CS 155 Spring 2006

Network Defense Tools:
Firewalls, Traffic shapers, and Intrusion Detection

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Perimeter and Internal Defenses

- Commonly deployed defenses
  - Perimeter defenses – Firewall, IDS
    - Protect local area network and hosts
    - Keep external threats from internal network
  - Internal defenses – Virus scanning
    - Protect hosts from threats that get through the perimeter defenses
  - Extend the "perimeter" – VPN
- Common practices, but could be improved
  - Internal threats are significant
    - Unhappy employees
    - Compromised hosts

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This lecture

- Standard perimeter defense mechanisms
  - Firewall
    - Packet filter (stateless, stateful)
    - Application layer proxies
  - Traffic shaping
  - Intrusion detection
    - Anomaly and misuse detection
    - Methods applicable to network or host
- Future lectures
  - Virus and malware
  - Worm propagation and detection

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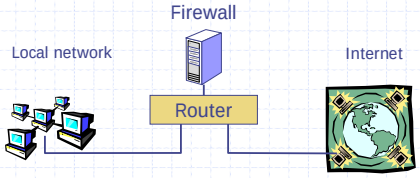
Basic Firewall Concept

- Separate local area net from internet



All packets between LAN and internet routed through firewall

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Firewall goals

- Prevent malicious attacks on hosts
  - Port sweeps, ICMP echo to broadcast addr, syn flooding, ...
  - Worm propagation
    - Exploit buffer overflow in program listening on network
- Prevent general disruption of internal network
  - External SMNP packets
- Provide defense in depth
  - Programs contain bugs and are vulnerable to attack
  - Network protocols may contain;
    - Design weaknesses (SSH CRC)
    - Implementation flaws (SSL, NTP, FTP, SMTP…)
- Control traffic between "zones of trusts"
  - Can control traffic between separate local networks, etc

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Two Separable Topics

- Arrangement of firewall and routers
  - Several different network configurations
    - Separate internal LAN from external Internet
    - Wall off subnetwork within an organization
    - Intermediate zone for web server, etc.
  - Personal firewall on end-user machine
- How the firewall processes data
  - Packet filtering router
  - Application-level gateway
    - Proxy for protocols such as ftp, smtp, http, etc.
  - Personal firewall
    - E.g., disallow telnet connection from email client

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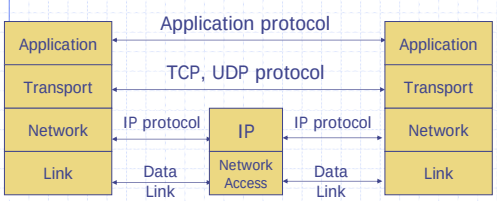
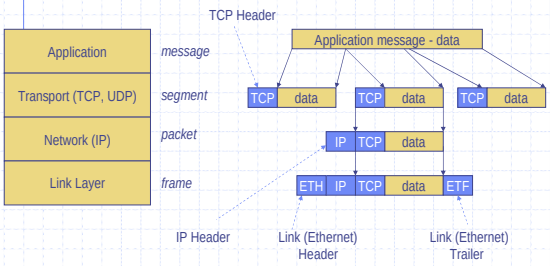
Review: TCP Protocol Stack

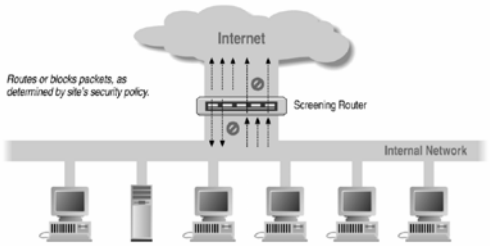


Transport layer provides *ports*, logical channels identified by number

Review: Data Formats



Screening router for packet filtering



Illustrations: Simon Cooper

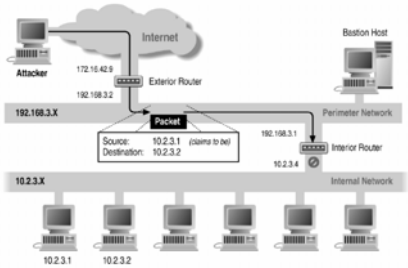
Packet Filtering

- Uses transport-layer information only
  - IP Source Address, Destination Address
  - Protocol (TCP, UDP, ICMP, etc)
  - TCP or UDP source & destination ports
  - TCP Flags (SYN, ACK, FIN, RST, PSH, etc)
  - ICMP message type
- Examples
  - DNS uses port 53
    - Block incoming port 53 packets except known trusted servers
- Issues
  - Stateful filtering
  - Encapsulation: address translation, other complications
  - Fragmentation

Packet filtering examples

Compare: Tiny Personal Firewall, ZoneAlarm

Source/Destination Address Forgery



More about networking: port numbering

- TCP connection
  - Server port uses number less than 1024
  - Client port uses number between 1024 and 16383
- Permanent assignment
  - Ports <1024 assigned permanently
    - 20,21 for FTP 23 for Telnet
    - 25 for server SMTP 80 for HTTP
- Variable use
  - Ports >1024 must be available for client to make connection
  - Limitation for stateless packet filtering
    - If client wants port 2048, firewall must allow incoming traffic
  - Better: stateful filtering knows outgoing requests
    - Only allow incoming traffic on high port to a machine that has initiated an outgoing request on low port

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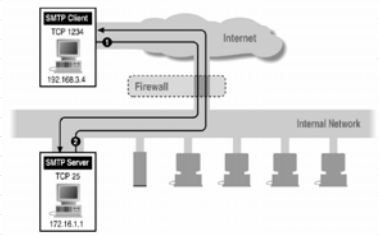
Filtering Example: Inbound SMTP



Can block external request to internal server based on port number

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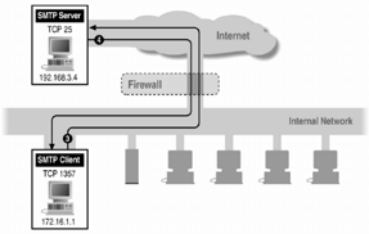
Filtering Example: Outbound SMTP



Known low port out, arbitrary high port in

If firewall blocks incoming port 1357 traffic then connection fails

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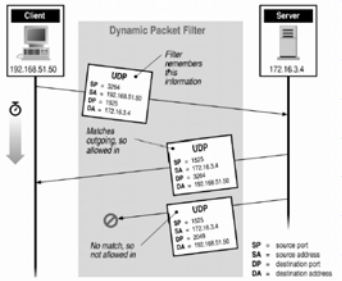
Stateful or Dynamic Packet Filtering



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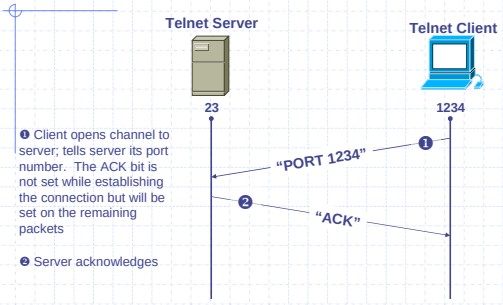
Telnet



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

❷ Server acknowledges

Stateful filtering can use this pattern to identify legitimate sessions

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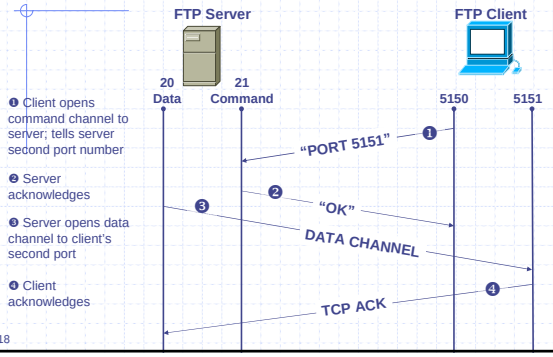
FTP



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

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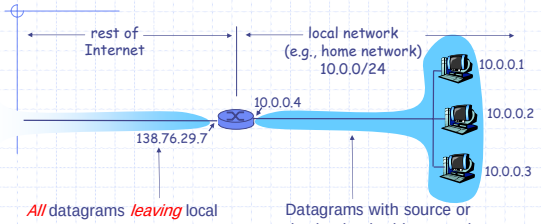
NAT: Network Address Translation



All datagrams *leaving* local network have same single source NAT IP address: 138.76.29.7, different source port numbers

Datagrams with source or destination in this network have 10.0.0/24 address for source, destination (as usual)

Illustration: Kurose and Ross

Advantages of NAT

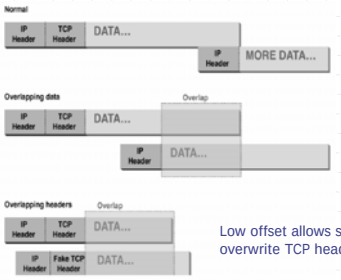
- Motivations for NAT
  - Limited address space
  - Prevent unsolicited inbound requests
    - Port numbering: host behind NAT not reachable as server
  - Avoid renumbering if provider changes
    - Small/mid-sized LANs inherit address space from ISP
- Addresses hidden by NAT
  - Normal routing
    - Outgoing msg from 171.64.78.90 contains sending address
    - Recipient or observer can access 171.64.78.90
  - Addressing with NAT
    - NAT rewrites outgoing packet so recipient sees public addr only
    - An outside computer cannot see 171.64.78.90

Complication for firewalls

Normal IP Fragmentation

Flags and offset inside IP header indicate packet fragmentation

Abnormal Fragmentation



Low offset allows second packet to overwrite TCP header at receiving host

Packet Fragmentation Attack

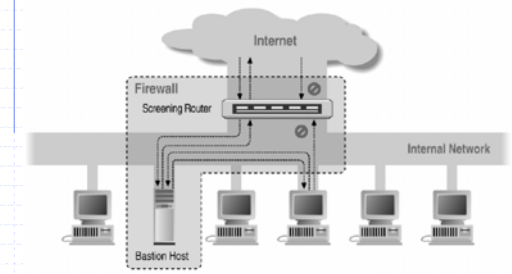
- Firewall configuration
  - TCP port 23 is blocked but SMTP port 25 is allowed
- First packet
  - Fragmentation Offset = 0.
  - DF bit = 0 : "May Fragment"
  - MF bit = 1 : "More Fragments"
  - Destination Port = 25. TCP port 25 is allowed, so firewall allows packet
- Second packet
  - Fragmentation Offset = 1: second packet overwrites all but first 8 bits of the first packet
  - DF bit = 0 : "May Fragment"
  - MF bit = 0 : "Last Fragment."
  - Destination Port = 23. Normally be blocked, but sneaks by!
- What happens
  - Firewall ignores second packet "TCP header" because it is fragment of first
  - At host, packet reassembled and received at port 23

Beyond packet filtering

Proxying Firewall

- Several network locations – see next slides
- Two kinds of proxies
  - Circuit-level proxies
    - Works at session layer (which I omitted from OSI diagram)
  - Application-level proxies
    - Tailored to http, ftp, smtp, etc.
    - Some protocols easier to proxy than others
- Policy embedded in proxy programs
  - Proxies filter incoming, outgoing packets
  - Reconstruct application-layer messages
  - Can filter specific application-layer commands, etc.
    - Example: only allow specific ftp commands
    - Other examples: ?

Screened Host Architecture



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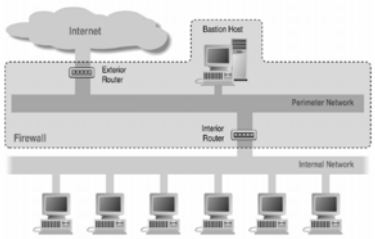
Screened Subnet Using Two Routers



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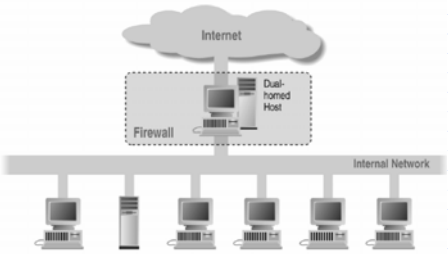
Dual Homed Host Architecture



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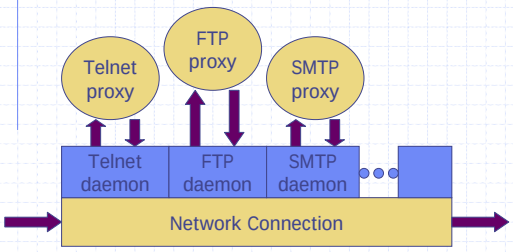
Firewall with application proxies



Daemon spawns proxy when communication detected ...

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Application-level proxies

- Enforce policy for specific protocols
  - E.g., Virus scanning for SMTP
    - Need to understand MIME, encoding, Zip archives
  - Flexible approach, but may introduce network delays
- "Batch" protocols are natural to proxy
  - SMTP (E-Mail)
  - NNTP (Net news)
  - DNS (Domain Name System)
  - NTP (Network Time Protocol
- Must protect host running protocol stack
  - Disable all non-required services; keep it simple
  - Install/modify services you want
  - Run security audit to establish baseline
  - Be prepared for the system to be compromised

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Configuration issues

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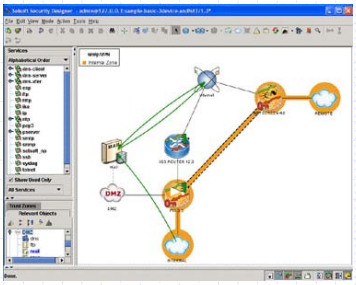
Solsoft



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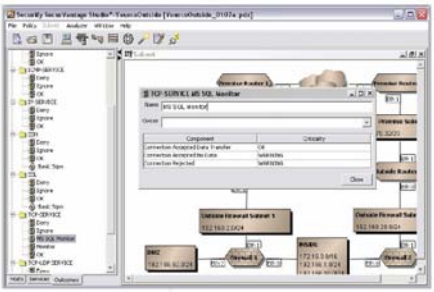
Securify



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Problems with Firewalls

- Performance
  - Firewalls may interfere with network use
- Limitations
  - They don't solve deeper problems
    - Buggy software
    - Bad protocols
  - Generally cannot prevent Denial of Service
  - Ineffective against insider attacks
- Administration
  - Many commercial firewalls permit very complex configurations

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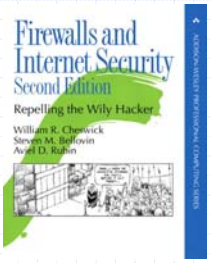
References

Elizabeth D. Zwicky
Simon Cooper
D. Brent Chapman



William R Cheswick
Steven M Bellovin
Aviel D Rubin

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Traffic Shaping

- Traditional firewall
  - Allow traffic or not
- Traffic shaping
  - Limit certain kinds of traffic
  - Can differentiate by host addr, protocol, etc
  - Multi-Protocol Label Switching (MPLS)
    - Label traffic flows at the edge of the network and let core routers identify the required class of service
- The real issue here on Campus:
  - P2P file sharing takes a lot of bandwidth
  - 1/3 of network bandwidth consumed by BitTorrent
    - Students: what are BitTorrent, Gnutella, Kazaa, ... used for?

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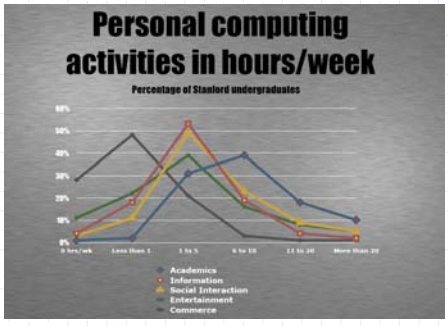
Stanford computer use



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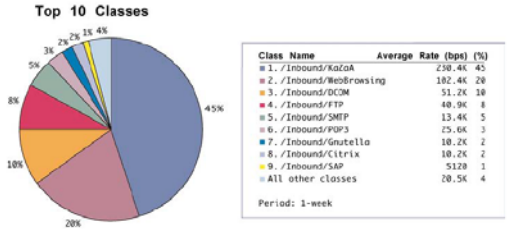
Sample traffic distribution



Class Name	Average Rate (bps)	(%)
1. /Inbound/KaZaA	230.4K	45
2. /Inbound/WebBrowsing	102.4K	20
3. /Inbound/DCOM	51.2K	10
4. /Inbound/FTP	40.9K	8
5. /Inbound/SMTP	13.4K	5
6. /Inbound/POP3	25.6K	3
7. /Inbound/Gnutella	10.2K	2
8. /Inbound/Citrix	10.2K	2
9. /Inbound/SAP	5120	1
All other classes	20.5K	4

Period: 1-week

Packeteer white paper example; not Stanford data

Traffic shaping functions

- Classify and analyze traffic
  - Classify by IP address and port number
  - Use application-specific information (layer 7)
- Control traffic
  - Selectively slow certain classes of traffic
- Monitor network performance
  - Collect performance data, used to improve policies
- Network resilience
  - Active traffic management can provide resilience to DoS attacks, at least within the enterprise network

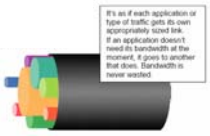
PacketShaper Classification

Classify 400+ Apps at OSI Layers 2-7

Peer-to-Peer Apps:
- Aimster
- AudioGalaxy
- CuteMX
- DirectConnect
- Gnutella
- Hotline
- iMesh
- KaZaA/Morpheus
- Napster
- ScourExchange
- Tripnosis….

Some Other Apps:
- H.323
- RTP-I/RTCP-I
- PASV FTP
- HTTP
- Real
- WinMedia
- Shoutcast
- MPEG
- Quicktime
- RTSP
- Chatting Apps
- Games

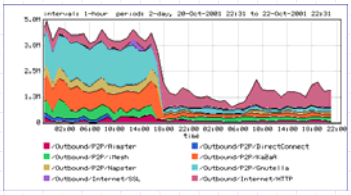
PacketShaper Controls



A partition:
- Creates a virtual pipe within a link for each traffic class
- Provides a min, max bandwidth
- Enables efficient bandwidth use

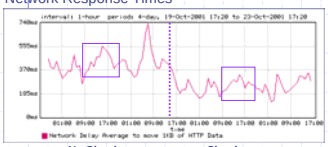
Rate shaped P2P capped at 300kbps

Rate shaped HTTP/SSL to give better performance



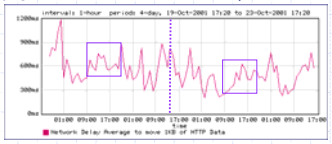
PacketShaper report: HTTP

Outside Web Server Normalized Network Response Times



No Shaping Shaping

Inside Web Server Normalized Network Response Times



No Shaping Shaping

Host and network intrusion detection

- Intrusion prevention
  - Network firewall
    - Restrict flow of packets
  - System security
    - Find buffer overflow vulnerabilities and remove them!
- Intrusion detection
  - Discover system modifications
    - Tripwire
  - Look for attack in progress
    - Network traffic patterns
    - System calls, other system events

Tripwire

- Outline of standard attack
  - Gain user access to system
  - Gain root access
  - Replace system binaries to set up backdoor
  - Use backdoor for future activities
- Tripwire detection point: system binaries
  - Compute hash of key system binaries
  - Compare current hash to hash stored earlier
  - Report problem if hash is different
  - Store reference hash codes on read-only medium

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Is Tripwire too late?

- Typical attack on server
  - Gain access
  - Install backdoor
    - This can be in memory, not on disk!!
  - Use it
- Tripwire
  - Is a good idea
  - Wont catch attacks that don't change system files
  - Detects a compromise that *has happened*

Remember: Defense in depth

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Detect modified binary in memory?

- Can use system-call monitoring techniques
- For example [Wagner, Dean IEEE S&P '01]
  - Build automaton of expected system calls
    - Can be done automatically from source code
  - Monitor system calls from each program
  - Catch violation

Results so far: lots better than not using source code!

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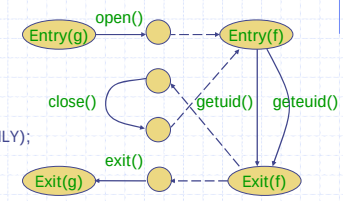
Example code and automaton

```
f(int x) {
  x ? getuid() : geteuid();
  x++
}
g() {
  fd = open("foo", O_RDONLY);
  f(0); close(fd); f(1);
  exit(0);
}
```



If code behavior is inconsistent with automaton, something is wrong

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General intrusion detection

http://www.snort.org/

- Many intrusion detection systems
  - Close to 100 systems with current web pages
  - Network-based, host-based, or combination
- Two basic models
  - Misuse detection model
    - Maintain data on known attacks
    - Look for activity with corresponding signatures
  - Anomaly detection model
    - Try to figure out what is "normal"
    - Report anomalous behavior
- Fundamental problem: too many false alarms

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Misuse example - rootkit

- Rootkit sniffs network for passwords
  - Collection of programs that allow attacker to install and operate a packet sniffer (on Unix machines)
  - Emerged in 1994, has evolved since then
  - 1994 estimate: 100,000 systems compromised
- Rootkit attack
  - Use stolen password or dictionary attack to get user access
  - Get root access using vulnerabilities in rdist, sendmail, /bin/mail, loadmodule, rpc.ypupdated, lpr, or passwd
  - Ftp Rootkit to the host, unpack, compile, and install it
  - Collect more username/password pairs and move on

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Rootkit covers its tracks

- Modifies netstat, ps, ls, du, ifconfig, login
  - Modified binaries hide new files used by rootkit
  - Modified login allows attacker to return for passwords
- Rootkit fools simple Tripwire checksum
  - Modified binaries have same checksum
  - But a better hash would be able to detect rootkit

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Detecting rootkit on system

- Sad way to find out
  - Disk is full of sniffer logs
- Manual confirmation
  - Reinstall clean ps and see what processes are running
- Automatic detection
  - Rootkit does not alter the data structures normally used by netstat, ps, ls, du, ifconfig
  - Host-based intrusion detection can find rootkit files
    - As long as an update version of Rootkit does not disable your intrusion detection system ...

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Detecting network attack (Sept 2003)

- Symantec honeypot running Red Hat Linux 9
- Attack
  - Samba 'call_trans2open' Remote Buffer Overflow (BID 7294)
  - Attacker installed a copy of the SHV4 Rootkit
- Snort NIDS generated alerts, from this signature

```
alert tcp $EXTERNAL_NET any -> $HOME_NET 139 \
(msg:"NETBIOS SMB trans2open buffer overflow attempt"; \
flow:to_server,established; \
content:"|00|"; offset:0; depth:1; \
content:"|ff|SMB|32|"; offset:4; depth:5;
content:"|00 14|"; offset:60; depth:2; \
...
```

More info: https://tms.symantec.com/members/AnalystReports/030929-Analysis-SHV4Rootkit.pdf

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Misuse example - port sweep

- Attacks can be OS specific
  - Bugs in specific implementations
  - Oversights in default configuration
- Attacker sweeps net to find vulnerabilities
  - Port sweep tries many ports on many IP addresses
  - If characteristic behavior detected, mount attack
    - SGI IRIX responds TCPMUX port (TCP port 1)
    - If machine responds, SGI IRIX vulnerabilities can be tested and used to break in
- Port sweep activity can be detected

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Anomaly Detection

- Basic idea
  - Monitor network traffic, system calls
  - Compute statistical properties
  - Report errors if statistics outside established range
- Example – IDES (Denning, SRI)
  - For each user, store daily count of certain activities
    - E.g., Fraction of hours spent reading email
  - Maintain list of counts for several days
  - Report anomaly if count is outside weighted norm

Big problem: most unpredictable user is the most important

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[Hofmeyr, Somayaji, Forrest]

Anomaly – sys call sequences

- Build traces during normal run of program
  - Example program behavior (sys calls)
    open read write open mmap write fchmod close
  - Sample traces stored in file (4-call sequences)
    open read write open
    read write open mmap
    write open mmap write
    open mmap write fchmod
    mmap write fchmod close
  - Report anomaly if following sequence observed
    open read read open mmap write fchmod close

Compute # of mismatches to get mismatch rate

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Difficulties in intrusion detection

- Lack of training data
  - Lots of “normal” network, system call data
  - Little data containing realistic attacks, anomalies
- Data drift
  - Statistical methods detect changes in behavior
  - Attacker can attack gradually and incrementally
- Main characteristics not well understood
  - By many measures, attack may be within bounds of “normal” range of activities
- False identifications are very costly
  - Sys Admin spend many hours examining evidence

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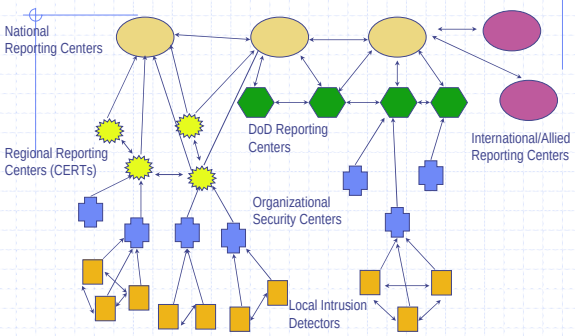
Strategic Intrusion Assessment [Lunt]



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www.blackhat.com/presentations/bh-usa-99/teresa-lunt/tutorial.ppt

Strategic Intrusion Assessment [Lunt]

- Test over two-week period
  - AFIWC’s intrusion detectors at 100 AFBs alarmed on 2 million sessions
  - Manual review identified 12,000 suspicious events
  - Further manual review => four actual incidents
- Conclusion
  - Most alarms are false positives
  - Most true positives are trivial incidents
  - Of the significant incidents, most are isolated attacks to be dealt with locally

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Lecture Review

- Firewalls
  - Packet filter (stateless, stateful)
  - Application-layer proxies
- Traffic Shaping
- Intrusion detection
  - Anomaly and misuse detection
  - Host and network intrusion detection

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