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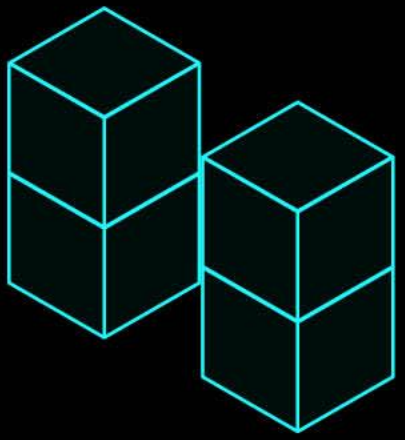

Analyzing volatile memory on a Google Kubernetes Engine node

Marcus Hallberg
Security engineer - Detection & Response
Spotify

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Disclaimer

- This talk presents personal research and applications of open source tools.
- Spotify is not liable for this content or published code.
- Questions, remarks or other actions should be aimed towards the presenter.

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Agenda

- Main takeaways
- Container workloads at Spotify
- Google Kubernetes Engine
- What are memory snapshots?
- How can we create a memory snapshot on GKE?
- Demo and analysis

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Main takeaways

- Accessing and analysing volatile memory on a GKE node.
- Complete setup using open source tools.
- All code used - https://github.com/Monrava/cyberthreat2023

Source: https://gifdb.com/images/high/funny-sassy-cat-waiting-hurry-up-1drmhnti7ucgiqee.webp

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Container workloads at Spotify

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5 GCP Regions

4096 nodes/cluster

+4000 services

+3000 namespaces

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Source https://image.cnbcfm.com/api/v1/image/107149511-1668071326472-gettyimages-997042320-148347209.jpeg?v=1668140224&w=740&h=416&ffmt=webp&vtcrop=y

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The problem:

- We get an alert that a user accessed a container in GKE.
- What did user do once they accessed the container?
- There are no commercial tools available.

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Source https://e0.pxfuel.com/wallpapers/26/241/desktop-wallpaper-art-owl-coffee-alarm-clock.jpg

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```
"principalEmail": "          @spotify.com"
"granted": true,
"permission": "io.k8s.core.v1.pods.exec.create",
"resource": "core/v1/namespaces/default/pods/pod-node-affinity-zeroday-attacker-pod/exec"
"callerIp": "195.178.178.197",
"callerSuppliedUserAgent": "kubectl/v1.25.4 (darwin/am
"resourceName": "core/v1/namespaces/default/pods/pod-n
"cluster_name": "zeroday-gke-cluster",
"project_id": "PROJECT_NAME",
"location": "europe-west1-b"
"timestamp": "2023-04-11T12:23:43.423331Z",
"logName": "projects/PROJECT_NAME/logs/cloudaudit.goog
"id": "d42f3772-56da-4658-b996-3eaf024b6b59",
"receiveTimestamp": "2023-04-11T12:23:57.235797324Z"
```


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Google Kubernetes Engine

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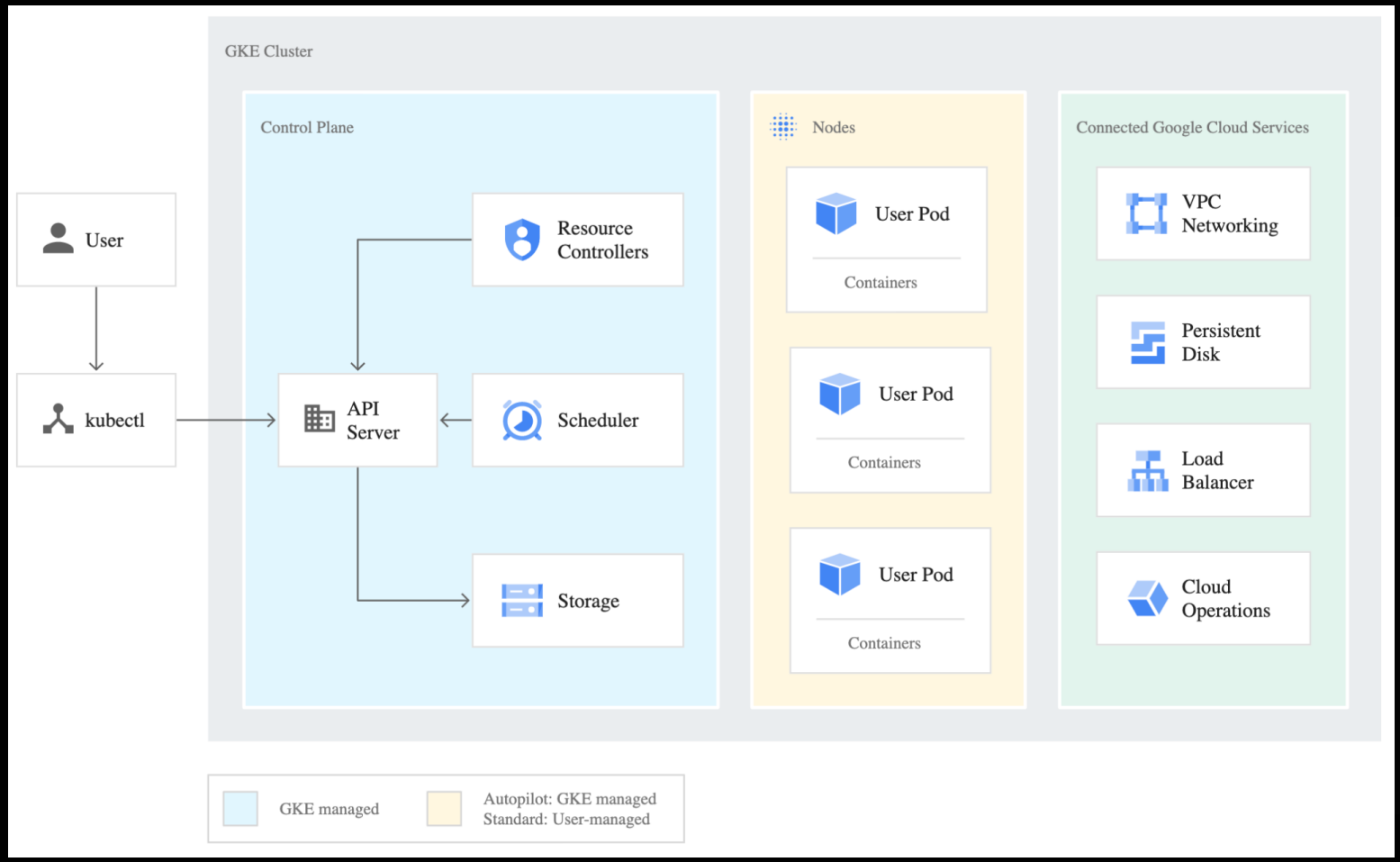

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Source https://cloud.google.com/kubernetes-engine/docs/concepts/cluster-architecture

What are memory snapshots?

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Memory snapshots

- What are they?
- Are they still used?
- Why would we take memory snapshots on GKE nodes?

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Source https://kodakdigitizing.com/blogs/news/what-is-a-polaroid-picture-1

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The problem:

- We get an alert that a user accessed a container in GKE.
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Source https://e0.pxfuel.com/wallpapers/26/241/desktop-wallpaper-art-owl-coffee-alarm-clock.jpg

How can we create a memory snapshot on GKE?

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How do we create a GKE memory snapshot?

- Step 1 - Kernel memory dump:
  - /proc/kcore
  - AVML
- Step 2 - Symbol file:
  - vmlinux
  - dwarf2json
- Step 3 - Analysis (Volatility3)

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The How:
Step 1 - Kernel memory dump

- /proc/kcore

This file represents the physical memory of the system and is stored in the ELF core file format.

The total length of the file is the size of physical memory (RAM) plus 4 KiB.

- AVML (Or other tool able to take dumps of this file)

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The How:
Step 1 - Kernel memory dump

- How do we access /proc/kcore?

```
container {
  name  = "avml-container"
  image = var.container_image_avml
  security_context {
      privileged = "true"
      capabilities {
        add = ["CAP_NET_ADMIN", "CAP_SYS_ADMIN"]
      }
    }
```

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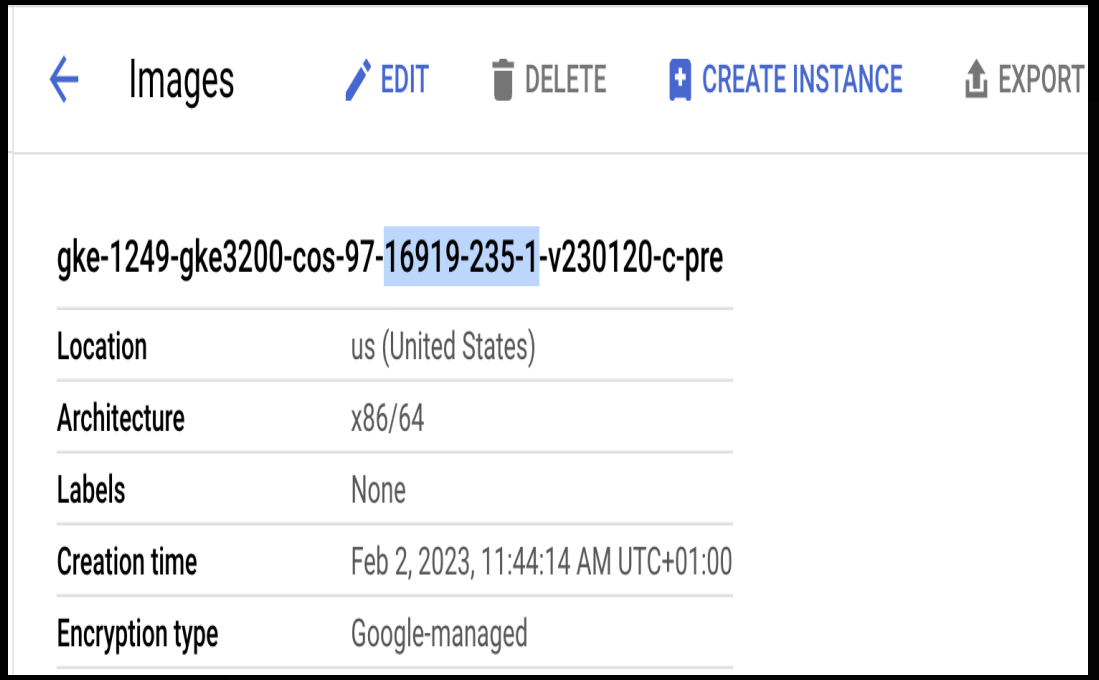
The How:
Step 2 - Symbol file

- vmlinux - what is it?

  https://storage.googleapis.com/cos-tools/$build_id/vmlinux

  https://storage.googleapis.com/cos-tools/**16919.235.1**/vmlinux

- dwarf2json



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Source: https://cloud.google.com/container-optimized-os/docs/concepts/versioning#milestones_and_build_numbers

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The How:
Step 3 - Analysis

- Volatility3

volatilityfoundation/
volatility3

Volatility 3.0 development

46 Contributors | 83 Used by | 2k Stars | 321 Forks

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Testing setup

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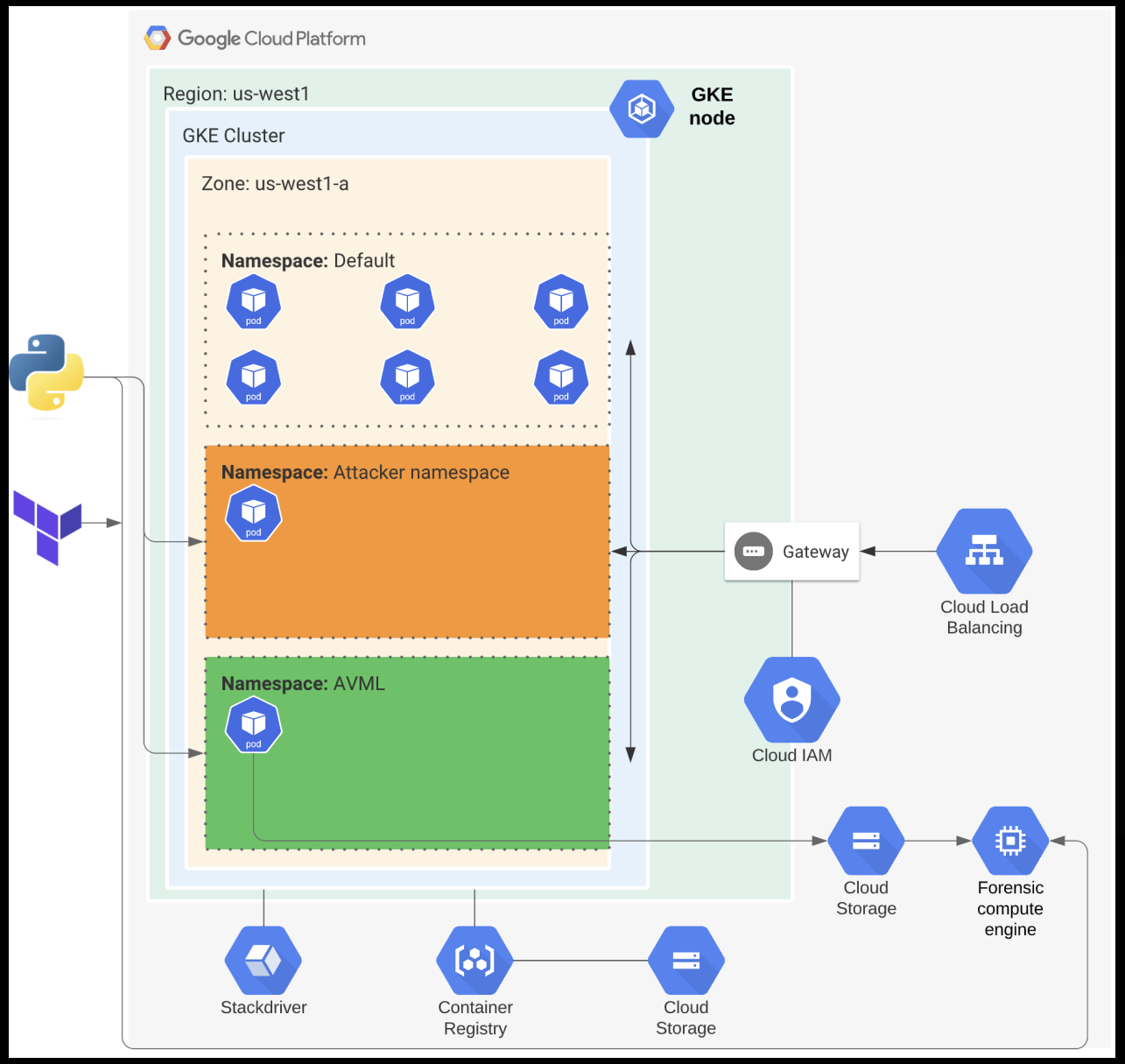

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Test and analysis

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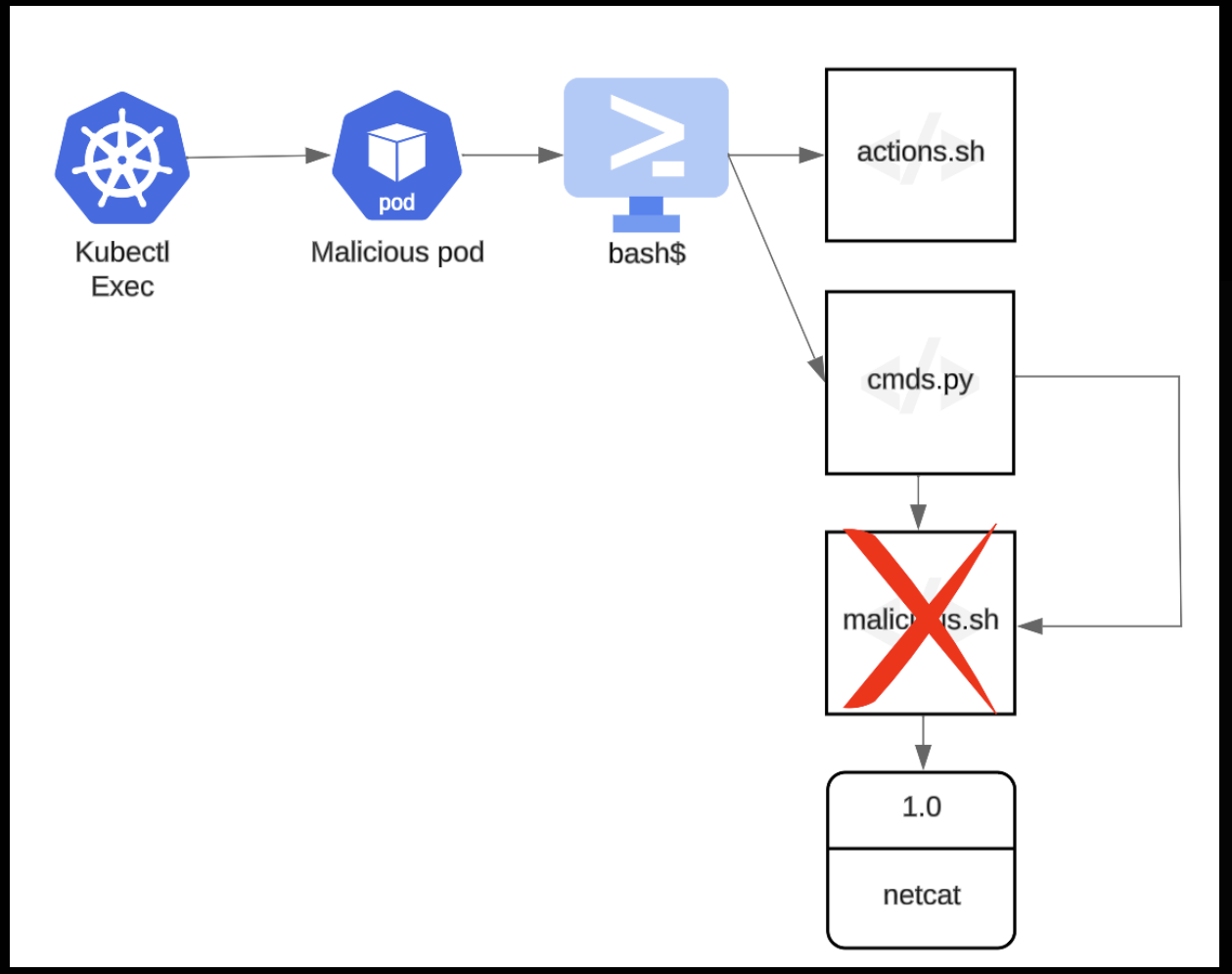
What we tested

- Various commands using bash
  - Running processes
  - Checking external IP address
  - Running scripts

- Started processes
  - Netcat
  - Python3
  - Bash shell script



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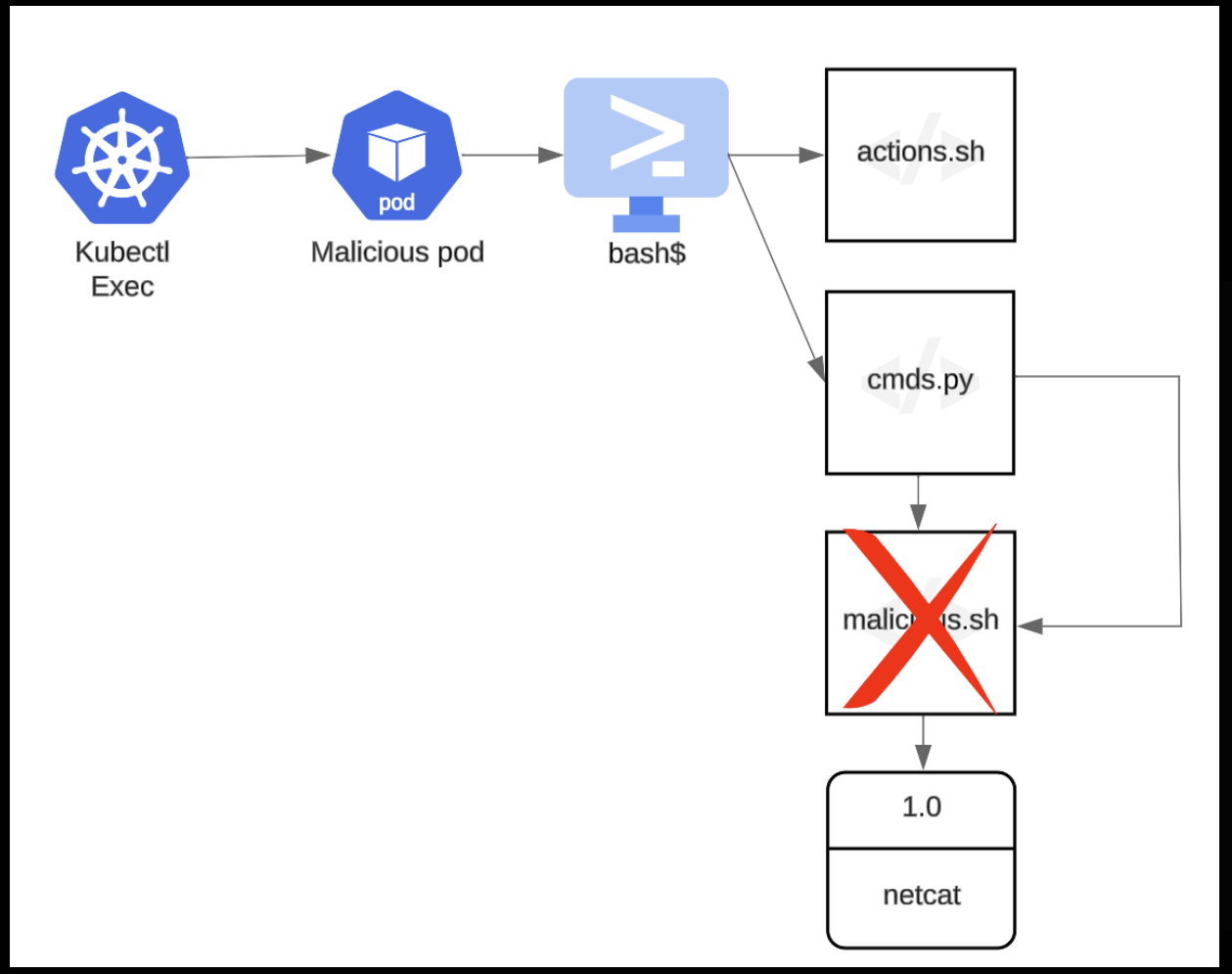
What can we see from the GKE memory dump?



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PID	Process	CommandTime	Command
82141	bash	2023-11-16 12:33:43.000000	ls -la /proc/
82141	bash	2023-11-16 12:33:43.000000	unshare -Urm
82141	bash	2023-11-16 12:33:43.000000	echo $SHELL
82141	bash	2023-11-16 12:33:43.000000	cat /proc/1/cgroup
82141	bash	2023-11-16 12:33:43.000000	HISTFILE=~/.bash_history
82141	bash	2023-11-16 12:33:43.000000	
82141	bash	2023-11-16 12:33:43.000000	#1700138023
82141	bash	2023-11-16 12:33:43.000000	#!/bin/bash -i
82141	bash	2023-11-16 12:33:43.000000	ps aux
82141	bash	2023-11-16 12:33:43.000000	nohup watch -n1 curl -s ifconfig.co &
82141	bash	2023-11-16 12:33:43.000000	grep Cap /proc/1/status
82141	bash	2023-11-16 12:33:43.000000	set -o history
82141	bash	2023-11-16 12:33:43.000000	whoami
82141	bash	2023-11-16 12:33:43.000000	ls -la
82141	bash	2023-11-16 12:33:43.000000	history
82141	bash	2023-11-16 12:33:43.000000	./actions.sh
82141	bash	2023-11-16 12:33:43.000000	ls /root
82141	bash	2023-11-16 12:33:43.000000	pwd
82141	bash	2023-11-16 12:33:43.000000	ls -la
82141	bash	2023-11-16 12:33:43.000000	df -h
82141	bash	2023-11-16 12:33:43.000000	exit

Bash history plugin (Commands are captured in memory)

0x9e2601848fc0	58495	58495	58054	watch
0x9e2603f94ec0	58531	58531	57701	bash
0x9e2528de1f80	58687	58687	58054	python3
0x9e260ace1f80	58754	58754	58687	sh
0x9e260ace2f40	58756	58756	58754	nc
0x9e260ace5e80	58763	58763	58687	bash
0x9e25018d5e80	58839	58839	57892	avml

PSList plugin (Both container activities)

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Source: https://volatility3.readthedocs.io/en/latest/volatility3.plugins.linux.html

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```
*** 0x9e2601848fc0  58495   58495   58054   watch
*** 0x9e2528de1f80  58687   58687   58054   python3
**** 0x9e260ace1f80 58754   58754   58687   sh
***** 0x9e260ace2f40    58756   58756   58754   nc
```

PSTree plugin (Attacker container)

PSaux plugin (Both container activities)

```
58054   watch   watch -n1 curl -s ifconfig.co
57701   bash    /bin/bash
58054   python3 python3 cmds.py
58687   sh  /bin/sh -c ./malicious_script.sh
58754   nc  /bin/nc -l 10514
58687   bash    [bash]
```

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Lessons learned

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What have we learned?

- AVML + Dwarf2json + Volatility3
  - NodeSelector
  - Acquire vmlinux for GKE/COS using build_id
  - Be aware of updates to kernel or compiler

- Avoid overutilization
  - Cluster rebalancing - evicted
  - ContainerStatusUnknown with exit code 137

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- Get in touch
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  - LinkedIn: in/hallbergmarcus
  - @: mhallberg@spotify.com

- Code
  - https://github.com/Monrava/cyberthreat2023

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