Lecture 5
Intrusion Detection

Print version of the lecture in *CPS633 Computer Security*

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Learning Objectives (page 252)

- Understand the basic principles of and requirements for intrusion detection.
- Discuss the key features of host-based intrusion detection and network-based intrusion detection
- Define the intrusion detection exchange format.
- Explain the purpose and the role of honeypots.

This set of slides closely follows Chapter 8 of the textbook.

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Contents

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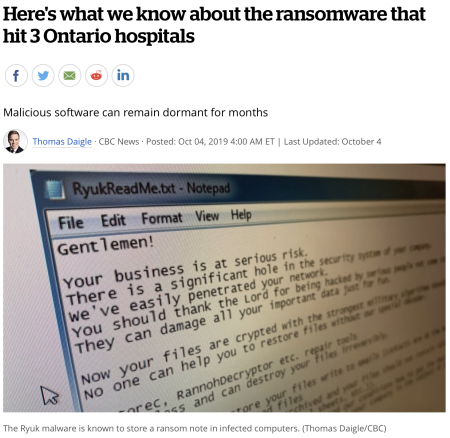
1 Preliminaries

1.1 Definitions

Definitions

Definition (*Merriam-Webster*) : *the act of intruding or the state of being intruded*
especially : the act of wrongfully entering upon, seizing, or taking possession of the property of another



source:https://www.cbc.ca/news/technology/ransomware-ryuk-ontario-hospitals-1.5308180

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Definitions

" `Intrusion detection` is the process of monitoring the events occurring in a **computer system** or **network** and analyzing them for signs of possible incidents, which are violations or imminent threats of violation of *computer security policies*, *acceptable use policies*, or *standard security practices*."

NIST 800-94: Guide to Intrusion Detection and Prevention Systems (IDPS), available at https://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-94.pdf

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1.2 Considerations

Design Considerations

- What to monitor?
- Where to do the monitoring?
- How to analyze the collected data, and what to do?

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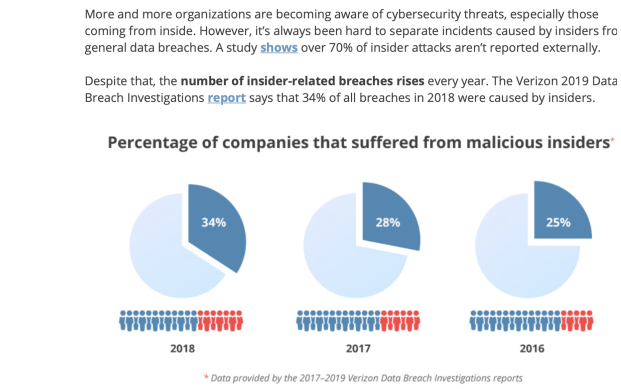
1.3 Observations

Observations

Attacks are not always from outside!!



source:https://www.ekransystem.com/en/blog/insider-threat-statistics-facts-and-figures

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Observations

Attackers may include state actors!!

source:Washington Post article, Jan 18, 2019

" The nation that *Lookout* is profiling started with a $23M budget for spyware ··· The government apparently negotiated with companies – including major spyware players such as Italy's Hacking Team, and Isarel's NSO Group – offering complex hacking tools that cost as little as $50,000 and as much as $7M.

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2 Detection

2.1 Components

Basic Components

- **Sensors**: Responsible for collecting data
- **Analyzers**: Responsible for analyzing sensors' data to determine whether an intrusion is occurred. May also be used to determine the next step, i.e. *response*, and logging the info for future use.
- **User interface**: It provide authorized users an an input and output (console) interface to the IDS.

Complete IDS systems often have other complementary components.

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2.2 Goals

Design Goals

```
Even best designed system will fail!
```

- **False Positives (FP)** or *false alarms*: identifying authorized users/process as intruders. This is in contrast with **True Positive (TP)**
- **False Negative (FP)**: intruders not being identified as intruders. This is in contrast with **True Negative (TN)**

Often, we are interested in the frequency (rate, or percentage) of these occurrences:

- The **detection rate**, or the **true positive rate**: $\frac{\text{TP}}{\text{TP+FP}} \times 100\%$ - the percentage of reported attack events that are real attack events
- The **false alarm rate**, or the **false positive rate**: $\frac{\text{FP}}{\text{FP+TN}} \times 100\%$ - the percentage of non-attack events reported as attack events
- The **accuracy**: $\frac{\text{TP+TN}}{\text{TP+FP+FP+FN}} \times 100\%$

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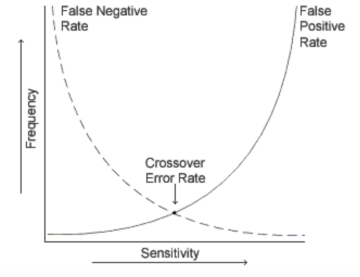
Design Goals

Improving accuracy is challenging task!



- **Base-Rate Fallacy**
  - If *TP* is low (compared to the actual number of intrusion) ← a false sense of security
  - If *FP* is high (compared to the actual number of intrusion) ← warnings generated may be ignored!

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Design Goals

- Detect a wide variety of intrusions
- Detect intrusions in a timely fashion
- Present the analysis in a simple, easy-to-understand format
- Be accurate

2.3 Requirements

Requirements

- Run continually (minimal supervision)
- Be fault tolerant
- Resist subversion
- Impose a minimal overhead
- Allow for (dynamic) configuration
- Be scalable
- Adapt to changes in system and user behaviour
- Provide graceful degradation of service

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2.4 Approaches

Approaches

Common Detection Methodologies:

"Once bitten, twice shy!"

- Study and analyze past attacks, and use that knowledge/patterns to detect the incoming attacks ⇒ **Signature-Based Detection**

"This does not feel right!"

- Study and analyze the 'normal' behaviour of users and systems, and use (significant) deviation from that behaviour as indication of possible attacks ⇒ **Anomaly Detection**

Other terms used in the literature: *misuse detection*, and *heuristic detection*

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Signature-Based Detection

Advantages:

- Simple - only need to compare against known attacks/patterns
- Low cost -in terms of time and resource use

Disadvantages:

- Signatures need to be large enough to reduce FPs
- Cannot detect new zero-day attacks, variants of known attacks, or those using evasion techniques
- Have little understanding of many network or application protocols and cannot track and understand the state of complex communications
- Typically lack the ability to remember previous events when processing the current event

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Anomaly Detection

Advantages:

- Many different attributes can be used to define a 'normal' behaviour
- Can be very effective at detecting previously unknown attacks.

Disadvantages:

- Need 'dynamic' profiles
- malicious activity may become part of a profile
- May be difficult to build profiles for highly complex computing activities
- May produce a large number of FP
- May be difficult for for analysts to determine the reason(s)

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More on Anomaly Detection

Different approches to anomaly detection

- **Threshold Metrics:** Expects the occurrence of particular event to be in a given range. If outside that range → anomalous.
- **Statistical:** Analysis of the observed behaviour using *univariate*, *multivariate*, or *time-series* models of observed metrics.
- **Knowledge based:** Approaches use an expert system that classifies observed behaviour according to a set of rules that model legitimate behaviour.
- **Machine-learning**: Approaches automatically determine a suitable classification model from the training data using data mining techniques.

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Machine-learning-based IDS

Machine-learning-based anomaly detection techniques:

- Bayesian networks
- Markov models
- Neural networks:
- Fuzzy logic
- Genetic algorithms
- Clustering and outlier detection

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Machine-learning-based IDS

Advantages:

- Flexibility
- Adaptability
- Ability to capture interdependencies between the observed metrics

Disadvantages:

- Dependency on assumption about accepted behaviour
- High FR
- High resource
- Need for 'rich' training set.

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2.5 Placement

Architectural Design Considerations*

- Where to place sensors and analyzers?
- How reliable the solution should be and what to do to achieve it?
- Where the other components of the IDS (management servers, database servers, consoles, $\cdots$ will be located?
- With which other systems the IDS needs to interface? For examples, SIEMS, log servers, email, routers, switches, firewalls, $\cdots$
- Whether or not a management network will be used?

*Based on NIST 800-94: Guide to Intrusion Detection and Prevention Systems (IDPS)

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Placement

Effectiveness and costs of IDS will depend on its placement within a system, as well as the characteristics being monitored.

- **Host-based IDS (HIDS)**
- **Network-based IDS (NIDS)**
- **Distributed or hybrid IDS**

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3 HIDS

3.1 Data Sources

HIDS Data Sources

Q. What should HIDS sensor monitor and log?

- **System call traces**
- **Audit (log file) records**
- **File integrity checksums**
- **Registry access**

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HIDS Data Sources

accept, access, acct, adjtime, aiocancel, aioread, aiowait, aiowrite, alarm, async_daemon, auditsys, bind, chdir, chmod, chown, chroot, close, connect, creat, dup, dup2, execv, execve, exit, exportfs, fchdir, fchmod, fchown, fchroot, fcntl, flock, fork, fpathconf, fstat, fstat, fstatfs, fsync, ftime, ftruncate, getdents, getdirentries, getdomainname, getdopt, getdtablesize, getfh, getgid, getgroups, gethostid, gethostname, getitimer, getmsg, getpagesize, getpeername, getpgrp, getpid, getpriority, getrlimit, getrusage, getsockname, getsockopt, gettimeofday, getuid, gtty, ioctl, kill, killpg, link, listen, lseek, lstat, madvise, mctl, mincore, mkdir, mknod, mmap, mount, mount, mprotect, mpxchan, msgsys, msync, munmap, nfs_mount, nfssvc, nice, open, pathconf, pause, pcfs_mount, phys, pipe, poll, profil, ptrace, putmsg, quota, quotactl, read, readlink, readv, reboot, recv, recvfrom, recvmsg, rename, resuba, rfssys, rmdir, sbreak, sbrk, select, semsys, send, sendmsg, sendto, setdomainname, setdopt, setgid, setgroups, sethostid, sethostname, setitimer, setpgid, setpgrp, setpgrp, setpriority, setquota, setregid, setreuid, setrlimit, setsid, setsockopt, settimeofday, setuid, shmsys, shutdown, sigblock, sigpause, sigpending, sigsetmask, sigstack, sigsys, sigvec, socket, socketaddr, socketpair, sstk, stat, stat, statfs, stime, stty, swapon, symlink, sync, sysconf, time, times, truncate, umask, umount, uname, unlink, unmount, ustat, utime, utimes, vadvise, vfork, vhangup, vlimit, vpixsys, vread, vtimes, vtrace, vwrite, wait, wait3, wait4, write, writev

Ubuntu Linux System Calls

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HIDS Data Sources

comctl32

kernel32

msvcpp

msvcrt

mswsock

ntdll

ntoskrnl

user32

ws2_32

Key Windows DLLs and Executables

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3.2 Distributed HIDS

Distributed HIDS

One vs Many!

- a more effective defence, if using cooperation HIDSs across the network.

However

- May need to deal with different sensor data formats
- Need to ensure integrity and confidentiality data sent across the network
- In a centralized architecture, it may create a bottle neck, and possible major point of attack
- In a decentralized architecture, it would require coordination

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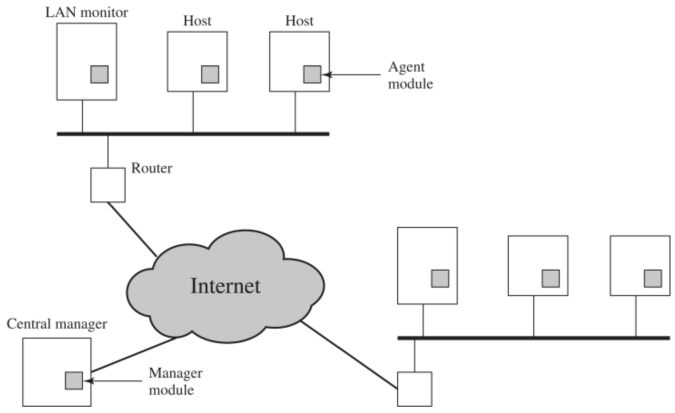
Distributed HIDS



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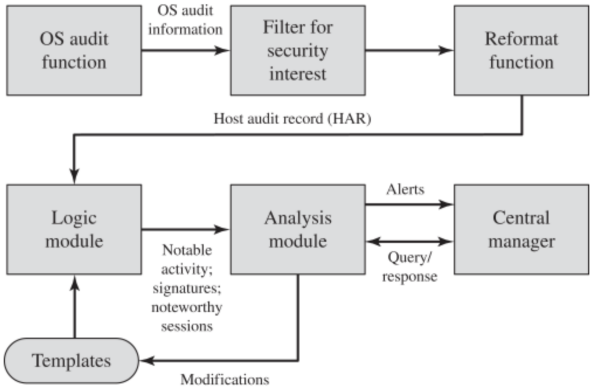
Distributed HIDS



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4 NIDS

4.1 Data Sources

NIDS Data Sources

- INIDS sensor monitors and analyzes network activity on one or more network segments → NICs have to be in '*promiscuous mode*'
- Sensors are available in two formats
  - **Appliances**: specialized hardware and sensor software. Typically have a security hardened OS, with no direct, network access
  - **Software Only**: can be installed on any, or customized OS.

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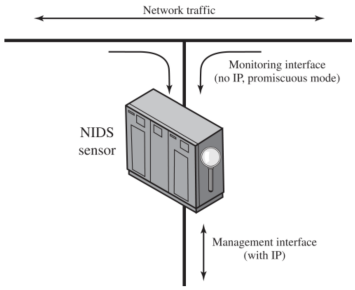
NIDS Sensor Types

NIDS sensors are also categorized into two types, depending on deployment modes:

- **Inline sensor:** It s inserted into a network segment so the traffic that it is monitoring must pass through the sensor
- **Passive sensor:** It monitors a copy of network traffic; the actual traffic does not pass through the device



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NIDS Data Sources

NIDS sensors collect information from different layers of network stack:

- **Application layer information:** DHCP, DNS, HTTP, FTP, IMAP and SMTP, POP, NFS, RPC, SIP, SMP, SNMP, $\cdots$; as well as attack patterns associated with buffer overflows, password guessing, and malware transmission.
- **Transport layer information:** TCP, UDP and other transport layer protocol info, such unusual packet fragmentation, scans for vulnerable ports, and TCP-specific attacks such as SYN floods.
- **Network layer info:** IPv4, IPv6, ICMP and IGMP info, such as spoofed IP addresses and illegal IP header values

Additionally, NIDS sensors can watch for:

- **Unexpected application services**
- **Policy violations**

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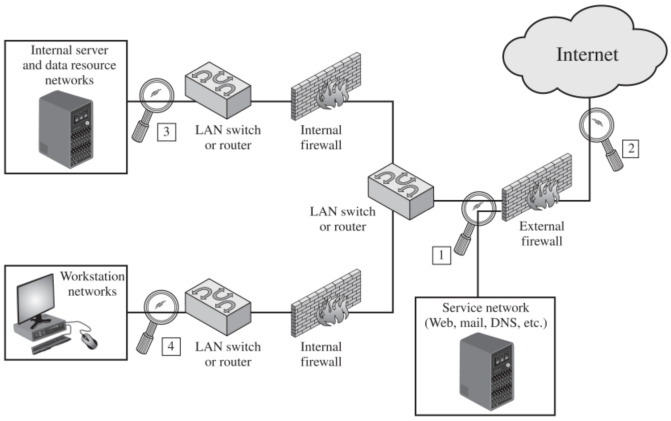
4.2 Deployment

Network Architectures and Sensor Locations



There are advantageous and disadvantageous for each deployment location. What are they?

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4.3 Capabilities

Capabilities

- **Information Gathering Capabilities:**
  - Identifying Hosts
  - Identifying Operating Systems
  - Identifying Applications
  - Identifying Network Characteristics

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Capabilities

- **Logging Capabilities:**
  - Timestamp
  - Connection or session ID
  - Event or alert type
  - Rating (e.g., priority, severity, impact, confidence)
  - Network, transport, and application layer protocols
  - Source and destination IP addresses
  - Source and destination TCP or UDP ports, or ICMP types and codes
  - Number of bytes transmitted over the connection
  - Decoded payload data, such as application requests and responses
  - State-related information

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Capabilities

- **Detection Capabilities:**
  - Signature-based detection
  - Anomaly-based detection
  - Stateful protocol analysis techniques

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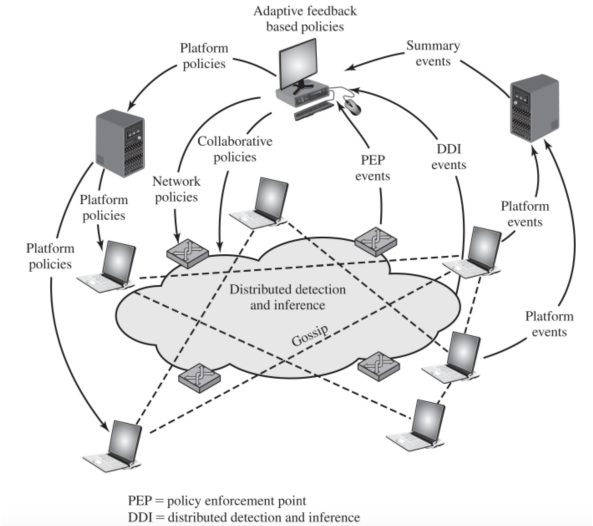
5 Hybrid IDS

5.1 Architecture

Hybrid IDS



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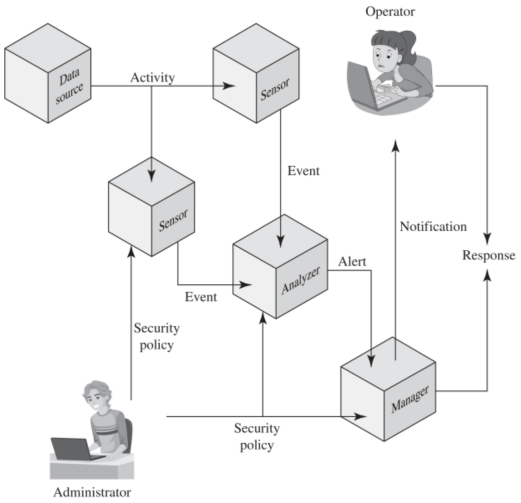
5.2 Exchange Format

Model



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Exchange Formats

Need to define exchange formats for

- event and alert messages
- message types
- exchange protocols for communication of intrusion detection

IETF has the following 3 RFC's to formalize this (2007):

- **Intrusion Detection Message Exchange Requirements (RFC 4766)**: specifies the exchange format requirements
- **The Intrusion Detection Message Exchange Format (RFC 4765)**: specifies a data model, such as XML to be used
- **The Intrusion Detection Exchange Protocol (RFC 4767)**: specifies an application-level protocol for data exchange between entities. Supports mutual-authentication, integrity, and confidentiality over a connection-oriented protocol

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6 Honeypots

6.1 Concept

Concept

Honeypots are decoys systems designed to

- Divert an attacker from accessing critical systems
- Collect information about the attacker's activity
- Encourage the attacker to stay on the system long enough for administrators to respond

- Low interaction honeypot: Not a full replica, but realistic enough (typically a software package)
- High interaction honeypot: a full-fledge, real-system replica

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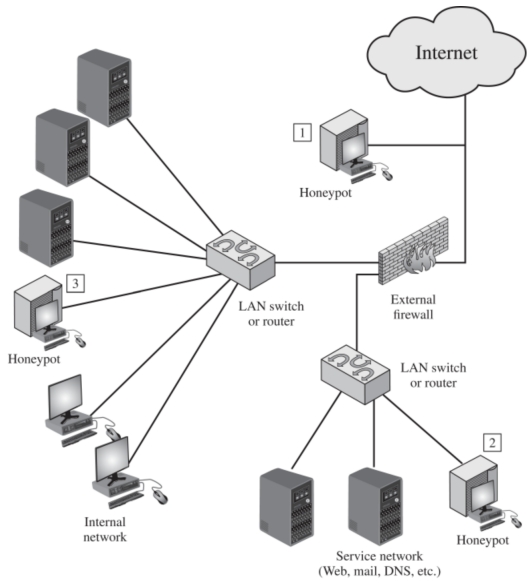
6.2 Deployment

Deployment



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7 Snort

7.1 Characteristics

Characteristics

Snort: An open-source (`https://www.snort.org`) NIDS

- Easily deployed on most network nodes
- Efficient operation
- Easily configurable
- Mainly designed to work with TCP, UDP and ICMP

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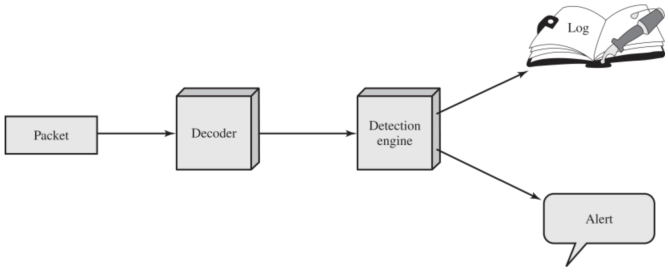
7.2 Architecture

Characteristics



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7.3 Rules

Rules

Action	Protocol	Source IP address	Source port	Direction	Dest IP address	Dest port

(a) Rule header

Option keyword	Option arguments	. . .

(b) Options

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