Basic Concept of Firewall

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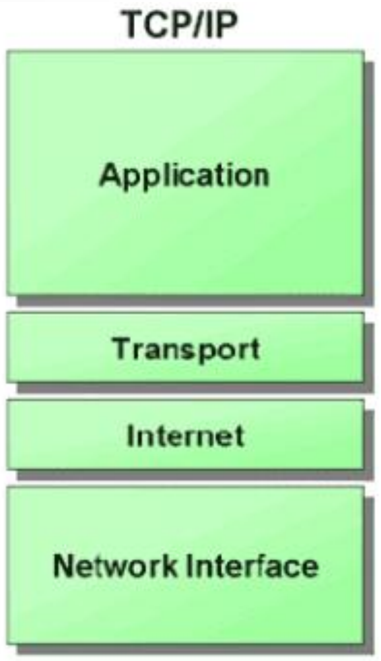
Firewalls

- Firewall
  - hardware/software
  - choke point between secured and unsecured network
  - filter incoming and outgoing traffic
  - prevent communications which are forbidden by the security policy

- What it can be used to do
  - Incoming: protect and insulate the applications, services and machines
    - Such as ssh, NFS, telnet, NetBIOS, internal web servers
  - Outgoing: limit or disable access from the internal network
    - Such as MSN, ssh, ftp, facebook, SC2, D3
  - NAT (Network Address Translation)

Firewalls – Capabilities

- Network Layer Firewalls
  - Operate at a low level of TCP/IP stack as IP-packet filters.
  - Filter attributes
    - Source/destination IP
    - Source/destination port
    - TTL
    - Protocols
    - ...
- Application Layer Firewalls
  - Work on the application level of the TCP/IP stack.
  - Inspect all packets for improper content, a complex work!
- Application Firewalls
  - The access control implemented by applications.
  - TCP Wrapper
    - hosts.allow, hosts.deny
    - In FreeBSD: tcpd(8)



Firewalls – Rules

- ❑ Exclusive
  - Only block the traffic matching the rulesets
- ❑ Inclusive
  - Only allow the traffic matching the rulesets
  - Offer much better control of the incoming/outgoing traffic
  - Safer than exclusive one
    - ➢ (Y) reduce the risk of allowing unwanted traffic to pass
    - ➢ (N) increase the risk to block yourself with wrong configuration
- ❑ State
  - Stateful
    - ➢ Keep track of which connections are opened through the firewall
    - ➢ Be vulnerable to Denial of Service (DoS) attacks
  - Stateless

Firewalls – Packages

- Linux
  - iptables (kernel 2.4+)
  - ipchains (kernel < 2.4)
  - firewalld
  - ufw (ubuntu)
- FreeBSD
  - IPFILTER (known as IPF)
  - IPFIREWALL (known as IPFW) + Dummynet
  - *Packet Filter (known as PF)+ ALTQ*
    - migrated from OpenBSD
    - http://www.openbsd.org/faq/pf/

Basic PF in FreeBSD

Packet Filter (PF)

- Functionality
  - **Filtering packets**
  - NAT
  - Load balance
  - QoS: (ALTQ: Alternate Queuing)
  - Failover (pfsync + carp)

$\left.\begin{array}{l} \text{NAT} \\ \text{Load balance} \\ \text{QoS} \\ \text{Failover} \end{array}\right\}$ Not covered today

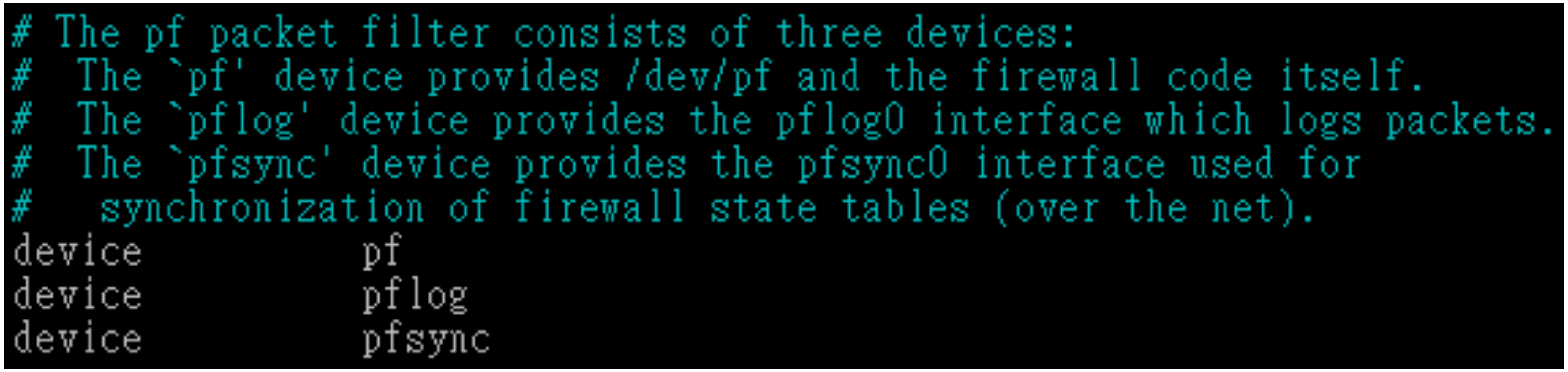
PF in FreeBSD – Enable pf*

- In /etc/rc.conf

```
pf_enable="YES"
pflog_enable="YES"
pfsync_enable="YES"
```

- Kernel configurations

```
device    pf
device    pflog
device    pfsync
```



```
# The pf packet filter consists of three devices:
#  The `pf' device provides /dev/pf and the firewall code itself.
#  The `pflog' device provides the pflog0 interface which logs packets.
#  The `pfsync' device provides the pfsync0 interface used for
#   synchronization of firewall state tables (over the net).
device          pf
device          pflog
device          pfsync
```

PF in FreeBSD – Commands and Config

- /etc/rc.d/pf
  - start / stop / restart / status / check / reload / resync
  - reboot if kernel modules is not loaded
- /etc/pf.conf
  - rules for PF
  - traffics to block/pass
  - tables to lookup
  - …

PF in FreeBSD – Example

❑ Ex.

```
# macro definitions
extdev='fxp0’
server_ext=‘140.113.214.13’

# options
set limit { states 10000, frags 5000 }
set loginterface $extdev
set block-policy drop
set skip on lo0

# tables
table <badhosts> persist file “/etc/badhosts.list”

# filtering rules
block in  all
pass out all
antispoof for $extdev
block in log on $extdev proto tcp from any to any port {139, 445}
block in log on $extdev proto udp from any to any port {137, 138}
block quick on $extdev from <badhosts> to any
pass in on $extdev proto tcp from 140.113.0.0/16 to any port {139, 445}
pass in on $extdev proto udp from 140.113.0.0/16 to any port {137, 138}
```

PF in FreeBSD – Tool

- pfctl
  - -e / -d
    - Enable/disable
  - -F {nat | rules | state | info | Tables | all | …}
    - Flush rules
  - -v -s {nat | rules | state | info | all | Anchors | Tables | …}
    - Show current rules
  - -v -n -f /etc/pf.conf
    - Parse the rule file without actually take effect
    - Suitable for testing marcos

PF in FreeBSD – Tool

- pfctl
  - -t *table_name* -T {add | delete| test} {*ip* …}
    - Modify lookup table, add/remove IP addresses
  - -t *table_name* -T {show | kill | flush | …}
    - Show/disable/reload tables
  - -k {host | network} [-k {host | network}]
    - Kill internal state entries for given host/network

PF in FreeBSD – Config ordering

- ❑ Macros
  - user-defined variables, so they can be referenced and changed easily.
- ❑ Tables “table”
  - similar to macros, but efficient and more flexible for many addresses.
- ❑ Options “set”
  - tune the behavior of pf, default values are given.
- ❑ Normalization “scrub”
  - reassemble fragments and resolve or reduce traffic ambiguities.
- ❑ Queueing “altq”, “queue”
  - rule-based bandwidth control.
- ❑ Translation (NAT) “rdr”, “nat”, “binat”
  - specify how addresses are to be mapped or redirected to other addresses
  - First match rules
- ❑ Filtering “antispoof”, “block”, “pass”
  - rule-based blocking or passing packets
  - Last match rules

PF in FreeBSD – Lists

- Lists
  - Allow the specification of multiple similar criteria within a rule
    - multiple protocols, port numbers, addresses, etc.
  - defined by specifying items within { } brackets.
  - eg.
    - pass out on rl0 proto { tcp, udp } from { 192.168.0.1, 10.5.32.6 } to any
    - pass in on fxp0 proto tcp to port { 22 80 }

PF in FreeBSD – Lists

- Lists
  - Pitfall
    - A lists will be expanded into rules.
    - Last matched rule takes effect
    - pass in on fxp0 from { 10.0.0.0/8, !10.1.2.3 }
    - You mean (It means)
      1. pass in on fxp0 from 10.0.0.0/8
      2. block in on fxp0 from 10.1.2.3
      2. pass in on fxp0 from !10.1.2.3
    - Use table, instead.

PF in FreeBSD – Macros

❑ Macros

- user-defined variables that can hold IP addresses, port numbers, interface names, etc.
- reduce the complexity of a pf ruleset and also make maintaining a ruleset much easier.
- Naming: start with [a-zA-Z] and may contain [a-zA-Z0-9_]
- eg.
  - ext_if = "fxp0“
  - block in on $ext_if from any to any
- Macro of macros
  - host1 = "192.168.1.1“
  - host2 = "192.168.1.2“
  - all_hosts = "{" $host1 $host2 "}"
    - Macros are not expanded within quotes!

PF in FreeBSD – Tables (1)

- Tables
  - used to hold a group of IPv4 and/or IPv6 addresses
    - Supports address lookup and query
    - hostname, inteface name, and keyword *self*
  - Lookups against a table are very fast and consume less memory and processor time than lists
  - Two attributes
    - persist: keep the table in memory even when no rules refer to it
    - const: cannot be changed once the table is created
  - eg.
    - table <private> const { 10/8, 172.16/12, 192.168/16 }
    - table <badhosts> persist
    - block on fxp0 from { <private>, <badhosts> } to any
    - table <spam> persist file "/etc/spammers" file "/etc/openrelays"

PF in FreeBSD – Tables (2)

- Tables – Address Matching
  - An address lookup against a table will return the most narrowly matching entry
  - eg.
    - table <goodguys> { 172.16.0.0/16, !172.16.1.0/24, 172.16.1.100 }
    - block in on dc0
    - pass in on dc0 from <goodguys>
  - Result

172.16.50.5	passed
172.16.1.25	blocked
172.16.1.100	passed
10.1.4.55	blocked

PF in FreeBSD – Options

- Format
  - control pf's operation, and specified in pf.conf using "set"
    - Format: set option [sub-ops] value
- Options
  - *loginterface* – collect packets and gather byte count statistics
  - *ruleset-optimization* – ruleset optimizer
    - none, basic, profile
    - basic: remove dups, remove subs, combine into a table, re-order rules
  - *block-policy* – default behavior for blocked packets
    - drop, return
  - *skip on* {ifname} – interfaces for which packets should not be filtered.
    - eg. set skip on lo0
  - *timeout, limit, optimization, state-policy, hostid, require-order, fingerprints, debug*

PF in FreeBSD – Normalization

- Traffic Normalization
  - IP fragment reassembly
    - scrub in all
  - Default behavior
    - Fragments are buffered until they form a complete packet, and only the completed packet is passed on to the filter.
    - Advantage: filter rules have to deal only with complete packets, and ignore fragments.
    - Disadvantage: caching fragments is the additional memory cost
    - The full reassembly method is the only method that currently works with NAT.

PF in FreeBSD – Packet Filtering (1)

- pf has the ability to *block* and *pass* packets based on
  - layer 3(ip, ip6) and layer 4(icmp, icmp6, tcp, udp) headers
- Each packet processed by the filter
  - The filter rules are evaluated in sequential order
  - The last matching rule decides what action is taken
  - If no rule matches the packet, the default action is to pass
- Format
  - {pass | block [drop | return]} [in | out] [log] [quick] [on ifname] … {hosts} …
  - The simplest to block everything by default: specify the first filter rule
    - block all

PF in FreeBSD – Packet Filtering (2)

- States
  - If the packet is *pass*ed, state is created unless the *no state* is specified
    - The first time a packet matches *pass*, a state entry is created
    - For subsequent packets, the filter checks whether each matches any state
    - For TCP, also check its sequence numbers
    - pf knows how to match ICMP replies to states
      - Port unreachable for UDP
      - ICMP echo reply for echo request
      - …
    - Stores in BST for efficiency

PF in FreeBSD – Packet Filtering (3)

- Block policy
  - drop
    - Incoming packet is silently dropped.
  - return
    - Incoming packet is dropped
    - for TCP packets
      - TCP RST is returned
    - for UDP packets
      - ICMP UNREACHABLE is returned
    - for other packets
      - no response is sent

PF in FreeBSD – Packet Filtering (3)

- Parameters
  - *in* | *out* – apply to imcoming or outgoing packets
  - *log* - generate log messages to pflog (pflog0, /var/log/pflog)
    - Default: the packet that establishes the state is logged
  - *quick* – the rule is considered the last matching rule
  - *on ifname* – apply only on the particular interface
  - *inet* | *inet6* – apply only on this address family
  - *proto* {*tcp* | *udp* | *icmp* | *icmp6*} – apply only on this protocol

PF in FreeBSD – Packet Filtering (4)

- Parameters
  - *hosts* : { *from* host [*port* [*op*] #] *to* host [*port* [*op*] #] | *all* }
  - host:
    - host can be specified in CIDR notation, hostnames, interface names, table, or keywords *any*, *self*, …
    - Hostnames are translated to address(es) at ruleset load time.
    - When the address of an interface or hostname changes, the ruleset must be reloaded
    - When interface name is surrounded by (), the rule is automatically updated whenever the interface changes its address
  - port:
    - ops: unary(=, !=, <, <=, >, >=), and binary(:, ><, <>)
  - eg.
    - block in all
    - pass in proto tcp from any port < 1024 to self port 33333:44444

PF in FreeBSD – Packet Filtering (5)

- Parameters
  - *flags* {<u>*<a>*</u>/<u>*<b>*</u> | *any*} – only apply to TCP packets
    - Flags: (F)IN, (S)YN, (R)ST, (P)USH, (A)CK, (U)RG, (E)CE, C(W)R
    - Check flags listed in <b>, and see if the flags (not) in <a> is (not) set
    - eg.
      - flags S/S : check SYN is set, ignore others.
      - flags S/SA: check SYN is set and ACK is unset., ignore others
    - Default *flags S/SA* for TCP
  - *icmp-type* <u>*type*</u> *code* <u>*code*</u>
  - *icmp6-type* <u>*type*</u> *code* <u>*code*</u>
    - Apply to ICMP and ICMP6 packets
  - *label* – for per-rule statistics
  - {*tag* | *tagged*} <u>*string*</u>
    - tag by nat, rdr, or binat, and identify by filter rules.

PF in FreeBSD – Stateful tracking

- Stateful tracking options
  - *keep state*, *modulate state*, and *synproxy state* support these options
    - keep state must be specidied explicitly to apply options to a rule
  - eg.
    - table <bad_hosts> persist
    - block quick from <bad_hosts>
    - pass in on $ext_if proto tcp to ($ext_if) port ssh keep state \
      (max-src-conn-rate 5/30, overload <bad_hosts> flush global)

PF in FreeBSD – Blocking spoofed

- Blocking spoofed traffic
  - *antispoof for ifname*
  - antispoof for lo0
    - block drop in on ! lo0 inet from 127.0.0.1/8 to any
    - block drop in on ! lo0 inet6 from ::1 to any
  - antispoof for wi0 inet (IP: 10.0.0.1, netmask 255.255.255.0)
    - block drop in on ! wi0 inet from 10.0.0.0/24 to any
    - block drop in inet from 10.0.0.1 to any
  - Pitfall:
    - Rules created by the *antispoof* interfere with packets sent over loopback interfaces to local addresses. One should pass these explicitly.
    - set skip on lo0

PF in FreeBSD – Example

❑ Ex.

```
# macro definitions
extdev='fxp0'
server_ext='140.113.214.13'

# options
set limit { states 10000, frags 5000 }
set loginterface $extdev
set block-policy drop
set skip on lo0

# tables
table <badhosts> persist file "/etc/badhosts.list"

# filtering rules
block in  all
pass out all
antispoof for $extdev
block in log on $extdev proto tcp from any to any port {139, 445}
block in log on $extdev proto udp from any to any port {137, 138}
block quick on $extdev from <badhosts> to any
pass in on $extdev proto tcp from 140.113.0.0/16 to any port {139, 445}
pass in on $extdev proto udp from 140.113.0.0/16 to any port {137, 138}
```

PF in FreeBSD – Debug by pflog

- Enable pflog in /etc/rc.conf
  - pflog_enable="YES"
    - Log to pflog0 interface
    - tcpdump -i pflog0
  - pflog_logfile="/var/log/pflog"
    - tcpdump -r /var/log/pflog

- Create firewall rules
  - Default configuration rules
    - pf_rules="/etc/pf.conf"
  - Sample files
    - /usr/share/examples/pf/*

iptables in Linux

iptables

- User-space software that control Linux kernel firewall
  - Control Linux kernel Netfilter modules
- Support kernel version 2.4+
  - Replace ipchains and ipfwadm
- iptables allows system administrators to define *tables* containing *chains* of *rules* for the treatment of packets

iptables

- ❑ In SA, we only cover high level idea of iptables
- ❑ Detailed configuration and usage are covered in NA

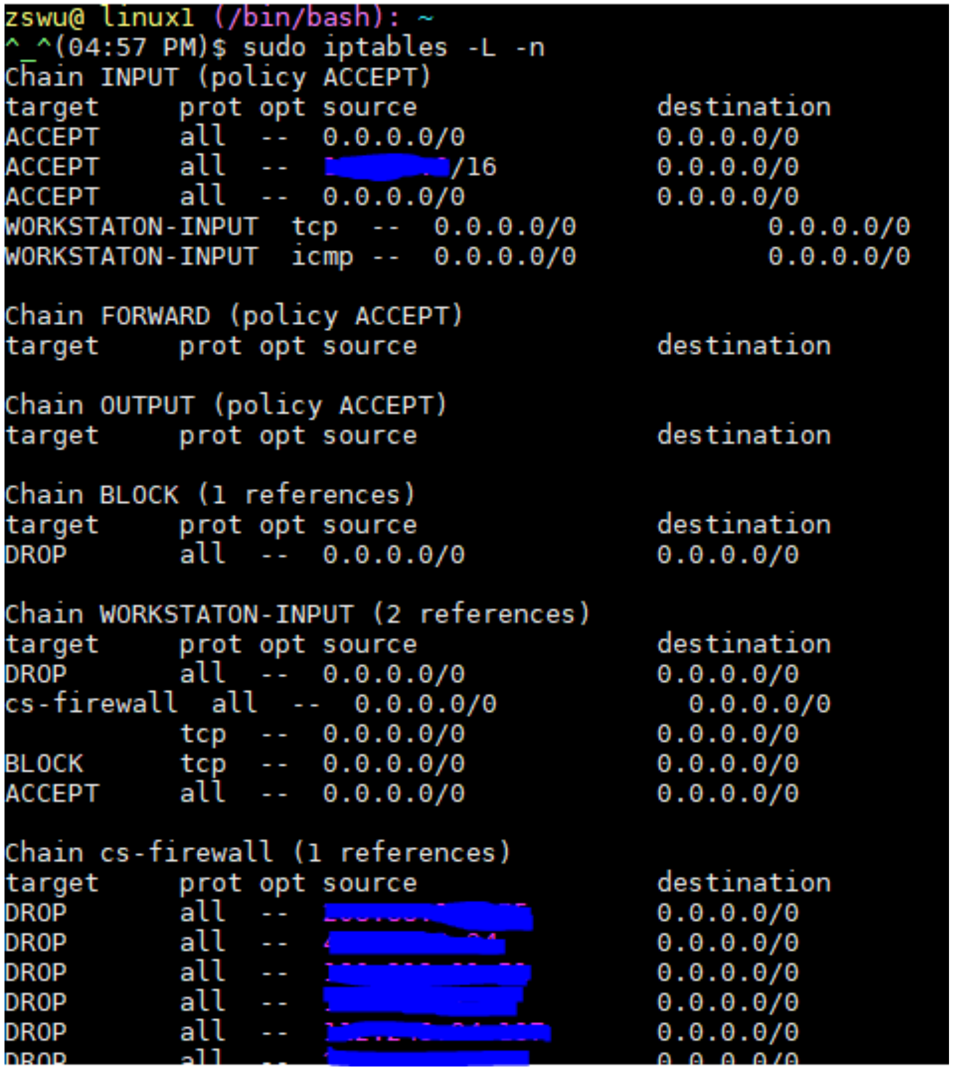
iptables - filtering

- Main command: iptables
- Almost everyhing is done by it
- iptables content for new machine (ubuntu)
  - iptables -L

```
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
```

iptables – List

- iptables
  - -t tables : Target table
  - -L : List all rules
  - -n : Don't lookup domain names
  - -v : Show details



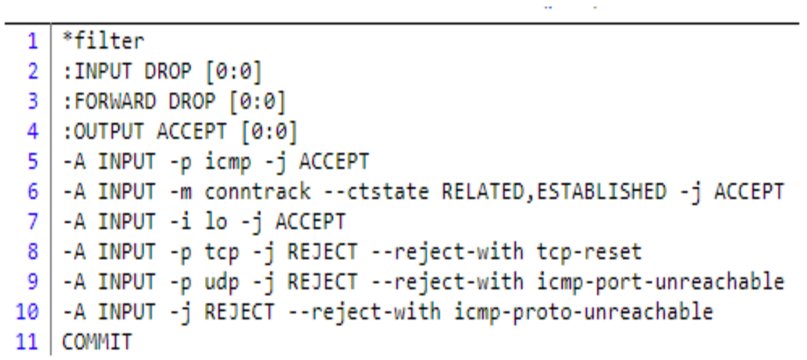
```
zswu@ linux1 (/bin/bash): ~
^_^(04:57 PM)$ sudo iptables -L -n
Chain INPUT (policy ACCEPT)
target     prot opt source               destination
ACCEPT     all  --  0.0.0.0/0            0.0.0.0/0
ACCEPT     all  --  [redacted]/16        0.0.0.0/0
ACCEPT     all  --  0.0.0.0/0            0.0.0.0/0
WORKSTATON-INPUT  tcp  --  0.0.0.0/0            0.0.0.0/0
WORKSTATON-INPUT  icmp --  0.0.0.0/0            0.0.0.0/0

Chain FORWARD (policy ACCEPT)
target     prot opt source               destination

Chain OUTPUT (policy ACCEPT)
target     prot opt source               destination

Chain BLOCK (1 references)
target     prot opt source               destination
DROP       all  --  0.0.0.0/0            0.0.0.0/0

Chain WORKSTATON-INPUT (2 references)
target     prot opt source               destination
DROP       all  --  0.0.0.0/0            0.0.0.0/0
cs-firewall  all  --  0.0.0.0/0            0.0.0.0/0
           tcp  --  0.0.0.0/0            0.0.0.0/0
BLOCK      tcp  --  0.0.0.0/0            0.0.0.0/0
ACCEPT     all  --  0.0.0.0/0            0.0.0.0/0

Chain cs-firewall (1 references)
target     prot opt source               destination
DROP       all  --  [redacted]           0.0.0.0/0
DROP       all  --  [redacted]           0.0.0.0/0
DROP       all  --  [redacted]           0.0.0.0/0
DROP       all  --  [redacted]           0.0.0.0/0
DROP       all  --  [redacted]           0.0.0.0/0
DROP       all  --  [redacted]           0.0.0.0/0
```

iptables – Init

- iptables
  - -F : Flush all rules
  - -X : Flush all custom chains
  - -Z : Flush all statistics data for all chains
- iptables
  - -P [INPUT,OUTPUT,FORWARD] [ACCEPT, DROP]
    - Change the default policy of the target chain

iptables – Save and Restore

- iptables-restore
  - Restore from restore file
- iptables-save
  - Export all rules and generate restore file
  - Some system will load restore file at boot
    - Ex: CentOS /etc/sysconfig/iptables /etc/sysconfig/ip6tables
- Restore file syntax
  - # comments
  - * table name
  - : chain default-policy [pkt:byte]
  - Rules
  - COMMIT (End of file)



```
*filter
:INPUT DROP [0:0]
:FORWARD DROP [0:0]
:OUTPUT ACCEPT [0:0]
-A INPUT -p icmp -j ACCEPT
-A INPUT -m conntrack --ctstate RELATED,ESTABLISHED -j ACCEPT
-A INPUT -i lo -j ACCEPT
-A INPUT -p tcp -j REJECT --reject-with tcp-reset
-A INPUT -p udp -j REJECT --reject-with icmp-port-unreachable
-A INPUT -j REJECT --reject-with icmp-proto-unreachable
COMMIT
```

iptables – Rules (1/2)

- Modify
  - -A, --append
  - -C, --check
  - -D, --delete
  - -I, --insert
  - -R, --replace

iptables – Rules (2/2)

- Filter
  - -i, -o [if] : incoming interface / outgoing interface
    - -i ens192 -o docker0
  - -s, -d [net] : Source / Destination
    - -s 192.168.0.1/24 –d 140.113.1.1
  - --sport, --dport [port] : Source port / Destination port
    - --sport 22 --dport 80
  - -p [protocol] : tcp, udp, icmp, all
    - -p icmp
  - -j [target]: target for matched packets
    - -j ACCEPT, -j DROP
  - ! (not) : Invert matching
    - ! -s 140.113.1.0/24
    - ! -i eth0
    - ! -p udp

Example

- ❑ Allow all packets from 192.168.1.0/24 on eth0
  - iptables -A INPUT -i eth0 -p tcp -s 192.168.1.0/24 -j ACCEPT
- ❑ Drop packets from 192.168.1.25
  - iptables -A INPUT -i eth0 -p tcp -s 192.168.1.25 -j DROP

Other tools

- These tools help user to manage iptables rules
  - UFW (Uncomplicated Firewall) (Ubuntu)
    - Easy to use
    - Hard to customize
  - Firewalld (Redhat)
    - Another way to manage your firewall
- Sometime even with these tools, you still need to understand iptables, otherwise you cannot manage complicated firewall rules like docker network, kubernetes