# WORKLOAD-AWARE LIVE MIGRATION OF VIRTUAL MACHINES

SCS 4224 FINAL YEAR PROJECT IN COMPUTER SCIENCE

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# INTRODUCTION

**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).**

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# BACKGROUND

- **Live Migration of VMs**

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# BACKGROUND

Google

## 1,000,000 Migrations Per Month

Ruprecht, A., Jones, D., Shiraev, D., Harmon, G., Spivak, M., Krebs, M., Baker-Harvey, M. & Sanderson, T. (2018), 'Vm live migration at scale', ACM SIG-PLAN Notices 53(3), 45–56.

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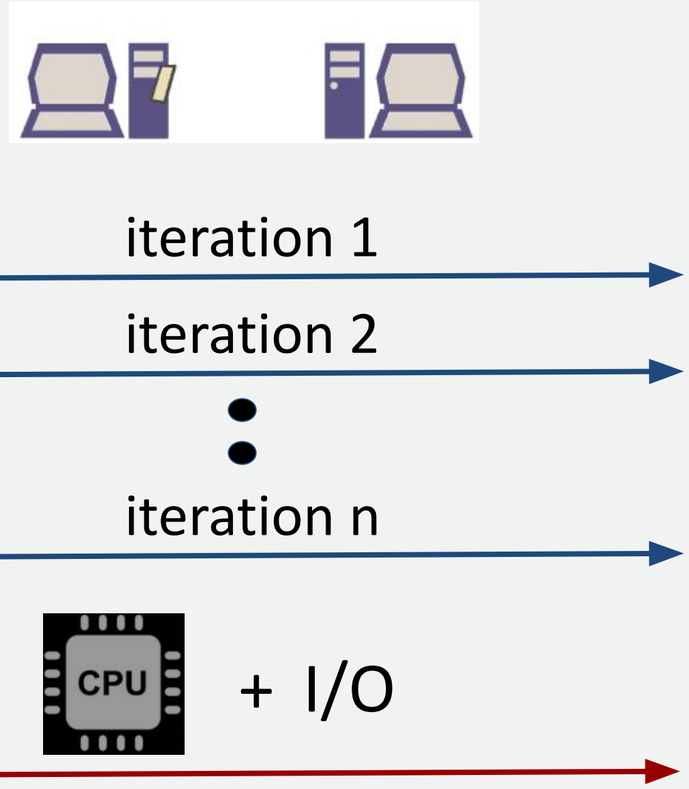
# BACKGROUND

- **Pre-copy Migration**

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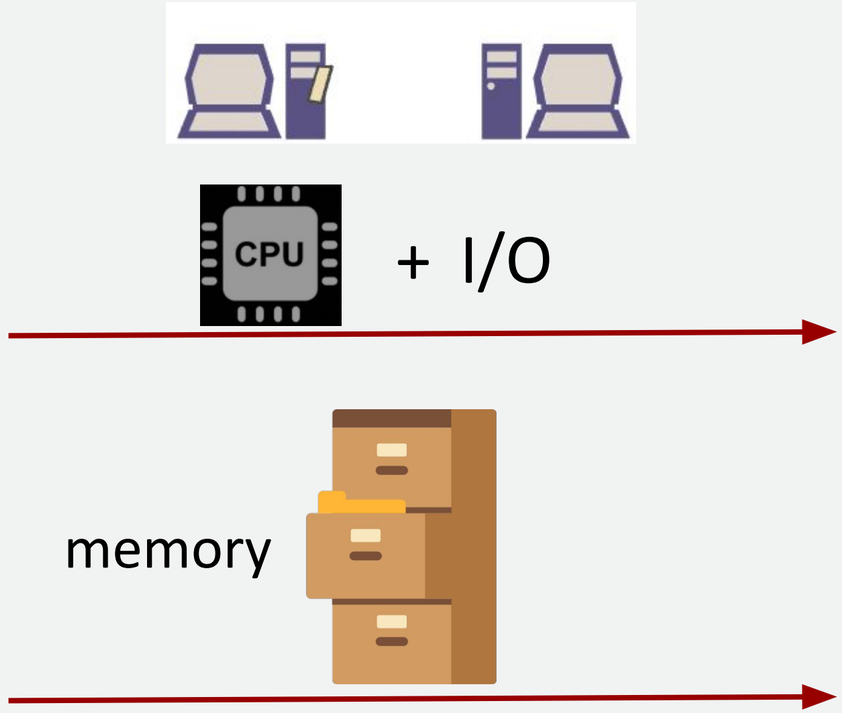
# BACKGROUND

- **Post-copy Migration**

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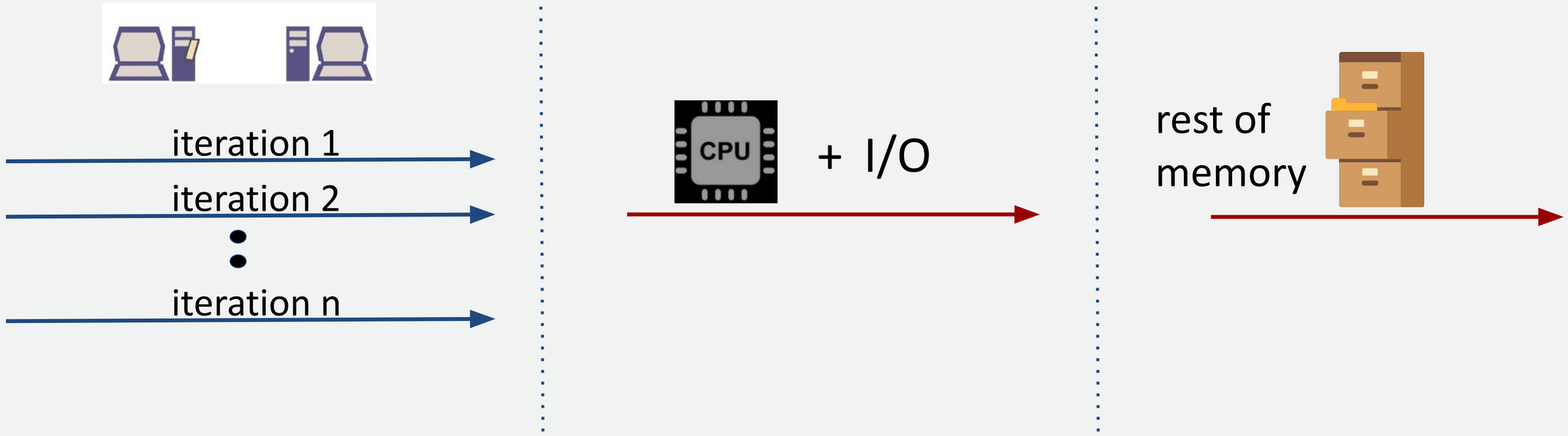
# BACKGROUND

- **Hybrid Migration**

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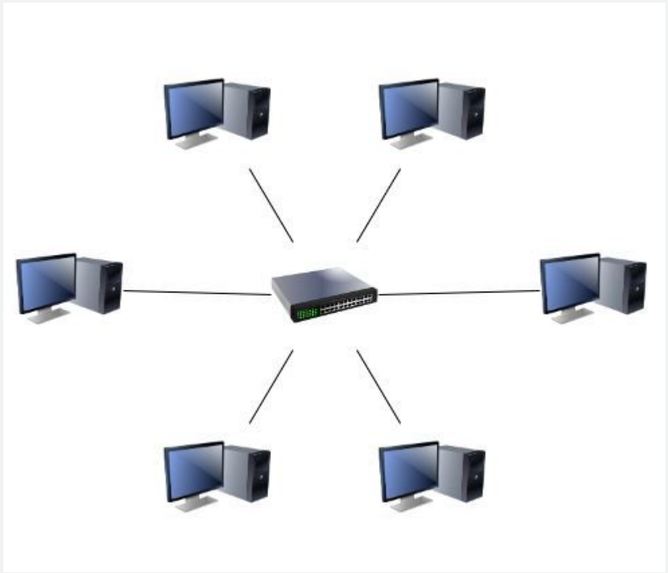
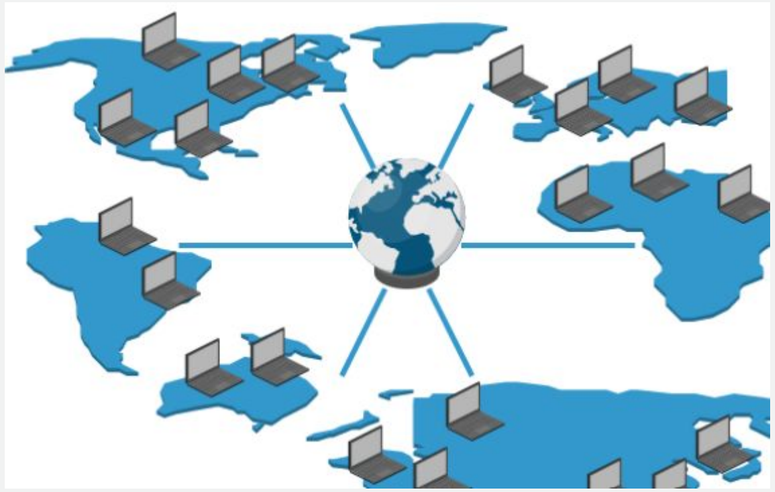
# BACKGROUND

- LAN Migration



- WAN Migration



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# BACKGROUND

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


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# MOTIVATION

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

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# 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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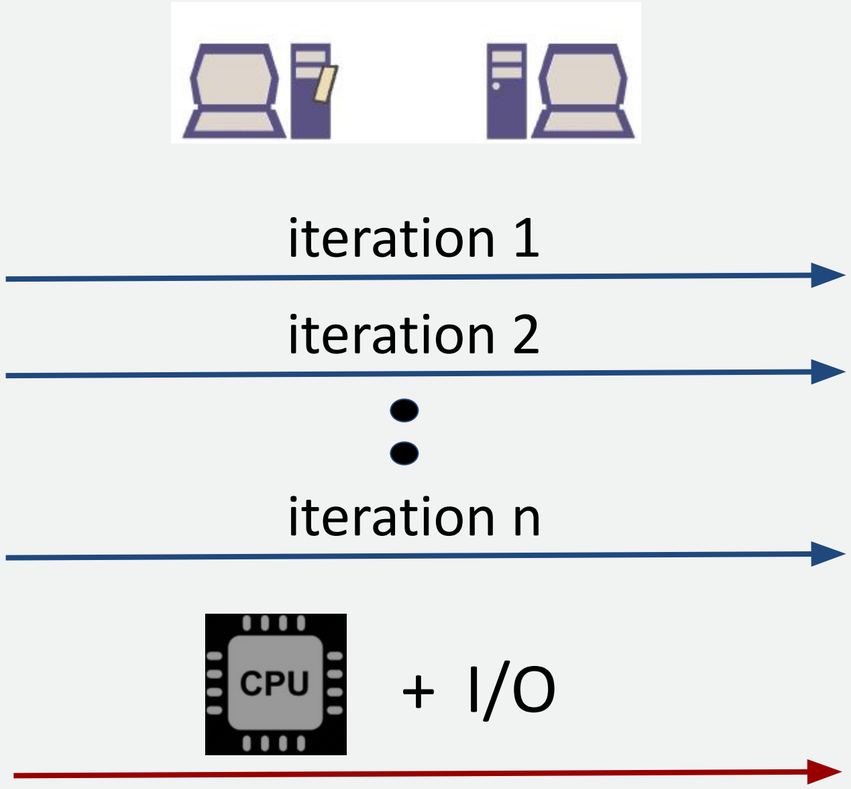
- **Pre-copy Migration**




**“...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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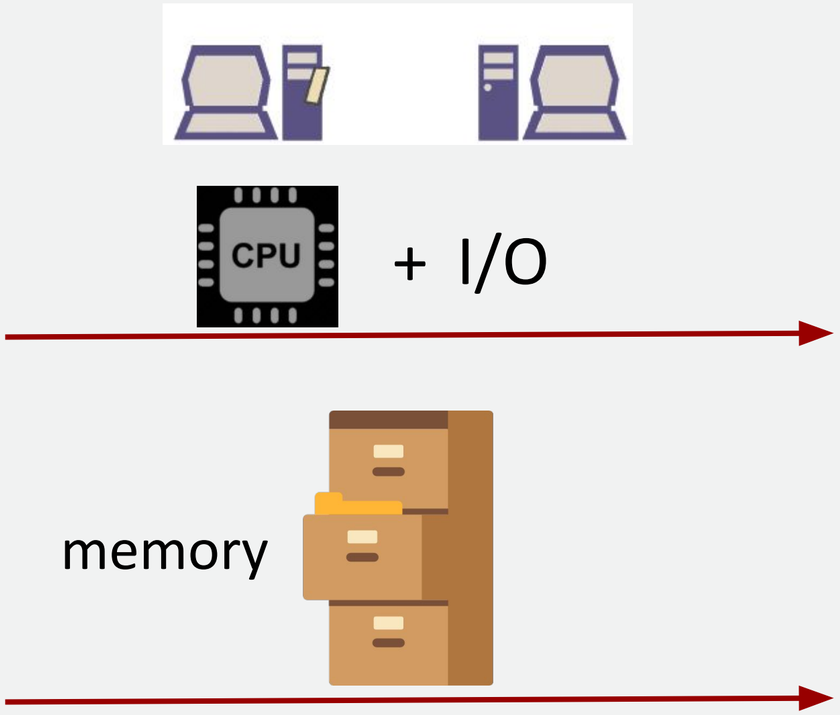
- **Post-copy Migration**




**“... 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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# RESEARCH GAP


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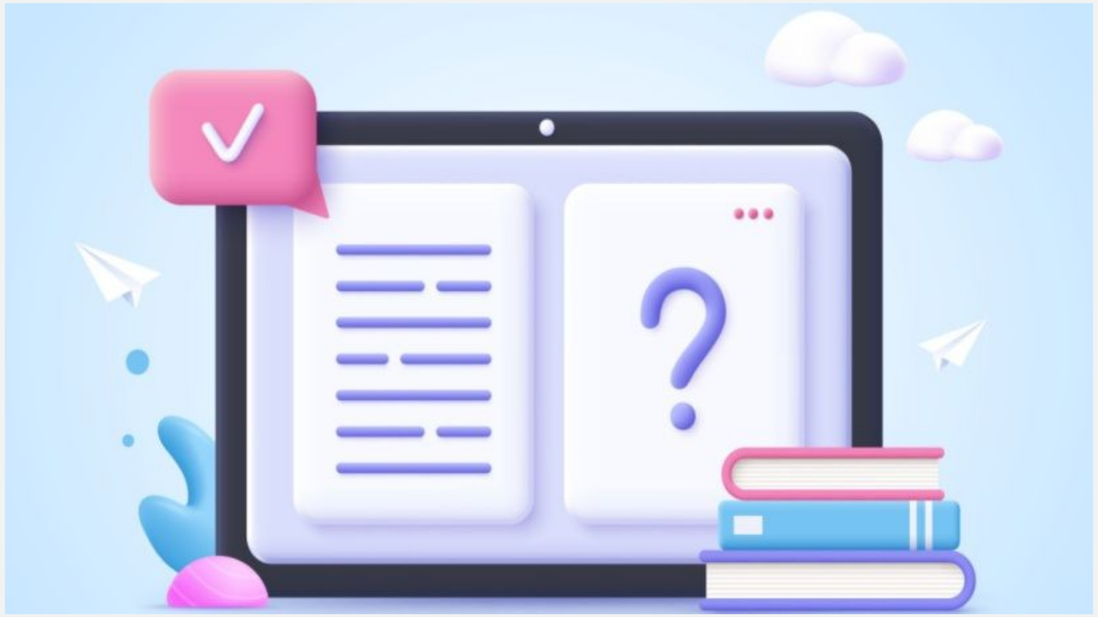
# RELATED WORK



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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)

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**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.**

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

- **Workload analysis.**
- **Order the VMs according to their workload types.**

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

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

- **Prioritizing pre-copy migration.**
- **Consider only non-demanding workloads.**

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

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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?

CPU Usage

Memory Usage,
Page Dirtying rate

Network Usage

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

Total Migration Time

Downtime

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# OBJECTIVES

- **Identify workload metrics that can capture the characteristics of different types of workloads.**
- **Identify the methods to capture the workload metrics dynamically while the VM is running.**
- **Create a classification model that can classify the workloads according to the workload metrics.**
- **Determine the correlation between migration methods and workload characteristics.**
- **Establish an algorithm that can select the most suitable migration method based on the workload analysis.**

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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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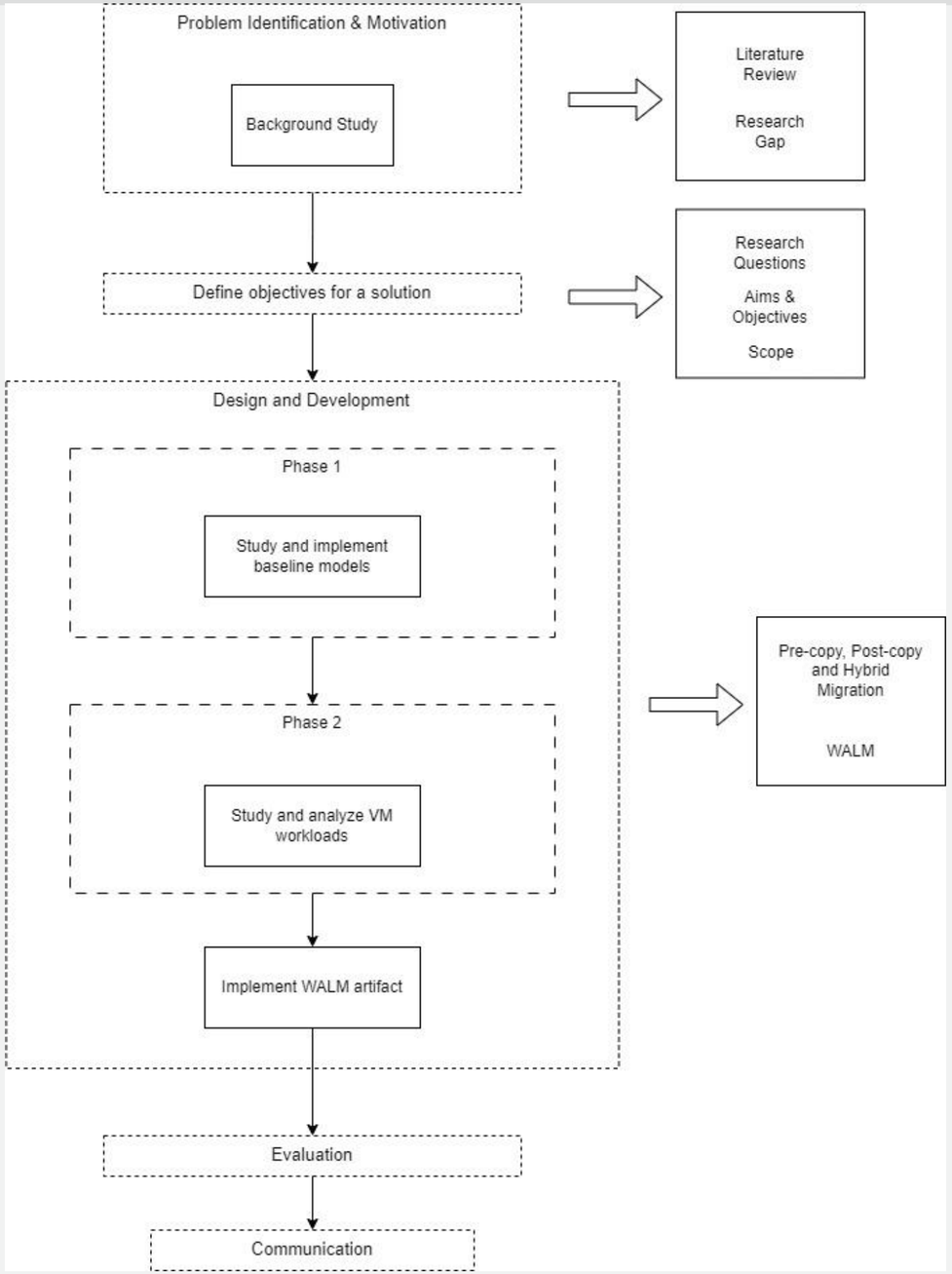
# RESEARCH METHODOLOGY

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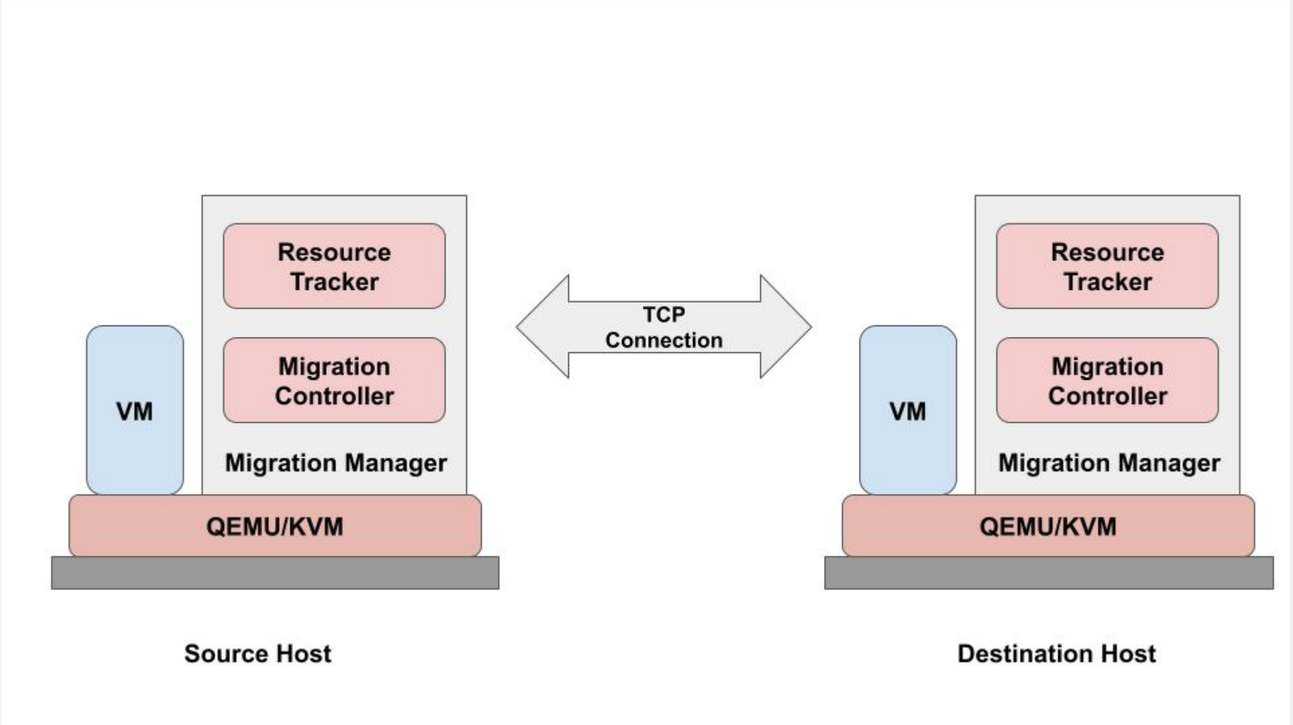
# RESEARCH DESIGN

## Architecture

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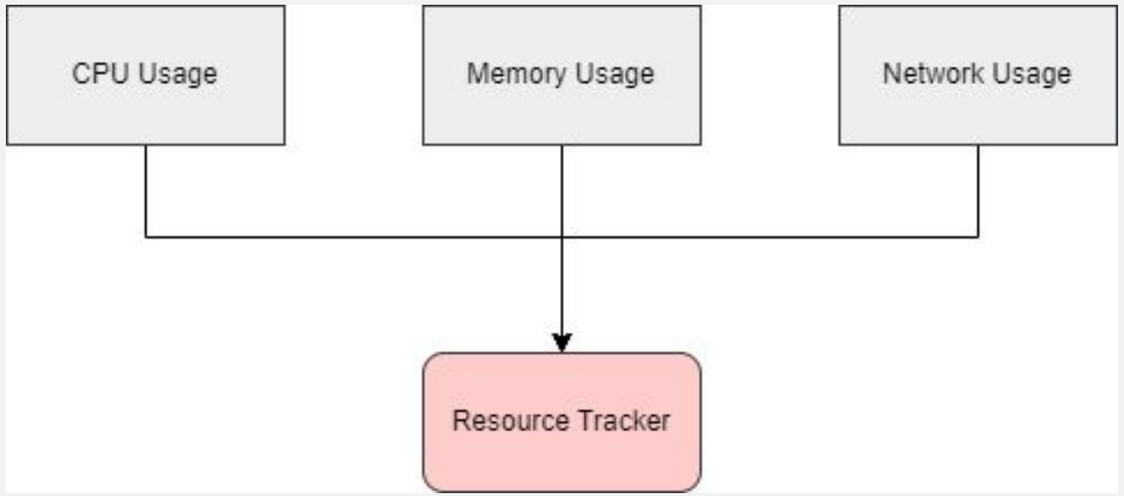
# RESEARCH DESIGN

## Resource Tracker

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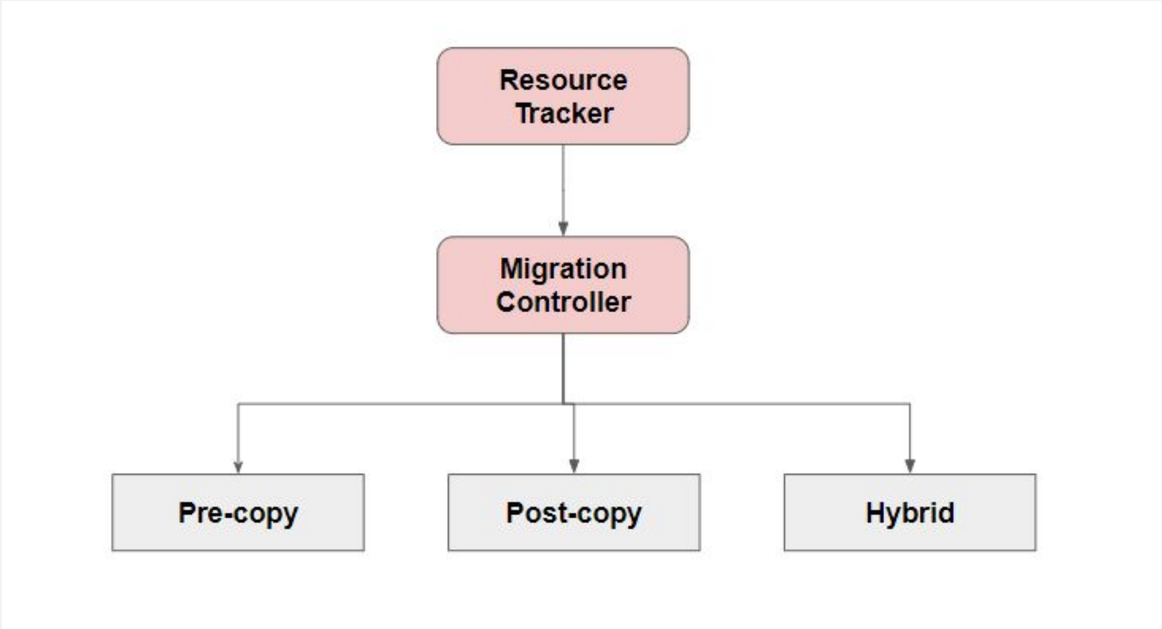
# RESEARCH DESIGN

## Migration Controller

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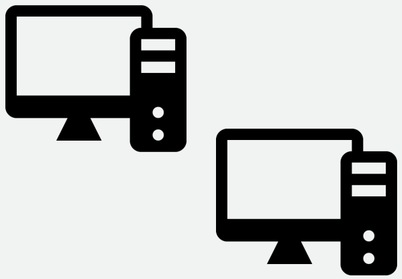
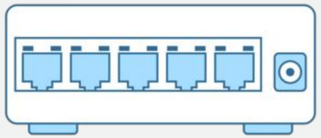
# PROGRESS SO FAR

## 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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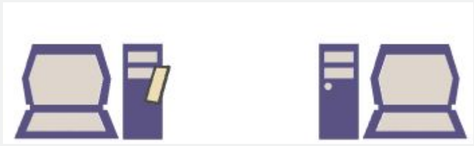
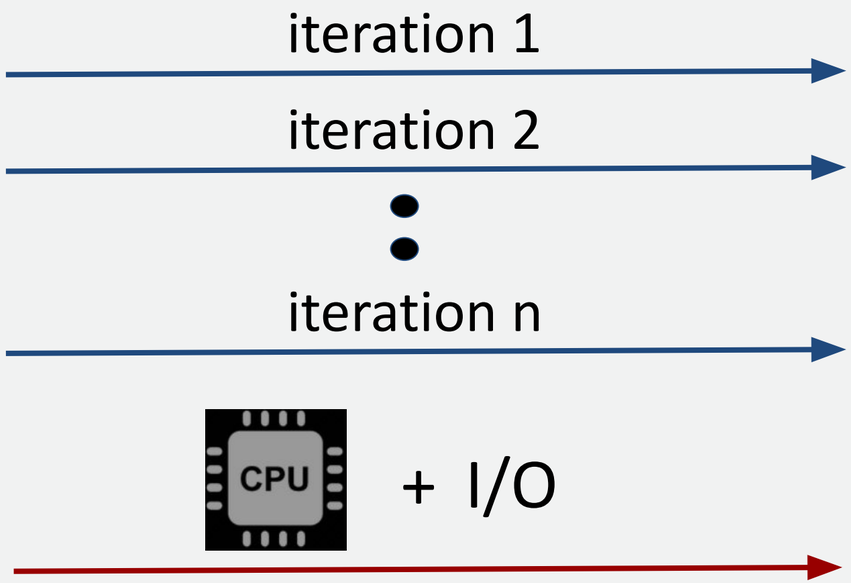
# PROGRESS SO FAR

- Baseline Models
- Pre-copy migration



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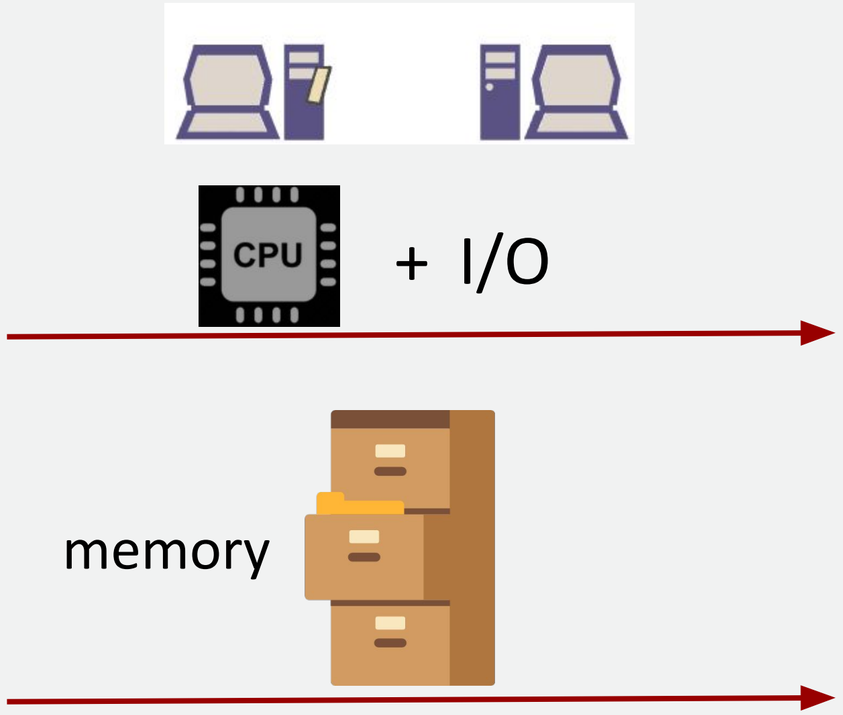
# PROGRESS SO FAR

- Baseline Models
- Post-copy migration

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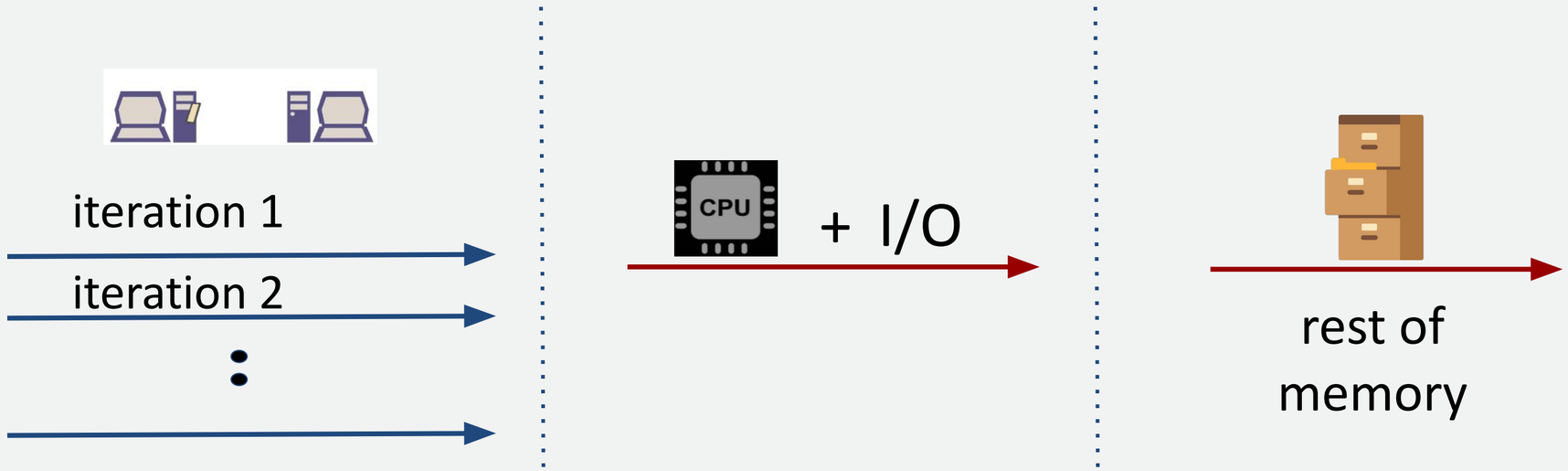
# PROGRESS SO FAR

- Baseline Models
- Hybrid migration

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# PROGRESS SO FAR

- **Workload Experiments**
  - **Memory Intensive**
  - **CPU Intensive**
  - **Network Intensive**

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# PROGRESS SO FAR

- **Working Set**
  - **Dirties pages to a variable writable working set.**
  - **Random numbers written to memory.**

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# PROGRESS SO FAR

## Working Set - Pre-copy migration

**Specifics:** 8GB RAM
1 CPU Core


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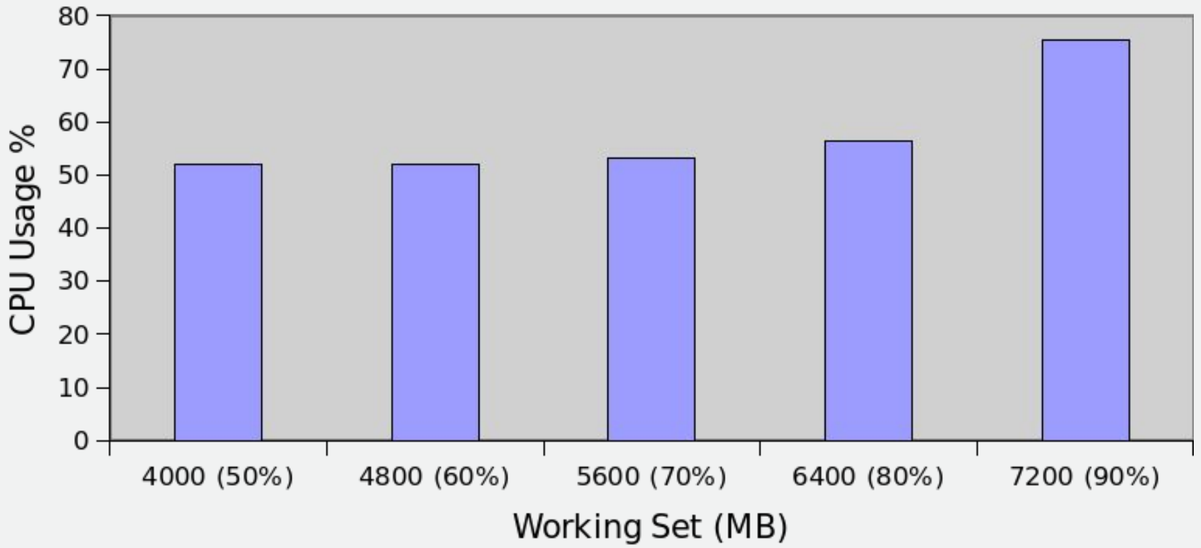
# PROGRESS SO FAR

## Working Set - Pre-copy Migration




**Specifics:** 8GB RAM

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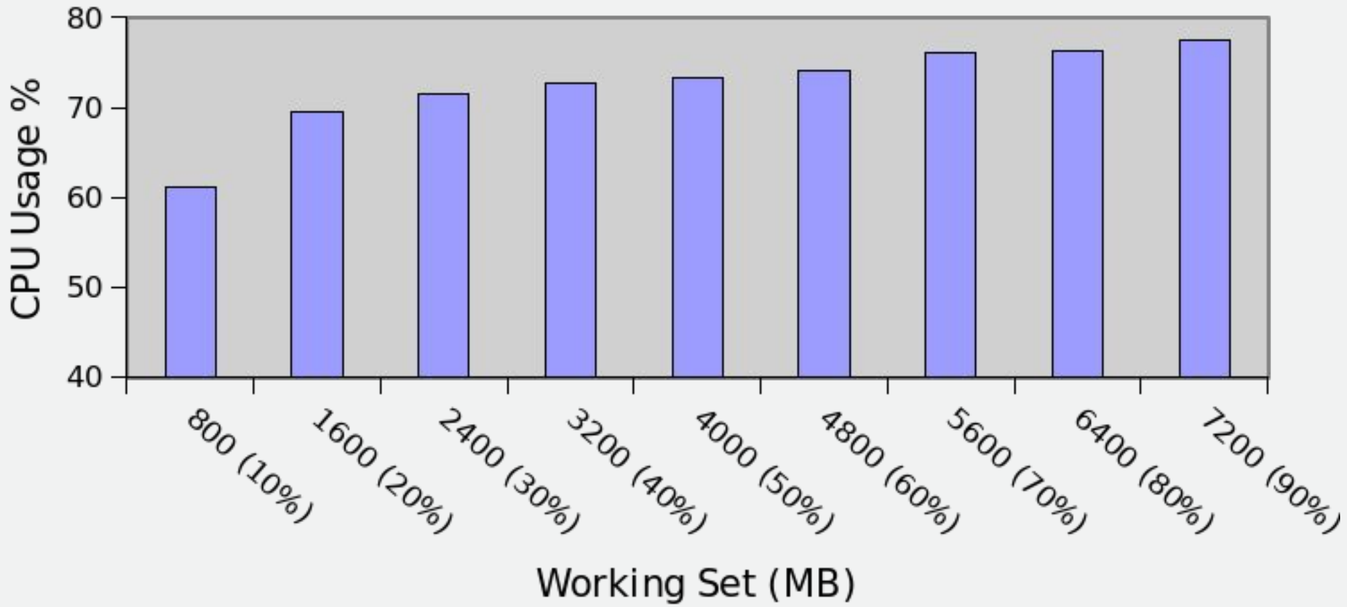
# PROGRESS SO FAR

## Working Set - Pre-copy Migration




**Specifics:** 8GB RAM

1 CPU Core

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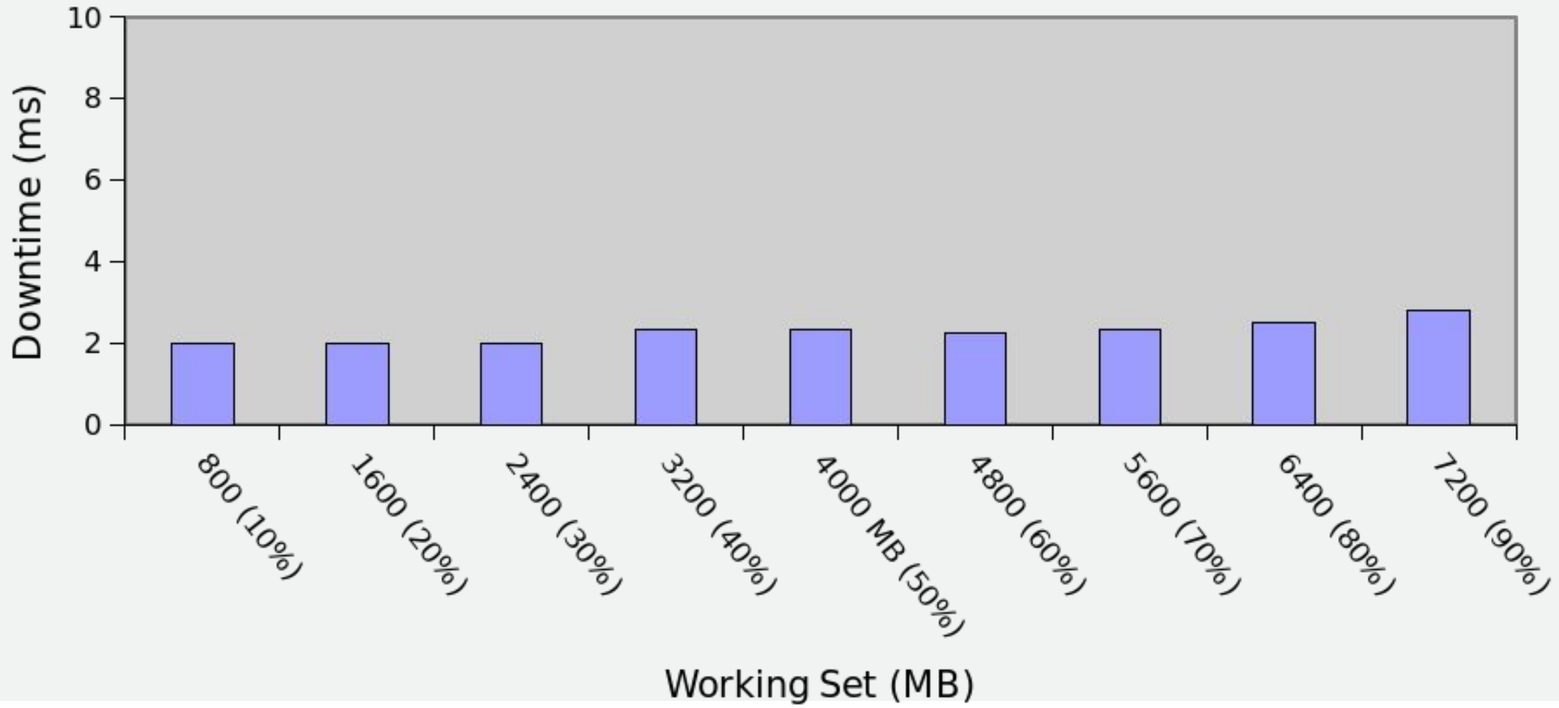
# PROGRESS SO FAR

## Working Set - Post-copy Migration

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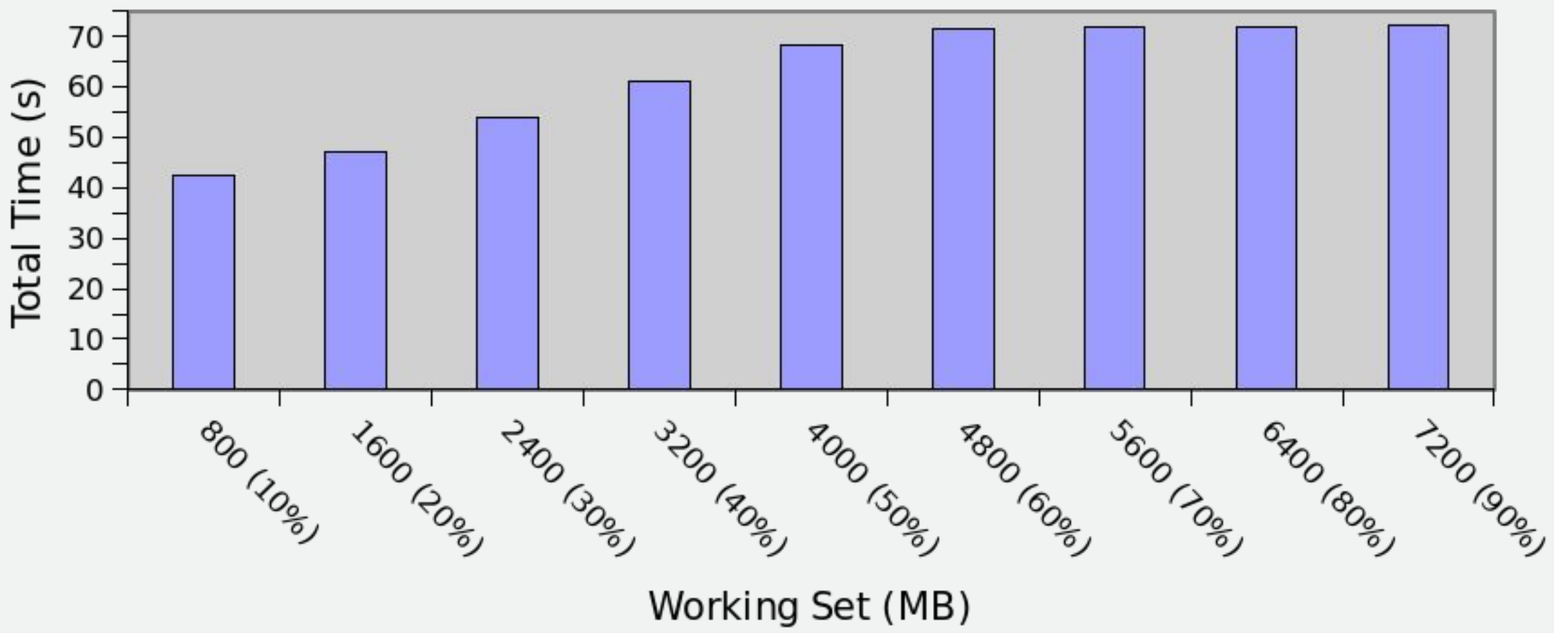
# PROGRESS SO FAR

## Working Set - Post-copy Migration

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# PROGRESS SO FAR

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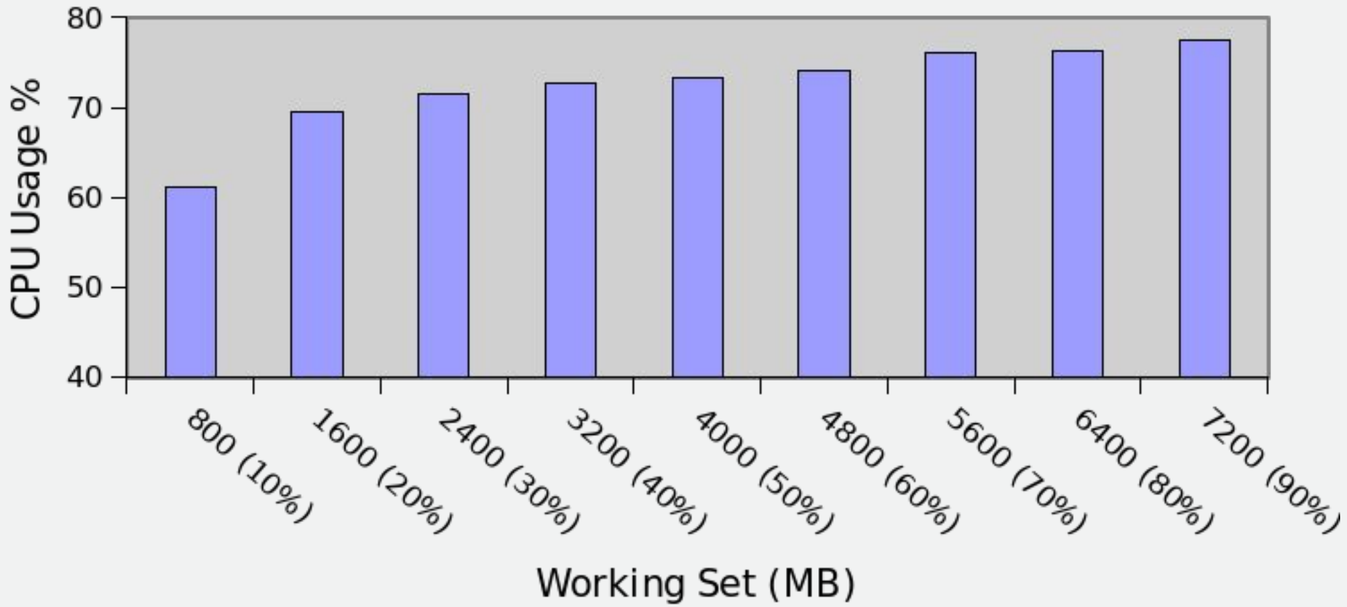


**Specifics:** 8GB RAM
1 CPU Core

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# PROGRESS SO FAR

- Sysbench
  - Open-source multi-purpose benchmarking tool
  - CPU benchmarking
  - Computes prime numbers
  - CPU usage on average 90%

```
#script to execute the sysbench within a VM
#copy this file to a VM and execute this using ssh

sysbench --test=cpu --cpu-max-prime=5000000 run > output.log 2>&1 &
```

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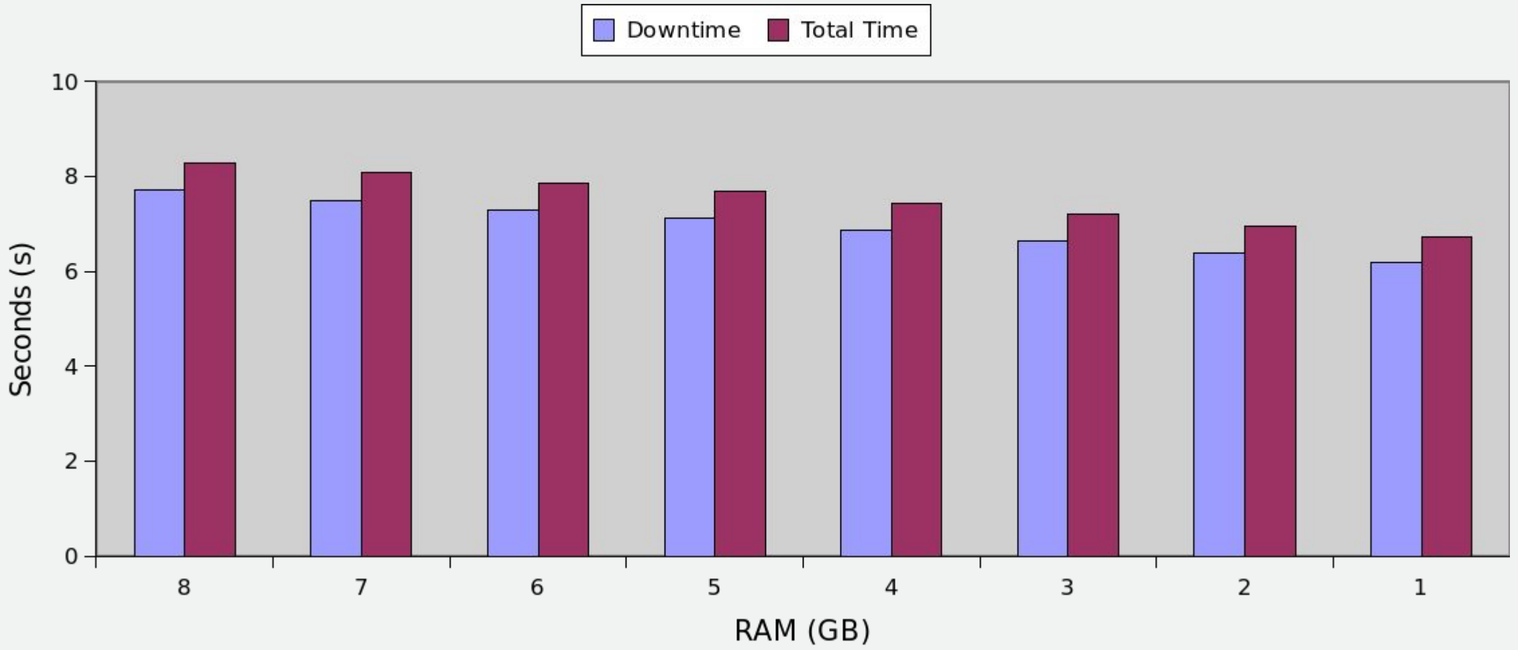
# PROGRESS SO FAR

## Sysbench - Pre-copy Migration

**Specifics:** 1 CPU Core

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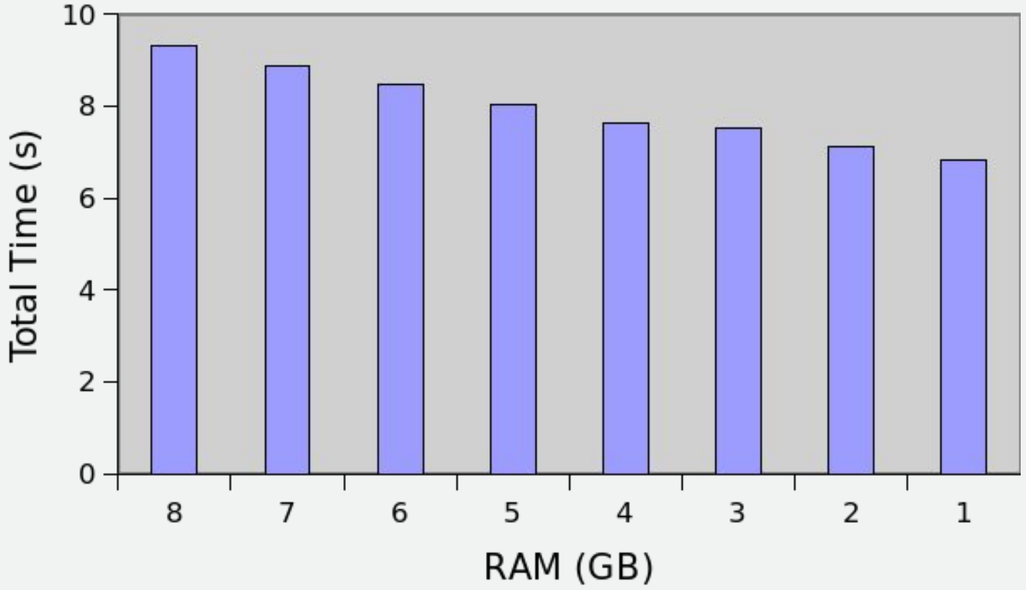
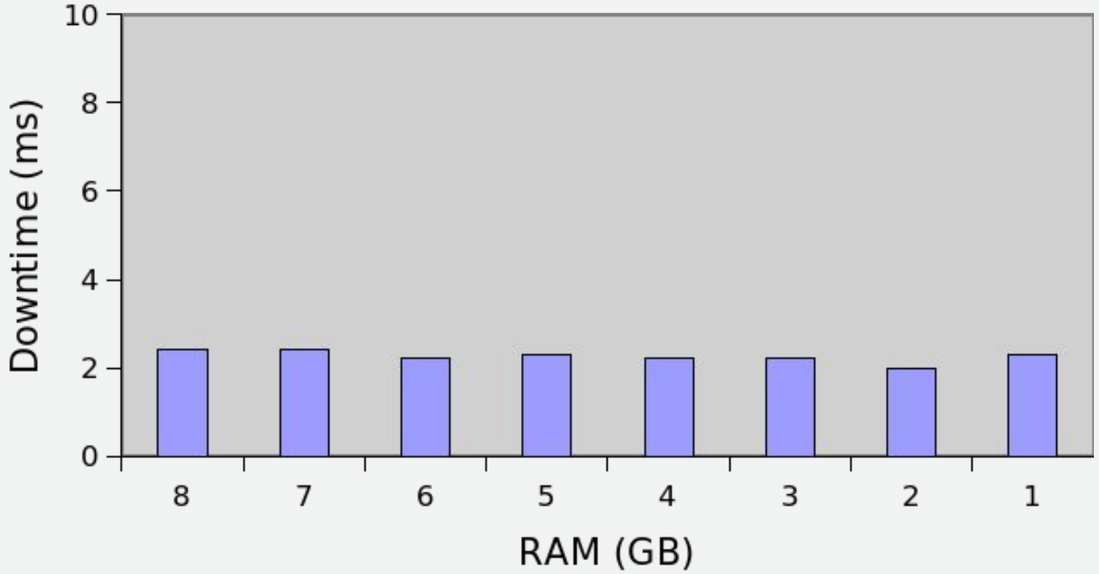
# PROGRESS SO FAR

**Specifics:** 1 CPU Core

## Sysbench - Post-copy Migration




**Total Migration Time (TMT)**




**Downtime (DT)**

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# PROGRESS SO FAR

- **iPerf**
  - **Network performance measurement tool.**
  - **Open-source cross platform tool.**
  - **Has client and server functionalities.**

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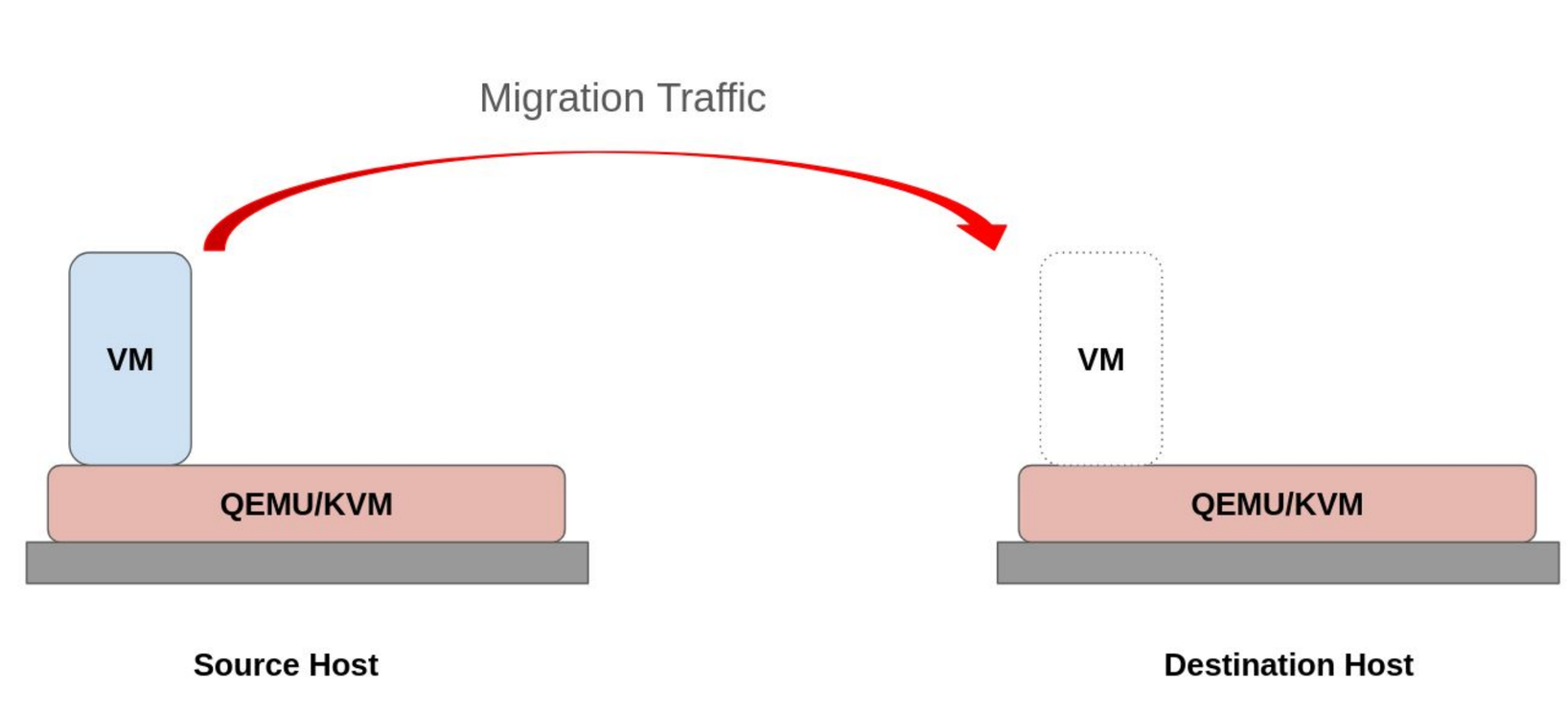
# PROGRESS SO FAR

- **iPerf - Pre-copy Migration**

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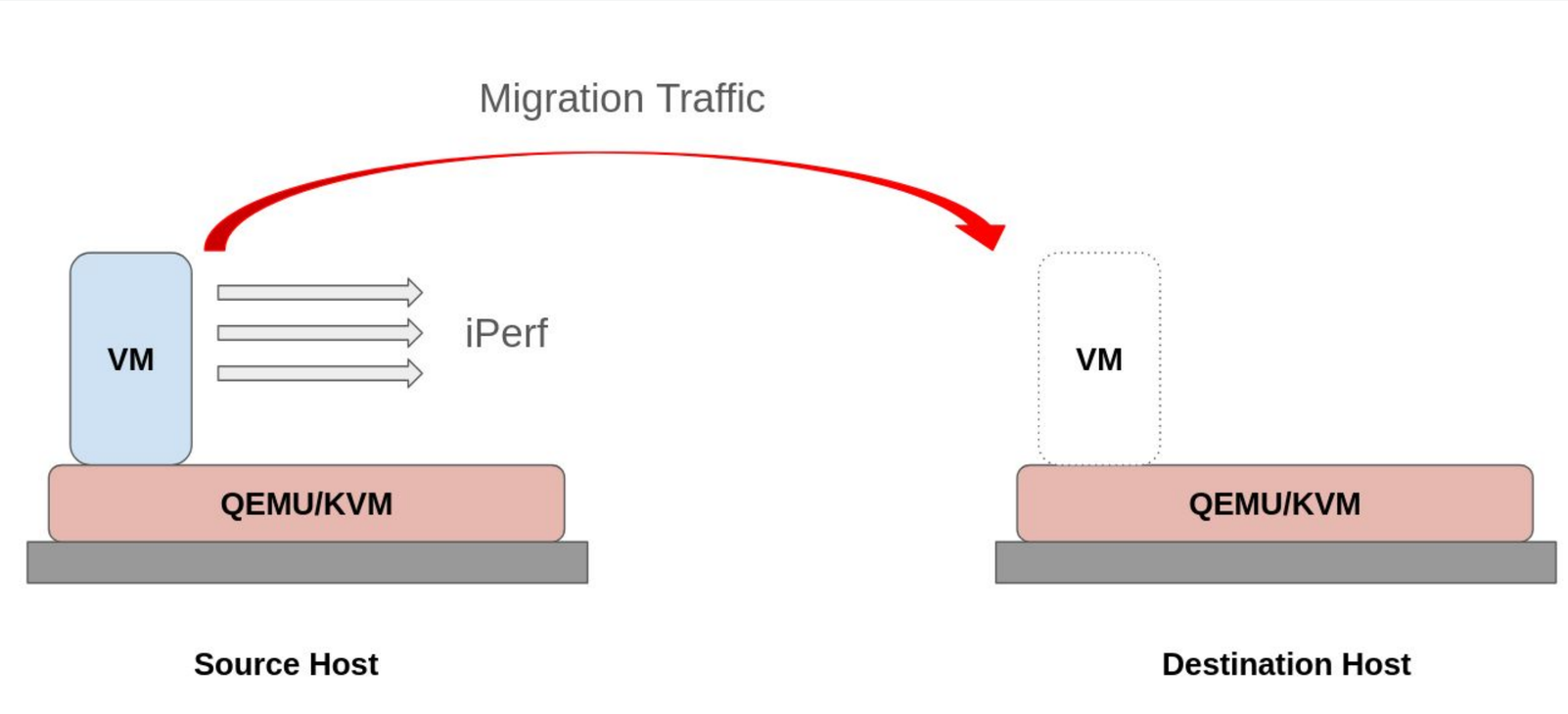


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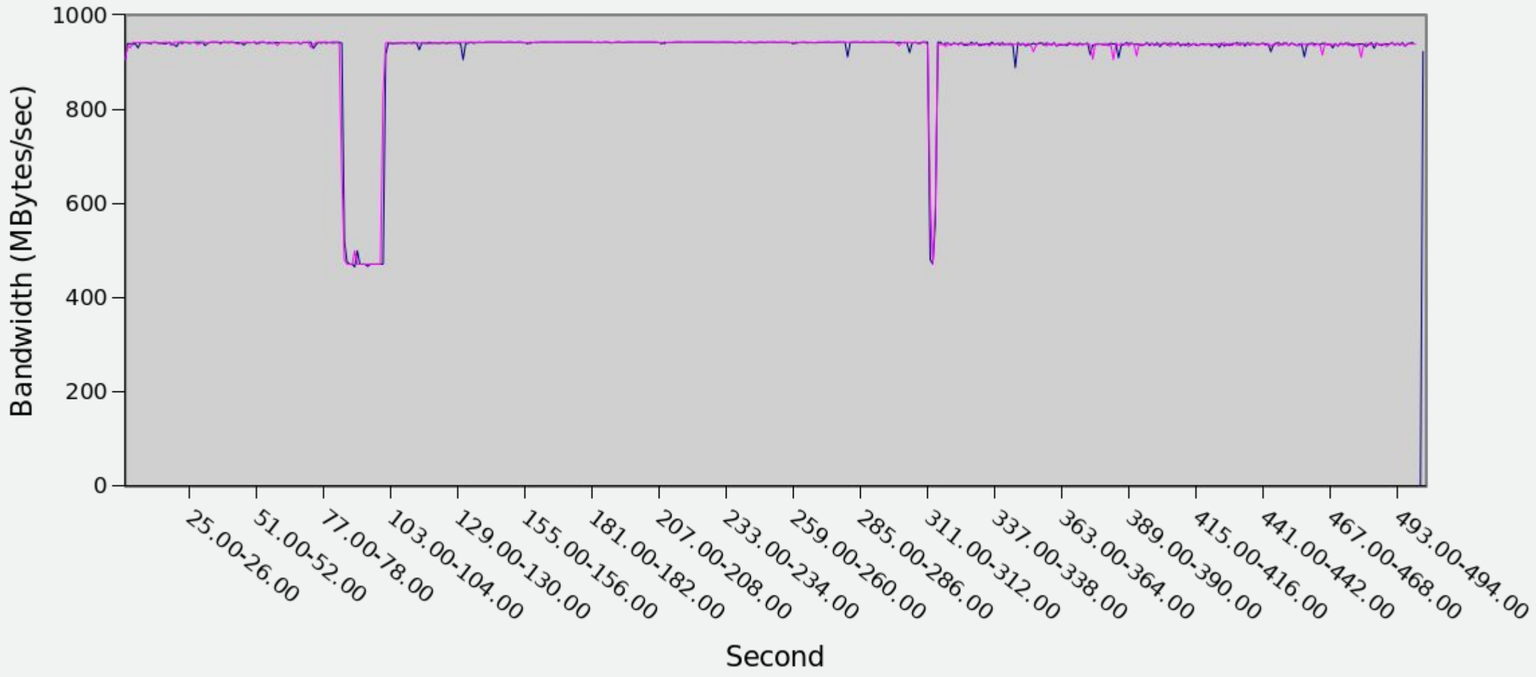
## iPerf - Pre-copy Migration

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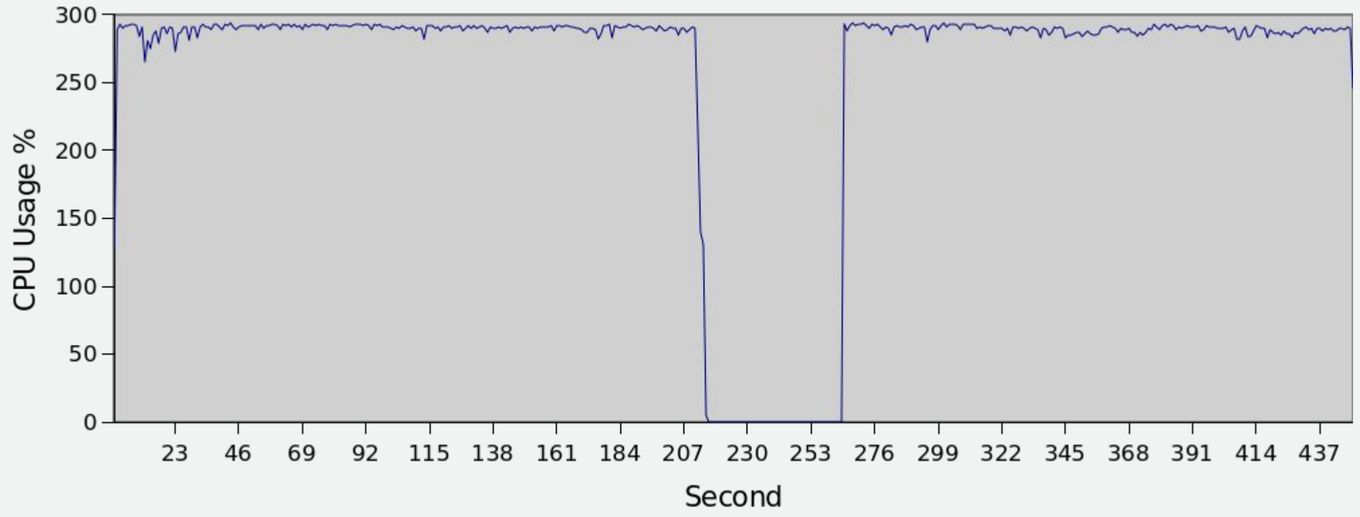
# PROGRESS SO FAR

## iPerf - Pre-copy Migration




**Specifics:** 8GB RAM

1 CPU Core

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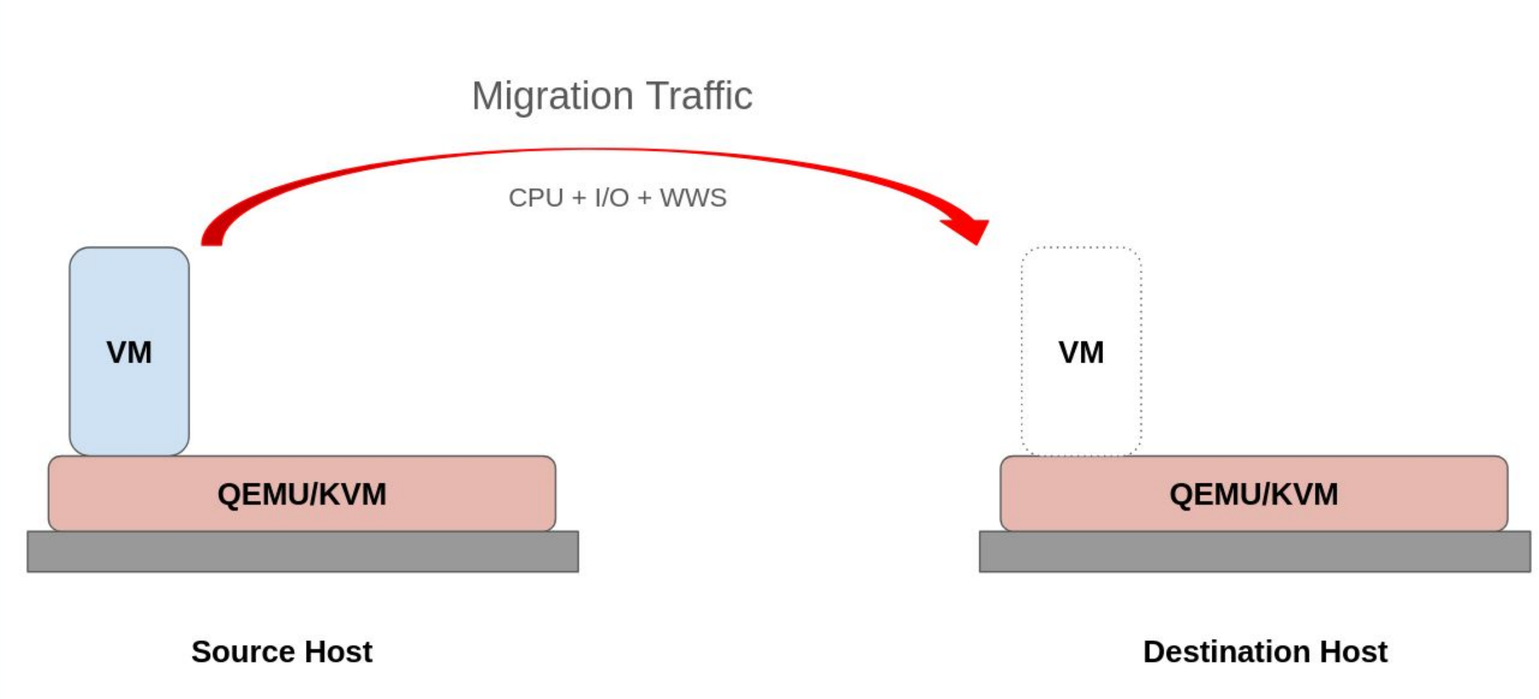
# PROGRESS SO FAR

- **iPerf - Post-copy Migration**

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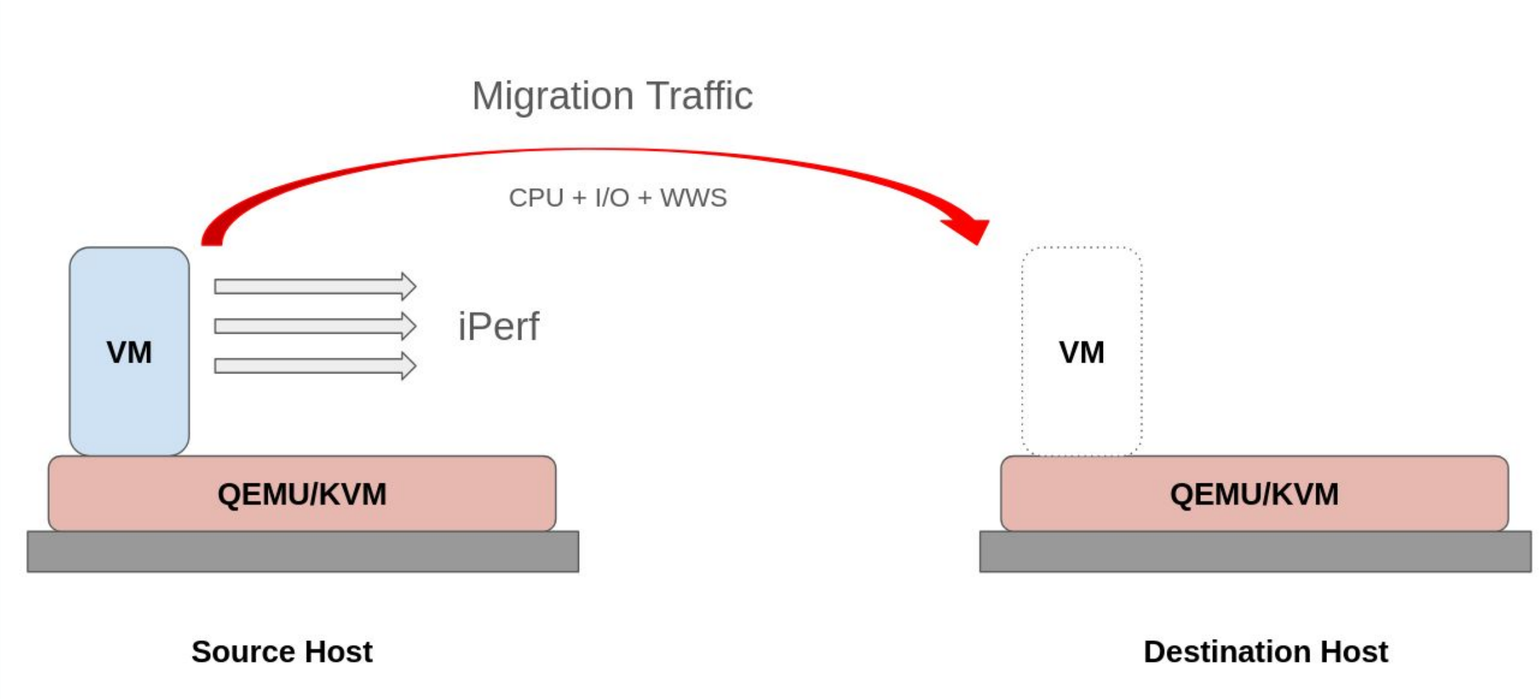


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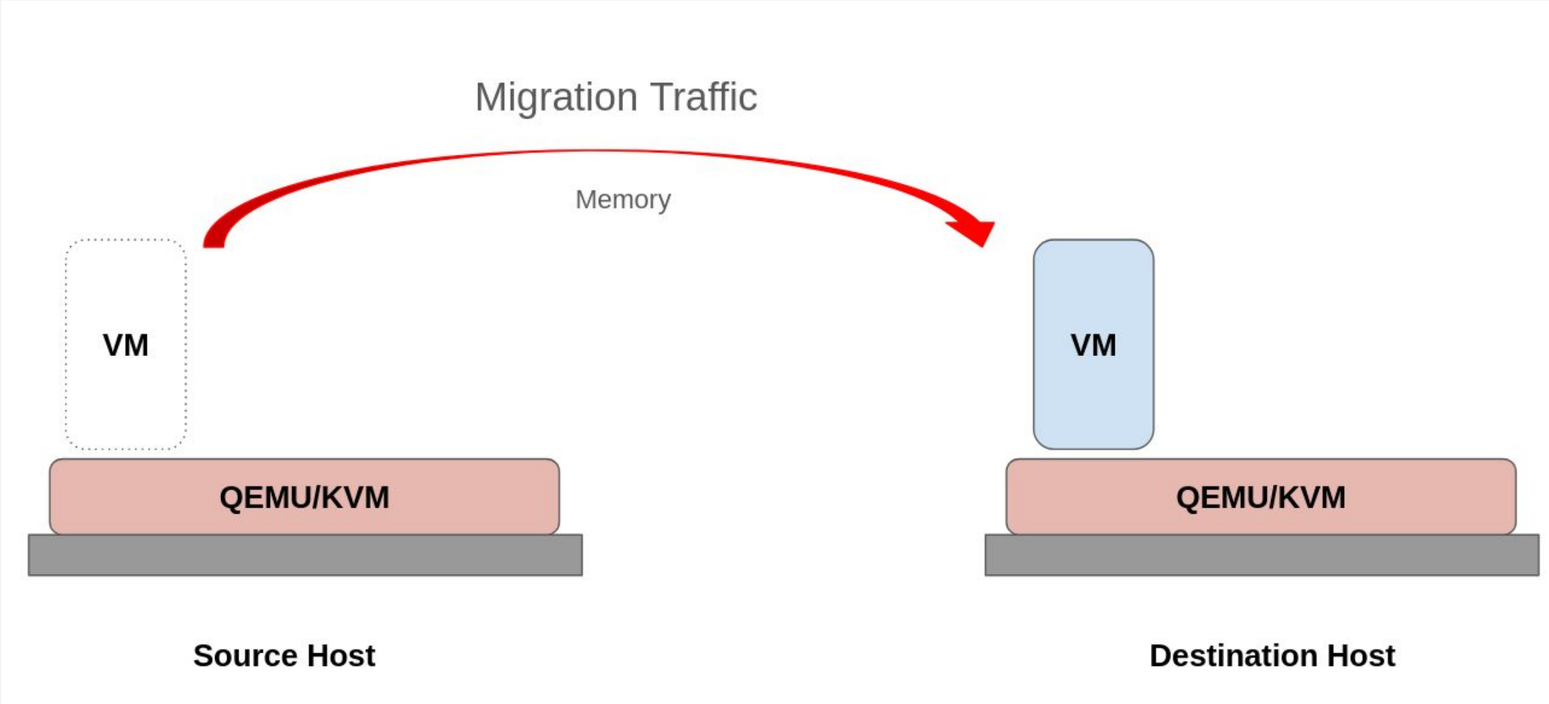


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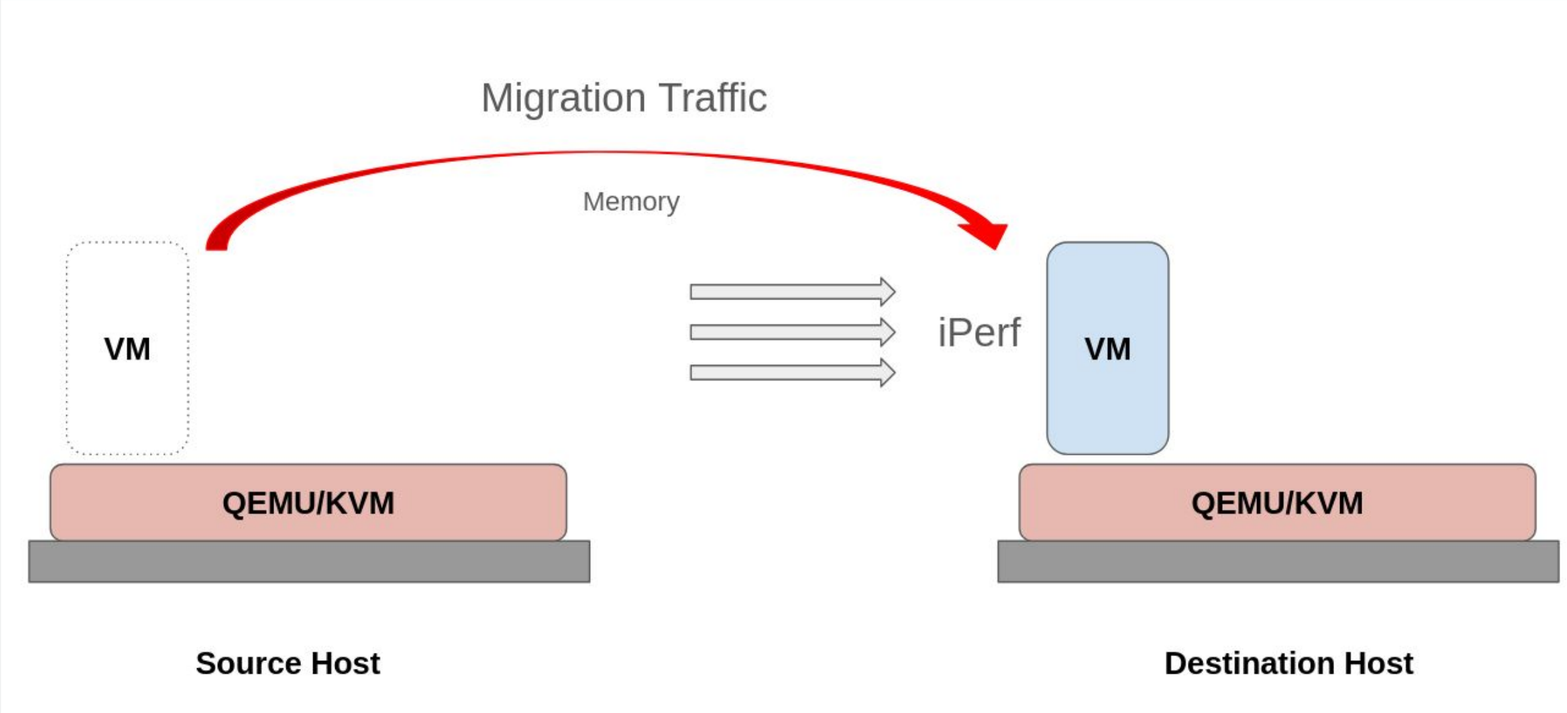


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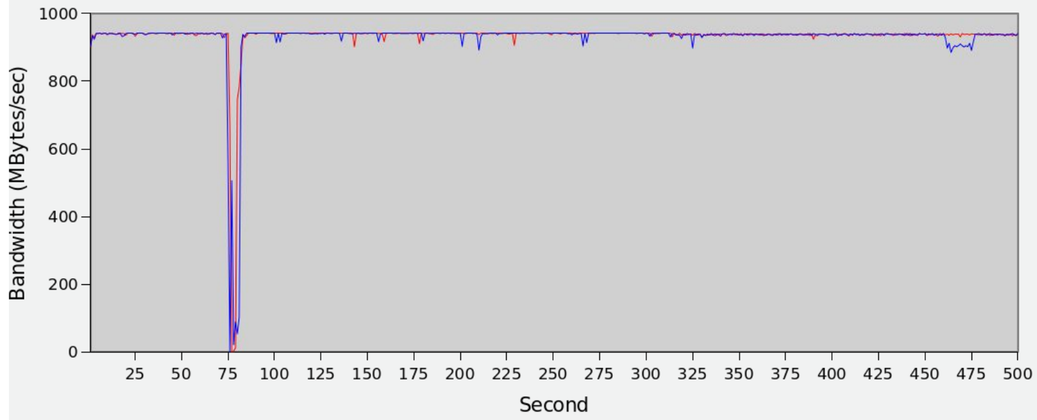
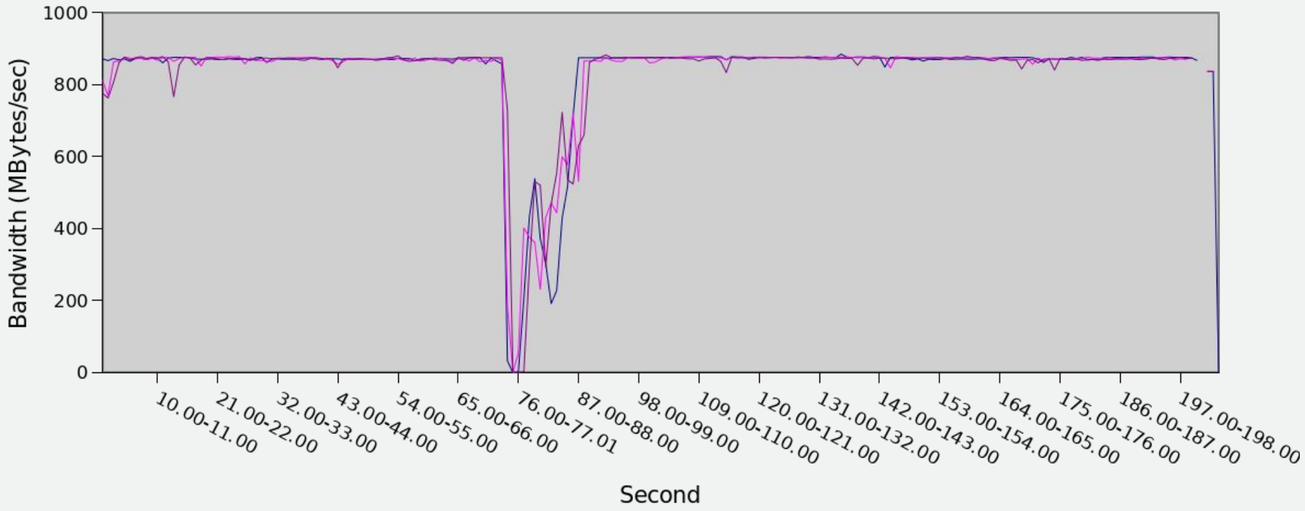



**Outgoing Traffic**




**Incoming Traffic**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# PROGRESS SO FAR

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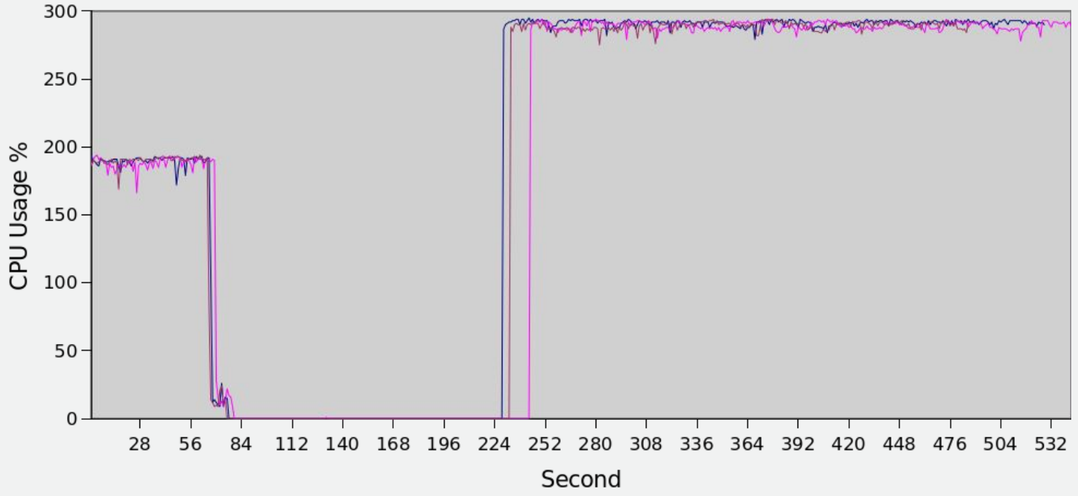
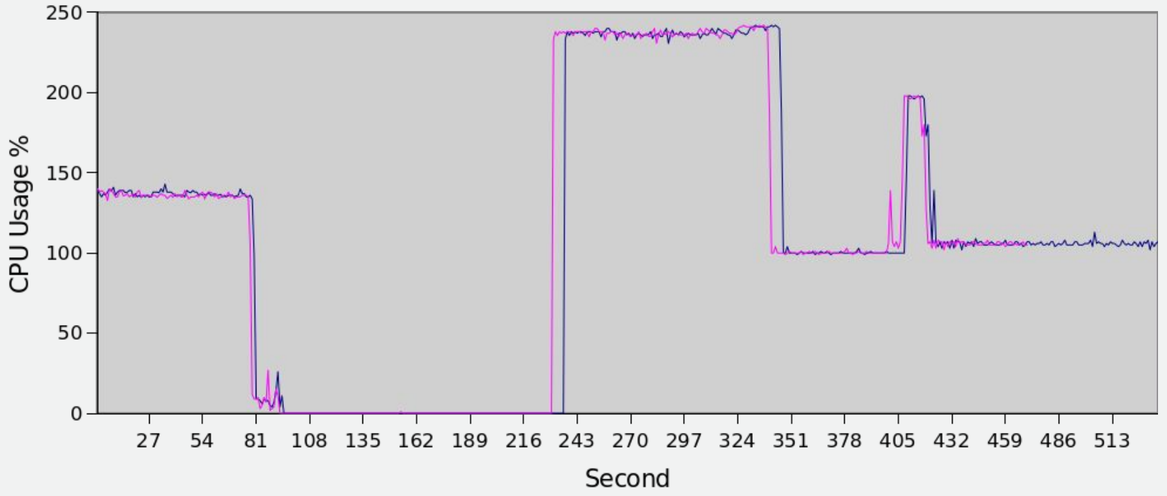



**Outgoing Traffic**




**Incoming Traffic**

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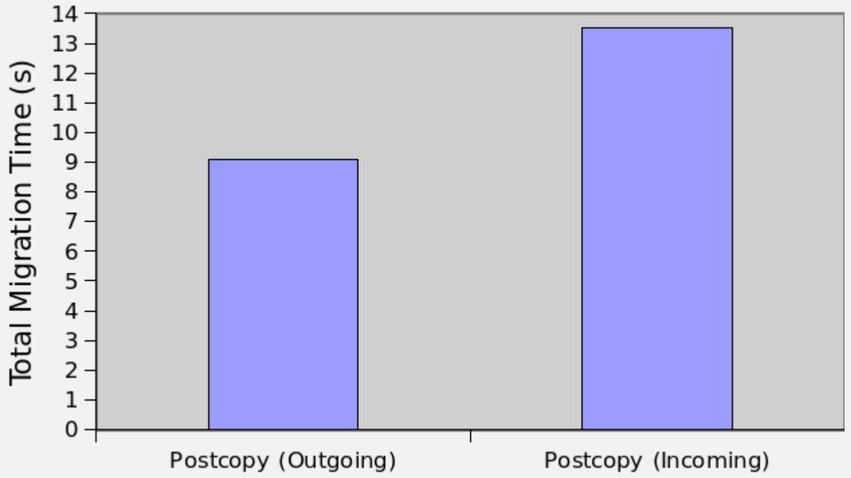


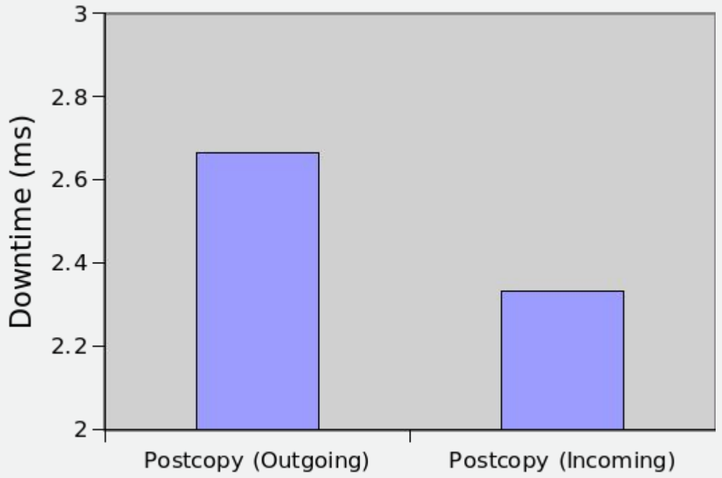


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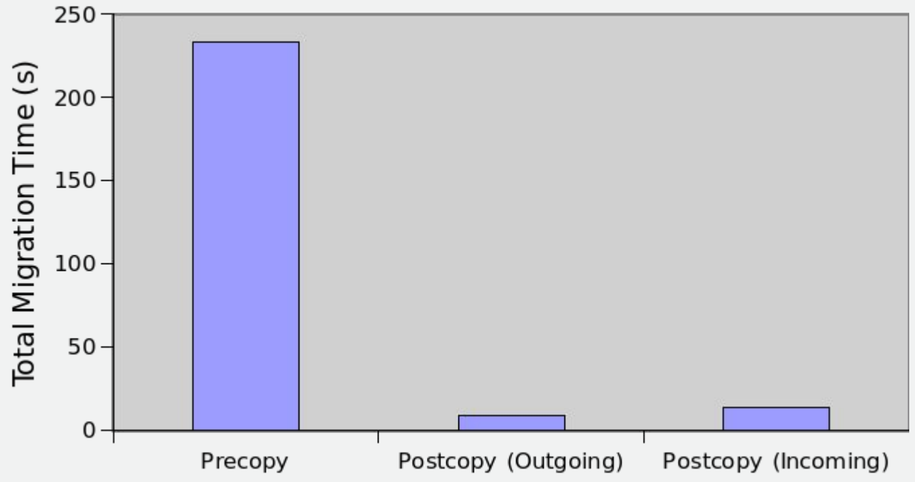


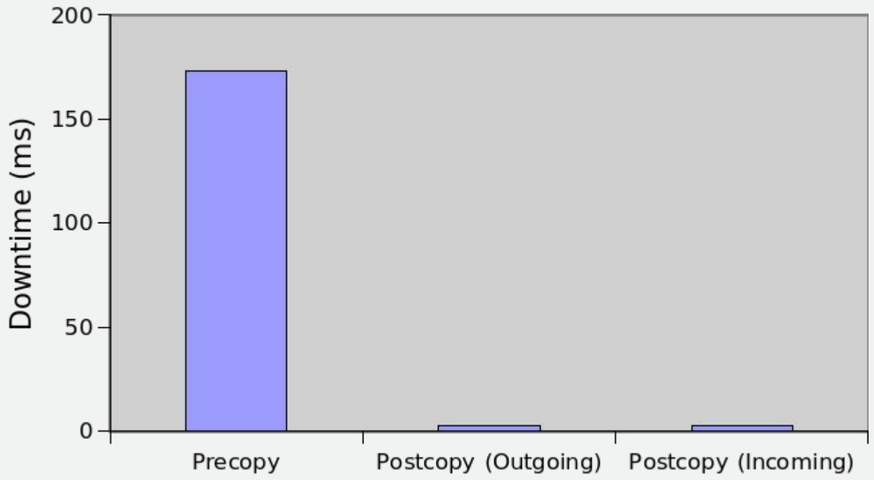


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# PROGRESS SO FAR

## Summary

- As WWS increases, TMT and DT increases.
- The working set program performs better under post-copy migration method.
- The DT of sysbench workload is significantly less under post-copy migration, compared to the DT of pre-copy migration.
- The TMT of sysbench workload migrated under pre-copy is less (by almost 1s) compared to the TMT of sysbench under post-copy migration.
- When a VM migrating with a network outgoing intensive application, post-copy performs significantly better than pre-copy migration.
- Post copy’s DT is less when there’s an incoming traffic as opposed to an outgoing traffic, while vice versa is true for TMT.

# Next Steps

- Hybrid experiments
- Identify thresholds empirically to select migration methods.
- WALM Algorithm
  - Implementation of the WALM artifact.
  - Integrate the solution into QEMU.

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# EVALUATION

- **Experimental Setup**

1. **Set up the environment.**
2. **Identify representative real-world workloads.**
   - **CPU Intensive**
   - **Network Intensive**
   - **Memory Intensive**

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# EVALUATION

- **Baseline Models**
  - **Pre-copy migration**
  - **Post-copy migration**
  - **Hybrid migration**

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# EVALUATION

- **Performance Metrics**
  - **Total Migration Time (TMT)**
  - **Downtime (DT)**
  - **Application Overhead**

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# EVALUATION

- **Tentative Benchmarks**

  - **STREAM benchmark from University of Virginia**
  - **OLTP (YCSB) - Yahoo Cloud Serving Benchmark**

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# EVALUATION

- **Experimental Procedure**

    1. **Trials with baseline models.**
    2. **Trials with WALM.**
    3. **Compare and contrast results of above.**

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# THANK YOU

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# Q & A

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# BENCHMARKS

| | | |
|---|---|---|
| Sysbench | CPU Intensive | |
| Kernbench | CPU Intensive | Synthetic (not completely) |
| Quick Sort | CPU Intensive | |
| Lookbusy | CPU Intensive | Synthetic |
| OpenMP | CPU Intensive | Real-world, Matrix multiplication, Used in scientific workloads |
| SPEC-CPU 2017 | CPU Intensive | |
| SPEC-CPU 2006 | CPU Intensive | 100% CPU Usage |
| Freebench Distray | CPU Intensive | 100% CPU Usage |
| Scientific | CPU Intensive | 90%-80% CPU Usage |

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# BENCHMARKS

| | | |
|---|---|---|
| Pagedirtier | Memory Intensive | 90% Memory Usage (3.6GB), Writes in memory pages in random order |
| Working set | Memory Intensive | Synthetic |
| Appmembench | Memory Intensive | Synthetic |
| SAP-HANA | CPU & Memory Intensive | Real-world, Database System, Simulates users logging in and executing queries |
| Httperf | Network Intensive | |
| iPerf | Network Intensive | |

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# RESULT

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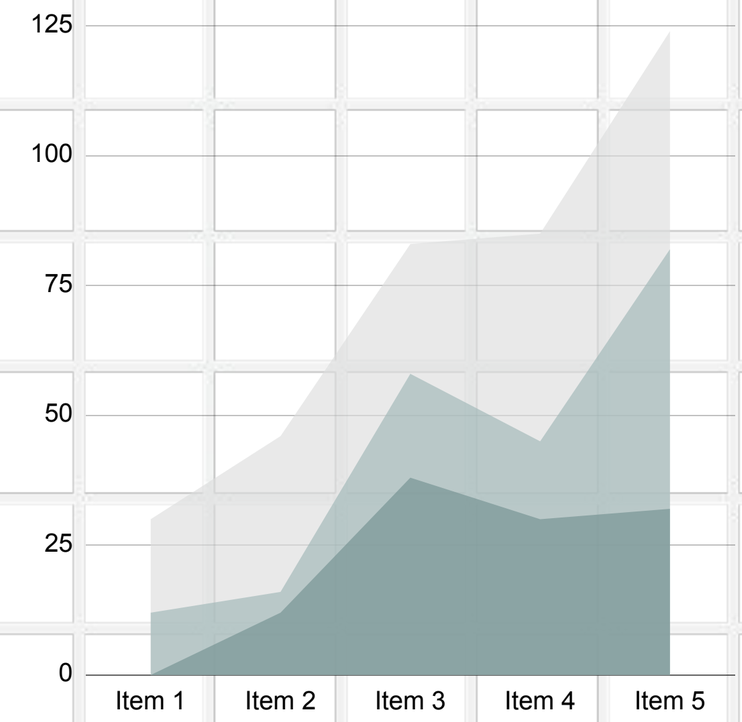

# SOLUTION

## SOLUTION 1

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## SOLUTION 2

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## SOLUTION 3

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# CONCLUSION

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# RECOMMENDATIONS

## RECOMMENDATION 1

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## RECOMMENDATION 2

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# APPROACH

| | | | | |
|---|---|---|---|---|
| **Creating Workloads** | **Lorem ipsum dolor sit amet, consectetur adipiscing elit.** | **Lorem ipsum dolor sit amet, consectetur adipiscing elit.** | **Lorem ipsum dolor sit amet, consectetur adipiscing elit.** | **Lorem ipsum dolor sit amet, consectetur adipiscing elit.** |