It's Never the Firewall: Diagnosing Linux Firewall Issues

...

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Who Am I?

Software Engineer
... turned Systems Administrator
... then Network Administrator
... and Penetration Tester

Now Security Software Engineer
... with some DevOps thrown in

Official title “Engineer”

Linux Firewall Underpinnings

- ipfwadm (Linux kernel <= 2.0)
- ipchains (Linux kernel 2.2 - 2.4)
- iptables/netfilter (Linux kernel 2.4) - Introduced 1998
- nftables (Linux kernel 3.13) - Introduced 2014
- ... XDP / eBPF (Linux kernel 4.8) - ~2016... kind of

Common Management Tools

- firewalld (RH Default - Fedora/RHEL/CentOS)
- ufw - Uncomplicated firewall (Ubuntu)
- fail2ban
- Shorewall
- fwsnort
- FireHOL

_____ isn’t working! Must be the firewall!

It’s Never the Firewall

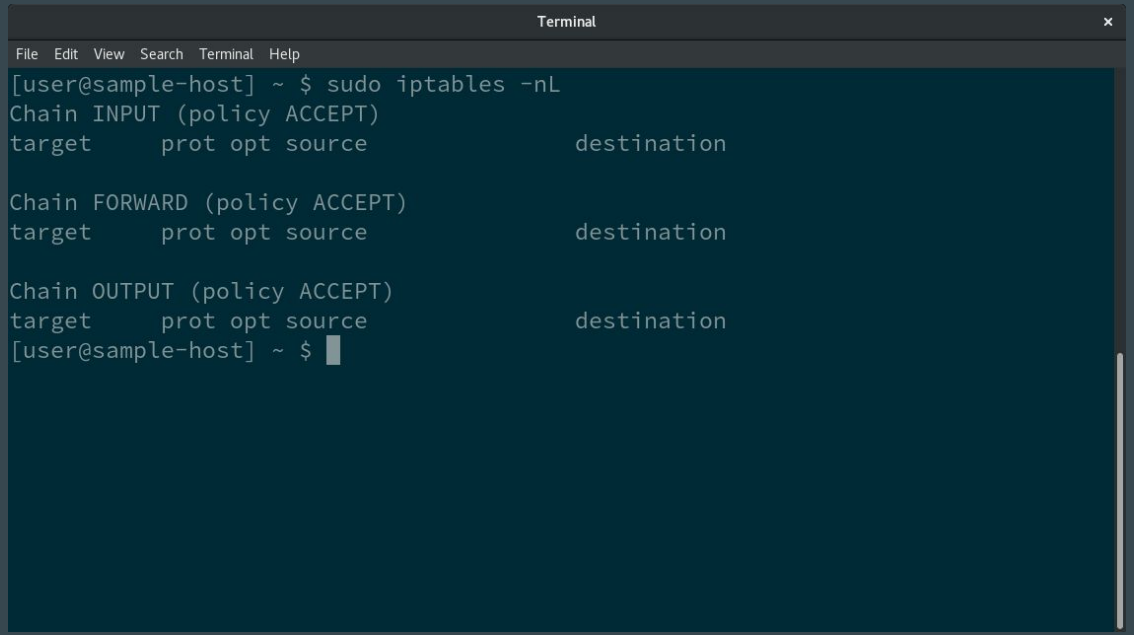
...probably...

If You're in the Cloud...

... the Linux firewall is likely not in use*

- AWS: Disabled
- GCP: Disabled
- Digital Ocean: Disabled
- Vultr: Disabled
- Pre-made Cloud-Init Linux Image: Likely Disabled

* Dependent on the image you choose, and can be enabled


Terminal
File Edit View Search Terminal Help
[user@sample-host] ~ $ sudo iptables -nL
Chain INPUT (policy ACCEPT)
target prot opt source destination
Chain FORWARD (policy ACCEPT)
target prot opt source destination
Chain OUTPUT (policy ACCEPT)
target prot opt source destination
[user@sample-host] ~ $

Done. Not the Firewall. Check DNS.

Initial Diagnostics

- Is the service actually unavailable?
- Do the DNS records match the IP addresses I expect?
- Has there been enough time for the old DNS records to expire?
- Does the system have the IP I expect?
- Can I ping the IP?
- Is the service running?
- Can I access the service from the host?
- Is the service bound to the correct interface?

... Alright, maybe it's *a* firewall ...

Universal Firewall Diagnostics

- Rule out the service as an issue. Replace it with something dead simple
- Start testing close to the service; Move outward from the service until it stops working. Test all zones a client is expected to be in.

Netcat

Simple TCP & UDP Client / Server Pair

- Shut down the target service
- Start up netcat on the port the service was running on:

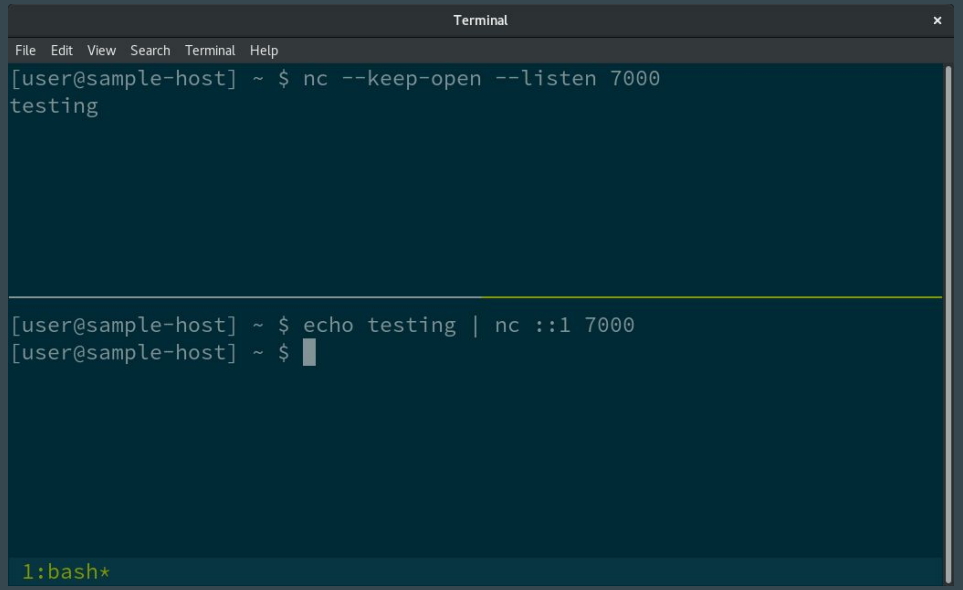
```
nc --keep-open --listen <port>
```

- Attempt to connect from the machine:

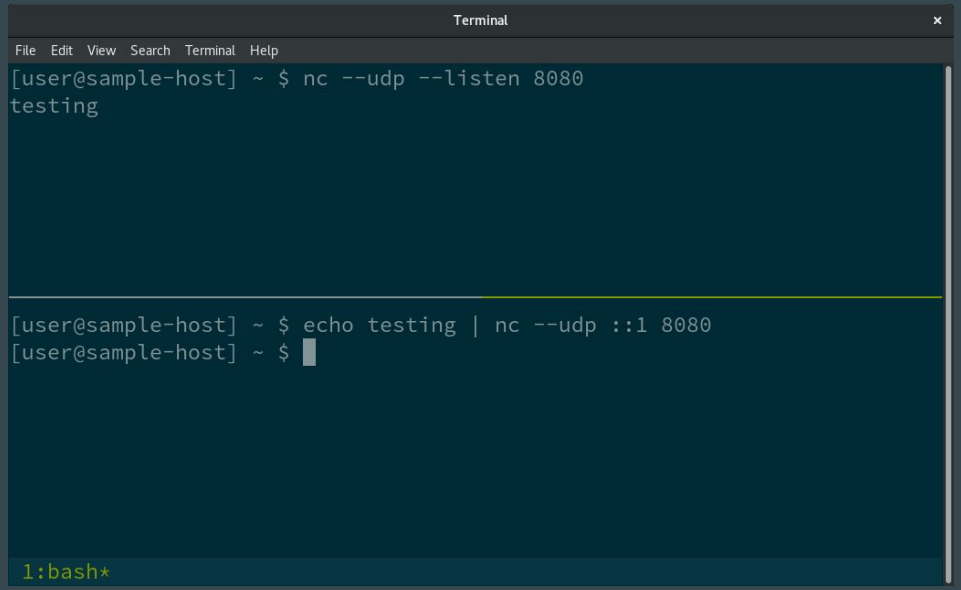
```
echo test | nc 127.0.0.1 <port>
```

- Repeat to it's external address, then from the perspective of the real client
- Where does it stop working?

Netcat


Terminal
File Edit View Search Terminal Help
[user@sample-host] ~ $ nc --keep-open --listen 7000
testing
[user@sample-host] ~ $ echo testing | nc ::1 7000
[user@sample-host] ~ $
1:bash*

Netcat


Terminal
File Edit View Search Terminal Help
[user@sample-host] ~ $ nc --udp --listen 8080
testing
[user@sample-host] ~ $ echo testing | nc --udp ::1 8080
[user@sample-host] ~ $
1:bash*

...Ok... Maybe it is the Firewall

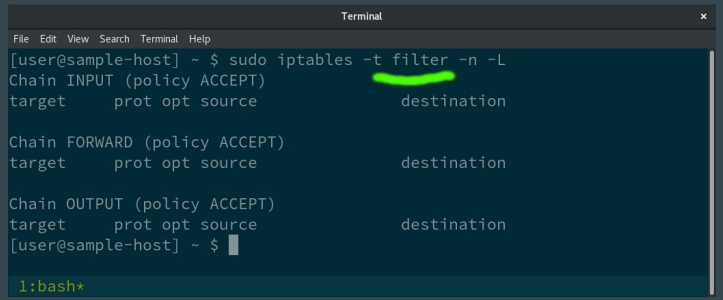
iptables Crash Course

Concepts

- Tables
- Chains
- Rules

Concepts - Tables

- Pre-defined and static
- All traffic passes through all tables*
- Different capabilities exist in different tables

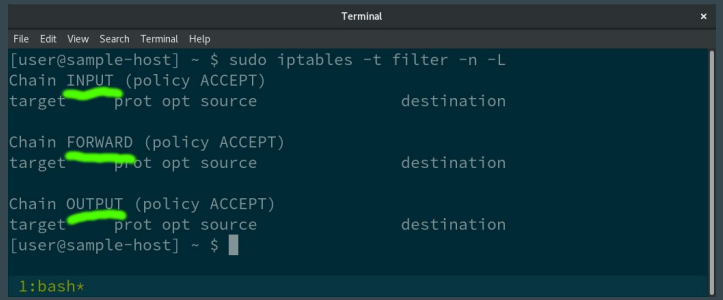


Concepts - Table List

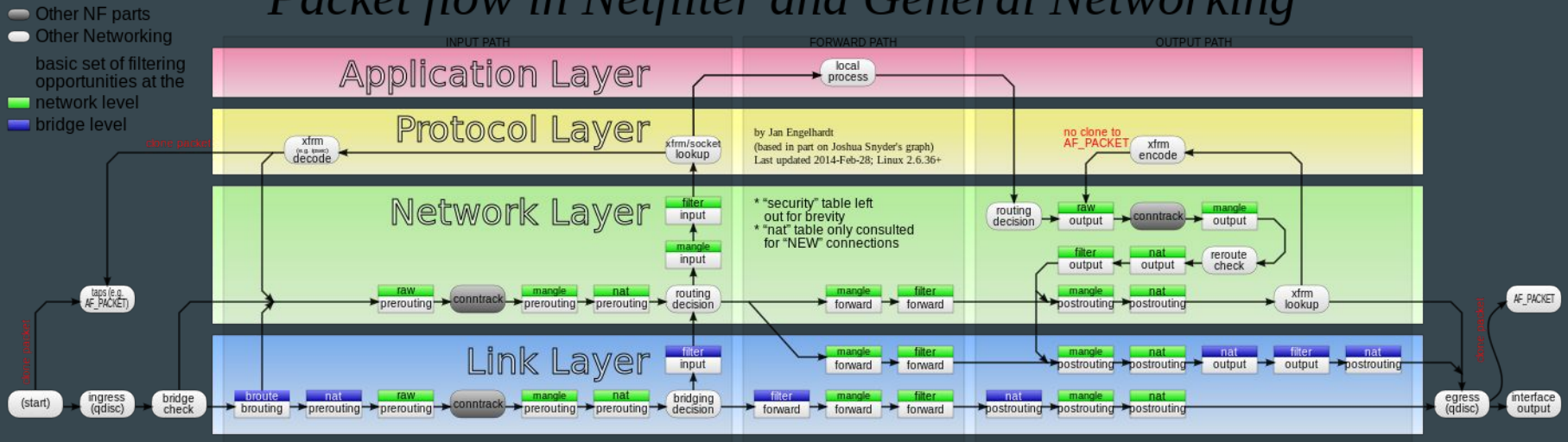
- **filter** - traditional ‘stateful firewall’
- **nat** - specify & track NAT’d connections
- raw - rules for untracked packets
- mangle - manipulate the bytes of the packet
- security - SELinux context tracking
- broute - Layer 2 routing, filtering, manipulation

Concepts - Chains

- Location where in the kernel the list of rules is getting applied
- Always displayed in ALL CAPS
- Contains a list of rules
- User can create custom chains that can be jumped to
- Defines the default action if nothing matches: ACCEPT, DROP, REJECT
- Custom chains can return to where they were called

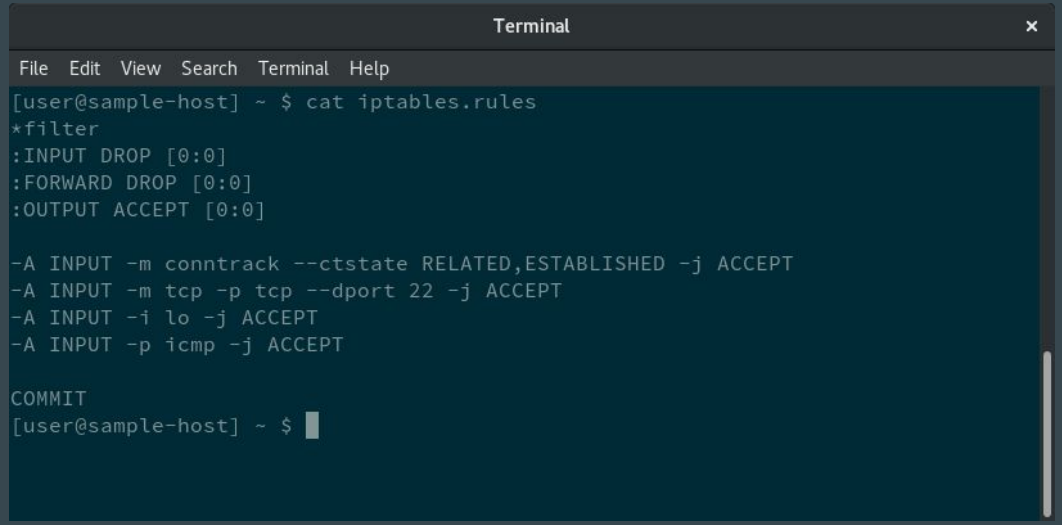


Packet flow in Netfilter and General Networking



Rules

- Individual statements of matching conditions and actions (target)
- Can choose to jump to a different chain as an action
- Each rule is evaluated in order until one matches... for every packet



Common Rule Matchers

-m <module name> - Load a match module for this rule

-p <protocol> - Match against a specific protocol (tcp, udp, icmp, etc)

-i <interface> - Match the interface the packet entered the system on

-o <interface> - Match the interface the packet will be leaving on

-s <IP> - The source IP address of the packet

-d <IP> - The destination IP address of the packet

--dport <port> - The destination port of the packet

--ctstate <state> - The tracked connection state

Crash course complete!

Diagnosing the Rules

Reset the rule counters and monitor them:

```
iptables -Z
iptables -L -v -n --line-numbers
```

```
Chain INPUT (policy DROP 0 packets, 0 bytes)
num   pkts bytes target  prot  opt  in  out  source         destination
1     19   4319  ACCEPT  all   --   lo  *    0.0.0.0/0      0.0.0.0/0
2      4   336   ACCEPT  icmp  --   *   *    0.0.0.0/0      0.0.0.0/0
3  43526   26M   ACCEPT  all   --   *   *    0.0.0.0/0      0.0.0.0/0      ctstate RELATED,ESTABLISHED

Chain FORWARD (policy ACCEPT 0 packets, 0 bytes)
num   pkts bytes target  prot  opt  in  out  source         destination

Chain OUTPUT (policy ACCEPT 116 packets, 8816 bytes)
num   pkts bytes target  prot  opt  in  out  source         destination
1     19   4319  ACCEPT  all   --   *   lo   0.0.0.0/0      0.0.0.0/0
2     16   1344  ACCEPT  icmp  --   *   *    0.0.0.0/0      0.0.0.0/0
3  42662    12M  ACCEPT  all   --   *   *    0.0.0.0/0      0.0.0.0/0      ctstate RELATED,ESTABLISHED
```

```
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num   pkts bytes target  prot  opt  in  out  source         destination
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2      4   336   ACCEPT  icmp  --   *   *    0.0.0.0/0      0.0.0.0/0
3  43526   26M   ACCEPT  all   --   *   *    0.0.0.0/0      0.0.0.0/0      ctstate RELATED,ESTABLISHED

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2     16   1344  ACCEPT  icmp  --   *   *    0.0.0.0/0      0.0.0.0/0
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2       16  1344  ACCEPT  icmp  --   *   *    0.0.0.0/0      0.0.0.0/0
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```

Diagnosing the Rules

Reset the rule counters and monitor them:

```
iptables -Z
iptables -L -v -n --line-numbers
```

Dump the full rule configuration:

```
iptables-save
```

```
*filter
:INPUT ACCEPT [2:120]
:FORWARD DROP [0:0]
:OUTPUT ACCEPT [81:4860]

-A INPUT -i lo -j ACCEPT
-A INPUT -p icmp -j ACCEPT
-A INPUT -m conntrack --ctstate RELATED,ESTABLISHED -j ACCEPT

-A OUTPUT -o lo -j ACCEPT
-A OUTPUT -p icmp -j ACCEPT
-A OUTPUT -m conntrack --ctstate RELATED,ESTABLISHED -j ACCEPT

COMMIT
```

```
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:INPUT ACCEPT [2:120]
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COMMIT
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COMMIT
```

Diagnosing the Rules

Reset the rule counters and monitor them:

```
iptables -Z
iptables -L -v -n --line-numbers
```

Dump the full rule configuration:

```
iptables-save
```

Insert tracing rule:

```
iptables -I <num> <rule conditions> (-j LOG)?
iptables -R <num> <rule conditions> (-j LOG)?
```

Tracing Rules

```
[root@sample-host] ~ # iptables -L -n --line-numbers
Chain INPUT (policy DROP)
num  target  prot opt source      destination
1    ACCEPT  all  --  0.0.0.0/0   0.0.0.0/0     ctstate RELATED,ESTABLISHED
2    ACCEPT  tcp  --  0.0.0.0/0   0.0.0.0/0     tcp dpt:22
3    ACCEPT  icmp --  0.0.0.0/0   0.0.0.0/0
<snip>
```

Tracing Rules

```
[root@sample-host] ~ # iptables -L -n --line-numbers
Chain INPUT (policy DROP)
num  target  prot opt source      destination
1    ACCEPT  all  --  0.0.0.0/0   0.0.0.0/0     ctstate RELATED,ESTABLISHED
2    ACCEPT  tcp  --  0.0.0.0/0   0.0.0.0/0     tcp dpt:22
3    ACCEPT  icmp --  0.0.0.0/0   0.0.0.0/0
<snip>
[root@sample-host] ~ # iptables -I INPUT 2 -s 10.0.0.100
[root@sample-host] ~ # iptables -L -n -v --line-numbers
Chain INPUT (policy DROP 0 packets, 0 bytes)
num  pkts bytes target  prot opt in  out  source     destination
1    597  44180 ACCEPT  all  --  *   *    0.0.0.0/0  0.0.0.0/0  ctstate RELATED,ESTABLISHED
2      0      0         all  --  *   *    10.0.0.100 0.0.0.0/0
3      0      0 ACCEPT  tcp  --  *   *    0.0.0.0/0  0.0.0.0/0  tcp dpt:22
4      0      0 ACCEPT  icmp --  *   *    0.0.0.0/0  0.0.0.0/0
<snip>
```

Tracing Rules

```
[root@sample-host] ~ # iptables -R INPUT 2 -s 10.0.0.100 -j LOG
[root@sample-host] ~ # iptables -L -n -v --line-numbers
Chain INPUT (policy DROP 0 packets, 0 bytes)
num  pkts bytes target  prot opt in  out  source     destination
1    597  44180 ACCEPT  all  --  *   *    0.0.0.0/0  0.0.0.0/0  ctstate RELATED,ESTABLISHED
2      1      1 LOG     all  --  *   *    10.0.0.100 0.0.0.0/0  LOG flags 0 level 4
3      1      1 ACCEPT  tcp  --  *   *    0.0.0.0/0  0.0.0.0/0  tcp dpt:22
4      0      0 ACCEPT  icmp --  *   *    0.0.0.0/0  0.0.0.0/0
<snip>
```

* The log target doesn't work inside of network namespaces

Tracing Rules - Log

```
IN=eth0 OUT= MAC=13:5b:00:d2:00:a0:13:5b:00:46:02:ef:01:00 SRC=10.0.0.100
DST=10.0.0.200 LEN=60 TOS=0x00 PREC=0x00 TTL=64 ID=14825 DF PROTO=TCP
SPT=49138 DPT=22 WINDOW=29200 RES=0x00 SYN URGP=0
```

Tracing Rules - Log

```
IN=eth0
OUT=
MAC=13:5b:00:d2:00:a0:13:5b:00:46:02:ef:01:00
SRC=10.0.0.100
DST=10.0.0.200
LEN=60
TOS=0x00
PREC=0x00
TTL=64
ID=14825
DF
PROTO=TCP
SPT=49138
DPT=22
WINDOW=29200 RES=0x00 SYN URGP=0
```

Don’t forget about IPv6

Each iptables Utility Has an IPv6 Equivalent

```
iptables <-> ip6tables
iptables-save <-> ip6tables-save
iptables-restore <-> ip6tables-restore
```

Make sure you're checking both

Check nftables

Just see if it's in use:

```
nft list ruleset
```

Nothing returned? It's not in use.

```
bash: nft: command not found
```

Also probably not in use...

Performance

Not the firewall. Check the database.

Performance

- Rule evaluation is very fast
- Each packet checks each rule until one matches
- Jumps to custom table “costs” more than a normal rule evaluation
- Connection tracking is relatively expensive

t3.small on AWS can handle ~105k pps
~1k 128kB HTTPS Requests

200 stateful rules dropped this 5%

500 stateful rules dropped this 15%

Performance

- Minimize the number of rules
- Rules should be ordered from mostly commonly evaluated to least
- Replace individual whitelist/blacklist rules with ipset hashes
- When mitigating malicious traffic, use the `raw` table before connection tracking is applied

ipset

- Aggregate ports / IPs into single iptables rule
- Atomic changes (add / remove / replace)
- Inclusion check much faster than individual rule evaluation
- Performance decreases the larger the size of set

ipset - blacklist example

```
ipset create blacklist iphash
iptables -t raw -A PREROUTING -m set \
    --match-set blacklist src -j DROP
```

Add an IP address to the blacklist:

```
ipset add blacklist 1.1.1.1
```

Removing:

```
ipset del blacklist 1.1.1.1
```

Network Namespaces

- Full independent network stack
- Has separate iptables configuration
- Can be used to sneak traffic through ‘`FORWARD`’ chains rather than ‘`OUTPUT`’ chains

Check for all active network namespaces:

```
ip netns list
```

Dump iptables rules in all non-default namespaces:

```
ip -all netns exec iptables -nL
```

Back to the Tools

- firewalld (RH Default - Fedora/RHEL/CentOS)
- ufw - Uncomplicated firewall (Ubuntu)
- Shorewall
- FireHOL

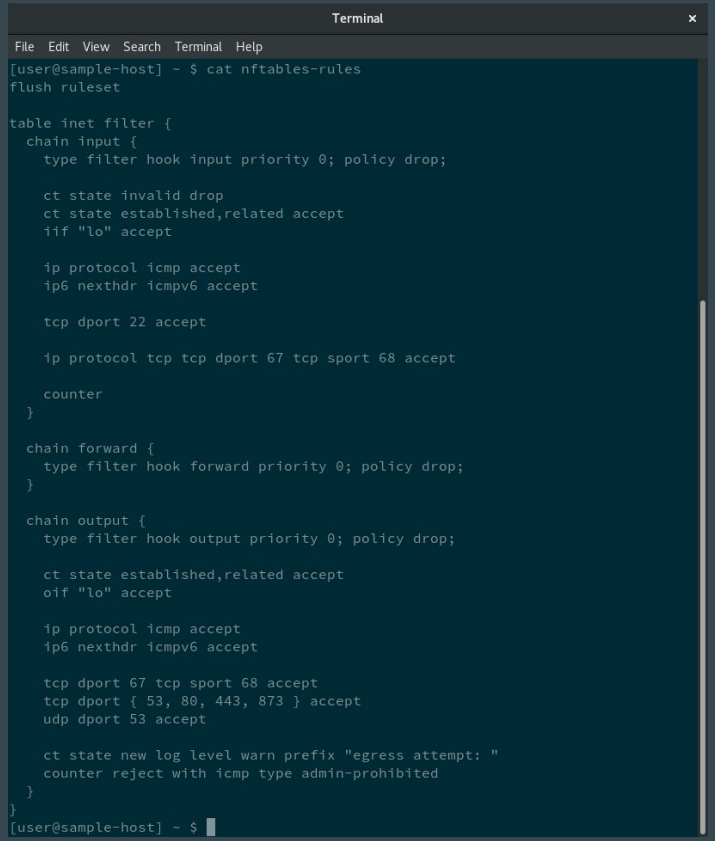
More Tools

- docker
- kubernetes
- libvirt
- fail2ban
- fwsnort

Next generations...

nftables

- New syntax - same primitives
- Uses a minimal VM running in kernel space
- Incremental changes
- Faster rule evaluation and set inclusion check
- Merges IPv4 & IPv6
- Supports individual rule tracing



XDP / eBPF

- eBPF introduced to provide diagnostic hooks into the kernel (dtrace equivalent)
- VM in kernel space
- Must be compiled / Examples written in C
- Not remotely friendly
- Can be hardware offloaded
- Incredibly fast (3x in software, 7x on hardware)

Questions?

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