# ContexIoT: Towards Providing Contextual Integrity To Appified IoT Platform

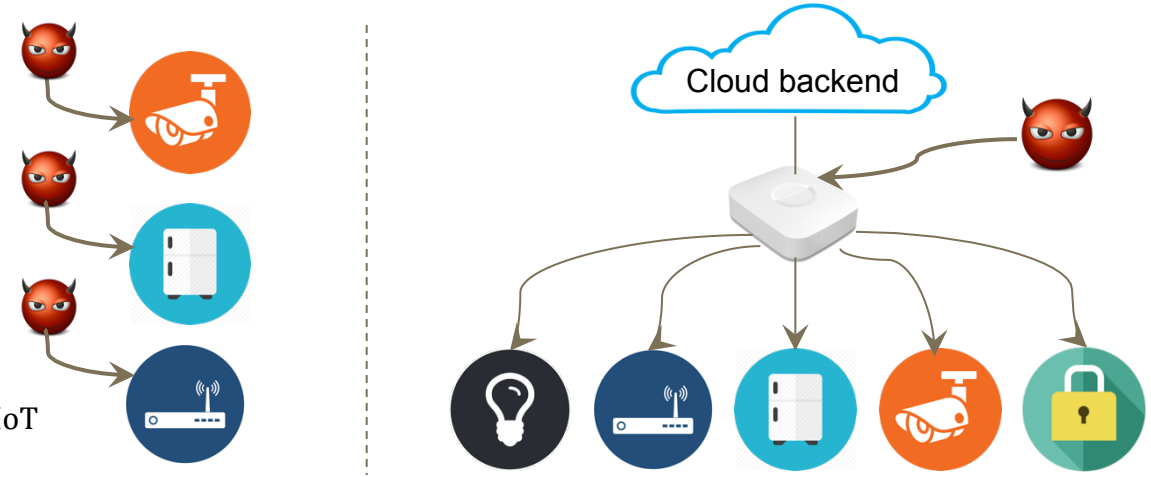
Yunhan Jack Jia, Qi Alfred Chen, Shiqi Wang, Amir Rahmati,
Earlence Fernandes, Z.Morley Mao, Atul Prakash

University of Michigan

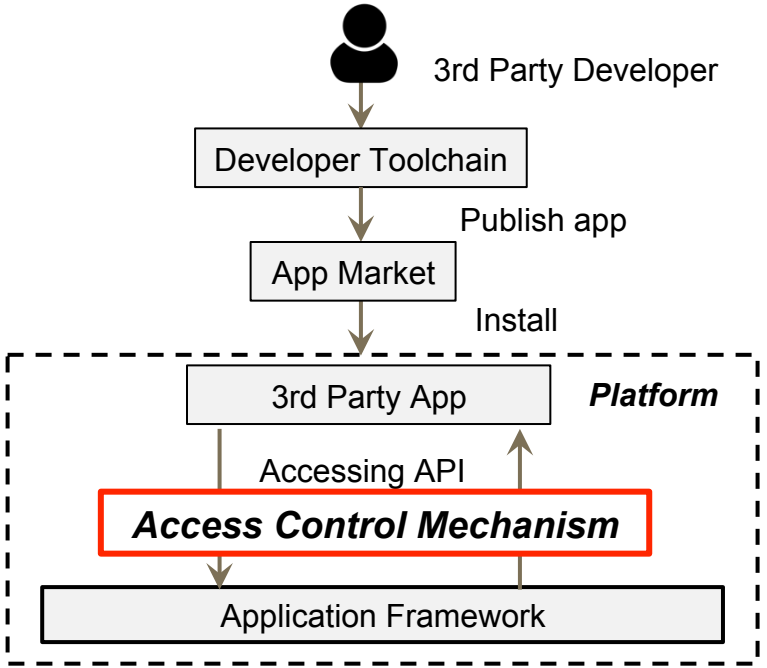
# Appified Platform

- Software platform that supports 3rd-party app development


- Emerging IoT threats ( *conventional* **vs.** *appified* )



# The Ecosystem and Threats

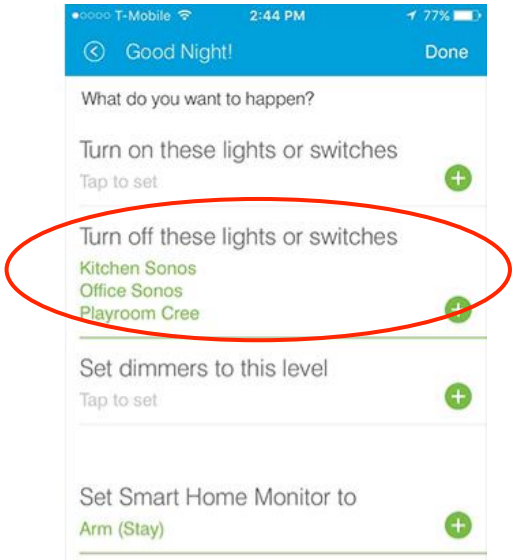



- **Problem** : allowing untrusted app to control the user's device
- **Solution** : access control system ( ***Permission system*** )

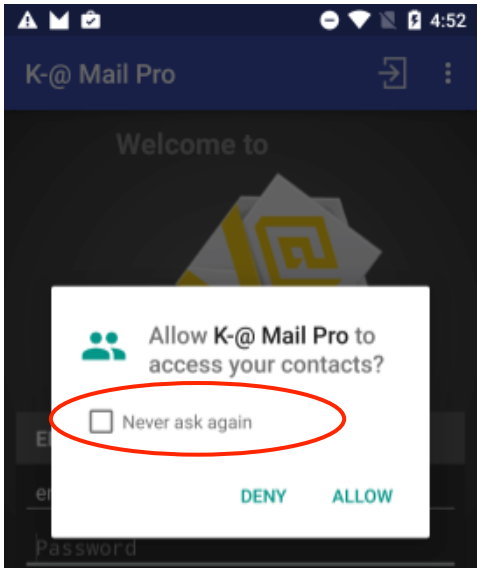
# Permission System: Practices & Limitations

Installation time prompts: decision made out-of-context

Runtime prompts: coarse-grained and insufficient




SmartThings app setup page




Android 6.0 runtime prompt

# Permission System: Practices & Limitations

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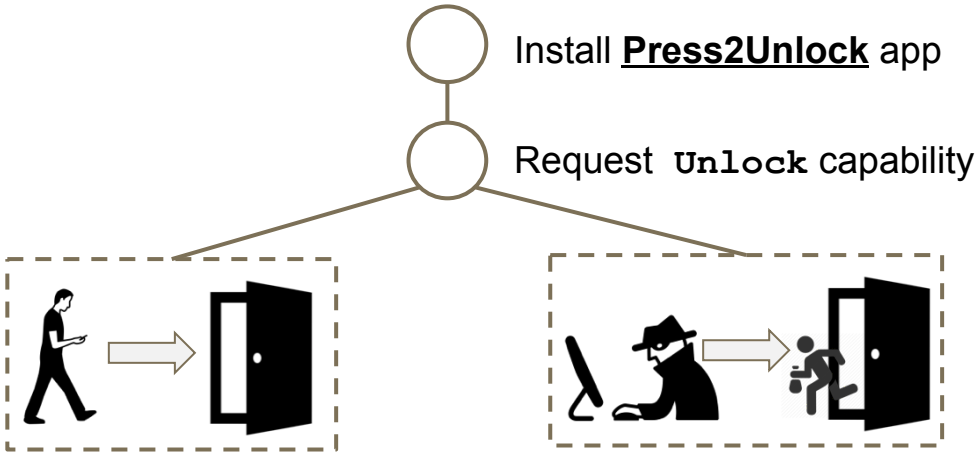



IoT malware example

Ideal access control needs to be **in context** and **sufficiently fine-grained**

# Contextual Integrity

- First appeared in  “Washington Law Review 2004”
  - Advocated as a benchmark for privacy
- Contextual integrity for access control
  - *A permission granted to an app shall only allow the app behavior under that specific context, in which the permission is granted.*

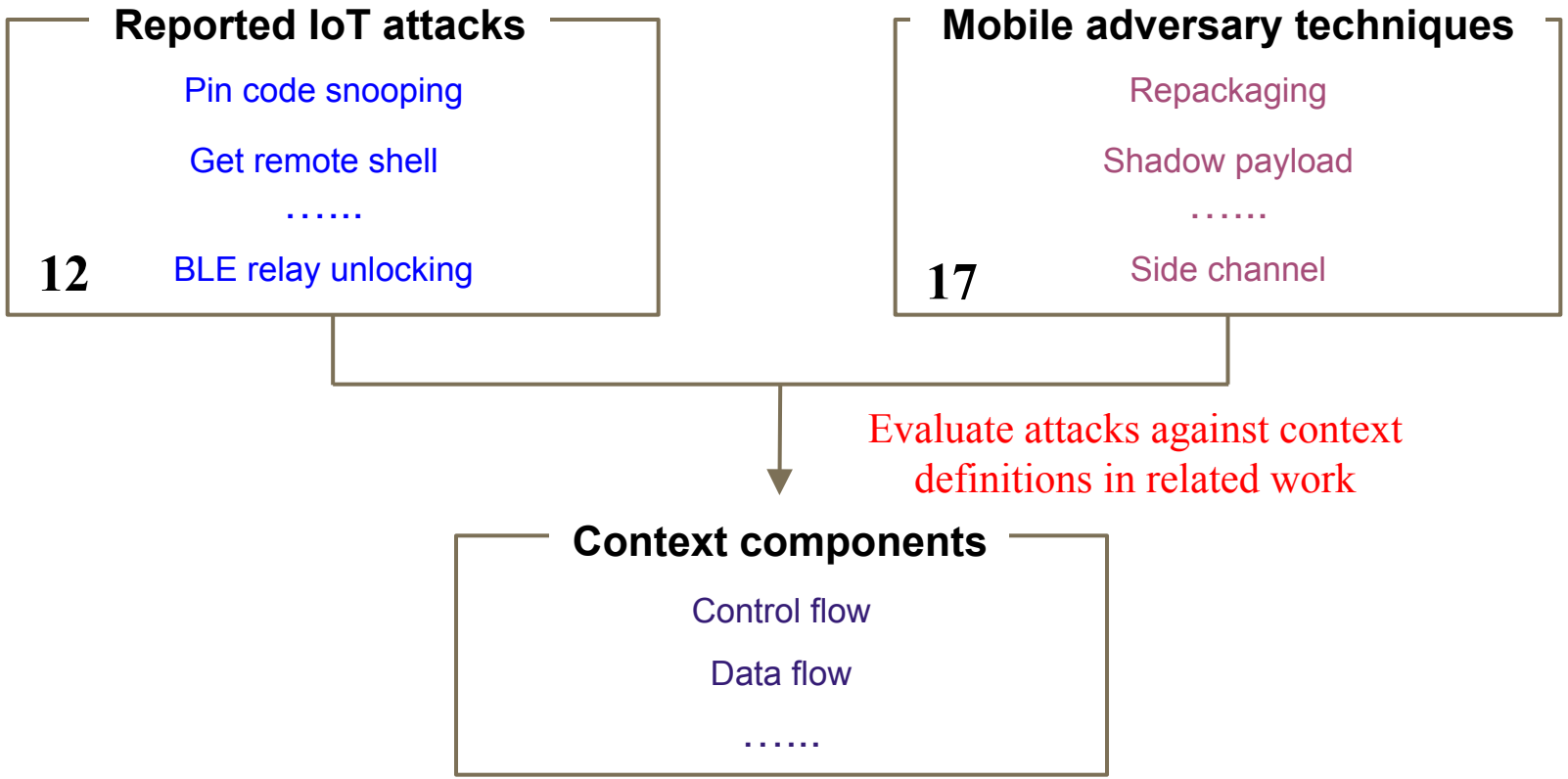
$$Context(T_{using}) == Context(T_{granted})$$

- Requirements for the context:
  - **Distinguishable** : differentiate context upon permission request
  - **Meaningful** :  tell benign from malicious

1. How to define context in an access control system for IoT?

2. How to enforce its integrity in the IoT apps?

# Attack Taxonomy Methodology

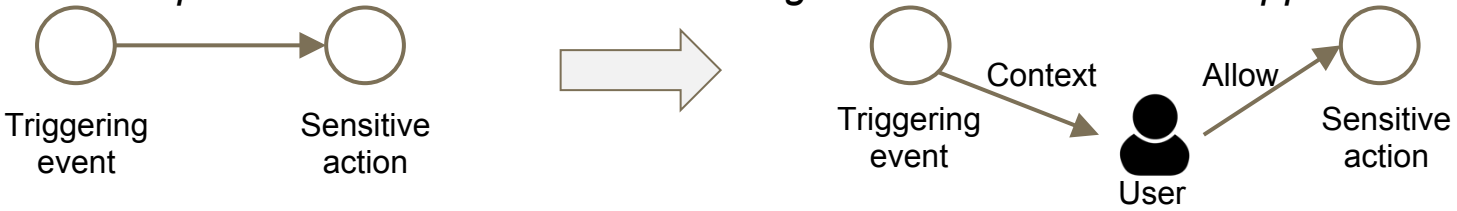


# Context Definition

| Related work | Context components | | | | | ***Decision made in context?*** |
|---|---|---|---|---|---|---|
| | *UID/GID* | *UI Activity* | *Control flow* | *Runtime value* | *Data flow* | |
| ACG | ✔ | ✔ | ✘ | ✘ | ✘ | ✔ |
| CRePE | ✔ | ✘ | ✘ | ✔ | ✘ | ✘ |
| AppContext | ✔ | ✘ | ✔ | ✘ | ✔ | ✘ |
| AppFence | ✔ | ✘ | ✘ | ✘ | ✔ | ✘ |
| Aurasium | ✔ | ✔ | ✘ | ✔ | ✘ | ✔ |
| FlaskDroid | ✔ | ✘ | ✘ | ✔ | ✘ | ✘ |
| SEAndroid | ✔ | ✘ | ✘ | ✘ | ✘ | ✘ |
| SEACAT | ✔ | ✔ | ✘ | ✔ | ✘ | ✔ |
| TaintDroid | ✔ | ✔ | ✘ | ✔ | ✔ | ✔ |
| TriggerScope | ✔ | ✘ | ✔ | ✘ | ✔ | ✘ |
| ***ContexIoT*** | ✔ | N/A | ✔ | ✔ | ✔ | ✔ |

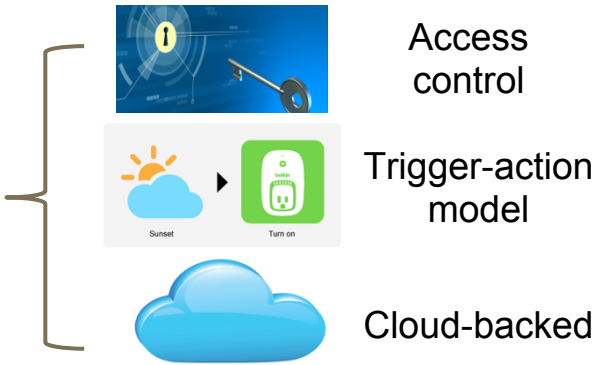
# ContexIoT Design Goal

- Objective: *Prompt user with essential context to grant access to desired app behavior*



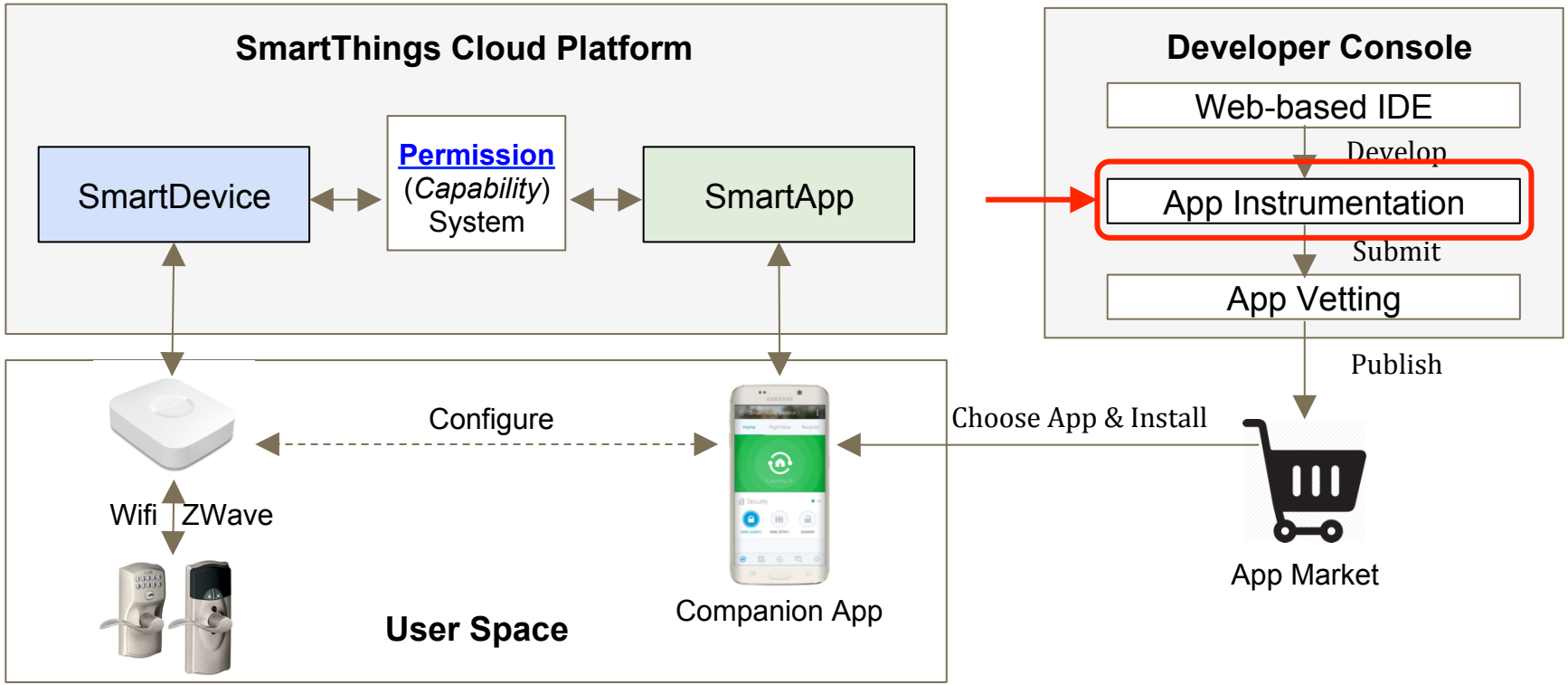

Why *SmartThings*:

- Relatively mature: 500~ apps, 150~ devices
- Sharing design principles with other platforms




- Design challenge: limited access to the cloud-backed IoT platform

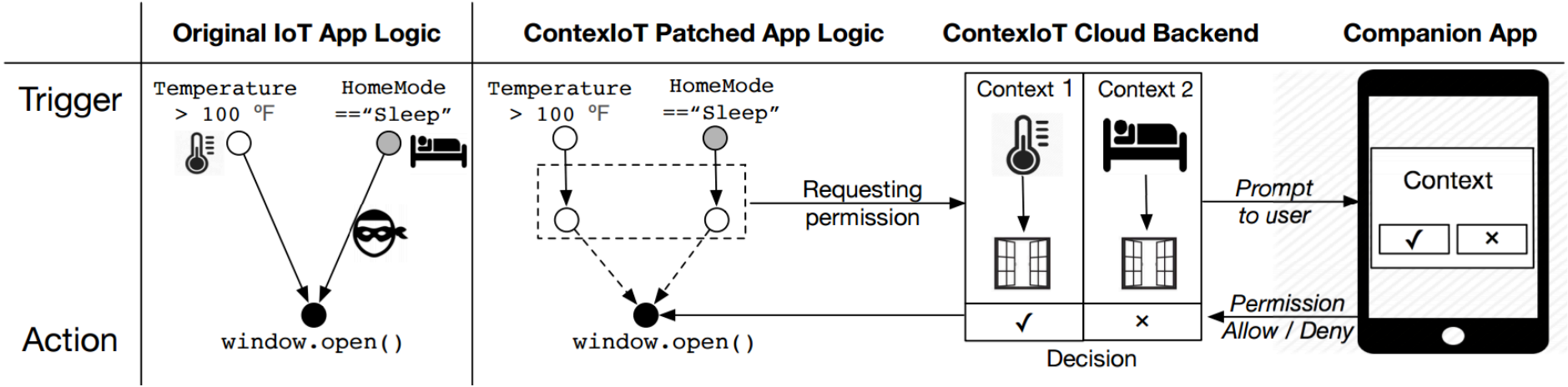
# Design: SmartThings Background




Cloud-backed SmartThings Ecosystem

# ContexIoT Design

- Patch SmartApps with the access control logic




$Context(T_{using}) == Context(T_{granted})$?

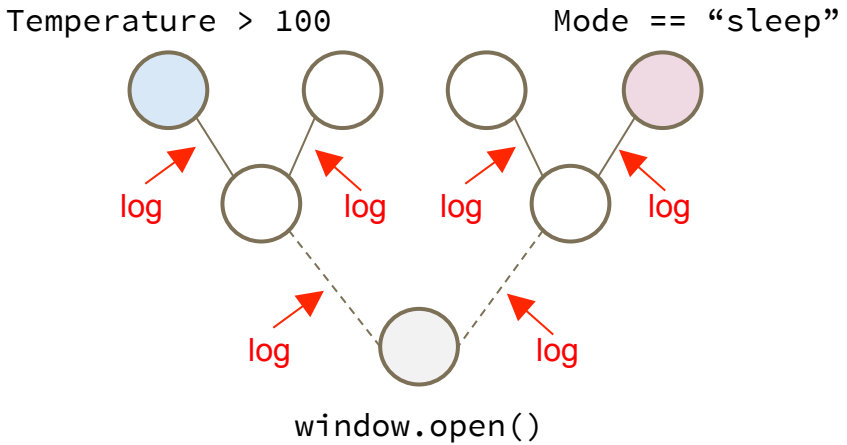
`Reuse() : Prompt()`

Context collection logic

End-to-end secure logic

# Implementation: Context Collection

- Patch SmartApp with context collection logic
  - Naive approach: add runtime logging to the entire instruction set
  - To reduce runtime overhead, use offline static analysis to:
    - **Prune**: Identify a subset of app code that requires runtime logging
    - **Precompute**: calculate context information that is deterministic



# Static Analysis: Precompute Context

- Precompute intra-procedure context that are deterministic
  - Chained later to construct complete context according to the call trace
  - **GString** -- dynamic feature in Groovy

```groovy
def temperatureHandler(evt)
{
    if(100<evt.value){
        window.open() //sink1
    }
}
def requestHandler(evt)
{
    def command = evt.params
    if("open" == command){
        window.open() //sink2
    }
}
```

```groovy
def intra_context_sink1="[
    {type: 'func', name: 'temeratureHandler', param: evt},
    {type: 'ifstmt',
        condition:[{left: evt.value, right: 100, op: '<'}],
        branch: true},
    {type: 'sink', entity: window, action: open, param: null}
]"
```

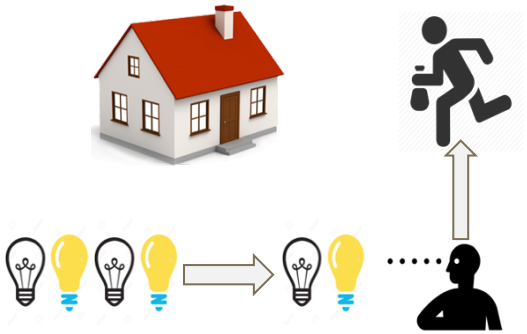
Open window when temperature goes high above 100

```groovy
def intra_context_sink2="[
    {type: 'func', name: 'requestHandler', param: evt},
    {type: 'ifstmt',
        condition:[{left: command, right: 'open', op: '=='}],
        branch: true},
    {type: 'sink', entity: window, action: open, param: null},
]"
```

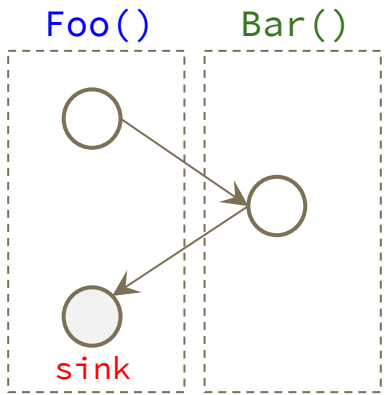
Open window when receiving network command

# Runtime Logging

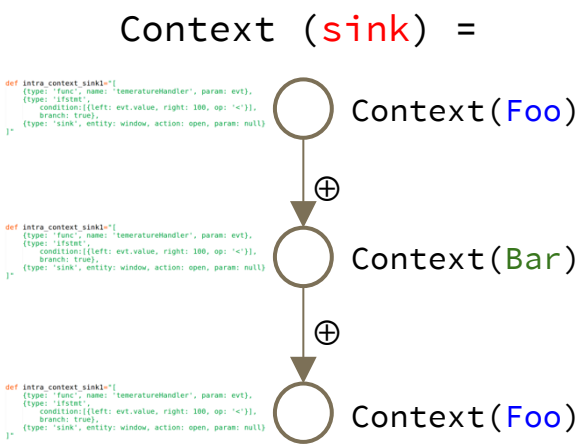
- Dynamic taint tracking for SmartThings' Groovy
  - Data dependency tracking: field-sensitive, implicit taint
    - E.g., luminance as side channel attack
  - Construct runtime context: maintain caller info for each method
    - Merge intra-procedure context based on the call stack



Luminance as side channel malware

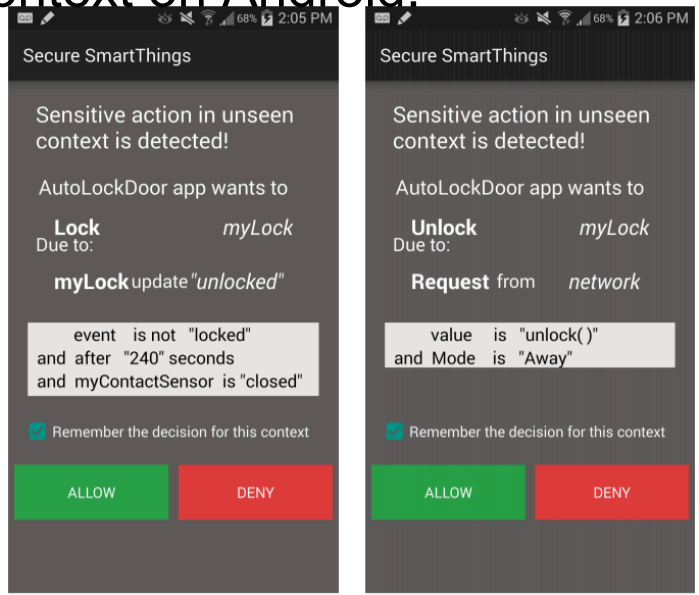



Runtime call stack



# End-to-end Implementation

- Patch the app with the context-based permission requesting logic
- A permission server to manage permission granting decisions
- Presentation of context on Android:




**Legitimate logic**: automatically lock door after 240 seconds

**Backdoor logic**: unlock the door when receiving network request

# Evaluation

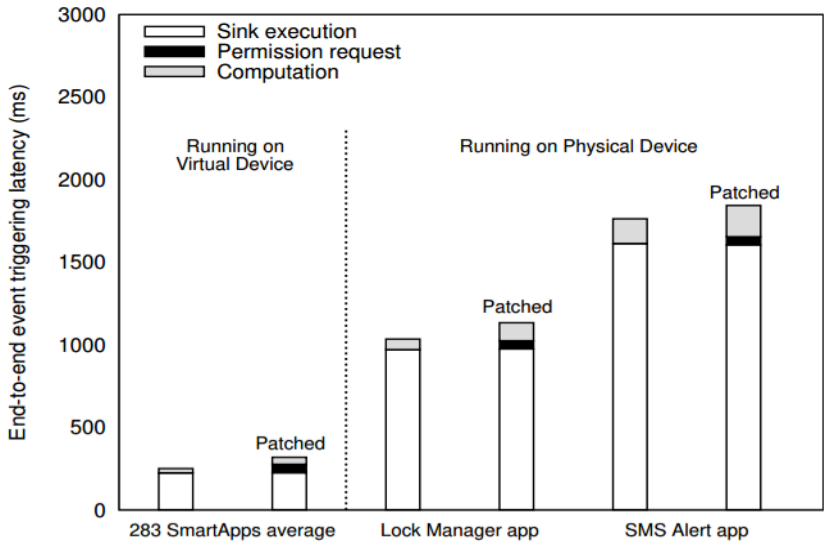
- Effectiveness:
  - Dataset: 283 commodity SmartApps, 25 malicious SmartApps created based on the evasion attack taxonomy, including 3 reported SmartThings malware[1]
  - Result:
    - Sensitive functionalities of all the SmartApps are correctly patched
    - Malicious paths of the 25 malware can be distinguished without ambiguity

- Prompt frequency:
  - Fuzz testing on the 283 commodity SmartApps by injecting events
  - Mean life-time permission prompts are only **3.5**

[1]"Secure Analysis of Emerging Smart Home Applications", *Fernandez et al. Oakland' 16*

# Evaluation (Cont'd)

- Performance overhead: latency
  - Tested on both virtual and physical devices
    - +26.7% latency on virtual devices
    - +4.5% ~ 9.6% latency on physical devices




Breakdown of the end-to-end event trigger latency on virtual and physical devices

# Conclusion and Future Work

Future Work:

Usability:  better presentation of context in IoT scenarios

Efficiency: adapt when app functionality is enriched

Conclusion:

A context definition that defeats known classes of malware on appified platforms

***ContexIoT*** approach that help enforce contextual integrity in IoT apps

We released our malware dataset:

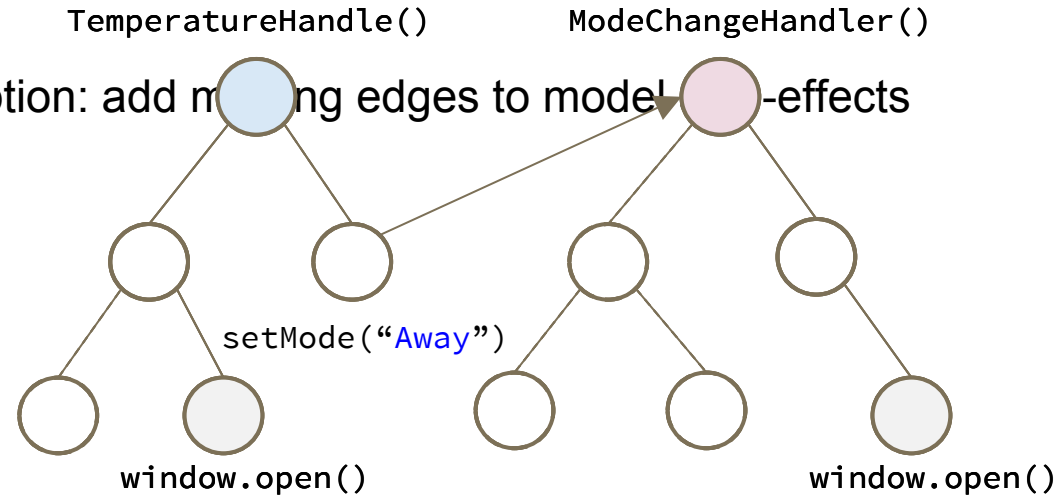
**https://tinyurl.com/contexIoT**

# Conclusion

# Backup

# Static Analysis: Pruning

- Instrument Groovy AST transformation to build CFG
  - Prune code that are not in the CFG from `Source` to `Sink`
  - Adapt to the trigger-action based programing model
  - Exception: add m ng edges to model -effects



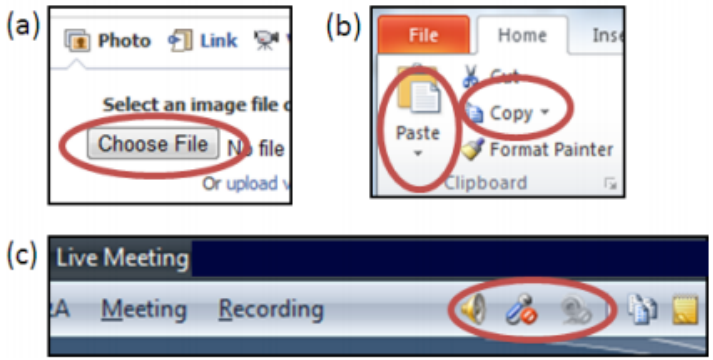
# Appification of IoT

- Evolution of software platform:

**Functional** | **Software Defined** | **Appified**

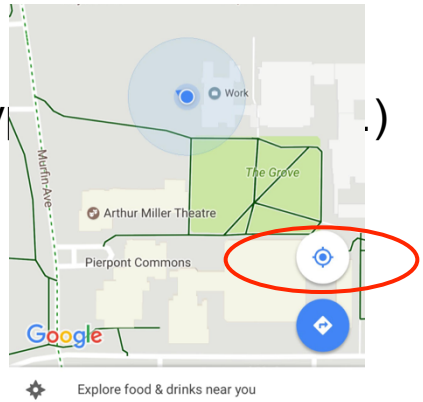

# Permission System Revisit: Implementations

- Contemporary implementations:
  - Install time prompt ( Android 5.x, SmartThings, … )
  - Runtime prompt (iOS, OSX, Windows, …)




Example Access Control Gadgets

rch prototy .)




Location button on Google Maps

# Appified Platform

- Software platform that supports 3rd party app development
- The evolution of software platform

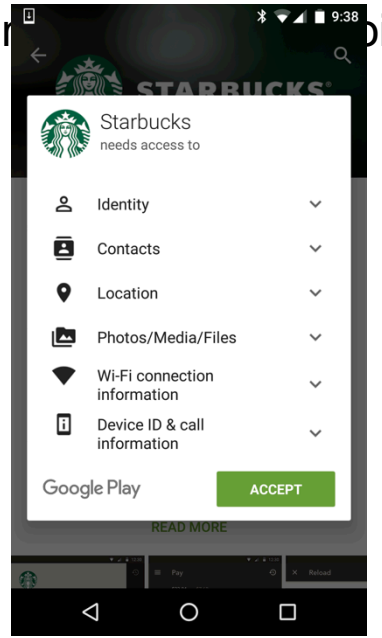
**Functional**

**Software Defined**

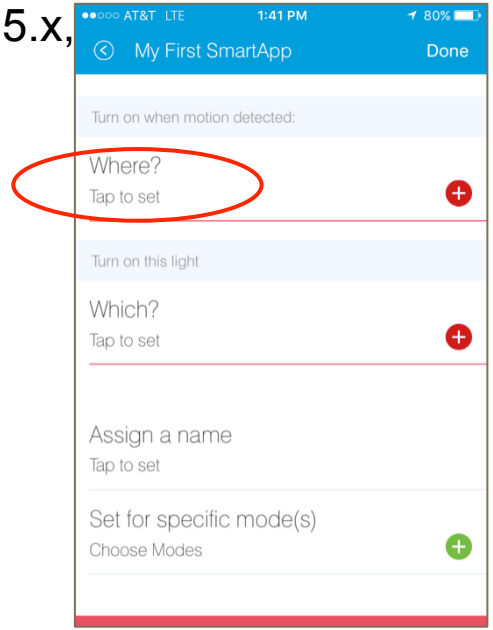
**Appified**


# Permission System Revisit: Implementations

- Contemporary implementations:
  - Install ti[illegible]oid before 5.x,



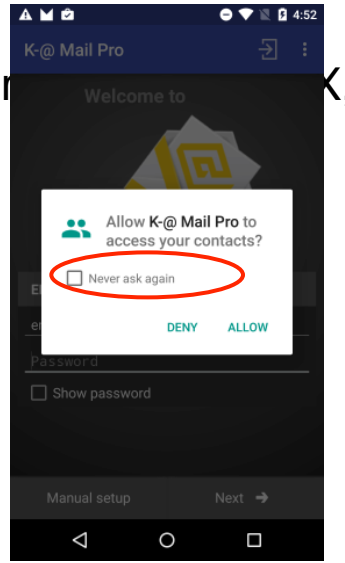

App installation on Android 5.0



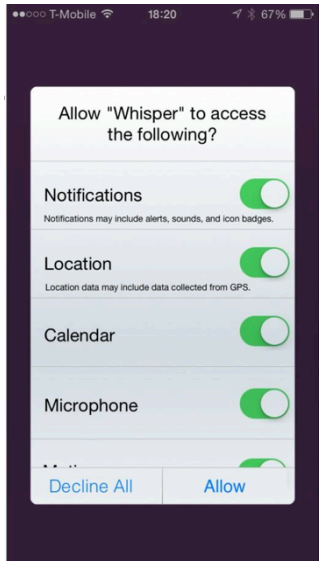

App installation on Samsung SmartThings

# Permission System Revisit: Implementations

- Contemporary implementations:
  - Install time prompt ( Android 5.x, SmartThings, … )
  - Runtime pr…X, Windows, …




Runtime prompt on Android 6.0




Runtime prompt on iOS 9.x

# Permission System Revisit: Limitations

Installation time and runtime prompt solutions:


Ideal access control needs to be **In-Context !**

# Providing Contextual Integrity to IoT Platform

| *Challenges* | *Solutions* |
| --- | --- |
| (1) **Definition** of context | [1] Extensive survey of evasion attacks |
| (2) **Availability** of context | [2] **ContexIoT** to extract context information |
| (3) **Frequency** of prompts | [3] Adapt context comparison to reduce prompts |

# Attack Taxonomy Methodology

- Extensive survey of attacks reported on
  - Existing IoT devices (12)
  - Smartphone platform (17)
- Construct misbehave SmartApps that achieve similar malicious functionality (25)
- Evaluate the attacks against representative work in permission evolution/revolution

# Context Definition

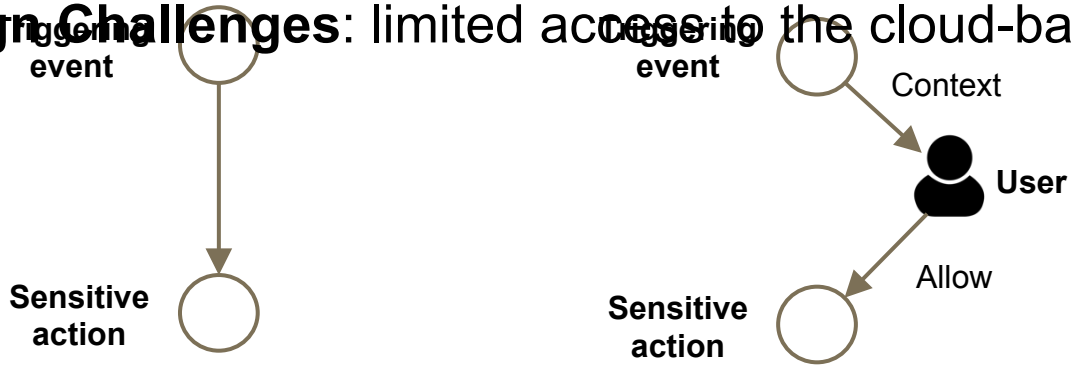
| Name | Description | Definition of context | | | | | Decision made in context? |
|---|---|---|---|---|---|---|---|
| | | Uid/Gid | UI Activity | Control flow | Runtime value | Data flow | |
| ACG [56] | User-driven access control | ✓ | ✓ | | | | ✓ |
| AppContext* [68] | Static context-based analysis for malware detection | ✓ | | ✓ | | ✓ | - |
| AppFence [41] | Protecting private data from being exfiltrated | ✓ | | | | ✓ | |
| Aurasium [67] | Repackaging app to attach policy enforcement code | ✓ | ✓ | | ✓ | | ✓ |
| CRePE [30] | Enforcing context-based fine-grained policy | ✓ | | | ✓ | | |
| FlaskDroid [25] | Fine-grained MAC on middleware and kernel layer | ✓ | | | ✓ | | |
| SEAndroid [60] | Flexible MAC for Android apps | ✓ | | | | | |
| SEACAT [31] | Integrating both MAC and DAC in the policy checks | ✓ | ✓ | | ✓ | | ✓ |
| TaintDroid [33] | Dynamic taint tracking and analysis system | ✓ | ✓ | | ✓ | ✓ | ✓ |
| TriggerScope* [39] | Static trigger-based analysis for malware detection | ✓ | | ✓ | | ✓ | - |
| ***ContexIoT*** | Providing contextual integrity to permission granting | ✓ | - | ✓ | ✓ | ✓ | ✓ |

* These work focus on detecting malicious behavior with static analysis, but not enforcing access control at runtime. However, their methodologies of distinguishing benign and malicious behavior are based on their definitions of context.

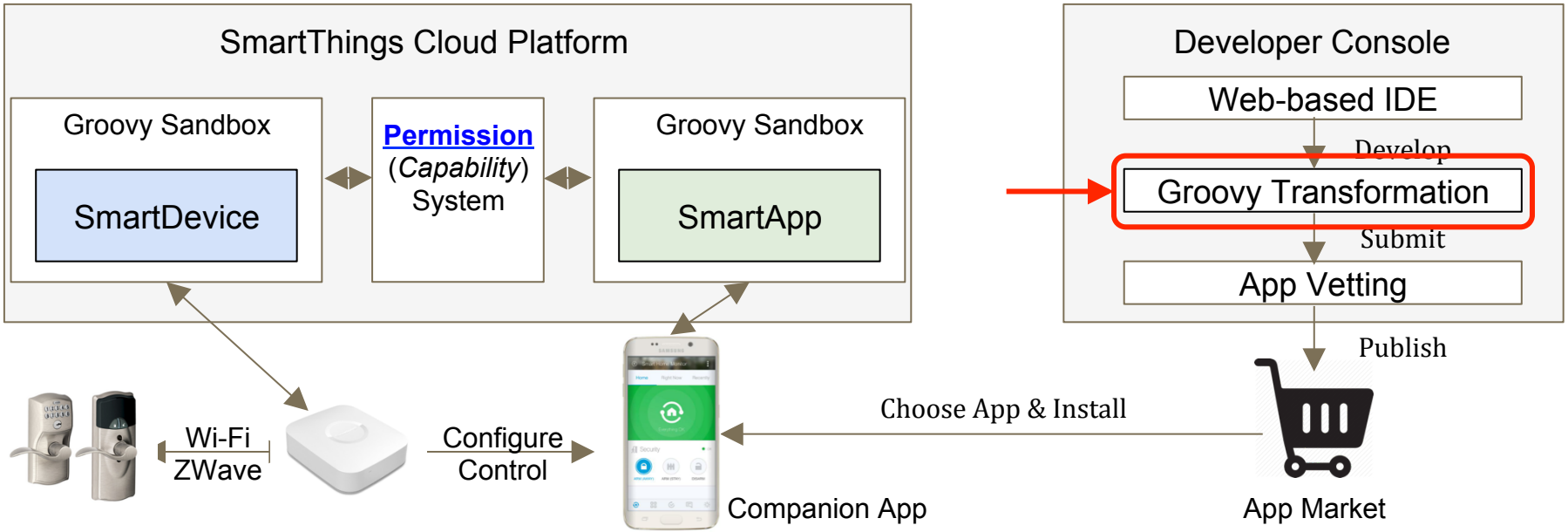
Context definition comparison among representative related work

# ContexIoT Design Goal

- **Objective**: *Prompt users with essential context to grant access to desired app behavior*
- Why SmartThings:
  - Relatively mature: 500~ apps, 1
- **Design Challenges**: limited access to the cloud-backed IoT platform



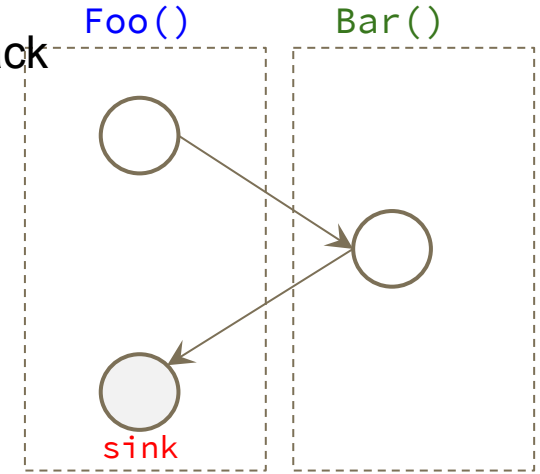
# Design: SmartThings Background




Cloud-baked SmartThings Ecosystem

# Runtime Logging: Construct Context

- Construct inter-procedural context
  - Reconstruct call stack by maintaining the caller function for each method
  - Construct context by assembling intra-procedure context based on the call stack




```
Context (sink) =
          Context(Foo)
  ⊕ Context(Bar)
  ⊕ Context(Foo)
```

# Outline:

- Methodology:
  - Attack & related work taxonomy
    - Extensive survey of evasion attacks to complete the definition of context
  - Design of ***ContexIoT*** on SmartThings platform, which
    - Collects essential context of IoT apps in real time
    - Enforces contextual integrity for each permission granting decisions
  - Evaluation on commodity apps and sample malware