Provenance-based Intrusion Detection: Opportunities and Challenges

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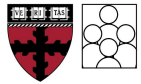
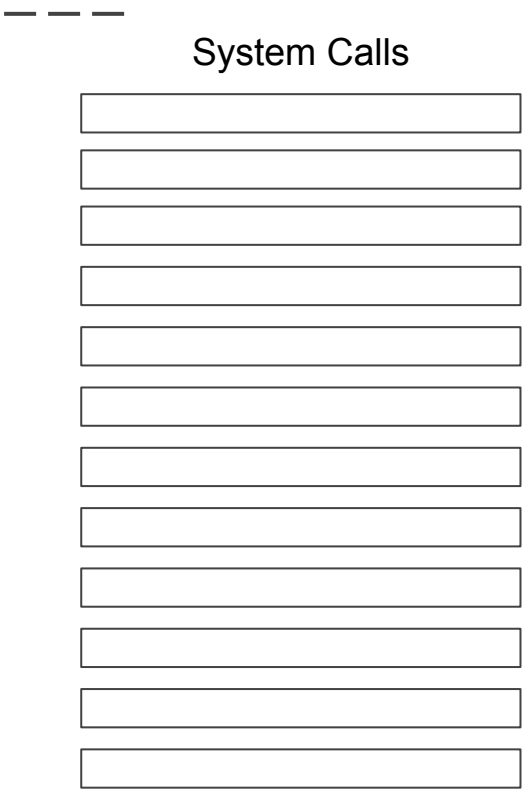


CRCS Center for Research on Computation and Society
at Harvard John A. Paulson School of Engineering and Applied Sciences

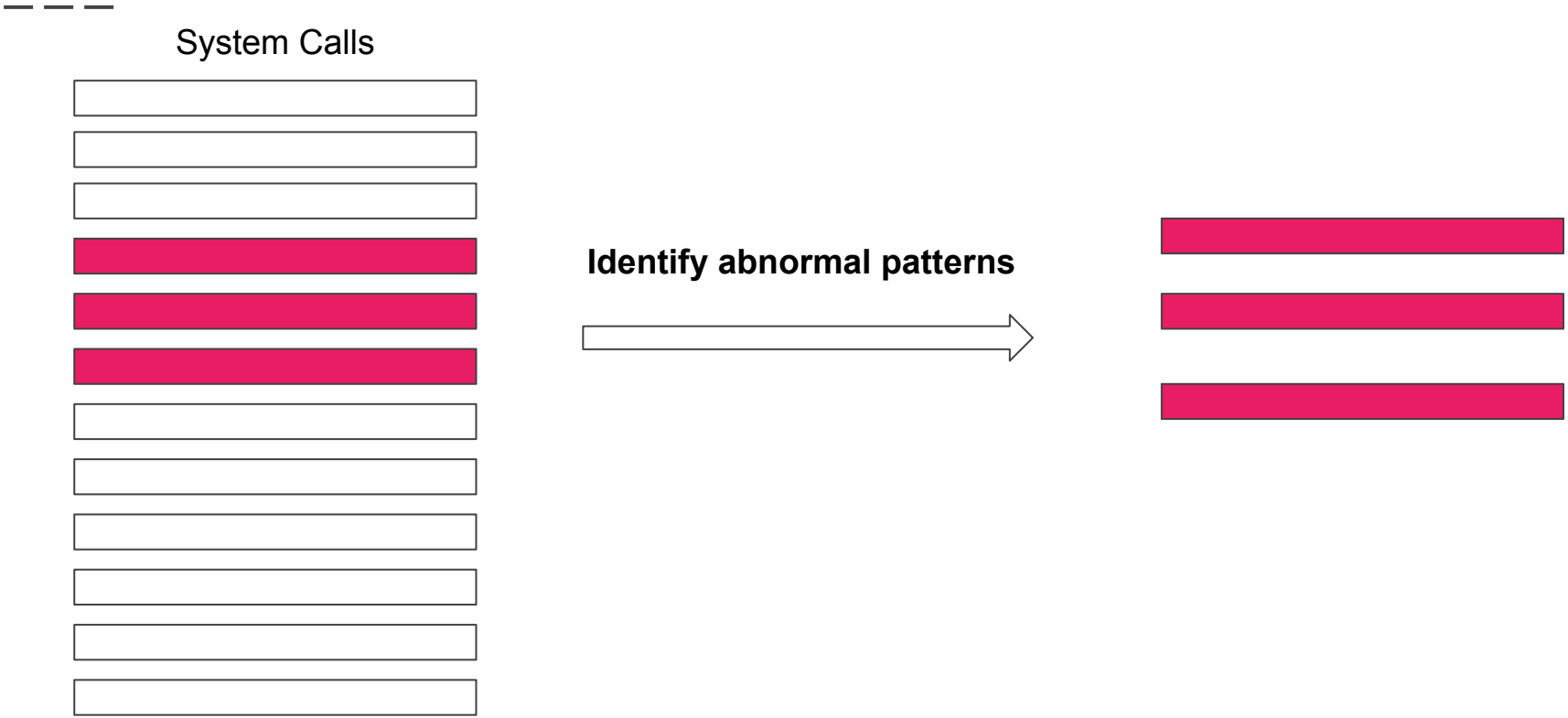
Discussion paper

- (quick) problem description
- (some) interesting challenges

System call based intrusion detection



System call based intrusion detection



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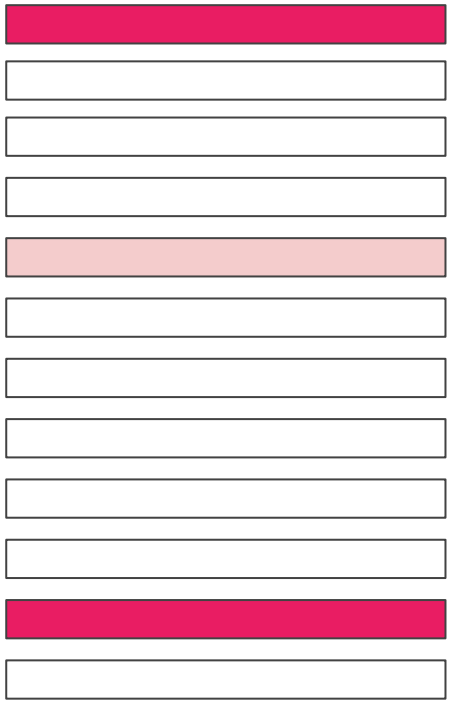
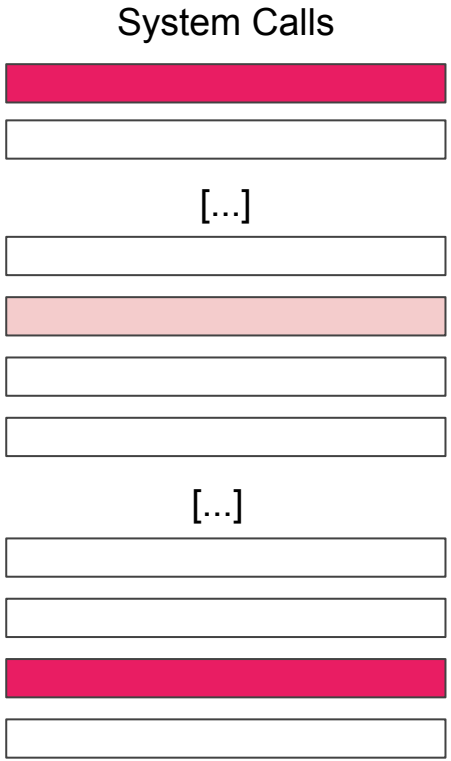


Identify abnormal patterns

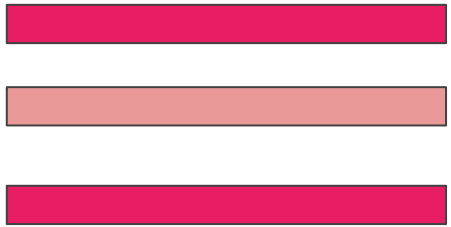
Hidden among benign actions
Masquerading as bening action

System call based intrusion detection



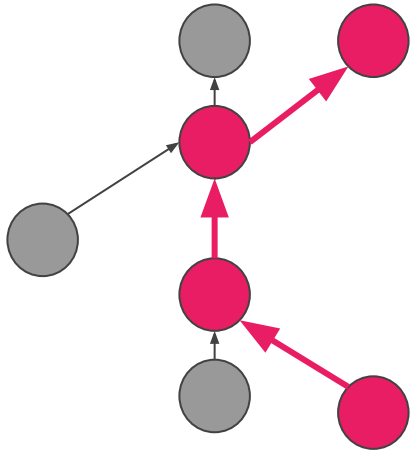
Identify abnormal patterns

Hidden among benign actions
Masquerading as bening action
Over a long period of time



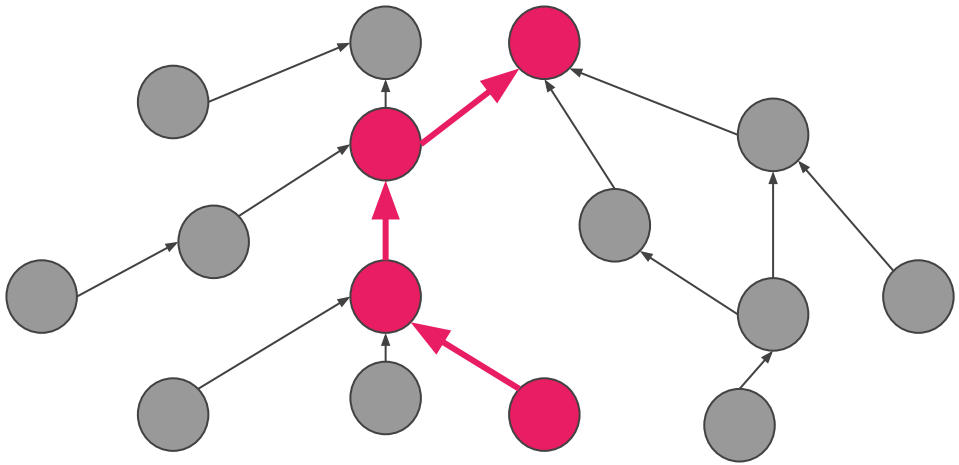
Provenance-based intrusion detection

- **Intuition**: provenance graph **exposes causality relationships** between events

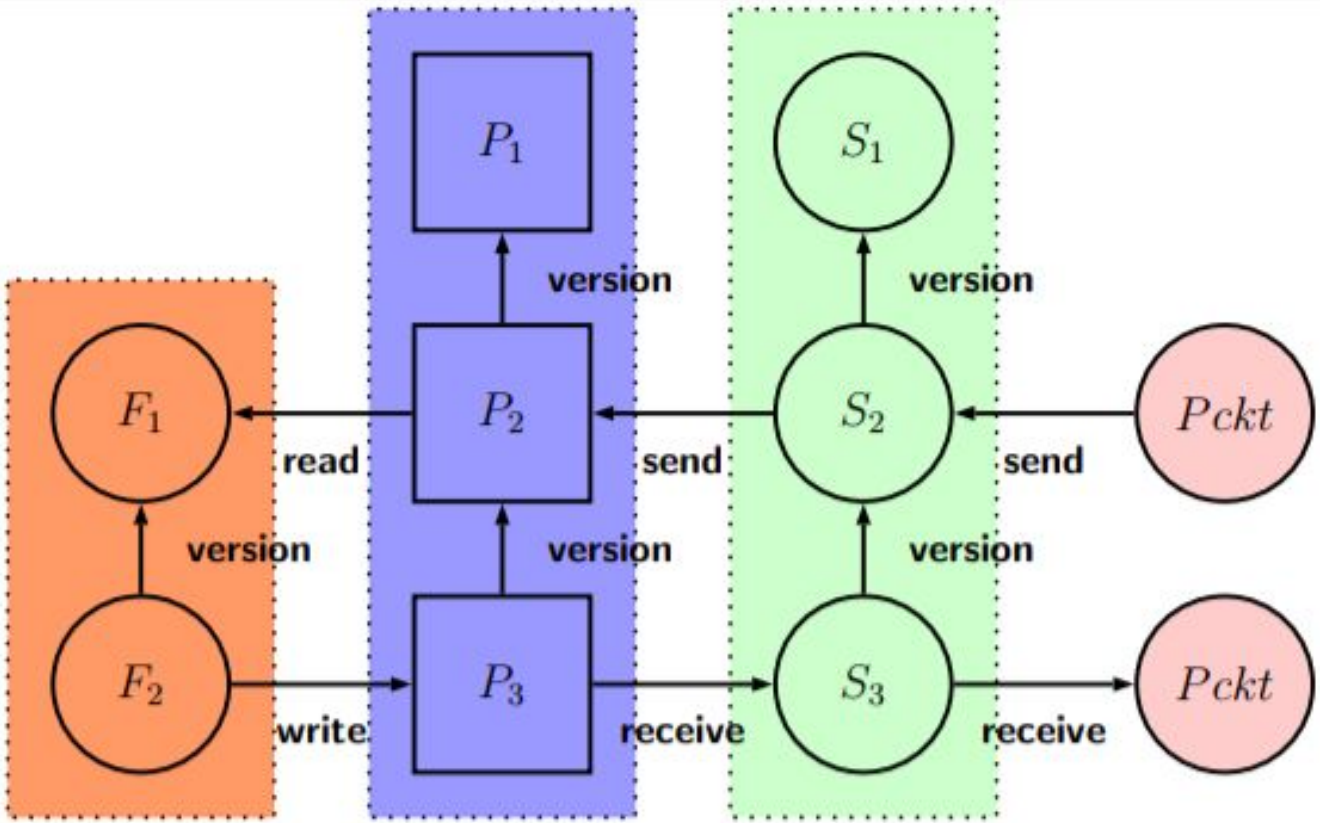


Provenance-based intrusion detection

- Intuition: provenance graph **exposes causality relationships** between events



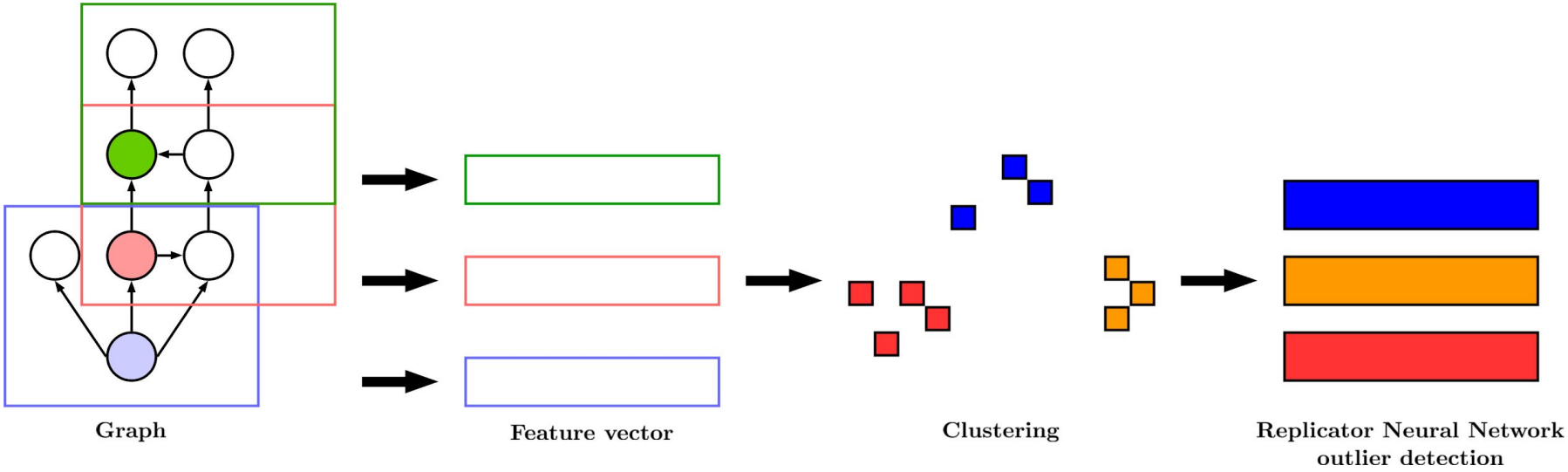
Example: what provenance?



Example: How?

- Principles first introduced in Han et al.(USENIX HotCloud 2017)
- In a cloud computing context (self-contained VMs)
- Capture uncompromised behaviour
  - in a controlled environment
  - from a representative workload
- Build a model of system behaviour
  - Unsupervised learning
  - Neural Network, Statistical Model, etc.
- Detect deviations from the model
- Several approaches explored
  - e.g., see Ghita talk on Friday

Example: How?


Graph
Feature vector
Clustering
Replicator Neural Network
outlier detection

(some) challenges

- Capture
- Analysis
- Take away

Capture: Provenance, but what provenance?

- **Whole-system** provenance (defined quite broadly)
- A number of implementations
  - e.g., SPADE, HiFi, LPM, CamFlow, CADETS, etc.
  - similarity in capture mechanisms…
  - … yet very different semantics.
- This has been driven by systems research
  - … but maybe it is time for some formalism?
  - early exploration ProvMark to compare the produced provenance.
- What are we trying to represent?
- How do we represent it?
- More than syntax! (see James/Bertram talks)

Capture: open source (and maintained) capture mechanism

SPADE: http://spade.csl.sri.com

CADETS: https://github.com/cadets

CamFlow: http://camflow.org

Capture: is the provenance correct/complete/accurate?

- Need to solve the previous questions!
- Proof?
  - Operating systems are very complex
- Smaller steps?
  - CamFlow: we did some static analysis to show what is captured and how it is represented…
  - ProvMark: runtime equivalent (multiple systems) [talk to James]
- Nothing quite satisfactory yet (need formalisation)
- … security/ threat model

Analysis: machine learning on structured graphs

- A much harder problem than on flat data pattern discovery
  - Nodes/edges have different numbers of attributes
  - Need to learn various relations (i.e., graph structures) among them
  - **But most ML algorithms learn from fixed-length, real-valued vectors**
  - What information matter? How to represent it?
- Online deployment requires learning and detection in a streaming fashion
  - Analysing the entire graph is impossible
    - **What's the trade-off?**
  - Complexity vs Performance
  - Complexity vs Interpretability

Analysis: comparing results

- Abnormal patterns are not known
  - Machine Learning
  - **Unsupervised learning**
- What model, based on what properties?
  - Neural networks
  - Statical models, etc…
  - What assumptions made about the provenance?
- What dataset?
  - i.e., graph representing “uncompromised” executions
  - … and “similar” compromised executions
  - Where do we get the datasets?
  - DARPA TC? Unicorn effort(https://github.com/crimson-unicorn/dataset)
  - Towards a community effort?

Analysis: constraints

- Runtime vs Post-mortem
- Detecting vs Explaining
  - Frappuccino (HotCloud 2017 Han et al.)
  - Backtracking intrusions (SOSP 2003 King and Chen)
- More complex algorithms **may** do better…
- …but they may not scale
- Systems engineering constraints
  - Need to work on real data
  - On real sized problems
  - There is no solution if the idea cannot get deployed
- **Graph structure/properties matters**

Take away

- Interesting, but complex problem
- Community effort to improve reproducibility/comparison
- Provenance “solved” problems need to be re-explored
  - different scale
  - different threat model
  - different performant constraints
  - **system engineering and security matters**
- Need a venue to discuss engineering/security problems

Thank you!

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Questions?

http://camflow.org