Intrusion Detection Systems

Intrusion Detection Systems (IDS)

An IDS is any combination of hardware & software that monitors a system or network for malicious activity.

An IPS (Intrusion Prevention System) is a network IDS that can cap network connections.

Examples of IDSs in real life

- Car alarms
- Fire detectors
- House alarms
- Surveillance systems

What should be detected?

- Attempted and successful break-ins
- Attacks by legitimate users
  - For example, illegitimate use of root privileges
  - Unauthorized access to resources and data
- Trojan horses
- Viruses and worms
- Denial of service attacks

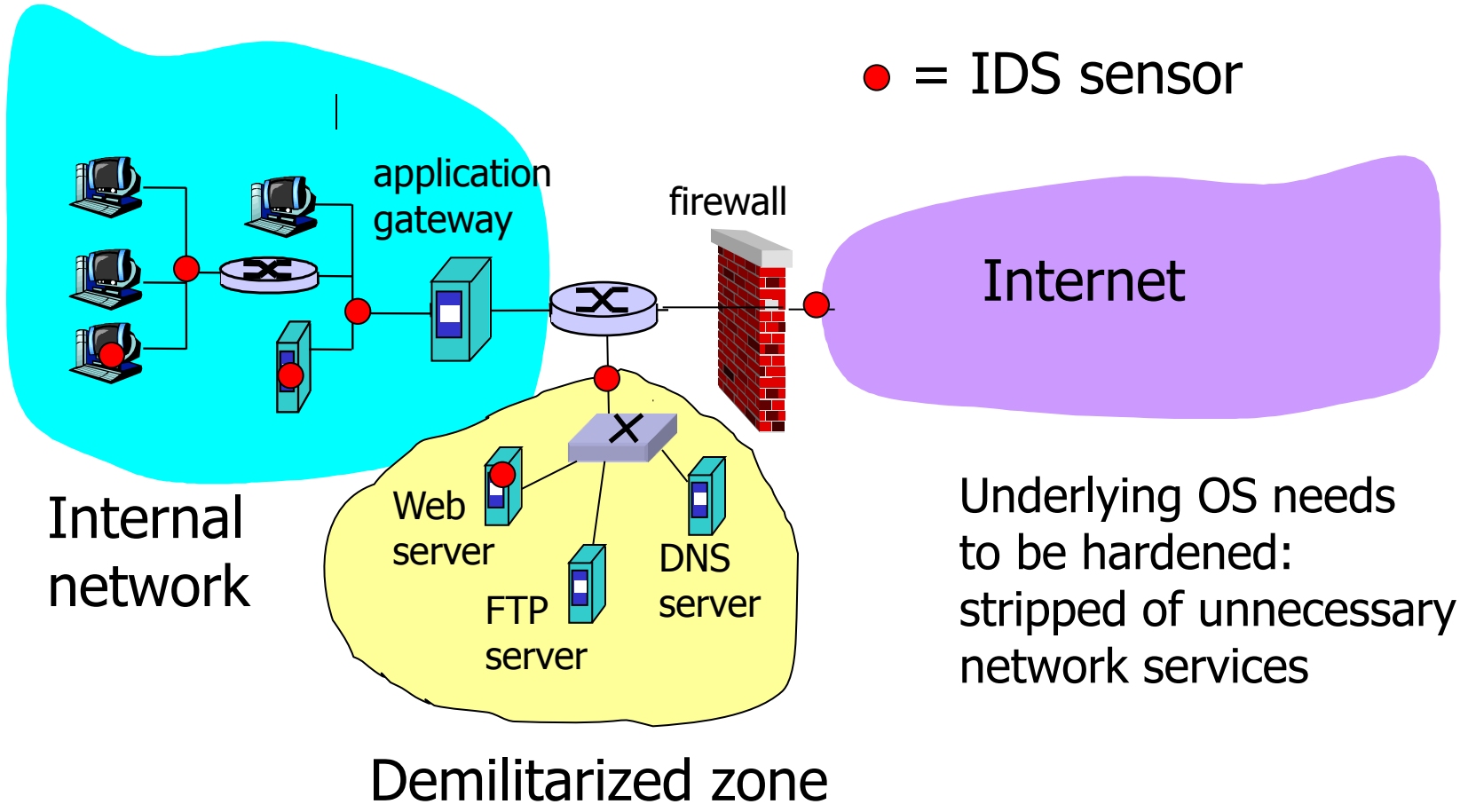
Where are IDS deployed?

- Host-based
  - Monitors host activity
  - Advantage: visibility of individual applications on host
  - Disadvantage: attackable from host
- Network-based (NIDS)
  - Often placed on a router or firewall
  - Monitor traffic == examine pkt headers/payloads
  - Advantages:
    - Single NIDS for many hosts
    - Can look for global patterns
  - Disadvantage: has to reverse engineer app. behavior

Intrusion detection techniques

- Misuse detection
  - Use attack "signatures" (need a model of attack)
    - Sequences of system calls, patterns of network traffic, etc.
  - Must know what attacker will do (how?)
  - Can only detect known attacks
- Anomaly detection
  - Tries to detect deviations and abnormalities based on a model of normal system behavior
  - Can detect unknown attacks
  - Abnormal behavior not necessarily attack
- Most IDS use a mix of both, although misuse detection dominates

Possible IDS deployments



Underlying OS needs to be hardened: stripped of unnecessary network services

Misuse vs. anomaly

Password file modified	Misuse
Four failed login attempts	Anomaly/Misuse
Failed connection attempts on 50 sequential ports	Anomaly/Misuse
User who usually logs in around 10am from Berlin dorm logs in at 4:30am from a Russian IP address	Anomaly
UDP packet to port 1434	Misuse
"DEBUG" in body of a SMTP message	Most likely: not an attack!

Misuse detection (signature-based)

- Rules that define a behavioral signature associated with certain attacks
  - Example: buffer overflow
    - Setuid program spawns shell with certain arguments
    - Packet with lots of NOPs
    - Very long argument to string function
  - Example: SYN flooding (Denial of Service)
    - Large number of SYN packets without ACKs coming back
- Attack signatures disadvantage:
  - Very specific
  - May miss variants of known attacks
  - Hard for unknown attacks

Extracting misuse signatures

- Use invariant characteristics of known attacks
  - Bodies of known viruses and worms
  - Port numbers of apps with known buffer overflows
  - Return addresses of overflow exploits
  - Hard to handle mutations
    - Polymorphic viruses: each copy has different body
- Disadvantages (research challenges):
  - No knowledge of intention of activity
  - Large signature sets (=> performance issues)
  - Fast, automatic extraction of new attack signatures
  - Honeypots: easy targets to attract malicious activity
    - Useful for signature extraction

Anomaly detection

- Based on deviation from normal behavior
- Define profile of "normal" behavior
  - Good for "small", well-defined systems (single program vs. multi-user OS)
- IDS flags deviations from the "normal" profile
  ⇨ abnormal behavior might or might not be attack
- Profile can be statistical
  - Build manually (hard)
  - Use machine learning/data mining techniques
    - Log activities for some time
    - "train" IDS to differentiate normal and abnormal patterns
    - Risk: attacker trains IDS to accept his activity as normal
      e.g., low-volume port scan may train IDS to accept port scans

What is a "profile?"

- Login/session activity
  - Frequency; last login; password failures; elapsed time; session output, CPU, I/O
- Command/program execution
  - Frequency; program CPU, I/O, other resources (watch for exhaustion); denied executions
- File access activity
  - Read/write/create/delete frequency; failed reads, writes, creates, deletes; resource exhaustion
- How can that be done in a scalable manner?

Efficiency of IDS systems

- Accuracy:
  - Proper detection of attacks
  - Absence of false alarms
  - Trade-off between those two goals
- Performance: processing traffic and audit events
  - Not all IDS are able to handle traffic at Gigabit rates
  - Solution: use multiple NIDSs; use clusters of NIDSs
- Fault tolerance: resistance to attacks
  - Should run on dedicated hardened hosts
- Timeliness: time elapsed between intrusion and detection

Intrusion detection errors

- False negatives:
  attack is not detected
  - E.g.: signature-based misuse detection
- False positives:
  harmless behavior classified as attack
  - E.g.: statistical anomaly detection
- Both types of IDS suffer from both error types

- Which is the bigger problem?
  - Attacks are fairly rare events
  - IDS often suffer from base-rate fallacy

Base-rate fallacy

- 1% of traffic is SYN floods; IDS accuracy is 90%
  - SYN flood classified as attack: prob. 90%
  - Benign connection classified as attack: prob. 10%
- Probability conn. flagged as SYN flood is benign?

Pr(benign | alarm) = ?

Conditional probability

- Suppose events A and B occur with probability Pr(A) and Pr(B)
- Let Pr(AB) be probability that both A and B occur
- Conditional probability that A occurs assuming B has occurred?

$$\Pr(A \mid B) = \frac{\Pr(AB)}{\Pr(B)}$$

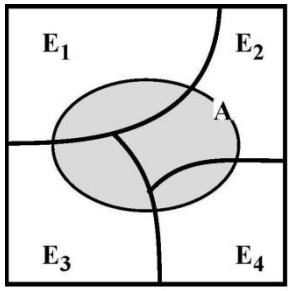
Bayes' theorem

- Mutually exclusive events $E_1, \ldots, E_n$
- Probability of any event A is

$$\Pr(A) = \sum_{1 \le i \le n} \Pr(A \mid E_i) \bullet \Pr(E_i)$$

  - Intuition: whenever A occurs, some event E_i must have occurred

=>



$$\Pr(E_i \mid A) = \frac{\Pr(A \mid E_i) \bullet \Pr(E_i)}{\Pr(A)}$$

Base-rate fallacy

- 1% (=Pr(SYN flood) = 1-Pr(benign)) of traffic is SYN floods; IDS accuracy is 90%
  - SYN flood classified as attack: prob. 90% = Pr(SYN flood)
  - Benign connection classified as attack: prob. 10%
- Probability conn. flagged as SYN flood is benign?

$$\Pr(\text{benign} \mid \text{alarm}) = \frac{\Pr(\text{alarm} \mid \text{benign}) \bullet \Pr(\text{benign})}{\Pr(\text{alarm})}$$

$$= \frac{\Pr(\text{alarm} \mid \text{benign}) \bullet \Pr(\text{benign})}{\Pr(\text{alarm} \mid \text{benign}) \bullet \Pr(\text{benign}) + \Pr(\text{alarm} \mid \text{SYN flood}) \bullet \Pr(\text{SYN flood})}$$

$$= \frac{0.10 \bullet 0.99}{0.10 \bullet 0.99 + 0.90 \bullet 0.01}$$

=> 92% chance of false alarm!!!

Host-based IDS

- Monitor attacks on OSs, applications.
- Has access to audit logs, error messages, any resources that can be monitored on host
  - OS system calls
  - Command lines
  - Network data
  - Processes
  - Keystrokes
  - File and device accesses
  - Registry in Windows

Advantages

- Tuned for system/OS/apps
- High detection accuracy

Disadvantages

- Only covers one host
- IDS on every critical host
- Need versions for each OS
- Can be disabled by viruses, worms, …

Example: tripwire

- File integrity checker
  - Records hashes of critical files and binaries in read-only memory (why?)
  - Periodically checks that files have not been modified, verifies sizes, dates, permission
- Good for detecting rootkits
- Can be subverted by clever rootkit
  - Install backdoor in continuously running system process (no changes on disk!)
  - Install backdoor in kernel
  - Copy old files back into place before Tripwire runs
- How to detect modifications to running process?

Network-based IDS

- Passively inspect network traffic
  - Watches for protocol violations
  - Unusual connection patterns
  - Attack strings in packet payloads
  - Etc.
- If we actively change traffic ⇨ Intrusion Prevention System
- Disadvantage
  - Limited possibilities for encrypted traffic (IPSec, VPNs)
  - Not all attacks via the network
  - Large amount of traffic

U. of Toronto, 2004 (from David Lie)

- Date: Fri, 19 Mar 2004
- Quote from email:

"The campus switches have been bombarded with these packets […] and apparently 3Com switches reset when they get these packets. This has caused the campus backbone to be up and down most of yesterday. The attack seems to start with connection attempts to port 1025 (Active Directory logon, which fails), then 6129 (DameWare backdoor, which fails), then 80 (which works as the 3Com's support a web server, which can't be disabled as far as we know). The HTTP command starts with 'SEARCH /\x90\x02\xb1\x02' […] then goes off into a continual pattern of '\x90' "

Example: Port scan detection

- Many vulnerabilities are OS specific
  - Bugs in specific implementations
  - Oversights in default configuration
- Port scan often prelude to attack
  - Attacker tries many ports and/or many IP addresses
    - Looking for old versions of daemons with unpatched buffer overflows
  - Then mount attack
    - Example: SGI IRIX responds on TCPMUX port (TCP port 1)
    - If response detected use IRIX vulnerabilities to break in

Example: Port scan detection (2.)

- Scan suppression: Block traffic from addresses that have too many failed connection attempts
  - Requires network filtering, state maintenance
  - Susceptible to slow scans
- False positives possible, e.g.:
  - Web proxies
  - P2P hosts
  - Other innocent hosts due to stale IP caches, i.e., got an IP address that was previously used by P2P host

Popular open-source NIDS

- Snort (widely deployed (unfortunately☹))
  - Large rule sets for known vulnerabilities, e.g.:
    - 2007-03-22: Microsoft Windows Server Service Controller is prone to a buffer overflow vulnerability that may allow an attacker to take complete control of the target host.
    - 2007-03-08: The HP Mercury LoadRunner agent suffers from a programming error that may allow a remote attacker to cause a stack-based buffer overflow condition to occur.
- Bro (from Vern Paxson at ICSI)

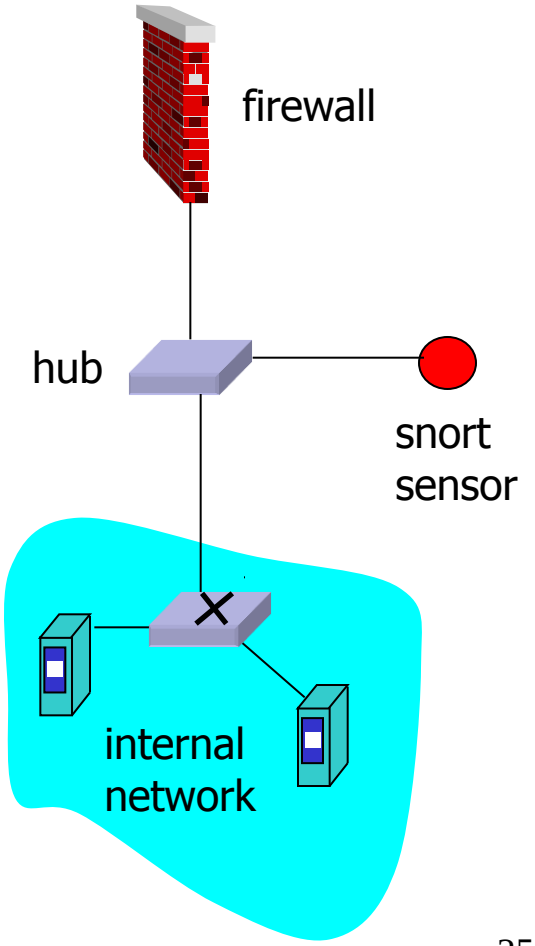
  - Separates data collection and security decisions
    - Event Engine distills packet stream into higher-level events
    - Policy Script Interpreter uses a script defining network's security policy to decide response

Snort

Good book: Intrusion Detection with Snort, by Jack Koziol

- Popular open source IDS
  - 200,000 installations
- Enhanced sniffer
  - Runs on Linux, Unix, Windows
  - Generic sniffing interface libpcap
- Signatures
  - Largest collection of signatures for NIDS
  - Written and released by Snort community within hours
  - Anyone can create one
  - Signature often undocumented and/or poor quality

Typical setup



snort.conf: example

```
var HOME_NET 193.152.1.1/24
var EXTERNAL_NET !193.152.1.1/24
Var HTTP_SERVERS 193.152.1.17
Var HTTP_PORTS 80 8080
```

Snort: Rule examples

- Nmap ping: ICMP type 8 packet with empty payload
  - Alert for ICMP type 8 with empty payload and arriving from outside

```
alert icmp $EXTERNAL_NET any -> $HOME_NET any
(msg:"ICMP PING NMAP"; dsize: 0; itype: 8;)
```

- Server message block service buffer overflow attack: TCP packet to port 139 (netbios) contains `|57724c6568004577a|` in payload
  - Alert for TCP pkt to internal network with that content to that port

```
alert tcp $EXTERNAL_NET any -> $HOME_NET 139
(msg: "DOS SMBdie attack":; flags: A+;
  content:"|57724c6568004577a|";)
```

Bro: A flexible NIDS

- Facts
  - Open source
  - Developed since 1995 by Vern Paxson
  - Used in many research environments, e.g., UCB, LBL, TUM, The Grid, NERSC, ESnet, NCSA
  - Supports anomaly as well as misuse detection
- Design goals
  - Reliable detection of attacks
  - High-performance
  - Separation of base functionality from site specific security policy
  - Robust against attacks on itself

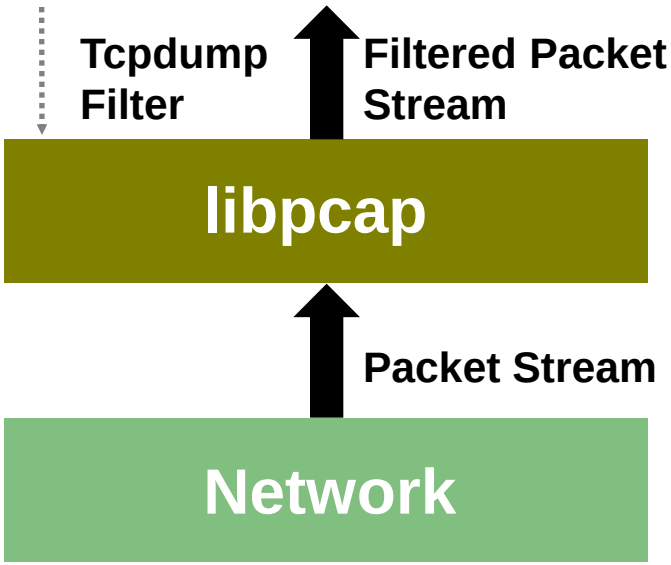
Bro features

- Full TCP stream reassembly
- Stateful protocol analysis
- Can import (some) SNORT signature rulesets
- Dynamic Protocol Detection
- BinPAC – a network protocol description language
- Very flexible policy scripting language (called Bro as well)
  - Specialized for traffic analysis
  - Strongly typed for robustness (conn_id, addr, port, time, …)
  - Can trigger alarms and/or program execution
  - Supports dynamic timeouts
- Clustering support for analysis of multi Gbps links
- Cooperates with Network Time Machine

Inside Bro

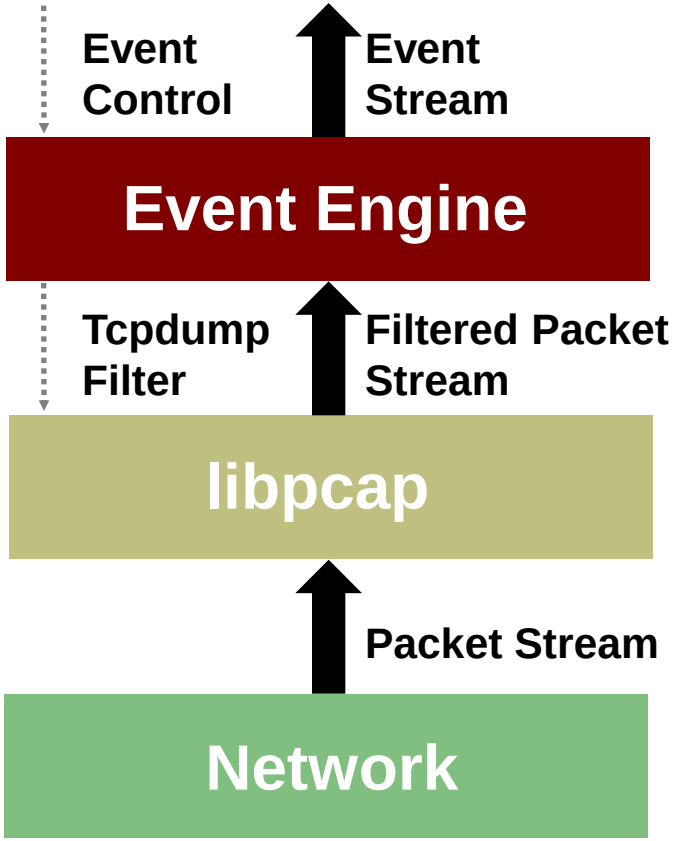
- Passive link tap copies all traffic

Inside Bro



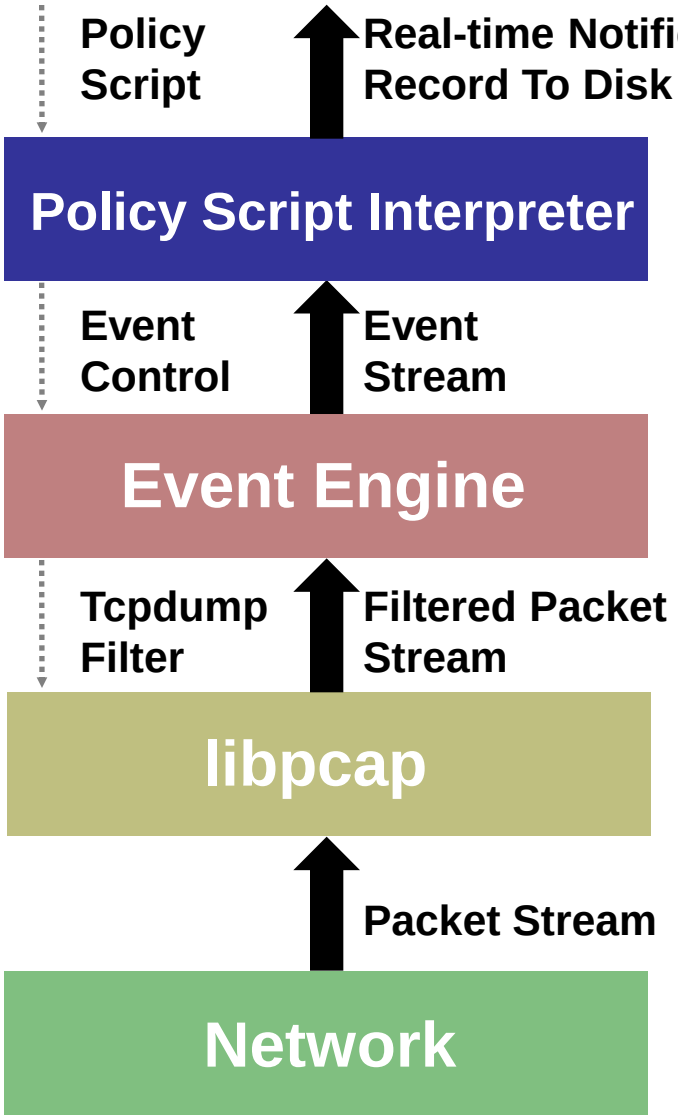
- Kernel filters high-volume stream

Inside Bro



- "Event engine" produces *policy-neutral* events, e.g.:
  - Connection-level:
    - connection attempt
    - connection finished
  - Application-level:
    - ftp request
    - http_reply
  - Activity-level:
    - login success

Inside Bro



- "Policy script" incorporates:
  - Context from past events
  - Site's particular policies
- ... and *takes action*:
  - Records to disk
  - Generates alerts
  - Executes programs as response

Bro policy example

```
global ssh_log = open_log_file("ssh") &redef;
global did_ssh_version: table[addr, bool] of count
                    &default = 0 &read_expire = 7 days;

event ssh_client_version(c: connection, version: string)
   {
   if ( ++did_ssh_version[c$id$orig_h, T] == 1 )
        print ssh_log, fmt("%s %s \"%s\"", c$id$orig_h, "C",
                           version);

   skip_further_processing(c$id);
   }

event ssh_server_version(c: connection, version: string)
   {
   if ( ++did_ssh_version[c$id$resp_h, F] == 1 )
        print ssh_log, fmt("%s %s \"%s\"", c$id$resp_h, "S",
                           version);
    }
```

Bro's protocol analyzers

- Full analysis
  - HTTP, FTP, telnet, rlogin, rsh, RPC, DCE/RPC, DNS, Windows Domain Service, SMTP, IRC, POP3, NTP, ARP, ICMP, Finger, Ident, Gnutella, BitTorrent, NNTP
- Partial analysis
  - NFS, SMB, NCP, SSH, SSL, IPv6, TFTP, AIM, Skype
- In progress
  - BGP, DHCP, Windows RPC, SMB, NetBIOS, NCP, …
- Data sources
  - DAG, libpcap, NetFlow

Protect your NIDS

Sourcefire Snort Remote Buffer Overflow

- Notification Type: IBM Internet Security Systems Protection Advisory
- Notification Date: Feb 19, 2007
- Description: Snort IDS and Sourcefire Intrusion Sensor IDS/IPS are vulnerable to stack-based buffer overflow, which can result in remote code execution.

… patched since then

Attacking and evading NIDS

- Looking for patterns / signatures seems pretty easy and straightforward
- But .....

Attacking and evading NIDS

- Attackers do not want to be detected by IDS
  - Often attackers are intimately familiar with popular IDS products, including their weaknesses
- Ideas:
  - Overload NIDS then attempt the intrusion
    - E.g.: huge workload, packets requiring detailed analysis, massive SYN floods
  - Manipulate attack data
    - Use encryption to hide packet contents
    - Use data fragmentation (either physical or logical)

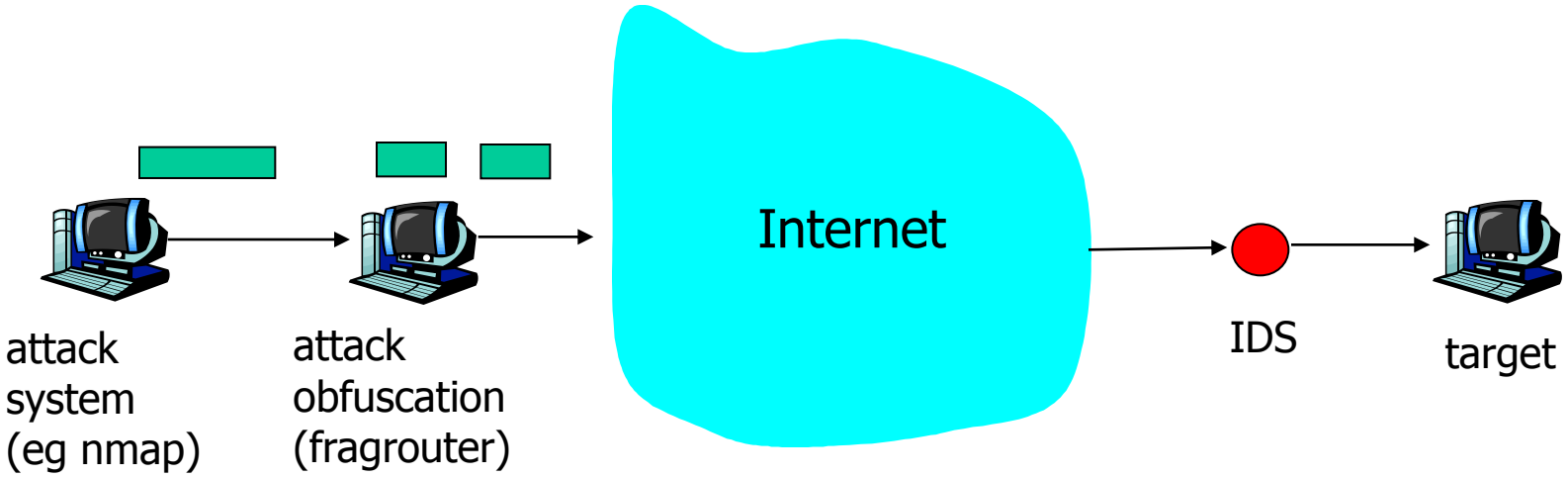
NIDS evasion: Fragmentation

- Send flood of fragments
  - May saturate NIDS
  - Once saturated, NIDS unable to detect new attacks
- Fragment packets in unexpected ways (possibly violating RFCs)
  - NIDS may not understand how to properly reassemble attack packets
  - Network stacks are resilient => will try and often succeed
  - Network stack may reassemble fragments differently (OS dependent) => state explosion

Example: Fragment overlap attack

- Attacker uses two fragments for every attack datagram
  - First fragment: TCP header, incl. port number of innocuous service not monitored by NIDS
  - Second fragment: offset value overlaps with original and includes a different port number
- IDS might let both fragments pass:
  - First fragment to innocuous port
  - Second fragment part of same "good datagram"
- Once the two fragments arrive at target host:
  - IP reassembles datagram, possibly overwriting TCP header with port in fragment 2
  - Malicious segment delivered to monitored port!

NIDS evasion tool: FragRouter



- Runs on Unix/Linux systems
- Offers > 35 schemes for fragmenting data flow
- Separates attack functionality from fragmentation functionality

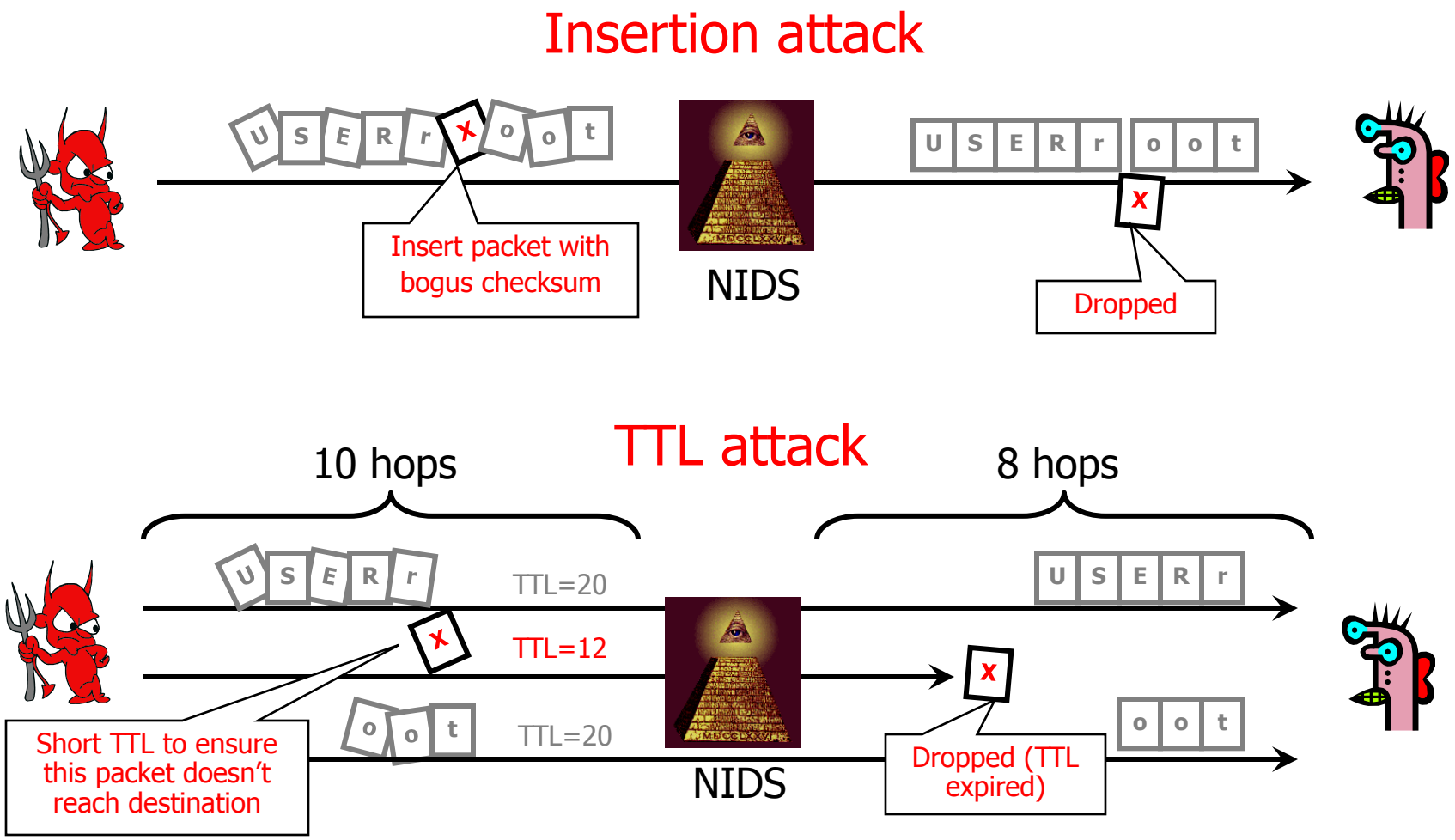
FragRouter examples

- Sends data in ordered 8-byte fragments
- Sends data in ordered 24-byte fragments
- Sends data in ordered 8-byte fragments with one out of order fragment
- Complete TCP handshake, send fake FIN and RST (with bad checksums), send data in ordered 1-byte items

Example: Payload ambiguity

- Want to detect "USER root" in packet stream
- Scanning every packet is not sufficient
  - Attacker can split attack string into several packets; defeats stateless NIDS
- Recording previous packet is not sufficient
  - Send packets out of order
- Full reassembly of TCP state is not sufficient
  - Attacker can use TCP tricks, e.g.:
    - Certain packets seen by NIDS but dropped at receiver
    - Manipulate checksums, TTL (time-to-live), fragmentation
    - Segment reassembly differs by OS
  - Use of application layer protocol polymorphism

NIDS evation:



Solving evasion: Easy?

- Just flag everything that's weird
  - E.g., Overlapping fragments
- Golden rule of protocol implementation: "be strict in what you send but liberal in what you accept"
  - Advantage: the Internet works
  - Impact: Lots of crud seen in every network:
    - Violation of RFCs but it still works
  - Problem for IDS, since it cannot flag weird stuff
- Different OSes, browsers, implementations handle crud differently
  - Impossible for the IDS to know how exactly a receiver is going to react

Developing an IDS: Intrusion detection problems

- Lack of training data with real attacks
  - But lots of “normal” network traffic, system call data
  - "Ground truth"
- 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
  - Sysadmin will spend many hours examining evidence