Analysis of computer clusters

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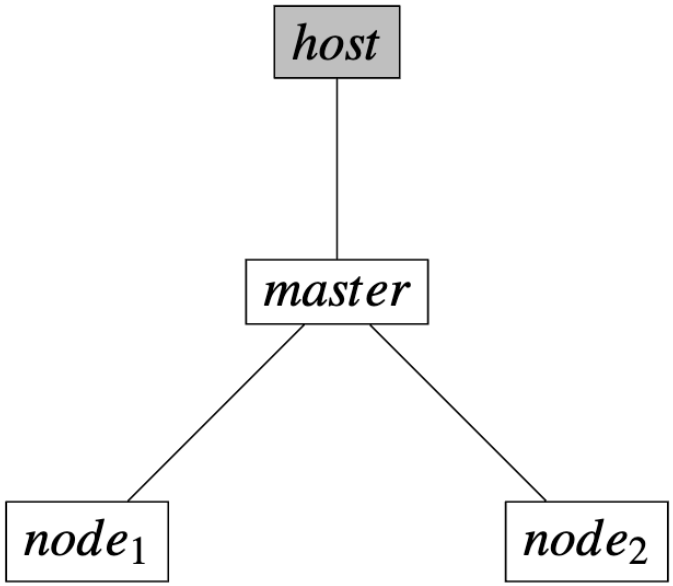
Cluster Characteristics



- **One master node** connected to the Internet through NAT connection
- **Two worker nodes** connected to the master node with Internal Network (not directly to Internet)
- 2GB of RAM, 2 CPUs, 25GB of storage each

VM steps

1. Configuration of the master node
   - Adapters
   - Port Forwarding
   - (SSH connection to the host)
   - Network configuration
2. Creation of the worker nodes
3. DHCP and DNS configuration
4. Configuration of the Master node as Gateway
5. (SSH on worker nodes)
6. Creation of a distributed file system

Containers' steps

1. Creation of a `Dockerfile`
2. Creation of the `docker-compose.yaml` file
3. Start the containers

Dockerfile

```
FROM ubuntu:latest

# Set non-interactive mode for apt-get
ENV DEBIAN_FRONTEND=noninteractive

# Install required packages
RUN apt-get update && apt-get install -y \
    openssh-server rsync iputils-ping \
    sysbench stress-ng iozone3 iperf3 \
    netcat-openbsd wget unzip hpcc \
    mpich vim \
    openmpi-bin openmpi-common openmpi-doc libopenmpi-dev \
    sudo \
    && rm -rf /var/lib/apt/lists/*

# Create SSH folder and set correct permissions
RUN mkdir -p /var/run/sshd /home/user/.ssh /shared \
    && chmod 700 /home/user/.ssh

# Create a new user 'user' with a home directory
RUN useradd -m -s /bin/bash user \
    && echo "user:userpassword" | chpasswd \
    && echo "user ALL=(ALL) NOPASSWD:ALL" >> /etc/sudoers

# Ensure SSH is configured for user
RUN sed -i 's/#PermitRootLogin prohibit-password/PermitRootLogin no/' /etc/ssh/sshd_conf
    && sed -i 's/UsePAM yes/UsePAM no/' /etc/ssh/sshd_config \
    && sed -i 's/#PubkeyAuthentication yes/PubkeyAuthentication yes/' /etc/ssh/sshd_conf
    && sed -i 's|#AuthorizedKeysFile.*|AuthorizedKeysFile .ssh/authorized_keys|' /etc/ss

# Copy SSH keys for user (passwordless login)
COPY ssh_keys/id_rsa.pub /home/user/.ssh/authorized_keys
COPY ssh_keys/id_rsa /home/user/.ssh/id_rsa

# Set correct permissions for SSH keys (user)
RUN chmod 600 /home/user/.ssh/id_rsa /home/user/.ssh/authorized_keys \
    && chown -R user:user /home/user/.ssh

# Expose SSH port
EXPOSE 22

# Switch to user
USER user
WORKDIR /home/user

# Start SSH service correctly with host key generation
CMD sudo ssh-keygen -A && sudo /usr/sbin/sshd -D -e && sudo chown -R user:user /shared &
```

Figure: `Dockerfile`

```
services:
  master1:
    build: .  # Use the Dockerfile in the current directory to build the image
    container_name: master  # Set the container name to 'master'
    networks:
      - my_network  # Attach this container to the custom bridge network
    deploy:
      resources:
        limits:
          cpus: "2"  # Restrict the container to use a maximum of 2 CPU cores
          memory: 2G  # Limit the container's memory usage to 2GB
    ports:
      - "2220:22"  # Map port 2220 on the host to port 22 inside the container (SSH acce
    volumes:
      - shared_volume:/shared  # Mount shared volume for data exchange between container
      - ./ssh_keys:/root/.ssh  # Mount pre-generated SSH keys for passwordless access
    tmpfs:
      - /shared:mode=777  # Create a temporary filesystem at /shared with full permissic

  node1:
    build: .  # Use the same Dockerfile for worker node
    container_name: node1  # Set the container name to 'node1'
    networks:
      - my_network  # Attach to the same network as the master node
    deploy:
      resources:
        limits:
          cpus: "2"
          memory: 2G
    ports:
      - "2221:22"  # Assign a different SSH port for node1
    volumes:
      - shared_volume:/shared  # Mount shared volume to enable data sharing
      - ./ssh_keys:/root/.ssh  # Use the same SSH keys for passwordless login
    tmpfs:
      - /shared:mode=777  # Temporary shared filesystem with full permissions

  node2:
    build: .  # Build using the same configuration
    container_name: node2  # Name this container 'node2'
    networks:
      - my_network
    deploy:
      resources:
        limits:
          cpus: "2"
          memory: 2G
    ports:
      - "2222:22"  # Assign another unique SSH port for node2
    volumes:
      - shared_volume:/shared
      - ./ssh_keys:/root/.ssh
    tmpfs:
      - /shared:mode=777

networks:
  my_network:
    driver: bridge  # Use a bridge network for inter-container communication

volumes:
  shared_volume:
    driver: local  # Use a local volume for persistent shared storage
```

Figure: `docker-compose.yaml`

Measuring performances

Different tests have been performed to measure the performances of the clusters:

- **HPCC**: Includes tests for computational power, memory bandwidth, and inter-node communication.
- **Iperf3**: is a network performance measurement tool used to test bandwidth, latency, and jitter between two endpoints.
- **Stress-ng**: is a stress testing tool that can apply workloads to various system components such as CPU, memory, I/O, and more.
- **Sysbench**: is a benchmarking tool used to evaluate the performance of various system components such as CPU, memory, disk I/O, and database systems.
- **IOzone**: is a benchmark tool used to evaluate file system performance by testing various I/O operations.

Test	Unit	VMs	Containers
MPIRandomAccess	GUP/s	0.003	0.01
PTRANS (Wall)	s	0.550	0.42
StarDGEMM	Gflop/s	2.909	3.95
StarSTREAM Copy	GB/s	23.20	21.66
MPIFFT	Gflop/s	2.133	8.43
Avg. Ping Pong Bandwidth	GB/s	4.756	17.148
HPL	Gflop/s	10.64	12.32

Table: Main results of the HPCC tests

Overall, containers provide a more efficient execution environment for most HPCC workloads, especially in **memory access**, **computational efficiency**, and **communication latency**, making them a compelling choice for HPC workloads.

Iperf3

Category	Nodes	Transfer(GB)	Bitrate(GB/s)
VMs	Master-Node1	2.09	1.79
	Node1-Node2	2.15	1.84
Containers	Master-Node1	142	122
	Node1-Node2	140	120

Table: Main results of the Iperf3 tests categorized by type

Overall, containers are more efficient, with significantly **higher transfer rates** and **fewer network issues** compared to VMs.

Stress-ng

	Bogo ops		Bogo ops/s	
Test	**VM**	**Containers**	**VM**	**Containers**
CPU	21532	24523	358.71	408.43
Memory	760052	7099658	12634.09	118275.80
I/O	2799634	505508	46659.86	8425.03

Table: Main results of the Stress-ng tests

Overall, containers demonstrate **better CPU and memory handling**, while VMs outperform containers in **disk I/O operations**. This suggests containers are more suitable for applications with high CPU and memory demands, while VMs may be more appropriate for disk-heavy workloads.

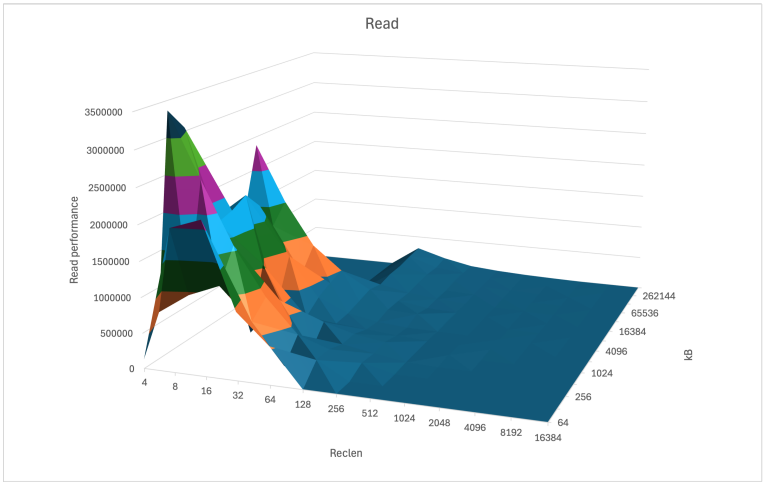
Sysbench

	Ops/s		Avg. Latency	
Test	**VM**	**Containers**	**VM**	**Containers**
CPU	2,198.45	3,303.00	0.46	0.31
Memory	19,327.09	41,471.36	0.05	0.03

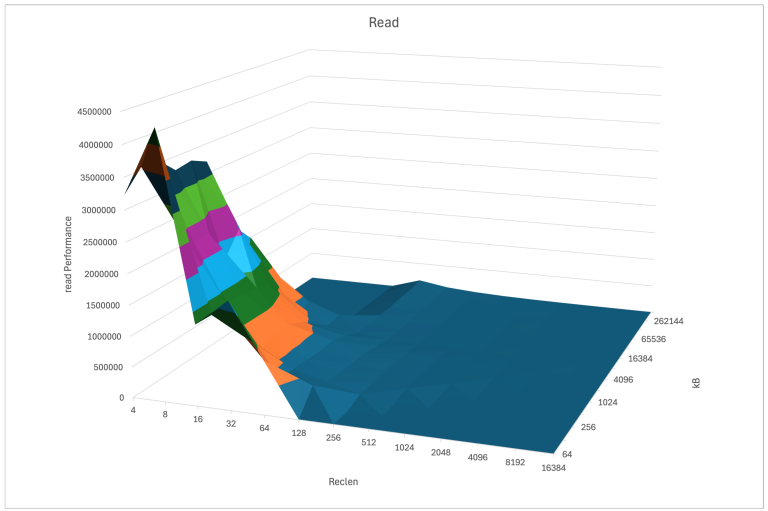
Table: Main results of the Stress-ng tests (max values)

Overall, containers demonstrate better CPU and memory handling, with **higher throughput** and **lower latency** compared to VMs.

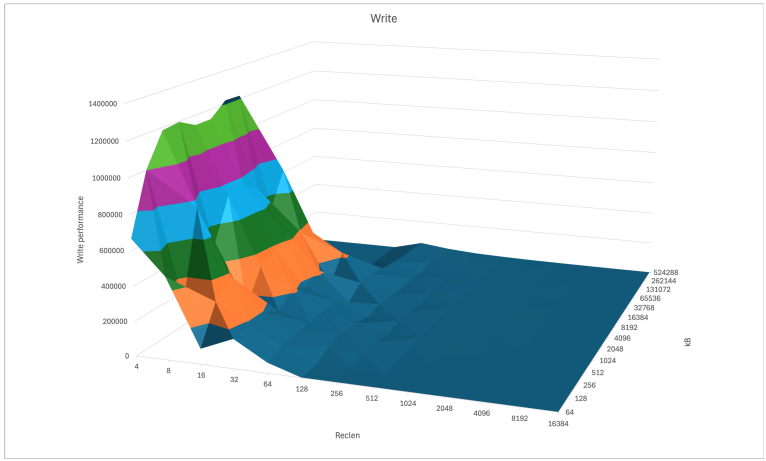
VM Read



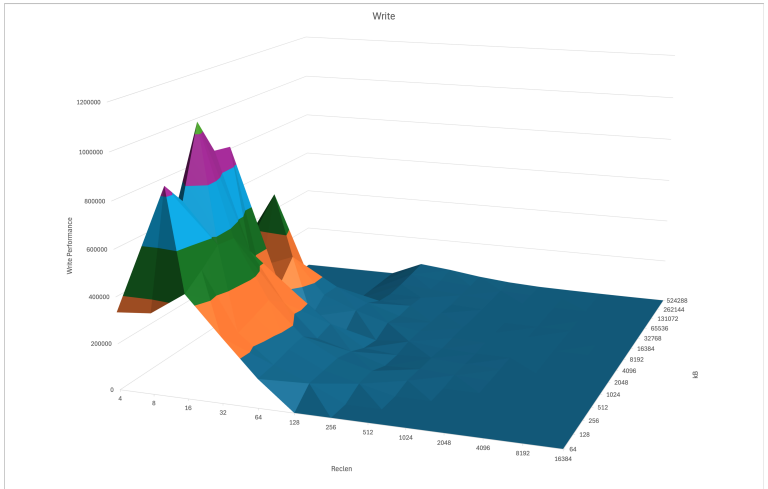
Containers Read



VM Write



Containers Write



Conclusion

Containers generally provide better **performance** and **efficiency** for high-performance computing, networking, and I/O workloads. VMs still offer stronger isolation, but for resource-intensive tasks with heavy inter-process communication, containers tend to be **faster** and more **lightweight**.