

浙江大学



课程综合实践 实验报告

实验名称 简单集群的搭建

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目录

1	实验目的和要求	1
2	操作方法和实验步骤	1
2.1	安装 openmpi	1
2.2	安装 hpl	2
2.3	克隆虚拟机并进行 ip 地址配置	4
2.4	ssh 集群免密登录配置	4
2.5	使用 openmpi 和 hpl 进行性能测试	6
3	实验结果与分析	7
3.1	openmpi 性能测试结果	7
3.2	hpl 性能测试结果	8

插图

1	openmpi 安装测试结果	2
2	ssh 登录测试结果 1	5
3	ssh 登录测试结果 2	6
4	openmpi 性能测试结果	7
5	hpl 测试结果	8

1 实验目的和要求

本次实验要求使用四台虚拟机搭建一个简易的集群，并对该集群进行性能测试，最后提交测试结果和实验报告。集群搭建的任务包括创建虚拟机、安装 Linux 发行版、配置 网络和 ssh 通信。性能测试通过使用 OpenMPI 将 HPL 测试程序分配到四个虚拟机节点上执行。因此，需要下载并编译 OpenMPI、BLAS 和 HPL 的源代码，其中 OpenMPI、BLAS 是 HPL 的依赖项。

2 操作方法和实验步骤

2.1 安装 openmpi

1、前置环境安装，确保安装了：gcc, g++, python; 如果缺少对应的环境，在 ubuntu 环境下使用 apt-get 安装

```
1 sudo apt-get install gcc
2 sudo apt-get install g++
3 sudo apt-get install python
```

2、下载 openmpi

```
1 wget https://download.open-mpi.org/
2 release/open-mpi/v4.0/openmpi-4.0.4.tar.gz
```

3、解压 openmpi

```
1 tar -zxvf openmpi-4.0.4.tar.gz
```

4、检查配置文件

```
1 cd openmpi-4.0.4
2 ./configure
```

5、编译安装

```
1 sudo make all install
```

6、配置 openmpi 环境变量

```
1 vim /etc/profile
2 # 在这个文件末尾添加如下两行
3 export PATH=/usr/local/path:$PATH
4 export LD_LIBRARY_PATH=$LD_LIBRARY_PATH:/usr/local/lib
```

编辑完成之后需要执行 `source /etc/profile` 使其生效进入到 `examples` 文件夹中，执行 `make` 编译一下测试代码，如果编译没有报错执行下面的测试语句

```
1 | mpirun -np 4 hello_c
```

如果正常输出结果则说明安装完成

```

thy@thy-virtual-machine:~$
Executable: hello_c.c
-----
$ cat processes failed to start
thy@thy-virtual-machine:~/bin/openmpi-4.0.4/examples $ ls
connectivity_c.c      hello_oshmnhf.f90    oshmn_max_reduction.c  ring_cxx      ring_usempi.f90
hello_c.c             hello_oshmnhf.f90    oshmn_shmatloc.c       ring_cxx.cc   ring_usempi.f90
hello_cxx.c           hello_usempi.f90     oshmn_strided_puts.c   ring_java     spc_example.c
hello_mpihf.f         Makefile             oshmn_symmetric_data.c ring_mpihf.f   ring_oshmnhf.f
hello_mpihf.f         README
thy@thy-virtual-machine:~/bin/openmpi-4.0.4/examples $ cd ..
thy@thy-virtual-machine:~/bin/openmpi-4.0.4 $ ls
Makefile  NEWS  VERSION
AUTHORS  config.log  configure.ac  INSTALL  Makefile.am  omp1  README.JAVA.txt
configure  config.h  config.status  Makefile  Makefile.am.rules  omp2  README
config     examples  LICENSE  Makefile.omp1-rules  omp3  test
thy@thy-virtual-machine:~/bin/openmpi-4.0.4 $ source ./etc/profile
thy@thy-virtual-machine:~/bin/openmpi-4.0.4 $ cd openmpi-4.0.4/examples
bash: cd: openmpi-4.0.4/examples: 没有那个文件或目录
thy@thy-virtual-machine:~/bin/openmpi-4.0.4 $ cd openmpi-1.6.2/examples
bash: cd: openmpi-1.6.2/examples: 没有那个文件或目录
thy@thy-virtual-machine:~/bin/openmpi-4.0.4 $ cd examples
thy@thy-virtual-machine:~/bin/openmpi-4.0.4/examples $ make
mpicc -g hello_c.c -o hello_c
mpicc -g ring_cxx.c -o ring_cxx
mpicc -g connectivity_c.c -o connectivity_c
mpicc -g spc_example.c -o spc_example
make[1]: 进入目录 /home/tyh/bin/openmpi-4.0.4/examples
make[1]: 离开目录 /home/tyh/bin/openmpi-4.0.4/examples
thy@thy-virtual-machine:~/bin/openmpi-4.0.4/examples $ mpi-run -np 4 hello_c
hello_world, I am 3 of 4. (Open MPI v4.0.4, package: Open MPI thy@thy-virtual-machine Distribution, ident: 4.0.4, repo rev: v4.0.4, Jun 10, 2020, 118)
hello_world, I am 2 of 4. (Open MPI v4.0.4, package: Open MPI thy@thy-virtual-machine Distribution, ident: 4.0.4, repo rev: v4.0.4, Jun 10, 2020, 118)
hello_world, I am 1 of 4. (Open MPI v4.0.4, package: Open MPI thy@thy-virtual-machine Distribution, ident: 4.0.4, repo rev: v4.0.4, Jun 10, 2020, 118)
thy@thy-virtual-machine:~/bin/openmpi-4.0.4/examples $ cd ..
thy@thy-virtual-machine:~/bin/openmpi-4.0.4 $ cd ..
thy@thy-virtual-machine:~/bin $ cd ..
thy@thy-virtual-machine:~$

```

图 1: openmpi 安装测试结果

2.2 安装 hpl

- 1、下载 hpl-2.3 的压缩包并解压在相应路径
- 2、下载 GotoBLAS，解压编译
- 3、修改 hpl 的 Makefile 文件，选择相应的文件复制到根目录并重命名（这里我命名为 Make.test），Make.test 的部分文件内容如下：

```

1 #
2 SHELL          = /bin/sh
3 #
4 CD             = cd
5 CP             = cp
6 LN_S          = ln -s
7 MKDIR          = mkdir
8 RM             = /bin/rm -f
9 TOUCH          = touch
10 #
11 ARCH          = test
12 #
13 # -----
14 # - HPL Directory Structure / HPL library -
15 # -----
16 #
17 TOPdir         = /home/thy/桌面/hpl-2.3
18 INCdir         = $(TOPdir)/include
19 BINDir         = $(TOPdir)/bin/$(ARCH)
20 LIBdir         = $(TOPdir)/lib/$(ARCH)
21 #
22 HPLlib         = $(LIBdir)/libhpl.a
23 #
24 MPdir          = /usr/local/lib/openmpi
25 MPinc          = -I$(MPdir)/include
26 MPLib          = /usr/local/lib/libmpi.so
27 #
28 LAdir          = /home/thy/桌面/GotoBLAS2
29 LAinc          =
30 LAlib          = $(LAdir)/libgoto2_nehalem-r1.13.a
31 #
32 CC             = /usr/local/bin/mpicc
33 CCNOOPT        = $(HPL_DEFS)
34 CCFLAGS        = $(HPL_DEFS) -fomit-frame-pointer

```

```

35 #                                -O3 -funroll-loops -W -Wall
36 #
37 LINKER      = $(CC)
38 LINKFLAGS   = $(CCFLAGS)
39 #
40 ARCHIVER     = ar
41 ARFLAGS     = r
42 RANLIB      = echo
43 #
44 # -----

```

2.3 克隆虚拟机并进行 ip 地址配置

在 vmawre 中选择虚拟机克隆“完整克隆”；使用 ip addr 命令查看当前虚拟机的 ip 地址

2.4 ssh 集群免密登录配置

1、安装 SSH Server

```

1 yitian@ubuntu:~$ sudo apt-get update
2 yitian@ubuntu:~$ sudo apt install openssh-server

```

2、开启 Openssh 服务

```

1 sudo service ssh start

```

3、修改 hosts 文件

```

1 vim /etc/hosts

```

hosts 文件内容如下：

```

1 127.0.0.1      localhost
2 127.0.1.1     thy-virtual-machine
3 # The following lines are desirable

```

```

4 for IPv6 capable hosts
5 ::1      ip6-localhost ip6-loopback
6 fe00::0  ip6-localnet
7 ff00::0  ip6-mcastprefix
8 ff02::1  ip6-allnodes
9 ff02::2  ip6-allrouters
10
11 172.16.6.138 slave3
12 172.16.6.136 slave1
13 172.16.6.132 slave2
14 172.16.6.140 slave4

```

4、生成公钥和私钥

```

1 ssh-keygen -t rsa

```

5、执行 ssh-copy-id

```

1 ssh-copy-id -i ~/.ssh/id_rsa.pub thy@slave2
2 ssh-copy-id -i ~/.ssh/id_rsa.pub thy@slave3
3 ssh-copy-id -i ~/.ssh/id_rsa.pub thy@slave4

```

6、进行 ssh 远程登录测试：

```

* Support:      https://ubuntu.com/advantage
163 updates can be installed immediately.
0 of these updates are security updates.
To see these additional updates run: apt list --upgradable

Your Hardware Enablement Stack (HWE) is supported until April 2025.
Last login: Sun Jul 25 13:58:13 2021 from 172.16.6.136
vhythy@virtual-machine:~$ exit
注销
Connection to slave1 closed.
vhythy@virtual-machine:~$ ssh -l hpl-2.3/b1n/test5 ssh slave2
Welcome to Ubuntu 20.04.2 LTS (GNU/Linux 5.8.0-59-generic x86_64)

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

163 updates can be installed immediately.
0 of these updates are security updates.
To see these additional updates run: apt list --upgradable

Your Hardware Enablement Stack (HWE) is supported until April 2025.
Last login: Sun Jul 25 13:33:35 2021 from 172.16.6.136
vhythy@virtual-machine:~$ exit
注销
Connection to slave2 closed.
vhythy@virtual-machine:~$ ssh -l hpl-2.3/b1n/test5 ssh slave3
Welcome to Ubuntu 20.04.2 LTS (GNU/Linux 5.8.0-59-generic x86_64)

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

159 updates can be installed immediately.
0 of these updates are security updates.
To see these additional updates run: apt list --upgradable

Your Hardware Enablement Stack (HWE) is supported until April 2025.
*** System restart required ***
Last login: Sun Jul 25 13:34:26 2021 from 172.16.6.136
vhythy@virtual-machine:~$ exit
注销
Connection to slave3 closed.
vhythy@virtual-machine:~$ ssh -l hpl-2.3/b1n/test5

```

图 2: ssh 登录测试结果 1

```
终端 7月25日 13:51
thy@thy-virtual-machine: ~

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

163 updates can be installed immediately.
0 of these updates are security updates.
To see these additional updates run: apt list --upgradable

Your Hardware Enablement Stack (HWE) is supported until April 2025.
Last login: Sun Jul 25 13:33:35 2021 from 172.16.6.136
thy@thy-virtual-machine:~$ exit
注销
Connection to slave2 closed.
thy@thy-virtual-machine:~/hpl-2.3/bin/test$ ssh slave3
Welcome to Ubuntu 20.04.2 LTS (GNU/Linux 5.8.0-59-generic x86_64)

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

159 updates can be installed immediately.
0 of these updates are security updates.
To see these additional updates run: apt list --upgradable

*** System restart required ***
Last login: Sun Jul 25 13:34:26 2021 from 172.16.6.136
thy@thy-virtual-machine:~$ exit
注销
Connection to slave3 closed.
thy@thy-virtual-machine:~/hpl-2.3/bin/test$ ssh slave4
Welcome to Ubuntu 20.04.2 LTS (GNU/Linux 5.8.0-59-generic x86_64)

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

163 updates can be installed immediately.
0 of these updates are security updates.
To see these additional updates run: apt list --upgradable

Your Hardware Enablement Stack (HWE) is supported until April 2025.
Last login: Sun Jul 25 13:34:33 2021 from 172.16.6.136
thy@thy-virtual-machine:~$
```

图 3: ssh 登录测试结果 2

2.5 使用 openmpi 和 hpl 进行性能测试

1、分别编写 hostfile 文件，文件内容如下

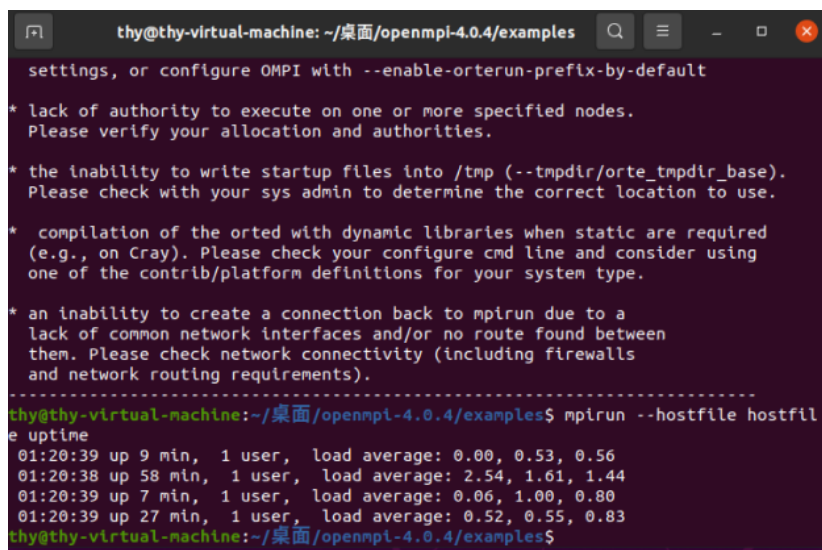
```
1 slave1
2 slave2
3 slave3
4 slave4
```

2、执行以下两条指令分别使用 openmpi 和 hpl 进行性能测试

```
1 mpirun --hostfile hostfile uptime
2 mpirun --hostfile hostfile ./xhpl
```


3 实验结果与分析

3.1 openmpi 性能测试结果



```
thy@thy-virtual-machine: ~/桌面/openmpi-4.0.4/examples
settings, or configure OMPI with --enable-orterun-prefix-by-default

* lack of authority to execute on one or more specified nodes.
  Please verify your allocation and authorities.

* the inability to write startup files into /tmp (--tmpdir/orte_tmpdir_base).
  Please check with your sys admin to determine the correct location to use.

* compilation of the orted with dynamic libraries when static are required
  (e.g., on Cray). Please check your configure cmd line and consider using
  one of the contrib/platform definitions for your system type.

* an inability to create a connection back to mpirun due to a
  lack of common network interfaces and/or no route found between
  them. Please check network connectivity (including firewalls
  and network routing requirements).

-----
thy@thy-virtual-machine:~/桌面/openmpi-4.0.4/examples$ mpirun --hostfile hostfil
e uptime
01:20:39 up 9 min,  1 user,  load average: 0.00, 0.53, 0.56
01:20:38 up 58 min, 1 user,  load average: 2.54, 1.61, 1.44
01:20:39 up 7 min,  1 user,  load average: 0.06, 1.00, 0.80
01:20:39 up 27 min, 1 user,  load average: 0.52, 0.55, 0.83
thy@thy-virtual-machine:~/桌面/openmpi-4.0.4/examples$
```

图 4: openmpi 性能测试结果

3.2 hpl 性能测试结果

```
thy@thy-virtual-machine: ~/bin/hpl-2.3/bin/test
IPL_pdgesv() end time Sun Jul 25 13:44:32 2021
=====
|Ax-b|_oo/(eps*(|A|_oo*|x|_oo+|b|_oo)*N)= 1.72533487e-02 ..... PASSED
=====
/V N NB P Q Time Gflops
-----
R00L2C4 29 1 2 2 0.12 1.4554e-04
IPL_pdgesv() start time Sun Jul 25 13:44:32 2021
IPL_pdgesv() end time Sun Jul 25 13:44:32 2021
=====
|Ax-b|_oo/(eps*(|A|_oo*|x|_oo+|b|_oo)*N)= 1.72533487e-02 ..... PASSED
=====
/V N NB P Q Time Gflops
-----
R00L2R2 29 1 2 2 0.12 1.5182e-04
IPL_pdgesv() start time Sun Jul 25 13:44:32 2021
IPL_pdgesv() end time Sun Jul 25 13:44:33 2021
=====
|Ax-b|_oo/(eps*(|A|_oo*|x|_oo+|b|_oo)*N)= 1.72533487e-02 ..... PASSED
=====
/V N NB P Q Time Gflops
-----
R00L2R4 29 1 2 2 0.12 1.4721e-04
IPL_pdgesv() start time Sun Jul 25 13:44:33 2021
IPL_pdgesv() end time Sun Jul 25 13:44:33 2021
=====
|Ax-b|_oo/(eps*(|A|_oo*|x|_oo+|b|_oo)*N)= 1.72533487e-02 ..... PASSED
=====
/V N NB P Q Time Gflops
-----
R00C2L2 29 1 2 2 0.14 1.2911e-04
IPL_pdgesv() start time Sun Jul 25 13:44:33 2021
IPL_pdgesv() end time Sun Jul 25 13:44:33 2021
=====
|Ax-b|_oo/(eps*(|A|_oo*|x|_oo+|b|_oo)*N)= 1.72533487e-02 ..... PASSED
thy@thy-virtual-machine:~/bin/hpl-2.3/bin/test$
```

图 5: hpl 测试结果