Intrusion Detection

Overview

- Principles and basics
- Denning’s Model
- Models of Intrusion Detection
- Architecture of an IDS

Principles of Intrusion Detection

Principles of Intrusion Detection

- Characteristics of systems not under attack
  - User, process actions conform to statistically predictable pattern
  - User, process actions do not include sequences of actions that subvert the security policy
  - Process actions correspond to a set of specifications describing what the processes are allowed to do
- Systems under attack do not meet at least one of these

Example

- Goal: insert a back door into a system
  - Intruder will modify system configuration file or program
  - Requires privilege; attacker enters system as an unprivileged user and must acquire privilege
    - Nonprivileged user may not normally acquire privilege (violates #1)
    - Attacker may break in using sequence of commands that violate security policy (violates #2)
    - Attacker may cause program to act in ways that violate program's specification

Basic Intrusion Detection

- *Attack tool* is automated script designed to violate a security policy
- Example: *rootkit*
  - Includes password sniffer
  - Designed to hide itself using Trojaned versions of various programs (*ps*, *ls*, *find*, *netstat*, etc.)
  - Adds back doors (*login*, *telnetd*, etc.)
  - Has tools to clean up log entries (*zapper, etc.)*

Detection

- *Rootkit* configuration files cause *ls*, *du*, etc. to hide information
  - *ls* lists all files in a directory
    - Except those hidden by configuration file
  - A locally written program to list directory entries
    - Run both and compare counts
    - If they differ, *ls* is doctored
- Other approaches possible

Denning’s Model

Denning’s Model

- Hypothesis: exploiting vulnerabilities requires abnormal use of normal commands or instructions
  - Includes deviation from usual actions
  - Includes execution of actions leading to break-ins
  - Includes actions inconsistent with specifications of privileged programs

Goals of Intrusion Detection Systems

- Detect wide variety of intrusions
  - Previously known and unknown attacks
  - Suggests need to learn/adapt to new attacks or changes in behavior
- Detect intrusions in timely fashion
  - May need to be be real-time, especially when system responds to intrusion
    - Problem: analyzing commands may impact response time of system
  - May suffice to report intrusion occurred a few minutes or hours ago

Goals of Intrusion Detection Systems

- Present analysis in simple, easy-to-understand format
  - Ideally a binary indicator
  - Usually more complex, allowing analyst to examine suspected attack
  - User interface critical, especially when monitoring many systems
- Be accurate
  - Minimize false positives, false negatives
  - Minimize time spent verifying attacks, looking for them

Models of Intrusion Detection

Models of Intrusion Detection

- Anomaly detection
  - What is usual, is known
  - What is unusual, is bad
- Misuse detection
  - What is bad, is known
  - What is not bad, is good
- Specification-based detection
  - What is good, is known
  - What is not good, is bad

Anomaly Detection

Anomaly Detection

- Analyzes a set of characteristics of system, and compares their values with expected values; report when computed statistics do not match expected statistics
  - Threshold metrics
  - Statistical moments
  - Markov model

Threshold Metrics

- Counts number of events that occur
  - Between *m* and *n* events (inclusive) expected to occur
  - If number falls outside this range, anomalous
- Example
  - Windows: lock user out after *k* sequential failed login attempts
    - Range is (0, k–1).
    - *k* or more failed logins deemed anomalous

Difficulties

- Appropriate threshold may depend on non-obvious factors
  - Typing skill of users
  - If keyboards are US keyboards, and most users are French, typing errors very common

Statistical Moments

- Analyzer computes standard deviation (first two moments), other measures of correlation (higher moments)
  - If measured values fall outside expected interval for particular moments, anomalous
- Potential problem
  - Profile may evolve over time; solution is to weigh data appropriately or alter rules to take changes into account

Potential Problems

- Assumes behavior of processes and users can be modeled statistically
  - Ideal: matches a known distribution such as Gaussian or normal
  - Otherwise, must use techniques like clustering to determine moments, characteristics that show anomalies, etc.
- Real-time computation a problem too

Markov Model

- Past state affects current transition
- Anomalies based upon *sequences* of events, and not on occurrence of single event
- Problem: need to train system to establish valid sequences
  - Use known, training data that is not anomalous
  - The more training data, the better the model
  - Training data should cover *all* possible normal uses of system

Example: TIM

- Time-based Inductive Learning
- Sequence of events is *abcdedeabcabc*
- TIM derives following rules:

  R_1: $ab \rightarrow c$ (1.0) R_2: $c \rightarrow d$ (0.5) R_3: $c \rightarrow e$ (0.5)

  R_4: $d \rightarrow e$ (1.0) R_5: $e \rightarrow a$ (0.5) R_6: $e \rightarrow d$ (0.5)
- Seen: *abd*; triggers alert
  - *c* always follows *ab* in rule set
- Seen: *acf*; no alert as multiple events can follow c
  - May add rule R_7: $c \rightarrow f$ (0.33); adjust R_2, R_3

Using Machine Learning

Machine Learning

- These anomaly detection methods all assume some statistical distribution of underlying data
  - IDES assumes Gaussian distribution of events, but experience indicates not right distribution
- Use machine learning techniques to classify data as anomalous
  - Does not assume *a priori* distribution of data

Types of Learning

- *Supervised learning methods*: begin with data that has already been classified, split it into "training data", "test data"; use first to train classifier, second to see how good the classifier is
- *Unsupervised learning methods*: no pre-classified data, so learn by working on real data; implicit assumption that anomalous data is small part of data
- Measures used to evaluate methods based on:
  - TP: true positives (correctly identify anomalous data)
  - TN: true negatives (correctly identify non-anomalous data)
  - FP: false positives (identify non-anomalous data as anomalous)
  - FN: false negatives (identify anomalous data as non-anomalous)

Measuring Effectiveness

- *Accuracy*: percentage (or fraction) of events classified correctly
  - ((*TP* + *TN*) / (*TP* + *TN* + *FP* + *FN*)) * 100%
- *Detection rate*: percentage (or fraction) of reported attack events that are real attack events
  - (*TP* / (*TP* + *FN*)) * 100%
  - Also called the *true positive rate*
- *False alarm rate*: percentage (or fraction) of non-attack events reported as attack events
  - (*FP* / (*FP* + *TN*)) * 100%
  - Also called the *false positive rate*

Clustering

- Clustering
  - Does not assume *a priori* distribution of data
  - Obtain data, group into subsets (*clusters*) based on some property (*feature*)
  - Analyze the clusters, not individual data points

Example: Clustering

proc	user	value	percent	clus#1	clus#2
p_1	matt	359	100%	4	2
p_2	holly	10	3%	1	1
p_3	heidi	263	73%	3	2
p_4	steven	68	19%	1	1
p_5	david	133	37%	2	1
p_6	mike	195	54%	3	2

- Cluster 1: break into 4 groups (25% each); 2, 4 may be anomalous (1 entry each)
- Cluster 2: break into 2 groups (50% each)

Finding Features

- Which features best show anomalies?
  - CPU use may not, but I/O use may
- Use training data
  - Anomalous data marked
  - Feature selection program picks features, clusters that best reflects anomalous data

Example

- Analysis of network traffic for features enabling classification as anomalous
- 7 features
  - Index number
  - Length of time of connection
  - Packet count from source to destination
  - Packet count from destination to source
  - Number of data bytes from source to destination
  - Number of data bytes from destination to source
  - Expert system warning of how likely an attack

Feature Selection

- 3 types of algorithms used to select best feature set
  - Backwards sequential search: assume full set, delete features until error rate minimized
    - Best: all features except index (error rate 0.011%)
  - Beam search: order possible clusters from best to worst, then search from best
  - Random sequential search: begin with random feature set, add and delete features
    - Slowest
    - Produced same results as other two

Results

- If following features used:
  - Length of time of connection
  - Number of packets from destination
  - Number of data bytes from source

  Classification error less than 0.02%

Misuse Modeling

Misuse Modeling

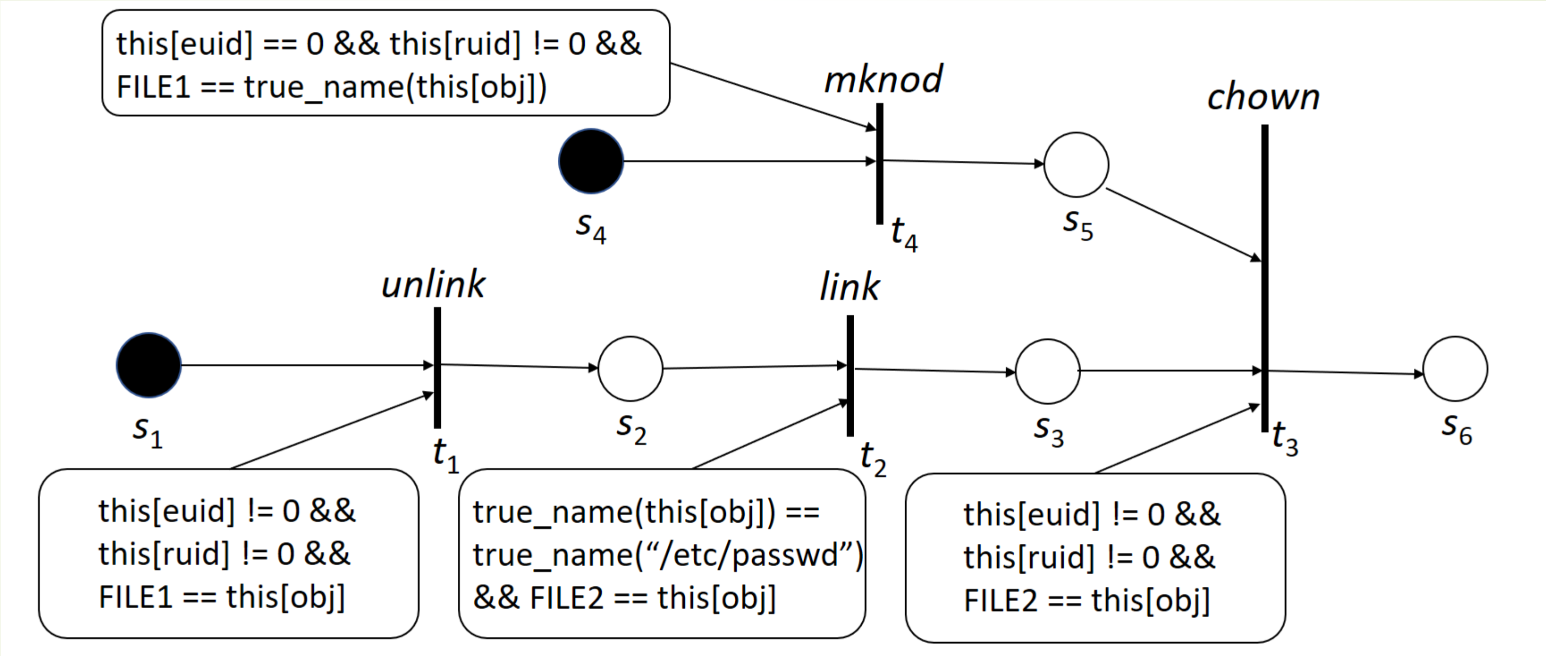
- Determines whether a sequence of instructions being executed is known to violate the site security policy
  - Descriptions of known or potential exploits grouped into *rule sets*
  - IDS matches data against rule sets; on success, potential attack found
- Cannot detect attacks unknown to developers of rule sets
  - No rules to cover them

Example: IDIOT

- Event is a single action, or a series of actions resulting in a single record
- Five features of attacks:
  - Existence: attack creates file or other entity
  - Sequence: attack causes several events sequentially
  - Partial order: attack causes 2 or more sequences of events, and events form partial order under temporal relation
  - Duration: something exists for interval of time
  - Interval: events occur exactly *n* units of time apart

IDIOT Representation

- Sequences of events may be interlaced
- Use colored Petri automata to capture this
- Example: *mkdir* attack



Specification Modeling

Specification Modeling

- Determines whether execution of sequence of instructions violates specification
- Only need to check programs that alter protection state of system
- System traces, or sequences of events $t_1, \ldots t_i, t_{i+1}, \ldots,$ are basis of this
- Still in its infancy
- Appealing part is the formalization

Comparison

Comparison and Contrast

- Anomaly detection
  - Detects unusual events, but these are not necessarily security problems
- Misuse detection
  - If all policy rules known, easy to construct rulesets to detect violations
  - Usual case is that much of policy is unspecified, so rulesets describe attacks, and are not complete
- Specification-based
  - Spec assumes if specifications followed, policy not violated

Intrusion Detection System Architecture

IDS Architecture

- Basically, a sophisticated audit system
  - *Agent* like logger; it gathers data for analysis
  - *Director* like analyzer; it analyzes data obtained from the agents according to its internal rules
  - *Notifier* obtains results from director, and takes some action
    - May simply notify security officer
    - May reconfigure agents, director to alter collection, analysis methods
    - May activate response mechanism

Organization of an IDS

- Monitoring network traffic for intrusions
- Combining host and network monitoring
- Making the agents autonomous

Agents

Agents

- Obtains information and sends to director
- May put information into another form
  - Preprocessing of records to extract relevant parts
- May delete unneeded information
- Director may request agent send other information

Example

- IDS uses failed login attempts in its analysis
- Agent scans login log every 5 minutes, sends director for each new login attempt:
  - Time of failed login
  - Account name and entered password
- Director requests all records of login (failed or not) for particular user
  - Suspecting a brute-force cracking attempt

Host-Based Agent

- Obtain information from logs
  - May use many logs as sources
  - May be security-related or not
- Agent generates its information
  - Scans information needed by IDS, turns it into equivalent of log record
  - Typically, check policy
  - May be very complex

Network-Based Agents

- Detects network-oriented attacks
  - Denial of service attack introduced by flooding a network
- Monitor traffic for a large number of hosts
- Examine the contents of the traffic itself
- Agent must have same view of traffic as destination
- End-to-end encryption defeats content monitoring

Network Issues

- Network architecture dictates agent placement
  - Ethernet or broadcast medium: one agent per subnet
  - Point-to-point medium: one agent per connection, or agent at distribution/routing point
- Focus is usually on intruders entering network
  - If few entry points, place network agents behind them
  - Does not help if inside attacks to be monitored

Aggregation of Information

- Agents produce information at multiple layers of abstraction
  - Application-monitoring agents provide one view (usually one line) of an event
  - System-monitoring agents provide a different view (usually many lines) of an event
  - Network-monitoring agents provide yet another view (involving many network packets) of an event

Director

Director

- Reduces information from agents
  - Eliminates unnecessary, redundant records
- Analyzes remaining information to determine if attack under way
  - Analysis engine can use a number of techniques, discussed before, to do this
- Usually run on separate system
  - Does not impact performance of monitored systems

Example

- Jane logs in to perform system maintenance during the day
- She logs in at night to write reports
- One night she begins recompiling the kernel
- Agent #1 reports logins and logouts
- Agent #2 reports commands executed
  - Neither agent spots discrepancy
  - Director correlates log, spots it at once

Adaptive Directors

- Modify profiles, rule sets to adapt their analysis to changes in system
  - Usually use machine learning or planning to determine how to do this
- Example: use neural nets to analyze logs
  - Network adapted to users' behavior over time
  - Used learning techniques to improve classification of events as anomalous
    - Reduced number of false alarms

Notifier

Notifier

- Accepts information from director
- Takes appropriate action
  - Notify system security officer
  - Respond to attack
- Often GUIs
  - Well-designed ones use visualization to convey information

Examples

- Credit card companies alert customers when fraud is believed to have occurred
  - Configured to send email or SMS message to consumer

Key Points

Key Points

- Intrusion detection is a form of auditing
- Anomaly detection
- Misuse detection
- Specification-based detection
- Intrusion detection is used for host-based monitoring, network monitoring, or combination of these
- Agent, director, and notifier