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Towards Improving Container Security by Preventing Runtime Escapes

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#IEEESecDev https://secdev.ieee.org/2021

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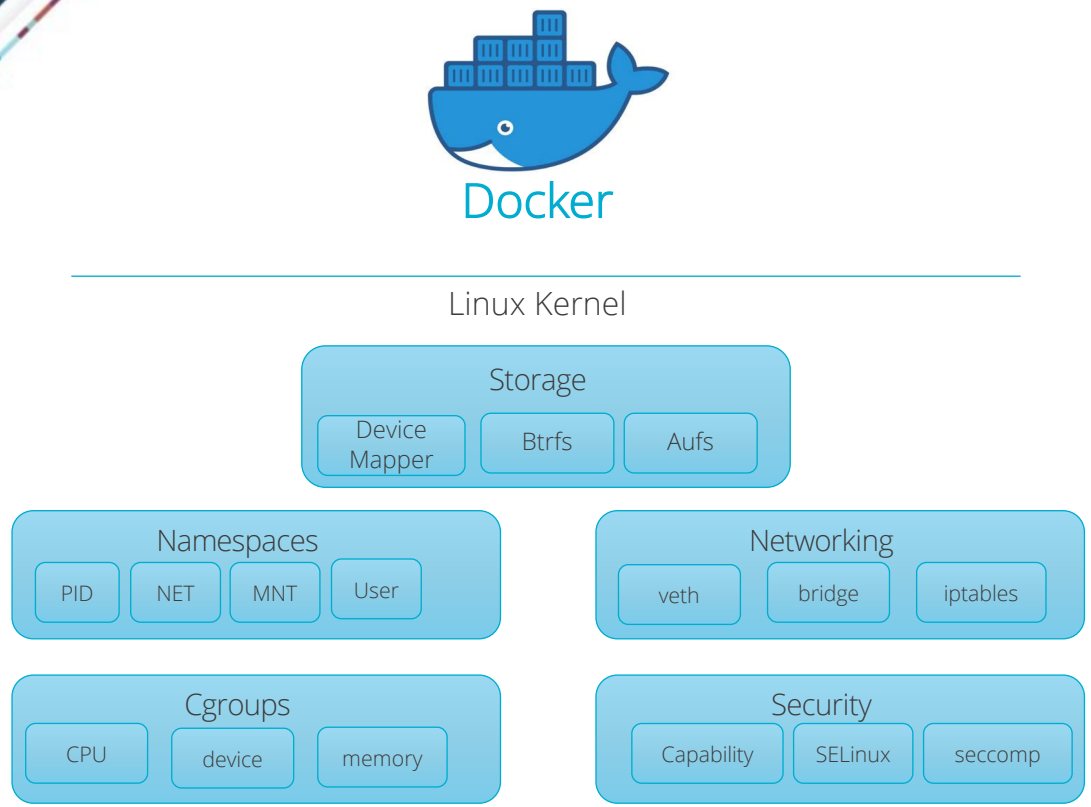
What is a container?



- Container: **Process**
  - Kernel Isolation Mechanisms
  - Kernel Security Mechanims
- Isolation: limit container's access
  - Cgroups
  - Namespaces
- Security: limit container abilities
  - Linux Security Modules
  - Seccomp
  - Capabilities

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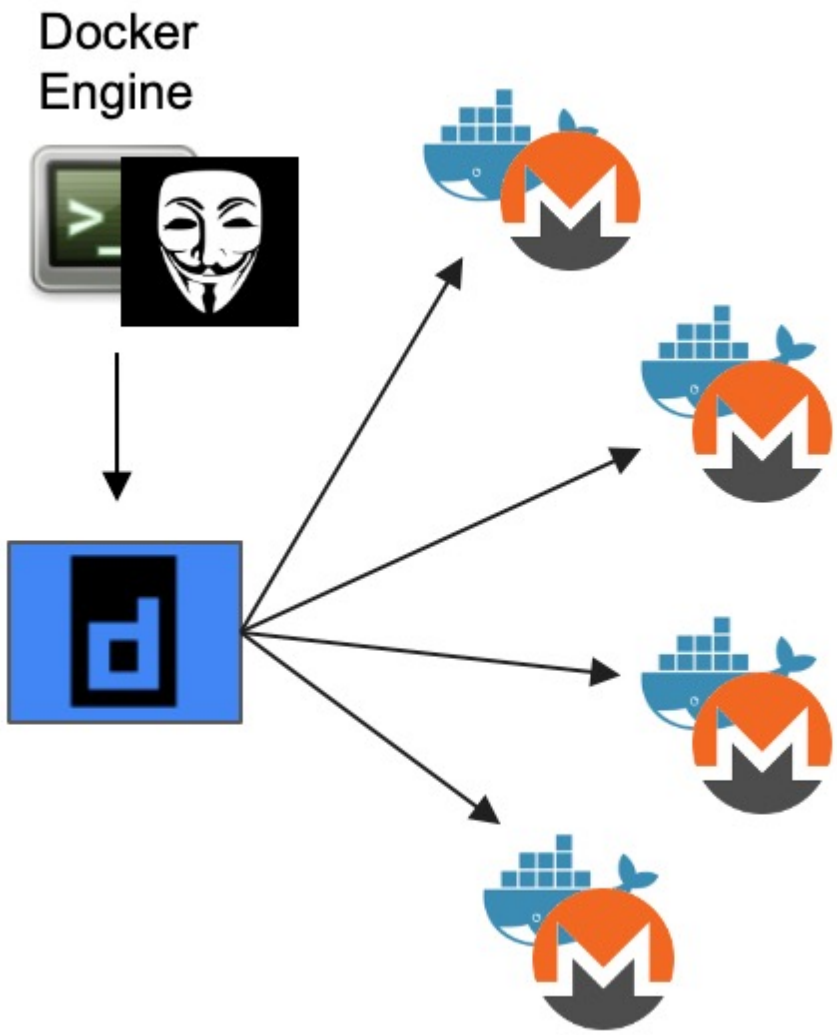
Why do adversaries want to control container hosts?

1. CryptoJacking
2. Corporate Espionage
3. Exfiltrate Customer Data



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How do adversaries attack container hosts?

- Misconfiguration (1)
- Kernel Bug (2)
- Runtime Vulnerability (3)

Container != VM

Vulnerabilities => Escape

Escape => Host Code Execution

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Related Work: Container Escapes

- Lin et al. (ACSAC):
  - measure kernel exploit container escapes
- Anton (Thesis):
  - measures container escape exploits, only 4 CVEs
- Martin et al.(Computer Communications) :
  - measure container configuration escapes
- Flauzac et al. (Procedia Computer Science):
  - limited comparison between technology features
- Allodi et al. (ACM):
  - conducted vulnerability risk assessment

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Contributions:

No work has analyzed container runtime vulnerabilities

1. Container security study:
   - 11 runtimes and 59 corresponding container runtime CVEs
   - 28 container runtime CVEs have PoC exploits
2. Container CVE taxonomy:
   - Container runtime PoC: **7**-class taxonomy
   - **46%** of all container runtime PoC CVEs => 9 different container escape exploits
   - Main cause of escape: host component leaked into the container
3. User namespace defense:
   - prevent exploitation of root privileges on host
   - 7 of 9 exploits prevented

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Security Study

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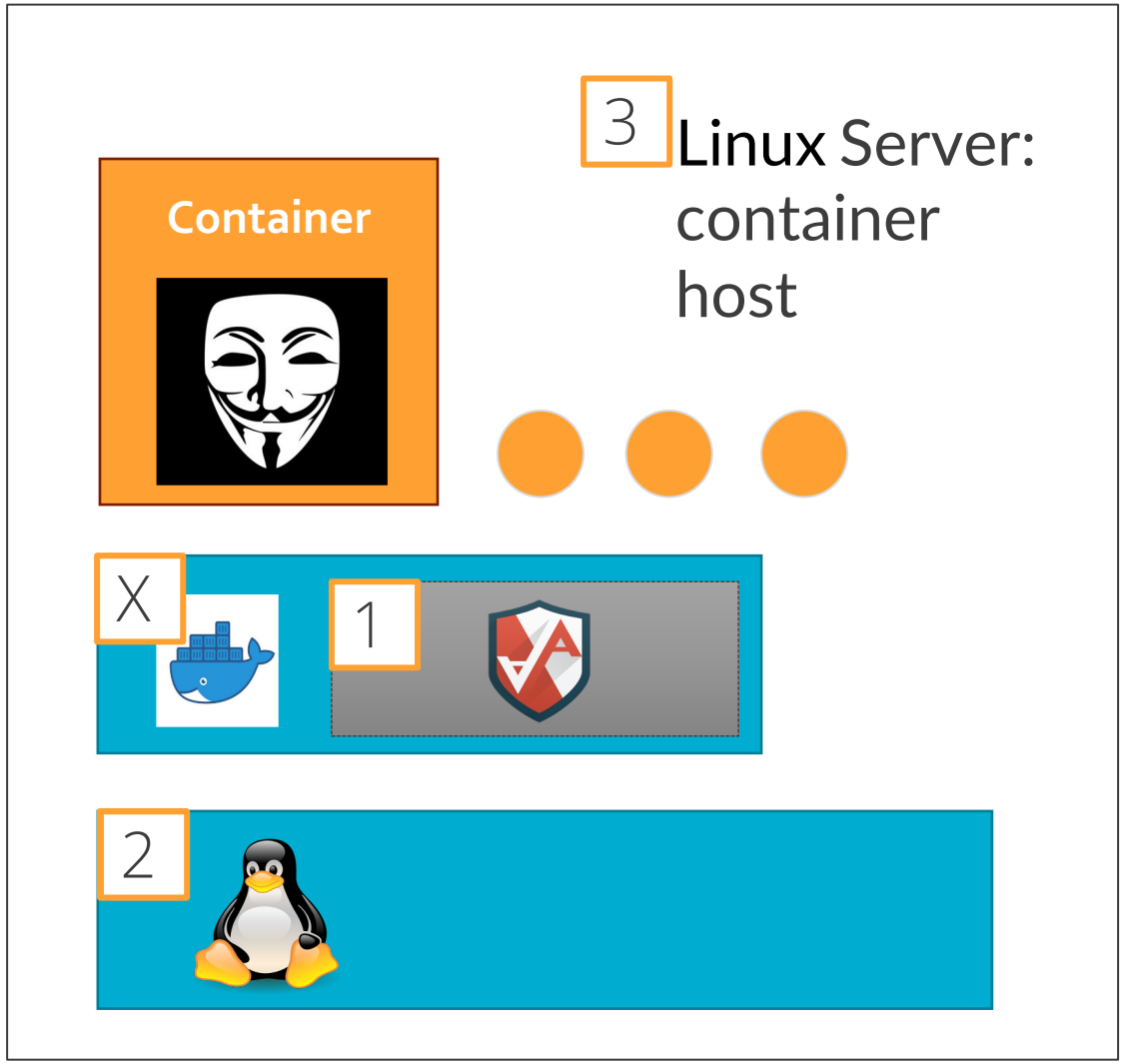
Threat Model:



- System:
  - Linux Server Container Host
- Adversary:
  - Container Code Execution
  - Goal: control host
- TCB:
  - Container Configuration
  - Linux Kernel
  - Server Hardware
- Threat:
  - Runtime Vulnerability

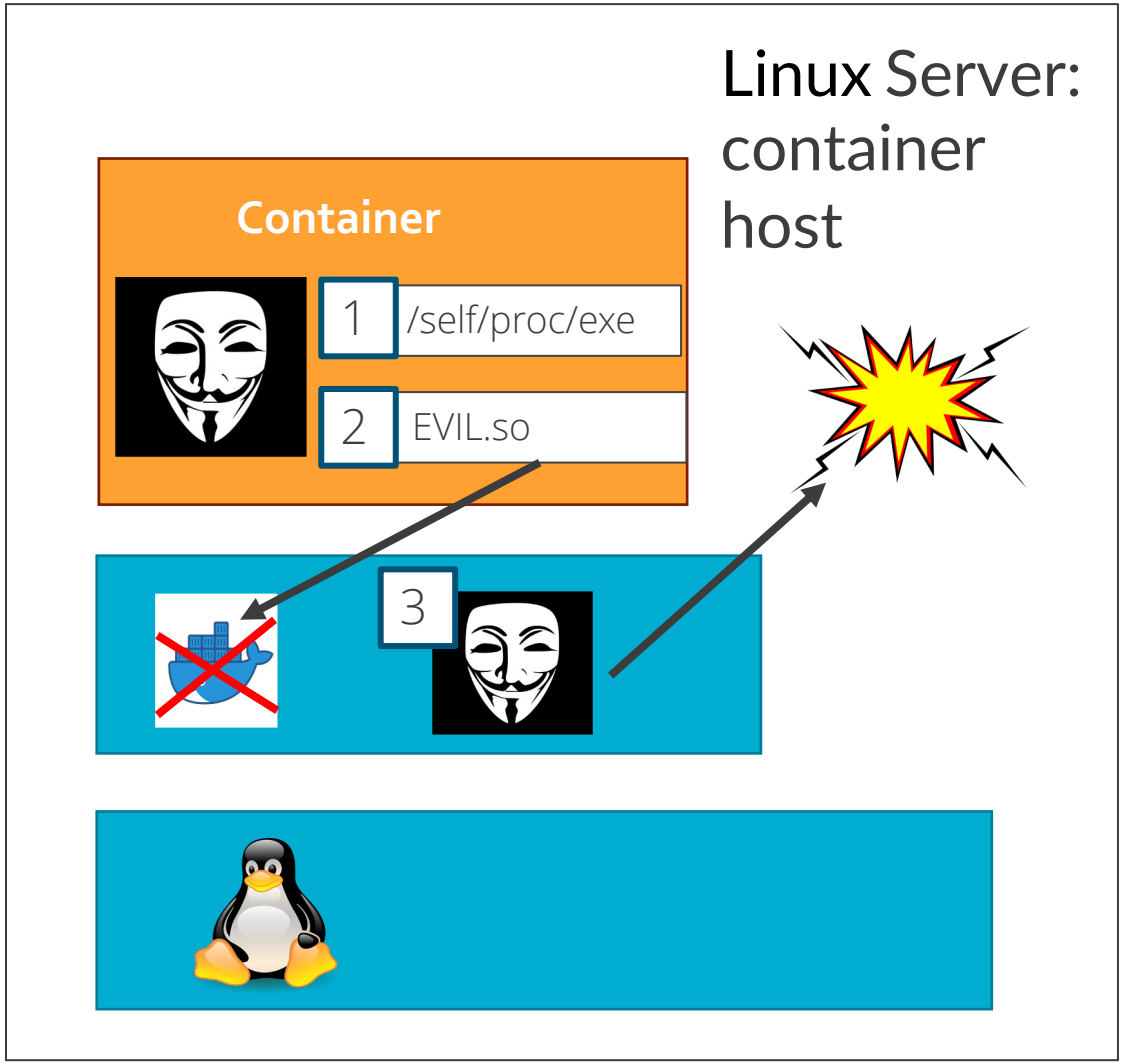
Runtime Vulnerability: Container Escape Exploit

CVE-2019-5736: runc vulnerability

1. Override Entrypoint
2. At initialization:
   a. EVIL.so loaded by entrypoint
   b. Overwrite container runtime with *evil* backdoor
3. New container executes *evil*

Adversary Escapes and executes

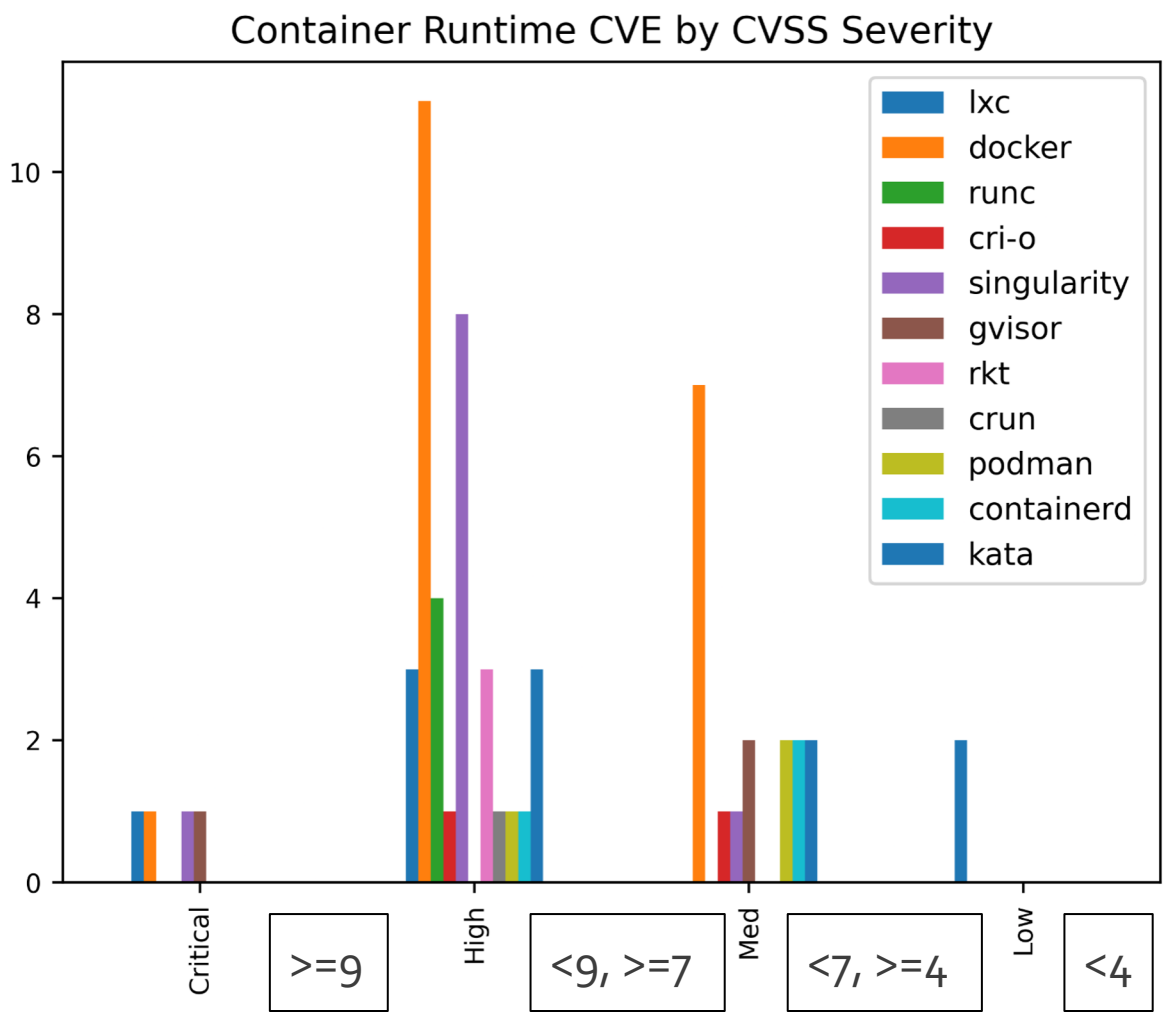
Code on the host!



Data Collection

1. Build List:
   a. 11 Runtimes

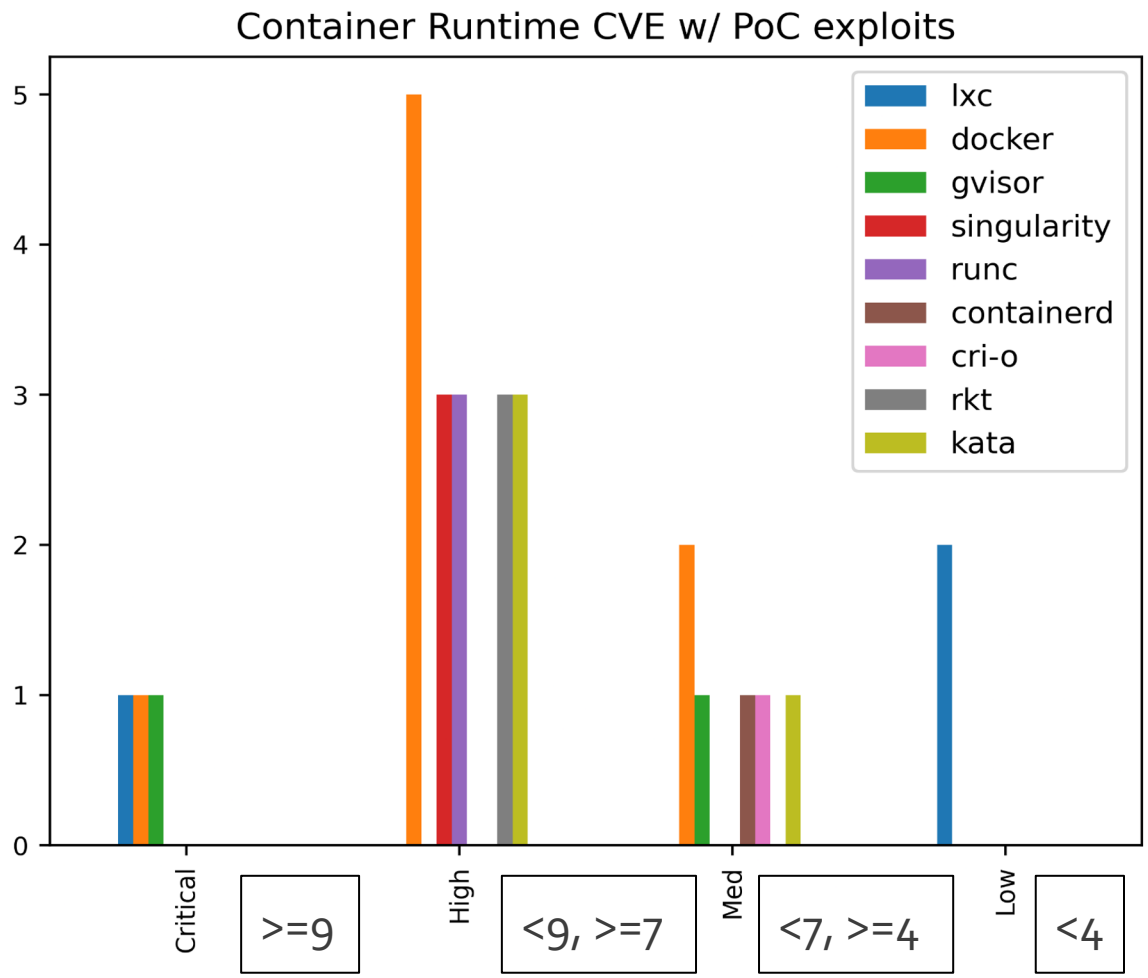
2. Query CVEs:
   a. NVDTOOLS 59 CVEs



Data Collection (Cont…)

3. Filter CVEs:
   a. remove 9 DoS CVEs
   b. focus on CVEs w/ PoC

4. Search PoC: Github/Google
   a. missing PoC (not in NVD or public internet)



Taxonomy

Exploit Analyzer Framework:

- binary analysis (low level)
- MITRE ATT&CK (high level)
- **steps (low + high level)**

Categories:

consider cause and impact

runc: CVE-2019-5736:

1. symlink container entry point to /proc/self/exe
2. save malicious.so with new function to overwrite host runtime engine onto container
3. entry point executes in the container on startup
4. /proc/self/exe executes container_runtime **ON CONTAINER**
5. host runtime loads the malicious.so
6. .so overwrites container_runtime -> evil
7. new containers will execute evil, code execution achieved

CVE Taxonomy

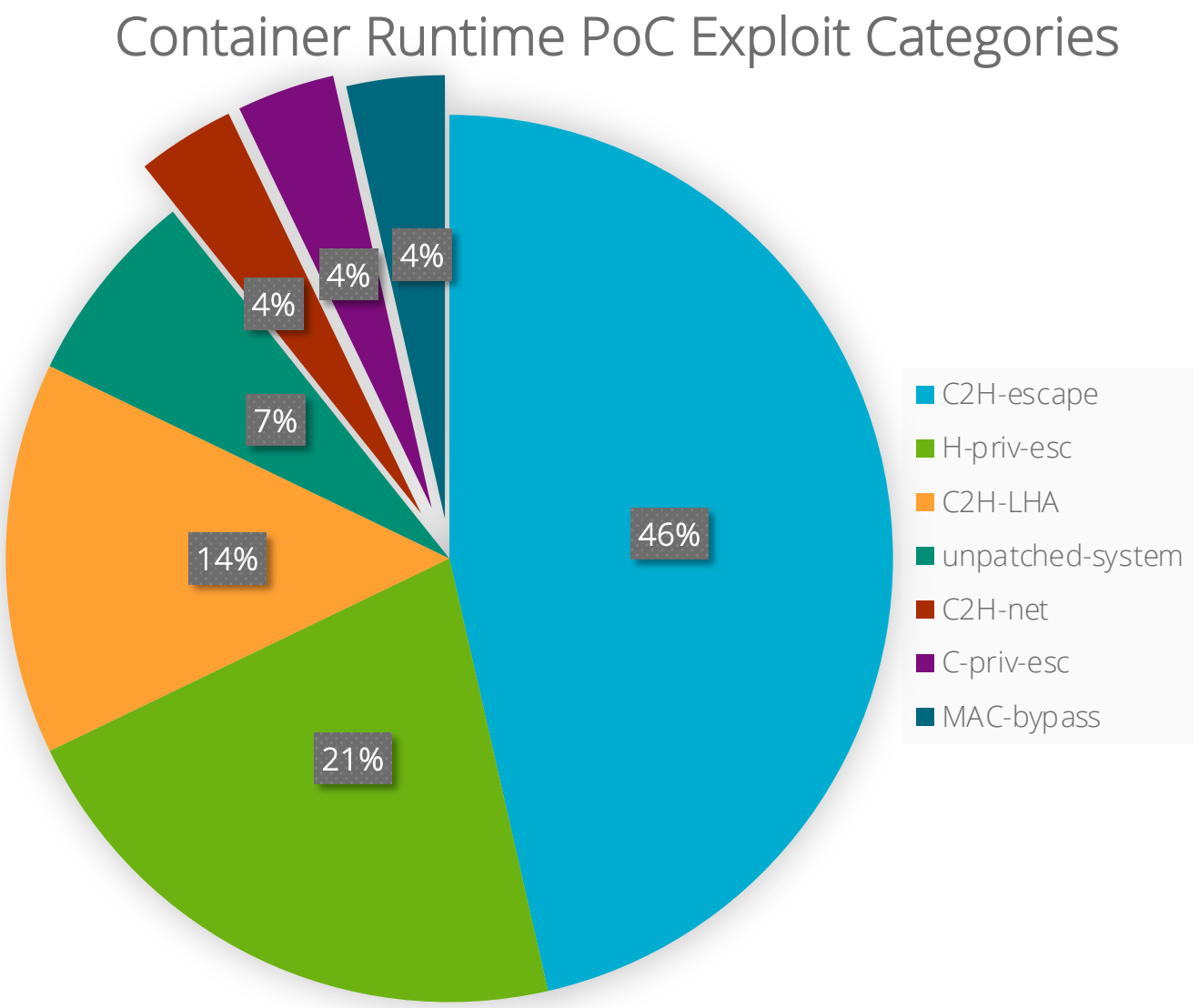
Key:

C2H: container to host

LHA: limited-host-access

H: host

C: container

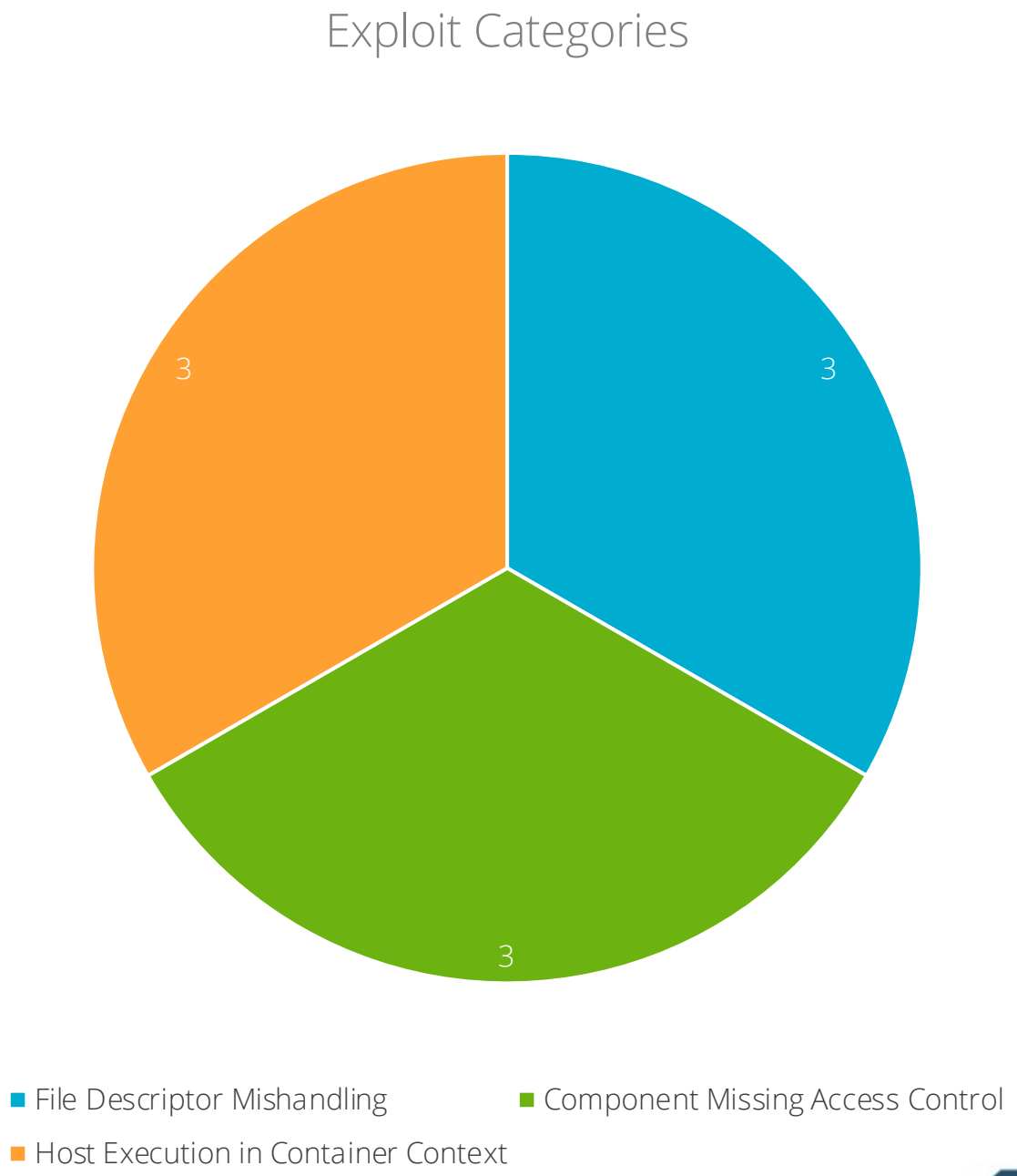


Escape Exploits

Main Issue:
Unintended host components exposed in container

3 Causes:

1. File Descriptor Mishandling
2. Component Missing Access Control
3. Host Execution in Container Context



Namespace Defense

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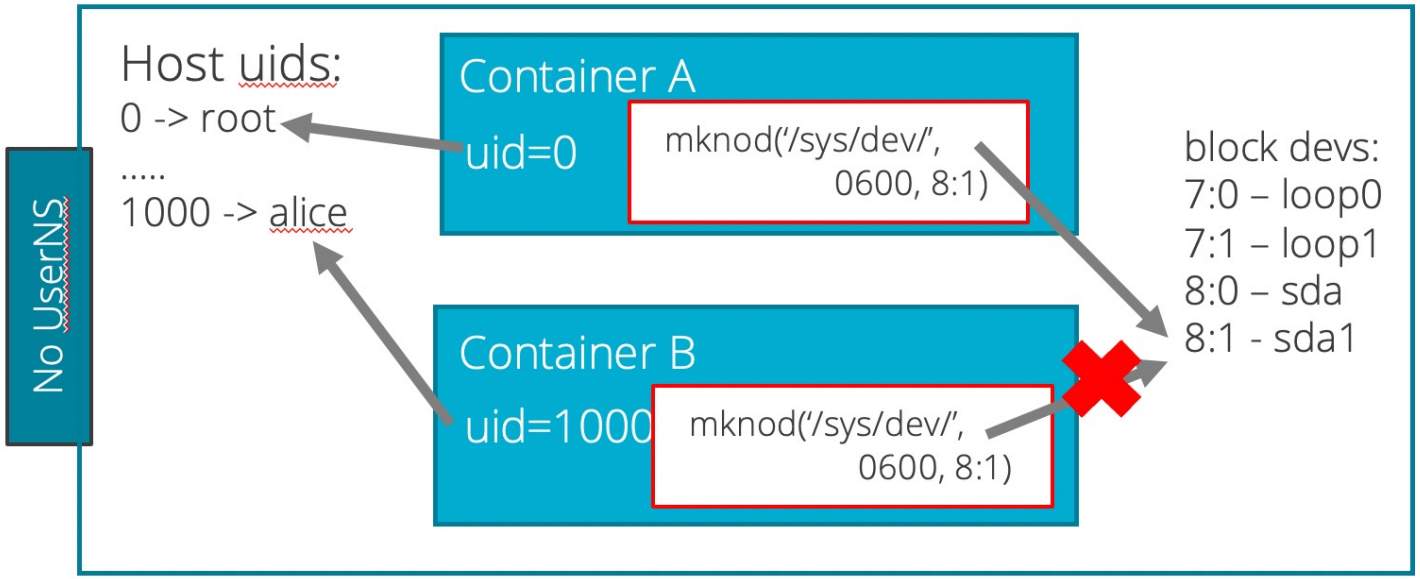
User Namespaces

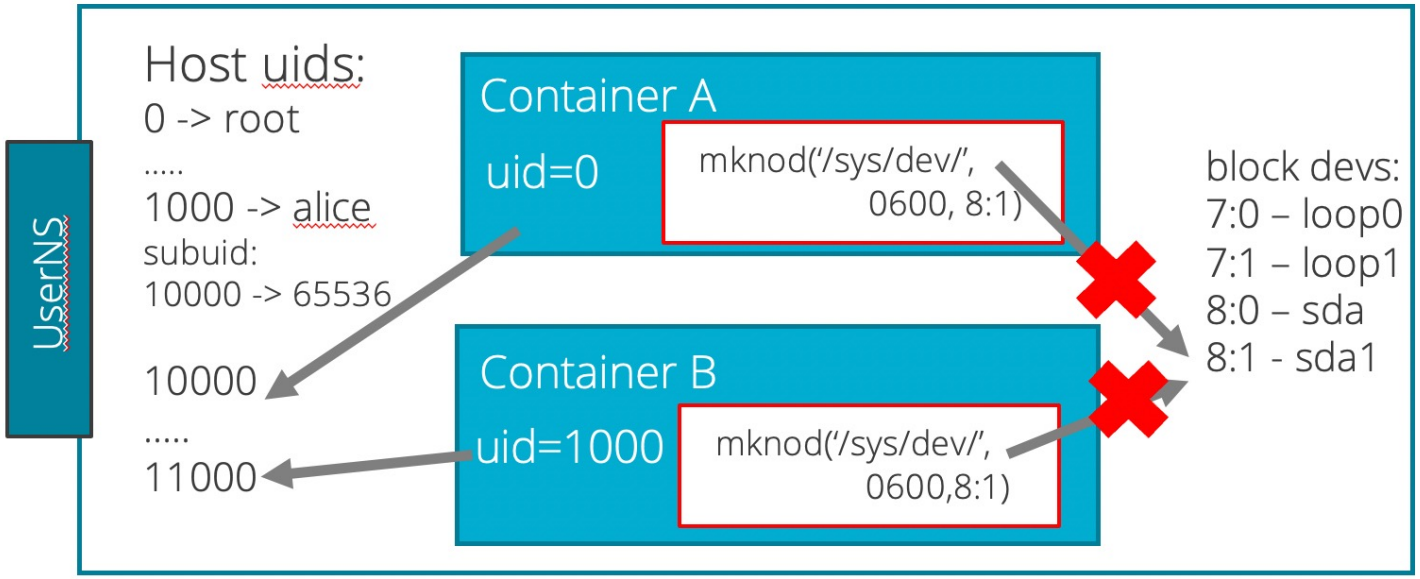
Design:

Container User mapped to non-privileged host user

Prevents:

Exploiting root permissions on the host





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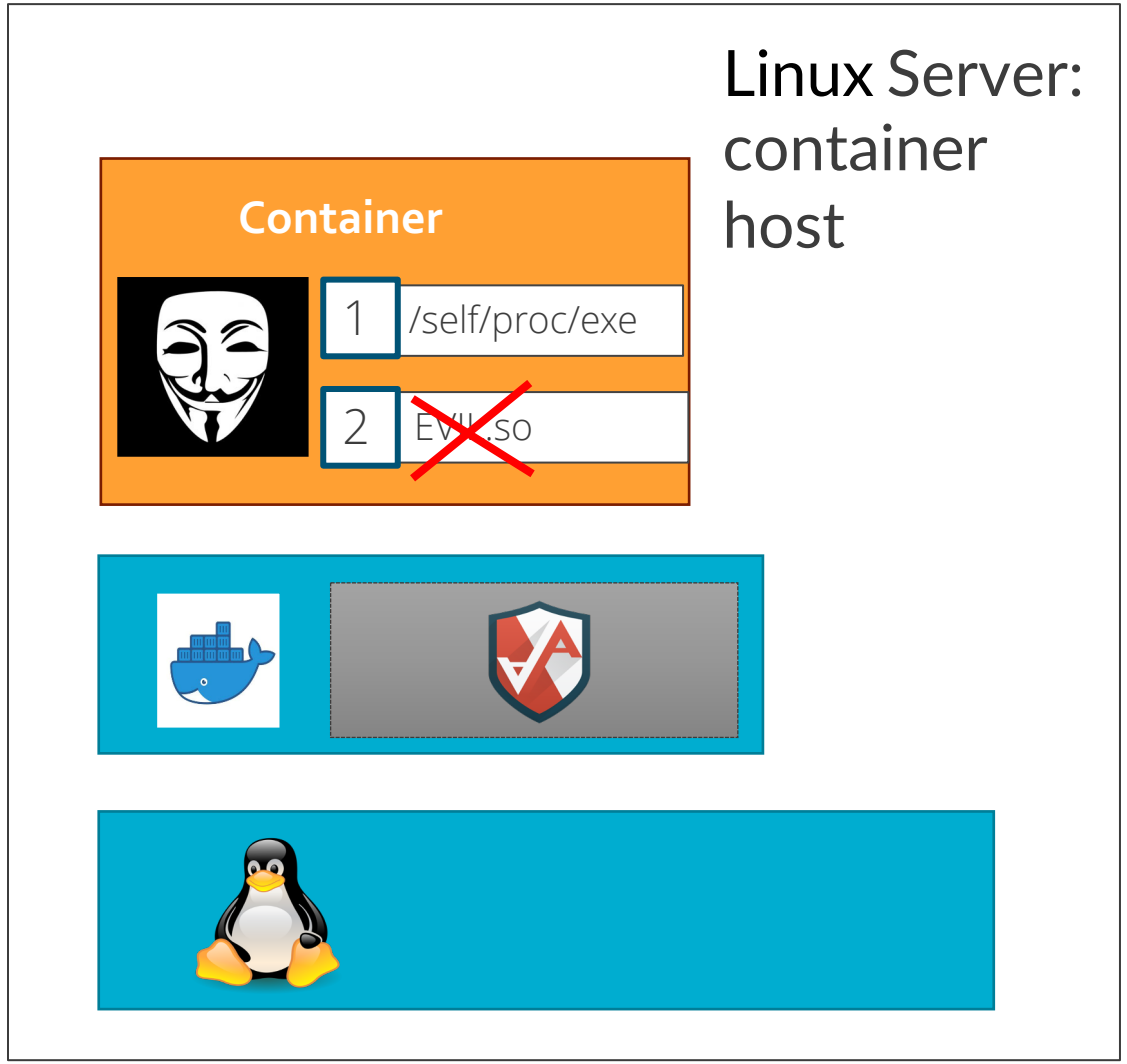
Prevented: Container Escape Exploit

CVE-2019-5736: runc vulnerability

1. Override Entrypoint
2. At initialization:
   a. EVIL.so loaded by entrypoint
   b. FAILS TO OVERRIDE ENTRY

Why?:
Container root user != host root user
No permissions on host to overwrite!



Defense Effectiveness

Exploits Prevented (Failed)	Exploits still Succeed	Effectiveness
7	2	78%

Defense Limitation

Main Limitation:
host runtime utility executes as root, but depends on adversary-controlled container objects

Why?:

CVE- 2019-19921: TOCTOU in runC's volume mount operation.

Occurs before container fully initialized

Solution:

Fix runC software to open volume mount directories as file descriptor rather than a string

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Conclusions

- Security Study:
  - 11 runtimes and their 59 CVEs.
- Taxonomy:
  - 7-classes over the 28 CVEs with publicly available PoC exploits
  - Main cause of container escapes is a host component leaked into the container
- Defense:
  - Main idea: prevent exploitation of root privileges on host
  - User namespace prevents 7 of 9 exploits

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Questions?

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https://mastermjr.com

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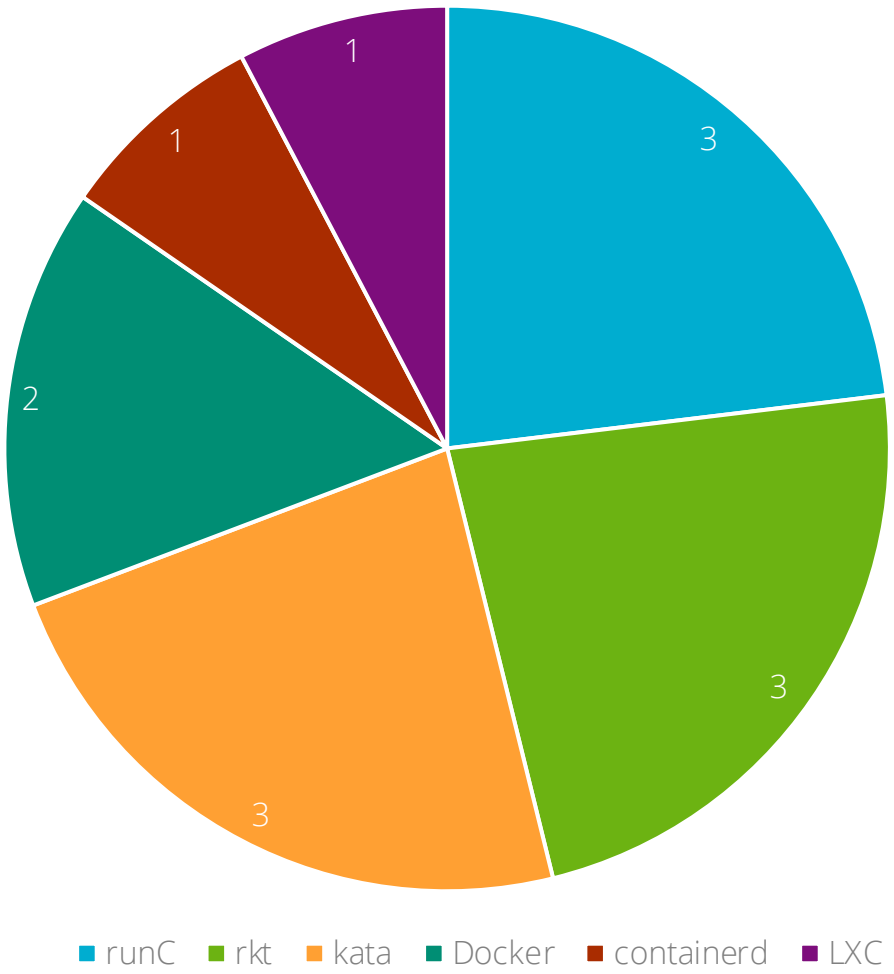
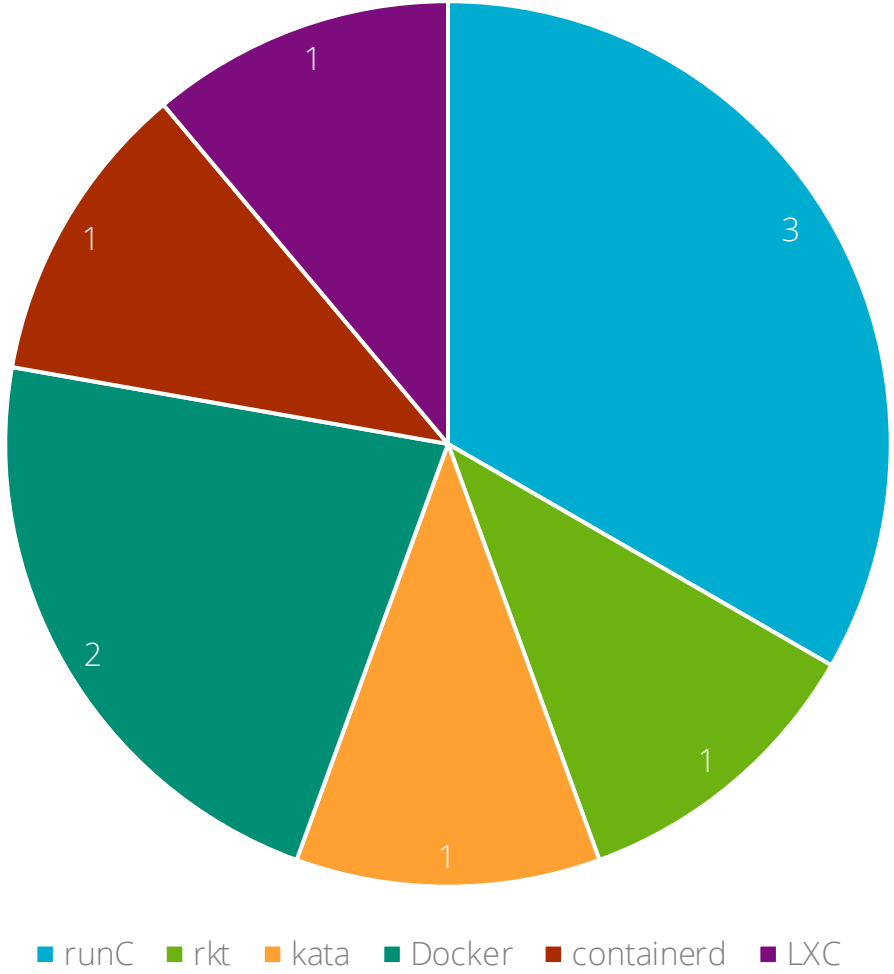
BACKUP:

12 Container Escape CVES -> 9 PoC Exploits

Container Escape CVEs by Runtime



Container Escape Exploits by Runtime



Namespaces Explained

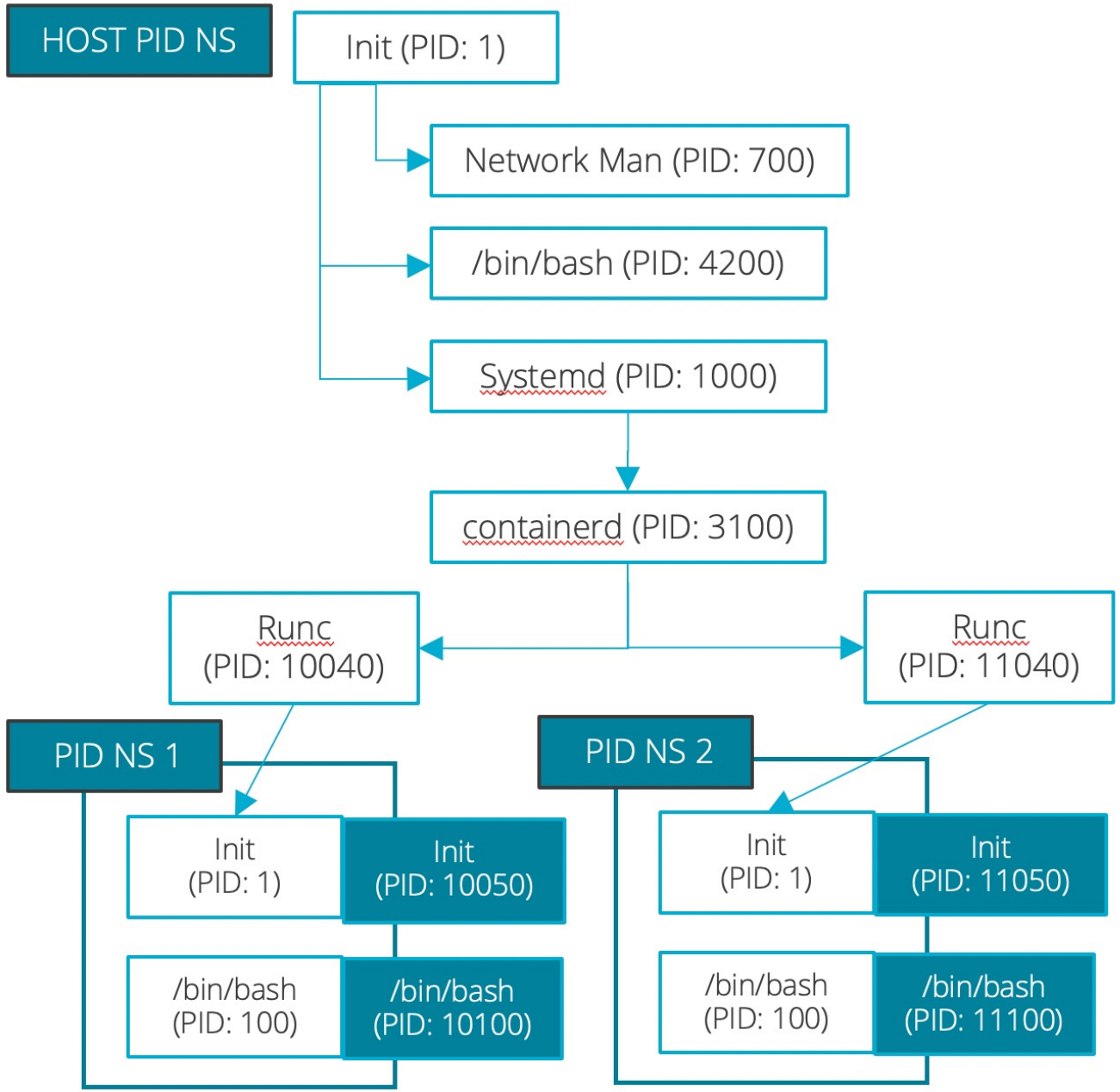
PID Namespace

Design:

Isolate the processes of separate containers

Prevents:

Observing processes across the whole operating system



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