



**UNIVERSITÀ  
DEGLI STUDI  
DI TRIESTE**

# Cloud Computing

## Final Exam Exercise

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# Introduction

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1. **Build** a cluster of virtual nodes as:
  - Virtual Machines → VirtualBox
  - Containers → Docker
2. **Assess** and **compare** the performance:
  - CPU
  - Memory
  - Disk I/O
  - Network

# (Virtual) Hardware Specification

## Host Machine:

**CPU** Intel Core i7-8550U CPU  
@ 1.80GHz,  
4 Cores / 8 Threads

**Memory** 8 GB

**Disk** 256 GB SSD

**OS** Ubuntu 24.04.2 LTS

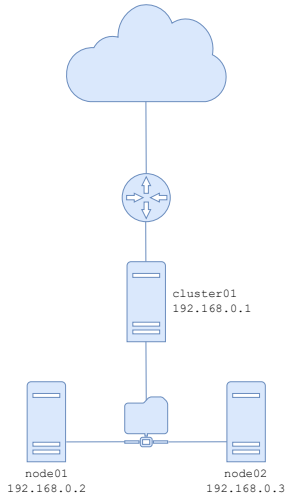
## Cluster Nodes:

**CPU** 2 Cores

**Memory** 2048 MB

**Disk** 20 GB

**OS** Ubuntu 22.04.5 live server



# Methodology

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# Virtual Machine Setup

1. Build a template machine (hardware & software) & clone (reinitializing the MAC)
2. Network Adapters (VirtualBox GUI):
  - 2.1 NAT, internal net
  - 2.2 Port Forwarding and SSH (Host→Master)
3. Master Node:
  - 3.1 `etc/hostname`, `etc/hosts`
  - 3.2 DHCP, DNS, gateway
  - 3.3 Shared file system (NFS)
4. Worker Node:
  - 4.1 `etc/hostname`
  - 4.2 SSH (Master→Worker)
  - 4.3 Shared file system (NFS)

1. Build a template machine (Dockerfile)

```
# Download the latest official Ubuntu image
FROM ubuntu:latest
```

```
# Update and install all the required software
RUN apt-get update && apt-get install -y \
...
```

```
# Expose the SSH port
EXPOSE 22
```

### 2. Build a cluster (Docker Compose)

```
services:
  cluster01:
    ...
  node01:
    ...
  node02:
    ...
networks:
  internal-net:
    driver: bridge
volumes:
  shared-data:
    driver: local

cluster01:
  build: .
  container_name: cluster01
  hostname: cluster01
  networks:
    internal-net:
  deploy:
    resources:
      limits:
        cpus: "2"
        memory: 2G
  ports:
    - "2220:22"
  volumes:
    - shared-data:/shared
```



- hpcc** suite of tests to measure the performance of high-performance computing systems
- stress-ng** stress-testing CPUs, memory and other components under heavy load
- sysbench** evaluating system parameters such as CPU, memory, and other components
- iozone** measure filesystem I/O performance
- iperf** measure network performance

General guidelines:

- no heavy processes on the host during the tests
- repeat each test multiple times to account for variability ( $1 \leq n_i \leq 5$ )
- monitorate the host resources during the tests
- repeat the tests on the host\*

1. `mpirun -np 4 -hostfile hosts <test>`

File `hosts`:

`node01 slots=2`

`node02 slots=2`

2. bash-script to automatize multiple repetition of each test

## Results

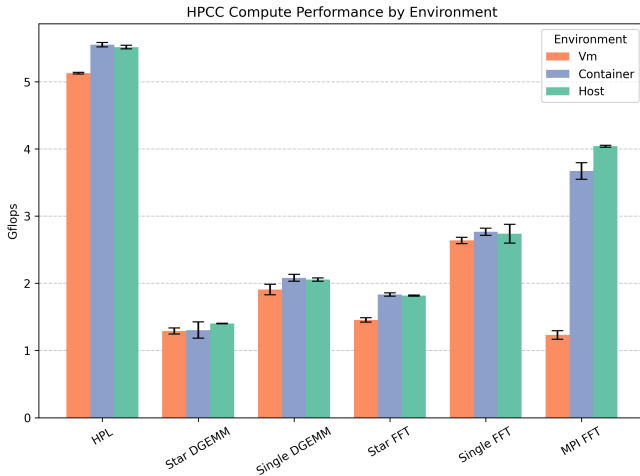
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Number of repetition: 3

Benchmark types:

- **Computational:** HPL, DGEMM, FFT
- **Memory:** STREAM, PTRANS, RandomAccess
- **Communication:** PingPong, (PTRANS)

# HPCC: Computational Performance



## HPCC: Nominal Memory Bandwidth

```
sudo dmidecode --type memory
```

Configured Memory Speed: 1867 MT/s

Bus width per channel: 64 bits = 8 bytes

Number of channels: 2

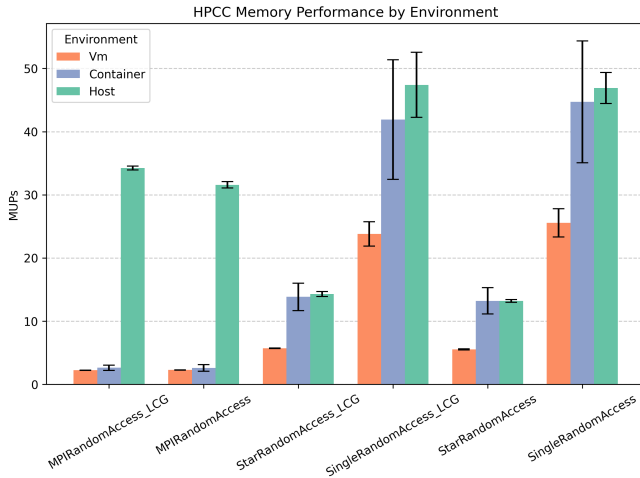
$$\text{Bandwidth} \left[ \frac{\text{GB}}{\text{s}} \right] = 2 C \times 1.867 \text{ GT} \times 8 \frac{\text{B}}{\text{CT}} = 29.9 \frac{\text{GB}}{\text{s}}$$

## HPCC: Memory Performance (1/2)

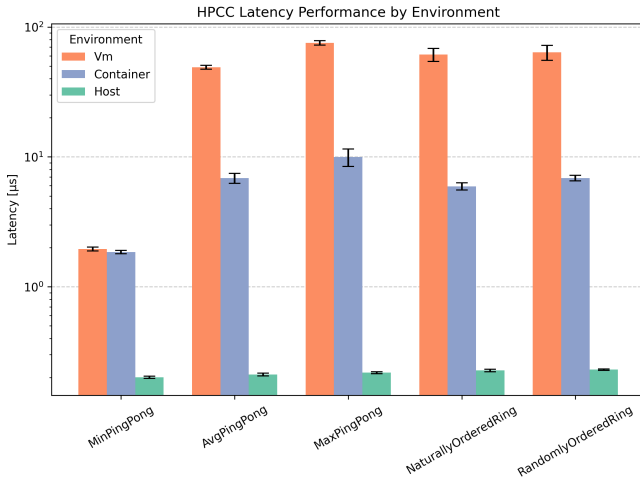
Benchmark	VM	Container	Host
<b>SingleSTREAM (GB/s)</b>			
Copy	22.30 $\pm$ 0.32	<b>24.11 <math>\pm</math> 0.20</b>	23.44 $\pm$ 0.06
Scale	13.26 $\pm$ 0.19	14.23 $\pm$ 0.06	14.06 $\pm$ 0.12
Add	14.40 $\pm$ 0.24	15.38 $\pm$ 0.16	15.06 $\pm$ 0.14
Triad	14.44 $\pm$ 0.28	15.48 $\pm$ 0.13	15.22 $\pm$ 0.05
<b>StarSTREAM (GB/s)</b>			
Copy	5.03 $\pm$ 0.03	<b>5.41 <math>\pm</math> 0.03</b>	5.39 $\pm$ 0.02
Scale	3.34 $\pm$ 0.03	3.55 $\pm$ 0.01	3.56 $\pm$ 0.01
Add	3.75 $\pm$ 0.01	4.08 $\pm$ 0.02	4.07 $\pm$ 0.01
Triad	3.72 $\pm$ 0.04	4.02 $\pm$ 0.02	4.00 $\pm$ 0.02
<b>PTRANS (GB/s)</b>	0.196 $\pm$ 0.014	1.181 $\pm$ 0.239	<b>1.495 <math>\pm</math> 0.019</b>



# HPCC: Memory Performance (2/2)



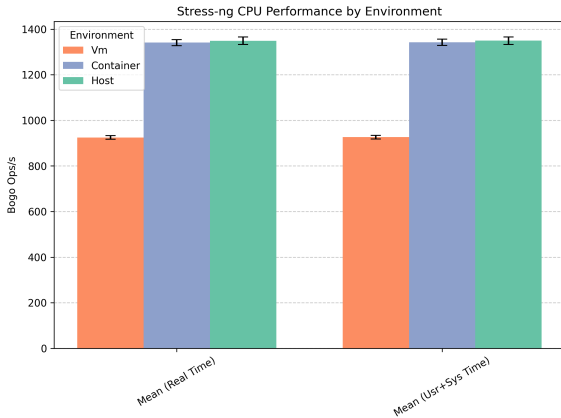
# HPCC: Communication Performance



Note the **log scale**!

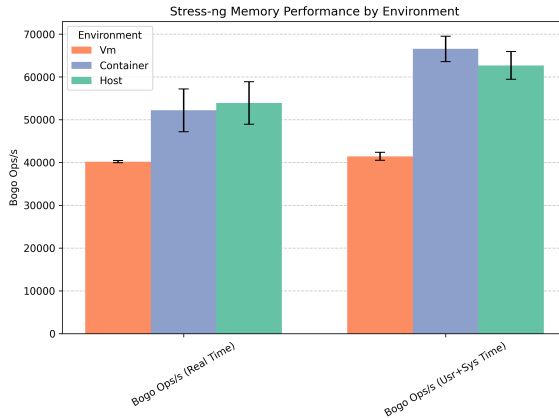
# Stress-ng: CPU

Number of repetition: 5



# Stress-ng: Memory

Number of repetition: 5



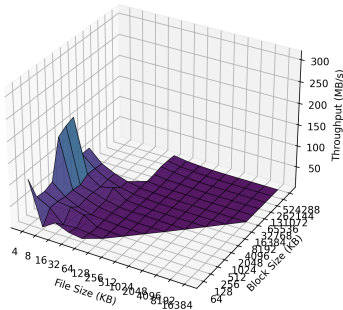
Asymmetry between two time scales

Number of repetition: 5

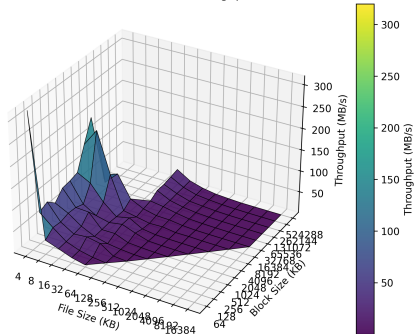
Benchmark	VM	Container	Host
<b>CPU</b>			
Events/s	$453.97 \pm 1.28$	$459.74 \pm 2.54$	$452.38 \pm 6.76$
Latency sum (ms)	$9998.15 \pm 0.70$	$9999.55 \pm 0.51$	$9999.56 \pm 0.72$
<b>Memory</b>			
Bandwidth (Gib/s)	$3.88 \pm 0.02$	<b><math>5.51 \pm 0.09</math></b>	$5.19 \pm 0.08$
Latency sum (ms)	$1066.09 \pm 8.01$	<b><math>839.99 \pm 14.63</math></b>	$895.79 \pm 18.40$

# IOZone: write local

VM local writer (Throughput)

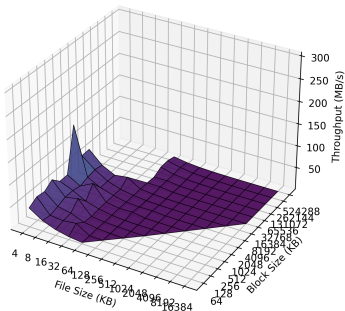


Container local writer (Throughput)

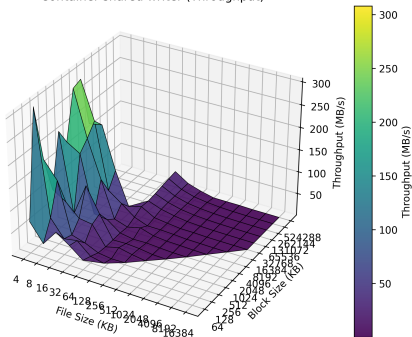


# IOZone: write shared

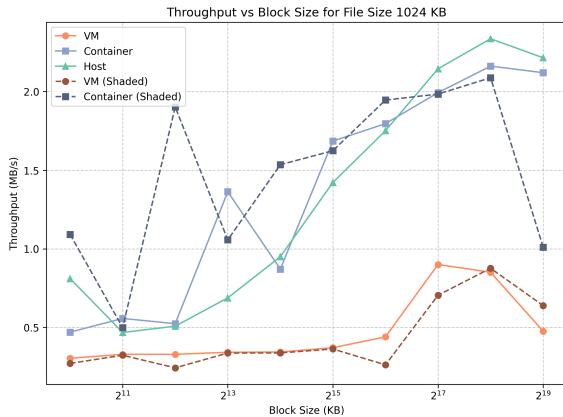
VM shared writer (Throughput)



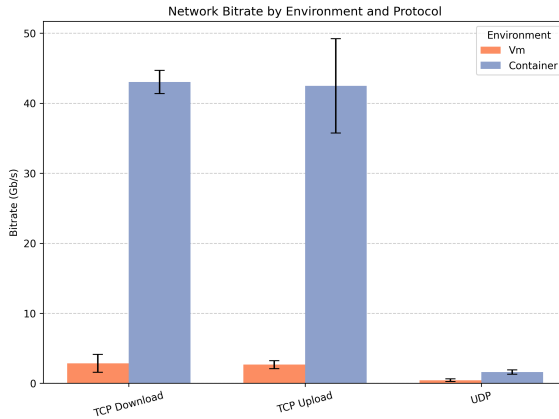
Container shared writer (Throughput)



# IOZone: writing comparison







## Conclusion

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## Docker Cluster

- Easier to configure (shared kernel and lightweight setup)
- Near-native or better performance in CPU and memory benchmarks
- More scalable

## VirtualBox Cluster

- More time-consuming to configure (multiple full OS instances)
- Higher overhead due to full hardware virtualization
- Lower memory bandwidth and network bitrate observed

Thank You!