

Cloud Computing Project (CS06L008)

Synchronization Algorithms - Distributed Systems

Report

Team Members:

1. Shreyas Sukhadeve
2. Rohan Akode
3. Pratik Sonawane

Flow of Report:

1. Problem Statement
 2. Flow Diagram of Solution
 3. Simulation Technique
 4. Results discussion (Example)
 5. Setup for demo including VM setup on Azure
-

Problem Statement:

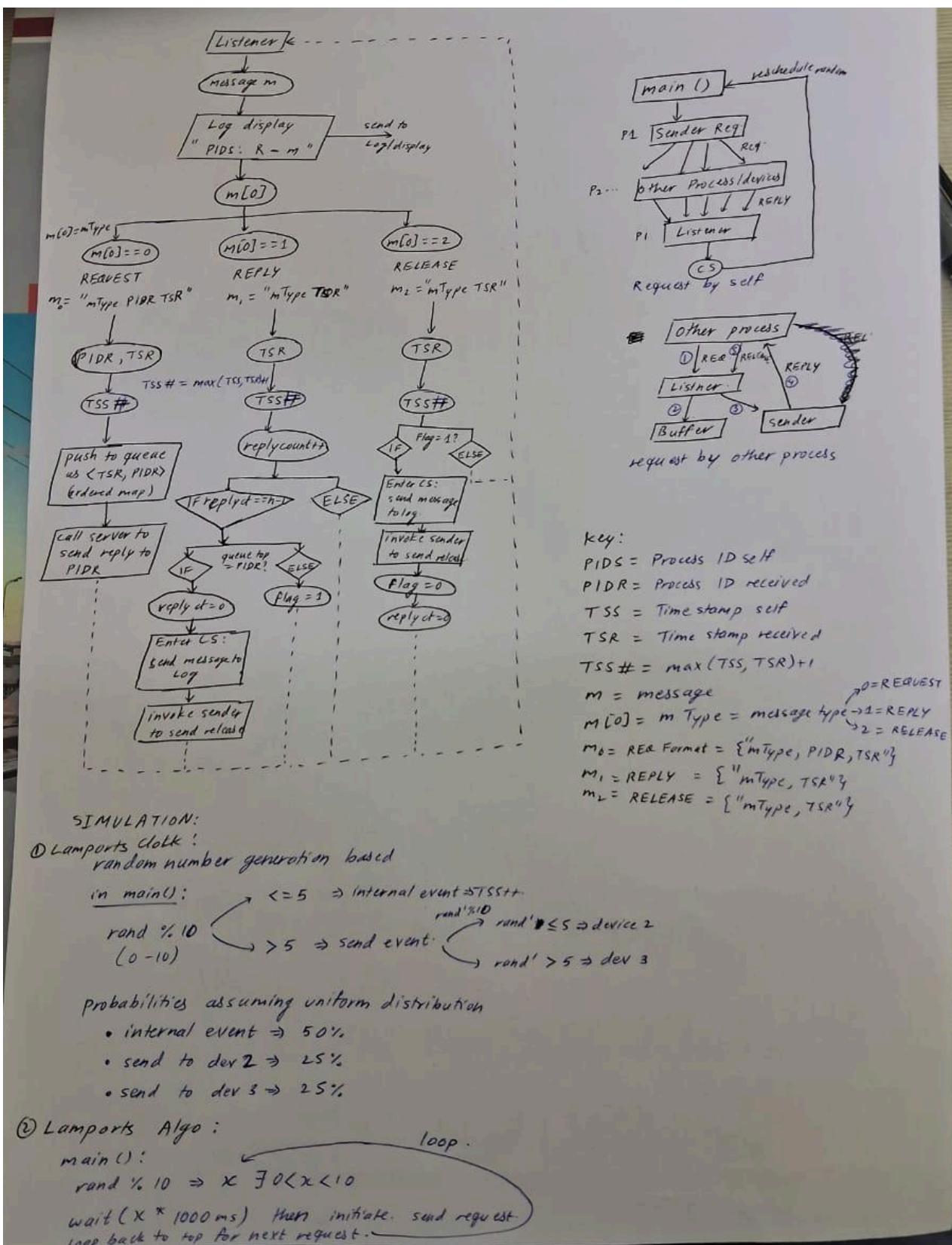
Source: Google Classroom

The project requires implementation of Lamport's Mutual exclusion using logical clock. The project has to be implemented via sockets because you need to communicate between 3 devices. The critical section can be assumed to be access to a file on any one of the 3 machines. As I explained in class, there need to be two threads per device. One thread shall create local event and send event; the send event should only be for mutual exclusion request. The other thread need to act as port listener and hence, receiver thread. The only catch here is to synchronise between sender and receiver thread to update the logical clock. The implementation needs to be done only in C++ or Java; I informed in class that Python is not allowed.

Summary:

- Implement Lamport's Clock
 - Implement Lamport's Mutual Exclusion Algorithm
 - 3 devices, 2 threads per device, only C++/Java allowed.
- + Additional Credit for implementation on Cloud - After Class**

Flow Diagram & Simulation Technique



Result: (Lamports Algo)

On running the code for 10 seconds without internal events activated:

Log Device 1:

```
Windows PowerShell      shreyas@CVM1: ~      shreyas@CVM1: ~
shreyas@CVM1:~$ vi device1.c
shreyas@CVM1:~$ gcc device1.c -o device1
shreyas@CVM1:~$ ./device1
P1 requests CS access
P1: P2 001
P1: P3 001
P1: P2 13
P1: P2 04
P1: P2 115
P1: P3 17
P1 entered CS section
P1 exits CS section
P1: P2 218
P1: P3 228
[[^C
shreyas@CVM1:~$
```

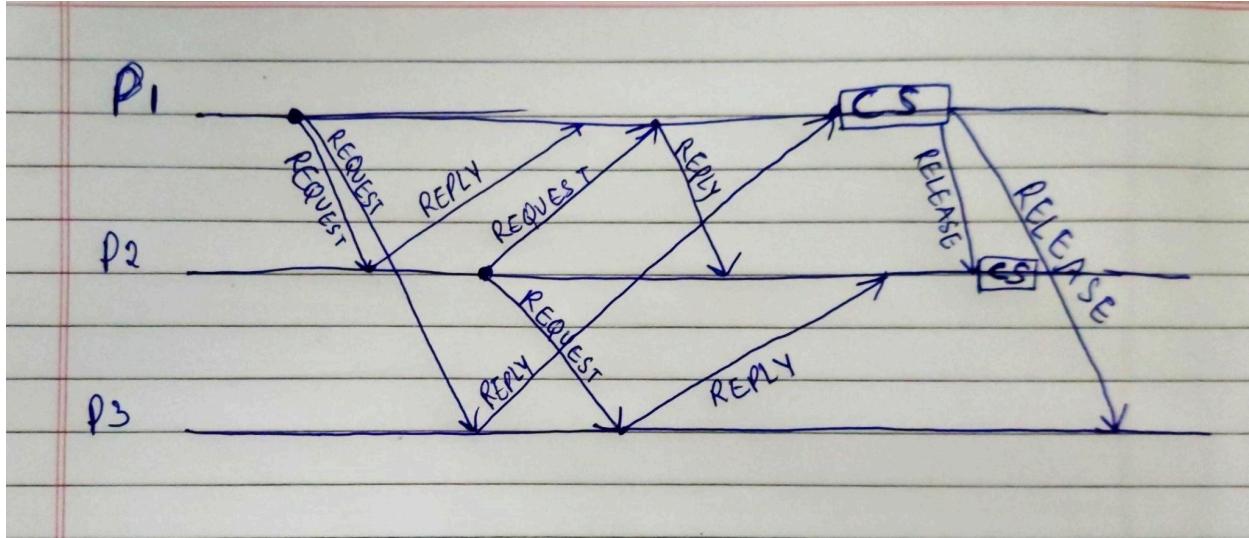
Log Device 2:

```
shreyas@CVM1: ~      shreyas@CVM2: ~      shreyas@CVM2: ~
shreyas@CVM2:~$ vi device2.c
shreyas@CVM2:~$ gcc device2.c -o device2
shreyas@CVM2:~$ ./device2
P2: P1 02
P2: P1 103
P2 requests CS access
P2: P1 004
P2: P3 024
P2: P1 16
P2: P3 17
P2: P1 27
P2 entered CS section
^C
shreyas@CVM2:~$
```

Log Device 3:

```
shreyas@CVM1: ~          X | shreyas@CVM2: ~          X | shreyas@CVM3: ~          X
shreyas@CVM3:~$ vi device3.c
shreyas@CVM3:~$ ls
device3.c
shreyas@CVM3:~$ gcc device3.c -o device3
shreyas@CVM3:~$ ls
device3 device3.c
shreyas@CVM3:~$ ./device
-bash: ./device: No such file or directory
shreyas@CVM3:~$ ./device3
P3: P1 02
P3: P1 103
P3: P2 04
P3: P2 106
P3: P1 28
[[^C
shreyas@CVM3:~$
```

Corresponding Chart drawn from data:



Note that the chart is similar to what we expected when drawn corresponding to the log. For clearer visibility we will be implementing a display device soon that will capture each message movement in sequence giving a global view rather than these 3 local views.

This Result is as expected => We implemented Lamports Mutual Exclusion Algorithm

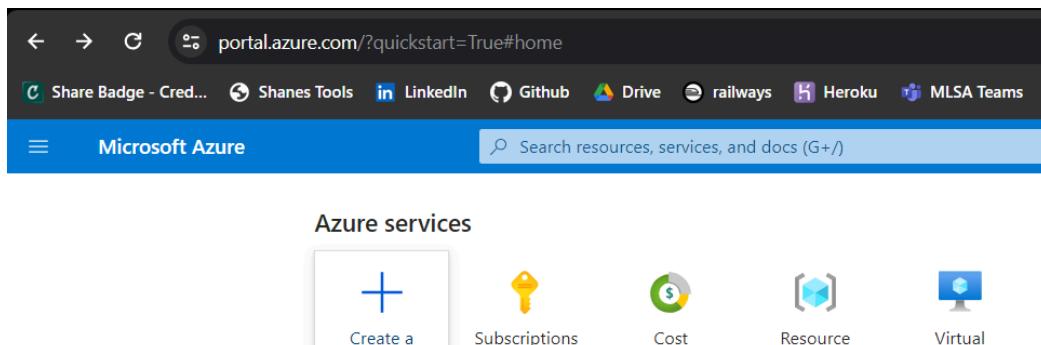
Setup for testing

Please follow these steps to set up a VM that can be used as a machine for this code. In case of testing on local machines within IIT network, skip the VM setup and directly replace IPs with corresponding device IPs. Then run all 3 using GCC similar to any C/C++ program. (Ensure that all 3 are turned on almost exactly at the same time else TCP connection would end up throwing an error if a CS request is sent.

Approximate testing cost expected: Total 5Rs on Azure using 2 processor, 4GB RAM VM with Global IP enabled per device x3 devices.

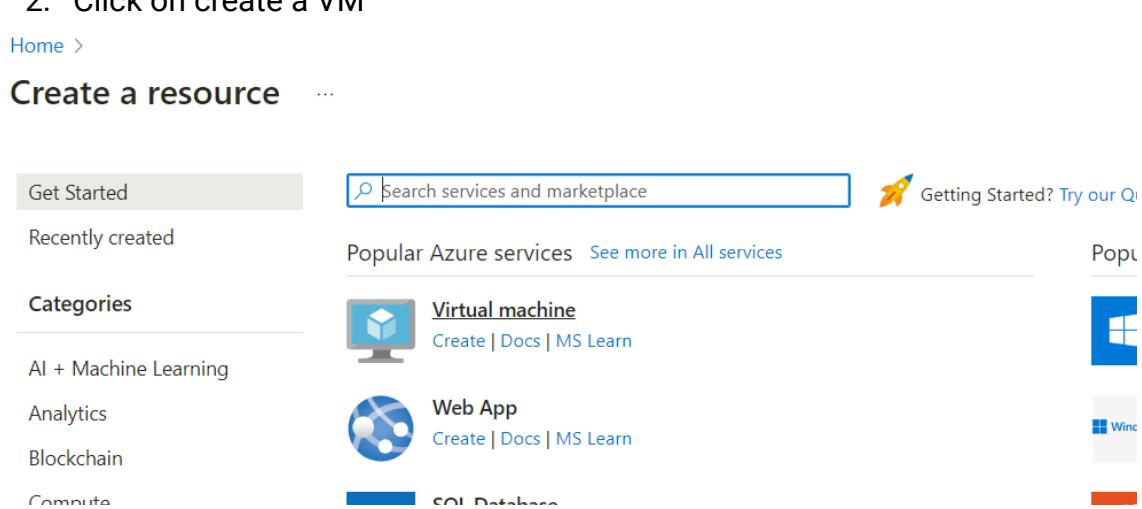
Creating VM:

1. Click on create a resource on azure portal (portal.azure.com)



The screenshot shows the Microsoft Azure portal homepage. At the top, there is a navigation bar with links for Share Badge - Cred..., Shanes Tools, LinkedIn, Github, Drive, railways, Heroku, and MLSA Teams. Below the navigation bar is a search bar with the placeholder 'Search resources, services, and docs (G+ /)'. The main content area is titled 'Azure services' and features a 'Create a resource' button with a plus sign icon, which is highlighted with a white box. Other buttons include 'Subscriptions' (key icon), 'Cost Management ...' (dollar sign icon), 'Resource groups' (cube icon), and 'Virtual machines' (monitor icon). Below this section is a 'Resources' heading.

2. Click on create a VM



The screenshot shows the 'Create a resource' page in the Azure portal. At the top left, there is a 'Get Started' button and a 'Search services and marketplace' bar. To the right, there is a 'Getting Started? Try our Q!' link with a yellow rocket icon. Below the search bar, there is a 'Recently created' section and a 'Popular Azure services' section with a 'See more in All services' link. The 'Virtual machine' service is selected and highlighted with a blue border. Other services listed include 'Web App' and 'SQL Database'. On the left, there is a 'Categories' sidebar with links for AI + Machine Learning, Analytics, Blockchain, and Compute.

3. Fill in the basic details as needed.

- Create a resource group (preferably separate per virtual machine)
- Enter a name for VM
- Select a Linux machine with x64 architecture (pref. Ubuntu 20.04)
- select standard B2s machine machine to a 2 processor, 4GB RAM
- Enter a username and keep login medium SSH key
- Rest to default
- On disk select a standard SSD
- Keep everything the same and move to review + create and create a VM.

Create a virtual machine

Click here to try out the Azure Copilot for additional recommendations while creating a virtual machine →

Basics Disks Networking Management Monitoring Advanced Tags Review + create

Create a virtual machine that runs Linux or Windows. Select an image from Azure marketplace or use your own customized image. Complete the Basics tab then Review + create to provision a virtual machine with default parameters or review each tab for full customization. [Learn more](#)

Project details

Select the subscription to manage deployed resources and costs. Use resource groups like folders to organize and manage all your resources.

Subscription * ⓘ Visual Studio Enterprise Subscription (38db08dc-7efd-4dc9-9c84-9a00e69d...)

Resource group * ⓘ (New) CCPVMG3

[Create new](#)

Instance details

Virtual machine name * ⓘ CVM3

Region * ⓘ (Asia Pacific) Central India

Availability options ⓘ Availability zone

[< Previous](#) [Next : Disks >](#) **Review + create**

Create a virtual machine

Click here to try out the Azure Copilot for additional recommendations while creating a virtual machine →

Availability zone * ⓘ Zone 1 ⓘ You can now select multiple zones. Selecting multiple zones will create one VM per zone. [Learn more](#)

Security type ⓘ Trusted launch virtual machines ⓘ [Configure security features](#)

Image * ⓘ Ubuntu Server 20.04 LTS - x64 Gen2 ⓘ [See all images](#) | [Configure VM generation](#)

VM architecture ⓘ Arm64 x64

Run with Azure Spot discount ⓘ

Size * ⓘ Standard_B2s - 2 vcpus, 4 GiB memory (₹2,720.80/month) ⓘ [See all sizes](#)

Enable Hibernation (preview) ⓘ ⓘ Hibernation does not currently support Trusted launch and Confidential virtual machines for Linux images. [Learn more](#)

[< Previous](#) [Next : Disks >](#) [Review + create](#)

Create a virtual machine

Click here to try out the Azure Copilot for additional recommendations while creating a virtual machine →

Administrator account

Authentication type ⓘ SSH public key Password

ⓘ Azure now automatically generates an SSH key pair for you and allows you to store it for future use. It is a fast, simple, and secure way to connect to your virtual machine.

Username * ⓘ shreyas ⓘ

SSH public key source ⓘ Generate new key pair ⓘ

Key pair name * ⓘ CVM3_key ⓘ

Inbound port rules

Select which virtual machine network ports are accessible from the public internet. You can specify more limited or granular network access on the Networking tab.

Public inbound ports * ⓘ None Allow selected ports

[< Previous](#) [Next : Disks >](#) [Review + create](#)

Create a virtual machine

...

 Click here to try out the Azure Copilot for additional recommendations while creating a virtual machine →

Username * 

shreyas 

SSH public key source

Generate new key pair 

Key pair name * 

CVM3_key 

Inbound port rules

Select which virtual machine network ports are accessible from the public internet. You can specify more limited or granular network access on the Networking tab.

Public inbound ports * 

None

Allow selected ports

Select inbound ports * 

SSH (22) 



All traffic from the internet will be blocked by default. You will be able to change inbound port rules in the VM > Networking page.

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Review + create

Home > Create a resource >

Create a virtual machine

...

default when persisting it to the cloud.

Encryption at host 



 Encryption at host is not registered for the selected subscription.

[Learn more about enabling this feature](#) 

OS disk

OS disk size 

Image default (30 GiB) 

OS disk type * 

Standard SSD (locally-redundant storage) 

The selected VM size supports premium disks. We recommend Premium SSD for high IOPS workloads. Virtual machines with Premium SSD disks qualify for the 99.9% connectivity SLA.

Delete with VM 



Key management 

Platform-managed key 

Enable Ultra Disk compatibility 



Data disks for CVM3

You can add and configure additional data disks for your virtual machine or attach existing disks. This VM also comes with a [temporary disk](#)

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Review + create

Home > Create a resource >

Create a virtual machine

 Validation passed

Basics Disks Networking Management Monitoring Advanced Tags **Review + create**

Price

1 X Standard B2s

by Microsoft

[Terms of use](#) | [Privacy policy](#)

Subscription credits apply ⓘ

3.7271 INR/hr

[Pricing for other VM sizes](#)

TERMS

By clicking "Create", I (a) agree to the legal terms and privacy statement(s) associated with the Marketplace offering(s) listed above; (b) authorize Microsoft to bill my current payment method for the fees associated with the offering(s), with the same billing frequency as my Azure subscription; and (c) agree that Microsoft may share my contact, usage and transactional information with the provider(s) of the offering(s) for support, billing and other transactional activities. Microsoft does not provide rights for third-party offerings. See the [Azure Marketplace Terms](#) for additional details.

Name

Shreyas Sukhadeve

Preferred e-mail address

Shreyas.Sukhadeve@studentambassadors.com

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Create

Home > Create a resource >

Create a virtual machine

 Validation passed

Basics

Subscription	Visual Studio Enterprise Subscription
Resource group	(new) CCPVMG3
Virtual machine name	CVM3
Region	Central India
Availability options	Availability zone
Availability zone	1
Security type	Trusted launch virtual machines
Enable secure boot	Yes
Enable vTPM	Yes
Integrity monitoring	No
Image	Ubuntu Server 20.04 LTS - Gen2
VM architecture	x64
Size	Standard B2s (2 vcpus, 4 GiB memory)
Enable Hibernation (preview)	No
Authentication type	SSH public key
Username	shreyas
Keypair name	CVM3_kev

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Create

- Save the private SSH key generated on your computer and then copy it to the root linux directory, usually visible at bottom of file manager for WSL and paste it on the path: linux>Ubuntu20.04>home>user>.ssh> and paste it. If you have never ran a VM on local machine, you may not have a .ssh folder, in such a case just create a simple new folder and paste it there.

Validation passed

Basics Disks Networking Management Monitoring Advanced Tags Review + create

Price

1 X Standard B2s by Microsoft

Subscription credits apply 3.7271 INR/hr

TERMS

By clicking "Create", I (a) agree to the legal terms and privacy statement(s) associated with the above; (b) authorize Microsoft to bill my current payment method for the fees associated with the billing frequency as my Azure subscription; and (c) agree that Microsoft may share my contact, information with the provider(s) of the offering(s) for support, billing and other transactional and provide rights for third-party offerings. See the [Azure Marketplace Terms](#) for additional details.

Name Shreyas Sukhadave

Preferred e-mail address Shreyas.Sukhadave@studentambassadors.com

Download a template for automation Give feedback

Save As

Cloud Computing > Project > Azure VM SSH > VM1

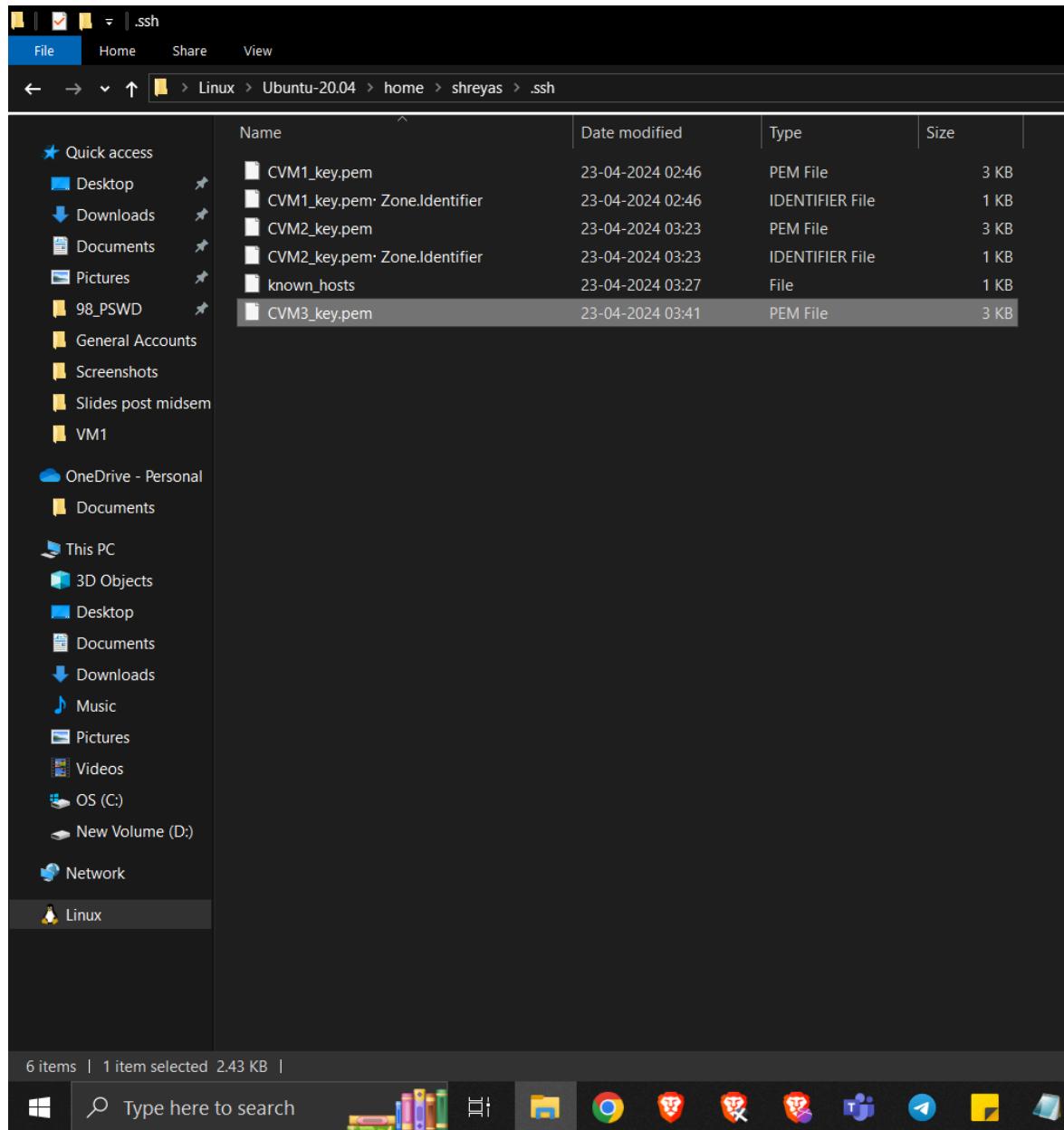
Organize New folder

Name	Date modified	Type	Size
CVM1_key.pem	23-04-2024 02:46	PEM File	3
CVM2_key.pem	23-04-2024 03:23	PEM File	3
SASVM1KP.pem	22-04-2024 04:22	PEM File	3
SASVM1PK1.pem	22-04-2024 06:19	PEM File	3

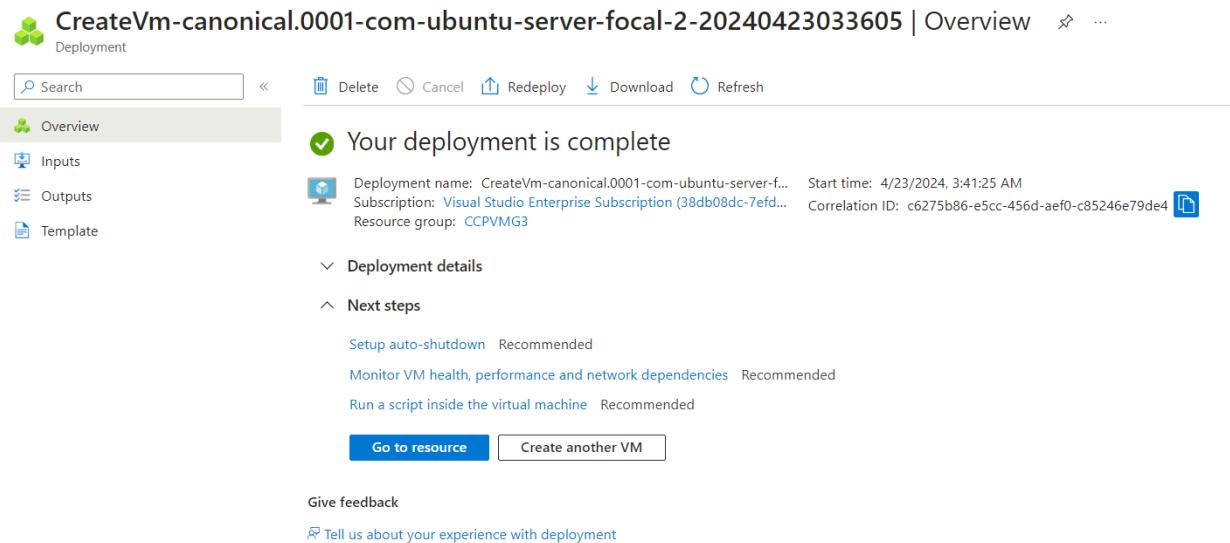
File name: CVM3_key.pem

Save as type: PEM File (*.pem)

Save Cancel



5. Now click on Go to resource and you will be able to see deployed machine specifications.



Deployment name: CreateVm-canonical.0001-com-ubuntu-server-focal-2-20240423033605 | Overview

Deployment is complete

Deployment name: CreateVm-canonical.0001-com-ubuntu-server-focal-2-20240423033605 | Start time: 4/23/2024, 3:41:25 AM

Subscription: Visual Studio Enterprise Subscription (38db08dc-7efd-4dc9-9c84-9a00e69dd3d2) | Correlation ID: c6275b86-e5cc-456d-aef0-c85246e79de4

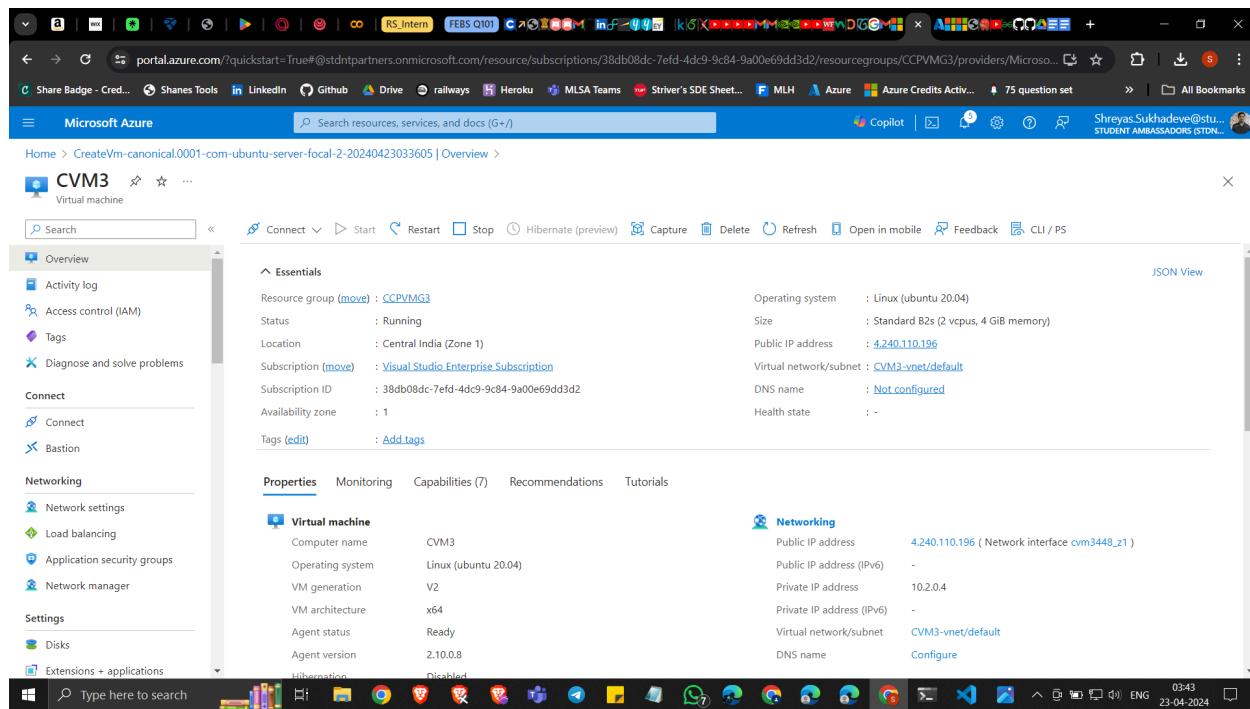
Resource group: CCPVMG3

Deployment details

Next steps

- Setup auto-shutdown Recommended
- Monitor VM health, performance and network dependencies Recommended
- Run a script inside the virtual machine Recommended

Go to resource | Create another VM



CVM3 | Overview

Resource group: CCPVMG3 | Status: Running | Location: Central India (Zone 1) | Subscription: Visual Studio Enterprise Subscription | Subscription ID: 38db08dc-7efd-4dc9-9c84-9a00e69dd3d2 | Availability zone: 1 | Tags: Add tags

Operating system: Linux (ubuntu 20.04) | Size: Standard B2s (2 vcpus, 4 GiB memory) | Public IP address: 4.240.110.196 | Virtual network/subnet: CVM3-vnet/default | DNS name: Not configured | Health state: -

Properties | Monitoring | Capabilities (7) | Recommendations | Tutorials

Virtual machine

Computer name	CVM3
Operating system	Linux (ubuntu 20.04)
VM generation	V2
VM architecture	x64
Agent status	Ready
Agent version	2.10.0.8
Hibernation	Disabled

Networking

Public IP address	4.240.110.196 (Network interface cvm3448_z1)
Public IP address (IPv6)	-
Private IP address	10.2.0.4
Private IP address (IPv6)	-
Virtual network/subnet	CVM3-vnet/default
DNS name	Configure

6. Now click on connect and then Native SSH, then follow the instructions on the right that show how to setup VM access on local desktop terminal. This includes running 2 commands:

1. **chmod 400 ./ssh/key.pem**
2. **ssh -i ./ssh/key.pem username@GlobalIP**

Recommended Most common

SSH using Azure CLI
Quickly connect in browser. Supports Microsoft Entra ID authentication. Private key not required.
Public IP address (4.240.110.196)

Select

Native SSH
No additional software needed. Private key required for connection. Best for those with existing SSH tools.
Public IP address (4.240.110.196)

Select

Native SSH
Connect from your local machine (Windows)

Switch local machine OS

1 Configure prerequisites for Native SSH
Azure needs to configure some features in order to connect to the VM.

Validating prerequisites before configuration

Port 22 access
Validating access to port 22 on the virtual machine. [Learn more](#)
i Change the port for connecting to this virtual machine on the Connect page of the virtual machine.

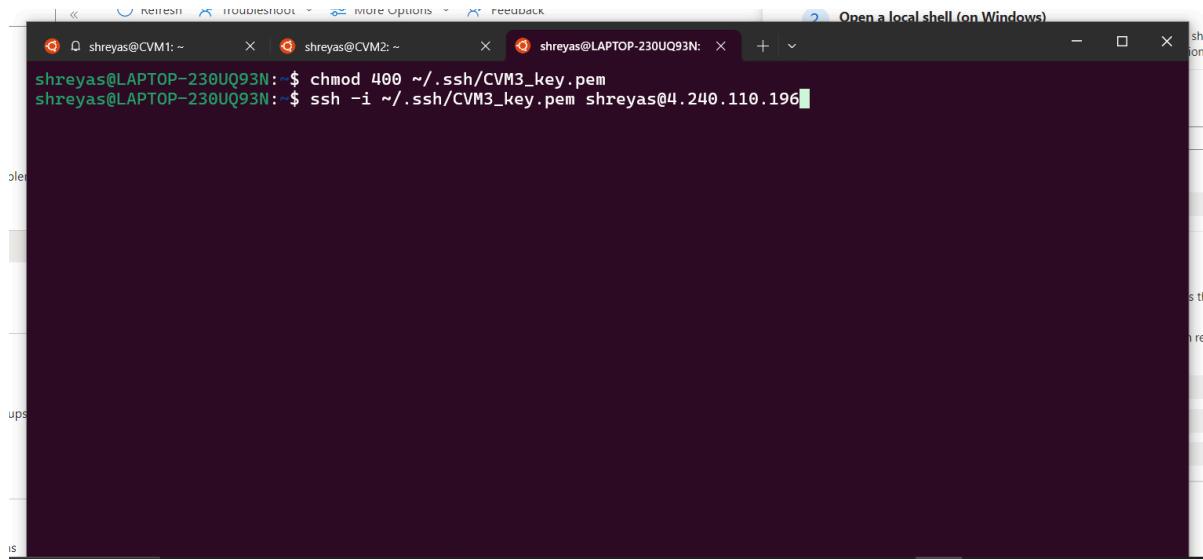
Public IP address: 4.240.110.196
A public IP address is required to connect via this connection method.
Validating...

2 Open a local shell (on Windows)
Open Terminal (Windows 11), PowerShell (Windows 10 or less), or a shell of your choice. Or switch the local machine OS above to view more instructions.

3 Copy and execute SSH command
Provide a path to your SSH private key file on your local machine.

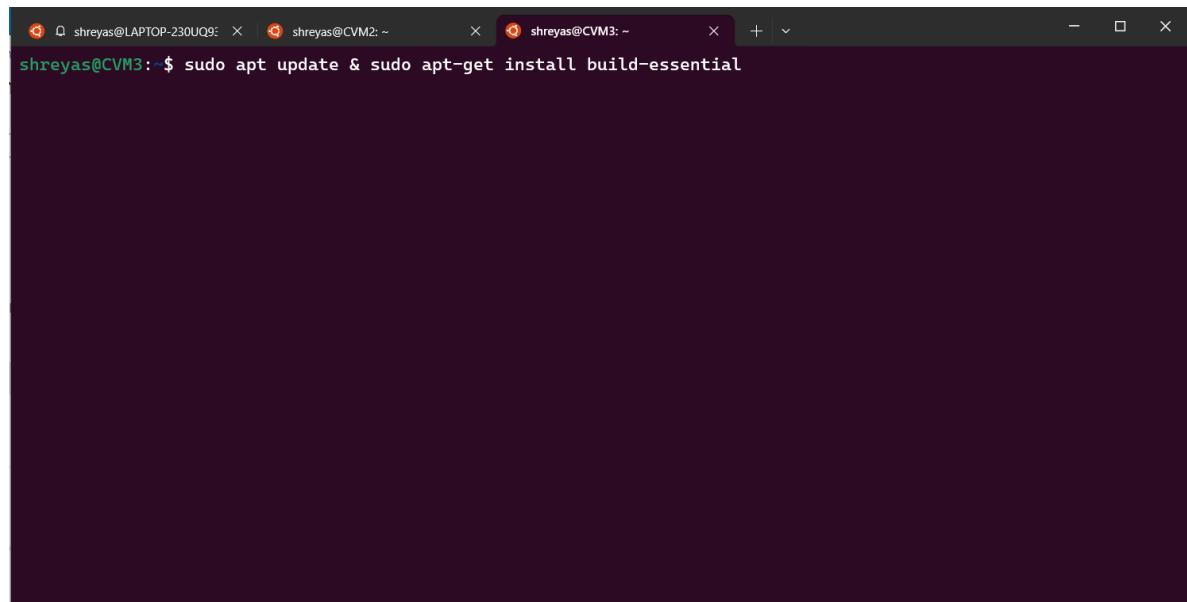
Can't find your private key? [Reset your SSH private key](#)
SSH to VM with specified private key.
`ssh -i ~/ssh/id_rsa.pem shreyas@4.240.110.196`

Close [Troubleshooting](#) [Give feedback](#)



shreyas@LAPTOP-230UQ93N:~\$ chmod 400 ~/.ssh/CVM3_key.pem
shreyas@LAPTOP-230UQ93N:~\$ ssh -i ~/.ssh/CVM3_key.pem shreyas@4.240.110.196

7. Now, you would be connected to a local instance of VM CLI.
Run ***sudo apt update*** and ***sudo apt-get install build-essential*** to install gcc compiler. Test with ***gcc -v***.

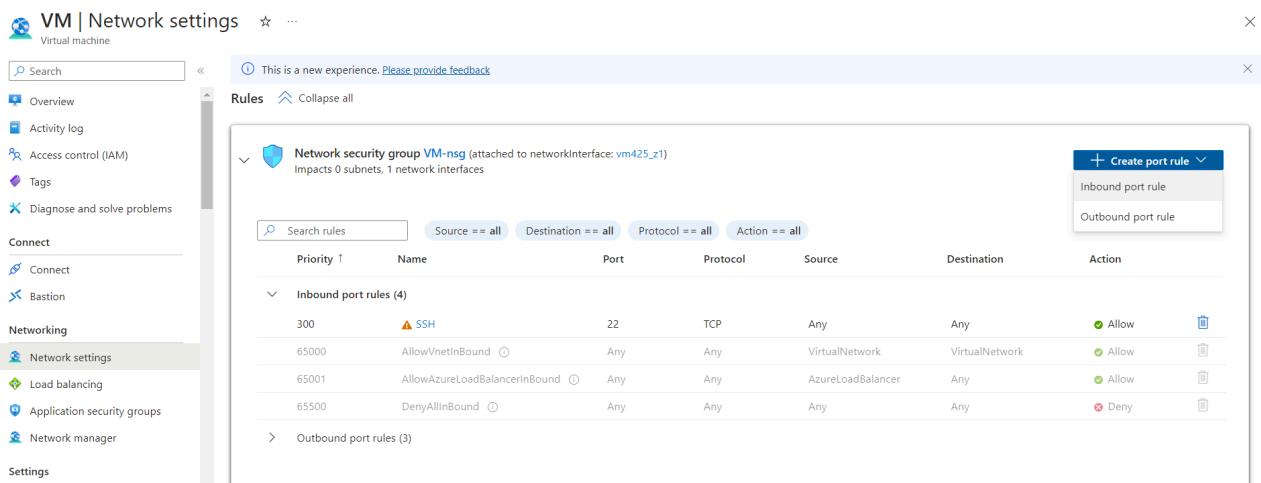


shreyas@CVM3:~\$ sudo apt update & sudo apt-get install build-essential

Setting up inbound and outbound port rules for network access

Go to Network settings from the left panel, starting on the VM stats page where we pressed connect. After that come down to rules heading where you will find the create port rules option.

Click on add rules and it gives 2 options to create an inbound rule and outbound rule where you fill in the allowed source port (*) and destination port (8001) for incoming and outgoing traffic for all IPs (*) respectively.



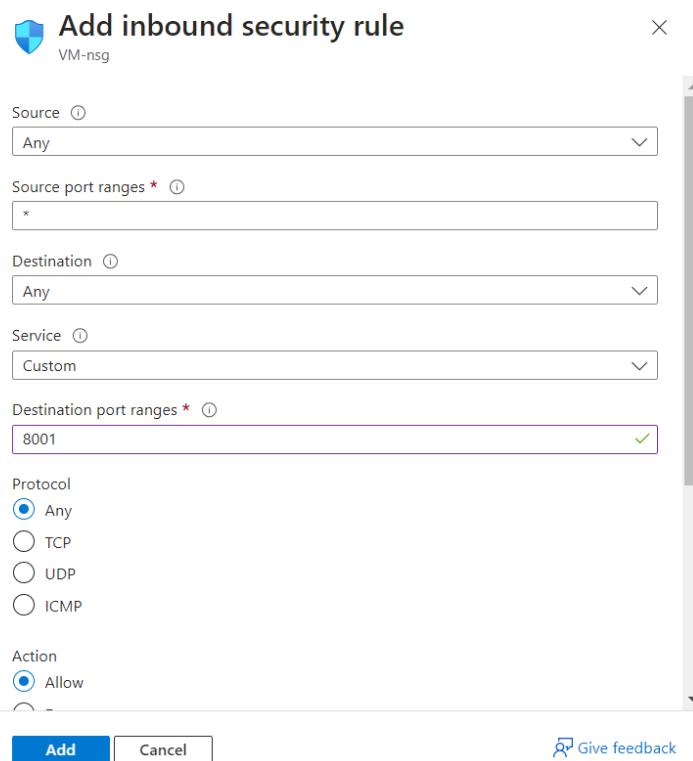
VM | Network settings

Virtual machine

Rules

Network security group VM-nsg (attached to networkInterface: vm425_x1)
Impacts 0 subnets, 1 network interfaces

Priority ↑	Name	Port	Protocol	Source	Destination	Action
300	SSH	22	TCP	Any	Any	Allow
65000	AllowVnetInBound	Any	Any	VirtualNetwork	VirtualNetwork	Allow
65001	AllowAzureLoadBalancerInBound	Any	Any	AzureLoadBalancer	Any	Allow
65500	DenyAllInBound	Any	Any	Any	Any	Deny



Add inbound security rule

VM-nsg

Source

Source port ranges *

Destination

Service

Protocol

Action

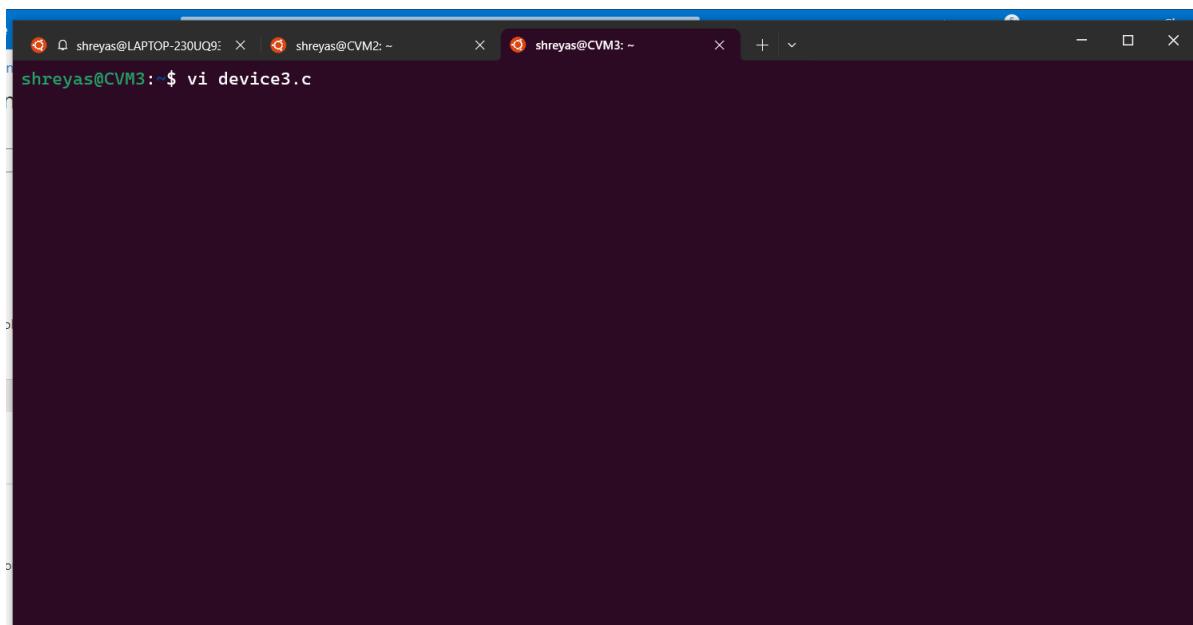
Destination port ranges *

8001

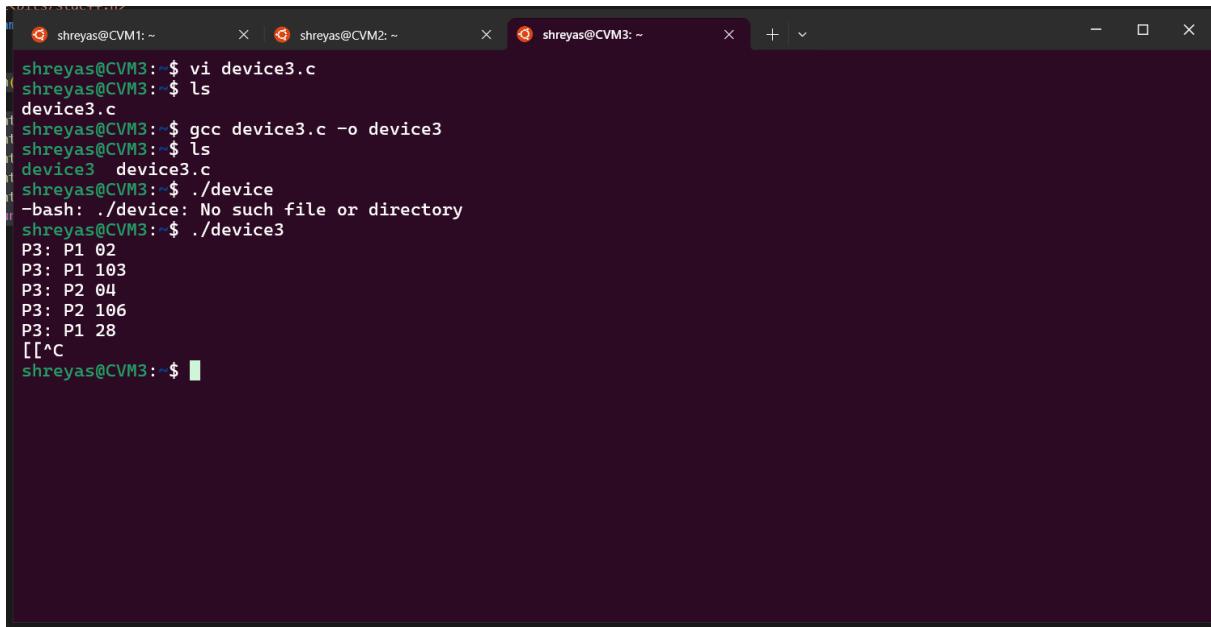
Add Cancel Give feedback

Running Code on VM CLI

Download the code from github and keep it ready. We will be copy-pasting it in VM CLI. Once ready run the command **vi device1.c**, this opens an editor with ~ to mark the left border as seen below. Click **i** to enter insert mode. Paste the code. Click **esc** to exit insert mode. Type **:wq** to save and exit the editor. Now you have a .c file ready. Now run **gcc device1.c -o device1** to compile the code and then the executable generated using **./device1** simultaneous to all other devices. Try to minimize differences in starting the program executions.



The screenshot shows a Linux desktop environment with a terminal window open. The terminal window has three tabs at the top: 'shreyas@LAPTOP-230UQ9: ~', 'shreyas@CVM2: ~', and 'shreyas@CVM3: ~'. The 'shreyas@CVM3: ~' tab is active. The terminal window has a dark background and a light-colored text area. The text area shows the command 'shreyas@CVM3: \$ vi device3.c' followed by a large number of tilde (~) characters, which are the visual representation of the left border in the vi editor. The bottom status bar of the terminal window shows the file name 'device3.c' and the status '0,0-1 All'.



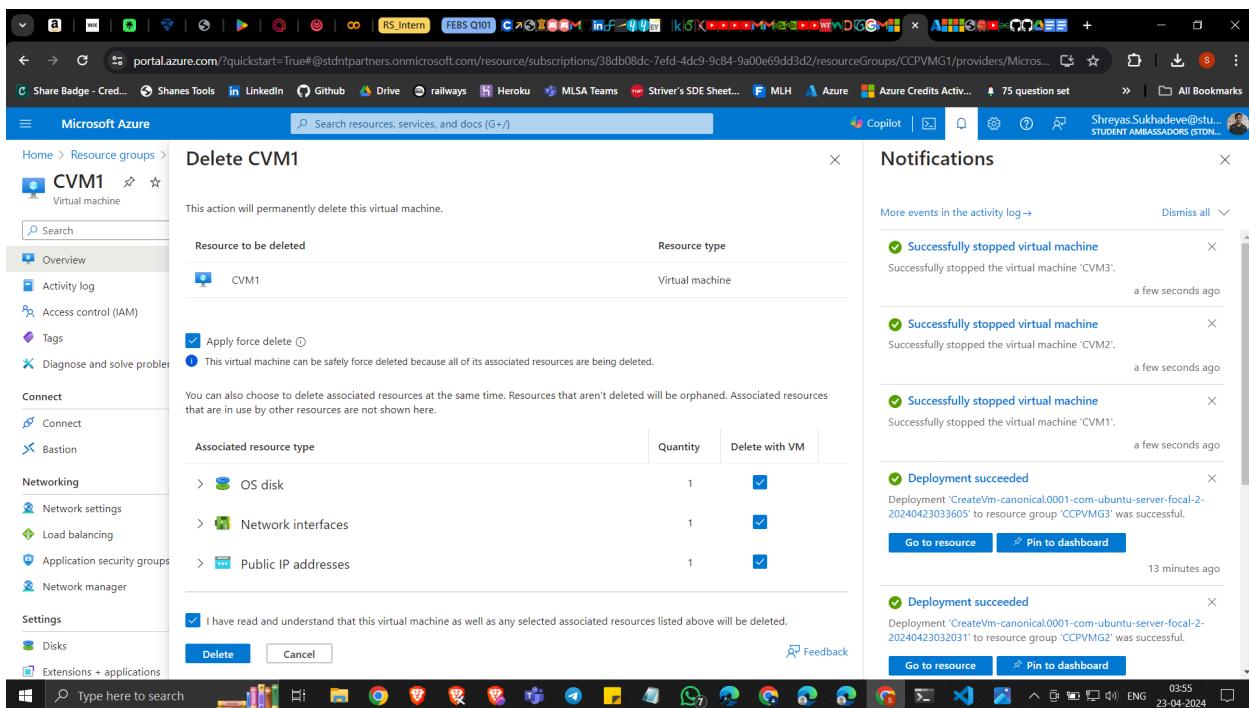
```

shreyas@CVM3: $ vi device3.c
shreyas@CVM3: $ ls
device3.c
shreyas@CVM3: $ gcc device3.c -o device3
shreyas@CVM3: $ ls
device3 device3.c
shreyas@CVM3: $ ./device
-bash: ./device: No such file or directory
shreyas@CVM3: $ ./device3
P3: P1 02
P3: P1 103
P3: P2 04
P3: P2 106
P3: P1 28
[[^C
shreyas@CVM3: ~

```

Now you have the result.

After testing, don't forget to close and delete the VMM and all other resources in the resource group to avoid unnecessary charges.



Delete CVM1

This action will permanently delete this virtual machine.

Resource to be deleted	Resource type
CVM1	Virtual machine

Apply force delete ⓘ
 ⓘ This virtual machine can be safely force deleted because all of its associated resources are being deleted.

You can also choose to delete associated resources at the same time. Resources that aren't deleted will be orphaned. Associated resources that are in use by other resources are not shown here.

Associated resource type	Quantity	Delete with VM
OS disk	1	<input checked="" type="checkbox"/>
Network interfaces	1	<input checked="" type="checkbox"/>
Public IP addresses	1	<input checked="" type="checkbox"/>

I have read and understand that this virtual machine as well as any selected associated resources listed above will be deleted.

Delete **Cancel** **Feedback**

Notifications

More events in the activity log → **Dismiss all**

- Successfully stopped virtual machine** Successfully stopped the virtual machine 'CVM3'. a few seconds ago
- Successfully stopped virtual machine** Successfully stopped the virtual machine 'CVM2'. a few seconds ago
- Successfully stopped virtual machine** Successfully stopped the virtual machine 'CVM1'. a few seconds ago
- Deployment succeeded** Deployment 'CreateVm-canonical.0001-com-ubuntu-server-focal-2-20240423033605' to resource group 'CCPVMG3' was successful. **Go to resource** **Pin to dashboard** 13 minutes ago
- Deployment succeeded** Deployment 'CreateVm-canonical.0001-com-ubuntu-server-focal-2-20240423032031' to resource group 'CCPVMG2' was successful. **Go to resource** **Pin to dashboard**

Thank you for reading through.