Bubblesort with MPI

Disusun Oleh:

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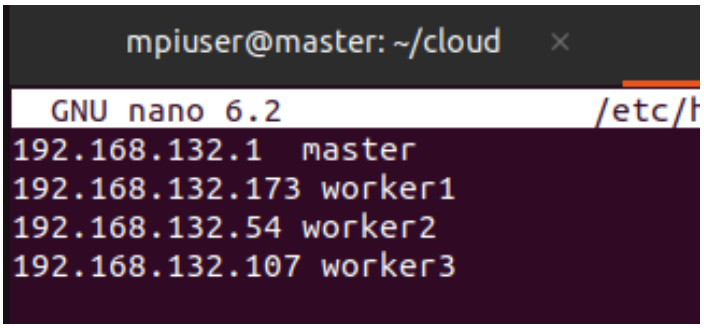
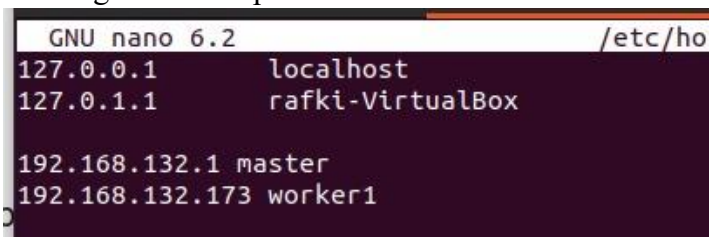
Langkah-Langkah Membuat Cluster MPI pada 1 Master dan 3 Worker

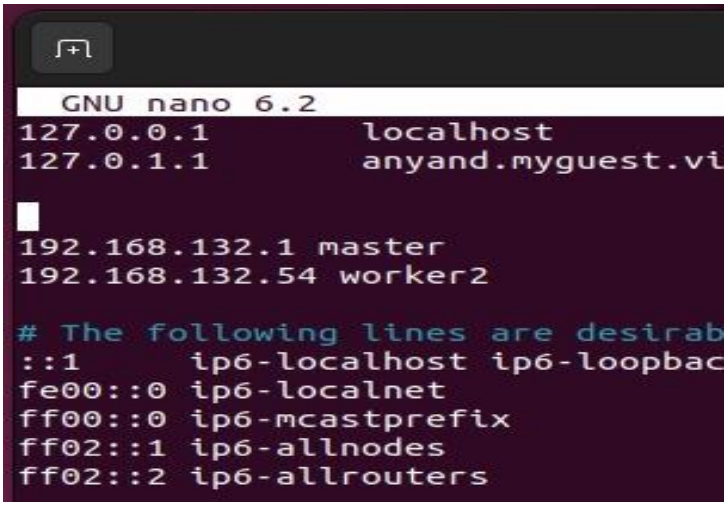
1. Siapkan 4 device laptop yang dimana 1 laptop bertindak sebagai master, 3 lainnya sebagai worker. Pastikan keempat device ini terhubung pada 1 jaringan internet yang sama.
2. Lakukan update sistem OS Linux dengan menggunakan command sudo apt update && sudo apt upgrade pada terminal Linux.
3. Lakukan konfigurasi hosts pada master dan worker dengan menggunakan command “sudo nano /etc/hosts”, setelahnya, masukkan ip master dan masing-masing worker ke dalam dokumen tersebut:



^konfigurasi hosts pada master



^Konfigurasi hosts pada worker1



^Konfigurasi hosts pada worker2

```
  GNU nano 6.2
127.0.0.1       localhost
127.0.1.1       mutiara-VirtualBox

192.168.132.1   master
192.168.132.107 worker3
```

^Konfigurasi hosts pada worker3

4. Buatlah sebuah user baru. Disini Master dan ketiga worker menggunakan username yang sama, yaitu “mpiuser”. Setelahnya, barulah user berpindah ke username barunya.

```
[sudo] password for mpiuser:
mpiuser@master:~$ sudo adduser mpiuser
adduser: The user `mpiuser' already exists.
mpiuser@master:~$
```

5. Setelahnya dilakukan konfigurasi SSH dengan menginstall SSH dengan menggunakan command “sudo apt install openssh-server”

```
mpiuser@master:~$ sudo apt install openssh-server
Reading package lists... Done
Building dependency tree... Done
Reading state information... Done
openssh-server is already the newest version (1:8.9p1-3ubuntu0.4).
0 upgraded, 0 newly installed, 0 to remove and 88 not upgraded.
```

6. Setelah itu, master akan melakukan pengecekan ssh pada masing-masing worker dengan menggunakan command “ssh mpiuser@worker1”. Pada kasus ini, master menggunakan worker1 sebagai sampel pengujian ssh:

```
mpiuser@master:~$ ssh mpiuser@worker1
Welcome to Ubuntu 22.04.3 LTS (GNU/Linux 6.2.0-36-generic x86_64)

 * Documentation:  https://help.ubuntu.com
 * Management:     https://landscape.canonical.com
 * Support:        https://ubuntu.com/advantage

Expanded Security Maintenance for Applications is not enabled.

5 updates can be applied immediately.
2 of these updates are standard security updates.
To see these additional updates run: apt list --upgradable

3 additional security updates can be applied with ESM Apps.
Learn more about enabling ESM Apps service at https://ubuntu.com/esm

Last login: Wed Nov 15 18:35:38 2023 from 192.168.132.1
```

Atau, untuk mengecek apakah master-worker terhubung, maka dapat digunakan perintah "ping master":

```
rafki@worker1:~$ ping master
PING master (192.168.132.1) 56(84) bytes of data.
64 bytes from master (192.168.132.1): icmp_seq=1 ttl=64 time=142 ms
64 bytes from master (192.168.132.1): icmp_seq=2 ttl=64 time=56.5 ms
64 bytes from master (192.168.132.1): icmp_seq=3 ttl=64 time=28.7 ms
64 bytes from master (192.168.132.1): icmp_seq=4 ttl=64 time=33.5 ms
64 bytes from master (192.168.132.1): icmp_seq=5 ttl=64 time=116 ms
64 bytes from master (192.168.132.1): icmp_seq=6 ttl=64 time=93.9 ms
64 bytes from master (192.168.132.1): icmp_seq=7 ttl=64 time=94.1 ms
64 bytes from master (192.168.132.1): icmp_seq=8 ttl=64 time=10.3 ms
64 bytes from master (192.168.132.1): icmp_seq=9 ttl=64 time=38.9 ms
64 bytes from master (192.168.132.1): icmp_seq=10 ttl=64 time=31.4 ms
^C
```

^worker1

```
mpiuser@worker2:~/cloud$ cd
mpiuser@worker2:~$ ping master
PING master (192.168.132.1) 56(84) bytes of data.
64 bytes from master (192.168.132.1): icmp_seq=1 ttl=64 time=8.18 ms
64 bytes from master (192.168.132.1): icmp_seq=2 ttl=64 time=69.2 ms
64 bytes from master (192.168.132.1): icmp_seq=3 ttl=64 time=88.3 ms
64 bytes from master (192.168.132.1): icmp_seq=4 ttl=64 time=30.5 ms
64 bytes from master (192.168.132.1): icmp_seq=5 ttl=64 time=10.5 ms
64 bytes from master (192.168.132.1): icmp_seq=6 ttl=64 time=38.7 ms
64 bytes from master (192.168.132.1): icmp_seq=7 ttl=64 time=10.3 ms
^C
--- master ping statistics ---
7 packets transmitted, 7 received, 0% packet loss, time 6016ms
rtt min/avg/max/mdev = 8.177/36.519/88.280/29.169 ms
```

^worker2

```
mpiuser@worker3:~$ ping master
PING master (192.168.132.1) 56(84) bytes of data.
64 bytes from master (192.168.132.1): icmp_seq=1 ttl=64 time=30.3 ms
64 bytes from master (192.168.132.1): icmp_seq=2 ttl=64 time=5.83 ms
64 bytes from master (192.168.132.1): icmp_seq=3 ttl=64 time=42.1 ms
64 bytes from master (192.168.132.1): icmp_seq=4 ttl=64 time=9.02 ms
64 bytes from master (192.168.132.1): icmp_seq=5 ttl=64 time=32.5 ms
64 bytes from master (192.168.132.1): icmp_seq=6 ttl=64 time=98.4 ms
64 bytes from master (192.168.132.1): icmp_seq=7 ttl=64 time=36.1 ms
64 bytes from master (192.168.132.1): icmp_seq=8 ttl=64 time=6.78 ms
^C
--- master ping statistics ---
8 packets transmitted, 8 received, 0% packet loss, time 7020ms
rtt min/avg/max/mdev = 5.831/32.632/98.401/28.232 ms
mpiuser@worker3:~$
```

^worker 3

7. Selanjutnya, master akan melakukan create keygen pada ssh dengan menggunakan command “ssh-keygen -t rsa”. Disini master telah melakukan generate ssh sebelumnya, jadi master tidak melakukan overwrite (tulis ulang pada ssh sebelumnya).

```
mpiuser@master:~$ ssh-keygen -t rsa
Generating public/private rsa key pair.
Enter file in which to save the key (/home/mpiuser/.ssh/id_rsa):
/home/mpiuser/.ssh/id_rsa already exists.
Overwrite (y/n)? n
mpiuser@master:~$
```

8. Selanjutnya, ssh keygen yang telah teregenerate akan dibagikan dari master ke worker dengan menggunakan command berikut:
   cd .ssh
   cat id_rsa.pub | ssh <username worker>@<server worker> “mkdir .ssh; cat >> .ssh/authorized_keys”
   Disini, master menggunakan worker2 sebagai sampel untuk membagikan ssh-keygen yang telah dibuat:

```
mpiuser@master:~/.ssh$ cat id_rsa.pub | ssh mpiuser@worker2 "mkdir .ssh; cat >> .ssh/authorized_key
The authenticity of host 'worker2 (192.168.132.54)' can't be established.
ED25519 key fingerprint is SHA256:RbgZrf3ypaBY+hPO/cA6SNEzNbKtPE96/mvfkqEAGP8.
This key is not known by any other names
Are you sure you want to continue connecting (yes/no/[fingerprint])? yes
Warning: Permanently added 'worker2' (ED25519) to the list of known hosts.
mpiuser@worker2's password:
```

9. Selanjutnya, master dan worker akan membuat sebuah direktori yang akan dibagikan satu-sama-lain. Disini, master dan worker membuat direktori yang memiliki nama yang sama, yaitu “cloud”:

```
mpiuser@master:~$ mkdir cloud
mkdir: cannot create directory ‘cloud’: File exists
```

10. Langkah selanjutnya ialah master menginstall NFS server dengan menggunakan command “sudo apt install nfs-kernel-server”

```
mpiuser@master:~$ sudo apt install nfs-kernel-server
[sudo] password for mpiuser:
Reading package lists... Done
Building dependency tree... Done
Reading state information... Done
nfs-kernel-server is already the newest version (1:2.6.1-1ubuntu1
.2).
0 upgraded, 0 newly installed, 0 to remove and 88 not upgraded.
```

Pada worker akan dilakukan installasi nfs common:

```
rafki@worker1:~$ sudo apt install nfs-common
Reading package lists... Done
Building dependency tree... Done
Reading state information... Done
nfs-common is already the newest version (1:2.6.1-1ubuntu1.2).
0 upgraded, 0 newly installed, 0 to remove and 10 not upgraded.
rafki@worker1:~$
```

^worker1

```
mpiuser@worker2: ~
anya@worker2:~$ sudo apt install nfs-common
[sudo] password for anya:
Reading package lists... Done
Building dependency tree... Done
Reading state information... Done
nfs-common is already the newest version (1:2.6.1-1ubuntu1.2).
The following packages were automatically installed and are no longer required:
  linux-image-5.19.0-32-generic linux-modules-5.19.0-32-generic
  linux-modules-extra-5.19.0-32-generic
Use 'sudo apt autoremove' to remove them.
0 upgraded, 0 newly installed, 0 to remove and 182 not upgraded.
```

^worker2

```
mutiara@worker3:~$ sudo apt install nfs-common
[sudo] password for mutiara:
Reading package lists... Done
Building dependency tree... Done
Reading state information... Done
nfs-common is already the newest version (1:2.6.1-1ubuntu1.2).
0 upgraded, 0 newly installed, 0 to remove and 343 not upgraded.
mutiara@worker3:~$
```

^worker 3

11. Lalu, master akan melakukan konfigurasi pada /etc/exports untuk memastikan bahwa folder cloud dapat dibagikan kepada seluruh worker dengan menggunakan command “sudo nano /etc/exports”. Setelah itu, masukkan perintah <Alamat direktori master yang ingin dibagikan> *(rw,sync,no_root_squash,no_subtree_check)

```
  GNU nano 6.2                 /etc/exports
# /etc/exports: the access control list for filesystems which ma>
#               to NFS clients.  See exports(5).
#
# Example for NFSv2 and NFSv3:
# /srv/homes       hostname1(rw,sync,no_subtree_check) hostname2>
#
# Example for NFSv4:
# /srv/nfs4        gss/krb5i(rw,sync,fsid=0,crossmnt,no_subtree_>
# /srv/nfs4/homes  gss/krb5i(rw,sync,no_subtree_check)
#
/home/mpiuser/cloud *(rw,sync,no_root_squash,no_subtree_check)
```

12. Selanjutnya, master memasukkan command “sudo exportfs -a” dan “sudo systemctl restart-kernel-server”

```
mpiuser@master:~$ sudo exportfs -a
mpiuser@master:~$ sudo systemctl restart nfs-kernel-server
```

13. Pada Worker, mereka akan melakukan mounting kepada direktori cloud milik master:

```
mpiuser@worker1:~$ cd cloud
mpiuser@worker1:~/cloud$ ls
bubble.py  bubblesort.py  test.py
mpiuser@worker1:~/cloud$ sudo mount master:/home/mpiuser/cloud /home/mpiuser/clo
ud
[sudo] password for mpiuser:
mpiuser@worker1:~/cloud$ ls
bubble.py  bubblesort.py  test.py
```

^worker 1

```
mpiuser@worker2:~/cloud$ sudo mount master:/home/mpiuser/cloud /home/mpiuser/cloud
mpiuser@worker2:~/cloud$ ls
bubble.py  bubblesort.py  test.py
```

^worker2

```
mutiara@worker3:~$ su - mpiuser
Password:
mpiuser@worker3:~$ cd cloud
mpiuser@worker3:~/cloud$ ls
mpiuser@worker3:~/cloud$ sudo mount master:/home/mpiuser/cloud /home/mpiuser/cloud
[sudo] password for mpiuser:
mpiuser@worker3:~/cloud$ ls
bubble.py  bubblesort.py  test.py
mpiuser@worker3:~/cloud$
```

^worker3

Untuk memastikan bahwa mounting telah berjalan, maka dapat digunakan perintah “df”:

```
rafki@worker1:~$ df
Filesystem     1K-blocks     Used Available Use% Mounted on
tmpfs             200672     1560    199112   1% /run
/dev/sda3       15887272 13397400   1661048  89% /
tmpfs            1003348        0   1003348   0% /dev/shm
tmpfs               5120        4      5116   1% /run/lock
/dev/sda2         524252     6220    518032   2% /boot/efi
tmpfs             200668      112    200556   1% /run/user/1000
```

14. Selanjutnya, worker dan master akan menginstall MPI dengan menggunakan command “sudo apt install openmpi-bin libopenmpi-dev”

```
mpiuser@master:~/cloud$ sudo apt install openmpi-bin libopenmpi-d
ev
[sudo] password for mpiuser:
Reading package lists... Done
Building dependency tree... Done
Reading state information... Done
libopenmpi-dev is already the newest version (4.1.2-2ubuntu1).
openmpi-bin is already the newest version (4.1.2-2ubuntu1).
0 upgraded, 0 newly installed, 0 to remove and 88 not upgraded.
```

15. Selanjutnya, master dan worker akan menginstall python dan mpi4py

```
mpiuser@master:~$ sudo apt install python3-pip
Reading package lists... Done
Building dependency tree... Done
Reading state information... Done
python3-pip is already the newest version (22.0.2+dfsg-1ubuntu0.3
).
0 upgraded, 0 newly installed, 0 to remove and 88 not upgraded.
mpiuser@master:~$ pip install mpi4py
Defaulting to user installation because normal site-packages is n
ot writeable
Requirement already satisfied: mpi4py in ./.local/lib/python3.10/
site-packages (3.1.5)
```

16. Lalu, master akan membuat program bubblesort pada direktori cloud dengan menggunakan perintah “sudo nano /cloud/bubblesort.py”

```
  GNU nano 6.2                                  bubblesort.py
from mpi4py import MPI
import random
import time

def bubble_sort(arr):
    n = len(arr)
    for i in range(n):
        swapped = False
        for j in range(0, n-i-1):
            if arr[j] > arr[j+1]:
                arr[j], arr[j+1] = arr[j+1], arr[j]
                swapped = True
        if not swapped:
            break

# Membuat 5 array acak
array_list = [random.sample(range(1, 1000), 10) for _ in range(5)]

# Menampilkan data mentah dan data yang sudah diurutkan
for i, arr in enumerate(array_list):
    print(f"Data array {i + 1}: {arr}")

    # Mengukur waktu eksekusi Bubble Sort dan mengurutkan array
    start_time = time.time()
    bubble_sort(arr)
    end_time = time.time()
    elapsed_time = end_time - start_time

    print(f"Data yang diurutkan {i + 1}: {arr}")
    print(f"Waktu pengurutan: {elapsed_time:.6f} detik\n")

# Menampilkan array yang belum terurut
unsorted_arrays = [arr.copy() for arr in array_list]

^G Help        ^O Write Out   ^W Where Is    ^K Cut         ^T Execute     ^C Location
^X Exit        ^R Read File   ^\ Replace     ^U Paste       ^J Justify     ^/ Go To Line
```

17. Selanjutnya, file bubblesort.py akan dijalankan oleh master dengan menggunakan fungsi mpirun:

```
mpiuser@master:~/cloud$ mpirun -np 4 -host master,worker1,worker2,worker3 python3 bubblesort.py
Authorization required, but no authorization protocol specified
Authorization required, but no authorization protocol specified
Authorization required, but no authorization protocol specified
Authorization required, but no authorization protocol specified
Authorization required, but no authorization protocol specified
Authorization required, but no authorization protocol specified
Authorization required, but no authorization protocol specified
Authorization required, but no authorization protocol specified
Authorization required, but no authorization protocol specified
Authorization required, but no authorization protocol specified
Authorization required, but no authorization protocol specified
Authorization required, but no authorization protocol specified
Data array 1: [56, 99, 862, 493, 877, 300, 936, 780, 294, 544]
Data yang diurutkan 1: [56, 99, 294, 300, 493, 544, 780, 862, 877, 936]
Waktu pengurutan: 0.000013 detik

Data array 2: [455, 847, 994, 50, 514, 471, 708, 881, 526, 643]
Data yang diurutkan 2: [50, 455, 471, 514, 526, 643, 708, 847, 881, 994]
Waktu pengurutan: 0.000011 detik

Data array 3: [694, 462, 604, 261, 251, 66, 365, 172, 856, 317]
Data yang diurutkan 3: [66, 172, 251, 261, 317, 365, 462, 604, 694, 856]
Waktu pengurutan: 0.000012 detik

Data array 4: [689, 85, 529, 619, 407, 646, 186, 687, 427, 228]
Data yang diurutkan 4: [85, 186, 228, 407, 427, 529, 619, 646, 687, 689]
Waktu pengurutan: 0.000011 detik

Data array 5: [502, 674, 120, 622, 74, 826, 368, 634, 584, 230]
Data yang diurutkan 5: [74, 120, 230, 368, 502, 584, 622, 634, 674, 826]
```