Intrusion Detection

- Define attacks using a signature
  - This is just a pattern on events/actions
- Three categories
  - Network Based
    - Inspect raw network packages
  - Host Based
    - Software that takes advantage of OS facilities
  - Stack Based
    - Integrated with the TCP/IP stack (vendor specific)

Network Intrusion Detection Systems (NIDS)

- Purpose
  - Detect an intrusion coming from the network
- Current Solutions (sketch)
  - Define attack as an attack signature
  - Match attack signature with ongoing activities
- How
  - Regular expression over events
  - Attack signatures capture a whole class of attack instances

Snort

- Snort
  - Preprocessor (after package decode)
  - Rule matching
  - Output (alerts, logs, counter measures)
- For example

```
alert tcp any any -> 192.168.1.0/24 111
  (content:''|0 01 86 a5|'';
  msg:''mountd access'';)
```

Problems

- Coming up with an attack signature
  - Analysts inspect examples
  - Hypothesize about the properties that must hold
  - Write down the expression
- No systematic way to
  - check for false positives or false negatives
  - evaluate the impact of attack signature changes

GARD

- Session Signatures
  - The **entire** attack as a regular language
- Attack invariant
  - Another representation of the attack, used to evaluate session signatures
- Semantic model of attack protocol
  - Finite state machine
    - How protocol commands alter protocol state
- Generation, Analysis, Refinement, Deployment

Systematic Method

(1) Initial session signature (syntactic features)

(2) Attack invariant (semantic features)

(3) Compare (1) with (2)

- If false positives or false negatives go to (1), else exit

Using an example

- Ftp-cwd attack (BlackMoon FTP server)
  - Login (anonymous)
  - Send cwd command with an overly long argument, will cause a buffer overflow.

Signature Specification

- Based on 3 parts
  - Preparation
    - Attacker sets up the attack's pre-conditions
  - Exploitation
    - Attacker launches the attack
  - Confirmation
    - Attacker determines that the attack succeeded

Events

- Events are observable sequences of bytes that may be part of an attack (Flex and friends)

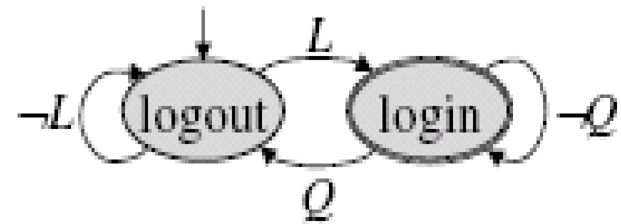
Event	Token	Lexeme	Description
SLOGIN	L	(^"230"(\w)\n)	User logged in
QUIT	Q	(^"QUIT"\n)	User Quit
CWD	C	(^"CWD")	Change Directory
ARG	A	([SP] <str> \n)	Argument of an FTP command
INVALID	I_R	(^[^1-5])	A non-FTP response

- Protocol Dependent
- Libraries for standard protocols

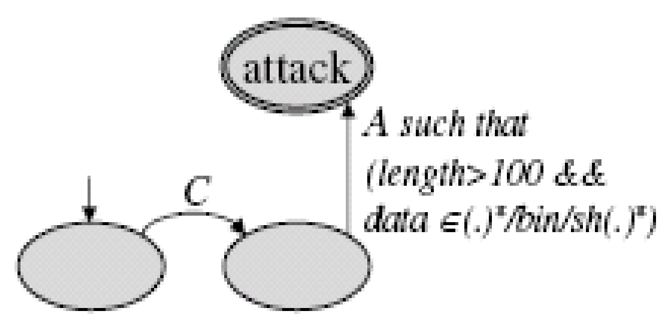
Regular Expressions

E ::= token
(E)* | (E)+
¬(E)
(E op1 E)
(token such that R)
R ::= (data ∈ raw_expr)
(length op2 INT)
(R op3 R)
op1 :≔ · | ∩ | ∪
op2 ::= < | > | = | ≠
op3 :≔ ∨ | ∧

- Precondition $((\neg L)^* \cdot L \cdot (\neg Q)^*)+$

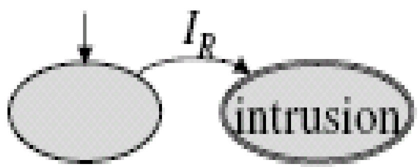


- Exploitation
  C · (*A such_that data* ∈ (.)*bin/sh(.)* && *length*>100)

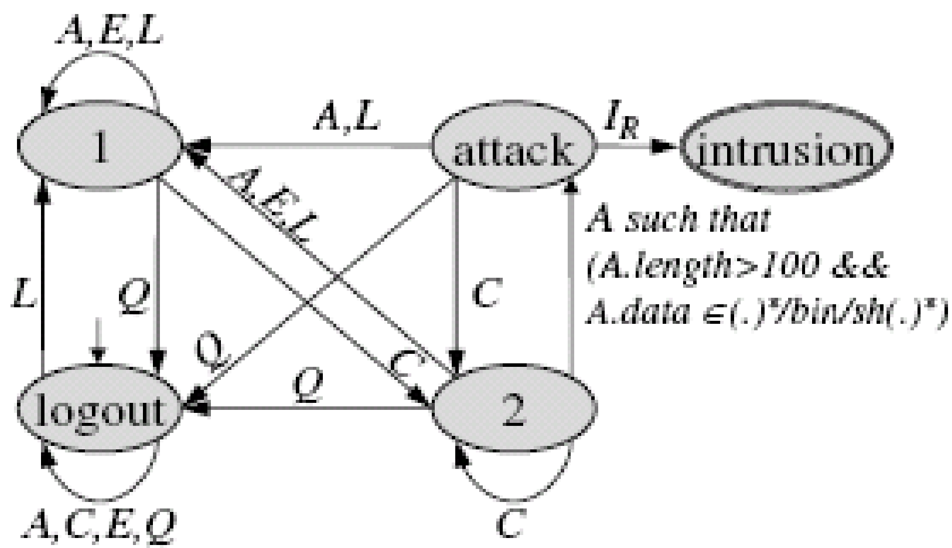


Regular Expressions(cont.)

- Confirmation I_R

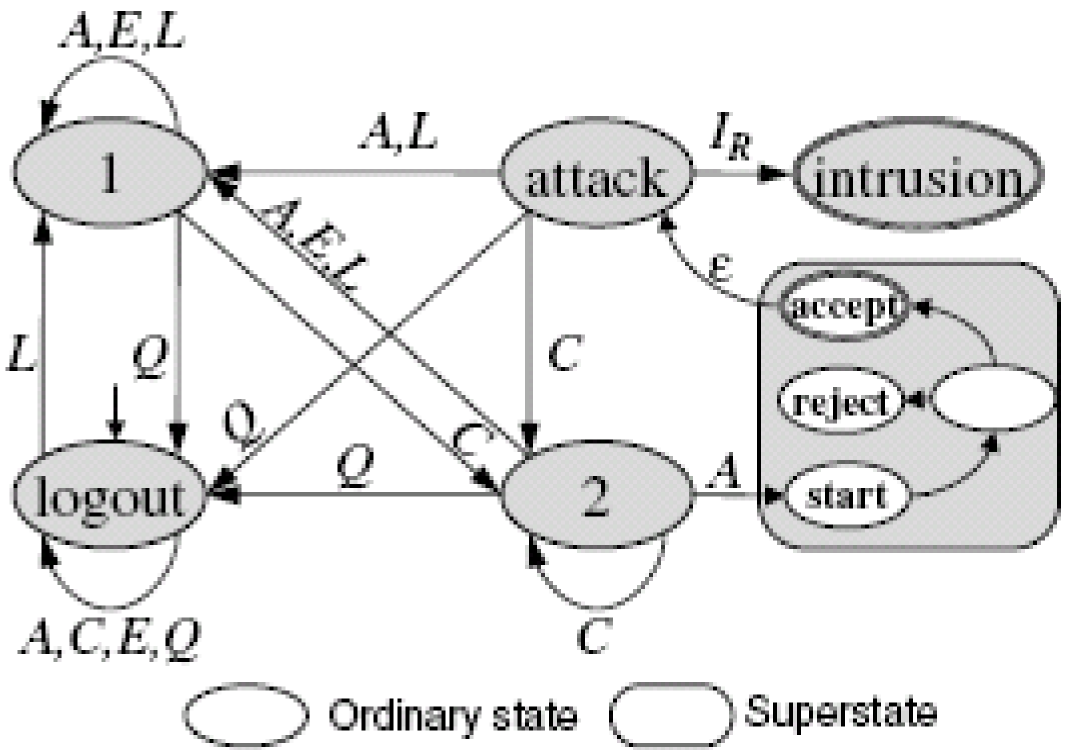


- Each expression defines a language L_{pre} , L_{exp}, L_{conf}



Putting the Signature Together

- GARD uses Hierarchical State Machines



Invariant Specification

- Invariant is a logical formula over the state variables of the finite state machine.

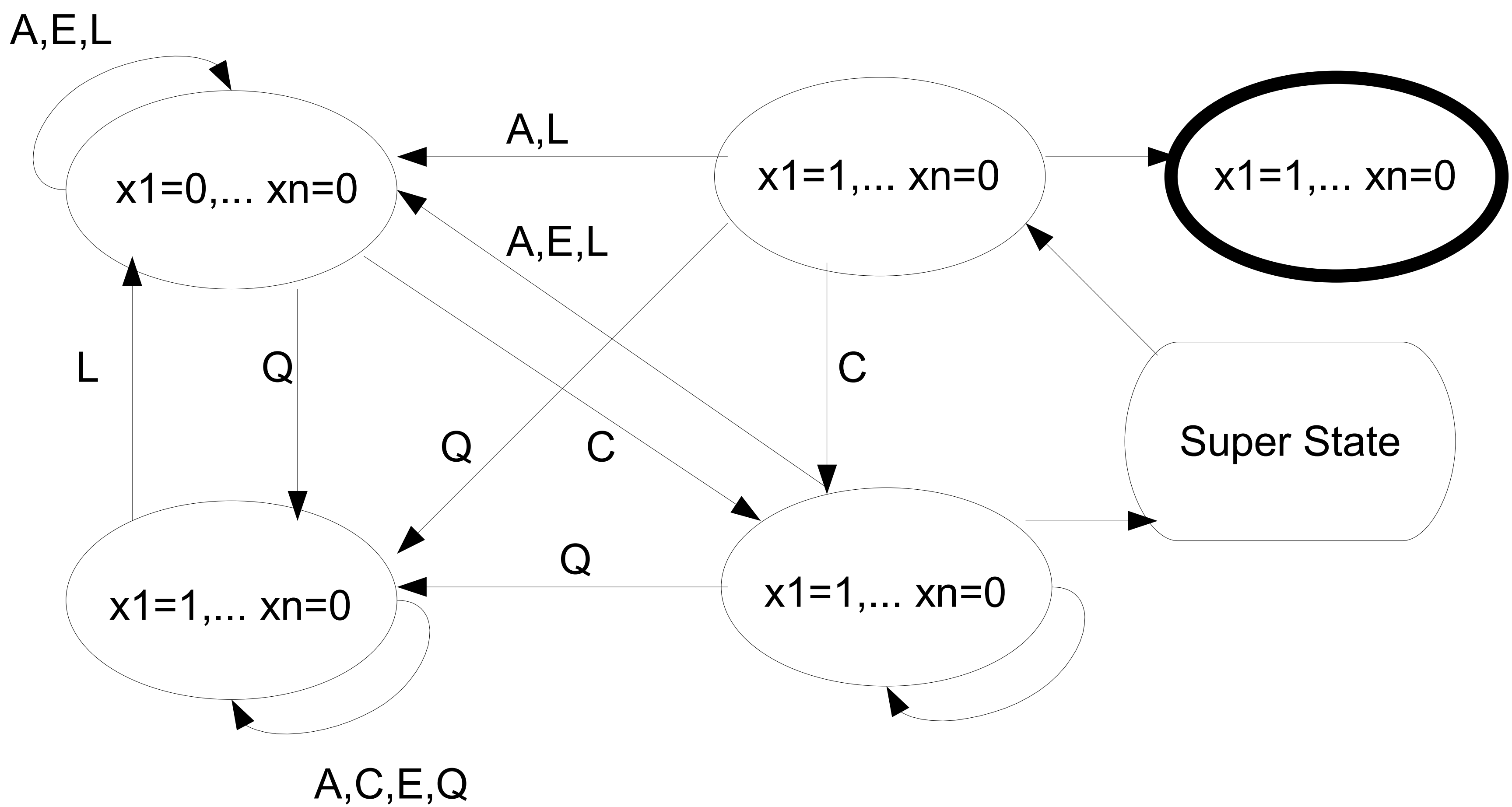
Var.	Values	Semantic Comments
$x1$	{0, 1}	A USER command was issued.
$x2$	{0, 1}	A PASS command was issued.
$x3$	{0, 1}	Victim has indicated a successful login.
$x4$	$\{U = 0, A = 0, B = 1, E = 2\}$	Holds session representation type
$x5$	$\{U = 0, S = 0, B = 1, C = 2\}$	Holds session transmission mode
$x6$	{0, 1}	A session is in passive mode.
$x7$	$\{0, \ldots, MAX\}$	Number of files uploaded in this session.
$x8$	$\{0, \ldots, MAX\}$	Number of files downloaded in this session.

Events and Variables

Event	Token	Lexeme	Pre-condition	Post-condition
SLOGIN	L	(^“230”(\w)\n)	-	x3=1
QUIT	Q	(^“QUIT”\n)	-	$\forall\ x_i = 0$
CWD	C	(^“CWD”)	-	-
ARG	A	([SP] <str> \n)	-	-
INVALID	I_R	(ˆ[ˆ1-5])	-	-

- We can translate the logical formula to a regular language, $L(I_{ftp})$

The whole picture

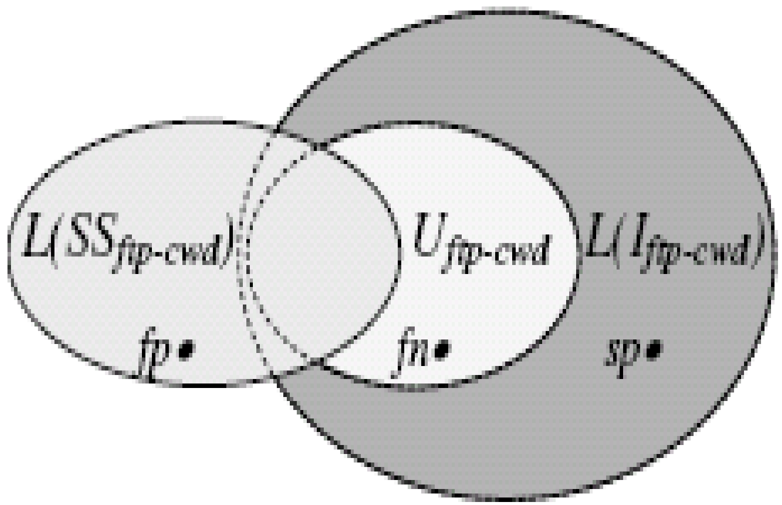


Signature Evaluation

- Define
  - $L(SS) = L_{pre} \bullet L_{exp} \bullet L_{conf}$
  - $L(I_{ftp})$
  - U_{FTP} = ultimate set of attacks
- Ideally we would like $L(SS) = U_{FTP}$
- Non-ideal situation generates false positives and false negatives.
  - $fp = L(SS) \cap \neg U_{FTP}$, $fn = \neg L(SS) \cap U_{FTP}$

Signature Evaluation(cont.)

- The methodology assumes $L(I_{ftp}) \supseteq U_{FTP}$



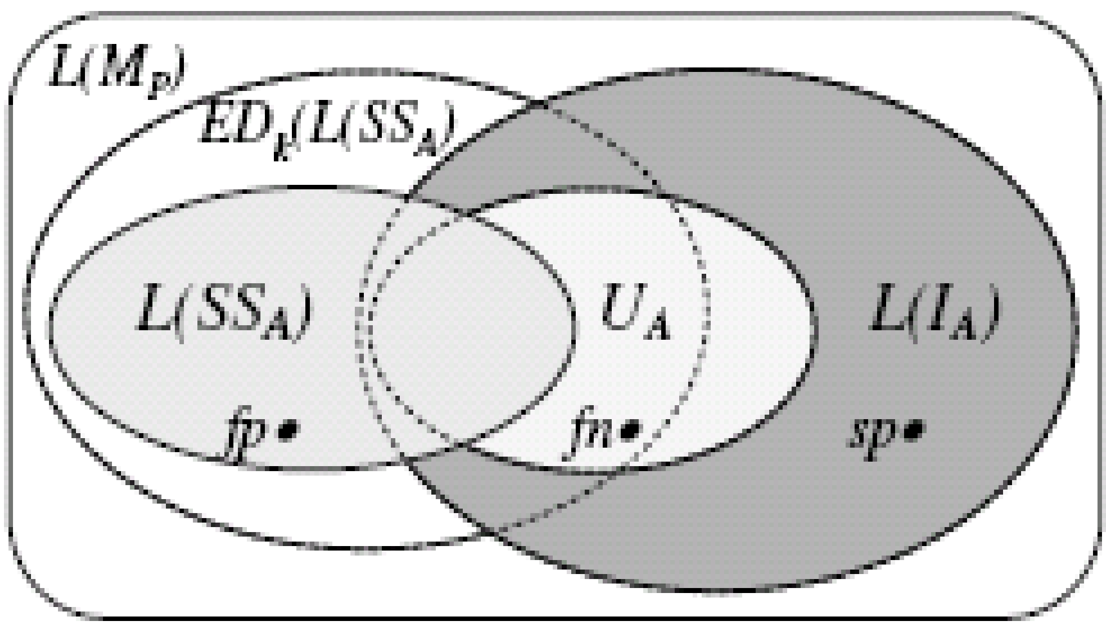
- But now we have to deal with spurious (*sp*) sequences.

Edit Distance

- Systematic method requires an iterative refinement
- Reduce the probability of *sp*, generate new instances through modifications to existing instances
  - Edit distance: ed(s1,s2) = number of deletions, insertions or substitutions to transform s1 to s2
  - $ED_k(L)=\{x \mid \exists y \in L$ *such that* $ed(x, y)<k\}$.

Modeling the Protocol

- Given a protol P, we construct a semantic model of M_P (a finite state machine)
- A state in M_P is a valuation of variables, transitions affect these variables.



Some pitfalls

- Operations on languages introduce *fp* or *fn.*
  - Union introduces extra paths
    - Not **really** an attack
    - An attack not captured by the session signature.
- GARD guarantees no false positives and no false negatives *with respect to the invariant*
- Domain experts come up with both the invariant and the session signatures
  - GARD assists in narrowing down *fp* and *fn* through automatic generation of attacks.

Automatic Generation and Analysis of NIDS Attacks

- Edit distance is one approach
- Attackers can be (and usually are) sneaky
  - Split the attack into multiple FTP sessions
    (1) Login and ftp over code and log out
    (2) Login and execute code from (1)
- Problem
  - Given an attack instance automatically generate all possible instances
  - Verify that these **are** attacks!

The problem(s) ...

- *Black Hat Problem*
  - Given an NIDS and an instance of an attack $\mathcal{A}$, find an instance of $\mathcal{A}$ that evades the NIDS
- *White Hat Problem*
  - Given an instance of an attack $\mathcal{A}$ and a sequence of packets s, determine whether s is an instance of $\mathcal{A}$

How do they do it?

- An attacker knows
  - The signature(s) used
  - The protocol(s) e.g., ftp, TCP etc.
  - An instance of the attack
- Based on the above knowledge
  - Perform transformations/rewrites on one attack instance to obtain a new attack instance

We'll do the same ...

- Attacker's knowledge as inference (or transformation) rules
- Use an inference engine to generate all possible attack instances
  - Starting from a known attack instance
- White Hat Problem : run the inference engine
- Black Hat Problem : check if the attack is a member of the set returned by the inference engine

Limitations

- Black Hat - Infinite traces
  - Partitions based on testing techniques
    - Each partition exercises different features an NIDS should handle
  - Prune some derivations
    - No packet fragmentation on packets with size less than 5 bytes
- White Hat – when to stop searching
  - Bottom up approach (shrinking rules)

Rules

- Application, Protocol Rules, OS Rules
- Split into two categories
  - Shrinking Rules
  - Expanding Rules
- TCP Fragmentation (*r*1)
  - Fragments an attack packet into two packets. Adds victim acknowledgment after each new packet.
- HTTP space padding (*r*7)
  - Insert spaces after an HTTP method:
    from “GET <URL>” into “GET___<URL>”

Formal Model of Attack Derivation

- Natural deduction system <$\mathcal{F},\Phi$>
  - $\mathcal{F}$ is the set of facts
  - Φ is the set of inference rules
- Derivations
  - $f1 \vdash_{\Phi} fn$, if there is a derivation sequence < $f1,\ldots,fn$> such that $f1 \in \mathcal{F}$ and each f_{i+1} is a result of applying a derivation rule $r \in \Phi$.

Assumptions

- Each rule has an expanding and a shrinking version.
- A derivation containing only shrinking rules has not cycles.
- Root(a)
  - A derivation containing only shrinking rules and starts from sequence a

Derivation model of an attack

- Derivation model of an attack
  - Given α as an instance of an attack $\mathcal{A}$ and a set of inference rules Φ
    - A derivation model of $\mathcal{A}$ is a natural deduction system of $\langle roots_{\Phi}(\alpha), \Phi \rangle$
    - The closure of a derivation model ($Cl_{\Phi}(roots_{\Phi}(\alpha))$) is the set of all TCP sequences that are derived from $roots_{\Phi}(\alpha)$ using Φ's rules.

Black Hat and White Hat

- NIDS view
  - N is a NIDS, N's view with respect to an attack $\mathcal{A}$ is the set of TCP sequences that N recognizes as $\mathcal{A}$
- Black Hat
  - Given $<roots_\Phi(\alpha), \Phi>$ for $\mathcal{A}$, and an NIDS view of $\mathcal{A}$ denoted as $V_{N\mathcal{A}}$ find $s \in Cl_\Phi(roots_\Phi(\alpha)) \setminus V_{N\mathcal{A}}$
- White Hat
  - Given $<roots_\Phi(\alpha), \Phi>$ for $\mathcal{A}$, find $s \in Cl_\Phi(roots_\Phi(\alpha))$

Properties of the Attack Derivation Model

- For an attack $\mathcal{A}$ and a set of rules Φ a derivation model is
  - Sound if it derives TCP sequences that implement $\mathcal{A}$,
  - Complete if it can derive any TCP sequences that implements $\mathcal{A}$
  - Decidable given a TCP sequence there is an algorithm that determines whether or not a sequence is derived from the root.

For our two Hat Problems

- Black Hat
  - Soundness
    - Any instance we discover is a vulnerability
  - Completeness
    - Eventually the model will generate all instances
- White Hat
  - Soundness
    - Lack of false positives
  - Completeness
    - Lack of false negatives

Proving Completeness

- There is no formal definition of the notion
  - "a TCP sequence that implements $\mathcal{A}$"
- However, the derivation model can be used to inductively define "implements" $\mathcal{A}$.
  - Each transformation rule preserves $\mathcal{A}$'s semantics.