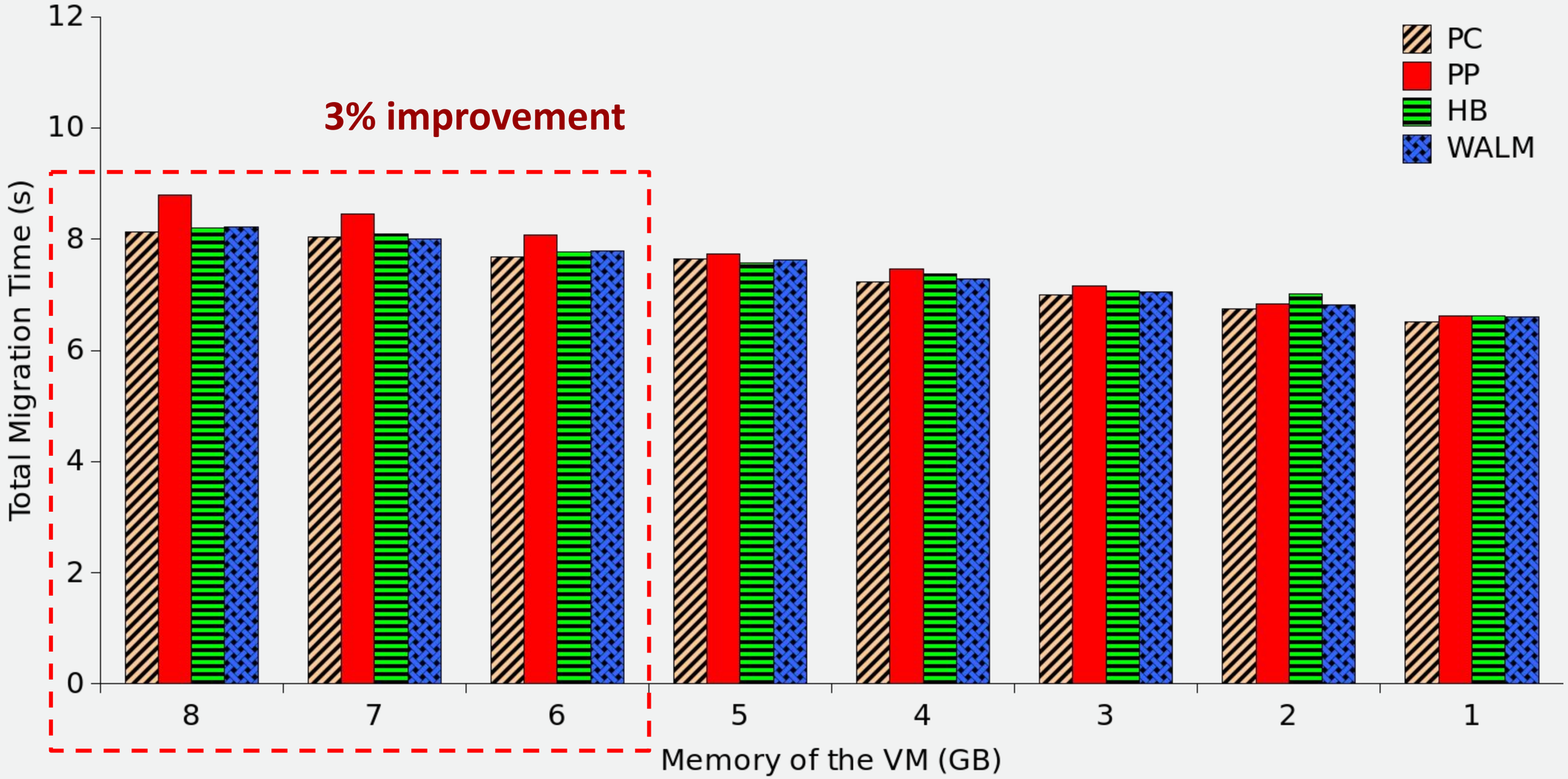


Outgoing Traffic

Pre-copy (PC) **Post-copy (PP)** **Hybrid (HB)**

Evaluation With CPU-intensive Workloads

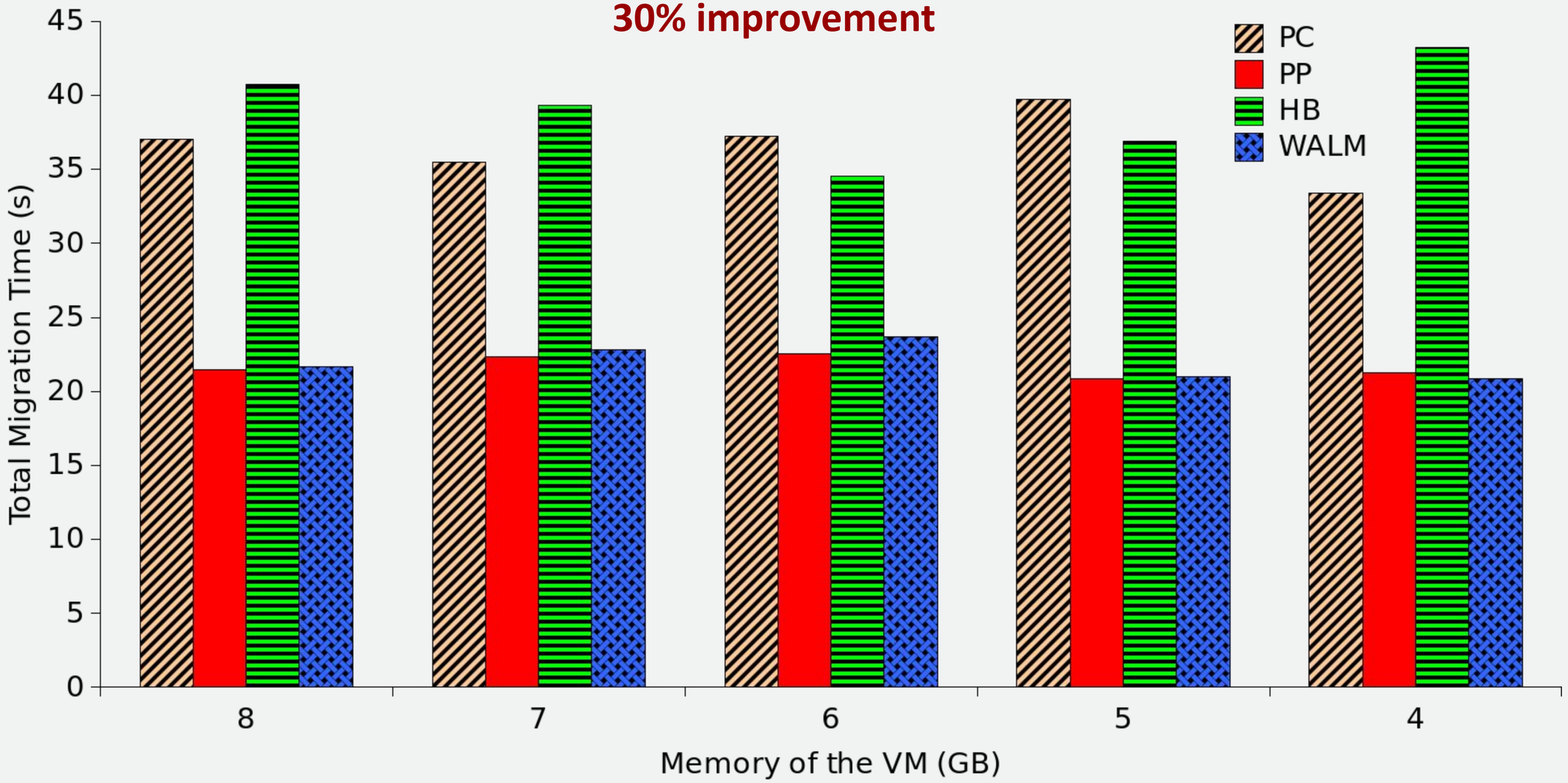
- Sysbench (CPU)



Pre-copy (PC) **Post-copy (PP)** **Hybrid (HB)** **WALM**

Evaluation With CPU-intensive Workloads

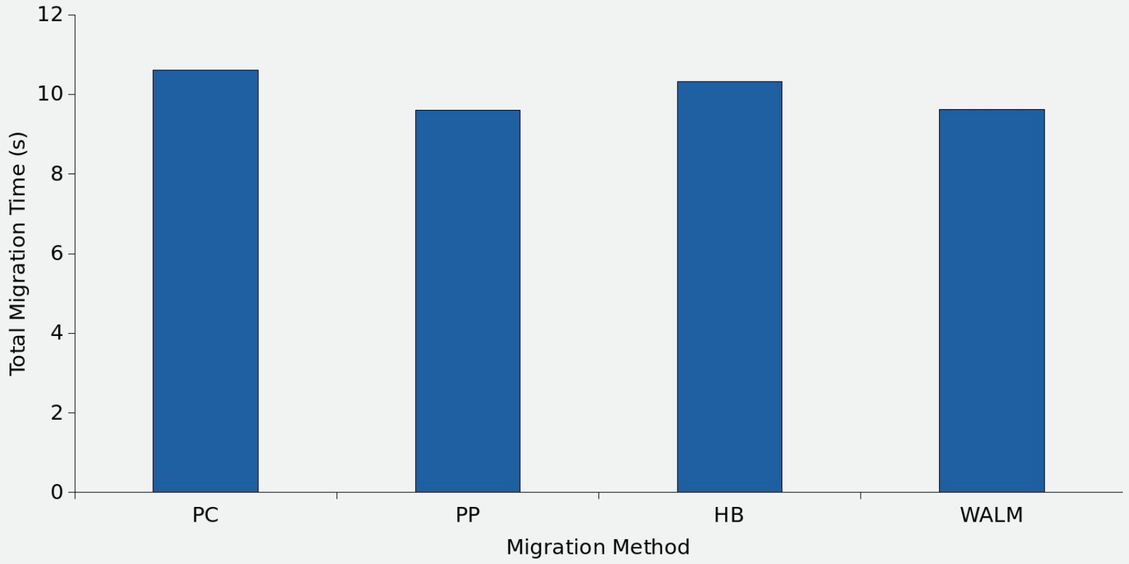
- Quicksort (CPU, Memory)

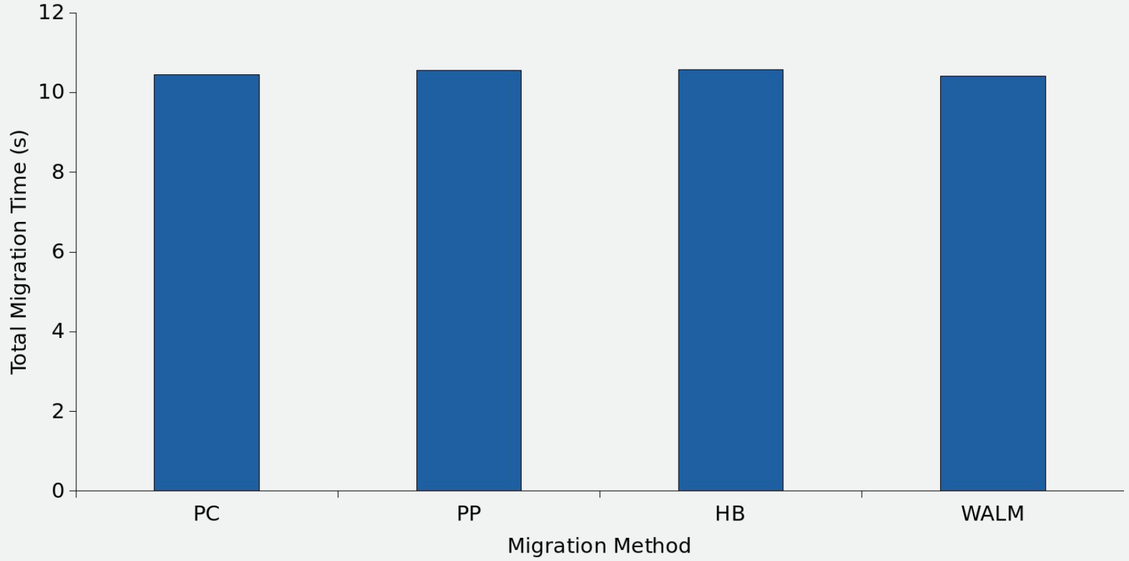


Pre-copy (PC) Post-copy (PP) Hybrid (HB) WALM

Evaluation With Multiple intensive Workloads

- YCSB (Yahoo! Cloud Serving Benchmark)





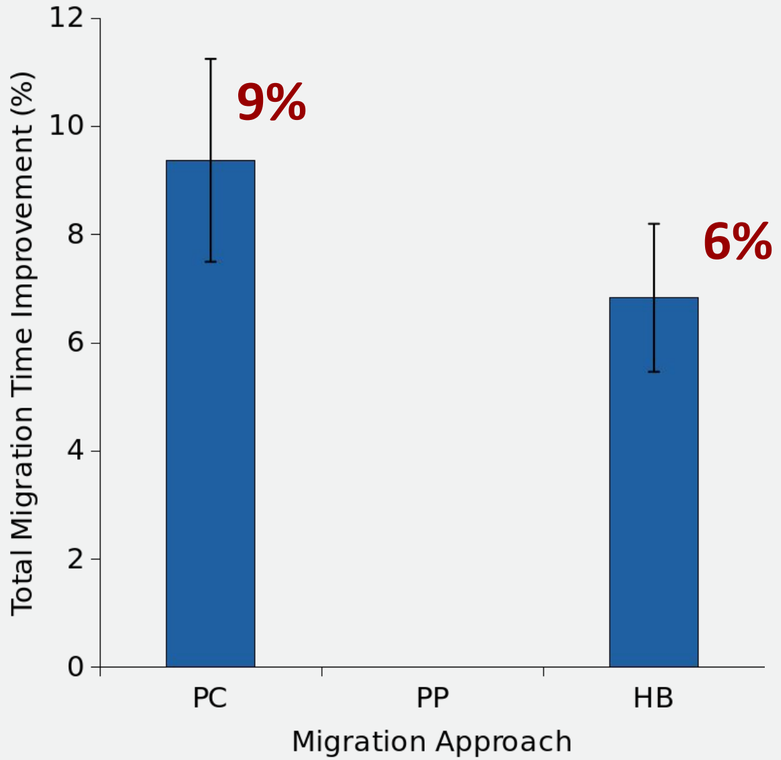
Local Database (Memory, CPU)

External Database (Network, Memory, CPU)

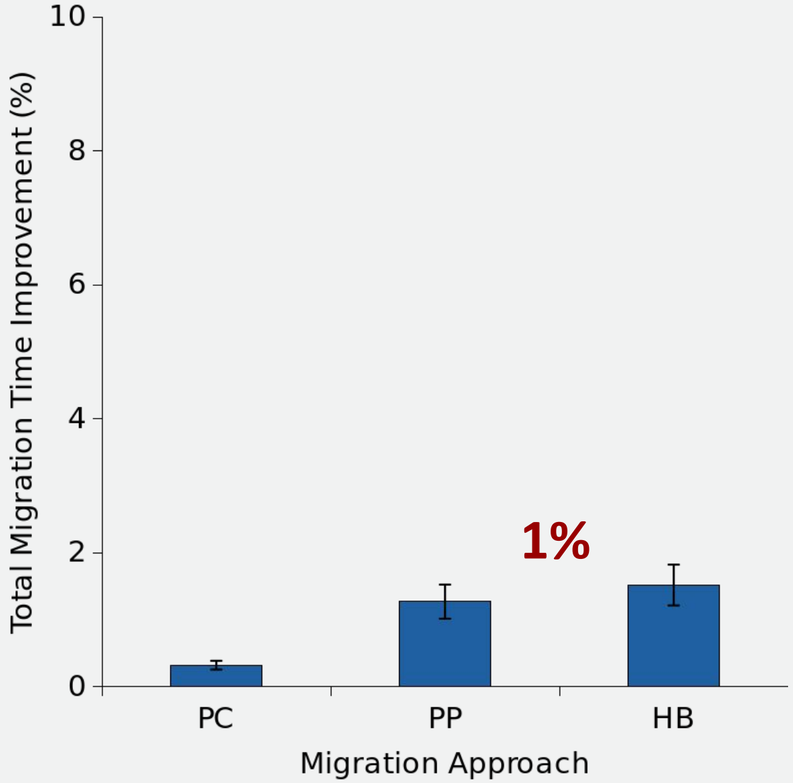
Pre-copy (PC) **Post-copy (PP)** **Hybrid (HB)** **WALM**

Evaluation With Multiple intensive Workloads

- YCSB (Yahoo! Cloud Serving Benchmark)



Local Database (Memory, CPU)

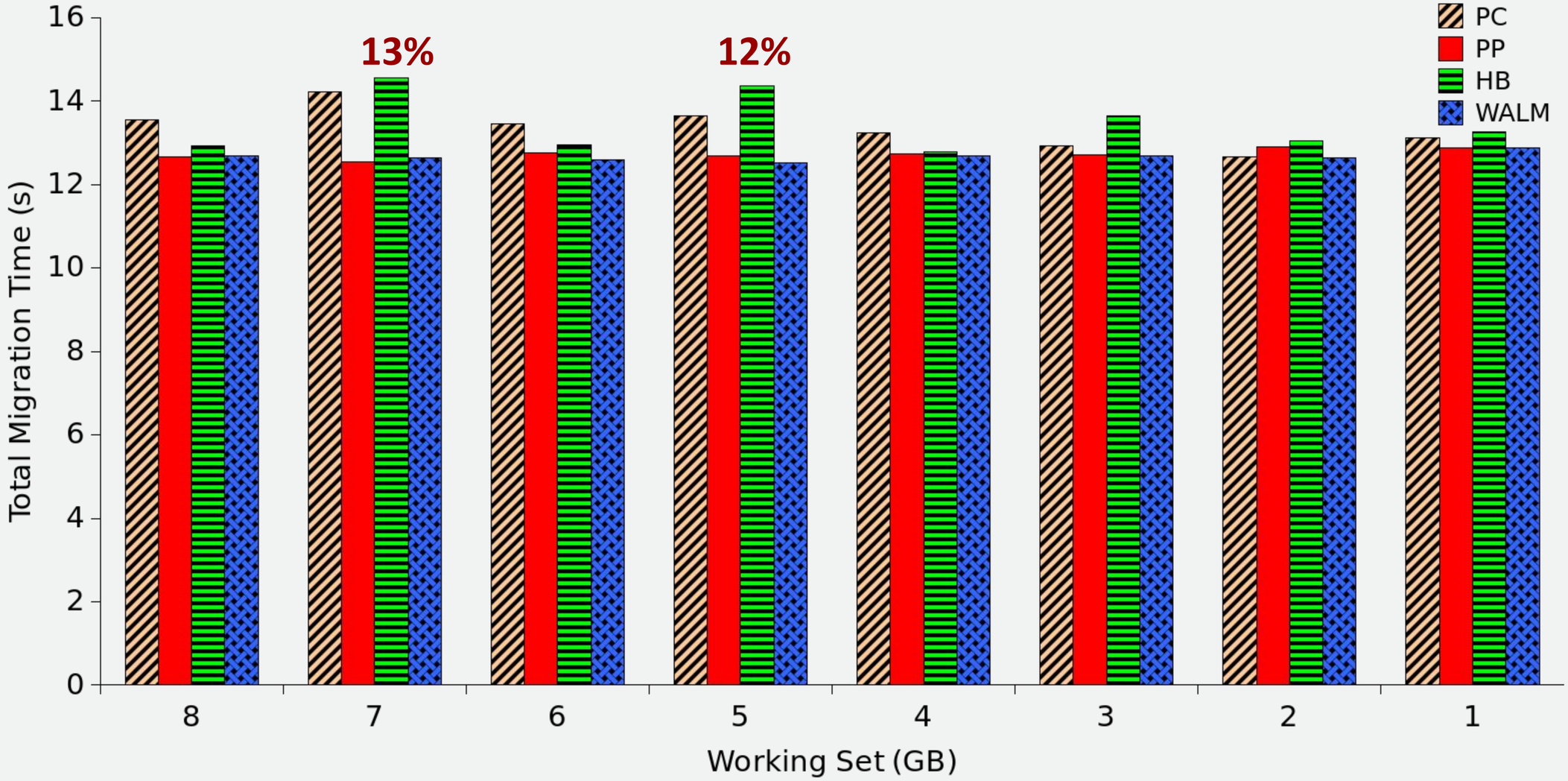


External Database (Network, Memory, CPU)

Pre-copy (PC) **Post-copy (PP)** **Hybrid (HB)**

Evaluation With Multiple intensive Workloads

- Memcached (Memory, Network, CPU)



Pre-copy (PC) Post-copy (PP) Hybrid (HB) WALM

9. CONCLUSION

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Conclusion On Research Questions

1. How can workload characteristics be effectively analyzed and classified to determine the most suitable migration method for a given virtual machine?

Page-dirtying Rate

Network Bandwidth Usage

CPU Utilization

Memory of the VM

Conclusion On Research Questions

2. What are the performance implications of different migration methods in workload-aware live migration?

- For all write-intensive workloads (Working Set, Memcached, YCSB), post-copy migration resulted in the least total migration time.
- For network intensive workloads, based on the direction of migration traffic, either pre-copy or post- copy performed better.
- For all CPU intensive and idle VMs, the intelligent hybrid migration mechanism gave the least total migration time.

10. OUTCOME

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Submitted Last Week

Under Review

Ilma, B., Cooray, Samindu. and Fernando, D., 2024, April. WALM: Workload-Aware Live Migration of Virtual Machines. In **IEEE Access (2024)**

REFERENCES

- https://chrischan.com.au/cropped-goldfish-jumping-out-of-bowl-blue-bg-1200x773-jpg/
- http://www.animated-gifs.fr/category_computing/internet-1/
- Hines, M. R., Deshpande, U. & Gopalan, K. (2009), 'Post-copy live migration of virtual machines', ACM SIGOPS operating systems review 43(3), 14–26.
- Deshpande, U., Wang, X. & Gopalan, K. (2011), Live gang migration of virtual machines, in 'Proceedings of the 20th international symposium on High performance distributed computing', pp. 135–146.
- Fernando, D., Bagdi, H., Hu, Y., Yang, P., Gopalan, K., Kamhoua, C. & Kwiat, K. (2016), Quick eviction of virtual machines through proactive snapshots, in '2016 IEEE International Conference on Cluster Computing (CLUSTER)', IEEE, pp. 156–157.

REFERENCES

- Deshpande, U., You, Y., Chan, D., Bila, N. & Gopalan, K. (2014), Fast server deprovisioning through scatter-gather live migration of virtual machines, in '2014 IEEE 7th International Conference on Cloud Computing', IEEE, pp. 376–383.
- Fernando, D., Yang, P. & Lu, H. (2020), Sdn-based order-aware live migration of virtual machines, in 'IEEE INFOCOM 2020-IEEE conference on computer communications', IEEE, pp. 1818–1827.
- Li, H., Xiao, G., Zhang, Y., Gao, P., Lu, Q. & Yao, J. (2021), Adaptive live migration of virtual machines under limited network bandwidth, in 'Proceedings of the 17th ACM SIGPLAN/SIGOPS International Conference on Virtual Execution Environments', pp. 98–110.

THANK YOU

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Q & A

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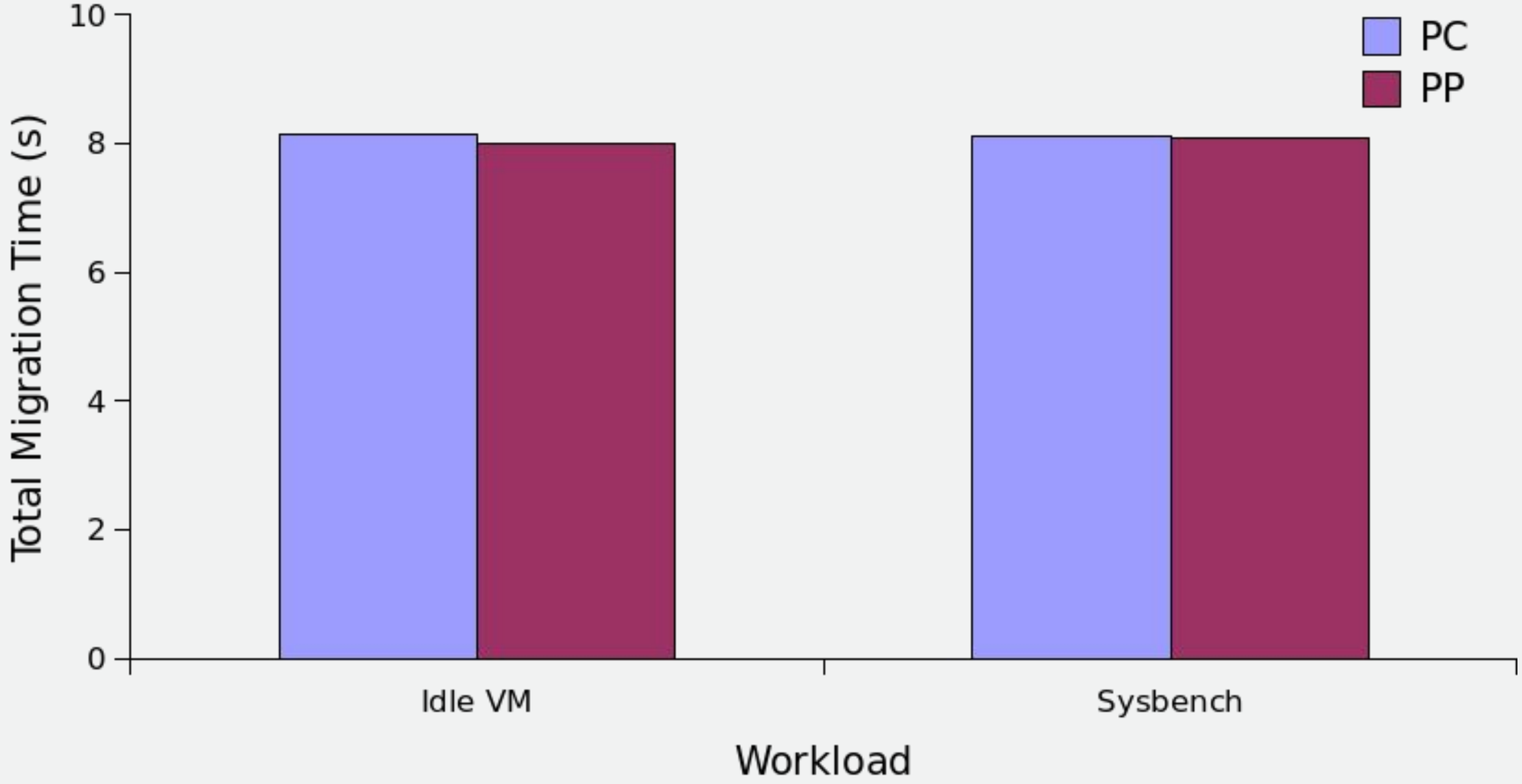
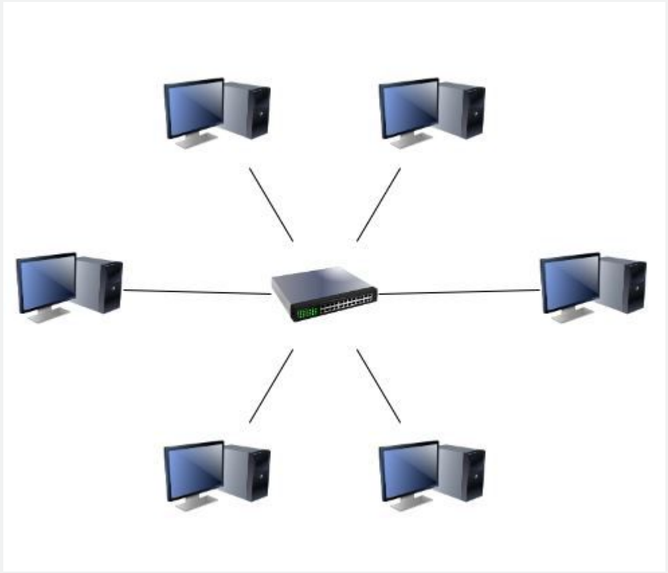
Performance Impact Of VM Workload Ctd.



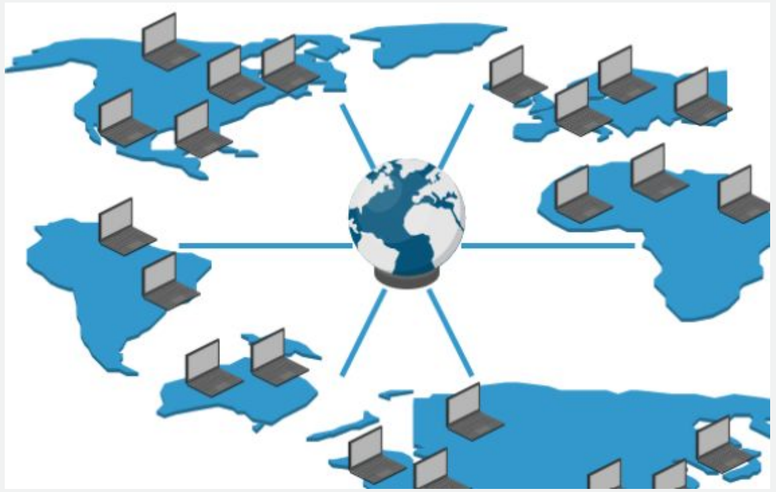
Background Ctd.

- LAN Migration



- Memory
- Execution State

- WAN Migration



- Memory
- Execution State
- Disk

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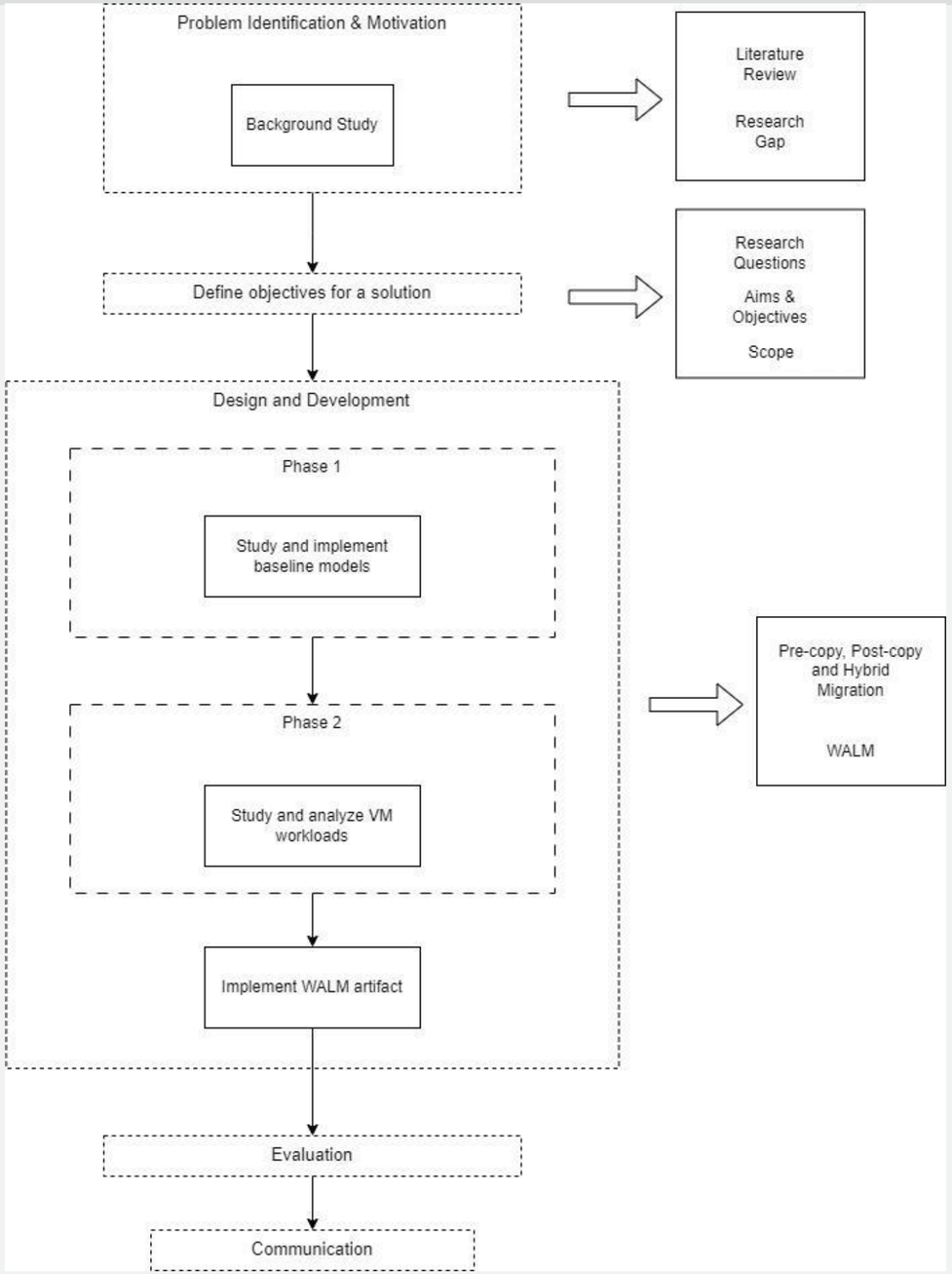
Optimization Mechanisms

- **Dynamic Self Ballooning** (Hines et al., ACM SIGOPS operating systems review, 2009)
- **Compression** (Deshpande et al., Proceedings of the 20th international symposium on High performance distributed computing, 2011)
- **Quick Eviction** (Fernando et al., IEEE International Conference on Cluster Computing (CLUSTER), 2016)
- **Deduplication** (Deshpande et al., IEEE 7th International Conference on Cloud Computing, 2014)

RESEARCH METHODOLOGY



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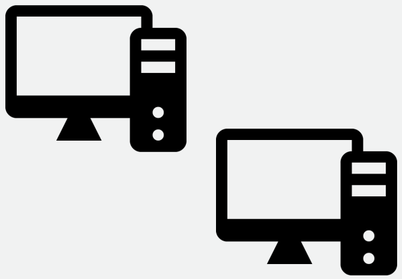
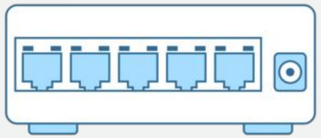
Testbed setup

Setup



Product	CPU	RAM	OS
HP Z620 Workstation	Intel(R) Xeon(R) CPU E5-1650 v2 @ 3.50GHz x 12	16GiB	Ubuntu 20.04 LTS



HPE OfficeConnect 1920S Series Switch (JL385A)

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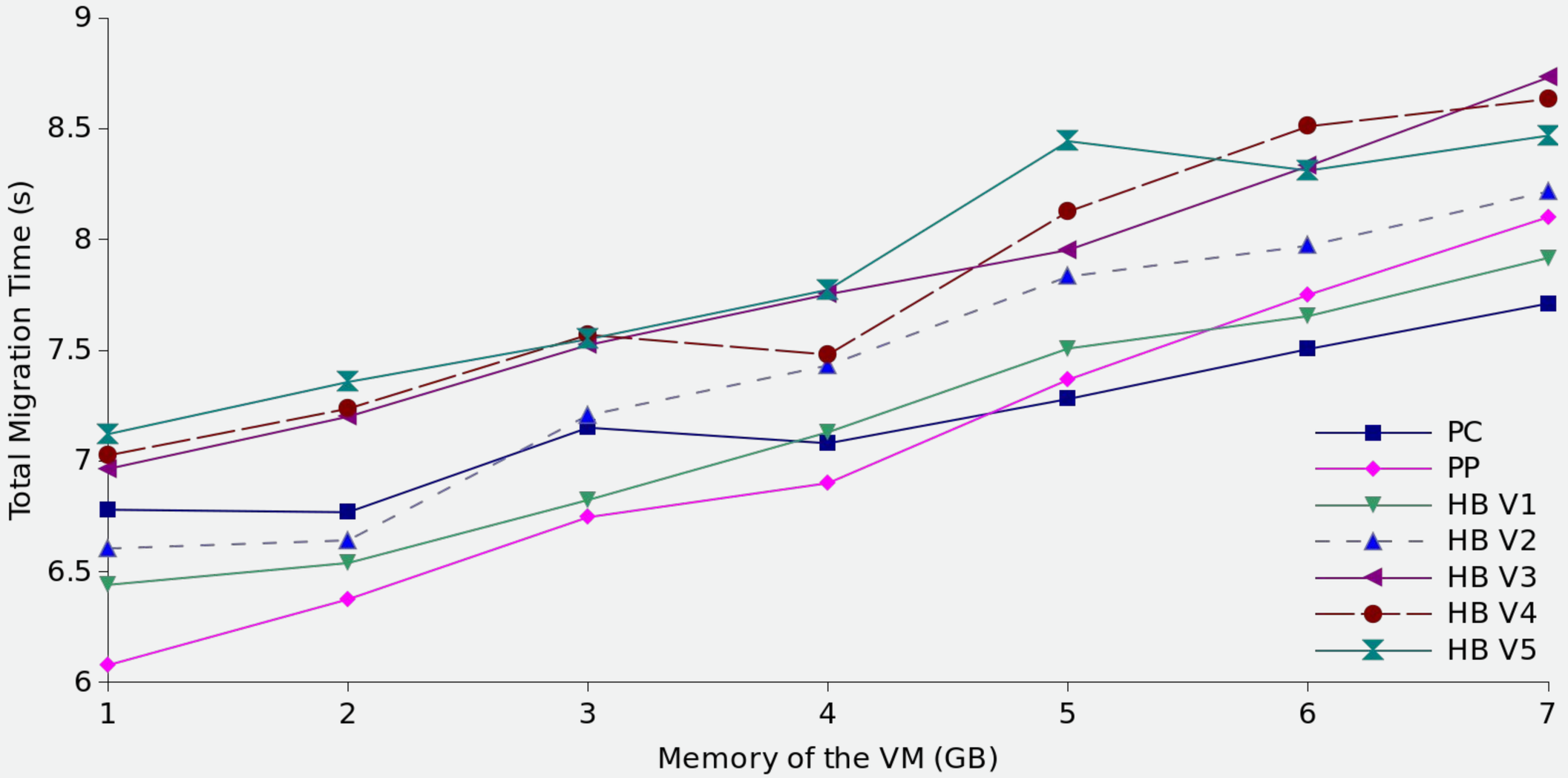

Limitations

- There might be other aspects of a VM (such as the amount of CPU cores allocated, ISA, guest OS, type of hypervisor etc.) which might affect the migration process.
- Workloads that change their resource usage in the middle of migration might perform differently with WALM.