Fear and Logging in the Internet of Things

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NDSS Symposium 2018

Feb 19, 2018

07 DEC 2017

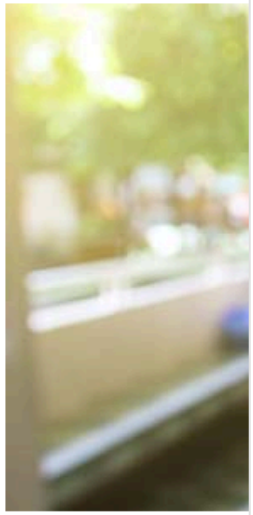
IDC Forecasts Worldwide Spending on the Internet of Things to Reach $772 Billion in 2018

FRAMINGH… billion in
2018, an in… tion (IDC)
Worldwide … l growth
rate (CAGR) … on in 2021.

Tech Trends

Report: Internet of Things to Tip $1 Trillion by 2020

By Joshua Bolkan | 12/12/17



IDC: Internet Of Things To Be Valued $1.1 Trillion By 2021

December 10, 2017 - Written By Manny Reyes

The Internet of Things is expected to grow to a value of $1.1 trillion in 2021 based on consumer spending worldwide, according to a new report by the International Data Corporation, which also forecasts hardware to account for the biggest technology segment of IoT next year with a value of $239 billion, followed by services, software and connectivity. The report projects majority of spending will be on sensors, modules, security and infrastructure, with the manufacturing industry being projected to make the largest investment of $189 billion on IoT products and services in 2018 alone to support operations and asset management efforts. According to IDC's forecast, overall spending on IoT is likely to hit $772.5 billion next year from the projected spending of $674 billion in 2017.


nest
AIRWAVE
74
wemo
wink
HomeKit
amazon
alexa
SmartThings

How to diagnose an incorrect behavior?

How to explain system behaviors?

IoT Logging

- Current logging mechanisms are **device-centric**
  - It is difficult to infer the *causal dependencies* between different events and data states.

……

Motion was detected at 11:13 AM

……

Front door was unlocked at 11:13 AM

Light was turned on at 11:14 AM

Why the light was turned on?

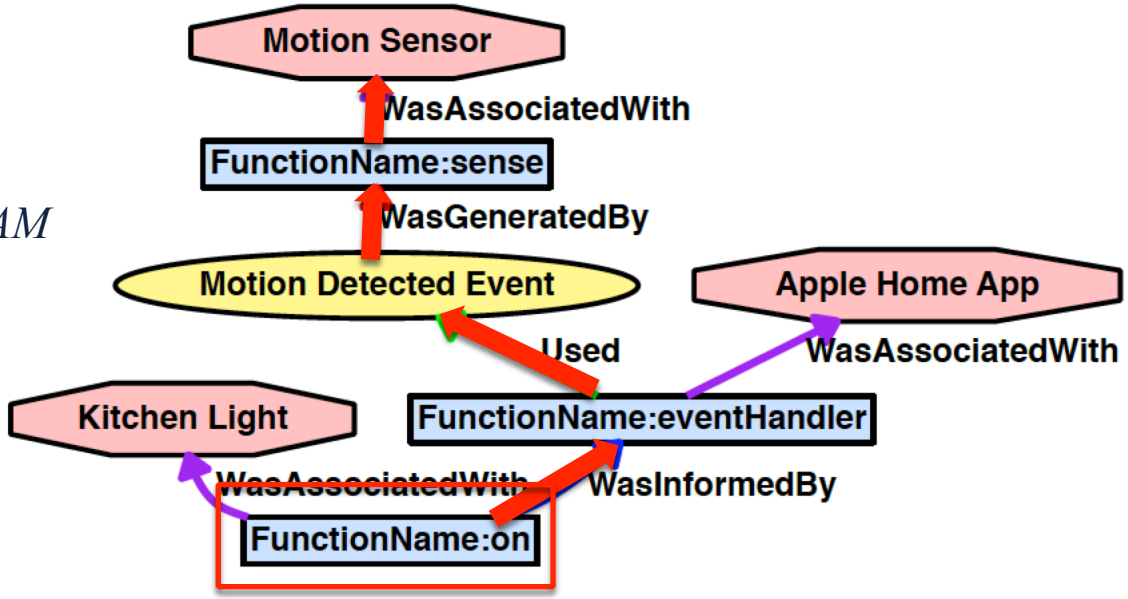
Data Provenance

- Data provenance describes the *history of actions* taken on a data object from its creation up to the present.

……
Motion was detected at 11:13 AM

……
Front door was unlocked at 11:13 AM

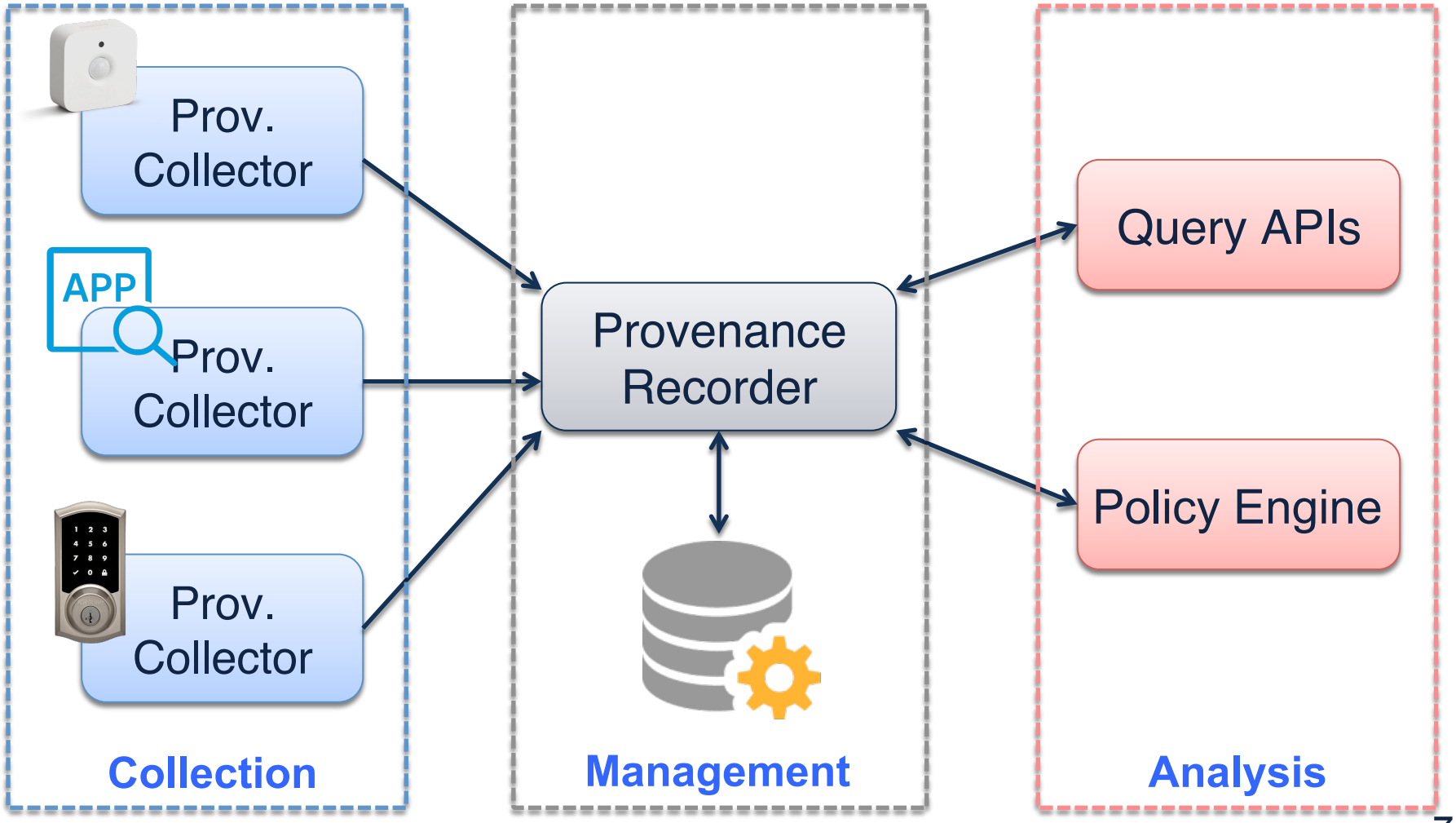
Light was turned on at 11:14 AM



Light was turned on because motion was detected.

Our Framework: ProvThings

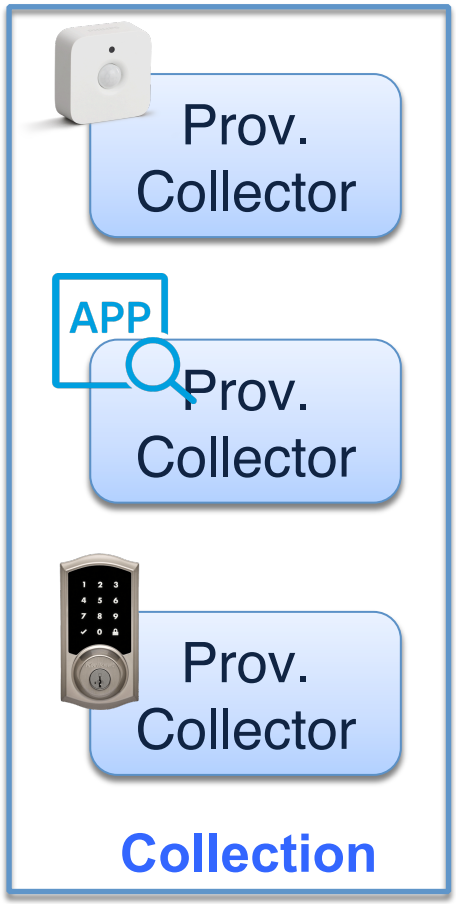
- A general framework for the ***capture***, ***management***, and ***analysis*** of data provenance in IoT platforms.



Provenance Collection

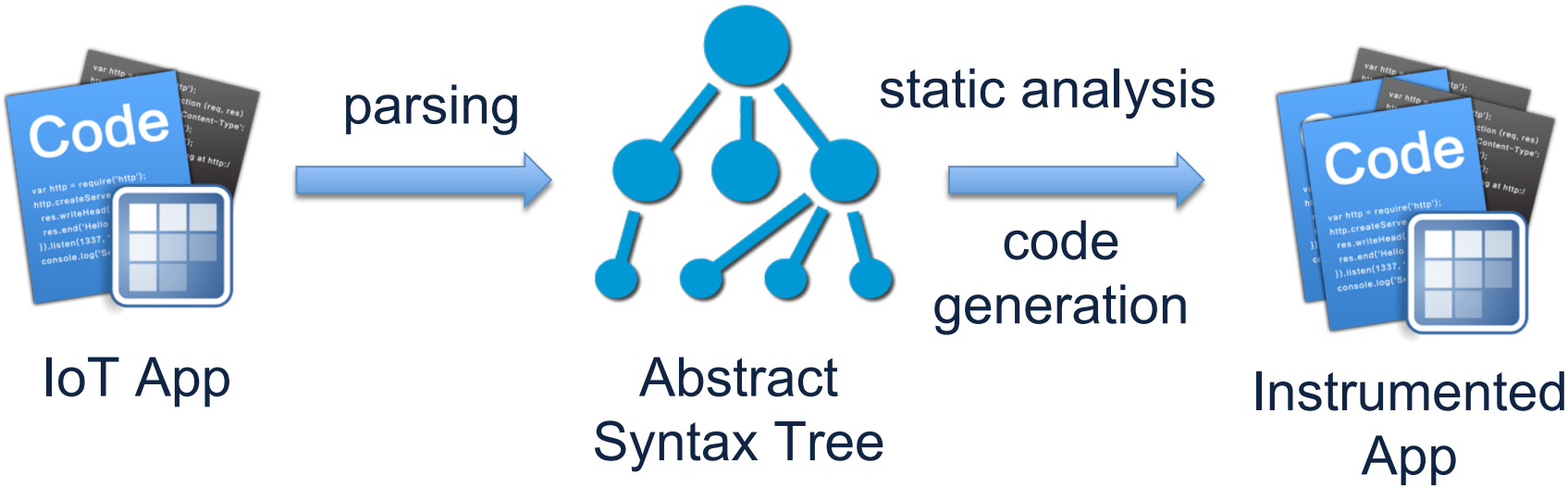
- ProvThings collects provenance metadata from *different* components in an IoT platform
  - IoT Apps
  - Device APIs (handlers)

- ProvThings uses *automated program instrumentation* to collect provenance metadata in a program
  - Minimally invasive to existing platforms



Instrumentation-based Collection

- ProvThings instruments IoT programs statically before a program is submitted for execution
  - Control flow and data flow analysis



- The instrumented code collects provenance metadata at runtime
  - Data creations, data derivations and actions

Instrumentation Example

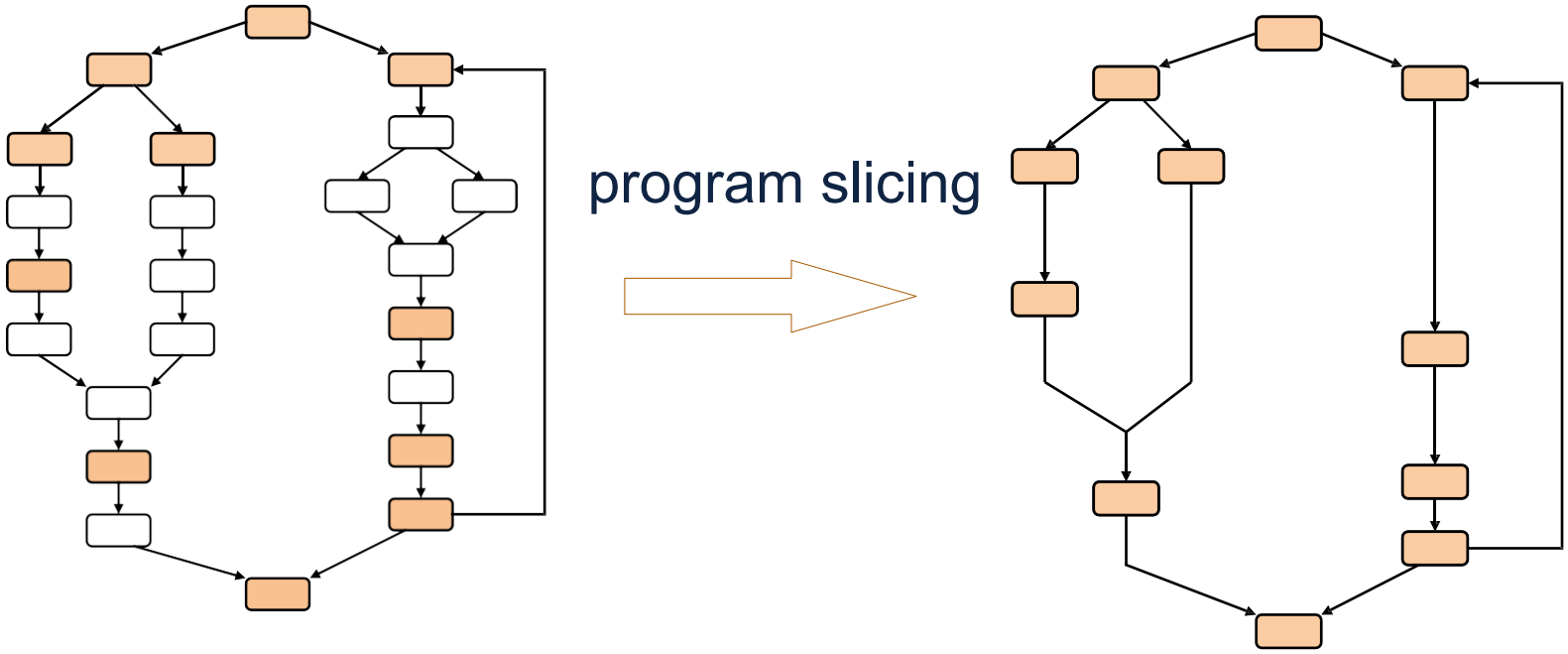
```
1   preferences {
2     input "lock", "capability.lock"
3   }
4   def installed() {
5     subscribe(lock, "lock", eventHandler)
6   }
7   def eventHandler(evt){
8
9
10    def name = evt.name
11
12    def value = evt.value
13
14    log.debug "Lock event: $name, $value"
15
16    def msg = "Lock event data:" + value
17
18    httpPost("http://www.domain.com", msg)
19
20  }
```

After Instrumentation

```
1  preferences {
2    input "lock", "capability.lock"
3  }
4  def installed() {
5    subscribe(lock, "lock", eventHandler)
6  }
7  def eventHandler(evt){
8    def scope = [:]
9    entryMethod(scope, "eventHandler", "evt", evt)
10   def name = evt.name
11   trackVarAssign(scope, "name", "evt")
12   def value = evt.value
13   trackVarAssign(scope, "value", "evt")
14   log.debug "Lock event: $name, $value"
15   trackCall(scope,"log.debug",["value", "name"], ["Lock
       event: $name, $value"])
16   def msg = "Lock event data:" + value
17   trackVarAssign(scope, "msg", "value")
18   httpPost("http://www.domain.com", msg)
19   trackSink(scope,"httpPost","msg", ["http://www.domain.com
       ",msg])
20 }
```

Selective Code Instrumentation

- To avoid collecting *unnecessary* provenance metadata, ProvThings performs *source-sink* based instrumentation
  - **Source**: a security sensitive data object, e.g., the state of a lock
  - **Sink**: a security sensitive method/action, e.g., the unlock command



Slicing Example

```
1  preferences {
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7  def eventHandler(evt){
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16   def msg = "Lock event data:" + value
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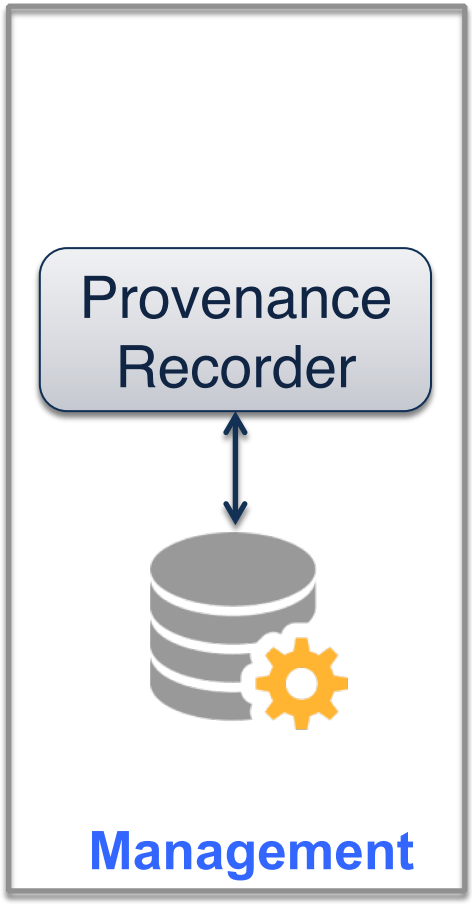
18   httpPost("http://www.domain.com", msg)
19
20 }
```

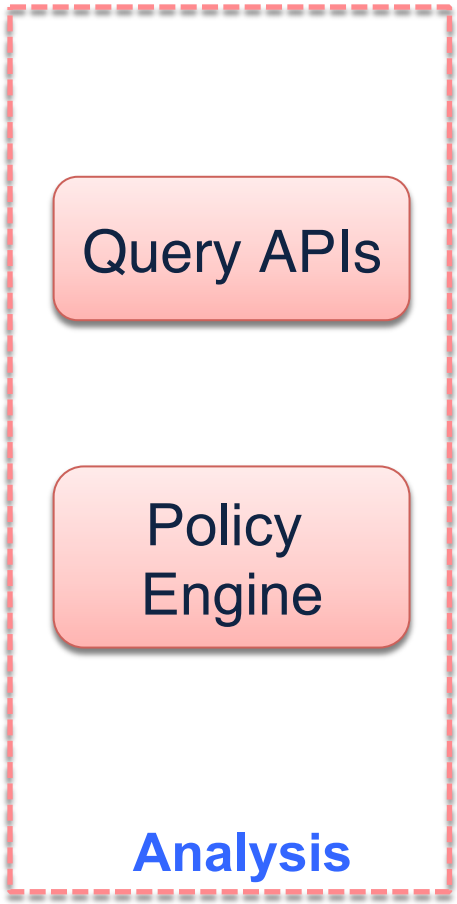
Provenance Management

- Process provenance metadata collected from different components
  - Aggregation, merging and filtering
- Convert metadata into a *unified* IoT provenance model and build provenance graphs
- Provide modular support to store provenance graphs into different storage backends



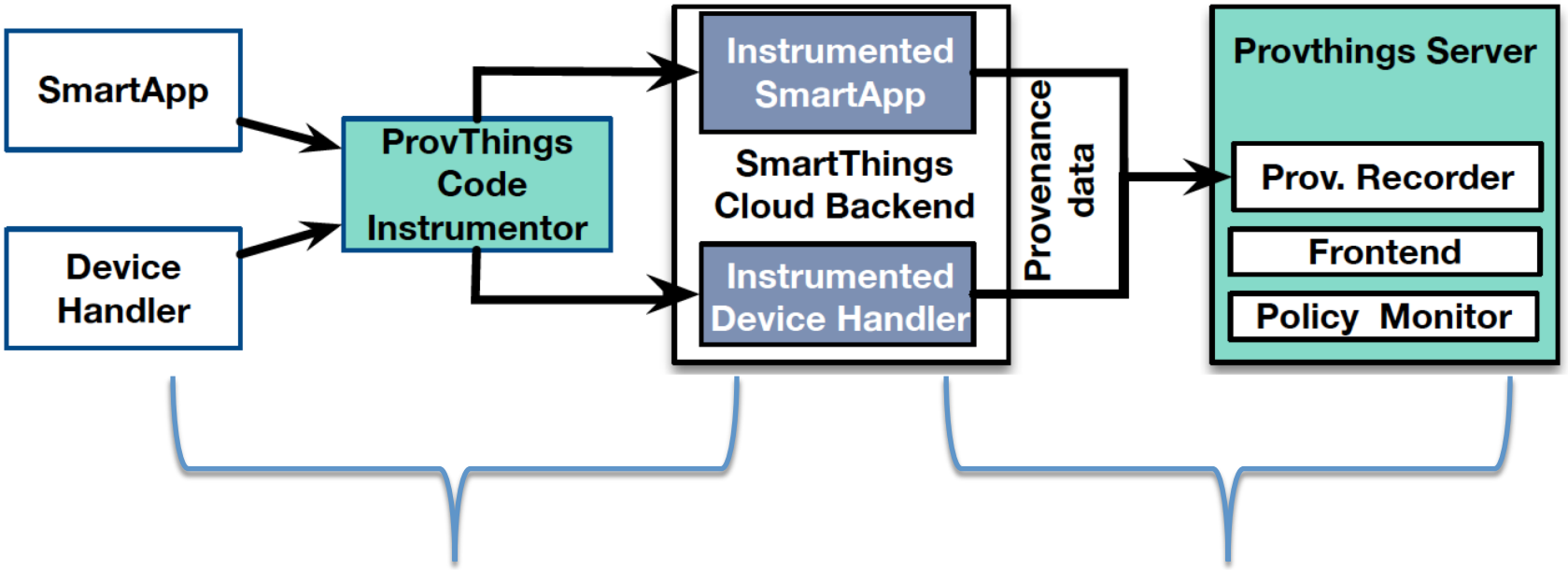
Provenance Analysis

- Query APIs
  - Forward and backward dependency analysis
- The policy engine allows specification of policies in the form of graph pattern
  - a sequence of activities
- The policy monitor queries the provenance graphs every time new records are added
  - Policy enforcement



Implementation

- We prototype ProvThings on Samsung SmartThings platform



Evaluation

- ***Datasets***
  - SmartApps of 26 possible IoT attacks[1] for effectiveness
  - 236 commodity SmartApps for performance

- ***Effectiveness***: *ProvThings was able to accurately reconstruct all the 26 tested IoT attacks!!*

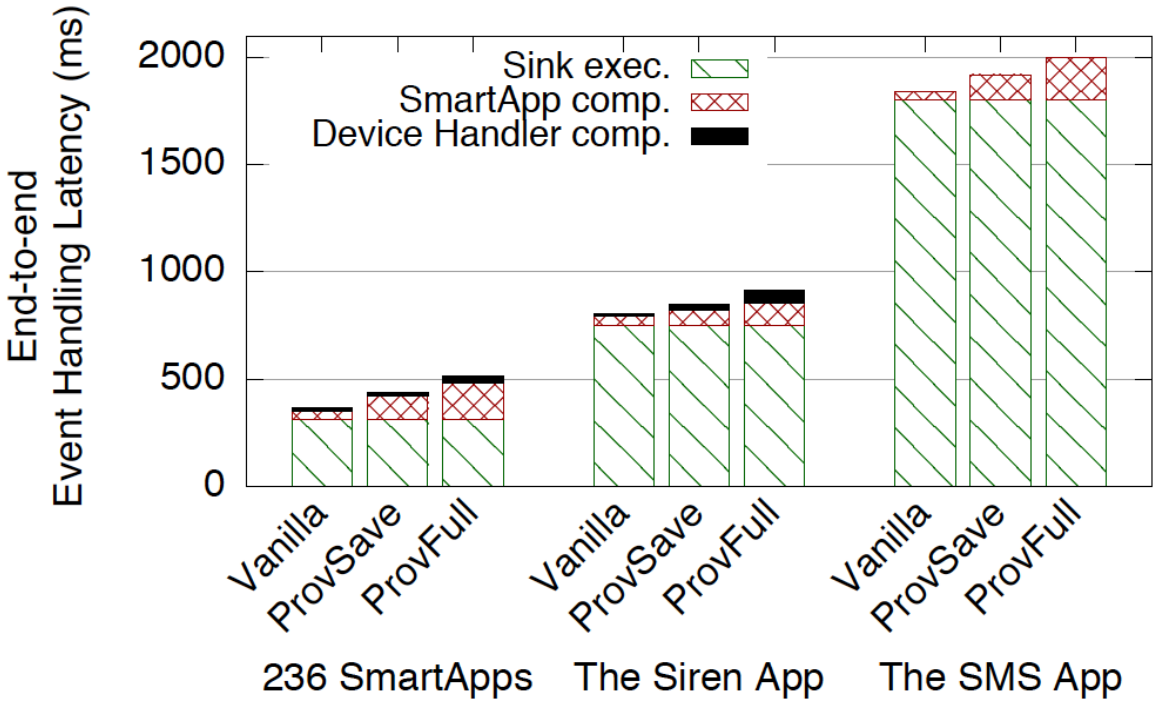
- ***Instrumentation overhead***: 34 ms for SmartApps and 27 ms for a Device Handlers. (*Note: one time cost!*)

- ***Storage overhead:*** *Just 260 KB of storage for daily use!!*

[1]" ContexIoT, *Jia et al. NDSS' 17*

Evaluation (Cont.)

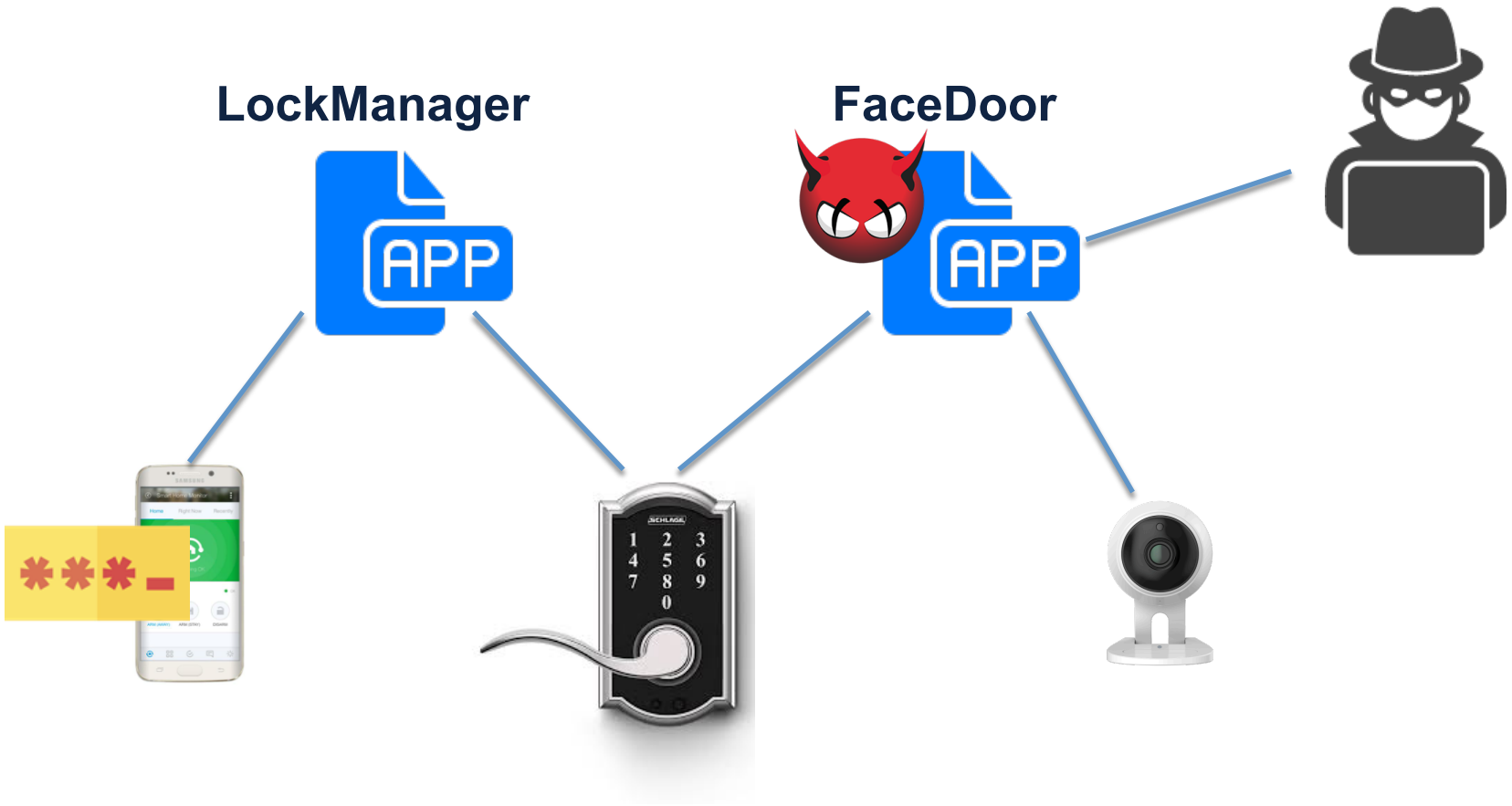
- ***End-to-end latency***
  - Tested on both virtual and physical devices
    - 20.6% latency on virtual devices
    - 4.5%~5.3% latency on physical devices



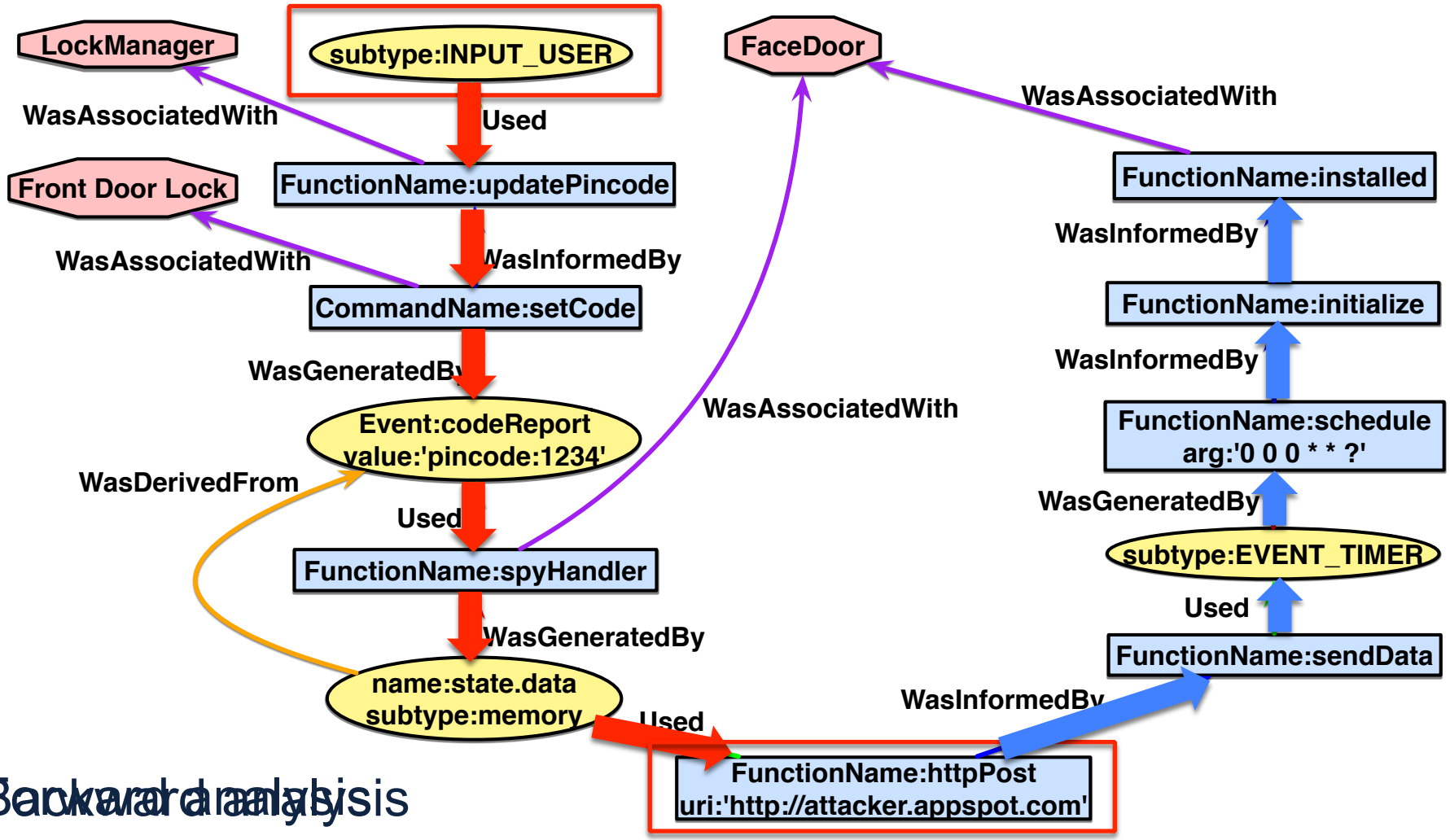
Breakdown of end-to-end event handling latency overhead

Case Study: Information Leakage

- **LockManager** is an app that updates or deletes lock pin codes.
- **FaceDoor** is an app that unlocks a door via face recognition using the front door camera.



Investigation



Backward analysis

Summary

- ProvThings is a general and practical framework for the capture, management and analysis of data provenance in IoT

- ProvThings is a first step towards providing solutions for different IoT stakeholders
  - System diagnosis, debugging, monitoring, investigation and access control

Questions?

Thank you for your time!

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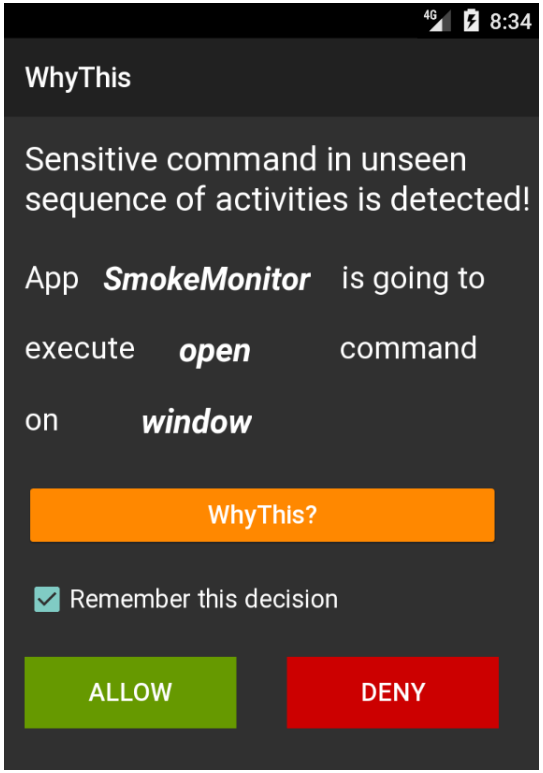
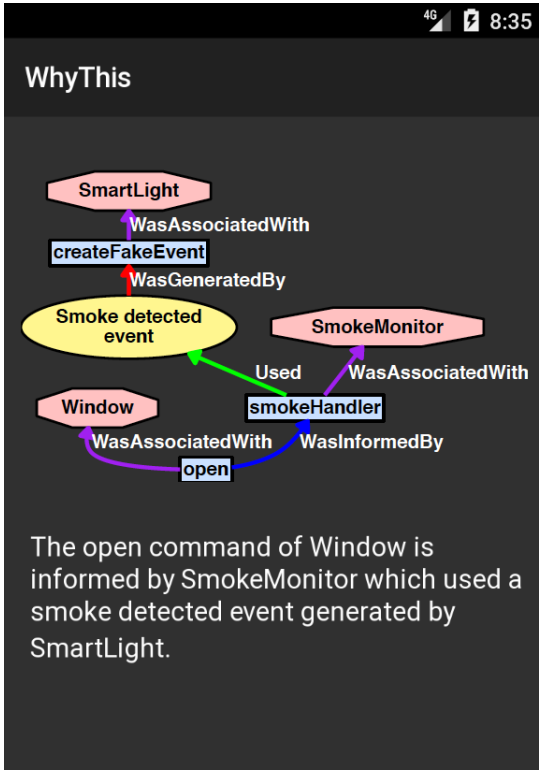
Backup slides

Consumer Application

- For typical consumers, we provide ***WhyThis?*** to explain unseen sequence of activities and allows them to allow or deny such activities.





Threat Model & Assumptions

- Malicious API-level attacks
  - Malicious apps
  - Device vulnerability
  - Proximity
- Accidental app misconfigurations

- Assumptions
  - We assume the devices are not compromised
  - We assume the entity responsible for executing the IoT's central management logic is not compromised
    - SmartThings cloud

User Scenarios

- ProvThings provides different frontends to meet the needs of a variety of stakeholders in the IoT ecosystem
  - Professionals could use the query APIs to investigate abnormal behaviors in their customers' homes
  - Techies could use the policy engine to create customized policies for their smart homes
  - Typical users could use the consumer app to understand and react to peculiar events that happening in their smart homes

Policy Engine

- Policy format

```
pattern:{   }
check:   exist | not exist
action: notify | allow | deny
```

- Policy example

```
pattern:{
  MATCH (a:DEVICE_CMD {name:"setCode"}) WasOriginatedFrom
        (b:INPUT_HTTP {name:"HTTP Request"}),
        (c:DEVICE {name:"Front Door Lock"})
  WHERE a.agentid = c.id
  RETURN a
}
check: exist
action: notify
```

IoT Provenance Model

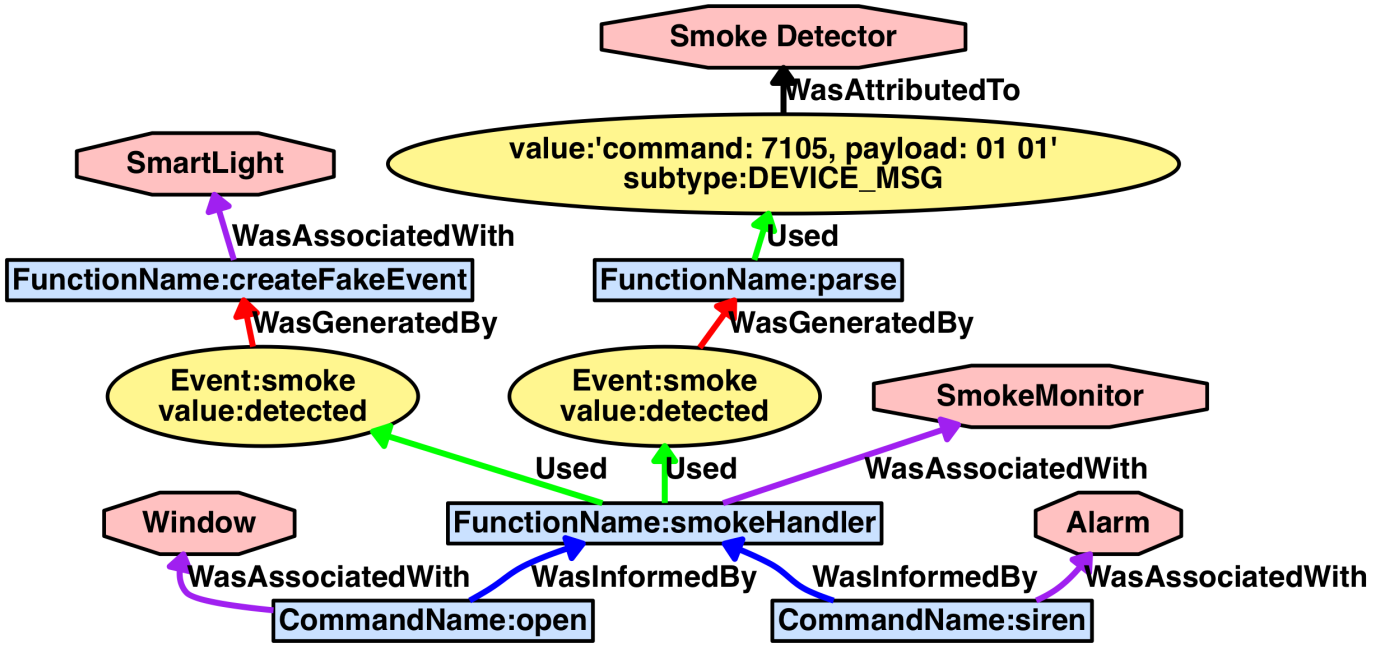
Concept	*Description*	*PORV Model*	*Subtype*
App	*An application in a IoT platform*	*Agent*	*APP*
Device	*A smart device in a platform.*	*Agent*	*DEVICE*
Device command	*A action supported by a device.*	*Activity*	*DEVICE_CMD*
Device event	*An object that represents a state change on a device.*	*Entity*	*EVENT_DEVICE*

Policy for the example

```
pattern:{
  MATCH (a:SINK)-[:Used]->(b:Entity),
        (c:APP_IOT {name:"FaceDoor"})
  WHERE a.agentid=c.id and
        (a.uri<>"http://trust.me" || b.taint <> "
     ImageCapture")
  RETURN a
}
check: exist
action: notify
```

Fake Device Events

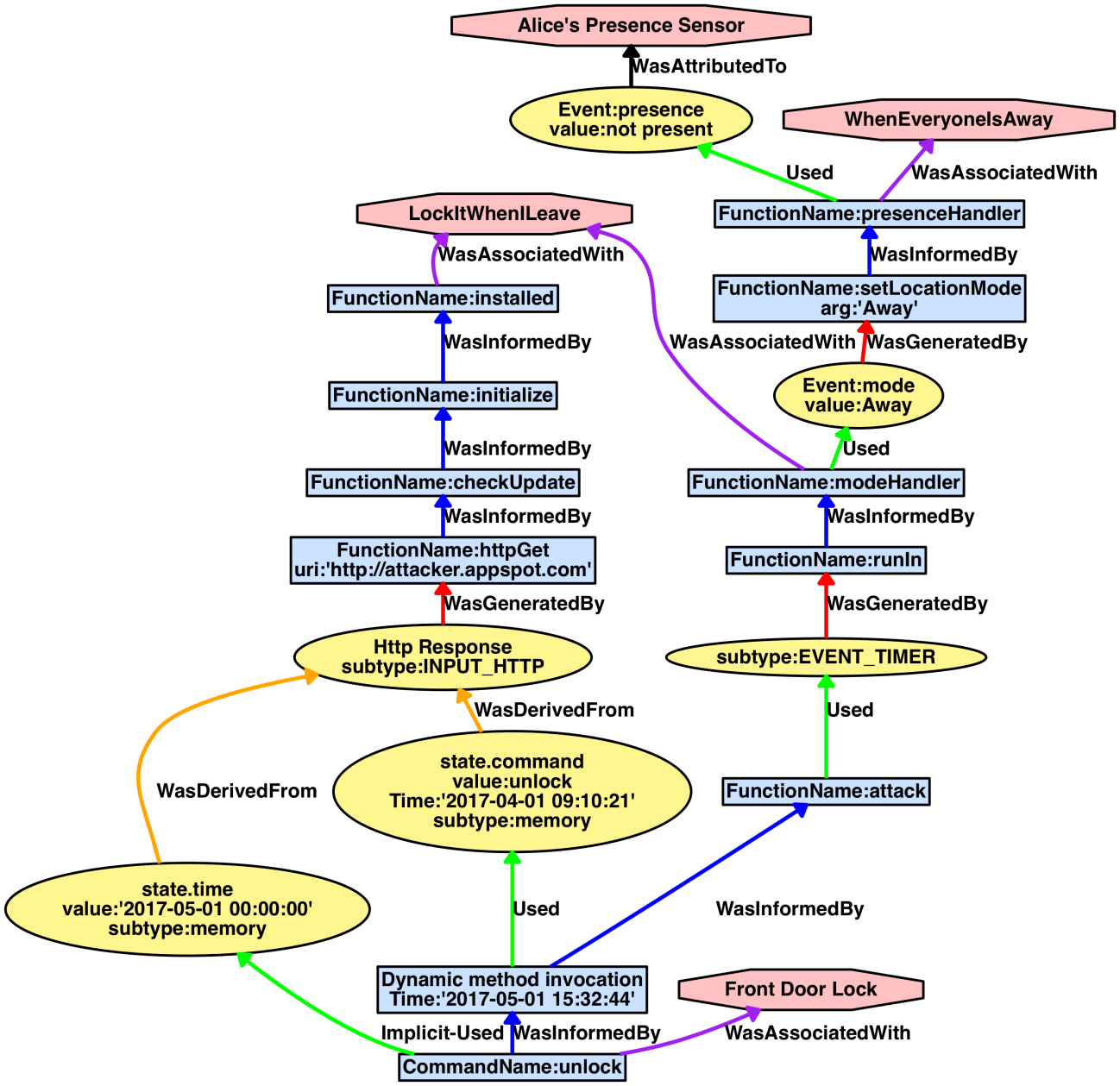
- **SmokeMonitor** is an app which will open the Window and sound the Alarm if smoke is detected by the Smoke Detector.
- **SmartLight** is a malicious app which will raise fake physical device events for Smoke Detector.



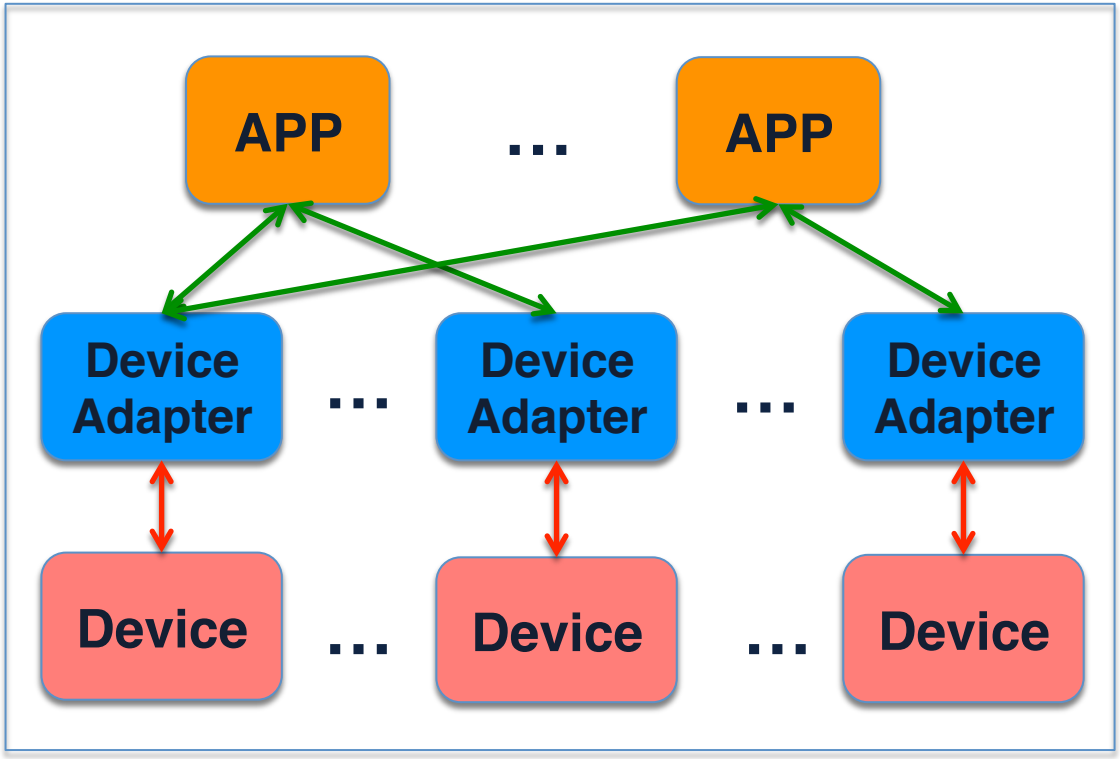
Remote Command

- **WhenEveryoneIsAway** is an app sets the mode of a home to Away when everyone has left home.

- **LockItWhenILeave** is an app locks the door when the mode is set to Away. However, when installed, the app will query a malicious domain to get an attack command and time. It waits until everyone is away to execute the attack command.


Alice's Presence Sensor
WasAttributedTo
Event:presence
value:not present
WhenEveryoneIsAway
Used
WasAssociatedWith
LockItWhenILeave
FunctionName:presenceHandler
WasAssociatedWith
WasInformedBy
FunctionName:installed
FunctionName:setLocationMode
arg:'Away'
WasInformedBy
WasAssociatedWith
WasGeneratedBy
FunctionName:initialize
Event:mode
value:Away
WasInformedBy
Used
FunctionName:checkUpdate
FunctionName:modeHandler
WasInformedBy
WasInformedBy
FunctionName:httpGet
uri:'http://attacker.appspot.com'
FunctionName:runIn
WasGeneratedBy
WasGeneratedBy
Http Response
subtype:INPUT_HTTP
subtype:EVENT_TIMER
WasDerivedFrom
Used
WasDerivedFrom
state.command
value:unlock
Time:'2017-04-01 09:10:21'
subtype:memory
FunctionName:attack
state.time
value:'2017-05-01 00:00:00'
subtype:memory
Used
WasInformedBy
Dynamic method invocation
Time:'2017-05-01 15:32:44'
Front Door Lock
Implicit-Used
WasInformedBy
WasAssociatedWith
CommandName:unlock

IoT Platforms



IoT APP

Device Abstraction

Heterogeneous Devices

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9    def value = evt.value
10   log.debug "Lock event: $name, $value"
11   def msg = "Lock event data:" + value
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13 }
```