A Semantic Framework for Data Analysis in Networked Systems

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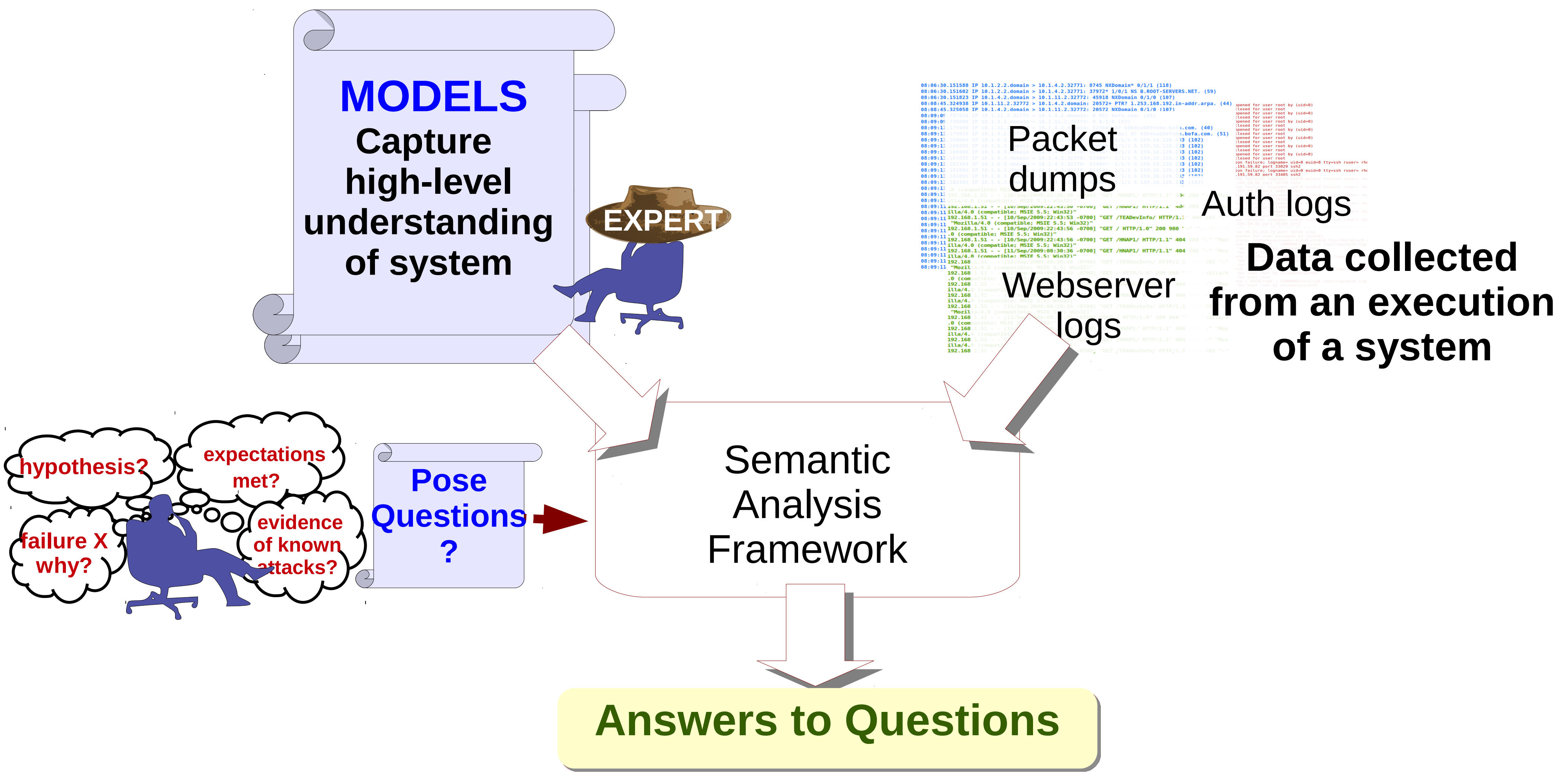
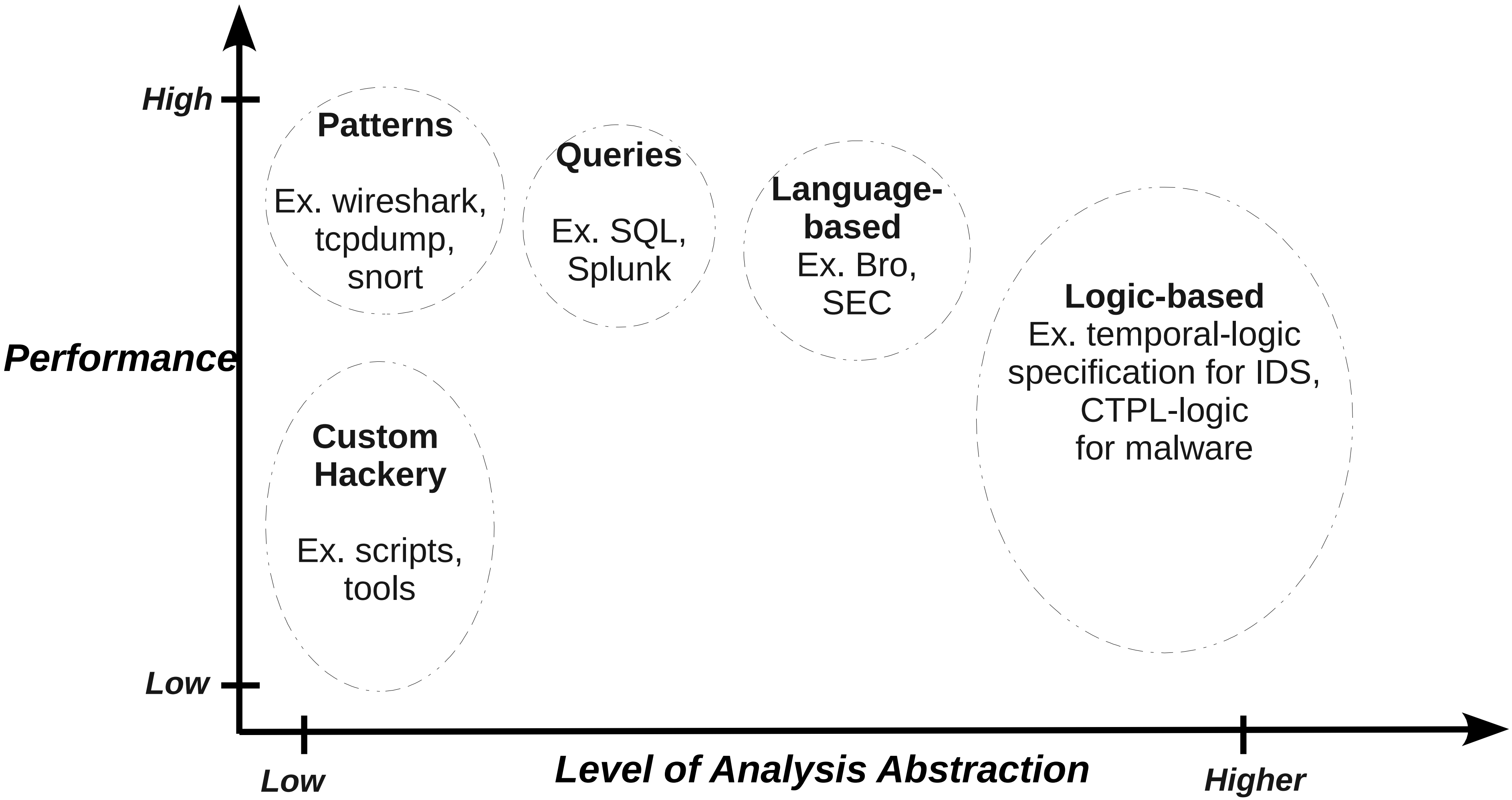
Data Analysis in Networked Systems

Our Semantic Approach

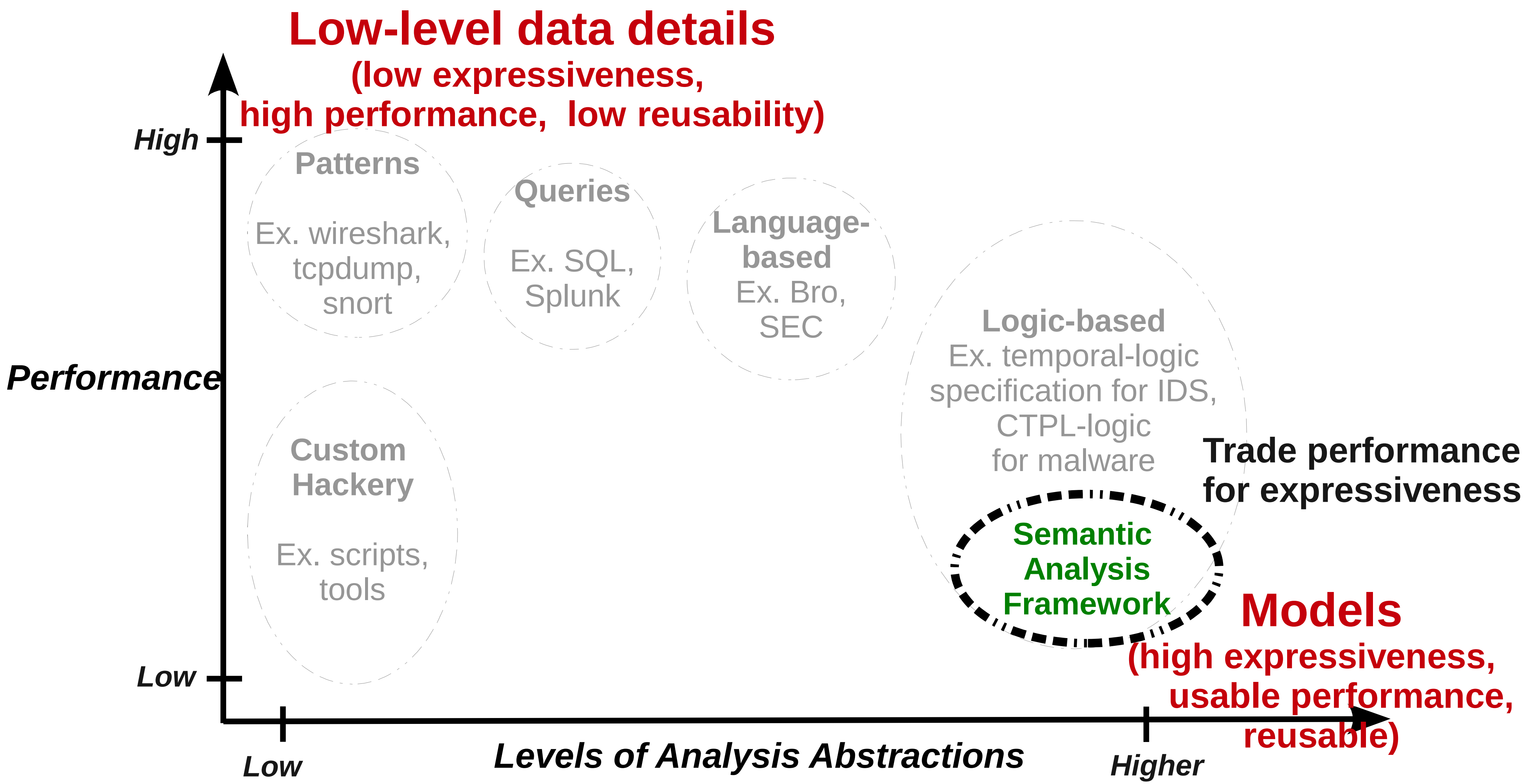


Models drive analysis over data!

Approximate Lay of the Land



Approximate Lay of the Land



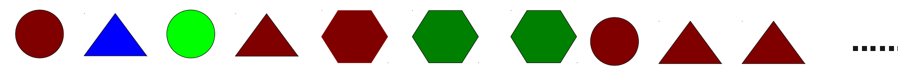
Key differences with other logic-based approaches

- **<u>Composable abstractions</u> to capture semantics**
- **<u>Expressive relationships</u> for networked systems**

Basics of our Modeling Approach

DATA
Multitype, multi-variate, timestamped

FACTS

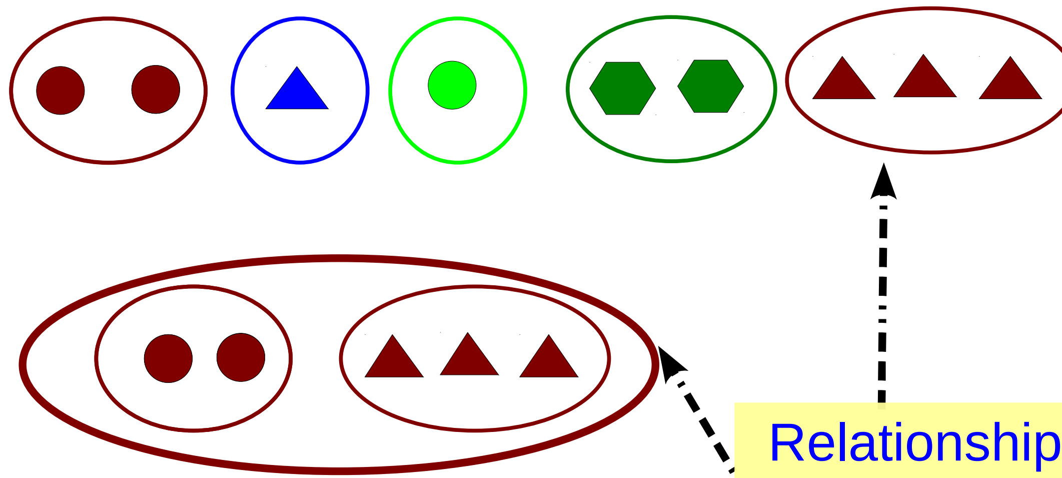


(ex: FILE_OPEN, FILE_CLOSE, TCP_PACKET, ...

Behavior
(fundamental abstraction)
Sequence or group of one or more **related** facts

Complex Behaviors
Related behaviors

Model
Top-level behavior



Relationships are key

Models encode higher-level system semantics!

Relationships in the Modeling Language

Temporal Relationships

Causality/Ordering
Eventuality
Invariance
Synchrony/Timing

A file open **eventually leads to** a file close

Temporal Operators

FILE_OPEN **~>** *FILE_CLOSE*

Concurrent Relationships

Parallelism
Overlaps

HTTP and FTP flows are **concurrent**.

Interval Temporal Operators

HTTP_FLOW ***olap*** *FTP_FLOW*

Logical Relationships

Combinations
Exclusions

Experiment **either** succeeds **or** fails

Logical Operators

EXPT_SUCCESS ***xor*** *EXPT_FAIL*

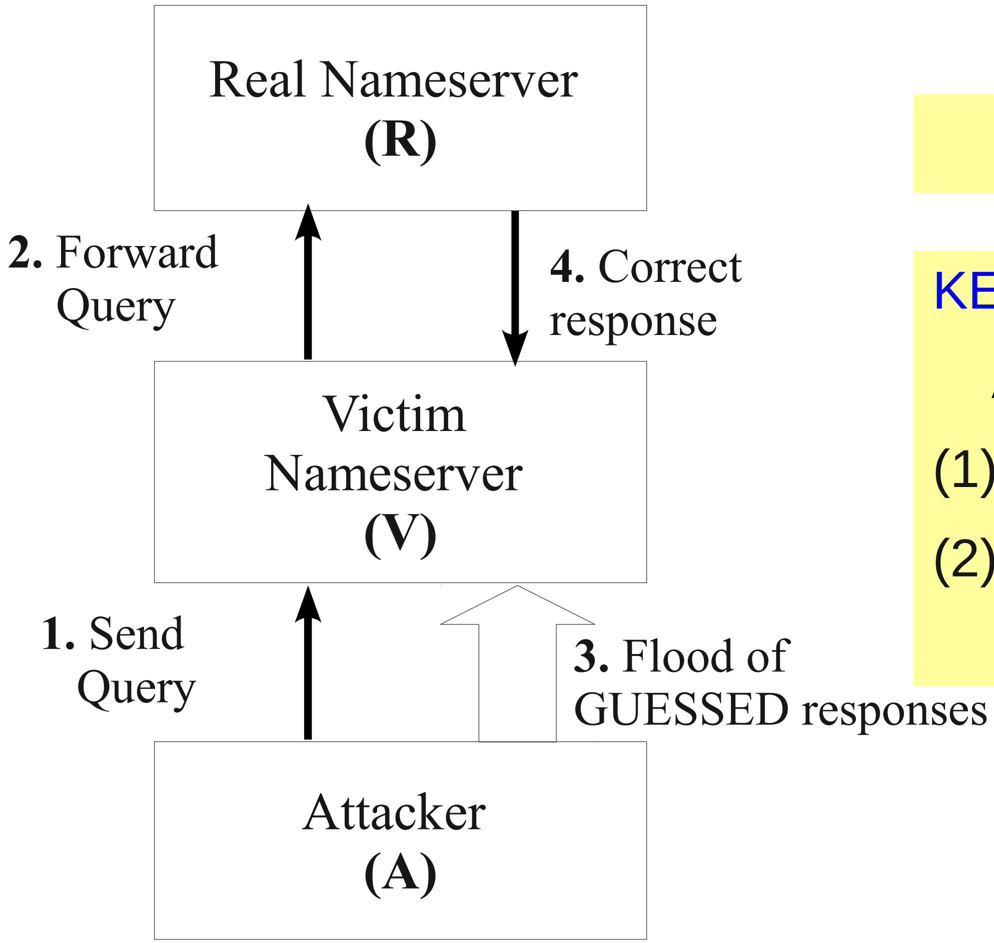
Dependency relationships b/w data attributes

File open and file close are behaviors **related by their filename**.

FILE_CLOSE.name = FILE_OPEN.name

Cache Poisoning Behavior

Cache Poisoning Behavior (DNS Kaminsky)



Objective: Attacker poisons the victim's DNS cache.

Steps 1-4 keep running in a loop.

KEY ISSUES

Attacker fails to poison cache due to

(1) Race conditions with real nameserver.

(2) Incorrectly GUESSED responses.

Analysis using typical approach

```
08:06:30.151588 IP 10.1.2.2.domain > 10.1.4.2.32771: 8745 NXDomain* 0/1/1 (118)
08:06:30.151602 IP 10.1.2.2.domain > 10.1.4.2.32771: 37972* 1/0/1 NS B.ROOT-SERVERS.NET. (59)
08:06:30.151823 IP 10.1.4.2.domain > 10.1.11.2.32772: 45918 NXDomain 0/1/0 (107)
08:08:45.324938 IP 10.1.11.2.32772 > 10.1.4.2.domain: 20572+ PTR? 1.253.168.192.in-addr.arpa. (44)
08:08:45.325058 IP 10.1.4.2.domain > 10.1.11.2.32772: 20572 NXDomain 0/1/0 (107)
08:09:09.787858 IP 10.1.11.2.32772 > 10.1.4.2.domain: 0 NS? bofa.com. (26)
```

Tricky to analyze

- Requires Expertise.
- Too many random values in the data to extract using simple patterns.
- Race conditions (timing issues) are hard to debug over 10's of thousands of packets.
- Many ways to fail.

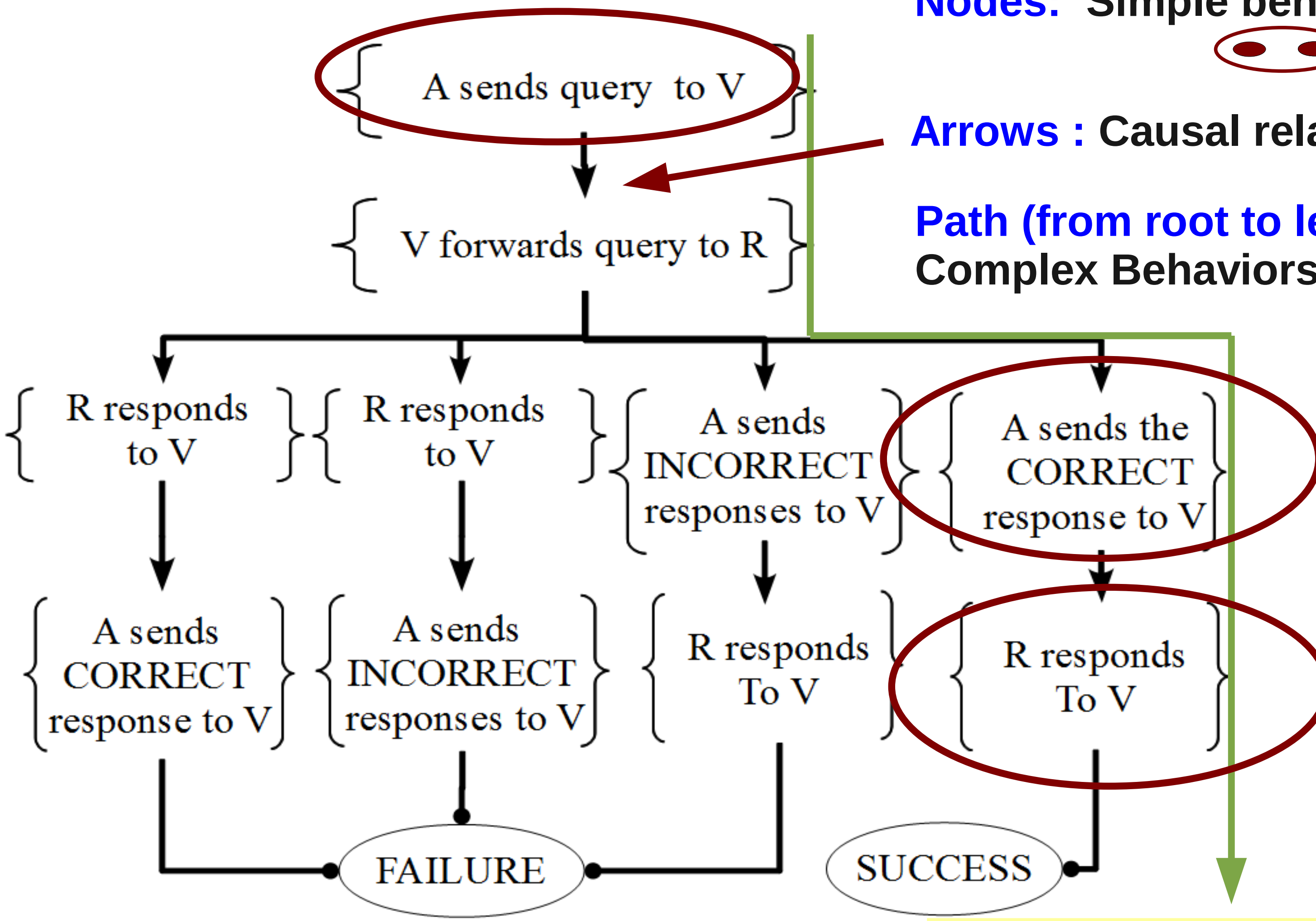
```
08:09:11.185802 IP 10.1.6.3.domain > 10.1.4.2.32778: 2228*- 1/1/1 A 159.16.126.233 (103)
08:09:11.186301 IP 10.1.6.3.domain > 10.1.4.2.32778: 2228*- 1/1/1 A 159.16.126.233 (103)
08:09:11.186551 IP 10.1.6.3.domain > 10.1.4.2.32778: 2228*- 1/1/1 A 159.16.126.233 (103)
08:09:11.186812 IP 10.1.6.3.domain > 10.1.4.2.32778: 2228*- 1/1/1 A 159.16.126.233 (103)
08:09:11.187051 IP 10.1.6.3.domain > 10.1.4.2.32778: 2228*- 1/1/1 A 159.16.126.233 (103)
```

Model of Behavior

Nodes: Simple behavior

Arrows : Causal relationships

Path (from root to leaf) :
Complex Behaviors



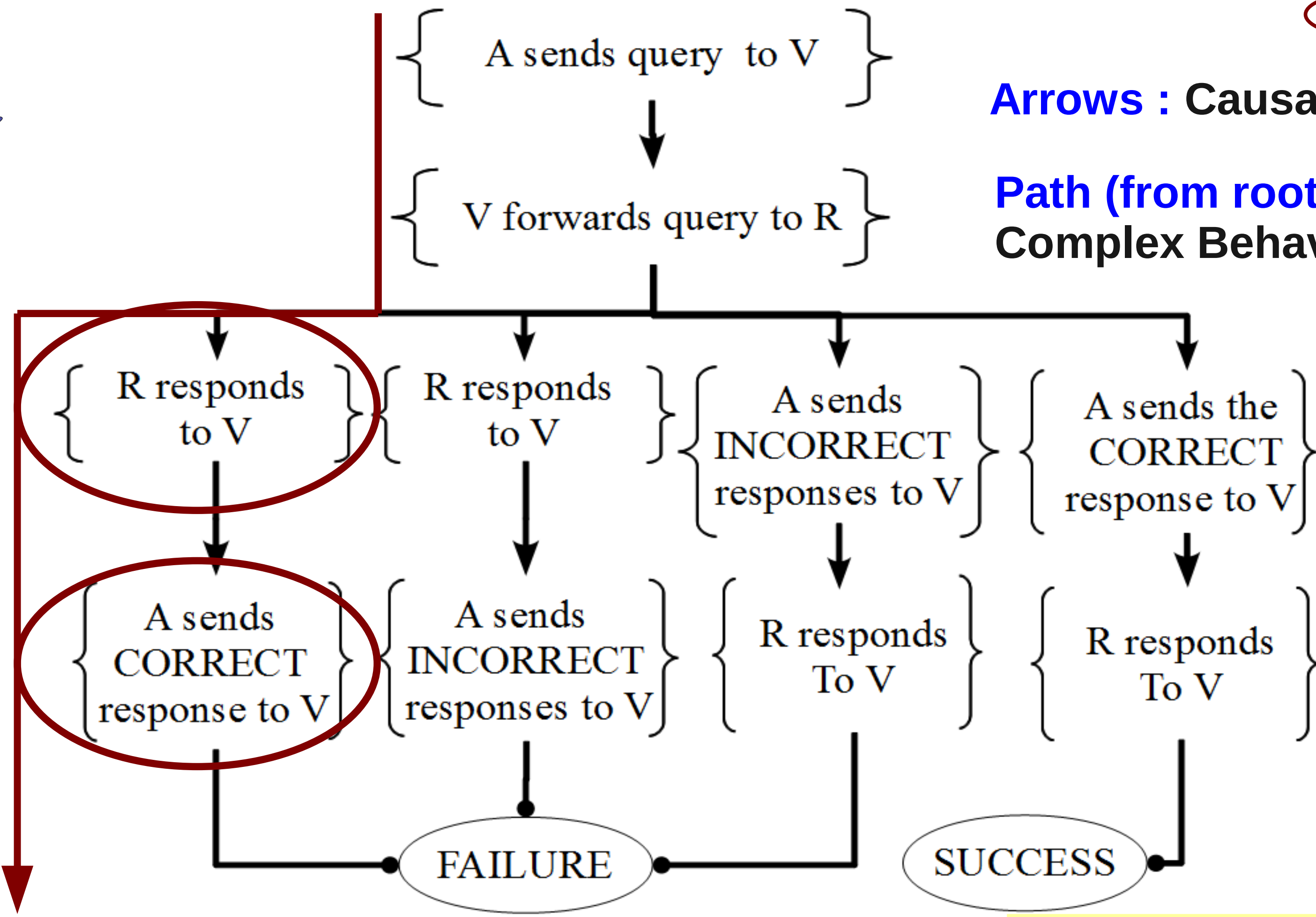
SUCCESS =
A guesses right and wins race with R

Model of Behavior

Nodes: Simple behavior

Arrows : Causal relationships

Path (from root to leaf) : Complex Behaviors



TIMING_FAIL =
A guesses right but
loses race to R.

SUCCESS =
A guesses right and
wins race with R

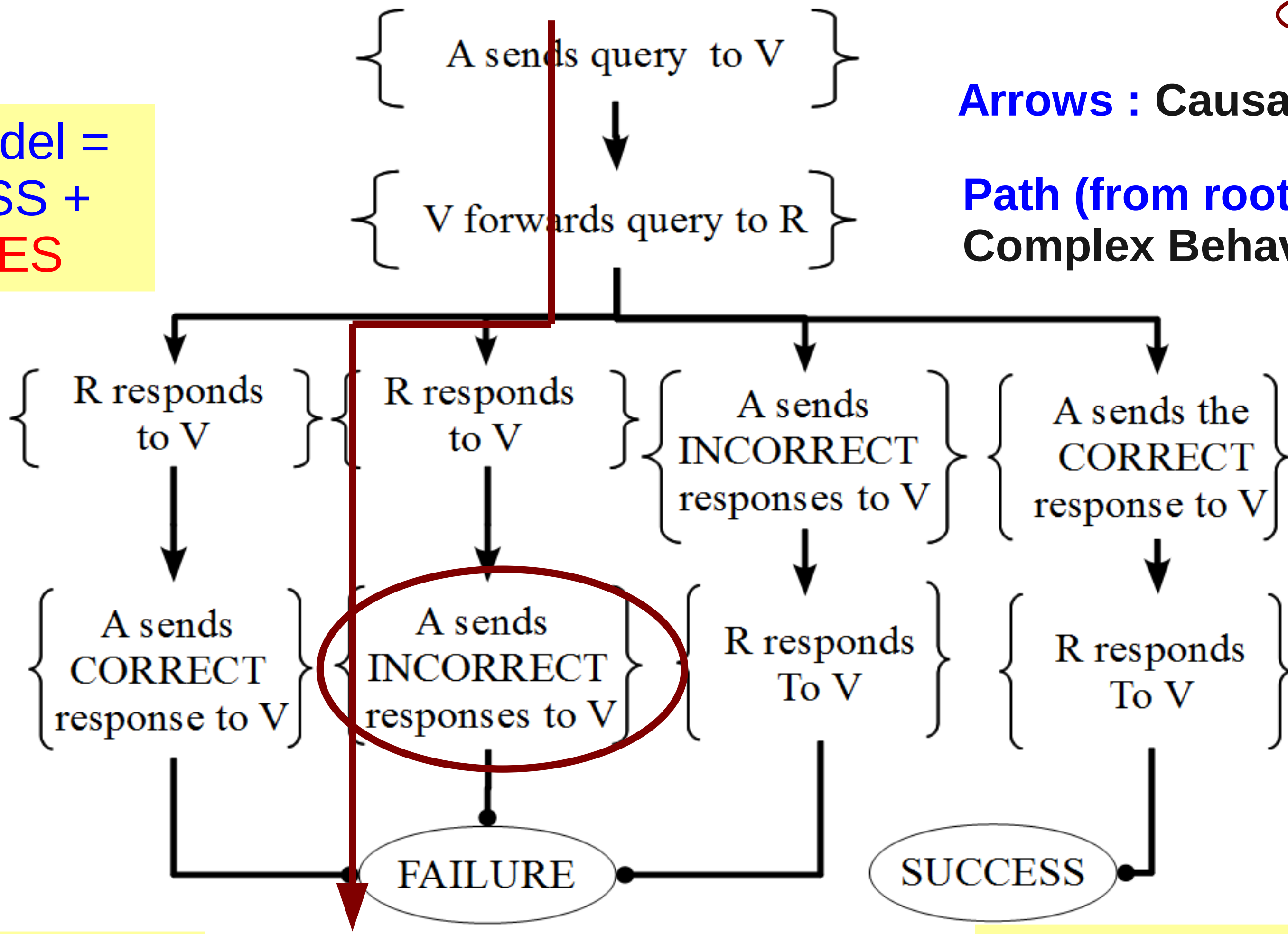
Model of Behavior

Behavior Model =
1 SUCCESS +
3 FAILURES

Node: **Simple behavior**

Arrows : **Causal relationships**

Path (from root to leaf) :
Complex Behaviors

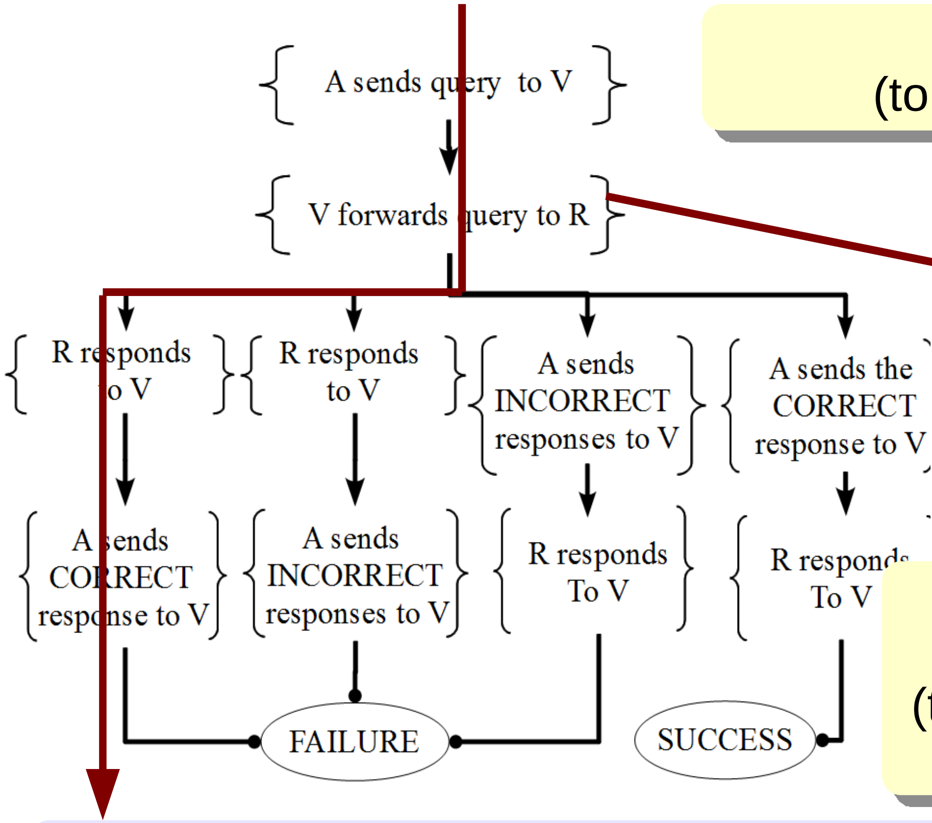


TIMING_FAIL =
A guesses right but
loses race to R.

BADGUESS_1 =
A guesses wrong
response

SUCCESS =
A guesses right and
wins race with R

Encoding the Model



#1. Capture simple behaviors
(to capture facts for each distinct attack step)

```
VtoR_query =
DNSREQRES.dns_req(sip=$AtoV_query.dip,
        dnsquesname=$AtoV_query.dnsquesname)
```

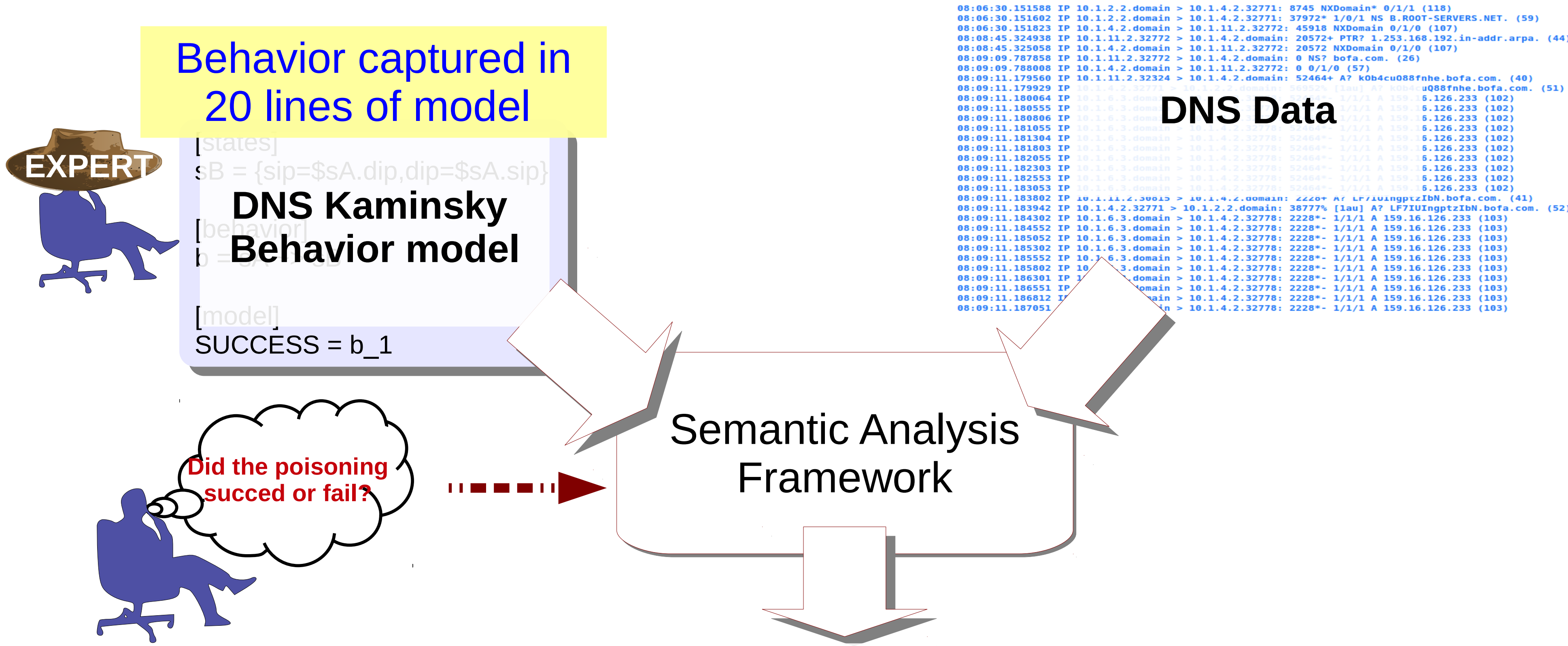
#2. Relate simple behaviors to form complex behaviors
(to capture the causal relationships between steps)
4 behaviors = 1 SUCCESS + 3 FAILURES

```
TIMING_FAIL = (AtoV_query ~> VtoR_query ~> RtoV_resp ~>AtoV_resp)
```

#3. Define Behavior Model
(assertion to capture users understanding of system operation)

```
DNSKAMINSKY = SUCCESS xor TIMING_FAIL xor BADGUESS_1 xor BADGUESS_2
```

Analysis Using the Model



Answers in the form of facts satisfying the model.

```
Summary : DNSCACHEPOISON_TIMING_FAIL
========================
Total Matching Instances: 622
  etype    | timestamp  | sip        | dip        | sport | dport | dnsid |   dnsauth
-------------------------------------------------------------------------------------------
  PKT_DNS | 1275515486 | 10.1.11.2 | 10.1.4.2 |  6916 |  53   | 47217 |
  PKT_DNS | 1275515486 | 10.1.4.2  | 10.1.6.3 | 32778 |  53   | 15578 |
  PKT_DNS | 1275515486 | 10.1.6.3  | 10.1.4.2 |  53   | 32778 | 15578 |realns.eby.com
  PKT_DNS | 1275515486 | 10.1.6.3  | 10.1.4.2 |  53   | 32778 | 47217 |fakens.fakeeby.com
  PKT_DNS | 1275515486 | 10.1.6.3  | 10.1.4.2 |  53   | 32778 | 47217 |fakens.fakeeby.com
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```

TIMING_FAIL
(A loses the race against R)

Current Implementation and Performance

- **Prototype algorithm for applying models over data.**
- **Algorithm performance**
  - $O(N^2)$ worst-case performance
  - Straight-forward
- **Analysis Framework**
  - Written in Python
  - SQLite-based storage backend
- Scalability and performance issues are under active investigation.

Applicability

- Broad range of event-based modeling in networked systems
- More examples in paper
  - Modeling hypotheses
    - Ex. Validating DoS detection heuristics over traces
  - Modeling a security threat
    - Ex. Model of a simple worm spread over IDS logs
  - Modeling dynamic change
    - Ex. Model of changes in traffic rate due to attack.

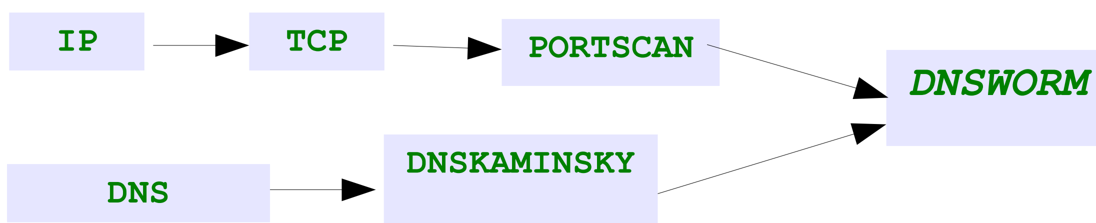
Future Work

- Extend Modeling Capabities
  - Modeling probabilistic behavior
  - Modeling packet distributions
- Analysis Framework
  - Scalability and performance
  - Reducing the computational complexity of correlations using dependent attributes.

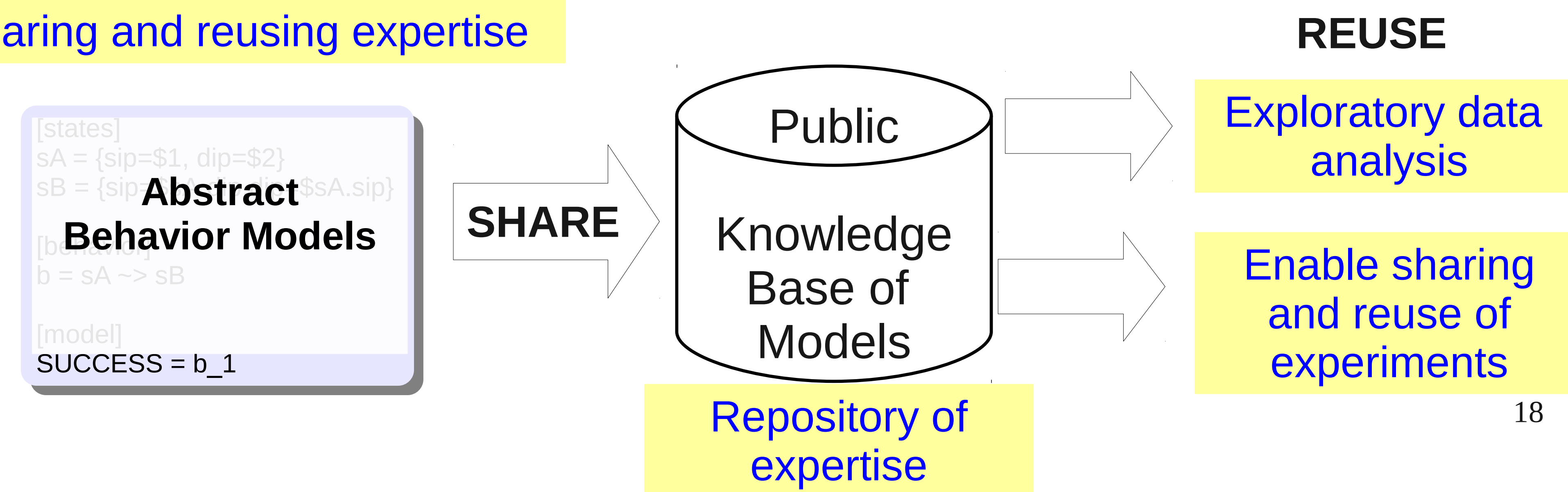
Composing, Sharing and Reusing

Semantic Analysis Framework enables data analysis at higher-levels of abstraction.

Composing models to create higher-level meaning



Sharing and reusing expertise



Thank You!

Our framework will soon be publicly available at
http://thirdeye.isi.deterlab.net

Please register on our mailing-list to stay in tune with release and updates