# Verifying Security for Smart Homes

CSE 564 project

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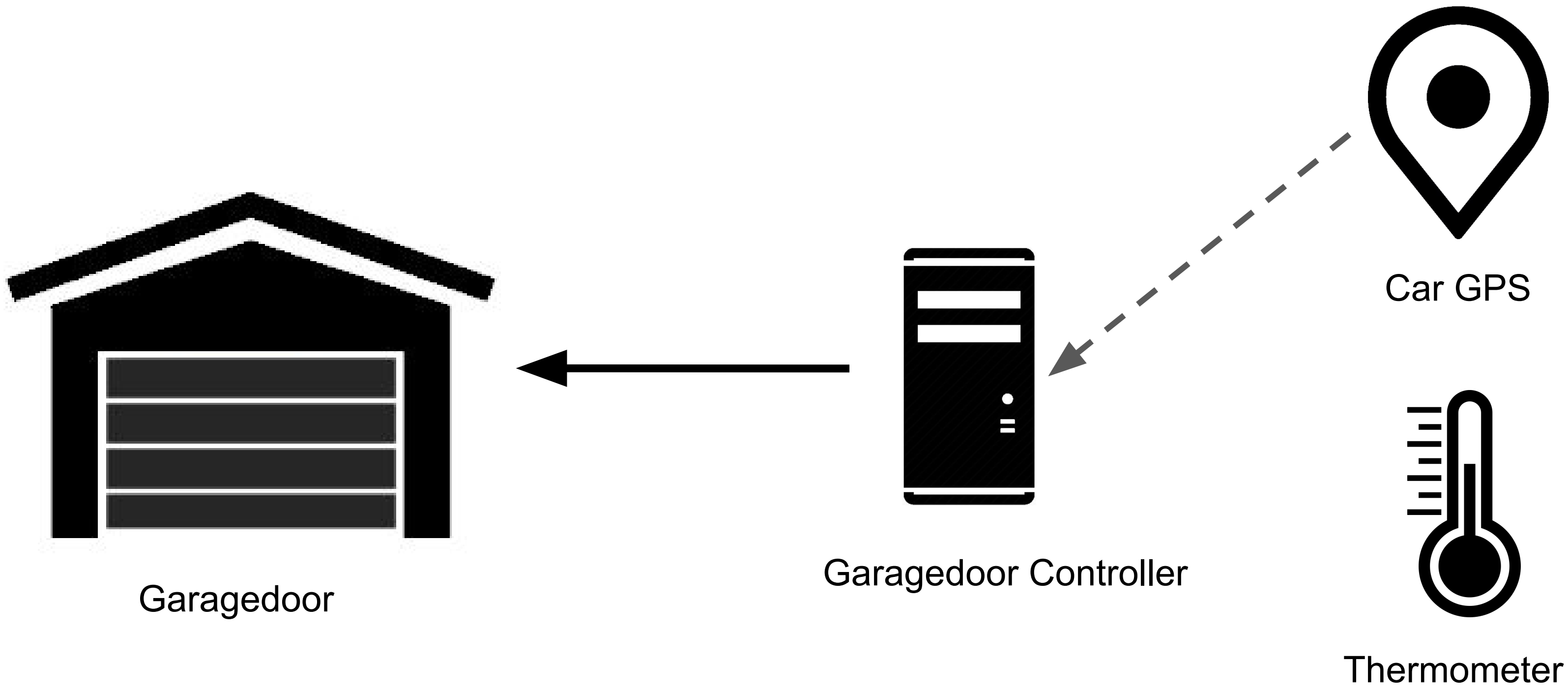
# Motivation



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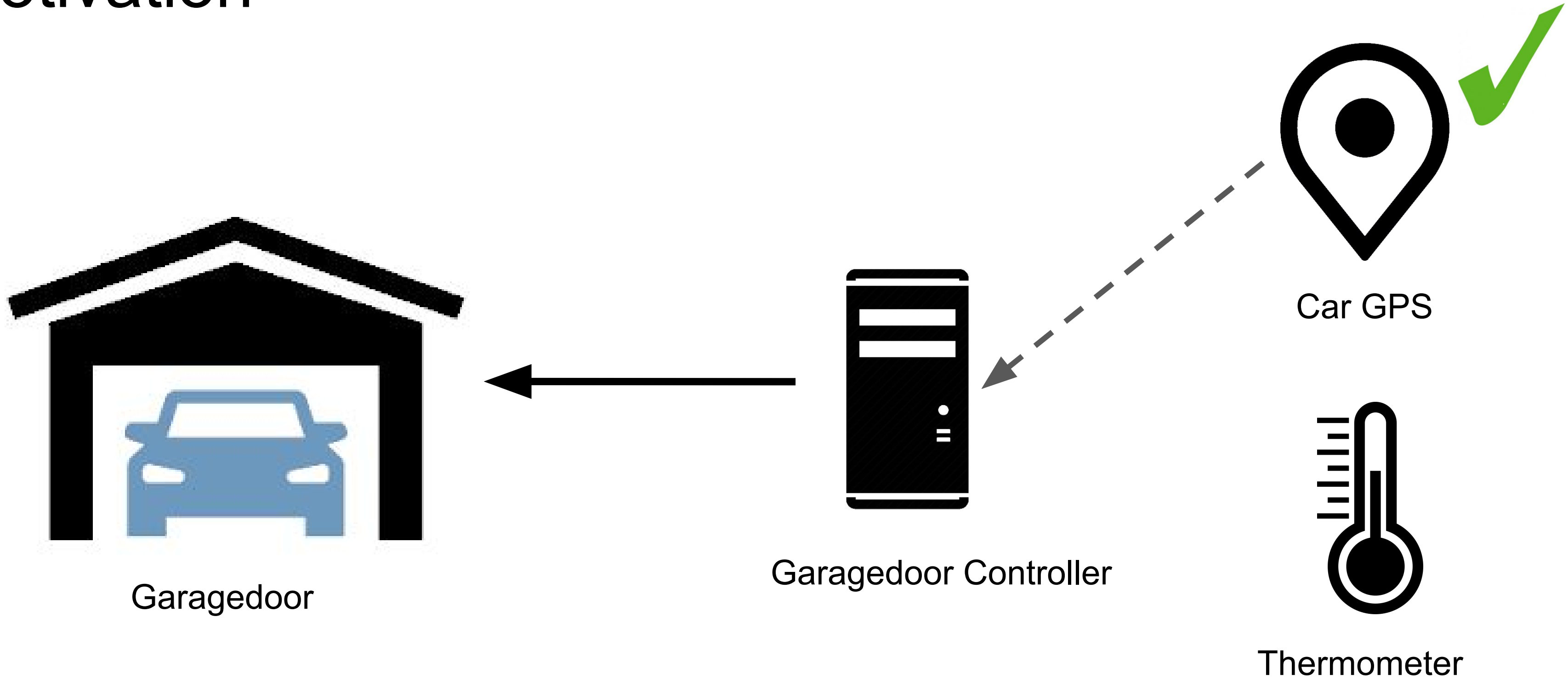

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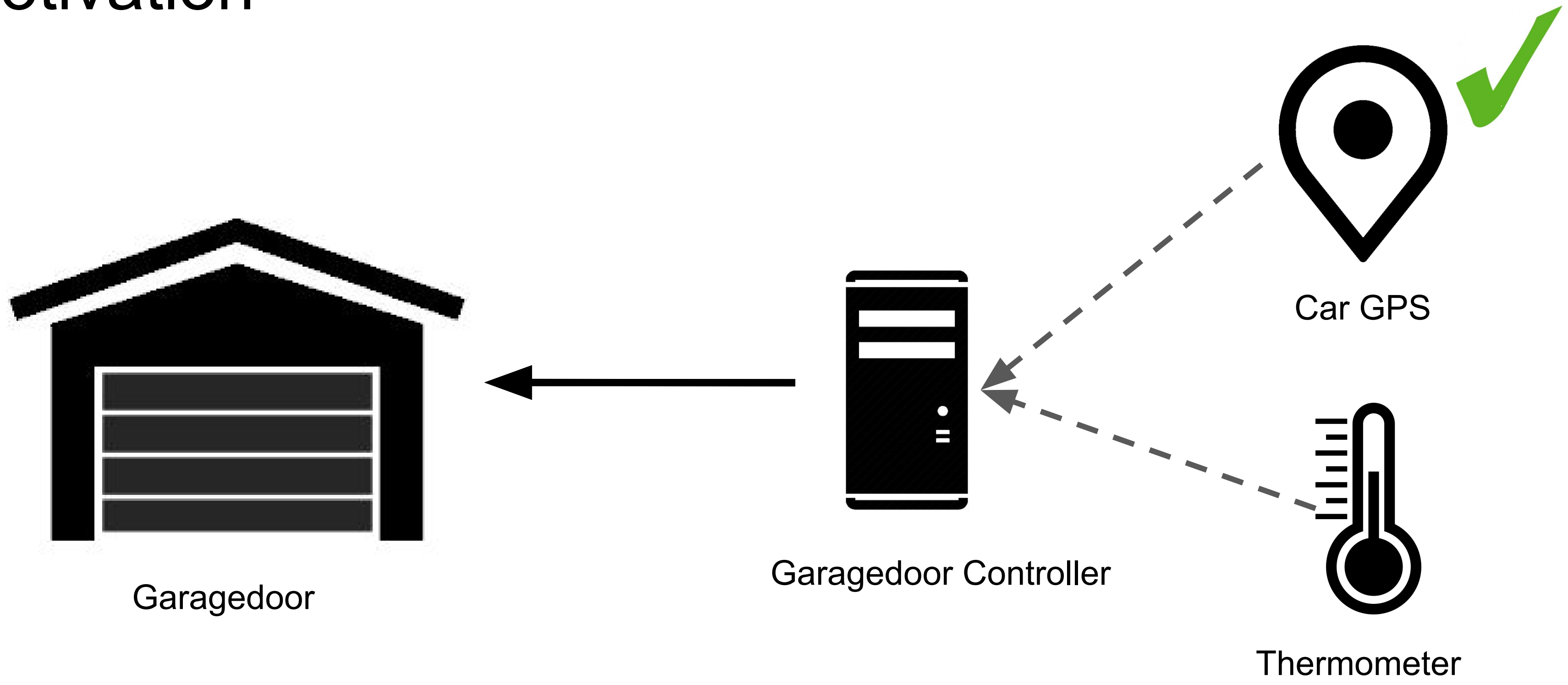

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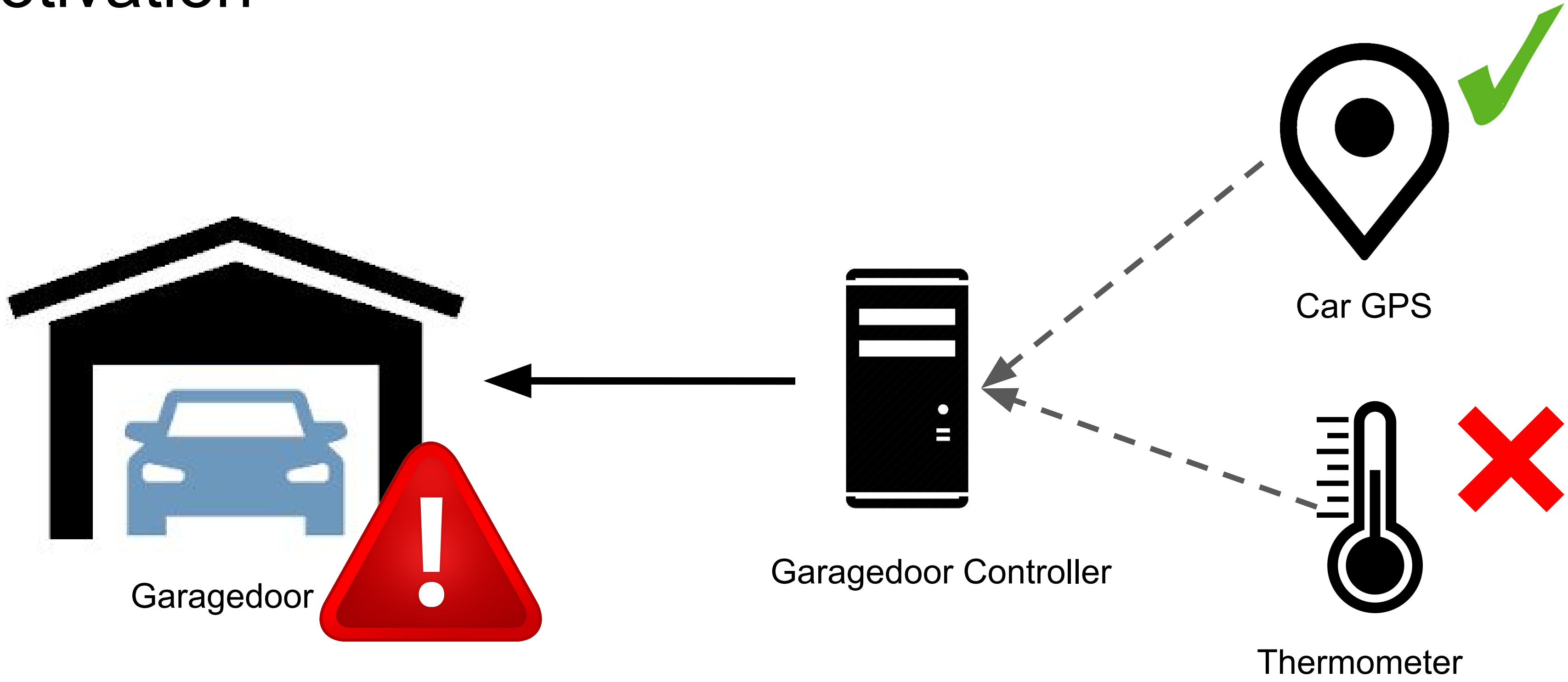
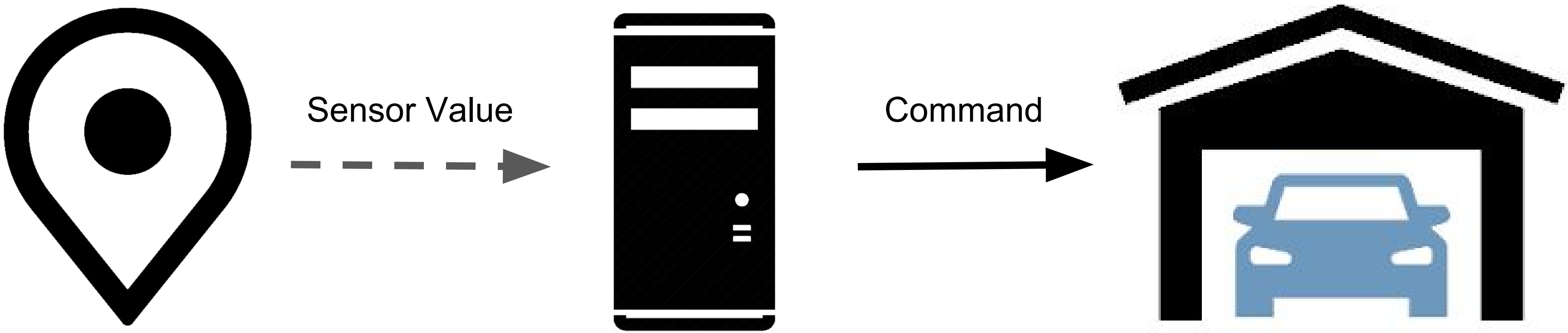


# Architecture



Sensor Value

Command

Sensor

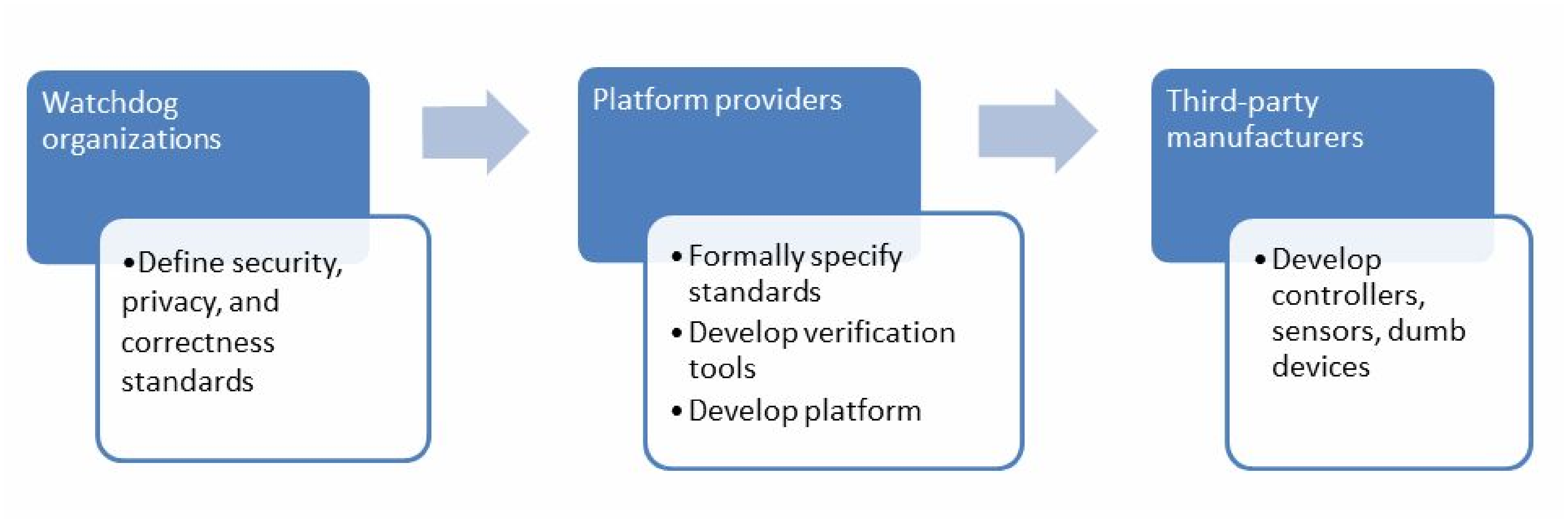
Controller

Dumb Device

# Our approach

- ❏ We implemented a simulation of a smart home
- ❏ Specified security policies for the different smart devices in first order logic
- ❏ Verified the code of the devices using static analysis
  - ❏ Provide compile time guarantees about security

# Business model



Watchdog organizations

- Define security, privacy, and correctness standards

Platform providers

- Formally specify standards
- Develop verification tools
- Develop platform

Third-party manufacturers

- Develop controllers, sensors, dumb devices

# Threat model

- ➔ Controllers developed by third-party manufacturers
    - ➔ Send commands under incorrect sensor conditions
    - ➔ Misuse sensor values
    - ➔ Send wrong commands to right device
    - ➔ Send right/wrong commands to wrong device

- ➔ Watchdog organizations
- ➔ Specification and verification tools
- ➔ End users
- ➔ Dumb devices
- ➔ Communication protocols

# Security policies

- Dependency policy
  - Commands are sent by controllers under correct sensor values
- Control policy
  - Controllers send right command to only those dumb-devices they can control
- Information flow policy
  - Sensitive information is not sent to the cloud without user permission and/or anonymization
- Temporal policy
  - Events respect the order in which they are supposed to happen: air-conditioner should turn on after windows are closed

# Dependency policies

- **The garage door opens if and only if it is closed, the owner is inside the car, and the car is either approaching nearby or running within the garage.**
    - $\text{GARAGEDOOR\_CONTROLLER}$ **sends** *open_garagedoor* $\Leftrightarrow (\neg \text{IS\_GARAGE\_OPEN}) \land ((\neg \text{IS\_CAR\_INSIDE\_GARAGE} \land \text{CAR\_DISTANCE} \leq \text{“50m”} \land \text{CAR\_SPEED} > 0) \lor (\text{IS\_CAR\_INSIDE\_GARAGE} \land \text{IS\_CAR\_RUNNING})) \land (\text{IS\_OWNER\_INSIDE\_CAR})$

- **The laundry machine may start when the doors are closed, the machine is not empty, the clothes are not already clean, and the machine is not already running.**
    - $\text{LAUNDRYMACHINE\_CONTROLLER}$ **sends** *start_washer* $\Rightarrow (\text{IS\_DOOR\_CLOSED}) \land (\neg \text{IS\_EMPTY}) \land (\neg \text{IS\_CLEAN}) \land (\neg \text{IS\_WASHER\_ON})$

# Verification

We implemented a static analysis tool based on Google’s error-prone framework

```
public void update() {
        if (Platform.washerCleanSensor.getEntities().get("IS_CLEAN").equals(false)
        && Platform.washerDoorSensor.getEntities().get("IS_DOOR_CLOSED").equals(true)
        && Platform.washerEmptySensor.getEntities().get("IS_EMPTY").equals(false)
        && Platform.washerSensor.getEntities().get("IS_WASHER_ON").equals(false)) {
                checkExecutabilityAndSend(new Command("start_washer"));
        }
}
```

Policy

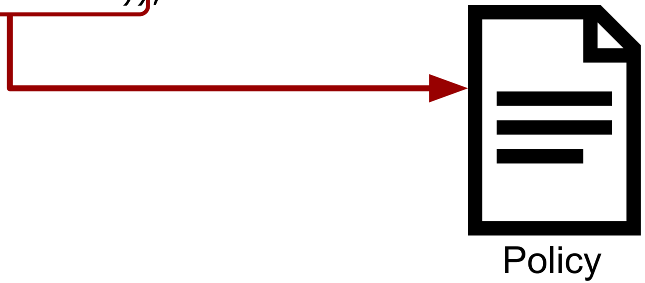
# Verification: Command sent inside update()

```
public void update() {
        if (Platform.washerCleanSensor.getEntities().get("IS_CLEAN").equals(false)
        && Platform.washerDoorSensor.getEntities().get("IS_DOOR_CLOSED").equals(true)
        && Platform.washerEmptySensor.getEntities().get("IS_EMPTY").equals(false)
        && Platform.washerSensor.getEntities().get("IS_WASHER_ON").equals(false)) {
                checkExecutabilityAndSend(new Command("start_washer"));
        }
}
```

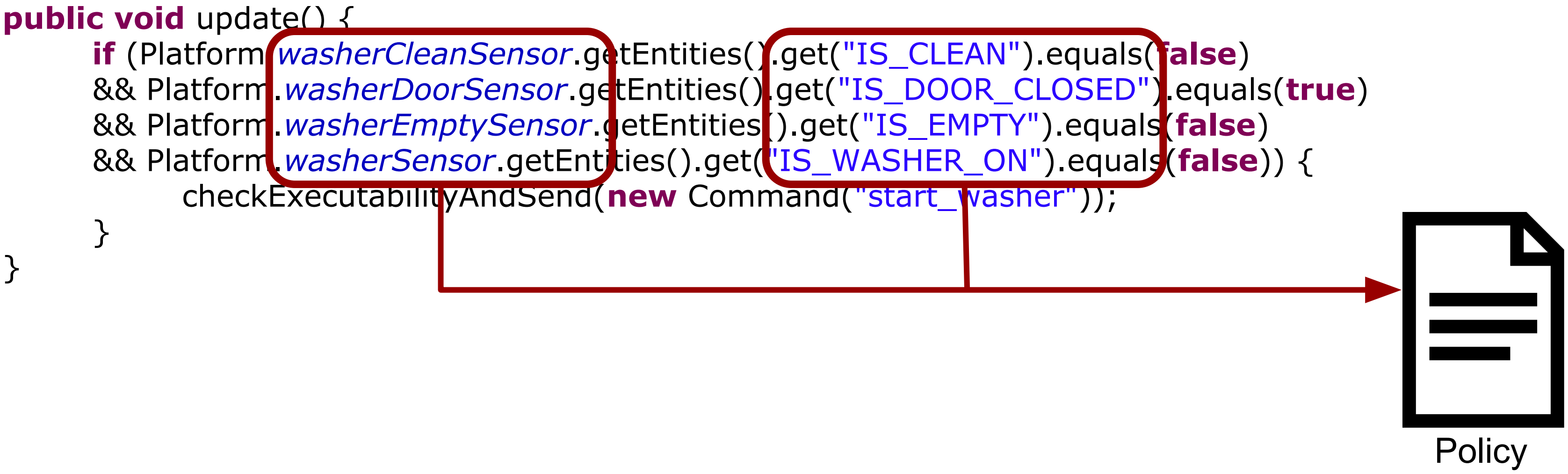
Policy

# Verification: Command exists in policy

```
public void update() {
        if (Platform.washerCleanSensor.getEntities().get("IS_CLEAN").equals(false)
        && Platform.washerDoorSensor.getEntities().get("IS_DOOR_CLOSED").equals(true)
        && Platform.washerEmptySensor.getEntities().get("IS_EMPTY").equals(false)
        && Platform.washerSensor.getEntities().get("IS_WASHER_ON").equals(false)) {
                checkExecutabilityAndSend(new Command("start_washer"));
        }
}
```



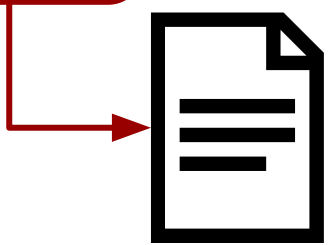
# Verification: Sensors correspond to policy



```
public void update() {
        if (Platform.washerCleanSensor.getEntities().get("IS_CLEAN").equals(false)
        && Platform.washerDoorSensor.getEntities().get("IS_DOOR_CLOSED").equals(true)
        && Platform.washerEmptySensor.getEntities().get("IS_EMPTY").equals(false)
        && Platform.washerSensor.getEntities().get("IS_WASHER_ON").equals(false)) {
                checkExecutabilityAndSend(new Command("start_washer"));
        }
}
```

# Verification: Correct sensor values

```
public void update() {
        if (Platform.washerCleanSensor.getEntities().get("IS_CLEAN").equals(false)
        && Platform.washerDoorSensor.getEntities().get("IS_DOOR_CLOSED").equals(true)
        && Platform.washerEmptySensor.getEntities().get("IS_EMPTY").equals(false)
        && Platform.washerSensor.getEntities().get("IS_WASHER_ON").equals(false)) {
                checkExecutabilityAndSend(new Command("start_washer"));
        }
}
```



# Results

Based on three simulated smart systems:

- ❑ HVAC
- ❑ Garage door
- ❑ Laundry machine

| Type of errors | Yes/No |
|---|---|
| Command inside wrong method with/without correct policy check | ✓ |
| Command inside right method without any policy check | ✓ |
| Command inside right method with some/wrong policy check | ✓ |
| Sensor values changed in the clauses | ✓ |
| Controller checks values of wrong sensors | ✓ |
| Controller sends commands not in specification | ✓ |
| Commands sent in proper temporal order | X |
| Commands sent to only those dumb devices that can execute them | X |
| Wrong sensor values indirectly set in the code | X |

# Conclusions & Future work

Verified security policies for a simulated smart home

- Designed and implemented a smart home simulation
- Defined a business model to assign roles to different organizations
- Defined and specified several policies for a smart home
- Implemented a static analysis to detect violations of the policies at compile time
- Evaluated our system on several malicious controllers

- Extend the verification to handle more complex properties
- Verify other security and correctness policies
- Evaluate our system on a real smart home

# Related work on security for smart homes

- ❏ Trivial security solutions such as strong passwords [1]

- ❏ Dynamic policy enforcement [2] causing system to stop if attack happens

- ❏ Crowdsourcing based solutions to create awareness about attacks [3]
    - ❏ Depends on the attacks published by individual organizations, no formal guarantee

# Example policy file

```
<controller name ="laundrymachinecontroller"
    <command name = "start_washer">
        <sensor name = "IS_DOOR_CLOSED" value ="true" class = "washerDoorSensor"/>
        <sensor name = "IS_EMPTY" value = "false" class = "washerEmptySensor"/>
        <sensor name = "IS_CLEAN" value = "false" class = "washerCleanSensor"/>
        <sensor name = "IS_WASHER_ON" value = "false" class = "washerSensor"/>
    </command>
    <command name = "stop_washer">
        <sensor name = "IS_CLEAN" value = "true" class = "washerCleanSensor"/>
        <sensor name = "IS_WASHER_ON" value = "true" class = "washerSensor"/>
    </command>
</controller>
```

# References

[1] M. B. Barcena and C. Wueest. Insecurity in the internet of things. 2015

[2] J. Al-Muhtadi, M. Anand, M. D. Mickunas, and R. Campbell. Secure smart homes using jini and uiuc sesame. In Computer Security Applications, 2000. ACSAC'00. 16th Annual Conference, pages 77–85. IEEE, 2000

[3] T. Yu, V. Sekar, S. Seshan, Y. Agarwal, and C. Xu. Handling a trillion (unfixable) flaws on a billion devices: Rethinking network security for the internet-of-things. In Proceedings of the 14th ACM Workshop on Hot Topics in Networks, HotNets-XIV, pages 5:1–5:7, New York, NY, USA, 2015. ACM