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CSCI 454/554 Computer and Network Security

Topic 8.4 Firewalls and Intrusion Detection Systems (IDS)

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Outline

- Firewalls
  - Filtering firewalls
  - Proxy firewalls
- Intrusion Detection System (IDS)
  - Rule-based IDS
  - Anomaly detection IDS
  - Host-based vs. network-based IDS

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Overview of Firewalls

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Internet Security Mechanisms

Prevent: Firewall, IPsec, SSL   Detect: Intrusion Detection   Survive/Response: Recovery, Forensics

- Goal: prevent if possible; detect quickly otherwise; and confine the damage

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Basic Terms

- *Vulnerabilities*
- *Intrusion*s (attacks) and Intrusion Detection Systems (IDS)
- *Alert or alarm*: message generated by IDS

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Example Attacks

- Disclosure, modification, and destruction of data
- Compromise host and then attack other systems
- Monitoring and capture of user passwords, then masquerade as authorized user
- Phishing attacks

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Firewalls

- Provides secure connectivity between networks
- Implements and enforces a security policy for communication between networks

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Firewalls (Cont'd)

- Many organizations have distinct needs
  - access by anyone to public data concerning the company
  - access only by employees to internal data
- Solution: inner and outer (DMZ) networks

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Firewall Capabilities

- Controlled access
  - restrict incoming and outgoing traffic according to security policy
- Other functions
  - log traffic, for later analysis
  - network address translation
  - encryption / decryption
  - application (payload) transformations

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Limitations of Firewalls

- Cannot protect against traffic that does not cross it
  - i.e., there may be other ingress points to the network, such as modems or wireless access points, that bypass the firewall
  - doesn't protect against "inside" attacks
- Configuration of firewalls to accomplish a desired high-level security policy is non-trivial

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Filtering and Proxy Firewalls

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Filtering

- Compare traffic to patterns, then process traffic according to rules if matched
- Two styles
  - packet filtering
  - session filtering

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Packet Filtering

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- Patterns specify values in the header of a single packet, e.g.,
  - source IP address and port number
  - destination IP address and port number
  - transport protocol type

Router / Firewall

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Packet Filtering (cont'd)

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- Decisions made on a per-packet basis
  - no state information (about previous packets) is maintained or used
- Assessment
  - easy to implement
  - but limited capabilities
- May be subject to tiny-fragment attack
  - first fragment has only a few bytes
  - rest of TCP header in a second fragment, not examined by firewall

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Session Filtering

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- Packet decisions are made in the context of a *connection* or *flow* of packets
- If packet is the start of a new connection…
  - check against rules for new connections
- If packet is part of an existing connection…
  - check against state-based rules for existing connections
  - update state of this connection

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Session Filtering (cont'd)

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- Assessment
  - more powerful than packet filtering, can recognize more sophisticated threats or implement more complex policies
  - also more expensive to implement

Router / Firewall

Dynamic State Tables

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Application: Telnet

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Telnet Server   Telnet Client

port=23   port=1234

❶ Client opens channel to server; tells server its port number. The ACK bit is not set when initiating the connection but will be set on the remaining packets.

❷ Server acknowleges.

"USE PORT 1234" ❶

❷ "ACK"

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Example: Firewall Access for Telnet

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Format:
access-list *<rule number>*
<permit|deny>
<protocol>
<SOURCE host with IP address| any|IP address and mask>
[<gt|eq port number>]
<DEST host with IP address| any|IP address and mask>
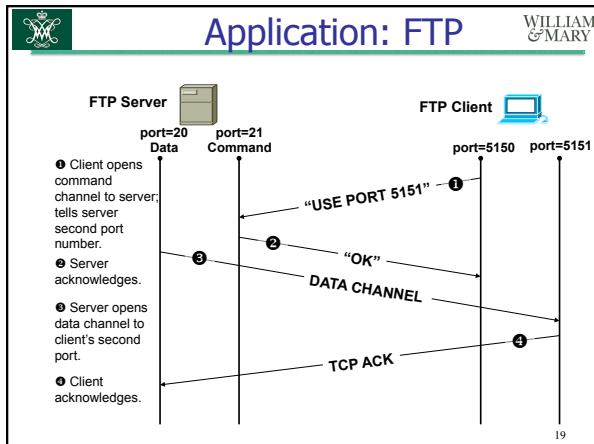*[<gt|eq port number>]*

Note: any packets not explicitly permitted in an access list assumed to be denied or dropped.

The following allows user to telnet from an IP address (172.168.10.11) to any destination, but not vice-versa:

access-list 100 permit tcp host 172.168.10.11 gt 1023 any eq 23
! Allows packets out to remote Telnet servers
access-list 101 permit tcp any eq 23 host 172.168.10.11 established
! Allows returning packets to come back in. It verifies that the ACK bit is set

interface Ethernet 0
access-list 100 out ! Apply the first rule to outbound traffic
access-list 101 in ! Apply the second rule to inbound traffic

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Application: FTP

FTP Server

port=20 port=21
Data   Command

FTP Client

port=5150 port=5151

❶ Client opens command channel to server; tells server second port number.

❷ Server acknowledges.

❸ Server opens data channel to client's second port.

❹ Client acknowledges.

"USE PORT 5151" ❶

❷ "OK"

❸ DATA CHANNEL

TCP ACK ❹

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Example: Firewall Access for FTP

Allow a user to FTP (not passive FTP) from any IP address to the FTP server (172.168.10.12) :

```
access-list 100 permit tcp any gt 1023 host 172.168.10.12 eq 21
access-list 100 permit tcp any gt 1023 host 172.168.10.12 eq 20
 ! Allows packets from any client to the FTP control and data ports
access-list 101 permit tcp host 172.168.10.12 eq 21 any gt 1023
access-list 101 permit tcp host 172.168.10.12 eq 20 any gt 1023
 ! Allows FTP server to send packets back to any IP address with TCP ports >
1023

interface Ethernet 0
 access-list 100 in    ! Apply the first rule to inbound traffic
 access-list 101 out   ! Apply the second rule to outbound traffic
```

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Proxy Firewalls

- Serve as *relays* for connections
- Two flavors
  1. application level
  2. circuit level

Telnet   FTP   HTTP

Applications   Applications   Applications
Presentations Presentations Presentations
Sessions   Sessions   Sessions
Transport   Transport   Transport
Network   Network   Network
DataLink   DataLink   DataLink
Physical   Physical   Physical

Application Gateway

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Application Proxies

- Understand specific application protocols, e.g., HTTP, SMTP, Telnet
  - proxy 'impersonates' both one side of connection to the other
- Can do arbitrary processing / inspection of application payloads
  - ex.: check mail for viruses before forwarding
- Computationally expensive
- Must write a new proxy application to support new protocols

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Application Proxies (Cont'd)

- May require hosts inside the organization to be configured to use the proxy

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Circuit-Level Proxies

- Sets up two connections, one to inside user, one to outside server
  - i.e., proxy at the TCP level, rather than the application level
  - client programs must be aware they are using a circuit-level proxy, by linking to modified libraries
- Users must authenticate to proxy before connection to outside will be established
- Example protocol: SOCKS

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Overview of IDS

Attack Stages

- Cyber Kill Chain
  - Intelligence gathering: attacker probes the system to determine vulnerabilities
  - Planning: deciding what resource to attack and how
  - Attack execution
  - Hiding: covering traces of the attack
  - Preparation for future attacks: install "back doors" for unhindered access

IDS

- Detect if attacks are being attempted, or if system has been compromised
- Desirable features
  - Accuracy
  - Fast
  - Flexible, general
  - Results easy to understand

Measuring Accuracy

- *Events* are actions occurring in the system (file accesses, login attempts, etc.)
  - an *intrusion* (I) is an event that is part of an attack
  - an *alarm* (A) is generated if an event is diagnosed as being an intrusion

	Intrusion	Not an Intrusion
Alarm Generated	True positive	False positive
Alarm Not Generated	False negative	True negative

Measuring (Cont'd)

- True positive rate (TPR): fraction of intrusions correctly diagnosed (detected)
- False negative rate: fraction of intrusions incorrectly diagnosed (not detected)
  - FNR = 1 - TPR
- True negative rate (TNR): fraction of non-intrusions correctly diagnosed
- False positive rate: fraction of non-intrusions incorrectly diagnosed
  - FPR = 1 - TNR

Which Ones Count

- It's trivial to have 100% TPR, and trivial to have 0% FPR
  - how?
- Needed: both

Example

- 70,000 events, 300 intrusions, 2800 alarms (of which 298 are correct diagnoses, 2502 are incorrect)
- TPR: 298 / 300 = 99.3%
- FNR: 0.7%
- TNR: (70000 - 300 - 2502) / (70000 - 300) = 96.4%
- FPR: 3.6%

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"Base-Rate Fallacy" Illustrated

- IDS often suffers from base-rate fallacy
  - intrusions are rare events
  - non-intrusions are common
  - correctly detected intrusions are swamped by incorrectly detected non-intrusions!
- Previous example: only 298 out of 2800 alarms (10.6%) are correct
  - in reality, often less than 1% of alarms are real intrusions

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Components of IDS

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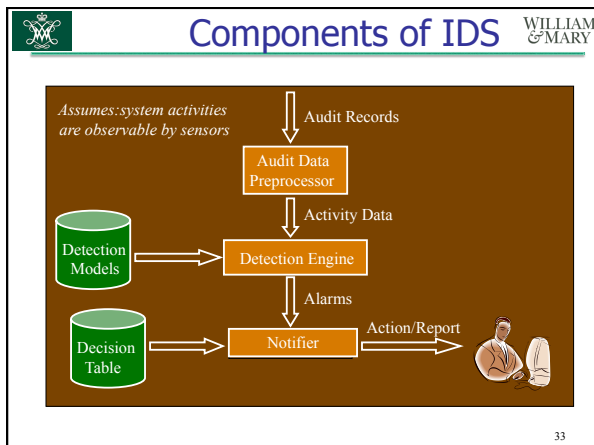
Signature-Based IDS

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Basic IDS Techniques

1. Misuse detection
   - use attack *signatures* (characteristics of real attacks, e.g., illegal sequences of system calls, invalid packets, etc.)
   - can only detect already-known attacks
   - false positive rate is low, but false negative rate is high

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Detection (Cont'd)

2. Anomaly detection
   - uses a model of "normal" system behavior
   - tries to detect deviations from this behavior, e.g., raises an alarm when a statistically rare event occurs
   - can potentially detect new (not previously-encountered) attacks
   - low false negative rate, high false positive rate
- Which is better?

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Ex.: Misuse vs. Anomaly Detection

Password file modified	?
Four failed login attempts	?
Failed connection attempts on 50 sequentially-numbered ports	?
User who usually logs in around 10am from dorm logs in at 4:30am from an IP address in Lower Slobovia	?
UDP packet to port 1434 (Slammer Worm)	?

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Example Signatures

- A sequence of connection attempts to a large number of ports
- A privileged program spawning a shell
- A network packet that has lots of NOOP instruction bytes in it
- Program input containing a very long string (parameter value)
- A large number of TCP SYN packets sent, with no ACKs coming back

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Signature Generation

- Research challenge: fast, automatic extraction of signatures for new attacks
  - *honeypots* are useful for attracting attacks to generate signatures
- Attack signatures are usually very specific
  - automated engines now generate unlimited variants of a single attack
  - program obfuscation, self-decrypting code
- Possible response: find attack characteristics that are difficult to conceal / obfuscate

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Anomaly-Based IDS

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Anomaly Detection

- Collect a profile of "normal" behavior
  - called *training phase*
  - works best for small, well-defined, stable systems
- IDS compares operational system to this profile, and flags deviations

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Examples of Metrics

- Count of the number of occurrences of an event per unit time
  - if count exceeded, raise an alarm
- Time elapsed between events
  - if time too small, raise an alarm
- Resource utilization
  - if utilization too high, raise an alarm
- Statistical measures
  - mean, standard deviation, etc.

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Examples (Cont'd)

- Markov process: use expected likelihood of transition from one system state to another, or from one output to another
- Short sequences of events
  - ex. suppose the normal sequences of system calls during execution of two programs has been measured
  - any serious deviation from such sequences will be flagged as possible signs of an attack

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Building Profiles

- Profiles are updated regularly, and older data must be "aged" out
  - ex.: $m_t = \alpha$ * most recent measured value + $(1-\alpha)$*m_{t-1}
  - where m_t is expected value for time period t, α is an experimentally-derived weighting factor between .5 and 1.0
- Risk: attacker trains IDS to accept his activity as normal
  - i.e., training data should be free of intrusions, or intrusions must be properly classified in the training data!

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Examples of Data Mining Techniques

- Association rule learning (find interesting relations between variables)
- Principal components analysis (isolate and focus on the high variance variables)
- Cluster analysis (group data into categories based on similarities)
- ...

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Conventional View

- Anomaly-based IDS by itself generates too many false positives
- Combination of anomaly-based and signature-based is best

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Host-Based vs. Network-Based IDS

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Where Is the IDS Deployed?

- Host-based intrusion detection system (HIDS)
  - monitor activity on a single host
- Network-based intrusion detection (NIDS)
  - monitor traffic, examine packet headers and payloads

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Host-Based IDS

- Use OS auditing and monitoring mechanisms to find applications taken over by an attacker. Ex.:
  - log all system events (e.g., file accesses)
  - monitor shell commands and system calls executed
- Advantage: better visibility into behavior of individual applications running on the host
- Example application: detecting rootkits

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Host-Based (Cont'd)

- Drawbacks / limitations
  - need an IDS for every machine
  - if attacker takes over machine, can tamper with IDS binaries and modify audit logs
  - only local view of the attack

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Rootkit

- Rootkit is a set of "Trojan" system binaries
- Break into a host, download rootkit by FTP, unpack, compile and install
- Possibly turn off anti-virus / IDS
- Hides its own presence!
  - installs hacked binaries for common system monitoring commands, e.g., `netstat`, `ps`, `ls`, `du`, `login`
- "Sniff" user passwords

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File Integrity Checking

- Tripwire
  - Records hashes of critical files and binaries
  - System periodically checks that files have not been modified by re-computing and comparing hash
- Ways to bypass?

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Network-Based IDS

- Inspects network traffic
  - passive (unlike packet-filtering firewalls)
  - often handled by a router or firewall
- Monitors user activities
  - e.g., protocol violations, unusual connection patterns, attack strings in packet payloads
- Advantage: single NIDS can protect many hosts and look for widespread patterns of activity

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Network-Based ... (cont'd)

- Drawbacks / limitations
  - may be easily defeated by encryption (data portions and some header information can be encrypted)
  - not all attacks arrive from the network
  - must monitor, record and process huge amount of traffic on high-speed links
- Attack: overload NIDS with huge data streams, then attempt the intrusion

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Popular NIDS : Snort

- Popular open-source tool
- Large (> 4000) ruleset for vulnerabilities; Ex.:

"Date: 2005-04-05
Synopsis: the Sourcefire Vulnerability Research Team (VRT) has learned of serious vulnerabilities affecting various implementations of Telnet […] Programming errors in the telnet client code from various vendors may present an attacker with the opportunity to overflow a fixed length buffer […]
Rules to detect attacks against this vulnerability are included in this rule pack"

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Some Snort Rule Categories

- Backdoors
- Chat
- DDoS
- Finger
- FTP
- ICMP
- IMAP

Multimedia
MySQL
NETBIOS
NNTP
Oracle
P2P

POP
RPC
Scan
Shellcode
SMTP
SNMP
SQL

Telnet
TFTP
Virus
Web…
X11

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Snort Rule Syntax

- Each snort rule has two logical sections: rule header and rule options
  - rule header contains action, protocol, source (IP address/port), direction, destination (IP address/port)
  - rule option contains alert messages, info on which parts of packet to be inspected

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Snort Rule Examples

- alert icmp $EXTERNAL_NET any <> $HOME_NET any
  (msg:"DDOS Stacheldraht agent->handler (skillz)";
  content:"skillz";
  itype:0;
  icmp_id:6666; reference:url,staff.washington.edu/dittrich/misc/
  stacheldraht.analysis;
  classtype:attempted-dos;
  sid:1855; rev:2;)
- alert any any -> 192.168.1.0/24 any
  (flags:A; ack:0; msg: "NMAP TCP ping";)
  # nmap send TCP ACK pkt with ack field set to 0
- alert tcp $EXTERNAL_NET any -> $HTTP_SERVERS $HTTP_PORTS
  (msg:"WEB-IIS cmd.exe access"; flow:to_server,established;
  content:"cmd.exe";
  nocase;
  classtype:web-application-attack;
  sid:1002; rev:5;)

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Detecting Attack Strings

- Scanning for a signature in each packet is not enough
  - attacker can split attack string into several packets; will defeat stateless NIDS
- Recording just previous packet's text is not enough
  - attacker can send packets out of order
- Attacker can use TCP tricks so that certain packets are seen by NIDS but dropped by the receiving application

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Honeypots

- Decoy systems to lure attackers
  - away from accessing critical systems
  - to collect information of their activities
  - to encourage attacker to stay on system so administrator can respond
- Filled with fabricated information
- High-interaction decoy vs. Low-interaction decoy
- Instrumented to collect detailed information on attackers activities
- May be single or multiple networked systems

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1. Firewalls widely used, packet filters most common
   - one valuable technique among many
2. IDS (both host-based and network-based) widely used
3. Attacks are constantly evolving; the "arms race"
4. False alarm volume, and providing clear feedback to administrators, is a problem

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