
# *Analysis of (Access Control) Policies*

# Outline

- Weighted Pushdown Systems
- Analysis of Security Policies
  - SELinux analysis of mine and Stoller
  - Program Analysis of Myers

# Weighted Pushdown Systems

- A model of programs that uses weights to encode the effect of each statement on the data state of the program
  - PDS still represents control flow
  - Weights provide data abstraction
- Weights will need to support a variety of possible abstractions

# Weighted Pushdown Systems

- Weight domains are a bounded idempotent semiring
  - Which is a tuple
    - Weight set (D)
    - Combine operator
    - Extend operator
    - $\bar{0}$ in D (identity element of combine)
    - $\bar{1}$ in D (identity element of extend)
- Weight domains must enable abstractions to be extended (values updated) and combined (via joins)

# Combine and Extend

- (D, combine) is a commutative monoid with $\bar{0}$ as its neutral element
  - Monoid – a set with a binary operation . that satisfies
    - Closure: *a,b* in *S*, *a.b* in *S*
    - Associativity: *(a.b).c* = *a.(b.c)*
    - Identity element: there exists *e* in *S*, s.t., forall *a* in *S*, *a.e* = *e.a* = *a*
  - Commutative monoid – is endowed with its algebraic preordering *x*<=*y*, iff there exists a *z*, s.t. *z* + *x* = *y* (enables join)
- Extend distributes over combine
- $\bar{0}$ is an annihilator wrt extend

# Weighted Pushdown System

- Definition
- WPDS is a triple (P, S, f) where
  - P is a PDS
  - S is a bounded idempotent semiring (weight domain)
  - f is a map that assigns a weight to each rule of P

# WPDS expresses PDS

- A PDS *P* is a WPDS *W* with the boolean weight domain *S*
  - *S = ({F, T}, OR, AND, F, T)*
  - Weight assignment *f(r)* = *T* for all rules in P
    - All rules are true
- JOVP(C1, C2) = T iff there exists a path from a configuration in C1 to a configuration in C2

# Finite-State Data Abstractions

- Can encode data abstractions for finite sets
- E.g., binary relations on a finite set
  - $S = (2^{G \times G}, union, compose, null, id)$, where
    - *Union* is combine and *compose* (relational composition) is extend
    - Empty relation *null* is $\emptyset$ and identity relation *id* is $1$
- Check properties of weight domain against definition

# Finite-State Data Abstractions

- JOVP(C1, C2)
  - From start to n, C1= {<p,start>} and C2= {<p, nu>}
    - Null if n cannot be reached
    - Otherwise, JOVP captures transformation on global state G through compose and union (join) creating the set of valuations that reach n
- Poststart(p, n1) in Fig 2.9 gives weight at n6 of w6, which represent possible values of x, y at that statement

# Infinite-State Data Abstractions

- Number of states is infinite, such as integers
- Verify definition 2.2.10 is a weight domain
  - Minpath semiring M = (N U {infinity}, min, +, infinity, 0}
- Find shortest path trace
  - E.g., give each rule a weight of 1
  - Then, JOVP is length of shortest path (assuming a combine of min)

# Weighted Relation

- A weighted relation is a function from (C1, C2) to D
  - Can compose two weighted relations
  - (R1;R2)(s1, s3) = combine?{w1 extend w2 | exists s2 : w1 = R1(s1, s2), w2 = R2(s2, s3)}
  - Can union two weighted relations
  - (R1 union R2)(s1, s2) = R1(s1, s2) combine R2(s1, s2)
- To find shortest path that exhibits some property R
  - Weight = 1 if (g1, g2) in R
  - Weight = infinity if (g1, g2) not in R

# Affine Programs

- Programs for which affine relation analysis can be precisely performed
  - Where linear-equality constraints between integer-valued variables can be determined
- Constraints
  - $x_j = a_0 + \text{sum}(i=1 \text{ to } n)\ a_i x_i$
  - Or assignments can be non-deterministic

# ARA Weight Domain

- Linear algebra formulation
  - Represented by a column vector (matrix): $[a_0, \ldots, a_n]$
    - n is the number of (global) variables
  - An affine relation represents the set of all valuations of program variables that satisfies it
  - A concrete valuation must be a subset of all satisficing valuations for affine relation

# ARA Weight Domain

- Problem: Find all affine relations in a program
  - Abstract each statement as a set of matrices of size *(n+1) x (n+1)*
  - Weakest pre-condition transformer of matrices (more to finding this)
- Weight Domain
  - Basis of their linear span
  - Creates a vector space within which all valuations of program variables exists
  - *Combine* creates the smallest vector space containing the input vector spaces

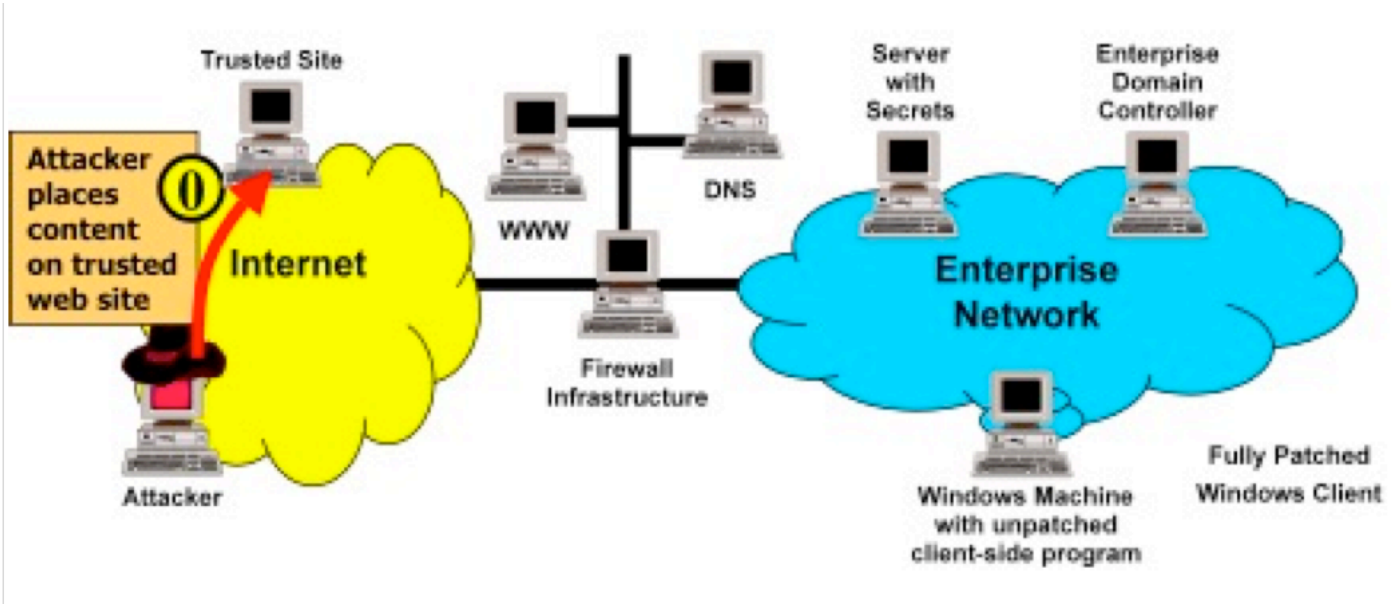
# Solving for JOVP

- Defining prestar and poststar for WPDSs
- Like PDSs, create an W-automaton, which is a P-automaton where each transition of the automaton is labeled with a weight
  - Weight of a path in the automaton is obtained by taking an *extend* of the weights in the transitions in the path
  - Acceptance of a configuration c = <p, u> with weight w = A(c) occurs if *w is the combine* of weights of all accepting paths for u starting from state p in A
- Prestar(A) produces JOVP({c}, L(A)) – i.e., configurations accepted starting from c in A – and Poststar(A) does opposite
  - Need both the forwards and backwards automata – why?

# Policy Analysis

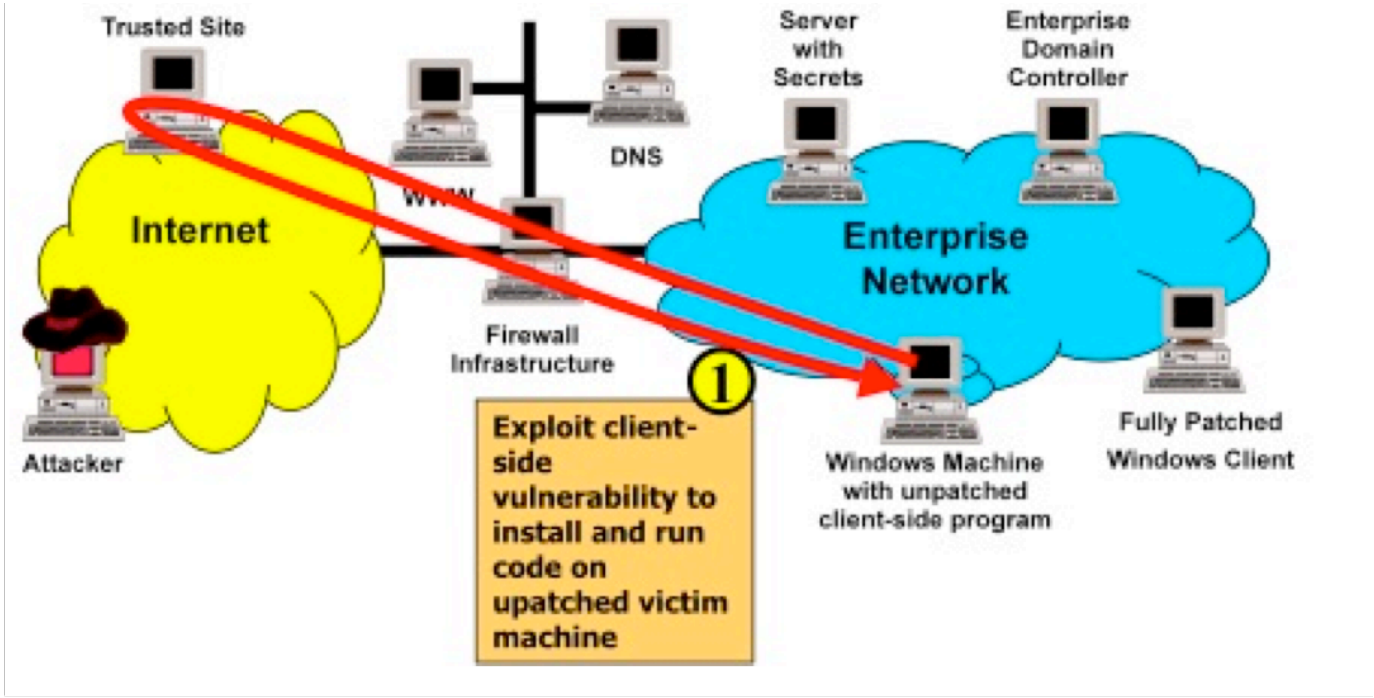
- Does a security policy in a program or a system prevent vulnerabilities?
  - What is an vulnerability?
  - How do we check that?

# Example Attack




From SANS : The Top Security Risks (Tutorial)

# SANS Example

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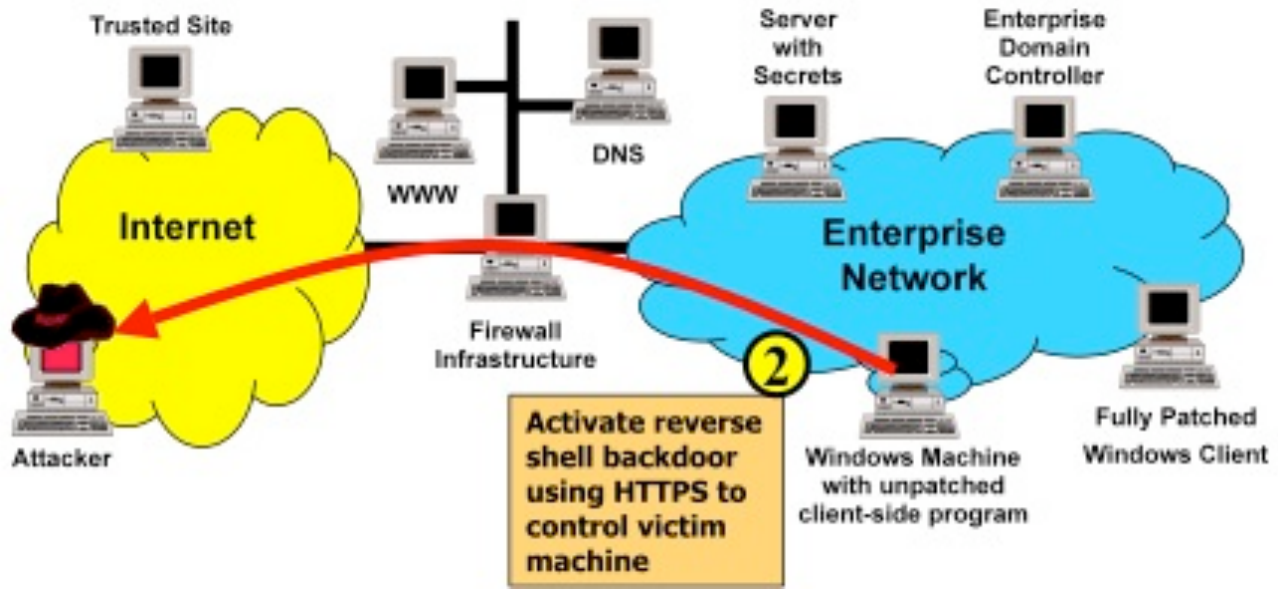


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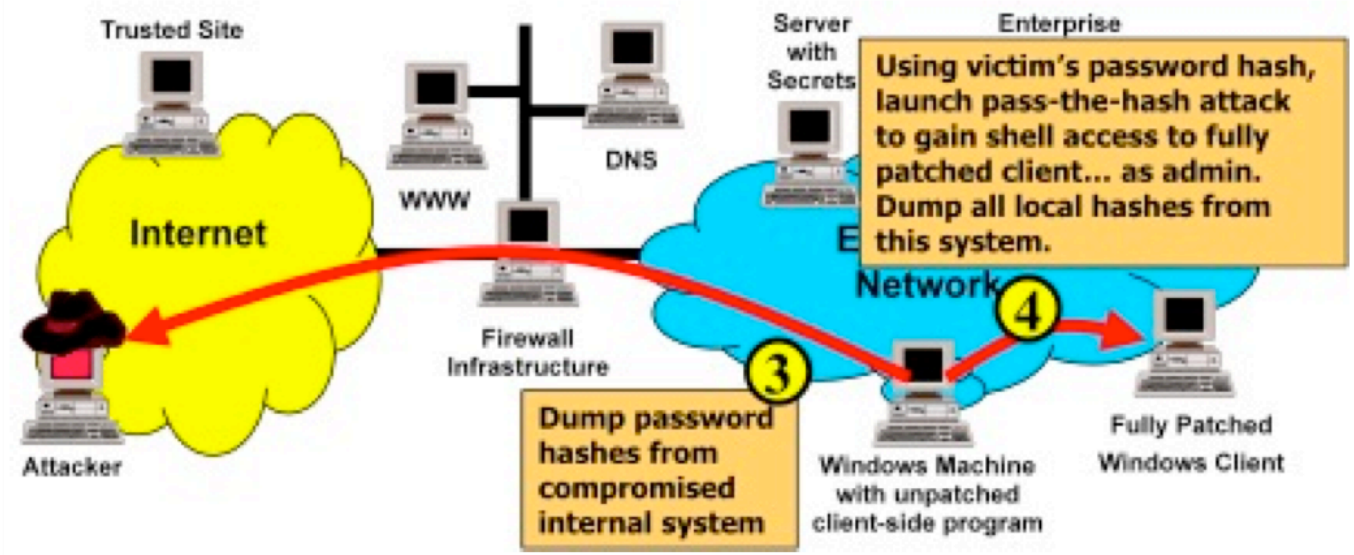


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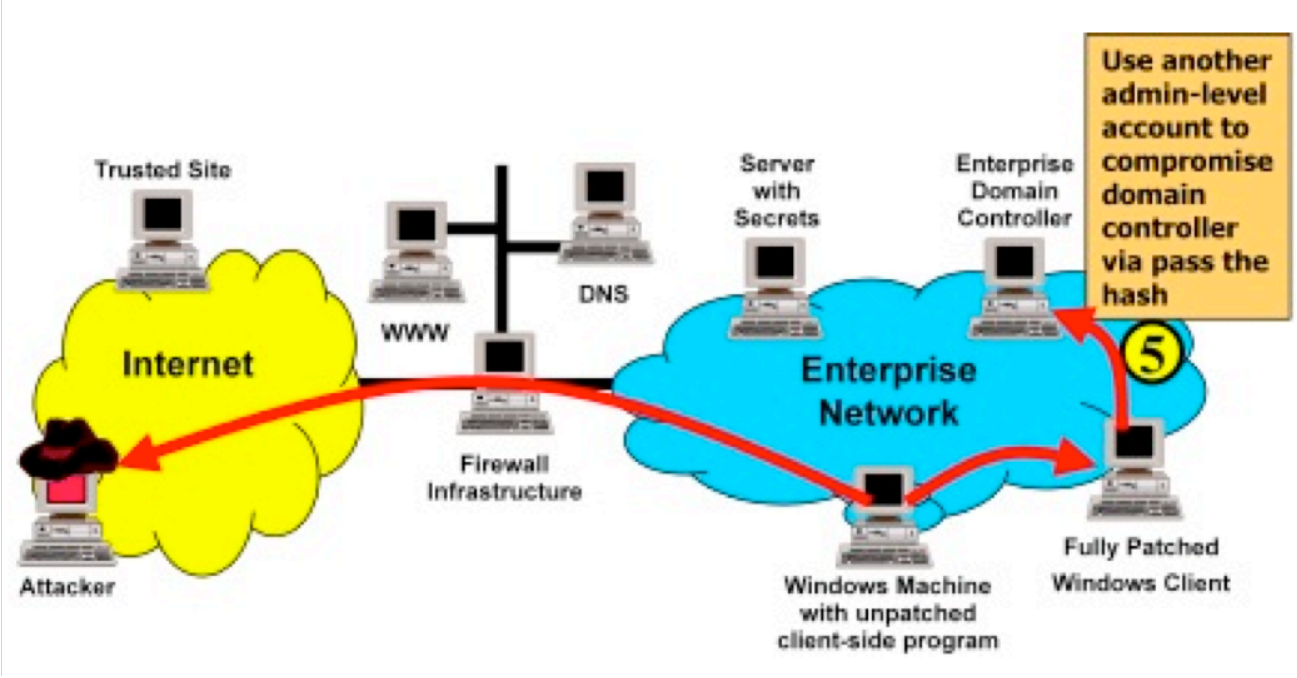


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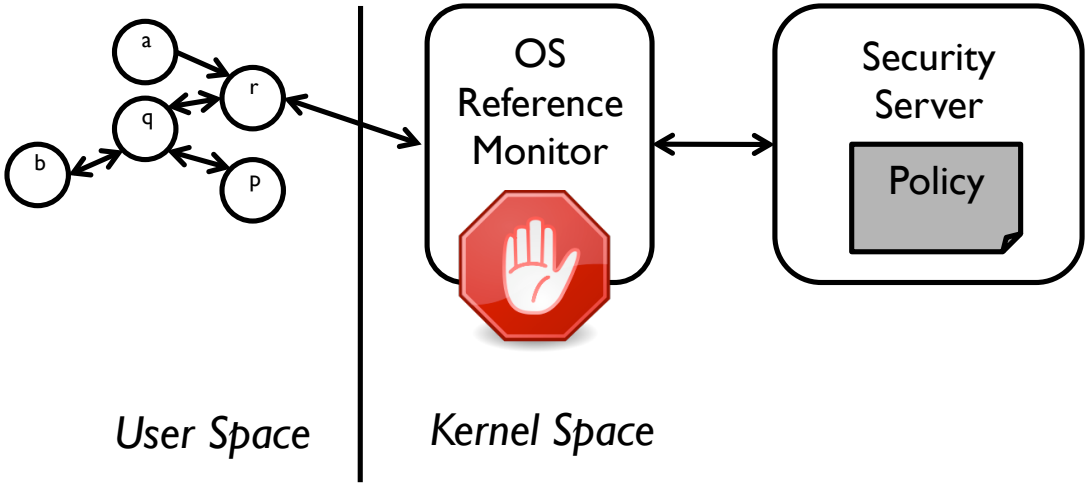
# Current Attacks

- Attack unprivileged processes first
  - Then, escalate privilege incrementally via local exploits
  - Leverage (unjustified) trust between processes/hosts to propagate attacks
- Such Attack Paths are ubiquitous in current systems
  - Processes are tightly interconnected
    - Historically, all user processes have same privilege and can utilize system services
  - Any control flow vulnerability can be leveraged to run any code
    - Return-oriented programming
- Claim: Adversaries will use any undefended path

# Current Defenses

- We have made progress the last 10 years or so
  - Vulnerable network services galore → hardened, privilege-separated daemons (OpenSSH)
  - Default-enabled services → hardened configurations (IIS)
  - Root system processes galore → Mandatory access control (Linux, BSD)
  - Application plug-ins in same address space → Run application code in separate processes (Chrome, OP browsers)
  - Email attachments compromise system → Prevent downloaded content from modifying system (MIC, antivirus)
  - A process in one host can easily access another host → Limit open ports (host firewalls, labeled networking)

# MAC Operating Systems



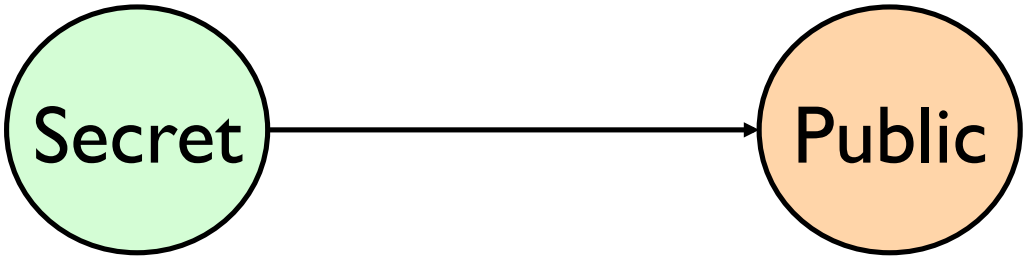

- Mandatory Access Control (MAC) operating systems
  - Define an immutable set of labels and assign them to every subject and object in the system
  - Define a fixed set of authorized operations based on the labels
- Now available in most commodity operating systems (Trusted Solaris, TrustedBSD, SELinux, AppArmor, Windows MIC*, etc)

# Idealized Security

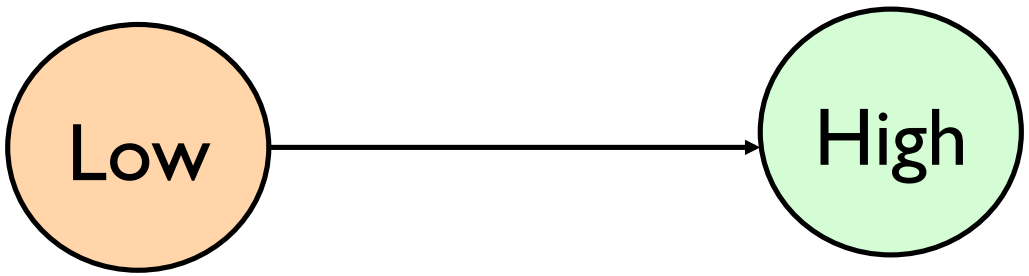
- **Multilevel Security** (MLS) for secrecy
  - Secrecy requirement: Do not *leak* data to unauthorized principals
  - Only permit information to flow from less secret to more secret principals/objects
  - E.g., Can only read a file if your clearance dominates that of the file
- **Biba Integrity**
  - Integrity requirement: Do not *depend* on data from lower integrity principals
  - Only permit information to flow from high integrity to lower integrity
  - E.g., Can only read a file if your integrity level is dominated by the file's

# Information Flows

- Secrecy (MLS): If the OS permits a secret application/object to flow to a public application/object, then there may be a leak (e.g., Trojan horse)




- Integrity (Biba): If the OS permits a low integrity input to flow to a high integrity application/object, then there may be a dependency (e.g., buffer overflow)



# Practical vs. Ideal

- Do these idealized approaches based on information flow enable practical realization of OS enforcement?
- Secrecy is possible in some environments
  - Implemented in a paper world, previously
  - Still depend on many "declassifiers"
- Integrity has not been realized in practice
  - Many processes provide high integrity services to others
- Result: Depend on many applications to manage information flows

# Example: logrotate

- *Logrotate* is a service that swaps logs
- It rotates logs through sequence
  - Secrecy: Logs may span all security levels on system
  - Thus, *logrotate* is trusted in MLS
- It reads a configuration to tell it what to do
  - Integrity: Logs must not leak into configuration files
  - Thus, *logrotate* is trusted to protect integrity

# SELinux/MLS Trusted Programs

- The OS trusts that privileged applications preserve system secrecy (30+ programs)

SELinux/MLS:

| | |
|---|---|
| Policy management tools | secadm, load_policy, setrans, setfiles, semanage, restorecon, newrole |
| Startup utilities | bootloader, initrc, init, local_login |
| File tools | dpkg_script, dpkg, rpm, mount, fsadm |
| Network utilities | iptables, sshd, remote_login, NetworkManager |
| Auditing, logging services | logrotate, klogd, auditd, auditctl |
| Hardware, device mgmt | hald, dmidecode, udev, kudzu |
| Miscellaneous services | passwd, tmpreaper, insmod, getty, consoletype, pam_console |

# Integrity Situation Is Much Worse

- Clients
  - Lots of client programs are entrusted with information with different secrecy/integrity requirements
  - Email, browser, IM, VOIP, …
- Servers
  - Historically, many servers have enforced security policies because they handle multiple clients
  - Web servers, databases, mail, respositories, …
- *Information flow alone is not enough to build a secure system!*

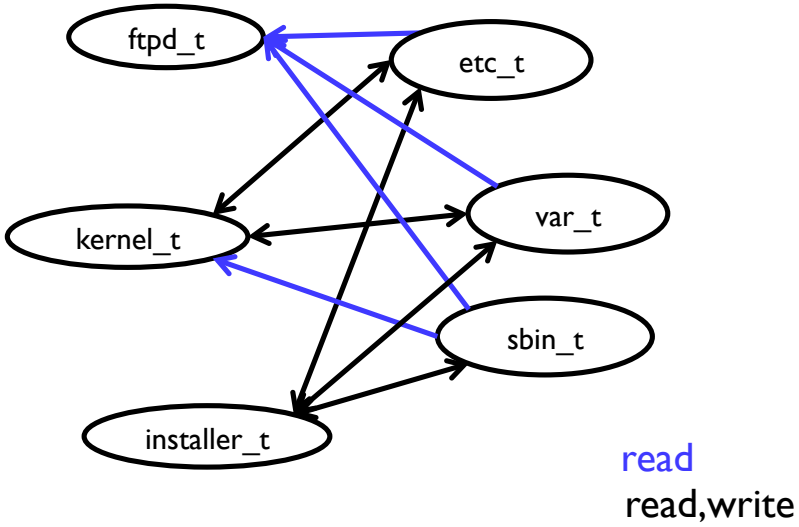
# Compliance Problem

- Evaluating whether a policy permits an adversary to have unauthorized access (i.e., contains an error) is a *compliance problem*:
  - System Policy: describes a system's behavior
  - Goal Policy: describes acceptable behavior
  - Mapping function: relates elements from the system policy to elements in the goal policy
  - A compliant system policy is guaranteed to meet the requirements defined by the goal policy

# Evaluating OS MAC Policy

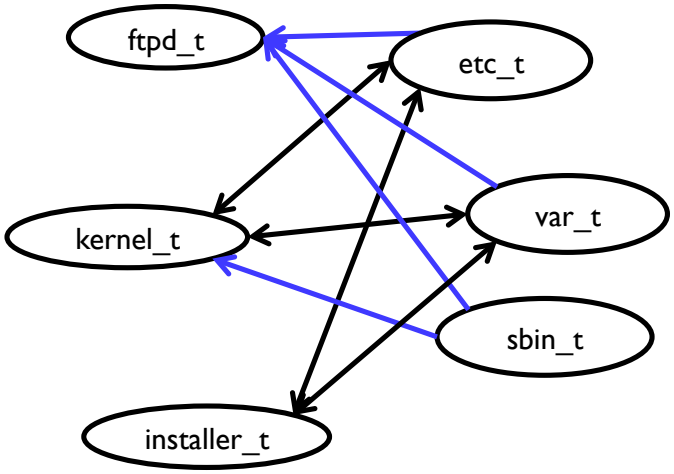
- We represent a single MAC policy with an information flow graph
  - Used in analyses for SELinux by Tresys, Stoller, Li, Jaeger, etc.

| | etc_t | var_t | sbin_t |
|---|---|---|---|
| installer_t | read,write | read,write | read,write |
| kernel_t | read,write | read,write | read |
| ftpd_t | read | read | read |



# Compliance Problem

- The policy compliance problem for a single policy is set up as follows:
  - *System policy* – The policy that we are analyzing is represented as a graph



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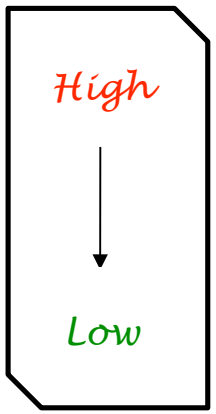

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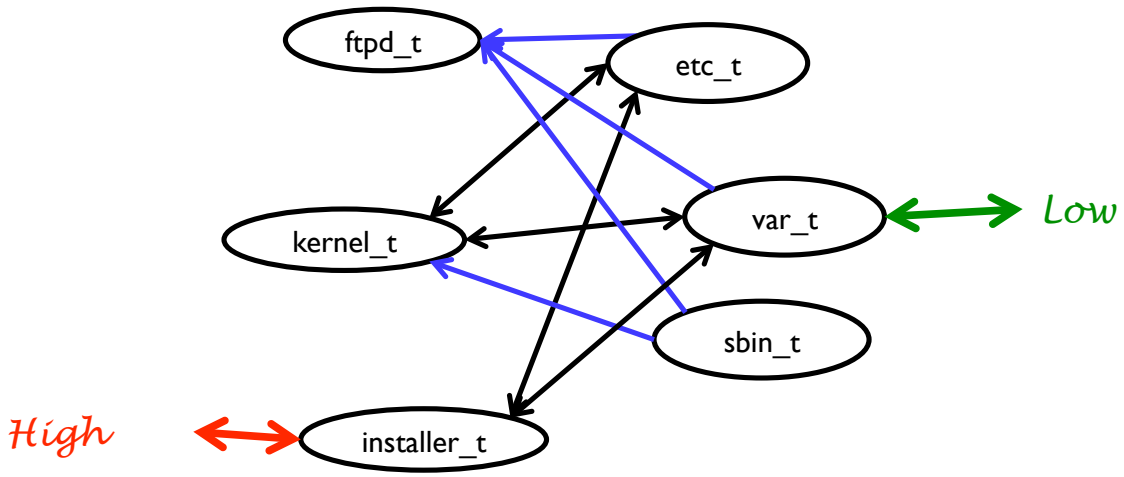

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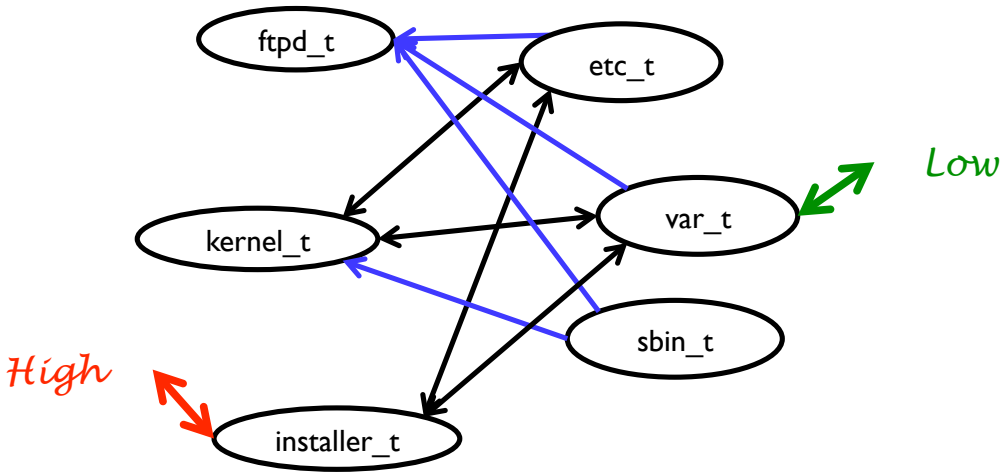
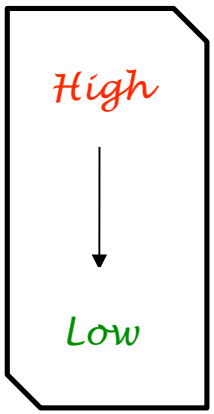



*Do all flows meet the requirements defined by the goal ?*

# Other Compliance Problems

- Information flow compliance in programs
  - Data flow is determined by program data flows – security-typed languages, such as Jif, Sif, SELinks, FlowCaml
- Goal policy is not a lattice
  - Illegal reachability: no path from u $\rightarrow_G$ v
  - Illegal sets of permissions: annotate edges with permissions
- Goals as functional requirements (e.g., obligations)
  - The presence of a node, edge, or path is required
  - These are functional constraints, rather than security

# Find SELinux TCB

- Can we identify a TCB in SELinux Example Policy whose integrity protection can be managed (circa Linux 2.4.19)?
  - See [USENIX Security 2003]
- Tasks:
  - Can We Identify Trusted Programs?
  - Can We Define a Security Goal to Protect These Programs?
  - Can We Verify This Goal?
  - How Do We Debug Conflicts?

# Type Enforcement

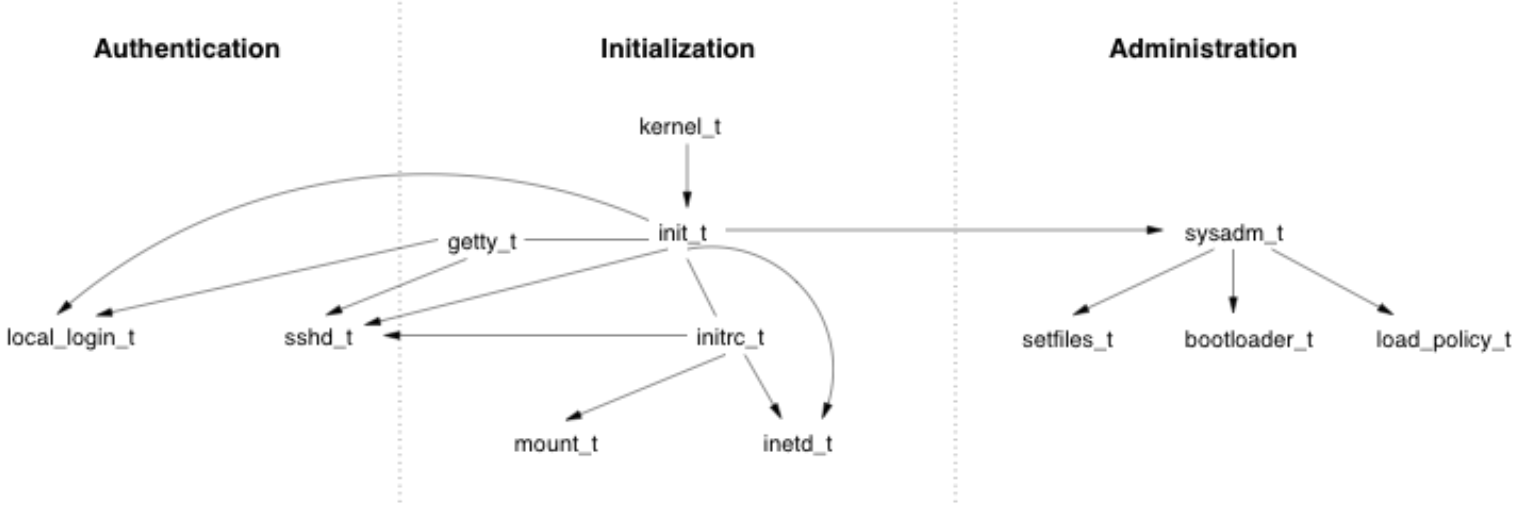
- Least privilege MAC policy used by SELinux
  - Subjects have a label
  - Objects have a label
  - Permissions define object labels accessible to subject labels
- Several systems use (or have used) a form of TE
  - SELinux uses labels called *types*
- TE policies are fine-grained and complex
  - SELinux has 10,000s of rules
- SELinux has added abstractions, such as attributes and roles

# Proposed Approach

- Propose a TCB from SELinux subjects
- Identify Biba integrity violations
- "Handle" integrity violations
  - Classify integrity violations
  - Remove violations that can be managed by application
    - Application is trusted to protect itself
  - Revise TCB proposal
  - Revise SELinux policy
- Result: All information flows are legal or accounted

# Propose a TCB - Detail

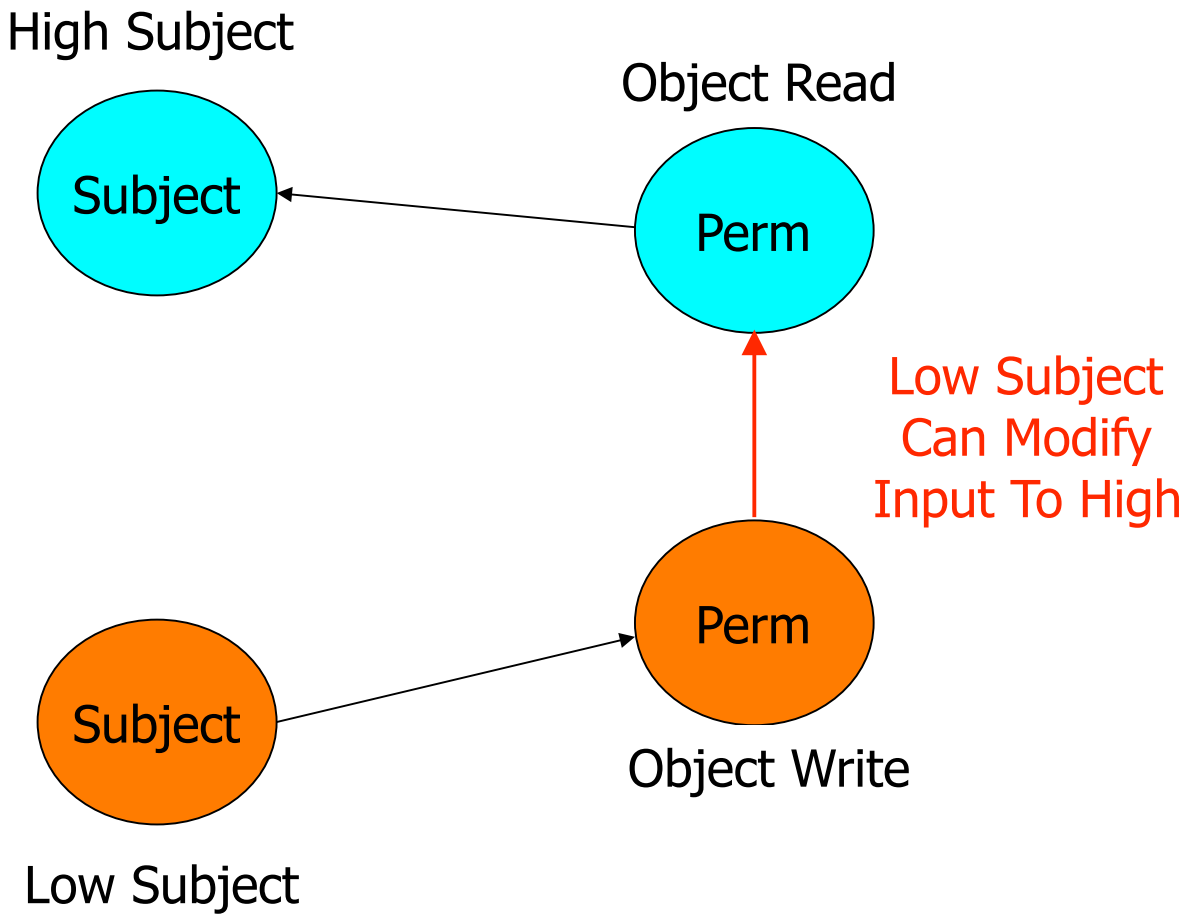
- Use SELinux transition graph (i.e., who can exec whom) for server programs (e.g., httpd_t) to identify base subject types
- Ones that provide TCB services (e.g., authentication)
- Others that have many transitions (hard to contain)



# Identify Integrity Violations

- Biba Integrity Analysis -- Gokyo, PAL, PALMS
- TCB subject types → read/exec perms
  - Generate corresponding "integrity-sensitive write" perms
- Others → write perms
  - Generate corresponding "integrity-sensitive read" perms
- Analysis
  - Do Others' write to integrity-sensitive writes?
  - Do TCB Subjects read from integrity-sensitive reads?

# Integrity Analysis

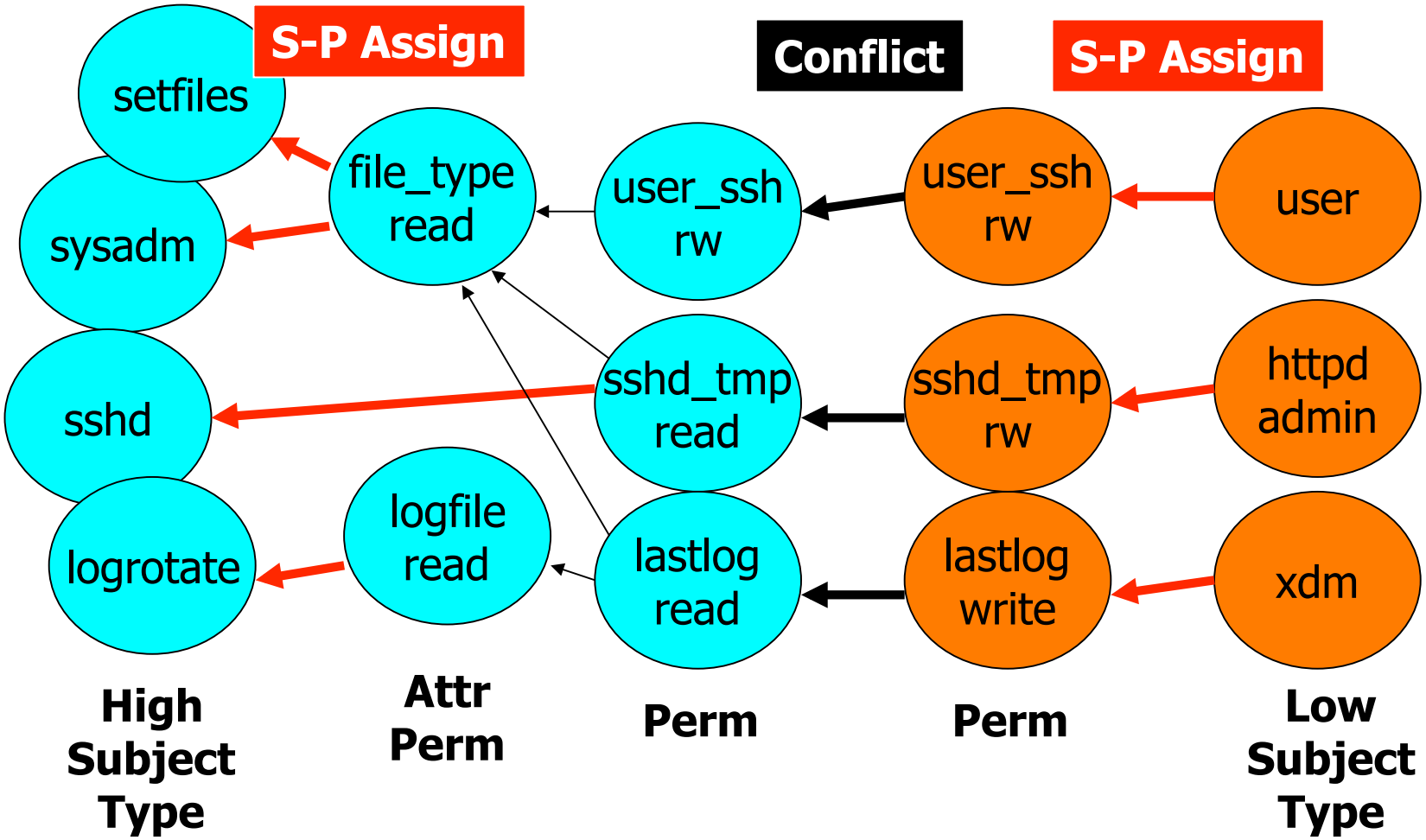


# Are There Integrity Violations?

PENNSTATE 1855

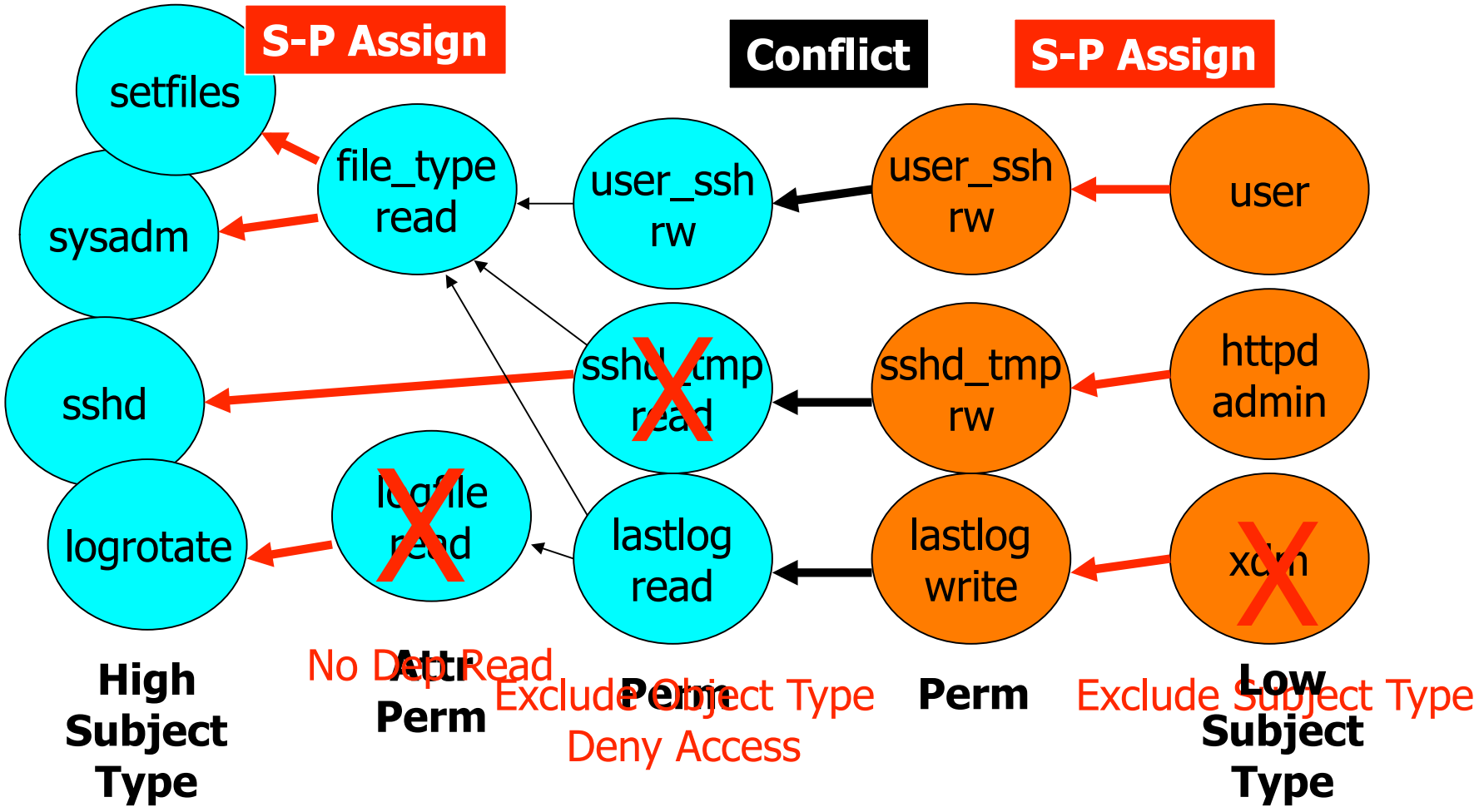
- For Linux 2.4.19 -- SELinux Strict Policy
- Permissions
  - 129 perms used to “read down”
    - 57 socket perms, 25 fifo perms
  - 1583 perms used to “write up”
- Subjects
  - 28 high integrity subjects “read down”
    - 35 for sysadm_t, 4 for load_policy_t
  - 150 low integrity subjects “write up”

# Expressing Conflicts




The subject-permission assignments that lead to a conflict result in a minimal cover of all conflicts

# Example Resolutions



# Integrity Resolutions

- Remove Subject Type or Object Type
- Reclassify Subject Type of Object Type
- Change Subject Type-Permission assignment
- Clark-Wilson reads
  - Allow reading of low integrity data that meet Clark-Wilson
- Deny Object Access
  - Track low integrity writes per object
- LOMAC Subject Type (sysadm)
  - Reduce integrity level of subject when reading low integrity data

# Analysis Summary

- Conclusions
  - Biba Information Flow Integrity
    - May not be so far off practical
    - But, we cannot force Biba (or other ideal models, e.g., LOMAC)
  - Need to address conflicts
    - Identify resolutions
- Approach
  - Compliance Problem
  - Multiple types of resolutions

# Questions