Take Only What You Need: Leveraging Mandatory Access Control Policy to Reduce Provenance Storage Costs

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Deal-breaker for system provenance?

Data Provenance
Provenance-Aware Adversaries

The environment we consider in this work is *not* benign.

**Active provenance-aware adversaries attempt to:**

- Evade monitoring
- Tamper with prov. logs
- Disable prov. mechanisms

**Provenance Monitors:**

- Record complete, gapless provenance
- Tamperproof
- Verifiably correct
High storage overheads for system layer provenance collection:

- Provenance-aware systems generate GB of metadata on the order of minutes.

- Hi-Fi module generates 4.8 GB during kernel compile.

- After processing, PASS reports similar overheads (~1.5 GB).
Deal-breaker for system provenance?

High storage overheads for system layer provenance collection:

• Worse, a percentage of that provenance is uninteresting.

• Provenance compression techniques cannot remove uninteresting data.

• In Discretionary Access Control systems, we cannot guarantee completeness without recording everything.
We propose that Mandatory Access Control (MAC) systems can facilitate the performance of selective provenance collection.

- **Background**
  - Threat Model
  - Storage Overheads

- **Provenance Walls**
  - Provenance & MAC
  - Policy Analysis

- **Future Work**
  - Design & Implementation
  - Challenges

- **Conclusion**
Provenance and Mandatory Access Control

What is the relationship between Provenance and MAC policy?

• With MAC, we can reason about where data will (not) flow.
  – MAC answers questions about possible future events

• With Prov., we can reason about where data did (not) flow.
  – Provenance answers questions about actual past events

• MAC systems assign a security label to every system object.
  – Objects in MAC namespace map to objects in provenance namespace.
We could define a *provenance policy* in terms of security labels…

… but where does that leave us in terms of assuring *completeness*?
Selective Completeness

**Definition:** A provenance sub graph that is complete in its description of a specified system activity… in perpetuity!

- Objects inside of policy will *always* have complete provenance histories.
- Objects outside of policy will *never* flow to objects inside of policy.
Policy Analysis

Integrity Walls [Vijayakumar et al. 2012]:

- MAC policy analysis tool that identifies an application’s attack surfaces.

- Static analysis identifies executable writers, kernel subjects, and helper subjects that form Minimum Trusted Computing Base (MTCB):

  \[ \text{http}_t, \text{http}_\text{config}_t, \text{http}_\text{user}_\text{content}_t, \text{lib}_t, \text{http}_\text{packet}_t \]

- Dynamic analysis is then used to identify adversary-controlled entry points:

  \[ \text{http}_\text{user}_\text{content}_t, \text{http}_\text{packet}_t \]

Figure adapted from [Vijayakumar et al. 2012]
Integrity Walls [Vijayakumar et al. 2012]:

- Adapt the static analysis tool to create a provenance policy:

- For a given application $S$, divide the policy $P$ into a set of trusted labels $I_s$ and an untrusted set $O_s$.

- $I_s$ exhaustively describes the objects that can flow into $S$.

- $I_s$ is a provenance policy that is selectively complete for $S$. 

Figure adapted from [Vijayakumar et al. 2012]
We propose that Mandatory Access Control (MAC) systems can be leveraged to perform policy-based provenance collection.

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Provenance Walls Architecture

Our architecture for selective provenance recording is shown below:

What applications do I want to Collect provenance for?

Administrator

- Application
- User Space (Unconfined)
- User Space (MAC Protected)
- Prov. Wall Policy
-Prov. Policy Generator
- MAC Policy
- Provenance Store
- Prov. Wall Utility
- Prov. Recorder
- Kernel
- Objects
- Reference Monitor
- If access granted: Create provenance only if access request matches policy...
- Provenance Monitor
We are developing Provenance Walls using the Linux Provenance Modules (LPM) Framework [Bates et al. 2015]:

• Satisfies “Provenance Monitor Concept”.

• Provenance hooks permit observation of all kernel objects.

• Can be simultaneously enabled with SELinux.

• We will create a policy-aware version of LPM’s Hi-Fi module [Pohly et al. 2012].
(Highly Contrived) Evaluation

- We made minimal modifications to Hi-Fi to access SELinux security contexts and perform a single policy check.

- **Our Policy:** “I am not interested in things that happen in user’s home directories (user_t)!!”

- We then performed kernel compilation test in our home directory:

<table>
<thead>
<tr>
<th>Module</th>
<th>Provenance Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hi-Fi</td>
<td>54 MB</td>
</tr>
<tr>
<td>Policy-Aware Hi-Fi</td>
<td>10 MB</td>
</tr>
</tbody>
</table>

*Note: Provenance logs are compressed with gzip here.*

- **Takeaway:** Savings are domain-specific, and dependent on how many system activities can be pruned.
Challenges

- Policy-Aware Provenance gives rise to new kinds of provenance queries, including:
  
  - *Why is this subgraph missing?*
    - *Proof that graph omissions are due to correct policy decisions, not error.*
  
  - *Where can this data go?*
    - *When reasoning about data provenance, use MAC policy to “look into the future” of system execution.*
  
  - *What other data objects are similar to this data object?*
    - *Leverage MAC policy to identify related items by security label*
    - *Objects that are related according to MAC policy may appear unrelated in the provenance graph.*
Challenges

Develop other algorithms for selectively complete policies

- “Provenance Walls” is great for monitoring a specific, mission-critical application.

- Is not adequate for other provenance use cases, such as monitoring data exfiltration:
Challenges

Will our approach conflict with other reduction techniques?

Policy → Filter → Compress

- What to collect?
- What to keep?
- How to store?

Tasks:

Specify scope of provenance collection
Reduce dependence explosion, collapse cycles, compact into supernodes, remove attributes.
Provenance-agnostic compression, optimize for storage and/or query.

Related Works:

- Provenance Walls
  [Bates et al. 2015]
- BEEP
  [Lee et al. 2013]
- Provenance Sketches
  [Malik et al. 2010]
- PASS
  [Muniswamy-Reddy et al. 2006]
- Web / Deduplication
  [Xie et al. 2011]
- Web + Dictionary
  [Xie et al. 2012, 2013]
Conclusion

• We are investigating MAC enforcement as a means of reigning in the scope of provenance collection.

• Depending upon the application, the savings are potentially large (82% storage reduction).

• Secure computing deployments not only provide an interesting use case, but also create new opportunities to address open challenges in provenance collection.

• LPM makes it easier to prototype provenance monitors, and simultaneously assures that collection mechanisms are tamper proof and have complete mediation of system activity.
Questions?

Thank you for your time.

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Linux Provenance Modules will be available in August at http://linuxprovenance.org