Behavioral Analysis for Intrusion Resilience

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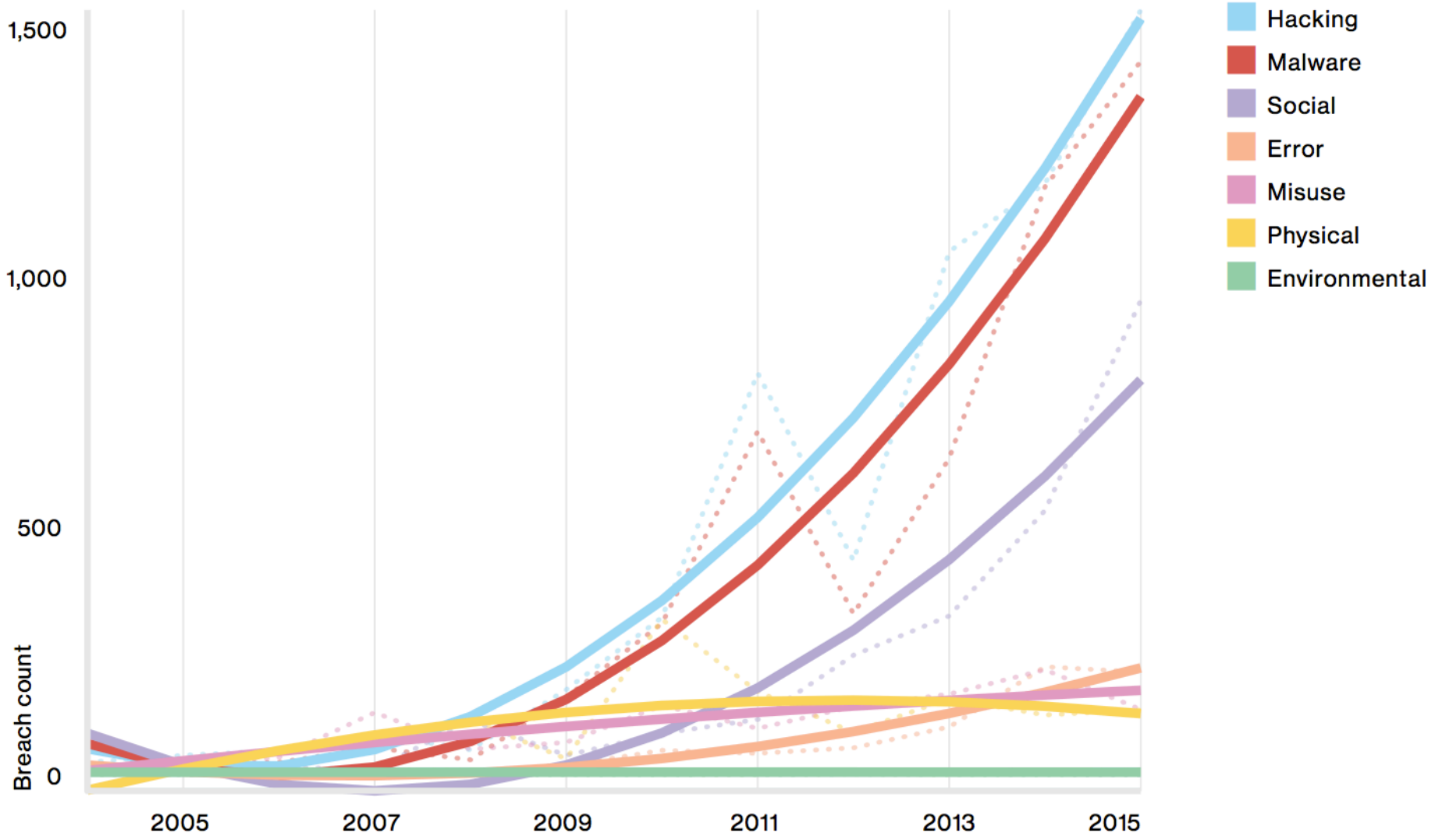
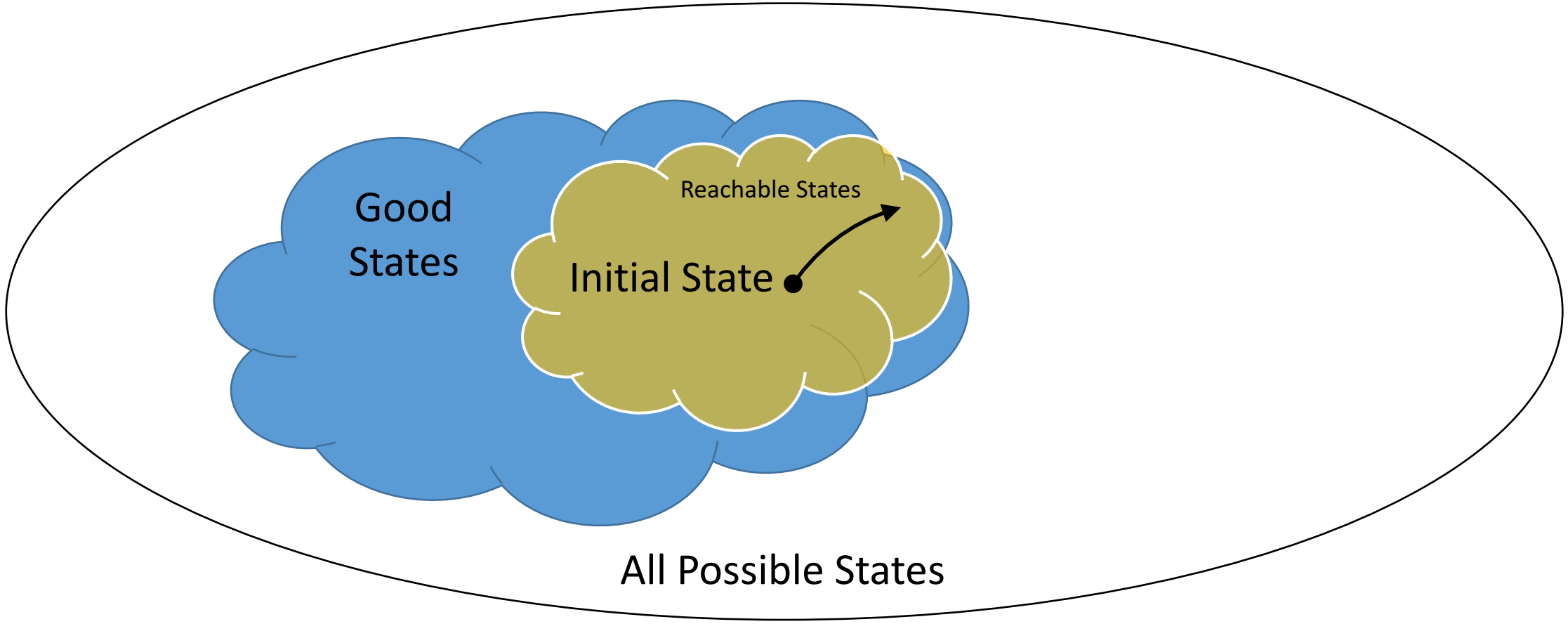
Recent Cyber Attacks on Private and Public Entities

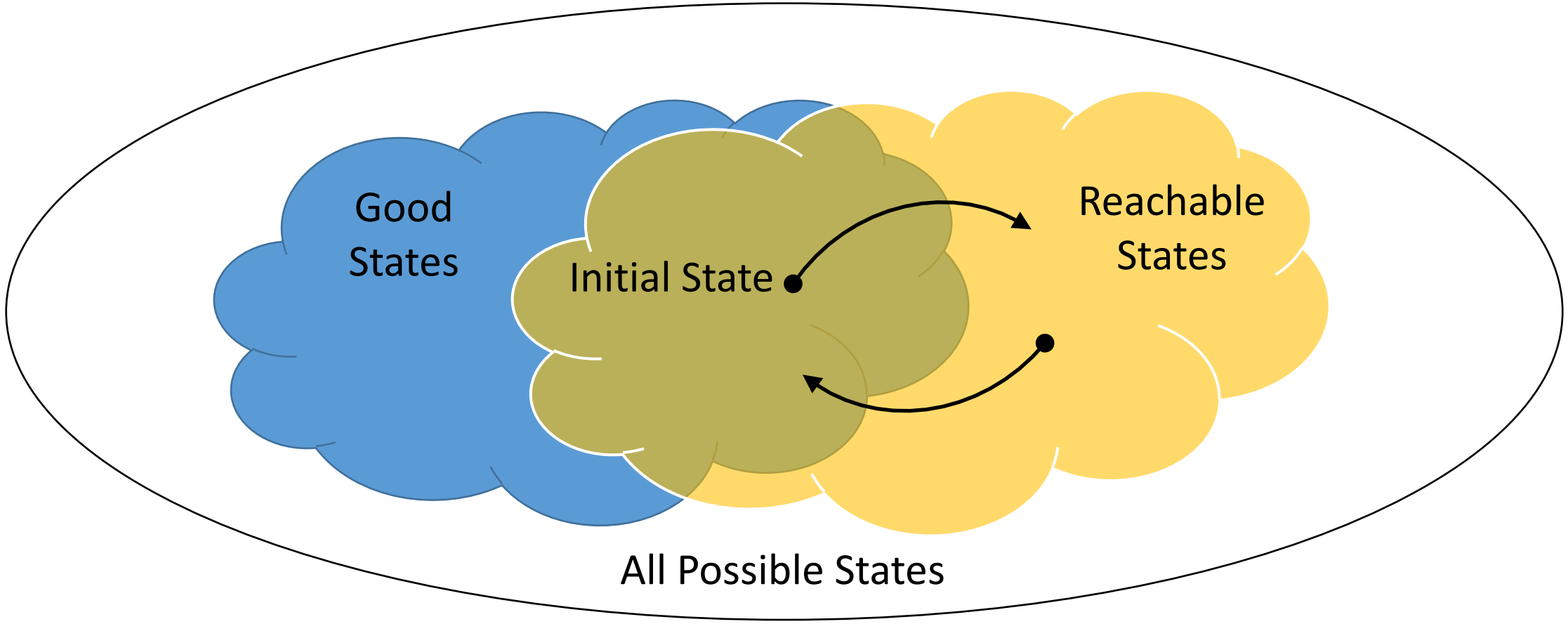


Source: Verizon 2016 Data Breach Investigation Report

Traditional Security



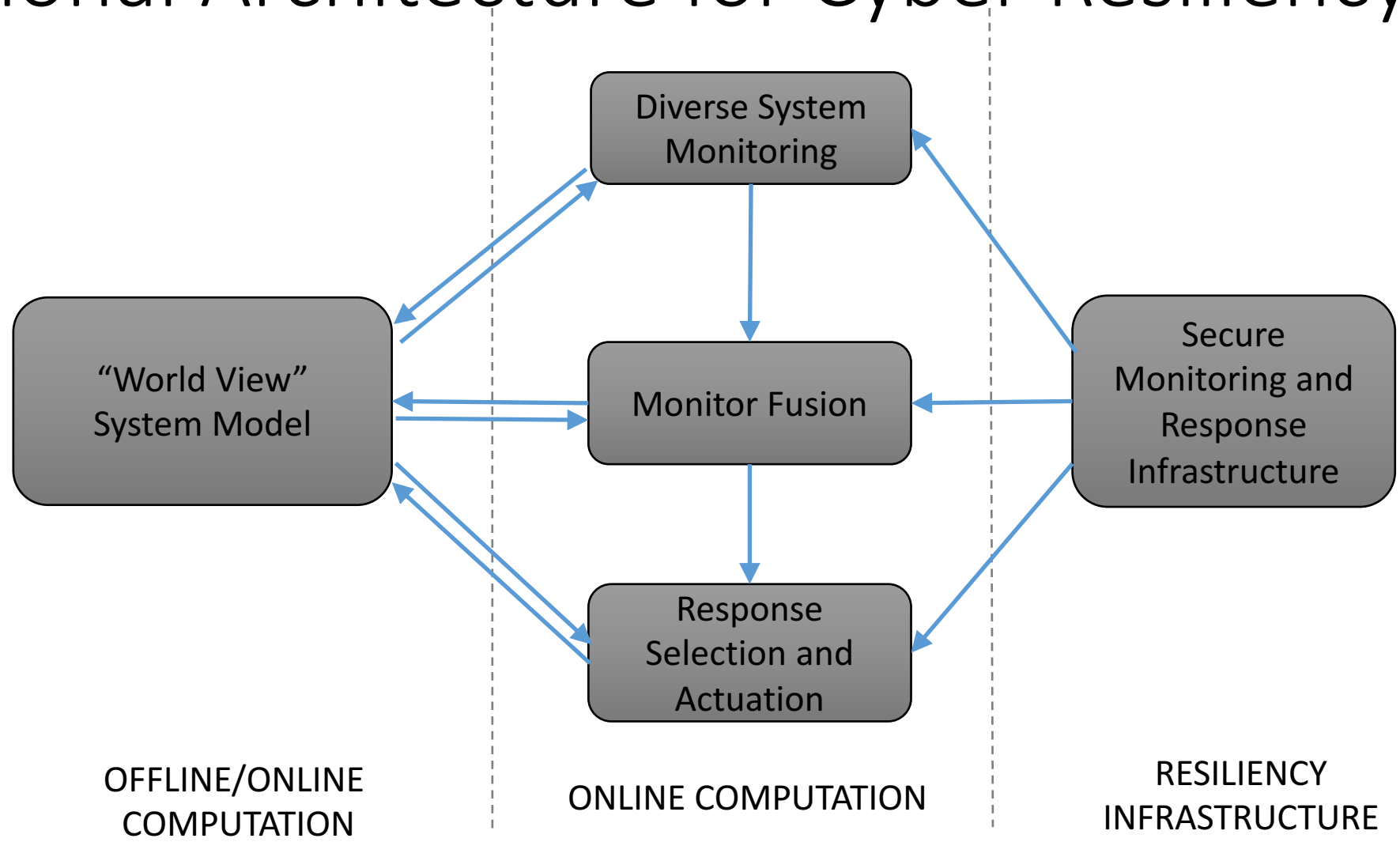
Resiliency Approach



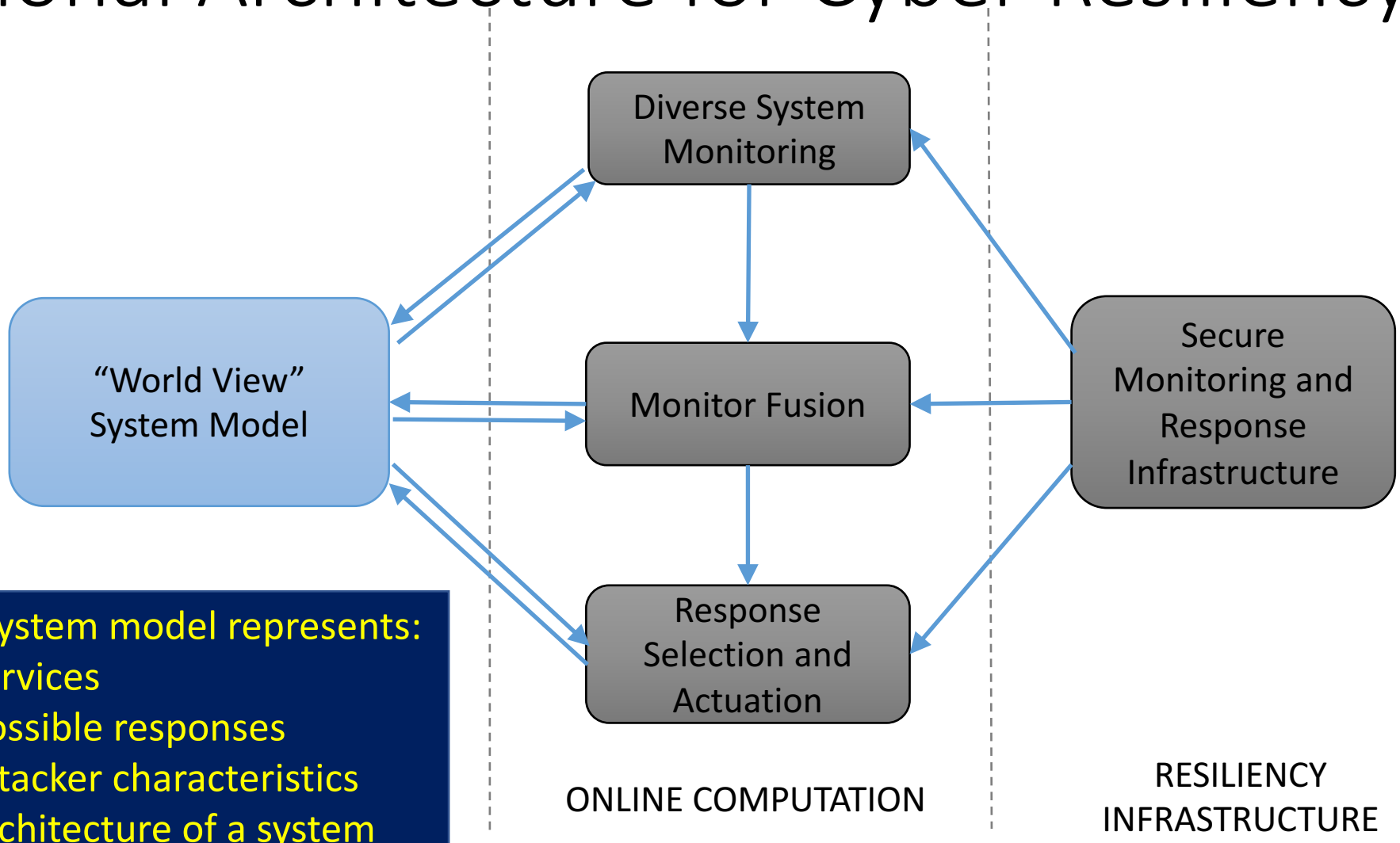
Cyber resilience is the ability to *identify*, *prevent*, *detect* and *respond* to malicious and random process or technology failures and recover— while maintaining an acceptable level of service.

Adapted from:
Presidential Policy Directive 21 (PPD-21), "Critical Infrastructure Security and Resilience," February 12, 2013.
Accenture Consulting, Making your Enterprise Cyber Resilient, 2015

Notional Architecture for Cyber Resiliency



Notional Architecture for Cyber Resiliency

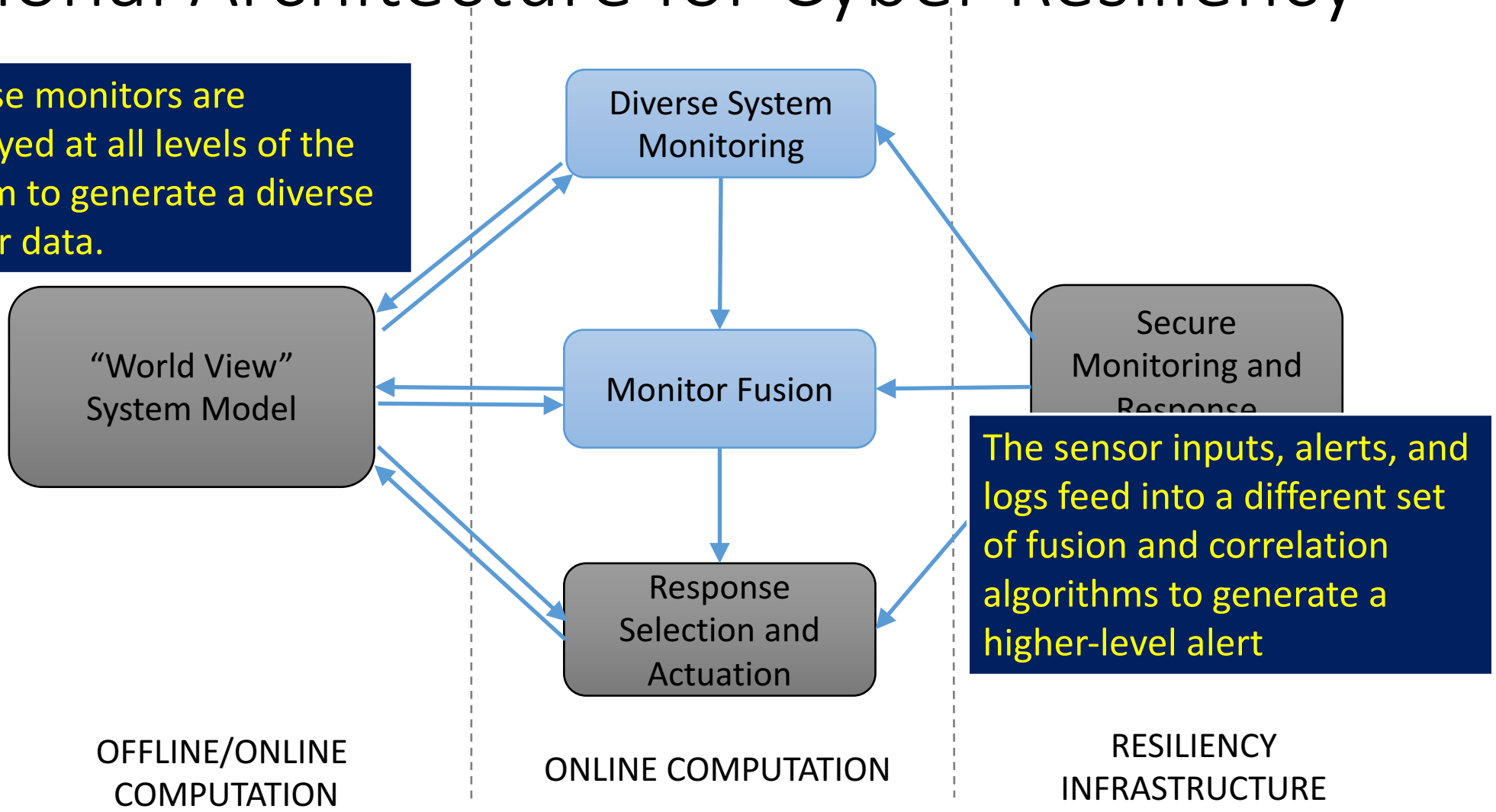


The system model represents:

- services
- possible responses
- attacker characteristics
- architecture of a system

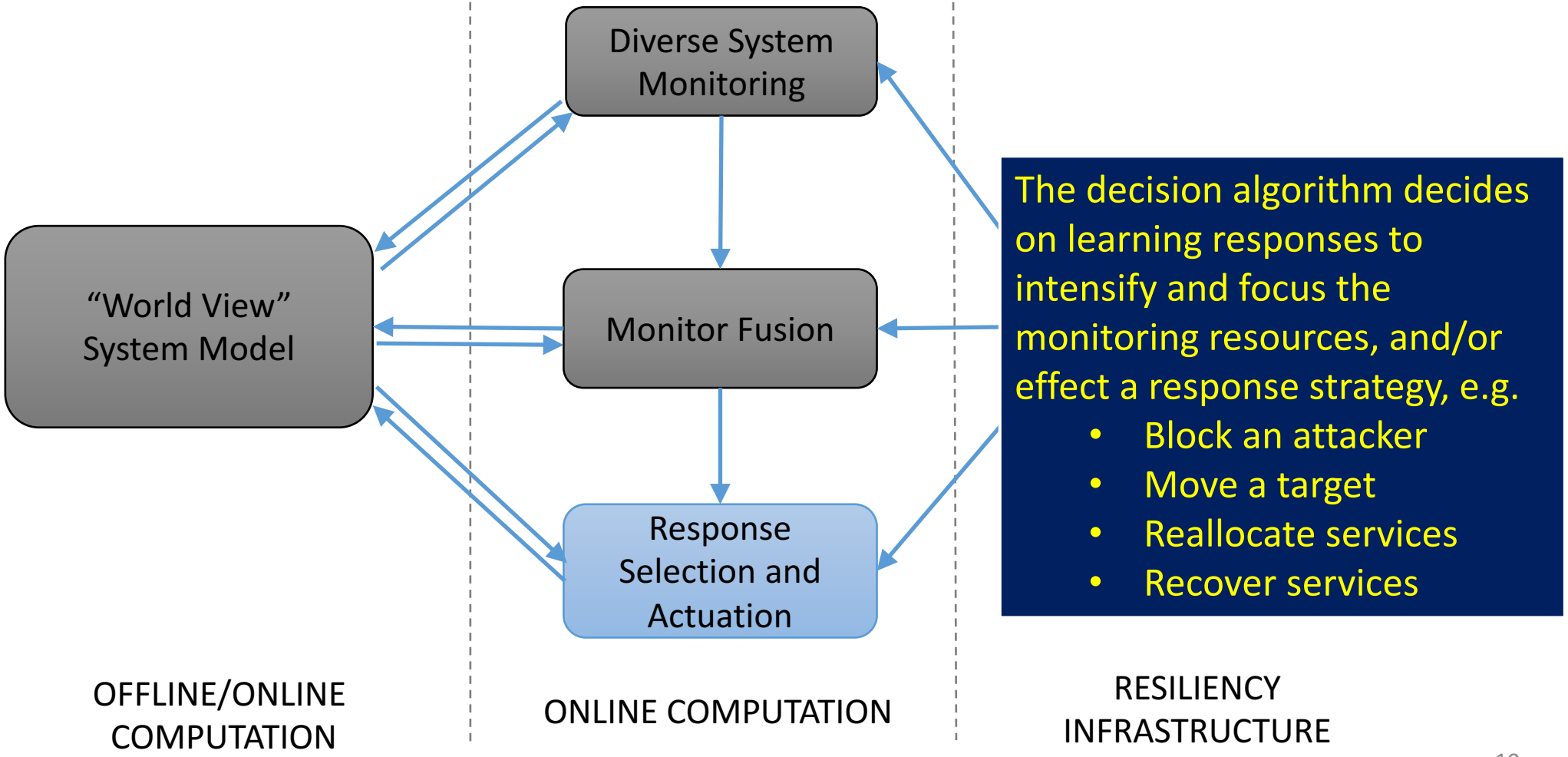
Notional Architecture for Cyber Resiliency

Diverse monitors are deployed at all levels of the system to generate a diverse sensor data.

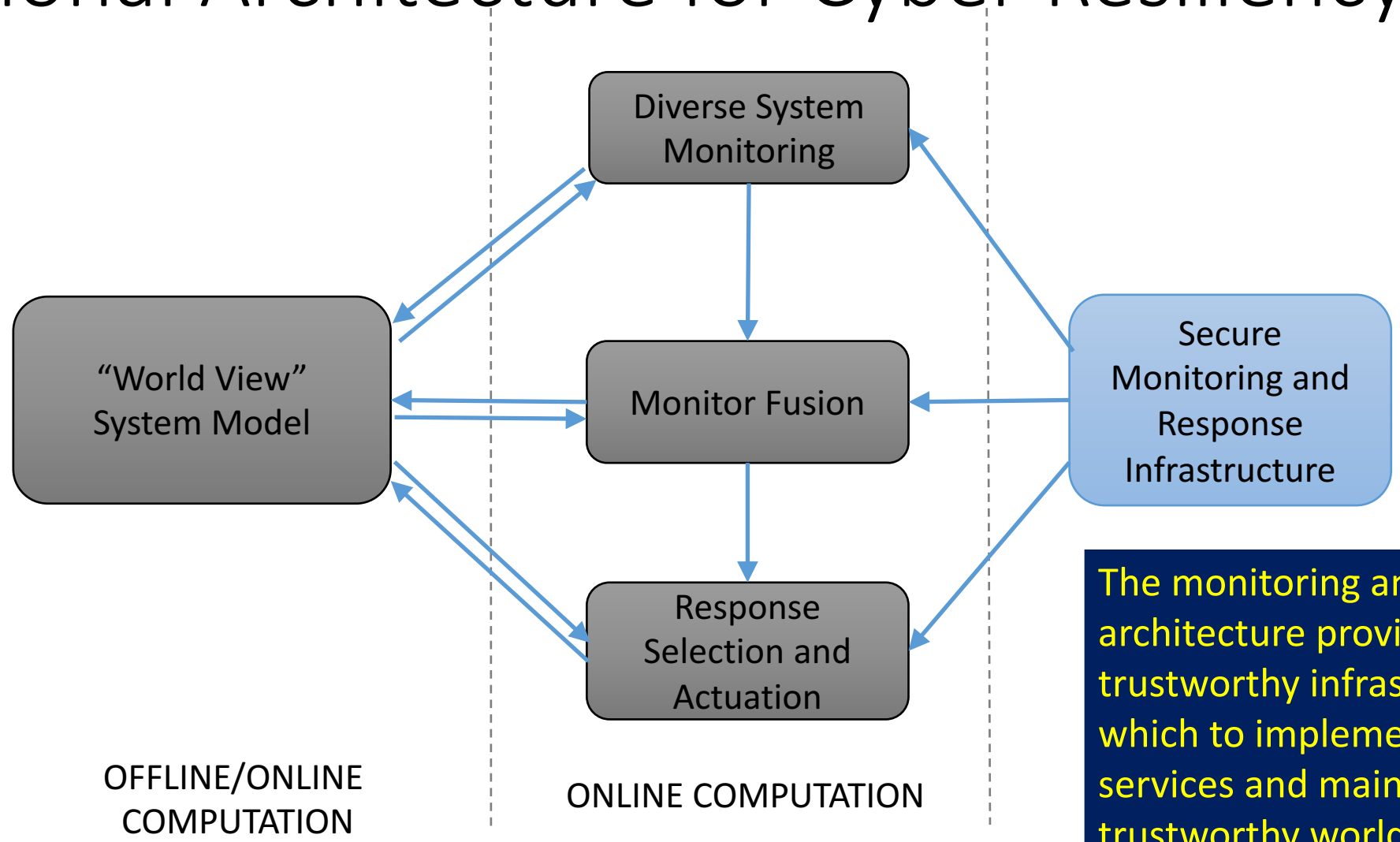


The sensor inputs, alerts, and logs feed into a different set of fusion and correlation algorithms to generate a higher-level alert

Notional Architecture for Cyber Resiliency

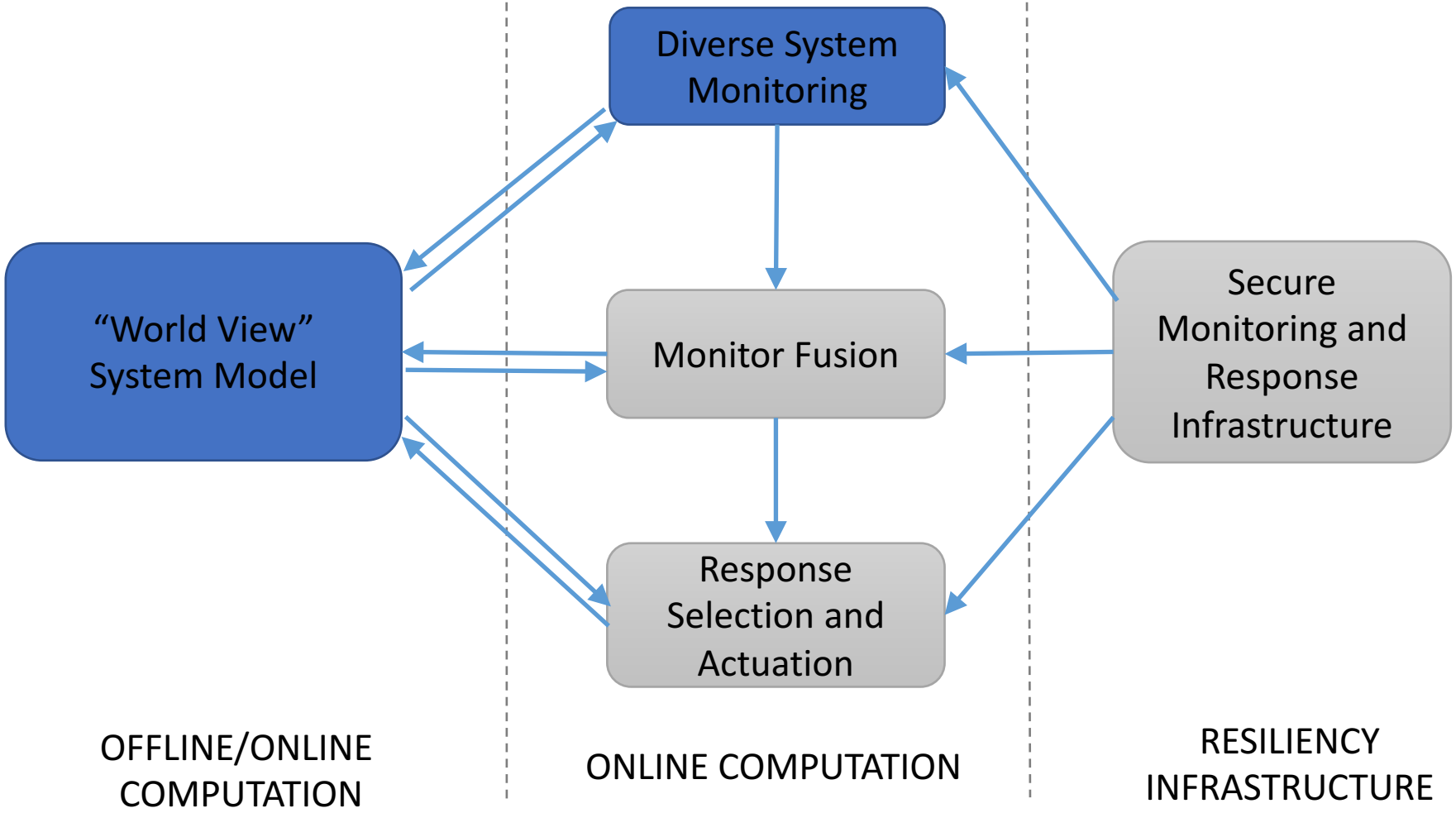


Notional Architecture for Cyber Resiliency



The monitoring and response architecture provides a trustworthy infrastructure on which to implement resiliency services and maintain a trustworthy world view.

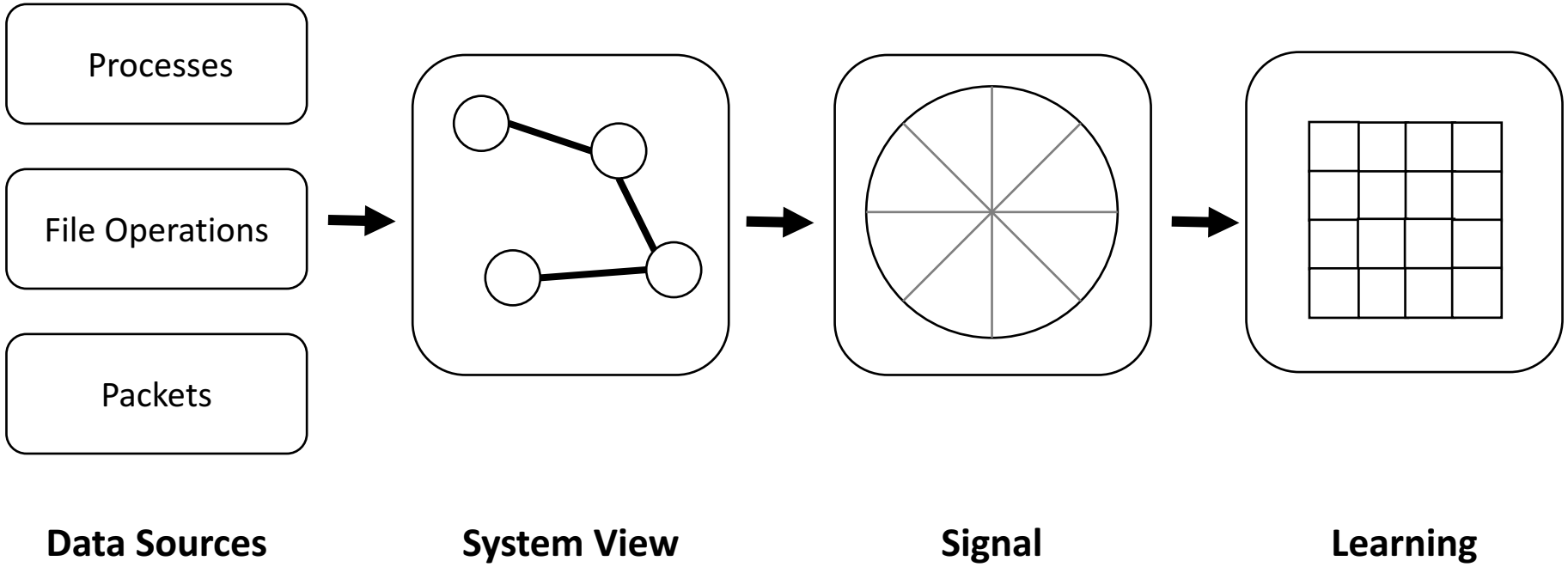
Kobra: A Kernel Monitoring Engine



Problem Description

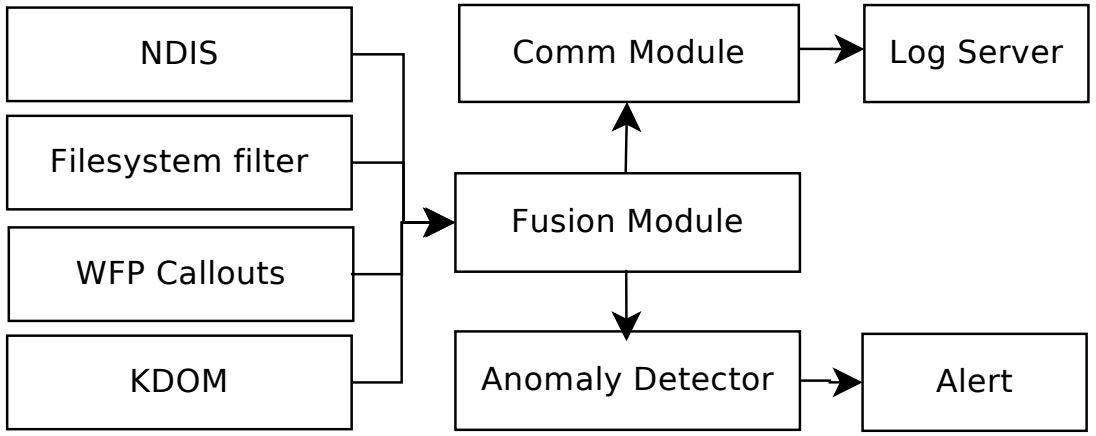
How to use diverse data types to model application behavior for anomaly detection?

Our Approach



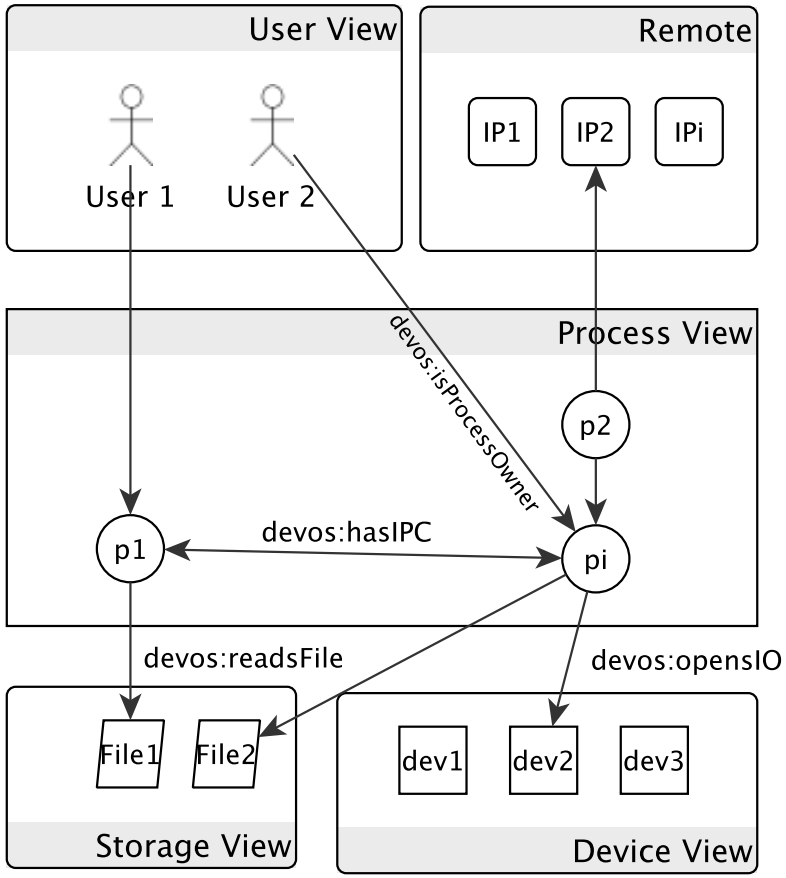
Kobra's Architecture

- Kernel-level monitor for Windows kernel
- Cooperative drivers that captures:
  - Network activity
  - Process communications
  - Process creation/termination
  - Objects access
  - File system activity
- Low-overhead



What is the System View?

- The intent of the system view is to provide high-level information about host state.
- Reflects the methods by which users and user processes access different resources.



File and Network behaviors

```
insert-edge{“VID.mp4” :?”
  2044} {devos:read} {512}
```

```
insert-edge{“VID.mp4” :?”
  2044} {devos:read} {512}
```

```
insert-edge{“VID.mp4” :?”
  2044} {devos:read} {4096}
```

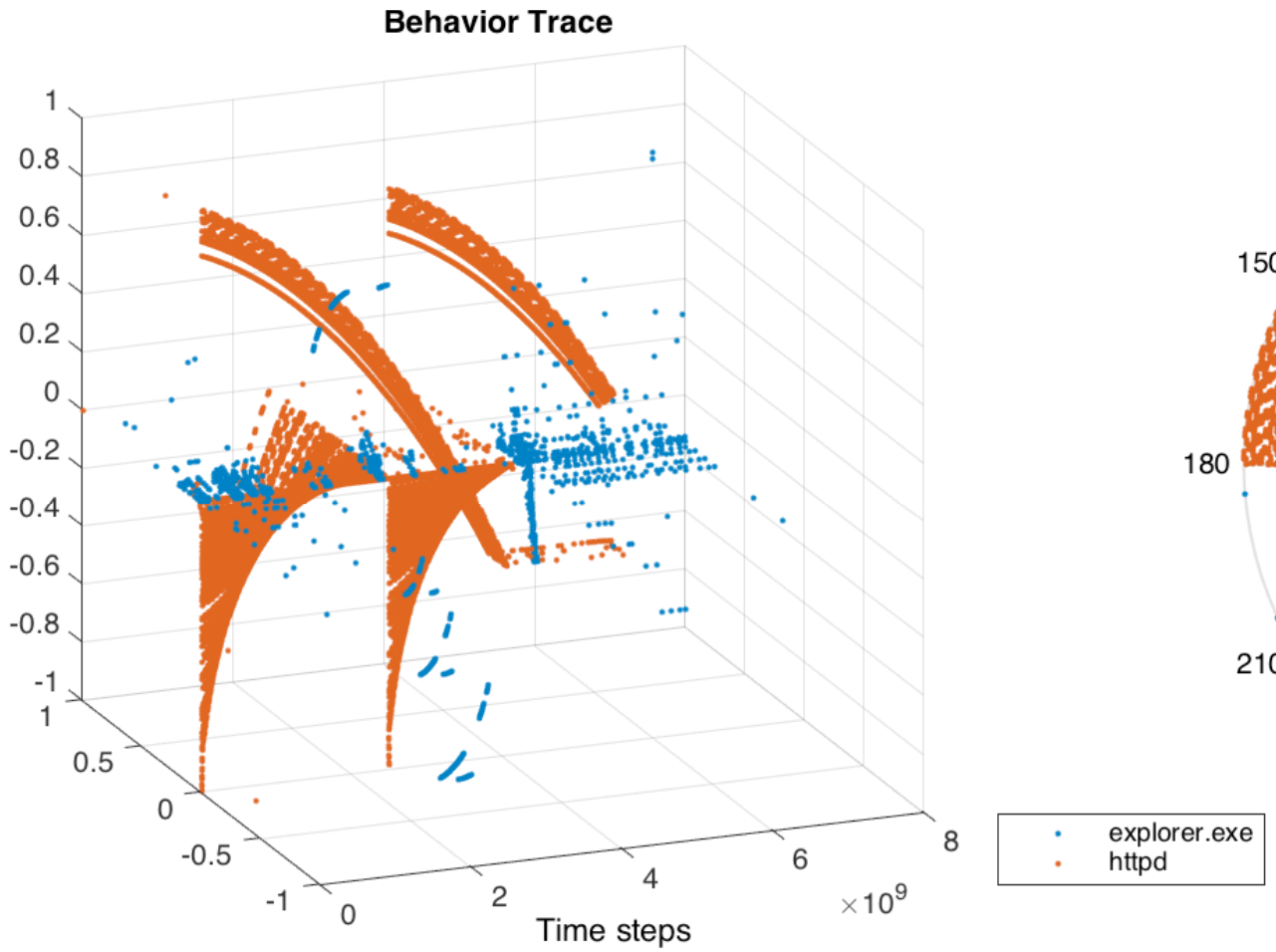
- Chromium
- VLC

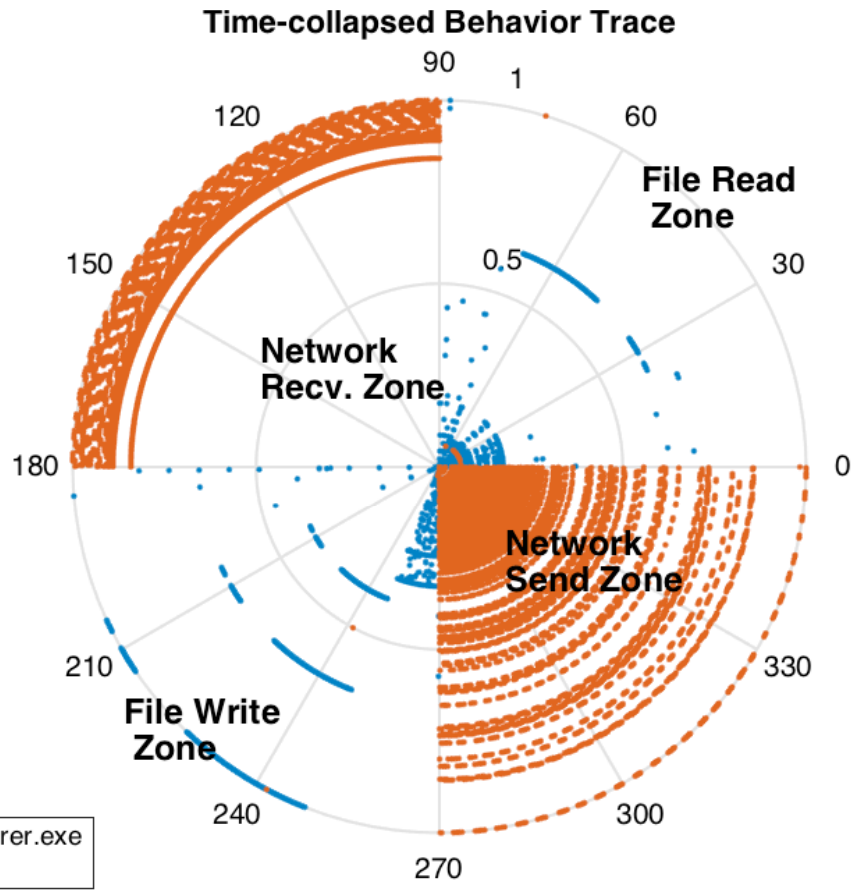
- Filter by Process and Application
- Data is converted to a discrete time signal

Map Discrete Events to a Polar Space

- Mapping inspired by digital modulation methods
- Partition space by quadrants according to type of events
- Map each event to a part of the quadrant
- The magnitude is a function of the “size” of event

Exampled


Behavior Trace
Time steps
×10^9
explorer.exe
httpd

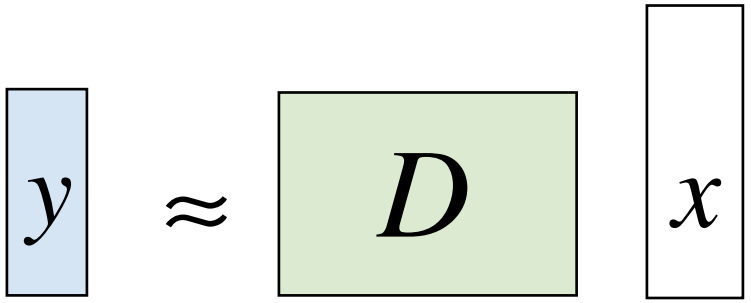

Time-collapsed Behavior Trace
File Read Zone
Network Recv. Zone
Network Send Zone
File Write Zone

Application Behavior Model

- Learn local patterns in the signal (sliding window)
- Learn the co-occurrence relationships between the patterns
- Model: **<Local Patterns, Co-occurrence>**

Learning Local Patterns

- Learn sparse representation dictionary on the time signals
- Dictionary atoms correspond to the local patterns



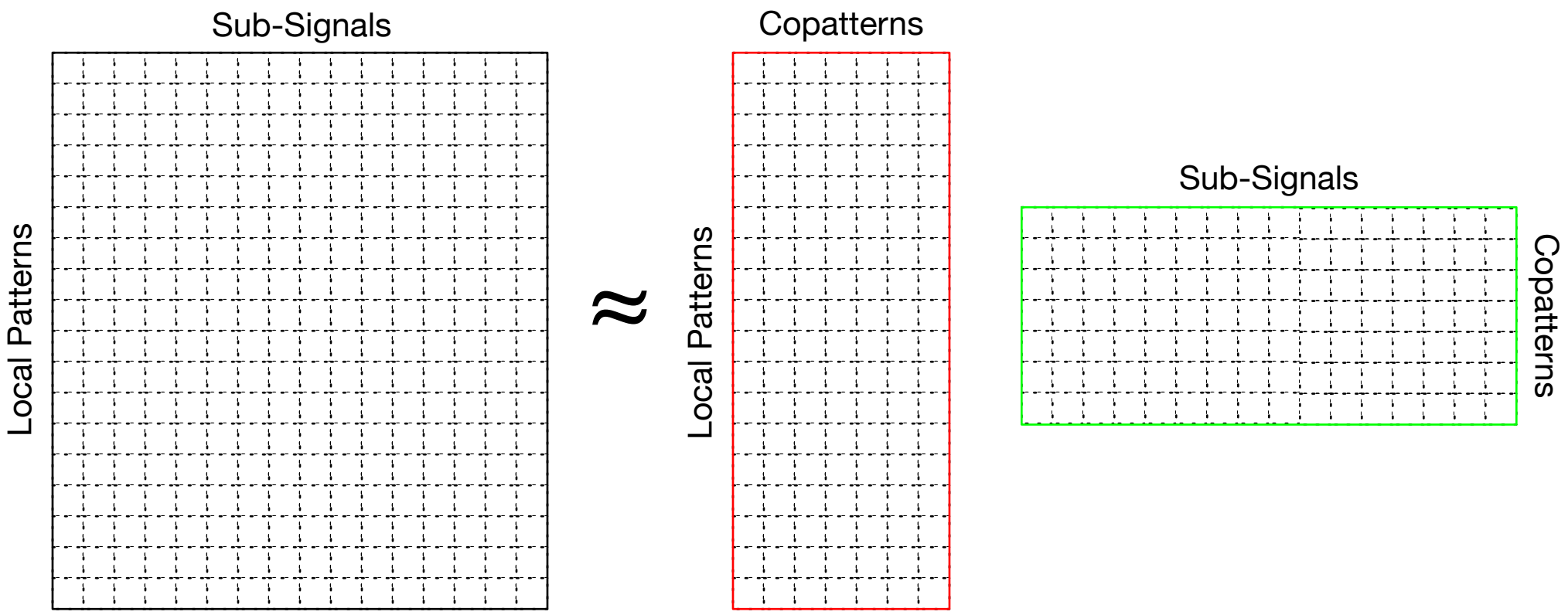
$y \in \mathbb{R}^n$ Input Signal

$D \in \mathbb{R}^{n \times p}$ Dictionary

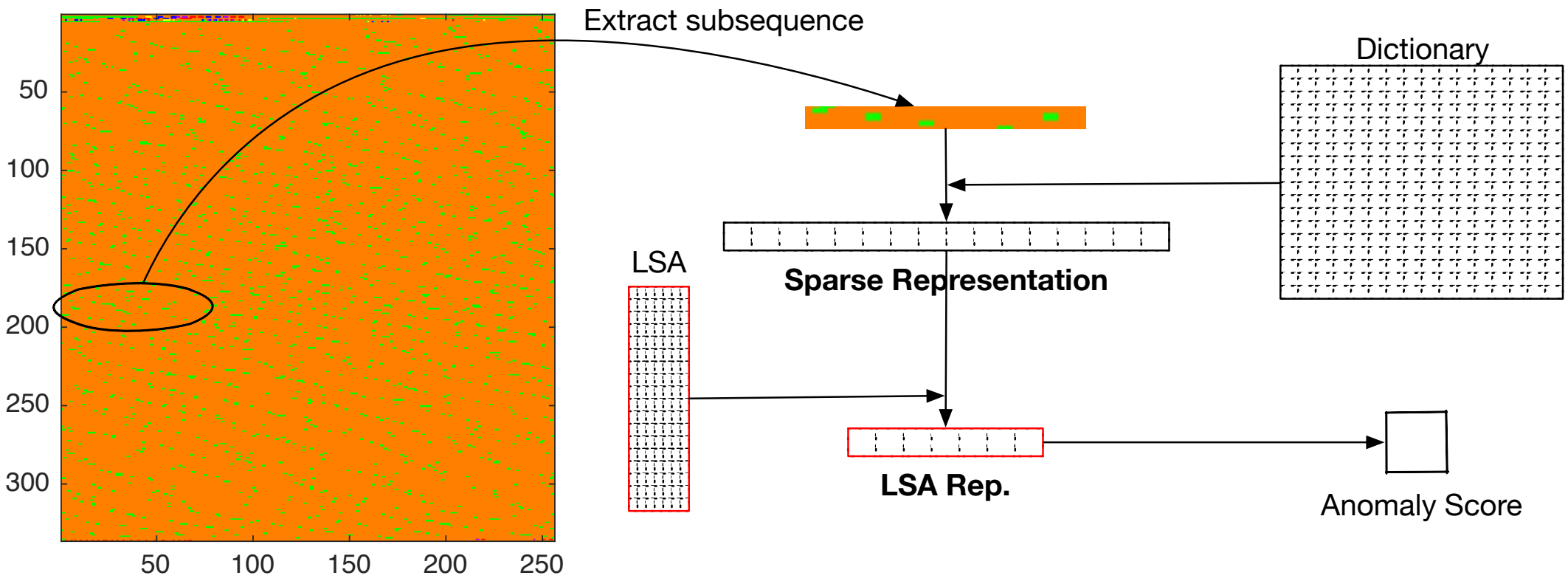
$x \in \mathbb{R}^p$ Sparse Approximation

$$\mathbf{D} = \arg\min_{D} \sum_{i=1}^{n} \min\{\|Dx_i - y_i\|^2 + \lambda \|x_i\|_1\}$$

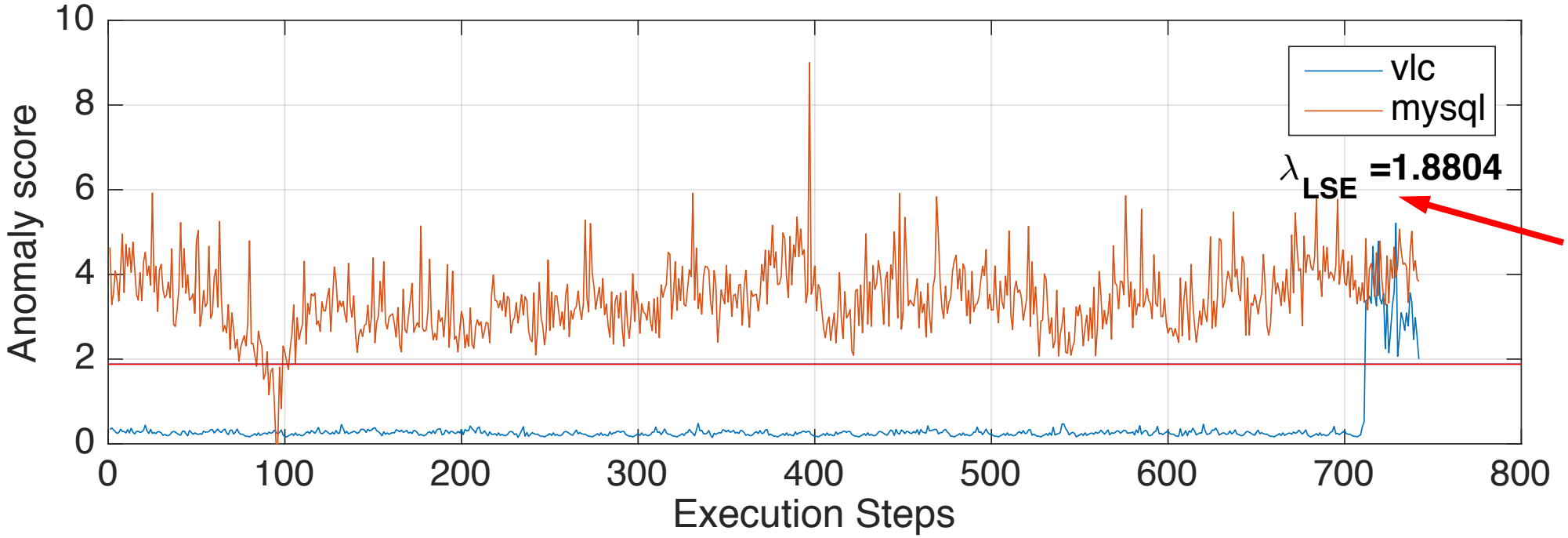
Learning Co-occurrence (LSA)



Anomaly Detection using Model



Reconstruction of MySQL using VLC Model



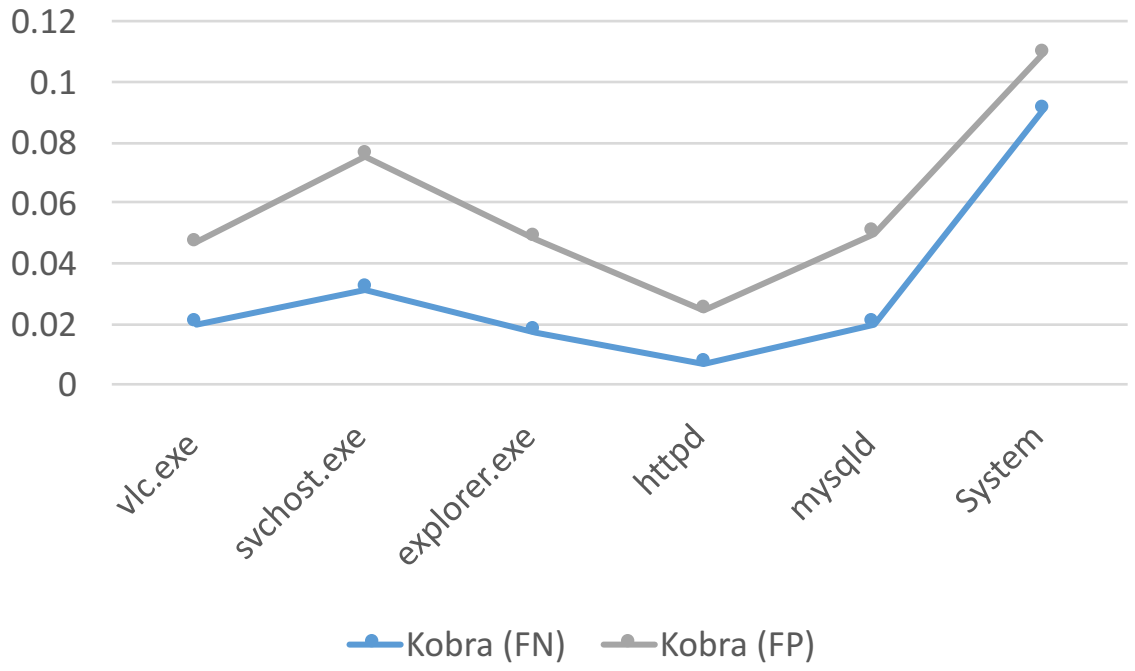
95th percentile of reconstruction error

Evaluation Methodology

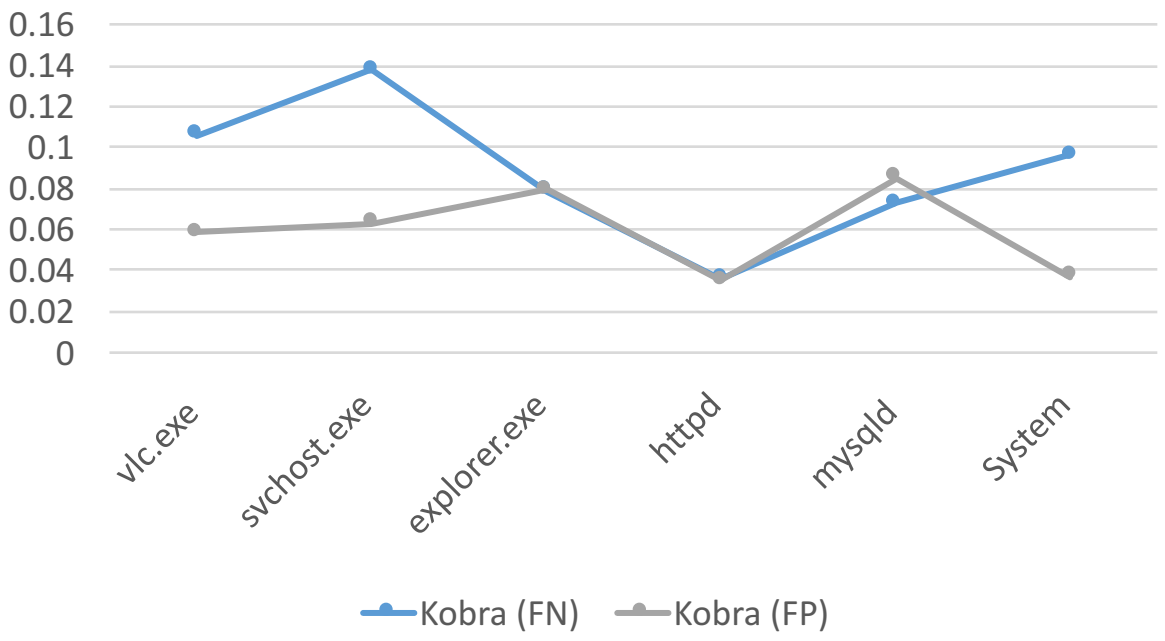
1. Generate traces of normal behavior of application
   - VLC playing local files
   - Apache + Mysql running wordpress
   - Windows services

2. Learn model of each application
3. Inject traces of shellcode behavior into testing traces
4. Compute anomaly scores

Evaluation Results

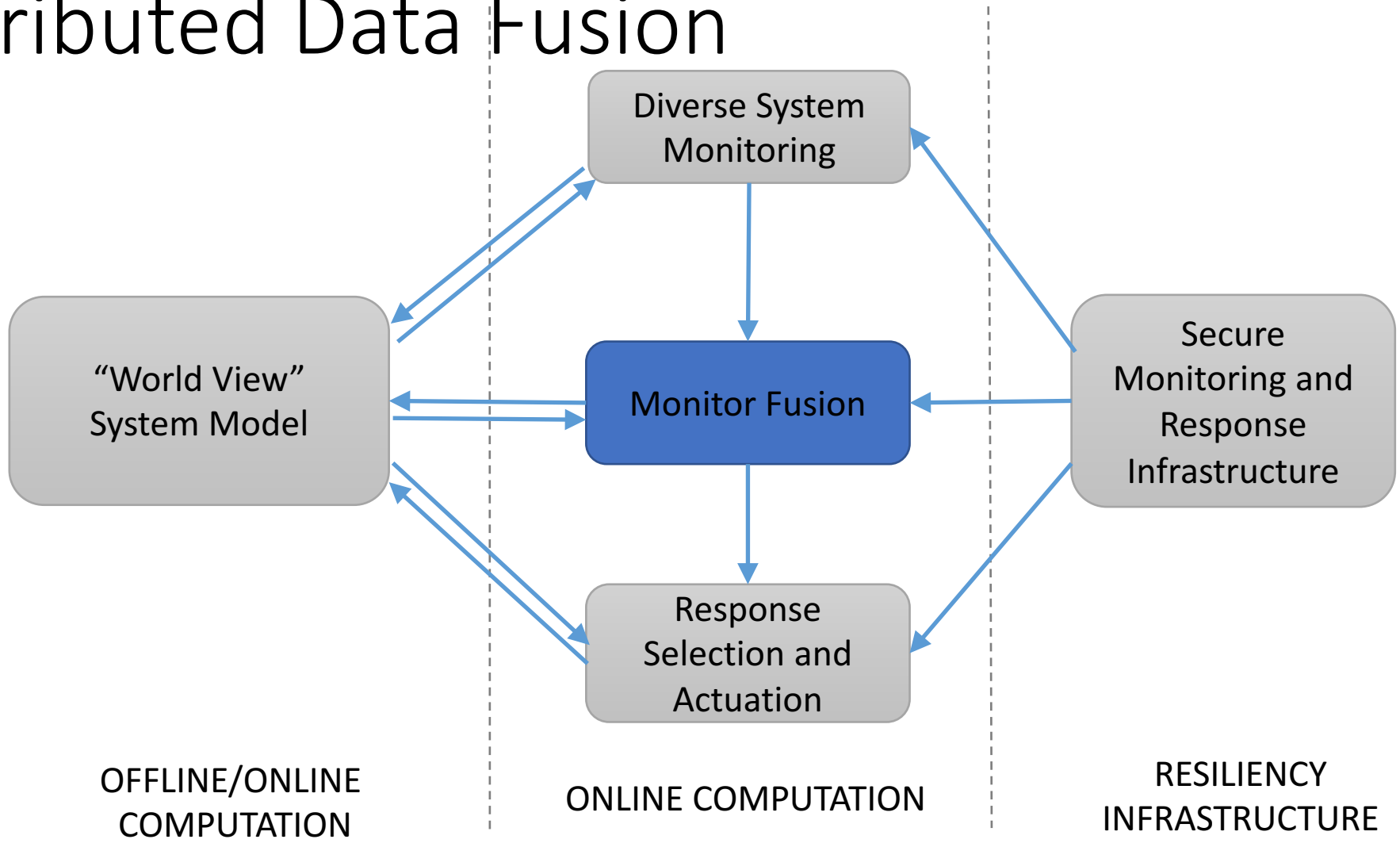


False Positive/Negative Rates for Reverse Shell



False Positive/Negative Rates for Drive-by-Download

Lateral Movement Detection Using Distributed Data Fusion

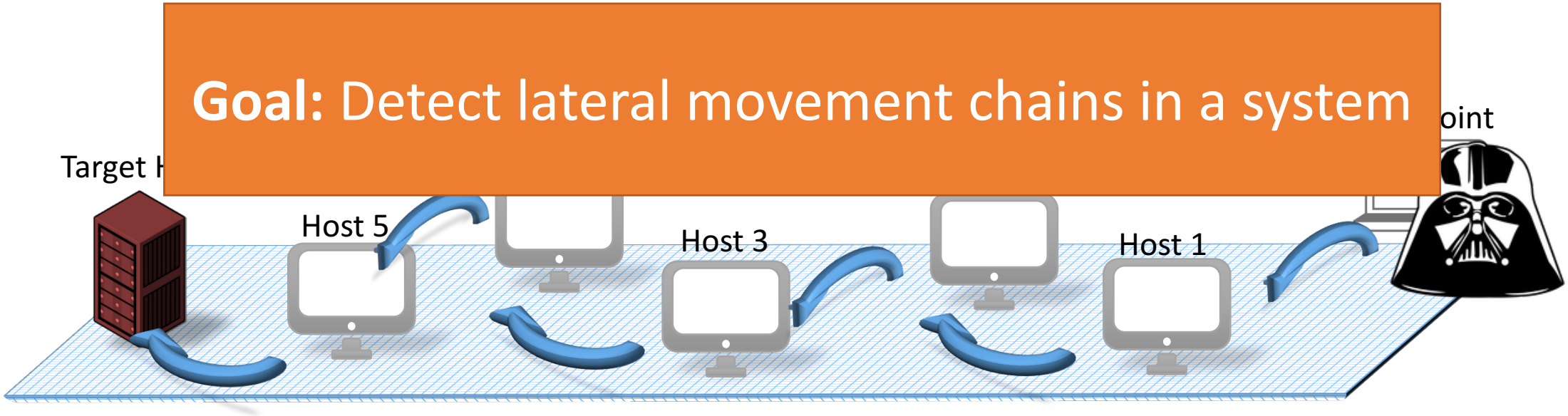


Problem Description

How do we fuse diverse data sources using a distributed agent-based system to detect lateral movement in a network while maintaining scalability?

Lateral Movement Explained

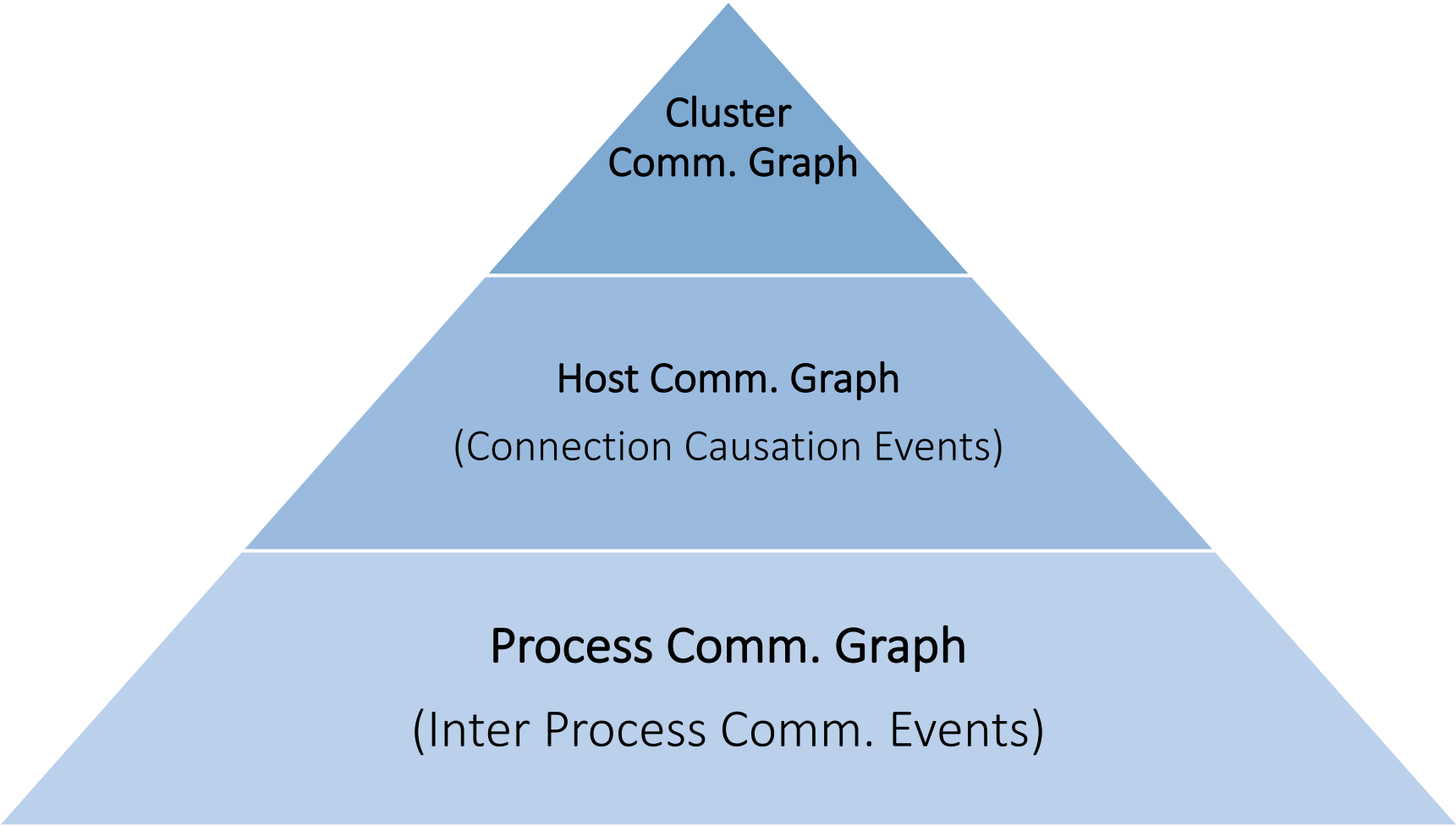
- Starting from the entry point attacker moves to target host
- Uses system services or custom tools



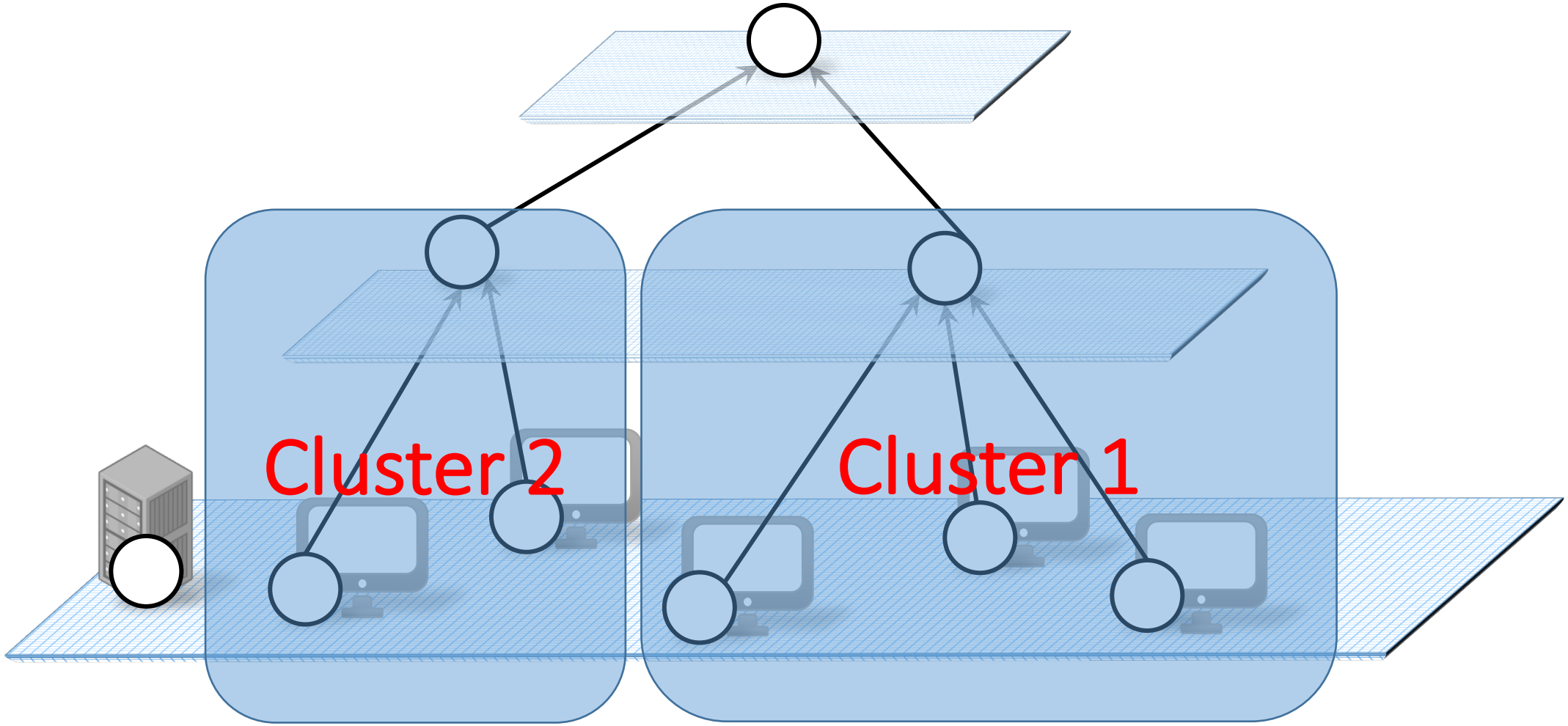
State-of-the-art

- Centrally correlate NetFlows to detect lateral movement
- NetFlow correlation method is not accurate
- Amount of information is too large to be handled centrally

Approach Overview

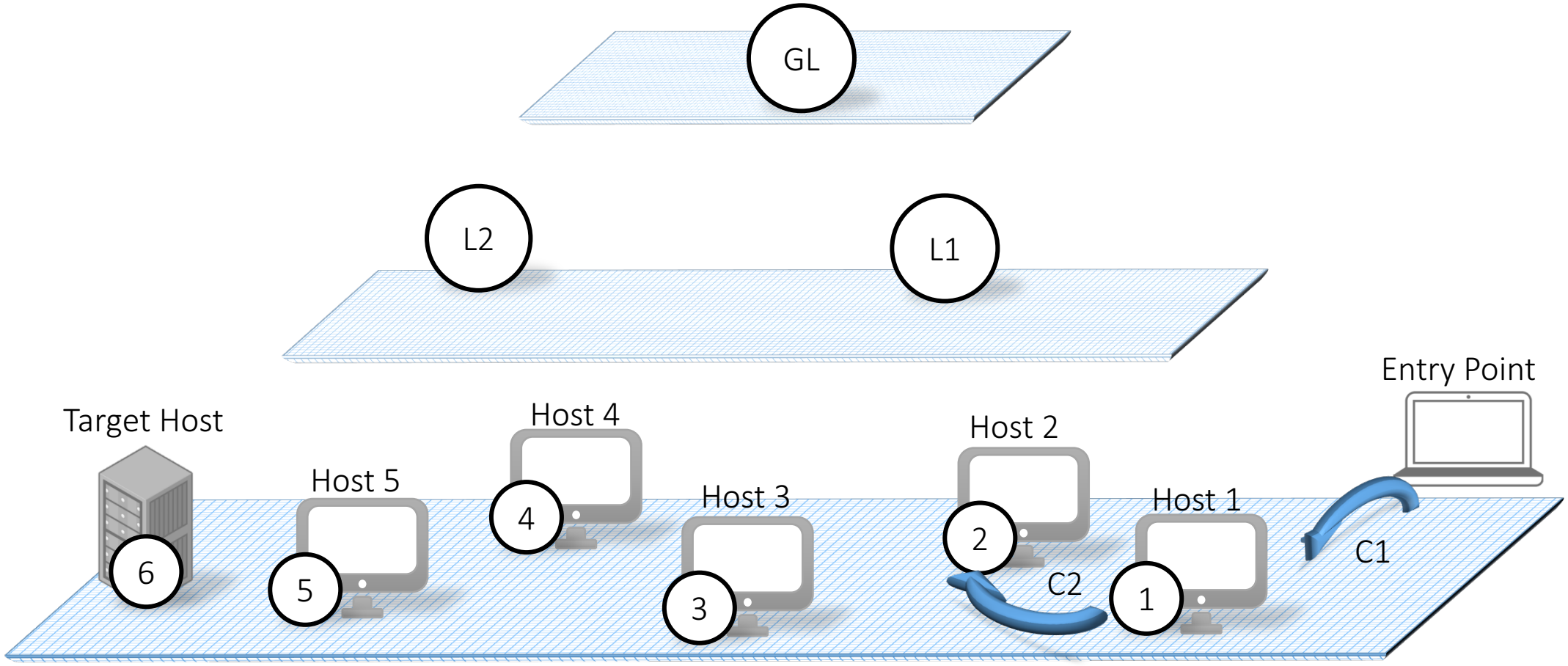


System Model



Lateral Movement

A critical step during APT to move from the entry point to target host



Inside Host 1

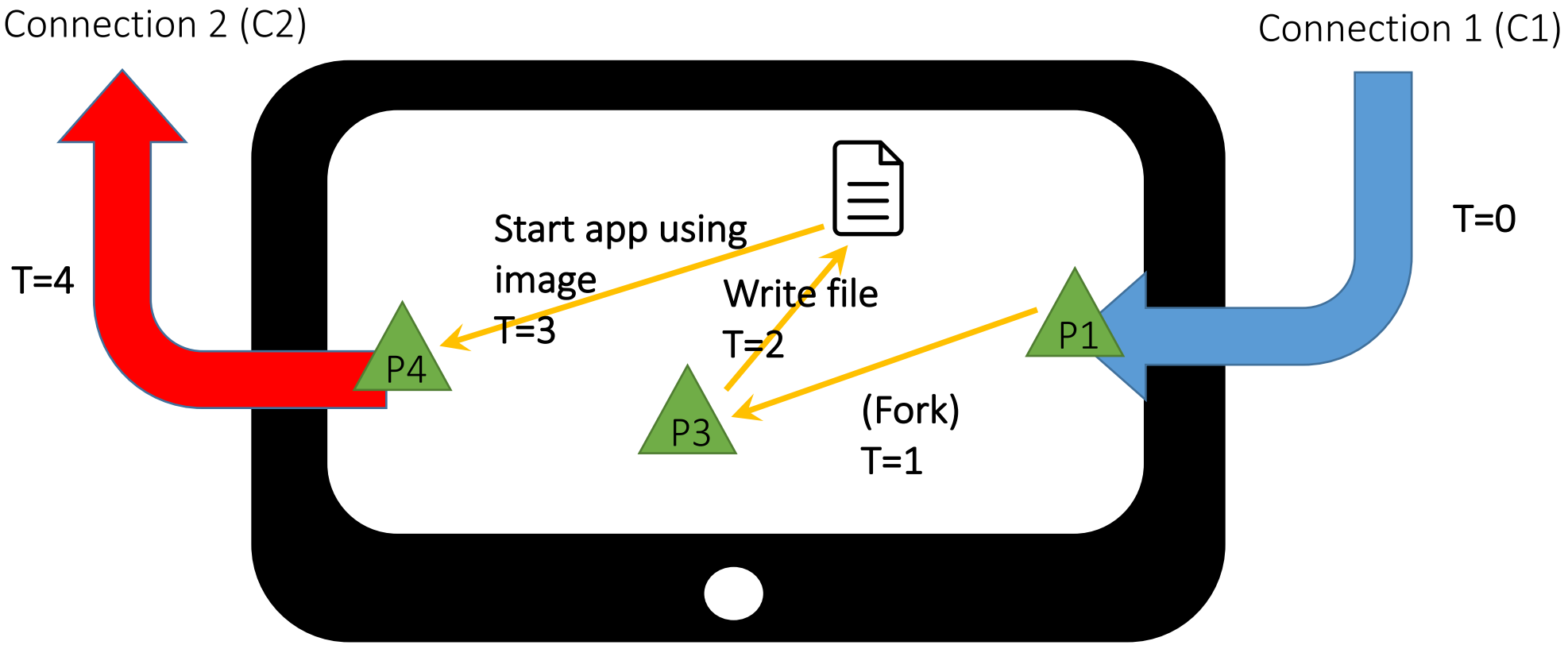
Process Communication View created by Kobra using timestamped events:

- Processes running
- Process communication (pipes, messages,…)
- Network connections (with a unique ID across system)
- File access

Connection causation event is generated when the agent find a path between incoming and outgoing connections

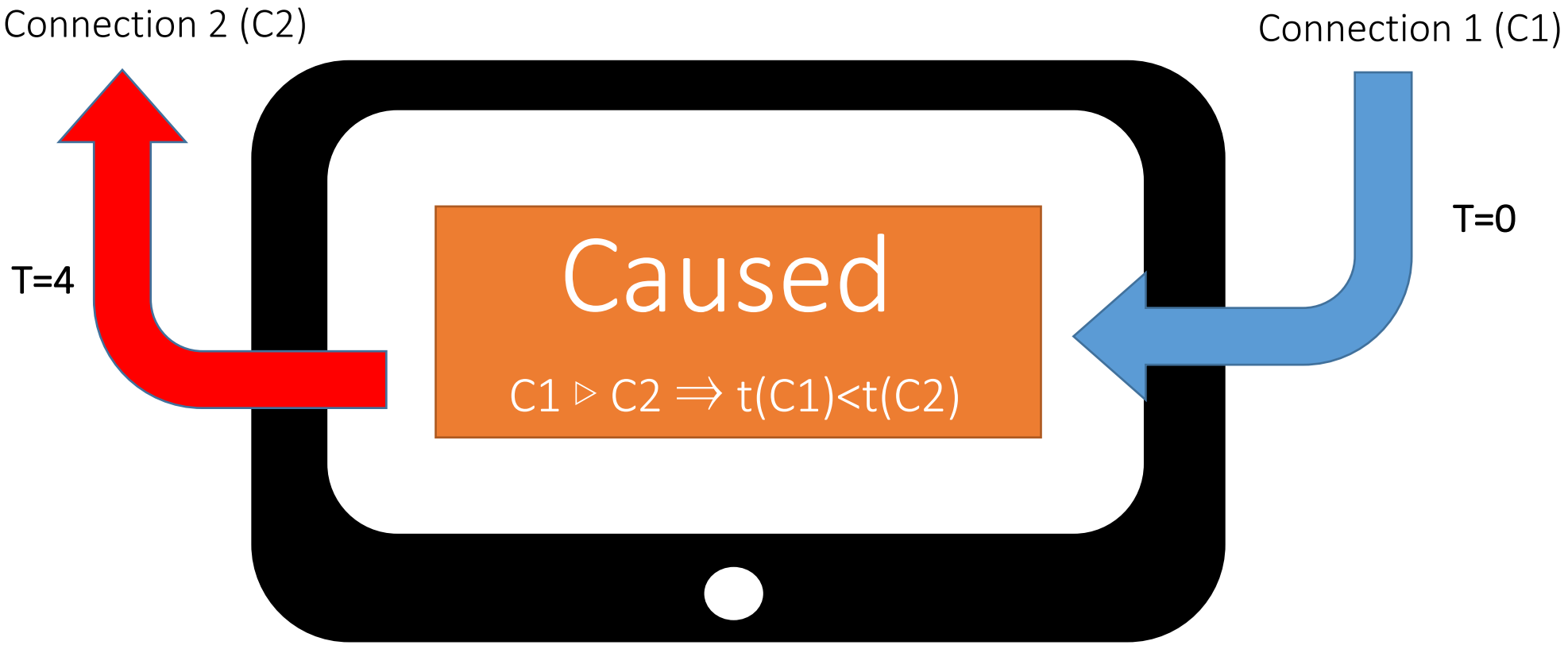
Inside Host 1

Local agent infers connection causation using the **Process Communication Graph**



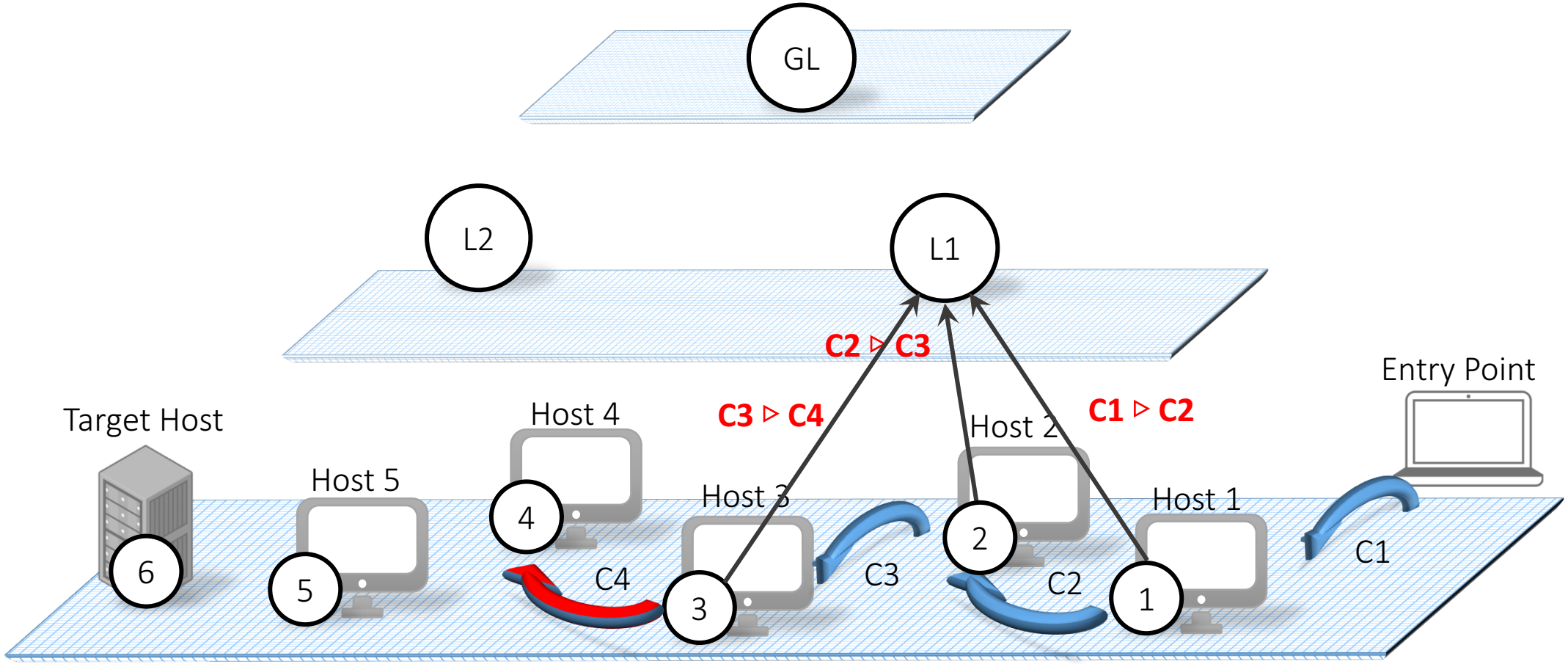
Inside Host 1

Local agent infers connection causation using the **Process Communication** Graph



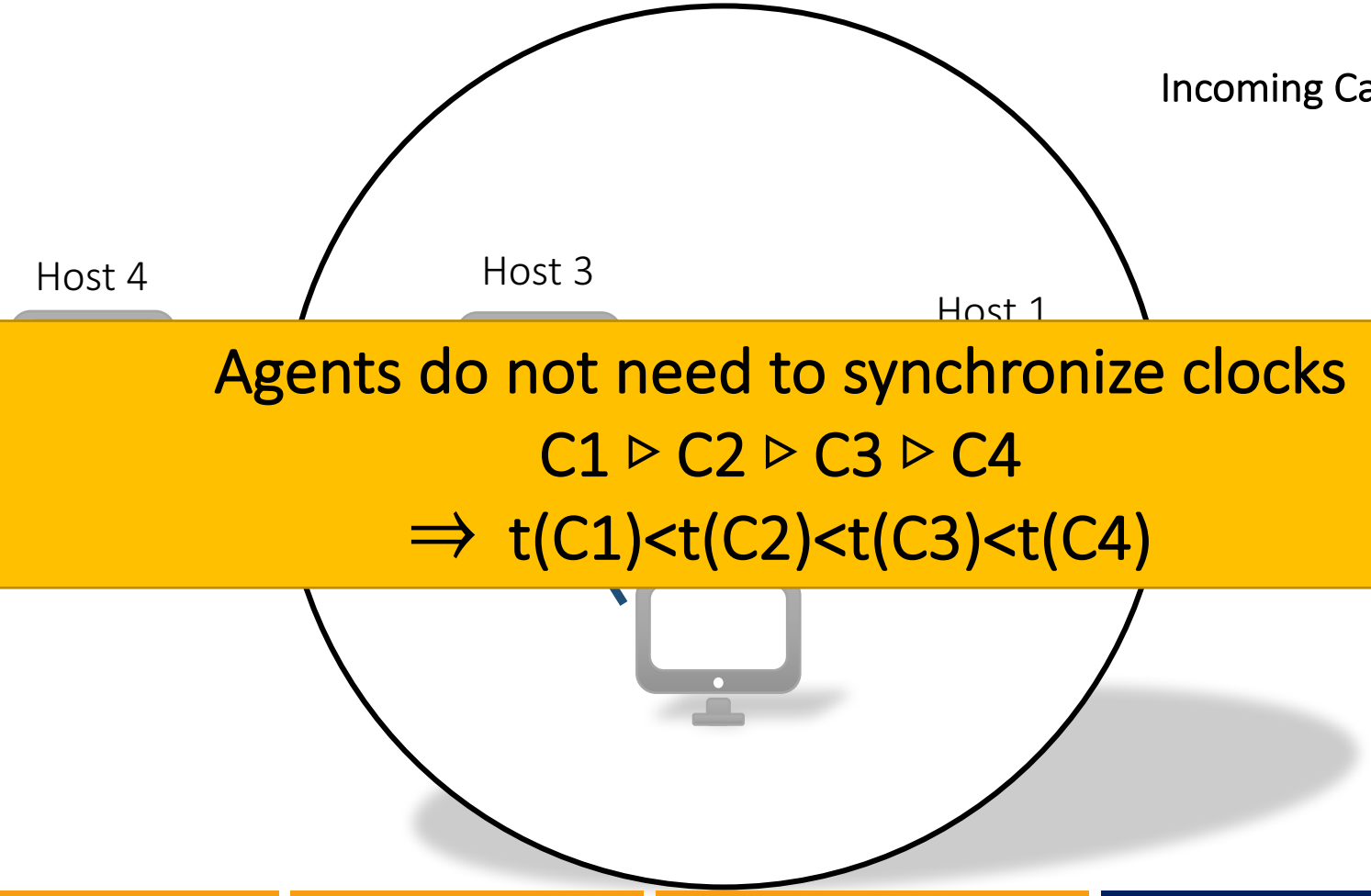
Lateral Movement

A critical step during APT to move from the entry point to target host



Inside Cluster Leader 1

Cluster head maintains **Host Communication** Graph



Incoming Causation Events:

C1 ▹ C2

C2 ▹ C3

C3 ▹ C4

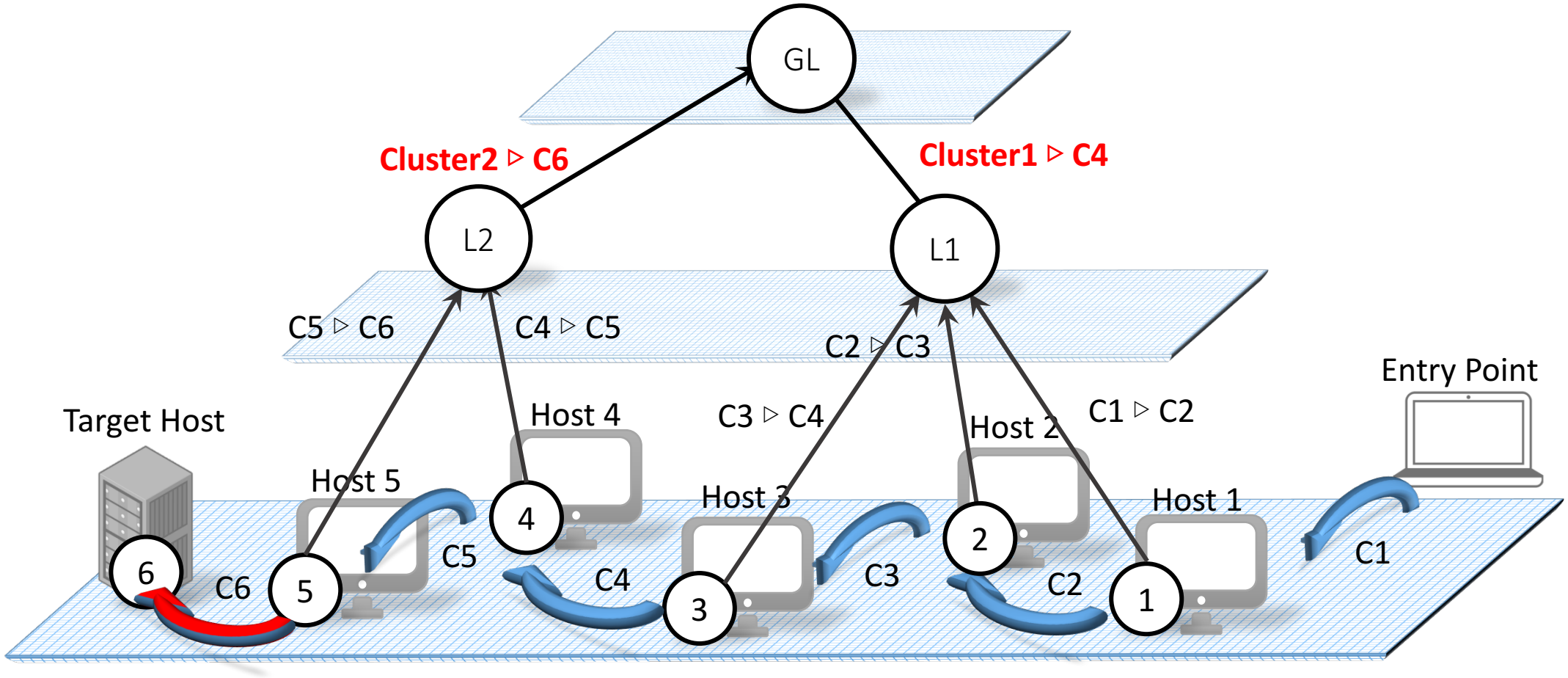
Agents do not need to synchronize clocks

C1 ▹ C2 ▹ C3 ▹ C4

⇒ t(C1)<t(C2)<t(C3)<t(C4)

Lateral Movement

A critical step during APT to move from the entry point to target host



Discussion

- Network level causation inference using host-level calls
- Detection load distributed over all agents via distributed fusion
- Eliminate the need for global clocks by abstracting data using hierarchy

Conclusion

- We designed an “end-to-end solution” that provides cyber resiliency against coordinated threats
  - Kobra generate views of a host and to learn models of applications
  - In a hierarchical manner, we used Kobra’s views to generate a network-wide chain of a coordinated attack

Future Work

- We will formulate a theory for resilient integrity checking when an attacker is attempting evasion
  - PowerAlert
  - Integrity checking of an SDN
  - Rekeying of smart meters
- We plan to develop a response mechanism for lateral movement using adaptive control
  - The attacker model is unknown, to be learned
  - Response actions change network topology and healing rates of machines

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