# Anomaly Detection in Cyber Networks using Graph-node Role-dynamics and NetFlow Bayesian Normalcy Modeling

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# Agenda

- Introduction
- Advanced Persistent Threats
- Graph-node Role-dynamics
- Bayesian Normalcy Modeling
- Summary

# Introduction

- **Context Aware INference for Advanced Persistent Threat (CAIN for APT)**
  - DARPA Phase II SBIR
- **Challenge**
  - Stealthy cyber attacks slip past state-of-the-art defenses, dealing crippling blows to critical US military and civilian infrastructure
- **Goal**
  - Rapid, automated, and accurate prioritization of cyber alerts provides timely and comprehensive cyber situational awareness (SA)
- **Technical Approach**
  - Novel graph-analytics makes sense of noisy IDS sensors
  - Novel Bayesian Dynamic Flow Model flags odd network traffic
  - Tests and evaluations with APT simulations

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# Advanced Persistent Threats

- **Often associated with nation-state espionage**
- **Targets include private organizations & nation-states**
- **Low and Slow: Attack campaigns may last months**
- **Notoriously difficult to detect**

(Preprint: A. Lemay, et al. 2018)

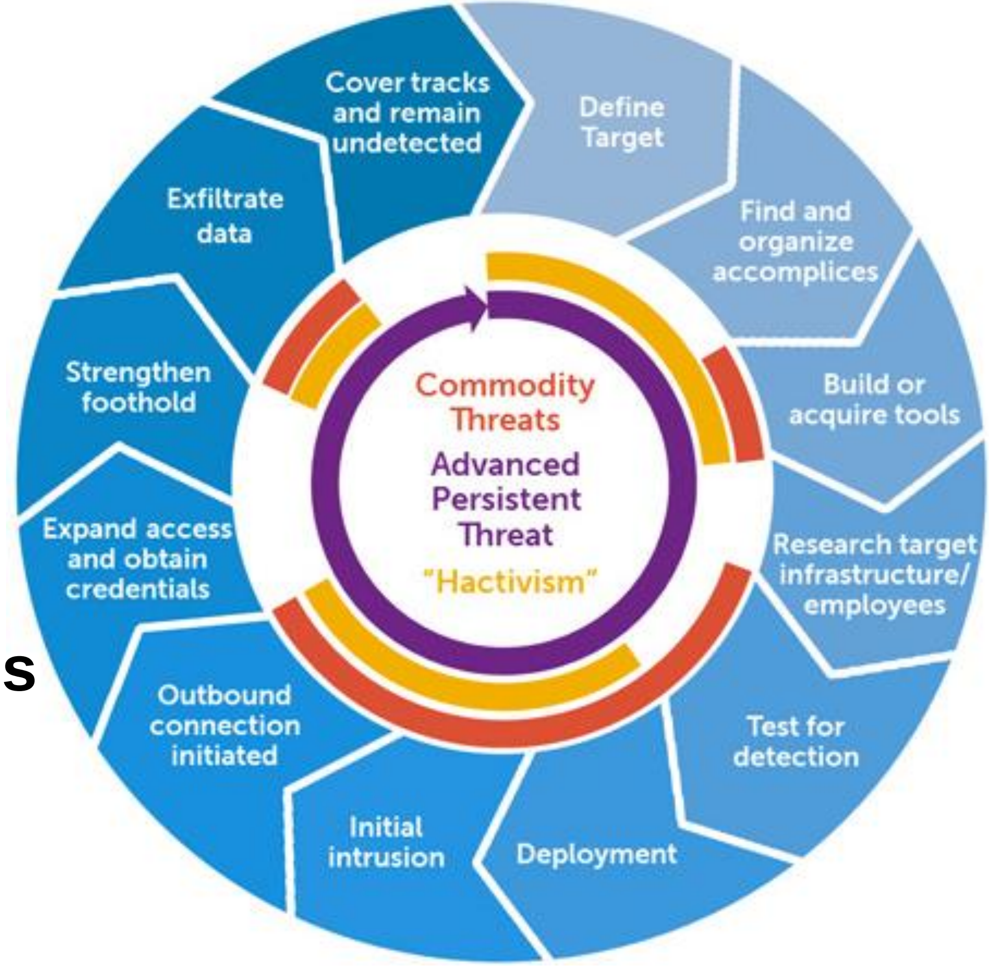
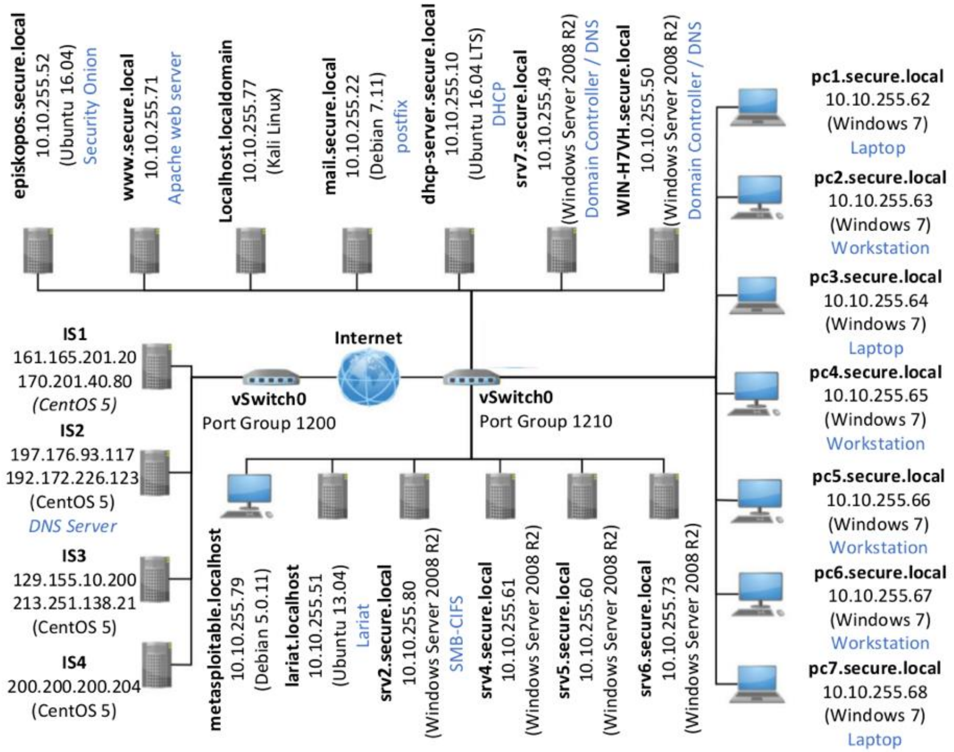



Image: https://www.secureworks.com/blog/advanced-persistent-threats-apt-a

# Simulated APT Scenarios

- **Simulation attributes**
  - Approx. 1 month of data per scenario
  - Servers, laptops, switches
  - Linux & Windows machines
  - Normal & attacked behavior
  - Generates IDS alerts and NetFlow traffic
  - Detailed attack timeline
- **Hurricane Panda simulation**
  - Attack distributed over 3 days
  - Database injection to gain credentials
  - Lateral movement and firewall deactivation
- **Energetic Bear (Crouching Yeti) simulation**
  - Attack distributed over 3 hours
  - Email phishing to redirect user to malicious website
  - Lateral movement through network using a remote-desktop exploit
  - Attacker attempted to clean-up logs and other traces




Network topology for simulations

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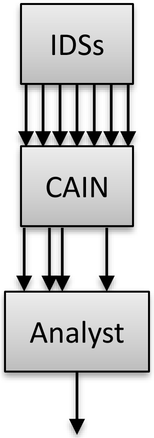
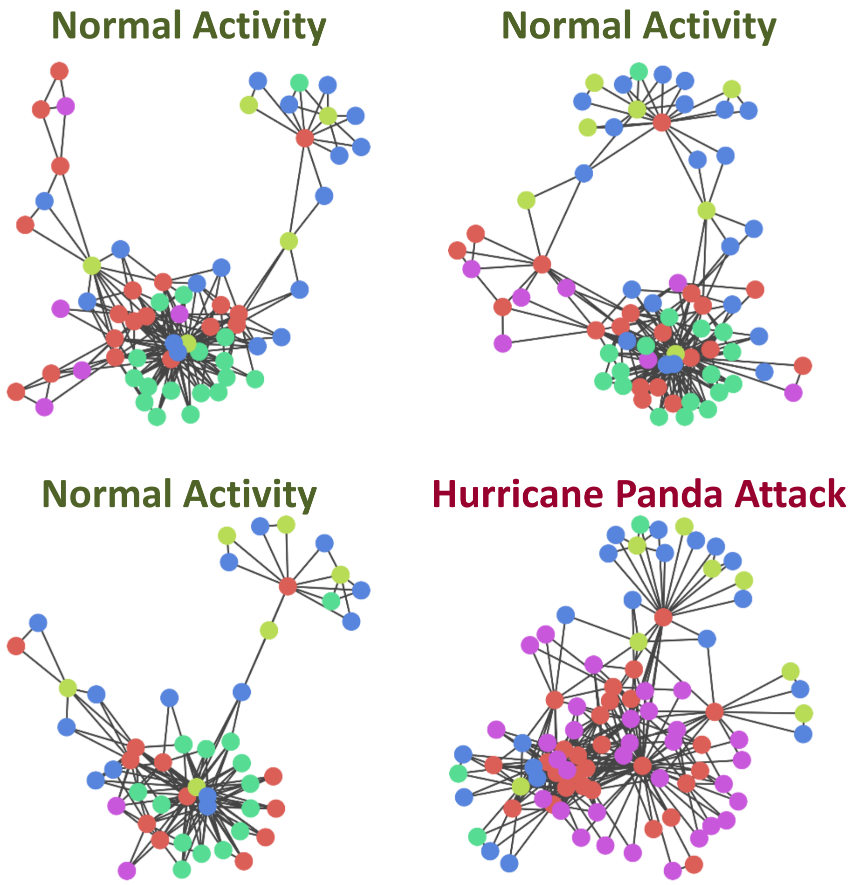
# Graph-based Approach

- Fuses disparate IDSs
- Captures alert interdependencies
- Efficiently represents many alerts
- Robust to circumvention
- Unsupervised
- Facilitates causal analysis
- Optimal parameters determined automatically



# Making Sense of Noisy IDS Sensors with Graph Analytics




**Alert Graphs from Hurricane Panda Simulation**

- **Novel, graph-based analysis of IDS alerts**
  - Load IDS alerts into alert graph
  - Detect graph anomalies
- **Advantages of graph-based approach:**
  - Captures alert interdependencies
  - Fuses disparate IDSs
  - Efficiently represents alerts
  - Robust to circumvention

*Akoglu et al. 2014*

# Alert Graphs

OSSEC Alert (Host IDS)

```
** Alert 1480536972.16316356: syslog, vsftpd,
connection_attempt 2016 Nov 30 20:16:12 (host)
10.10.255.79 -> /var/log/vsftpd.log Rule: 11401
(level 3) -> 'FTP session opened.' Src IP:
10.10.255.77 Wed Nov 30 15:17:25 2016 [pid 14562]
```

Snort Alert (Network IDS)

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11/30-15:32:15.407340  [**] [1:2010939:2] ET
POLICY Suspicious inbound to PostgreSQL port 5432
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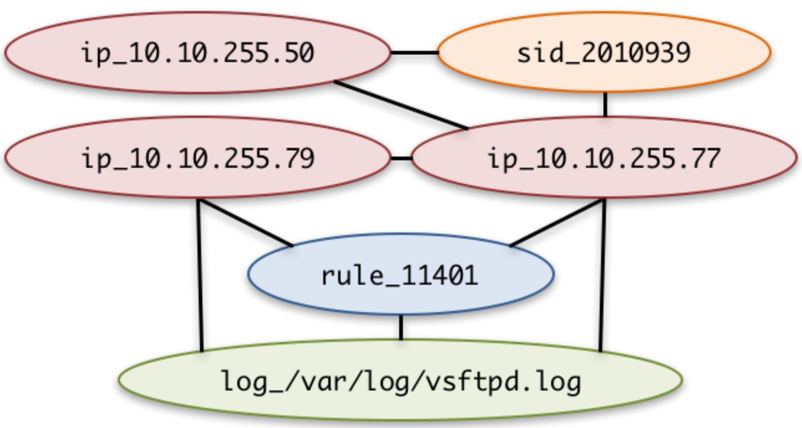
Alert Graph




- **Graph of alerts (Not network topology)**

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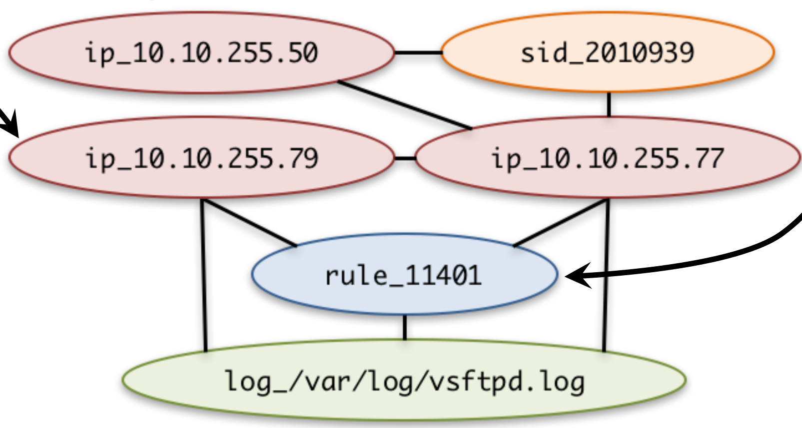


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- **Alert properties become nodes**
- **Node colors indicate property type**

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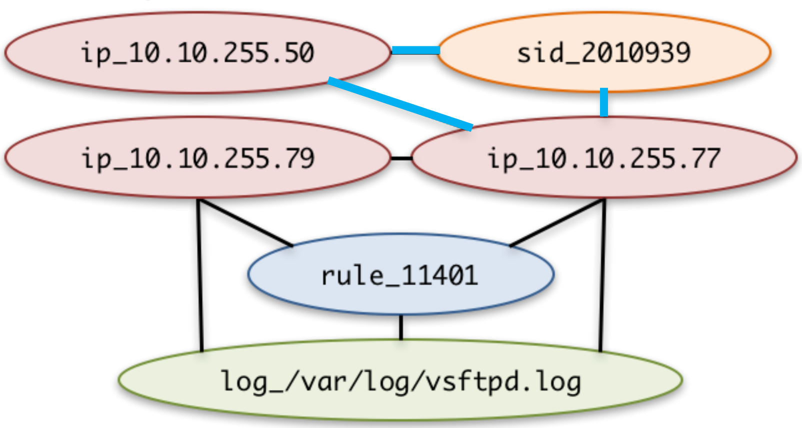
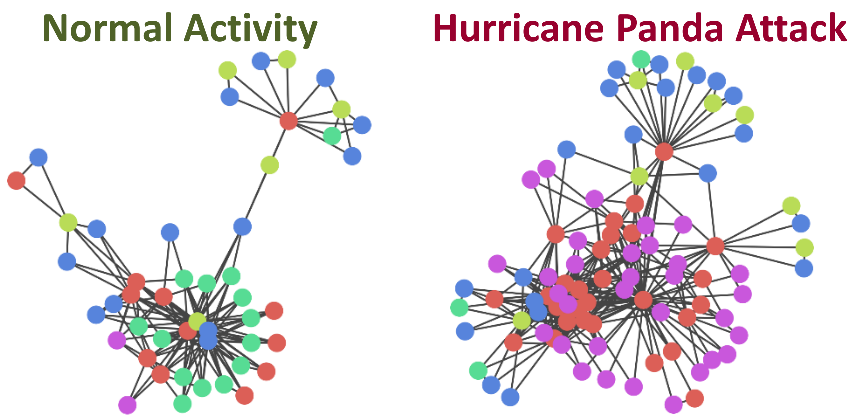
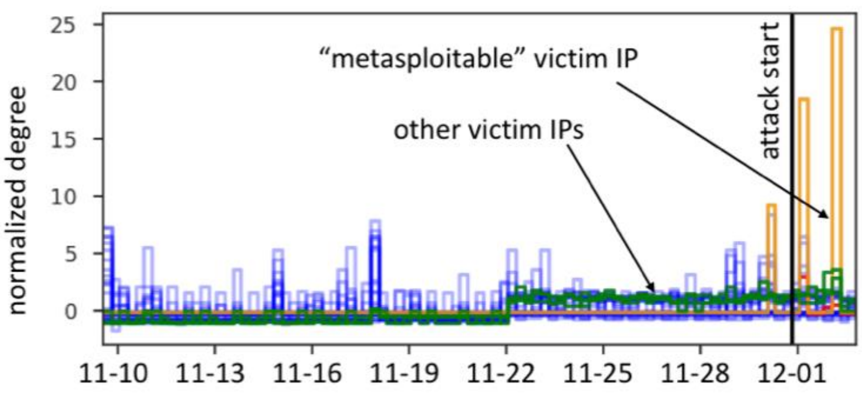



- **Graph of alerts (Not network topology)**
- **Alert properties become nodes**
- **Node colors indicate property type**
- **Edges connect nodes that co-occur in alerts**
- **Edges weighted by frequency of co-occurrence**

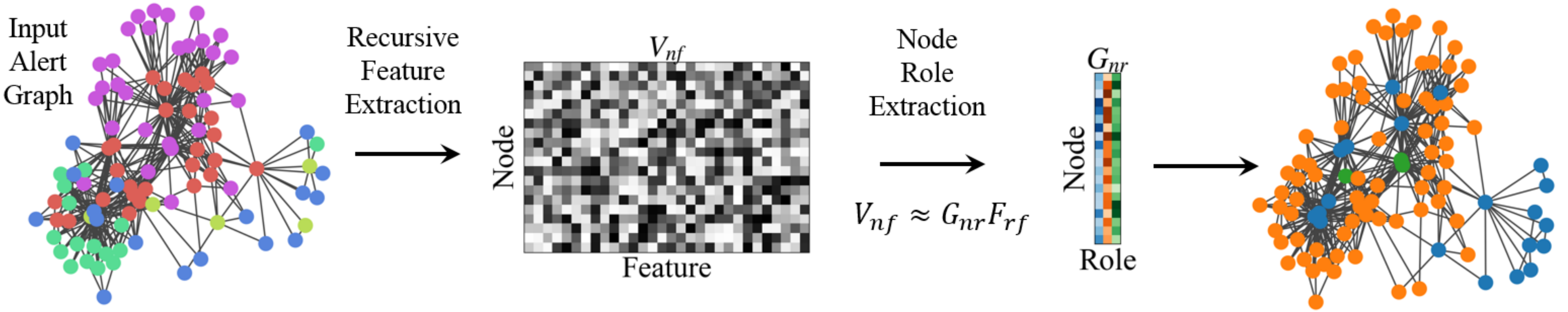
# Alert Graphs



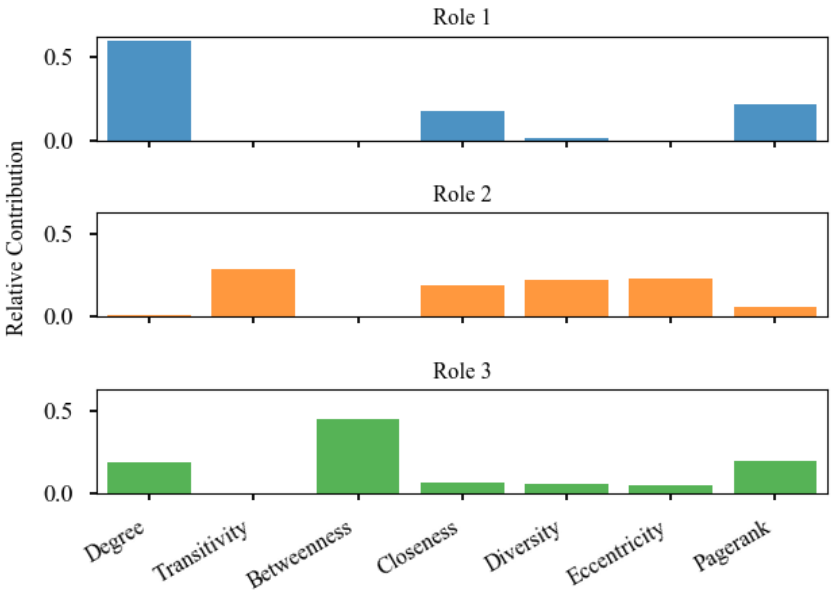




- **Cyber attacks change IDS alert logs**
- **Intuition**
  - Changes in alert logs modify alert graph
  - Anomalies in the graph features (properties) may indicate cyber attacks
- **Quick test**
  - Degree of IP nodes shows marked changes during simulated attack
  - But a single feature is likely insufficient
  - What features should we track?
  - Should we model all features for anomalies?

# Role Dynamics




- **Infeasible to model every feature of every node**
- **Instead, use graph-based anomaly detection algorithms**
- **Role dynamics (Rossi et al., 2012)**
  - Collect features and factorize as roles
  - Roles provide a succinct, integrated summary across a large number of features
  - Output is probability of membership in each role, for each node
  - Application to IDS alerts is novel



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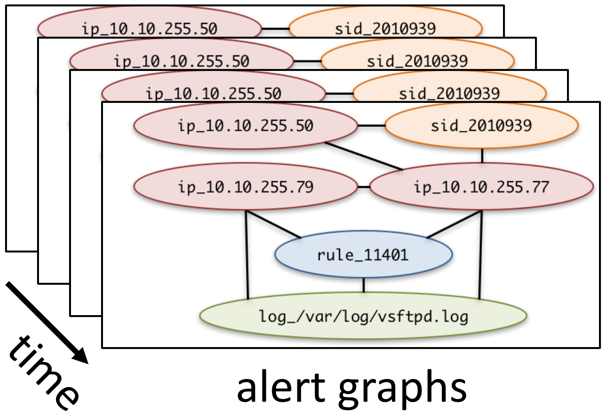


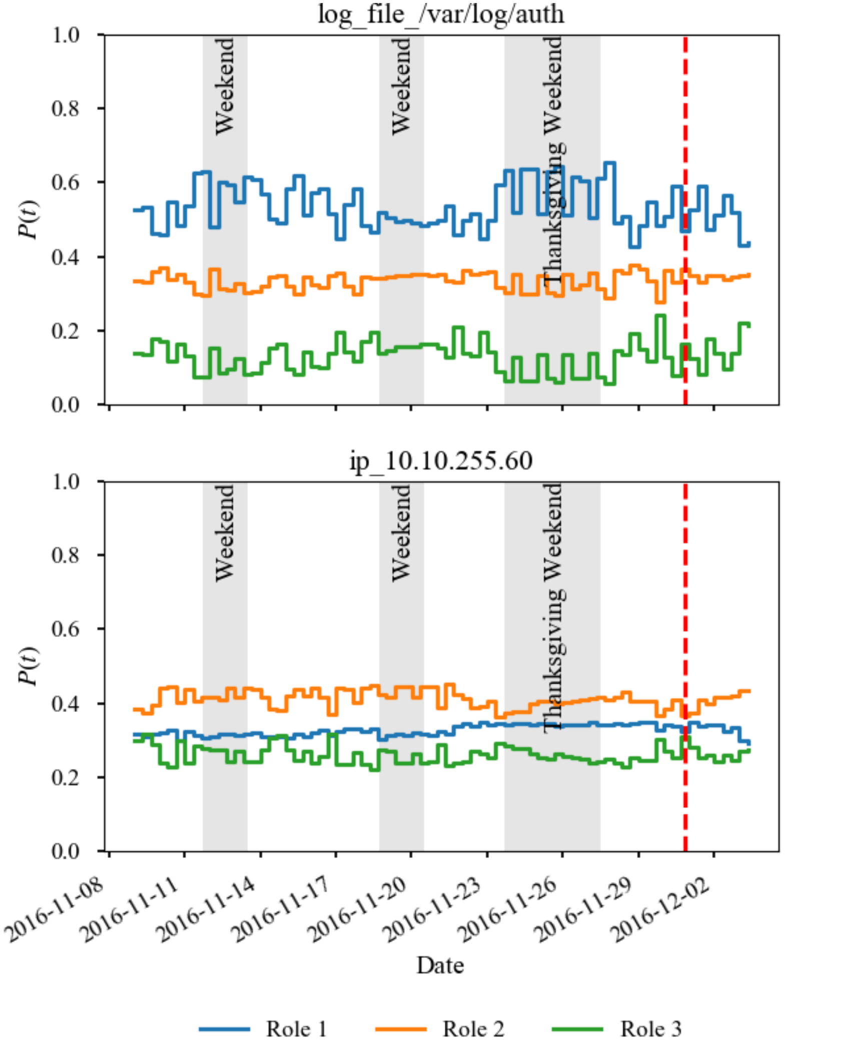


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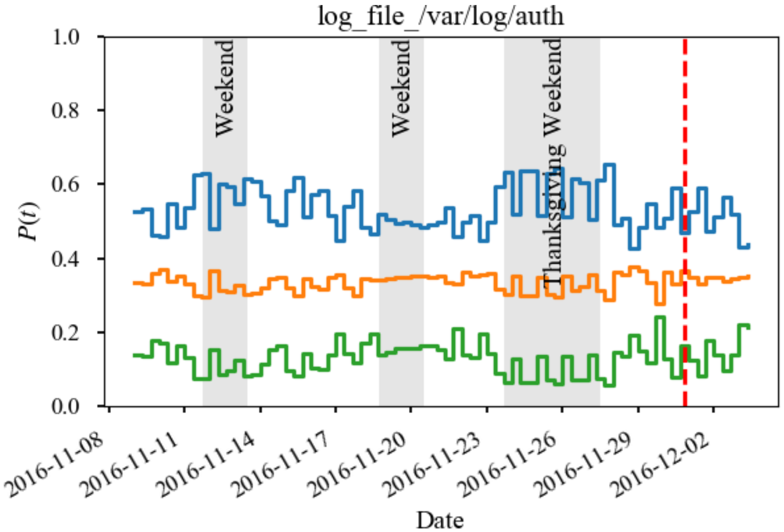
  - Application to IDS alerts is novel
  - **Track role memberships over time**

# Role Dynamics

- **Why role dynamics?**
  - Linear
  - Weighted
  - Dynamic
  - Attributed
  - Unsupervised
  - Explainable
  - Extensible
  - Automated parameter selection
  - Available

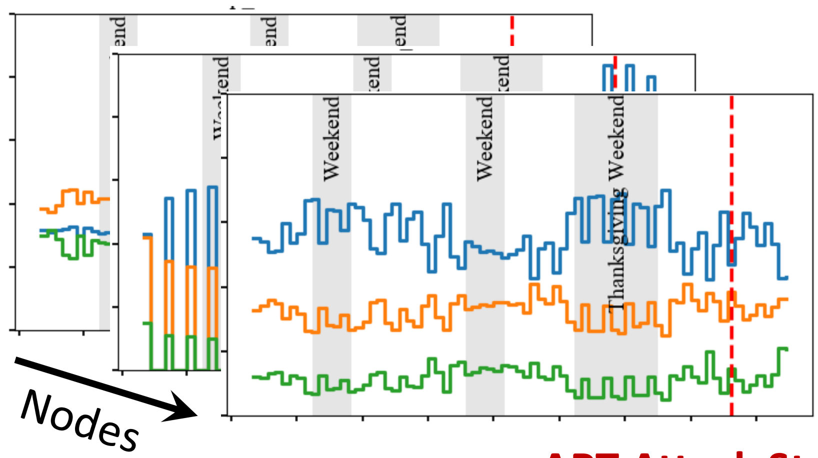


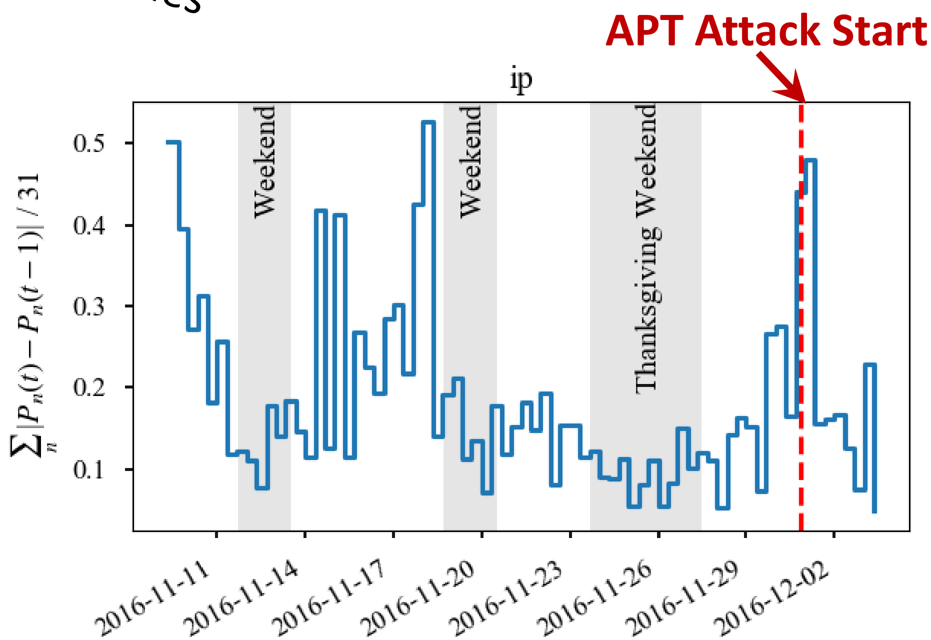

- **Explainable**
  - Identifies anomalous nodes
  - Helps with causal analysis
- **Automated parameter selection**
  - Recursive features
  - Optimal number of roles
  - Set during a training period

BOSTON FUSION

# Finding Role Anomalies

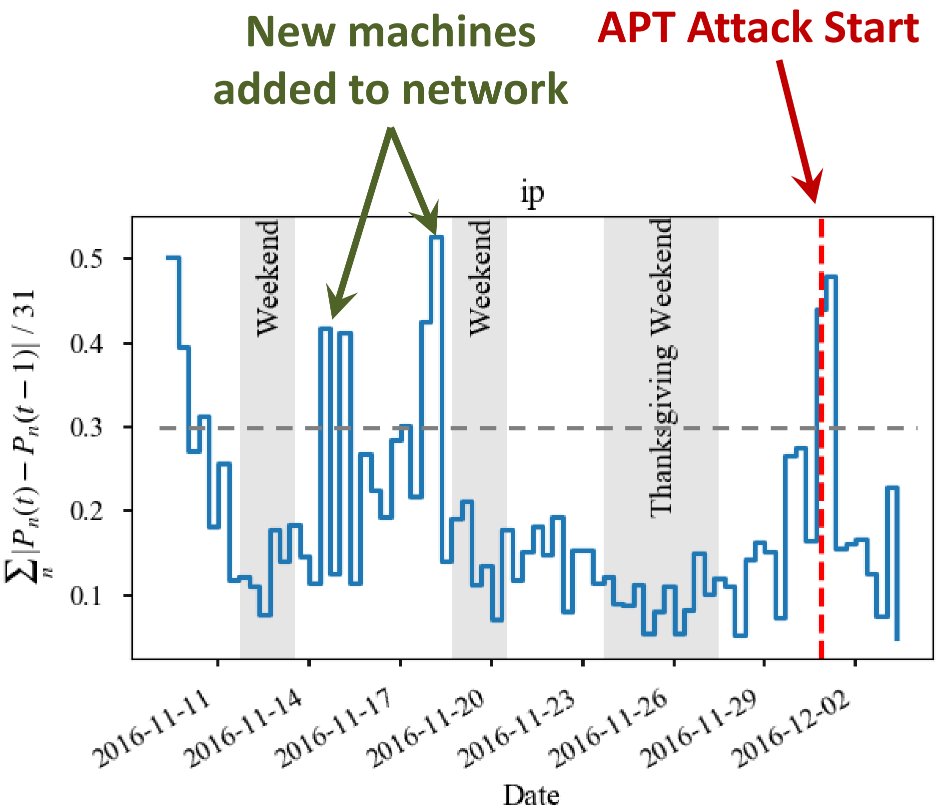
- **Role anomalies**
  - Now we have roles over time for all nodes in graph
  - How to identify anomalies in the roles?
- **Aggregate changes into a few useful metrics**
  - For example, average magnitude of the rate of change in role membership: $\sum_{n=1}^{N}|P_n(t) - P_n(t-1)|/N$
  - Monitor metrics for anomalies



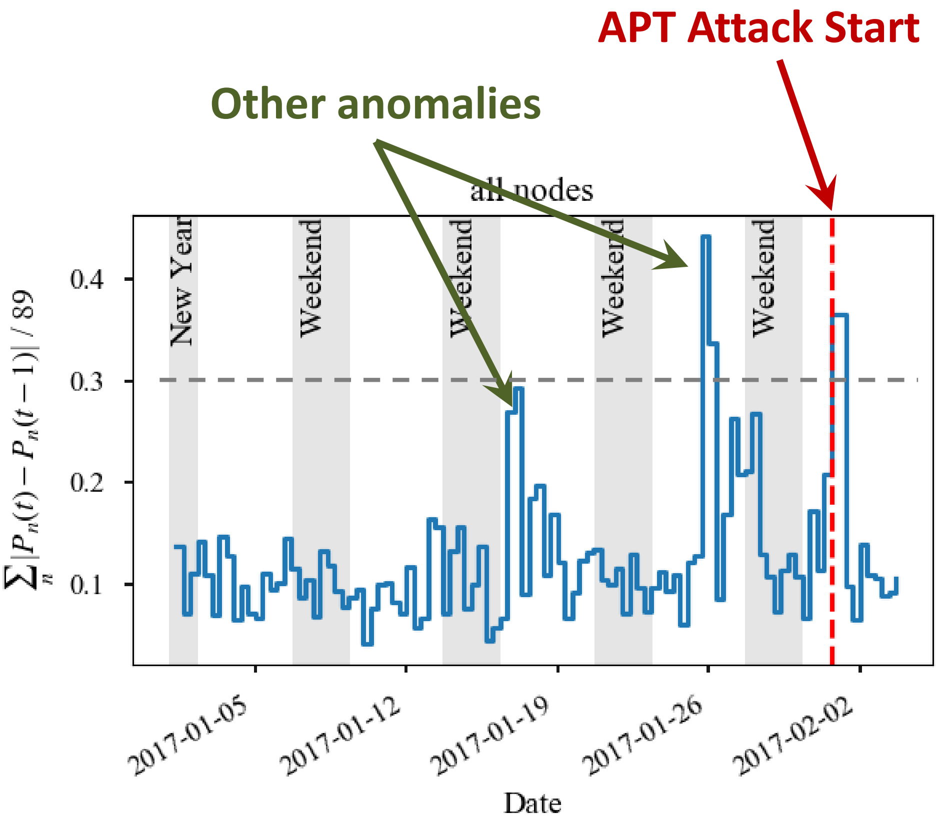
# Results: APT Scenario 1

- **Hurricane Panda scenario**
  - Virtual network of servers, laptops, switches, etc.
  - Linux & Windows machines
  - 9 Nov 2016 – 3 Dec 2016
  - Attack distributed 30 Nov – 2 Dec
  - Snort (NIDS) & OSSEC (HIDS)
  - Database injection to gain credentials
  - Lateral movement and firewall deactivation
- **Results**
  - Using threshold at 0.3, CAIN identified 4 anomalies
  - Second two anomalies relate to machines coming online for the first time
  - Last anomaly corresponds with the start of Hurricane Panda's attack



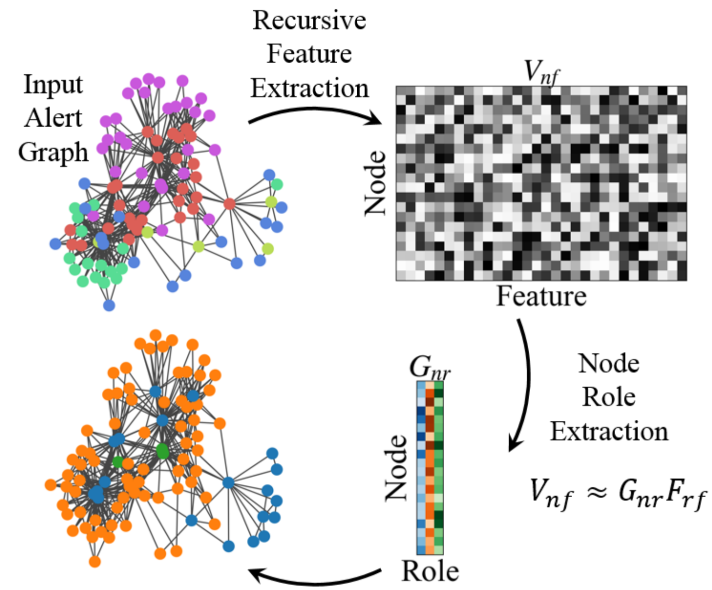
# Results: APT Scenario 2

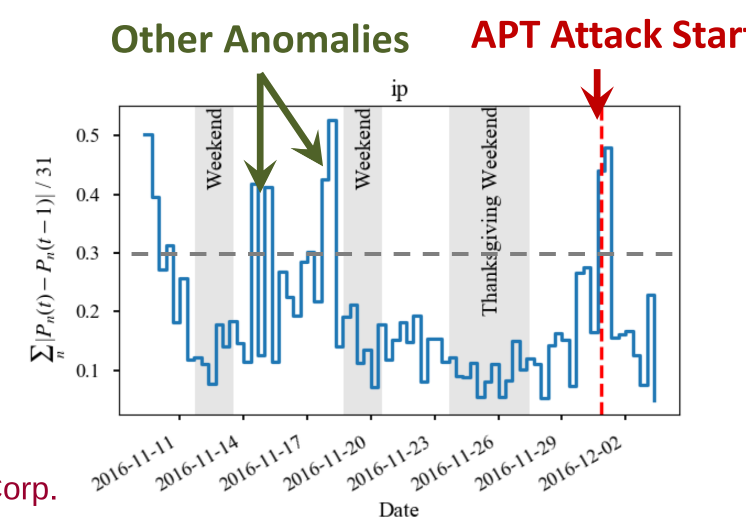
- **Energetic Bear scenario**
  - Same network as Hurricane Panda
  - 1 Jan 2017 – 4 Feb 2016
  - Attack on Jan 31, 2017
  - 644,067 OSSEC (HIDS) alerts
  - Email phishing to redirect user to malicious website
  - Lateral movement through networl using a remote-desktop exploit
  - Attacker attempted to clean-up logs and other traces
- **Results**
  - Using threshold at 0.3, CAIN identified 2 anomalies
  - Third anomaly corresponds with the start of the Energetic Bear attack



# Conclusions: Making Sense of Noisy IDS Sensors with Graph Analytics

- **Graph-based Role-dynamics:**
  - Fuses IDS sensor alerts
  - Reduces >750k alerts to a handful of anomalies
  - Identifies anomalies in IDS alerts during APT attacks
- **Success in 2 APT scenarios demonstrates:**
  - Robust to different types of APTs and attack vectors
  - Insensitive to IDS systems



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# Bayesian Dynamic Flow Model

- **Unsupervised model of NetFlow traffic dynamics**
- **Assume data follows Poisson distribution**

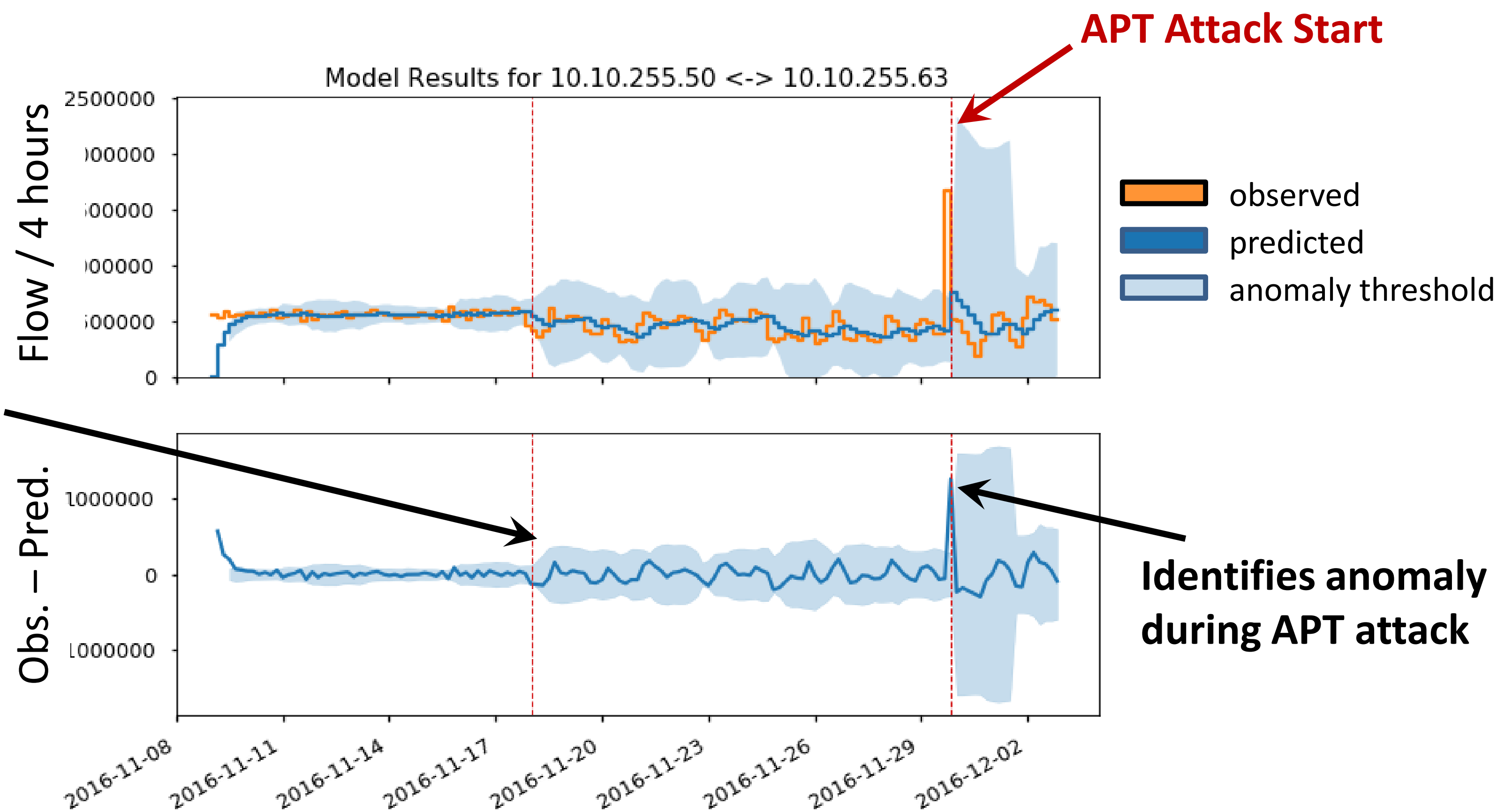
$$x_t \sim \text{Poisson}(\phi_t)$$

- **Model temporal evolution as Gamma-Beta discount model**
  - Prior: $x_t \sim P\left(\phi_t \middle| x_{0:(t-1)}\right) = \Gamma(\delta_t r_{t-1}, \delta_t c_{t-1})$
  - Posterior: $x_t \sim P(\phi_t | x_{0:t}) = \Gamma(\delta_t r_t, \delta_t c_t)$

(X. Chen, et al. 2016)

# Results
# Bayesian Dynamic Flow Model

**Identifies anomalous change in packet flow volatility**




- Complementary to graph-based role-dynamics
- Multiple methods corroborate detection

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# Summary

- **Developed two complementary anomaly detection techniques**
  - IDS: Graph-based Role Dynamics
  - NetFlow: Bayesian Dynamic Flow Model
- **Tested on two APT scenarios**
  - Hurricane Panda
  - Energetic Bear (a.k.a. Crouching Yeti)
- **Successful anomaly detection in two APT scenarios suggests:**
  - Robust to different types of APTs and attack vectors
  - Insensitive to IDS systems

# References


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# Statements / Disclaimers

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