

DEMO MPI

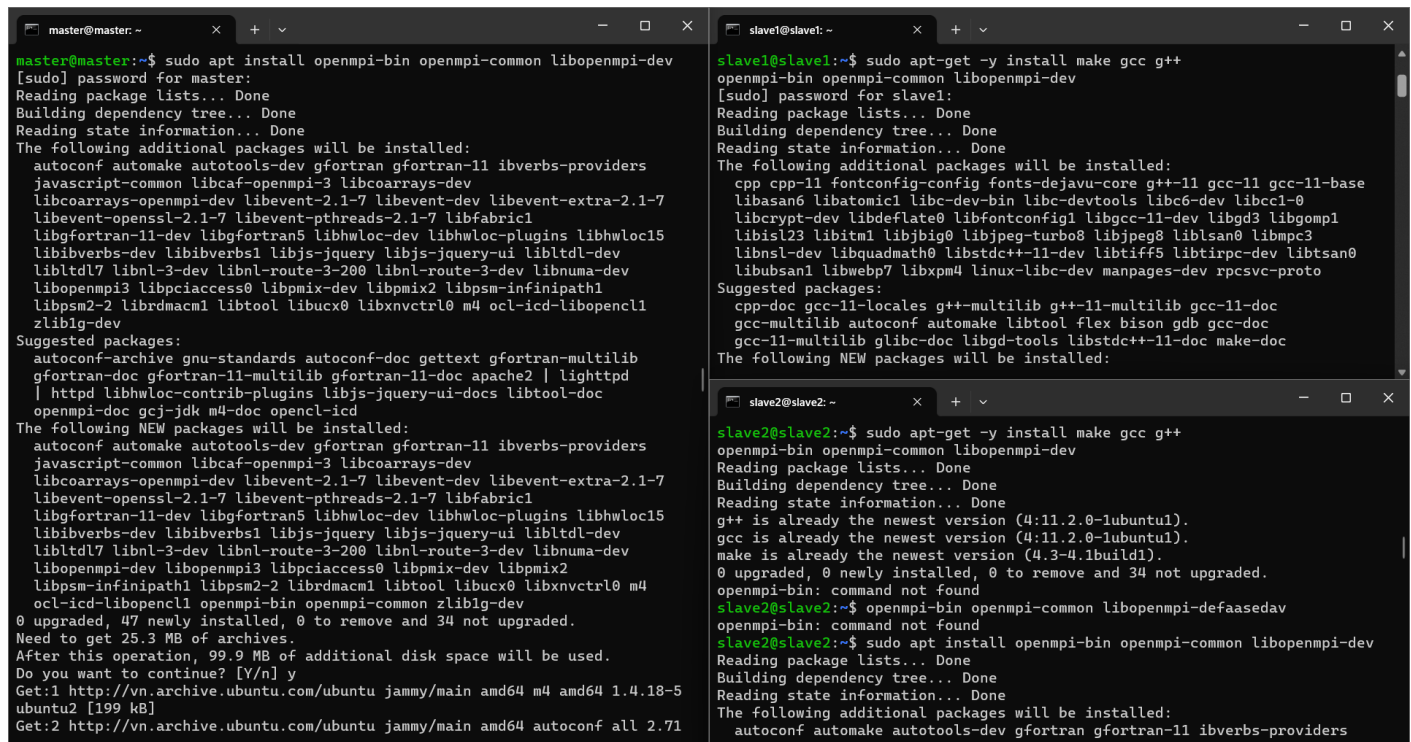
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II. Demo

1. Cài các package cần thiết cho quá trình compiler trên 3 máy ảo

- Chạy câu lệnh `sudo apt-get -y install make gcc g++ openmpi-bin openmpi-common libopenmpi-dev` trên 3 máy ảo



The image displays three terminal windows illustrating the installation of MPI-related packages on a master node and two slave nodes.

Master Node (master@master: ~):

```
master@master:~$ sudo apt install openmpi-bin openmpi-common libopenmpi-dev
[sudo] password for master:
Reading package lists... Done
Building dependency tree... Done
Reading state information... Done
The following additional packages will be installed:
  autoconf automake autotools-dev gfortran gfortran-11 ibverbs-providers
  javascript-common libcaf-openmpi-3 libcoarrays-dev
  libcoarrays-openmpi-dev libevent-2.1-7 libevent-dev libevent-extra-2.1-7
  libevent-openssl-2.1-7 libevent-pthreads-2.1-7 libfabric1
  libgfortran-11-dev libgfortran5 libhwloc-dev libhwloc-plugins libhwloc15
  libibverbs-dev libibverbs1 libjs-jquery libjs-jquery-ui libltdl-dev
  libltdl7 libnl-3-dev libnl-route-3-200 libnl-route-3-dev libnuma-dev
  libopenmpi3 libpciaccess0 libpmix-dev libpmix2 libpsm-infinipath1
  libpsm2-2 librdmacm1 libtool libucx0 libxnvctrl0 m4 ocl-icd-libopencl1
  zlib1g-dev
Suggested packages:
  autoconf-archive gnu-standards autoconf-doc gettext gfortran-multilib
  gfortran-doc gfortran-11-multilib gfortran-11-doc apache2 | lighttpd
  | httpd libhwloc-contrib-plugins libjs-jquery-ui-docs libtool-doc
  openmpi-doc gcj-jdk m4-doc opencl-icd
The following NEW packages will be installed:
  autoconf automake autotools-dev gfortran gfortran-11 ibverbs-providers
  javascript-common libcaf-openmpi-3 libcoarrays-dev
  libcoarrays-openmpi-dev libevent-2.1-7 libevent-dev libevent-extra-2.1-7
  libevent-openssl-2.1-7 libevent-pthreads-2.1-7 libfabric1
  libgfortran-11-dev libgfortran5 libhwloc-dev libhwloc-plugins libhwloc15
  libibverbs-dev libibverbs1 libjs-jquery libjs-jquery-ui libltdl-dev
  libltdl7 libnl-3-dev libnl-route-3-200 libnl-route-3-dev libnuma-dev
  libopenmpi-dev libopenmpi3 libpciaccess0 libpmix-dev libpmix2
  libpsm-infinipath1 libpsm2-2 librdmacm1 libtool libucx0 libxnvctrl0 m4
  ocl-icd-libopencl1 openmpi-bin openmpi-common zlib1g-dev
0 upgraded, 47 newly installed, 0 to remove and 34 not upgraded.
Need to get 25.3 MB of archives.
After this operation, 99.9 MB of additional disk space will be used.
Do you want to continue? [Y/n] y
Get:1 http://vn.archive.ubuntu.com/ubuntu jammy/main amd64 m4 amd64 1.4.18-5
ubuntu2 [199 kB]
Get:2 http://vn.archive.ubuntu.com/ubuntu jammy/main amd64 autoconf all 2.71
```

Slave Node 1 (slave1@slave1: ~):

```
slave1@slave1:~$ sudo apt-get -y install make gcc g++
openmpi-bin openmpi-common libopenmpi-dev
[sudo] password for slave1:
Reading package lists... Done
Building dependency tree... Done
Reading state information... Done
The following additional packages will be installed:
  cpp cpp-11 fontconfig-config fonts-dejavu-core g++-11 gcc-11 gcc-11-base
  libasan6 libatomic1 libc-dev-bin libc-devtools libc6-dev libcc1-0
  libcrypt-dev libdeflate0 libfontconfig1 libgcc-11-dev libgd3 libgomp1
  libisl23 libitm1 libjbig0 libjpeg-turbo8 libjpeg8 liblsan0 libmpc3
  libnsl-dev libquadmath0 libstdc++-11-dev libtiff5 libtirpc-dev libtsan0
  libubsan1 libwebp7 libxpm4 linux-libc-dev manpages-dev rpcsvc-proto
Suggested packages:
  cpp-doc gcc-11-locales g++-multilib g++-11-multilib gcc-11-doc
  gcc-multilib autoconf automake libtool flex bison gdb gcc-doc
  gcc-11-multilib glibc-doc libgd-tools libstdc++-11-doc make-doc
The following NEW packages will be installed:
```

Slave Node 2 (slave2@slave2: ~):

```
slave2@slave2:~$ sudo apt-get -y install make gcc g++
openmpi-bin openmpi-common libopenmpi-dev
Reading package lists... Done
Building dependency tree... Done
Reading state information... Done
g++ is already the newest version (4:11.2.0-1ubuntu1).
gcc is already the newest version (4:11.2.0-1ubuntu1).
make is already the newest version (4.3-4.1build1).
0 upgraded, 0 newly installed, 0 to remove and 34 not upgraded.
openmpi-bin: command not found
slave2@slave2:~$ openmpi-bin openmpi-common libopenmpi-dev
openmpi-bin: command not found
slave2@slave2:~$ sudo apt install openmpi-bin openmpi-common libopenmpi-dev
Reading package lists... Done
Building dependency tree... Done
Reading state information... Done
The following additional packages will be installed:
  autoconf automake autotools-dev gfortran gfortran-11 ibverbs-providers
```

Figure 1: Cài đặt phần mềm cần thiết

2. Cấu hình ssh để máy master có thể kết nối đến các máy slave

Trên máy master

- Dùng lệnh `ssh-keygen -t rsa` để tạo public key (để mặc định và nhấn enter)
- Dùng lệnh `cat .ssh/id_rsa.pub` để lấy public key trên máy server

Trên slave:

- Dùng lệnh `echo [public_key] > .ssh/authorized_keys`

```
master@master:~$ ssh-keygen -t rsa
Generating public/private rsa key pair.
Enter file in which to save the key (/home/master/.ssh/id_rsa):
Enter passphrase (empty for no passphrase):
Enter same passphrase again:
Your identification has been saved in /home/master/.ssh/id_rsa
Your public key has been saved in /home/master/.ssh/id_rsa.pub
The key fingerprint is:
SHA256:HPox6jV406t3eiWuUP+bm7grHB72vfqj4nKoU24EmcY master@master
The key's randomart image is:
+--[RSA 3072]-----+
|
| . o .
| Eo .
| ...S .
| +o+ . .
| o+B= . .+
| ..o+B.=ooo
| o+.*=B**0=
+--[SHA256]-----+
master@master:~$ cat .ssh/id_rsa.pub
ssh-rsa AAAAB3NzaC1yc2EAAAADAQABAAQGDikMwvGZpuaqnXaL6HL3opeejj8coykOP24U0t3LnrRCusML0T181k5DH9K5X8UNnvjUPcJD6Xv+BNPxlWh/B870I+S8ZzDrILB9I4bgxueBASc5MLEIFM704gmzmYib+Do9J8t86IxyaeHfVVFJpNxlT2Q+gBSI4i3Q8jUq3MwIavJtUJcqr1wzbH0c8/NUfc/X/PJmUattUESopqtmVJirsyl4BPSEnQ5zTe3/fu7YwOmbLK5C8RF1ApPUP8ufIW9xi0uifIqOmPPMYm3eNcOm5aHTJT0XaI5CkiY8ARpXctHk5vIWd/AoR02LqBjy2hos3g1Z/dYk8WPpKn6EWxi/Dlp+LgMUEguNymDbjAjJ08jJ2Vz0T4DX0h9j8LpYFm60kzTouA2pLB5Hp4d0vhhbEFVJ7pSng6P4et4cEpNFAJAhxyXdiXlZucCJaZyd/o6kediUjIh7WOKRDZSPQMb0r4mZzjqJa2H0Do+haNbwBzvcMX8ZS4Qj3AeabNRQCuc= master@master
master@master:~$ ssh -i .ssh/id_rsa slave1@192.168.25.138
The authenticity of host '192.168.25.138 (192.168.25.138)' can't be established.
ED25519 key fingerprint is SHA256:VdnW8zLT5GJPPai5Kes7AUd4Q9ep0hVL5qBuTvBx3Lc.
This key is not known by any other names
Are you sure you want to continue connecting (yes/no/[fingerprint])?yes
Please type 'yes', 'no' or the fingerprint: yes
Please type 'yes', 'no' or the fingerprint: yes

slave1@slave1:~$ echo "ssh-rsa AAAAB3NzaC1yc2EAAAADAQABAAQGDikMwvGZpuaqnXaL6HL3opeejj8coykOP24U0t3LnrRCusML0T181k5DH9K5X8UNnvjUPcJD6Xv+BNPxlWh/B870I+S8ZzDrILB9I4bgxueBASc5MLEIFM704gmzmYib+Do9J8t86IxyaeHfVVFJpNxlT2Q+gBSI4i3Q8jUq3MwIavJtUJcqr1wzbH0c8/NUfc/X/PJmUattUESopqtmVJirsyl4BPSEnQ5zTe3/fu7YwOmbLK5C8RF1ApPUP8ufIW9xi0uifIqOmPPMYm3eNcOm5aHTJT0XaI5CkiY8ARpXctHk5vIWd/AoR02LqBjy2hos3g1Z/dYk8WPpKn6EWxi/Dlp+LgMUEguNymDbjAjJ08jJ2Vz0T4DX0h9j8LpYFm60kzTouA2pLB5Hp4d0vhhbEFVJ7pSng6P4et4cEpNFAJAhxyXdiXlZucCJaZyd/o6kediUjIh7WOKRDZSPQMb0r4mZzjqJa2H0Do+haNbwBzvcMX8ZS4Qj3AeabNRQCuc= master@master" > .ssh/authorized_keys

slave2@slave2:~$ echo "ssh-rsa AAAAB3NzaC1yc2EAAAADAQABAAQGDikMwvGZpuaqnXaL6HL3opeejj8coykOP24U0t3LnrRCusML0T181k5DH9K5X8UNnvjUPcJD6Xv+BNPxlWh/B870I+S8ZzDrILB9I4bgxueBASc5MLEIFM704gmzmYib+Do9J8t86IxyaeHfVVFJpNxlT2Q+gBSI4i3Q8jUq3MwIavJtUJcqr1wzbH0c8/NUfc/X/PJmUattUESopqtmVJirsyl4BPSEnQ5zTe3/fu7YwOmbLK5C8RF1ApPUP8ufIW9xi0uifIqOmPPMYm3eNcOm5aHTJT0XaI5CkiY8ARpXctHk5vIWd/AoR02LqBjy2hos3g1Z/dYk8WPpKn6EWxi/Dlp+LgMUEguNymDbjAjJ08jJ2Vz0T4DX0h9j8LpYFm60kzTouA2pLB5Hp4d0vhhbEFVJ7pSng6P4et4cEpNFAJAhxyXdiXlZucCJaZyd/o6kediUjIh7WOKRDZSPQMb0r4mZzjqJa2H0Do+haNbwBzvcMX8ZS4Qj3AeabNRQCuc= master@master" > .ssh/authorized_keys

slave2@slave2:~$ hostname -I
192.168.25.139
slave2@slave2:~$ ls
pi
slave2@slave2:~$ top
top - 18:21:17 up 17 min, 2 users, load average: 0.57, 0.16, 0.13
Tasks: 215 total, 3 running, 212 sleeping, 0 stopped, 0 zombie
%Cpu(s): 97.7 us, 2.3 sy, 0.0 ni, 0.0 id, 0.0 wa, 0.0 hi, 0.0 si, 0.0 st
```

Figure 2: Màn hình terminal của máy master sau khi tạo và in ra public key

3. Kiểm tra kết nối ssh từ máy master đến máy slave

- dùng lệnh `ssh -i .ssh/id_rsa [username]@[ip_address]` (ex `slave1@slave1`) để kiểm tra kết nối

```

master@master:~$ ssh -i .ssh/id_rsa slave1@192.168.25.138
Welcome to Ubuntu 22.04.3 LTS (GNU/Linux 5.15.0-88-generic x86_64)

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

System information as of Mon Nov 20 05:48:36 PM UTC 2023

System load:  0.0048828125      Processes:           212
Usage of /:   50.0% of 9.75GB   Users logged in:     1
Memory usage: 21%              IPv4 address for ens33: 192.168.25.138
Swap usage:   0%

Expanded Security Maintenance for Applications is not enabled.

35 updates can be applied immediately.
To see these additional updates run: apt list --upgradable

Enable ESM Apps to receive additional future security updates.
See https://ubuntu.com/esm or run: sudo pro status

Last login: Mon Nov 20 17:38:16 2023 from 192.168.25.1

```

Figure 3: kết nối ssh đến máy slave thành công

4. Cấu hình file /etc/hosts

- Dùng lệnh sudo nano /etc/hosts để mở file /etc/hosts

The image shows two terminal windows. The left window is a nano editor editing /etc/hosts on the master machine. The right window shows two terminal sessions on slave machines.

```

GNU nano 6.2 /etc/hosts
127.0.0.1 localhost
127.0.1.1 master

# The following lines are desirable for IPv6 capable hosts
::1 ip6-localhost ip6-loopback
fe00::0 ip6-localnet
ff00::0 ip6-mcastprefix
ff02::1 ip6-allnodes
ff02::2 ip6-allrouters

192.168.25.137 master
192.168.25.138 slave1
192.168.25.139 slave2

```

```

slave1@slave1:~$ echo "ssh-rsa AAAAB3NzaC1yc2EAAAADAQABAAQDD1kMwVZpuaqnXa
l6HL3opeejj8coyk0P24U0t3lnkRCusMLOTi81k5DH9K5X8UNnvjUPcJD6Xv+BNPwh/B87OI+S8
ZzDrILB9I4bgxueBASc5MLIFM704gmzmYib+Do9J8t86IxyaeHfVVFJpNxlT2Q+gBSI4i3QBjUq
3MWiavJtUJcqR1wzbH0c8/NuFc/X/PJmUattUESopqtmVJirsyl48PsENQ5zTe3/Fu7YwOmbLK5C
8RF1ApPUP8ufIw9xi0uifIqOmPPHYm3eNcOm5aHTJT0XaI5CkiY8ARpXctHk5vIwd/AoR02lqBjy
2hos3g1Z/dYk8WPpKn6EWxi/DLp+LgMUEguNymDbjAjJ08jJ2Vz0T4DX0h9j8LpYFm60kzTouA2p
L85Hp4d0vhbEFVJ7pSng6P4et4cEpNFAJAhyXdiX1zucCJaZyd/o6kedIujIh7WOKRDZSPQMb0r
4mZzjqJa2H0Do+haNbWbZvcMX8Z54Qj3AeabNRQCuc= master@master" > .ssh/authorized
_keys

slave2@slave2:~$ echo "ssh-rsa AAAAB3NzaC1yc2EAAAADAQABAAQDD1kMwVZpuaqnXa
l6HL3opeejj8coyk0P24U0t3lnkRCusMLOTi81k5DH9K5X8UNnvjUPcJD6Xv+BNPwh/B87OI+S8
ZzDrILB9I4bgxueBASc5MLIFM704gmzmYib+Do9J8t86IxyaeHfVVFJpNxlT2Q+gBSI4i3QBjUq
3MWiavJtUJcqR1wzbH0c8/NuFc/X/PJmUattUESopqtmVJirsyl48PsENQ5zTe3/Fu7YwOmbLK5C
8RF1ApPUP8ufIw9xi0uifIqOmPPHYm3eNcOm5aHTJT0XaI5CkiY8ARpXctHk5vIwd/AoR02lqBjy
2hos3g1Z/dYk8WPpKn6EWxi/DLp+LgMUEguNymDbjAjJ08jJ2Vz0T4DX0h9j8LpYFm60kzTouA2p
L85Hp4d0vhbEFVJ7pSng6P4et4cEpNFAJAhyXdiX1zucCJaZyd/o6kedIujIh7WOKRDZSPQMb0r
4mZzjqJa2H0Do+haNbWbZvcMX8Z54Qj3AeabNRQCuc= master@master" > .ssh/authorized
_keys

slave2@slave2:~$ hostname -I
192.168.25.139
slave2@slave2:~$ ls
pi
slave2@slave2:~$ top
top - 18:21:17 up 17 min, 2 users, load average: 0.57, 0.16, 0.13
Tasks: 215 total, 3 running, 212 sleeping, 0 stopped, 0 zombie
%Cpu(s): 97.7 us, 2.3 sy, 0.0 ni, 0.0 id, 0.0 wa, 0.0 hi, 0.0 si, 0.0
st

```

Figure 4: Nội dung trong file /etc/hosts sau khi cấu hình

5. Tạo file hosts.mpi

- Dùng lệnh nano hosts.mpi để tạo file hosts.mpi
- Nội dung file sẽ bao gồm thông tin user name và ip address của các node.

The screenshot shows three terminal windows. The left window, titled 'master@master: ~', shows the nano editor editing 'hosts.mpi'. The content is:

```
master
slave1@slave1
slave2@slave2
```

The middle window, titled 'slave1@slave1: ~', shows the command 'ssh-keygen' being executed, creating a new key pair.

The right window, titled 'slave2@slave2: ~', shows the command 'hostname -I' being executed, returning '192.168.25.139', and the command 'ls' being executed, returning 'pi'. Below this, the 'top' command is executed, showing system statistics.

Figure 5: Nội dung trong file hosts.mpi sau khi cấu hình

6. Tạo file tên pi.c

- Dùng lệnh nano pi.c để tạo file pi.c

```
#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#include <mpi.h>

int main(int argc, char *argv[]) {
    int myid, numprocs;
    double PI25DT = 3.141592653589793238462643;
    double t1, t2;

    long long npts = 1e11;
    long long i, mynpts;

    long double f, sum, mysum;
    long double xmin, xmax, x;

    // Initialization routine => starts the MPI environment
    // Defines the communicator MPI_COMM_WORLD
    MPI_Init(&argc, &argv);
    // Determines the number of processes in a communicator
    MPI_Comm_size(MPI_COMM_WORLD, &numprocs);
    // Determines the rank (id) of the calling process in the communicator
    MPI_Comm_rank(MPI_COMM_WORLD, &myid);

    // Data decomposition. Each process gets a part of the work
    mynpts = npts / numprocs;

    if (myid == 0) {
        // Returns the time in seconds since an arbitrary time in the past
        t1 = MPI_Wtime();
    }

    mysum = 0.0;
    xmin = 0.0;
    xmax = 1.0;

    // Seed the pseudo random number generator
    srand(time(0));

    for (i = 0; i < mynpts; i++) {
```

```

for (i = 0; i < mynpts; i++) {
    x = (long double)rand() / (long double)RAND_MAX * (xmax - xmin) + xmin;
    mysum += 4.0 / (1.0 + x * x);
}

// Take all the processes' values of mysum and add them up into sum on process 0.
MPI_Reduce(&mysum, &sum, 1, MPI_LONG_DOUBLE, MPI_SUM, 0, MPI_COMM_WORLD);

if (myid == 0) {
    // Returns the time in seconds since an arbitrary time in the past
    t2 = MPI_Wtime();

    f = sum / npts;

    printf("Pi calculated with %ld points.\n", npts);
    printf("Pi calculated: %.16f\n", f);
    printf("Correct value of Pi: %.16f\n", PI25DT);
    printf("Error is: %.16f\n", fabs(f - PI25DT));
    printf("Elapsed time [s] for the relevant part of the program: %f\n", t2 - t1);
}

// Stop the MPI environment
MPI_Finalize();
return 0;
}

```

7. Compiler code và gửi code từ máy master đến các máy slave

- Dùng lệnh `mpicc pi.c -o pi` để compiler code trên máy master
- Dùng lệnh `ls ~` để xem các file và thư mục có trong thư mục home trên các máy slave

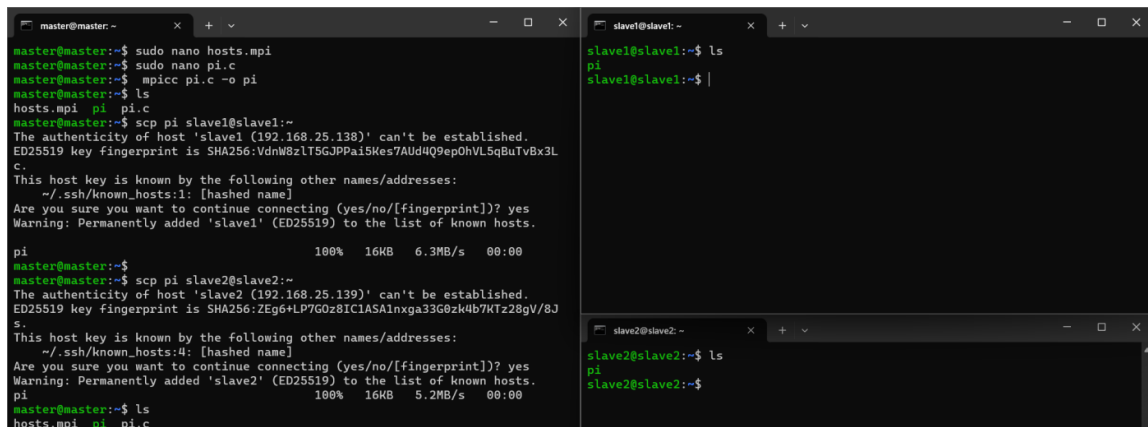
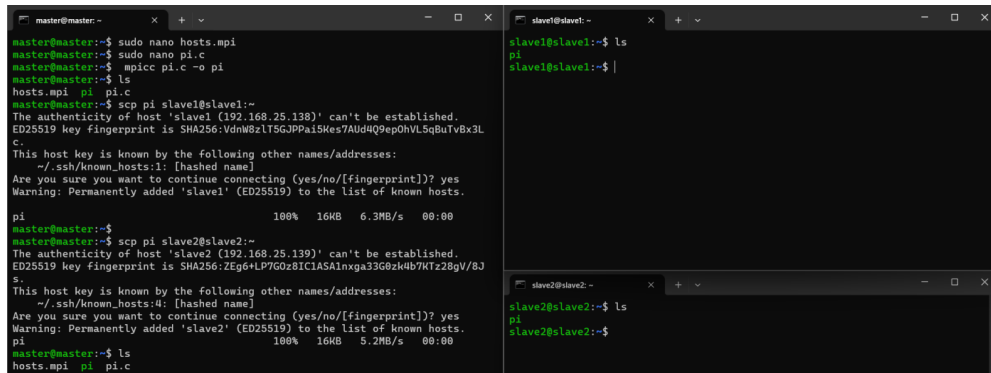


Figure 6: các file và thư mục có trong thư mục home trên các máy slave

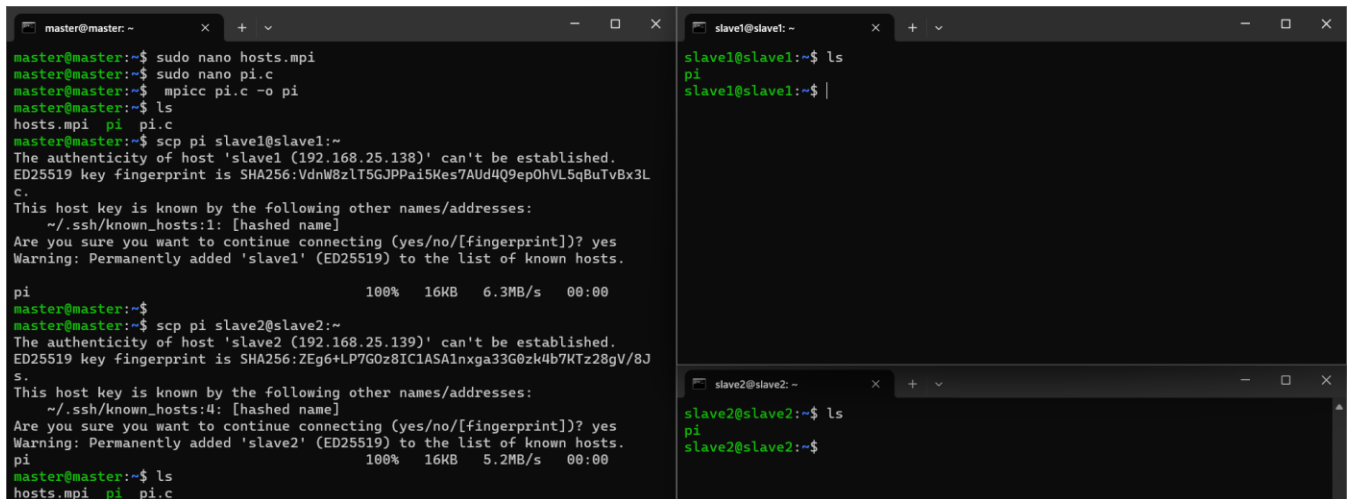
- Dùng lệnh `scp pi slave1@slave1:~ && scp pi slave2@slave2:~` để gửi file `pi` đã được compiler đến thư mục home của các máy slave.

The image shows three terminal windows. The leftmost window is on the 'master' machine, showing the execution of 'sudo nano hosts.mpi', 'sudo nano pi.c', 'mpicc pi.c -o pi', and 'scp pi slave1@slave1:~'. It shows the successful transfer of 'pi' to 'slave1' and then to 'slave2'. The middle window is on 'slave1', showing 'ls' and 'pi'. The rightmost window is on 'slave2', showing 'ls' and 'pi'.

```
master@master:~$ sudo nano hosts.mpi
master@master:~$ sudo nano pi.c
master@master:~$ mpicc pi.c -o pi
master@master:~$ ls
hosts.mpi  pi  pi.c
master@master:~$ scp pi slave1@slave1:~
The authenticity of host 'slave1 (192.168.25.138)' can't be established.
ED25519 key fingerprint is SHA256:VdnW8zLT5GJPPa15Kes7AUd4Q9ep0hVL5qBuTvBx3L
c.
This host key is known by the following other names/addresses:
~/ssh/known_hosts:1: [hashed name]
Are you sure you want to continue connecting (yes/no/[fingerprint])? yes
Warning: Permanently added 'slave1' (ED25519) to the list of known hosts.
pi
100% 16KB 6.3MB/s 00:00
master@master:~$
master@master:~$ scp pi slave2@slave2:~
The authenticity of host 'slave2 (192.168.25.139)' can't be established.
ED25519 key fingerprint is SHA256:ZEg+LP7G0z8IC1ASA1nxga33G0zk4b7KTz28gV/8J
s.
This host key is known by the following other names/addresses:
~/ssh/known_hosts:4: [hashed name]
Are you sure you want to continue connecting (yes/no/[fingerprint])? yes
Warning: Permanently added 'slave2' (ED25519) to the list of known hosts.
pi
100% 16KB 5.2MB/s 00:00
master@master:~$ ls
hosts.mpi  pi  pi.c
slave1@slave1:~$ ls
pi
slave1@slave1:~$
slave2@slave2:~$ ls
pi
slave2@slave2:~$
```

Figure 7: màn hình terminal của máy master sau khi gửi file pi đến các máy slave

- Dùng lệnh `ls ~` để xem nhận được file pi từ máy master chưa

The image shows three terminal windows. The leftmost window is on the 'master' machine, showing the execution of 'sudo nano hosts.mpi', 'sudo nano pi.c', 'mpicc pi.c -o pi', and 'scp pi slave1@slave1:~'. It shows the successful transfer of 'pi' to 'slave1' and then to 'slave2'. The middle window is on 'slave1', showing 'ls' and 'pi'. The rightmost window is on 'slave2', showing 'ls' and 'pi'.

```
master@master:~$ sudo nano hosts.mpi
master@master:~$ sudo nano pi.c
master@master:~$ mpicc pi.c -o pi
master@master:~$ ls
hosts.mpi  pi  pi.c
master@master:~$ scp pi slave1@slave1:~
The authenticity of host 'slave1 (192.168.25.138)' can't be established.
ED25519 key fingerprint is SHA256:VdnW8zLT5GJPPa15Kes7AUd4Q9ep0hVL5qBuTvBx3L
c.
This host key is known by the following other names/addresses:
~/ssh/known_hosts:1: [hashed name]
Are you sure you want to continue connecting (yes/no/[fingerprint])? yes
Warning: Permanently added 'slave1' (ED25519) to the list of known hosts.
pi
100% 16KB 6.3MB/s 00:00
master@master:~$
master@master:~$ scp pi slave2@slave2:~
The authenticity of host 'slave2 (192.168.25.139)' can't be established.
ED25519 key fingerprint is SHA256:ZEg+LP7G0z8IC1ASA1nxga33G0zk4b7KTz28gV/8J
s.
This host key is known by the following other names/addresses:
~/ssh/known_hosts:4: [hashed name]
Are you sure you want to continue connecting (yes/no/[fingerprint])? yes
Warning: Permanently added 'slave2' (ED25519) to the list of known hosts.
pi
100% 16KB 5.2MB/s 00:00
master@master:~$ ls
hosts.mpi  pi  pi.c
slave1@slave1:~$ ls
pi
slave1@slave1:~$
slave2@slave2:~$ ls
pi
slave2@slave2:~$
```

Figure 8: kiểm tra đã nhận được file pi từ máy master chưa

8. Chạy code tính số pi

- Dùng lệnh `time mpirun -np 6 --hostfile hosts.mpi` pi để chạy code tính số pi trên các máy đã cấu trong file hosts.mpi
- Dùng lệnh `top` trên các máy đã được cấu hình trong hosts.mpi xem nó có đang chạy code pi không.

```

top - 02:24:09 up 1:26, 3 users, load average: 0.83, 0.37, 0.38
Tasks: 221 total, 2 running, 218 sleeping, 1 stopped, 0 zombie
%Cpu(s): 51.8 us, 0.8 sy, 0.0 ni, 47.2 id, 0.0 wa, 0.0 hi, 0.2 si, 0.0 st
MiB Mem : 1928.3 total, 515.2 free, 340.2 used, 1073.0 buff/cache
MiB Swap: 1804.0 total, 1804.0 free, 0.0 used, 1421.8 avail Mem

  PID USER      PR  NI   VIRT   RES   SHR  S  %CPU  %MEM    TIME+  COMMAND
 4453 slave1    20   0 184988 15056 11880 R 99.7   0.8   1:18.06  pi
   825 root       20   0 1023132 48480 19732 S   5.0   2.5   0:05.35  snapd
   710 root       20   0 312204   9064  7468 S   0.3   0.5   0:21.93  vmtoolsd
  3589 root       20   0         0         0   0 I   0.3   0.0   0:00.53  kworker/1:2-events
  4328 slave1    20   0  17308   8096  5680 S   0.3   0.4   0:00.06  sshd
     1 root       20   0 102052 13052  8444 S   0.0   0.7   0:03.89  systemd
     2 root       20   0         0         0   0 S   0.0   0.0   0:00.06  kthreadd
     3 root       0 -20         0         0   0 I   0.0   0.0   0:00.00  rcu_gp
     4 root       0 -20         0         0   0 I   0.0   0.0   0:00.00  rcu_par_gp
     5 root       0 -20         0         0   0 I   0.0   0.0   0:00.00  slub_flushwq
     6 root       0 -20         0         0   0 I   0.0   0.0   0:00.00  netns
     8 root       0 -20         0         0   0 I   0.0   0.0   0:00.00  kworker/0:0H-events_highpri
    10 root       0 -20         0         0   0 I   0.0   0.0   0:00.00  mm_percpu_wq
    11 root      20   0         0         0   0 S   0.0   0.0   0:00.00  rcu_tasks_rude_
    12 root      20   0         0         0   0 S   0.0   0.0   0:00.00  rcu_tasks_trace
    13 root      20   0         0         0   0 S   0.0   0.0   0:00.30  ksoftirqd/0
    14 root      20   0         0         0   0 I   0.0   0.0   0:03.75  rcu_sched
    15 root      rt   0         0         0   0 S   0.0   0.0   0:00.04  migration/0
    16 root     -51   0         0         0   0 S   0.0   0.0   0:00.00  idle_inject/0
    18 root      20   0         0         0   0 S   0.0   0.0   0:00.00  cpuhp/0
    19 root      20   0         0         0   0 S   0.0   0.0   0:00.00  cpuhp/1
    20 root     -51   0         0         0   0 S   0.0   0.0   0:00.00  idle_inject/1
    21 root      rt   0         0         0   0 S   0.0   0.0   0:00.18  migration/1

```

Figure 9: Kết quả khi thực hiện câu lệnh top trên máy slave

9. Kết quả sau khi tính số pi

- Thời gian tiết kiệm được khi sử dụng 2 slave node trong bài toán tính pi:

$$\frac{(2000 - 900)}{2000} \times 100 = 55\%$$

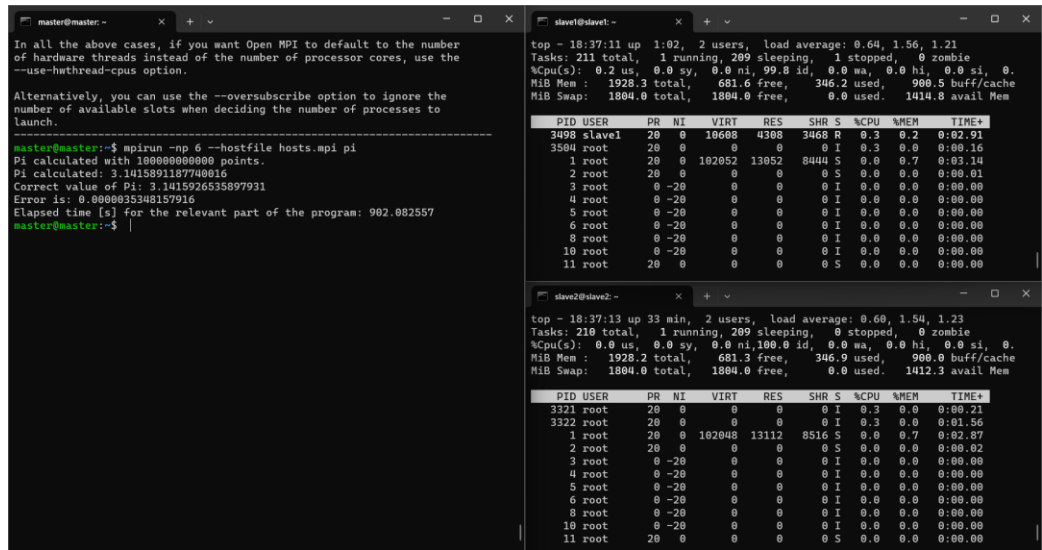


Figure 10: Kết quả sau khi tính số pi với 2 slave node

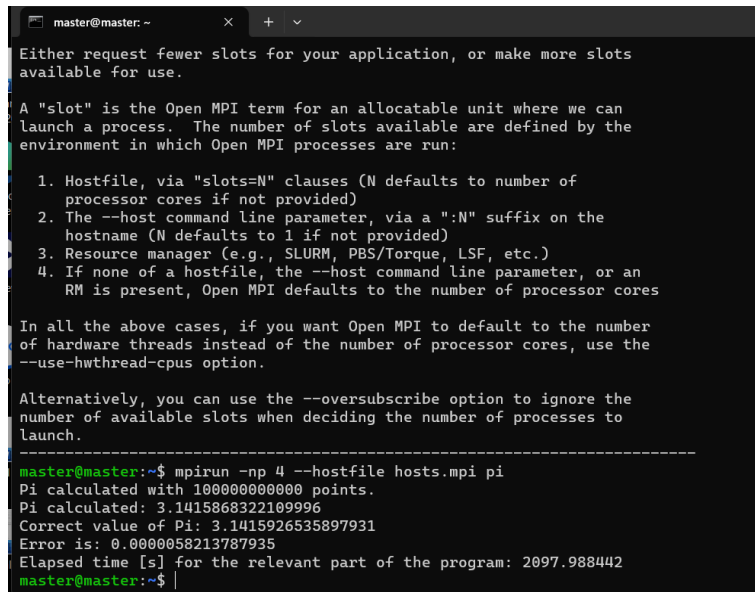


Figure 11: Kết quả sau khi tính số pi với 1 slave node

- Thời gian tiết kiệm được khi sử dụng 2 slave node trong bài toán word count:

$$\frac{(0.19 - 0.18)}{0.19} \times 100 = 5.26\%$$


```
Alphabet Counts:
a: 36
b: 8
c: 34
d: 19
e: 67
f: 8
g: 8
h: 5
i: 54
j: 3
k: 0
l: 29
m: 27
n: 37
o: 21
p: 12
q: 6
r: 21
s: 46
t: 48
u: 50
v: 6
w: 0
x: 0
y: 0
z: 0
Elapsed time [s]: 0.018012
master@master:~$
```

Figure 12: Kết quả sau khi tính word count với 2 slave node

```
master@master:~$ mpirun -np 4 --hostfile hosts.mpi wc3
Input String: Lorem ipsum dolor sit amet, consectetur adipiscing elit. Fusce
vel cursus augue. Pellentesque habitant morbi tristique senectus et netus e
t malesuada fames ac turpis egestas. Vestibulum commodo odio nec enim eleife
nd tincidunt. In hac habitasse platea dictumst. Integer eu justo nec nulla h
endrerit vehicula. Sed vestibulum dapibus bibendum. Quisque aliquam nunc vit
ae arcu fermentum, eget facilisis tortor elementum. Nunc ullamcorper, ipsum
id tincidunt accumsan, elit nunc dictum justo, nec fermentum ipsum mi ut dol
or. Donec consectetur justo a mi lacinia, nec suscipit felis fringilla. Susp
endisse potenti. Sed ac lacus vitae ligula scelerisque sagittis.
Alphabet Counts:
a: 36
b: 8
c: 34
d: 19
e: 67
f: 8
g: 8
h: 5
i: 55
j: 3
k: 0
l: 29
m: 27
n: 37
o: 21
p: 12
q: 6
r: 21
s: 46
t: 49
u: 50
v: 6
w: 0
x: 0
y: 0
z: 0
Elapsed time [s]: 0.019250
```

Figure 13: Kết quả sau khi tính word count với 1 slave node

