JACKSTRAWS: Picking Command and Control Connections from Bot Traffic

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Introduction: the botnet threat

What do botnets do?

- Support large-scale malicious activities and the underground economy
- Coordination of malicious attacks
  e.g., denial of service, spam campaigns, click fraud
- Sensitive information theft
  e.g., credentials, credit card numbers

Why are botnets so convenient for attackers?

- Command & Control (C&C) infrastructure for remote control
- Incoming commands to trigger attacks and updates
- Outgoing responses for status monitoring and information leakage

Introduction: fighting against botnets

Botnet detection and mitigation

- Host-based techniques
  - Traditional malware detection and mitigation
  - Signature matching and behavior monitoring
- Network-based techniques
  - Blacklisting IPs related to C&C servers
  - Signatures matching C&C protocol and commands
- Automatic generation of these signatures, IP lists or models
  - **Clean C&C only logs needed for traffic and system calls**

Difficulty of identifying C&C traffic

- Potentially encrypted C&C traffic
- Non-C&C or "noise" traffic interleaved
  - Malicious connections to 3^{rd} party websites (*e.g.*, part of the attacks)
  - Configuration connections (*e.g.*, connectivity tests, time recovery)
  - Fake benign connections (*e.g.*, mimicry of legitimate applications)

Introduction: identifying C&C traffic

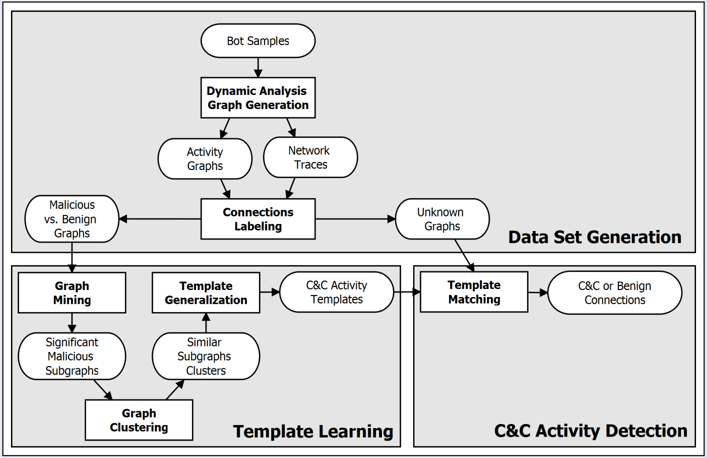
Our approach: JACKSTRAWS

- Combination of network traces and host-based activity
  - **Rationale:** C&C traffic results in observable host activity
    e.g. system modifications, critical information accesses
  - Host-based model: system call graphs with data dependency
  - Network-related link: each graph associated to a network connection

- Machine learning to identify and generalize C&C-related host activity
  - **Rationale:** similar commands result in similar core activities
    even for different bots
  - Mining significant activities: graph mining over *known* connections
  - Identifying similar activity types: graph clustering
  - Abstracting activity types: graph merging into templates
  - Detecting C&C activity: template matching over *unknown* connections

System: JACKSTRAWS overview

System architecture



System: graph collection

Analysis environment

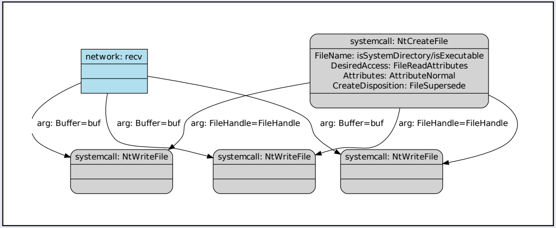
- Logging: system calls and network API calls
- Tainting: data flows in memory and over the file system

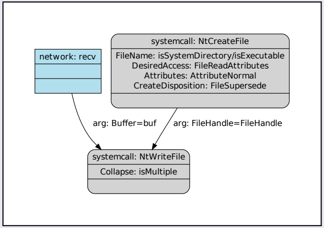
Graph generation

- **Input**: trace of system and network calls
- **Output**: a call graph for each successful connection
- **Algorithm**:
  - Graph root: successful `connect` and associated `sends`/`recvs`
  - Nodes extension: recursive backward dependency over system calls
  - Nodes labeling: call parameters, resource names being abstracted
  - Graph collapsing: collapse duplicate nodes

System: graph collection

Graph generation





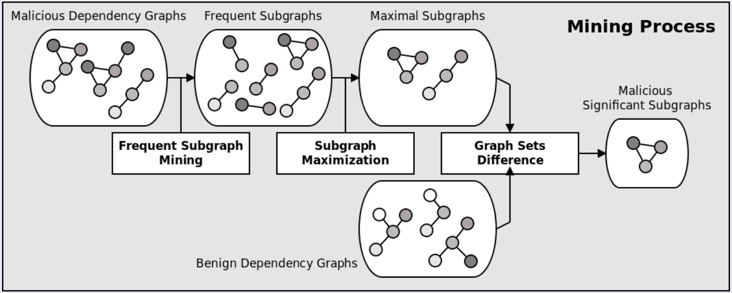
System: graph mining

Frequent subgraph mining:

- **Input**: call graphs associated to *malicious vs. benign* connections
- **Output**: significant subgraphs covering *only* malicious (C&C) activity
- **Algorithm**:
  - Graph mining: frequent subgraphs from malicious connections
  - Maximization: stripping induced subgraphs from the mined set
  - Set difference: stripping subgraphs included in benign connections

System: graph mining

Frequent subgraph mining



System: graph clustering and template generation

Graph clustering:

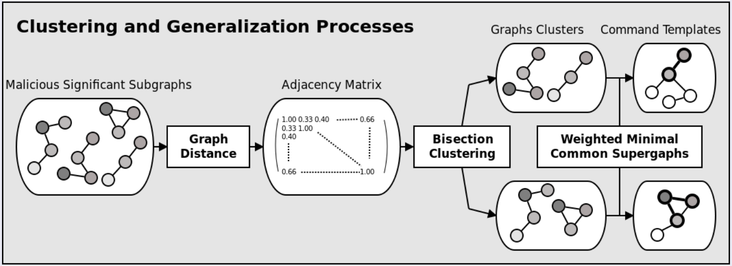
- **Input**: significant malicious subgraphs
- **Output**: clusters group graphs that represent similar activity
- **Algorithm**:
  - Graph similarity: common edges in the maximal common subgraph
  - Graph clustering: clustering by repeated bisection

Template generation:

- **Input**: clusters of similar malicious subgraphs
- **Output**: graph template covering the graphs of the cluster
- **Algorithm**:
  - Template construction: minimal common supergraph
  - Template generalization: supergraph weighted by node frequency
    - + Frequent nodes constitute the core activity shared by bots
    - + Infrequent nodes constitute optional activity specific to different bots

System: graph clustering and template generation

Graph clustering and template generation



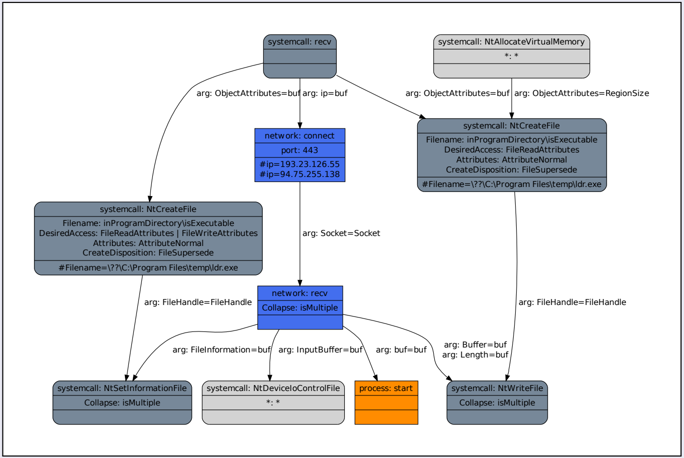
System: template matching

Template matching:

- **Input**: template, unlabeled collected call graphs
- **Output**: match result
- **Algorithm**:
  - Core matching: subgraph isomorphism with core nodes
    + Mandatory nodes must be present
  - Extended match: maximal common supergraph for optional nodes
    + Isomorphism result used to initialize search

System: template matching

Template matching



Evaluation: dataset presentation

Collected botnet traffic

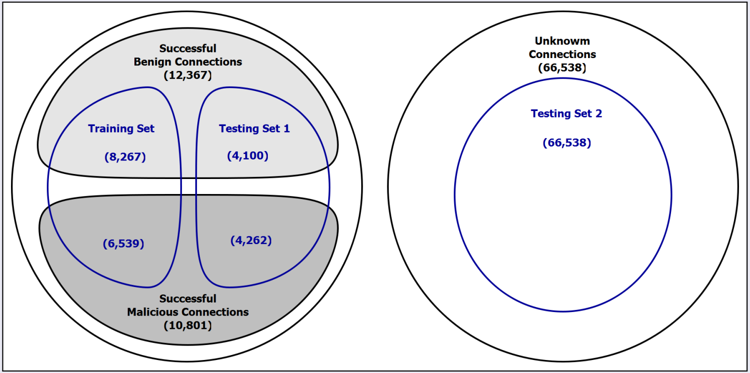
- 37,572 bot samples corresponding to 745 families (*e.g. EgroupDial, Palevo, Virut*)
- 130,635 network connections and associated behavior graphs (*successful connections only*)

Labeling connections for ground truth

- Manually-crafted network signatures: 385 C&C, 162 benign
- 10,801 malicious connections
- 12,367 benign connections
- 66,538 unknown connections
- 40,929 incomplete or irrelevant graphs removed

Evaluation: dataset presentation

Training and testing sets



Evaluation: training the system

System configuration

- Mining frequency threshold: 10%
  - Trade-off between maximum coverage and mining runtime
- Bisection threshold: 60% average and 40% minimal similarity
  - Higher thresholds reduce the effect of generalization

System runtime

- Mining: 16h, Clustering: 4.5h, Generalization: 30min
- Reasonable processing time *wrt.* the NP-hardness of algorithms

Templates quality

- 417 templates generated
  - 397 templates semantically meaningful
- Different types of commands covered
  - Information leakage, download and execute, startup, stealth

Evaluation: testing the system

Testing over labeled connections

- Detection rate: 81.6%
- Detection without the generalization: 66.0%
- Detection of new families that were missing in the training set
- False negatives: 18.4% mainly due to incomplete/infrequent activity
- False positives: 0.2% mainly due to weaker templates

Evaluation: testing the system

Testing over unknown connections

- 66,538 unknow connections
- New matches: 9,464 connections
- New detected families: 193 not covered by network signatures
- New detected variants: missed by outdated network signatures
- False negatives: high proportion of benign traffic (manual verification)
- False positives: 27

Evaluation: system limitations

Testing over unknown connections

Weakness	Consequences	Potential remediation	Supported
Dynamic analysis	Incomplete call logs	Enhanced analysis environment: *e.g.* multi-path execution	×
Computational time	Non-termination	Algorithm optimizations: *e.g.* node labeling, graph collapsing	✓ ✓
Interleaved calls	Noise against mining	System calls selection: *e.g.* calls with data dependency	✓
Functional polymorphism	No core activity	Normalizing graphs: *e.g.* duplicate nodes collapsing, Rewriting rules: *e.g.* equivalent operations	✓ ×

Conclusion: JACKSTRAWS

Contributions

- Solution to the problem of identifying C&C traffic from noise
- Automated generation of templates representing C&C behaviors
- Gains provided by the template generalization:
  - Protocol-agnostic representation of C&C activity
  - Increased level of understanding for analysts
  - Coverage extended to families unknown during training