POLITECNICO
DI TORINO

End User Development in the IoT: a Semantic Approach

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OUTLINE

1. PROBLEM STATEMENT AND RESEARCH GOAL
2. EUPont: **E**nd **U**ser **P**rogramming **Ont**ology
3. EUPont IN PRACTICE

- EUDoptimizer
- RecRules
- EUDdebug

1

Problem Statement and Research Goal

Helping End-Users in Customizing Their IoT Devices and Services

> *The Internet of Things is a recognized paradigm that already helps society in many different ways, through applications ranging in scope from the individual to the planetary, as well as across ventures in a variety of industries.*

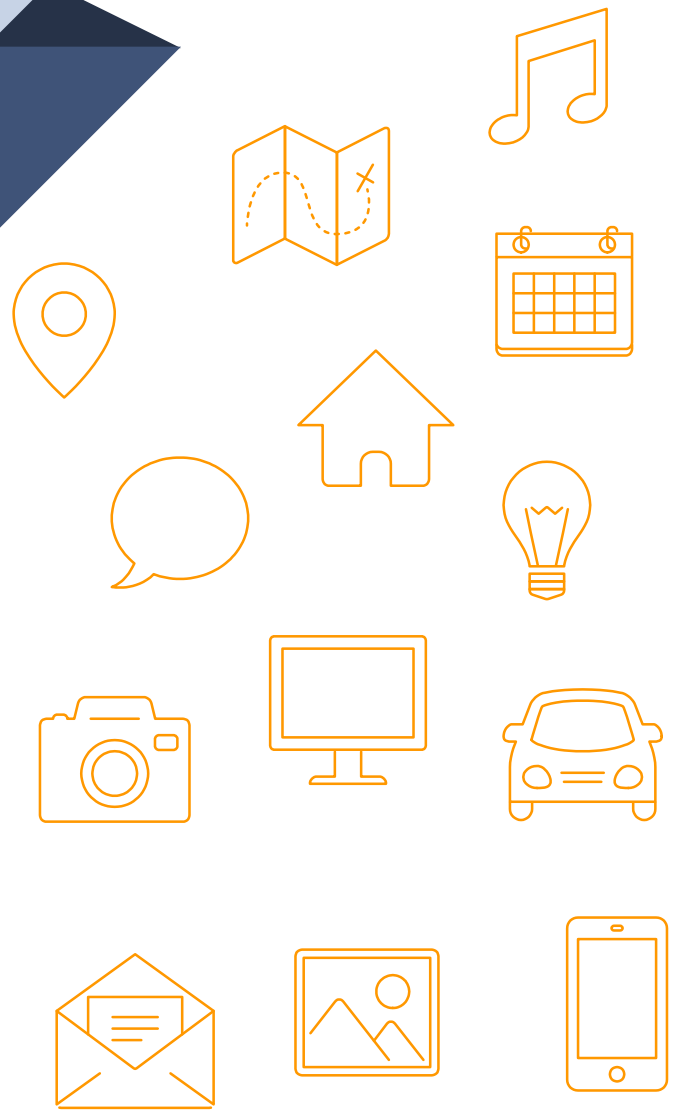
Vint Cerf and Max Senges, Google Research

HUMAN-COMPUTER INTERACTION IN THE IoT

However, the increasing complexity of the IoT ecosystem raises new challenges, especially in the interaction with final users:

- TECHNOLOGY DEPENDENCY
- INTEROPERABILITY
- INFORMATION OVERLOAD

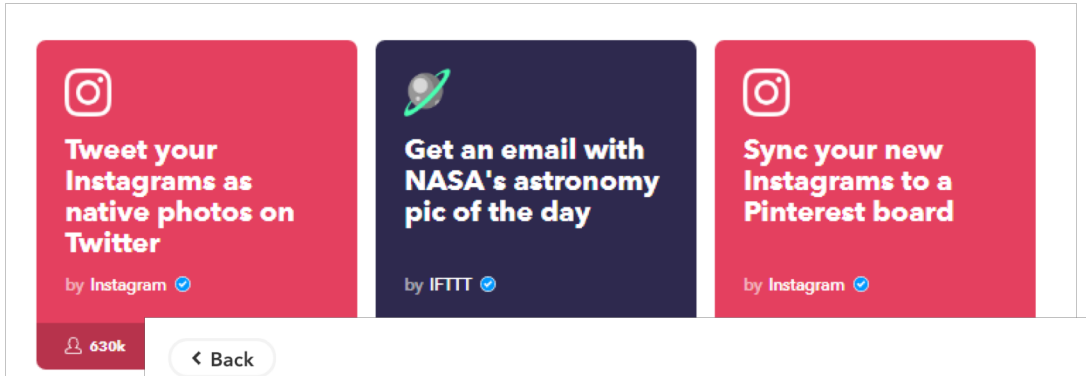
END USER DEVELOPMENT IN THE IoT

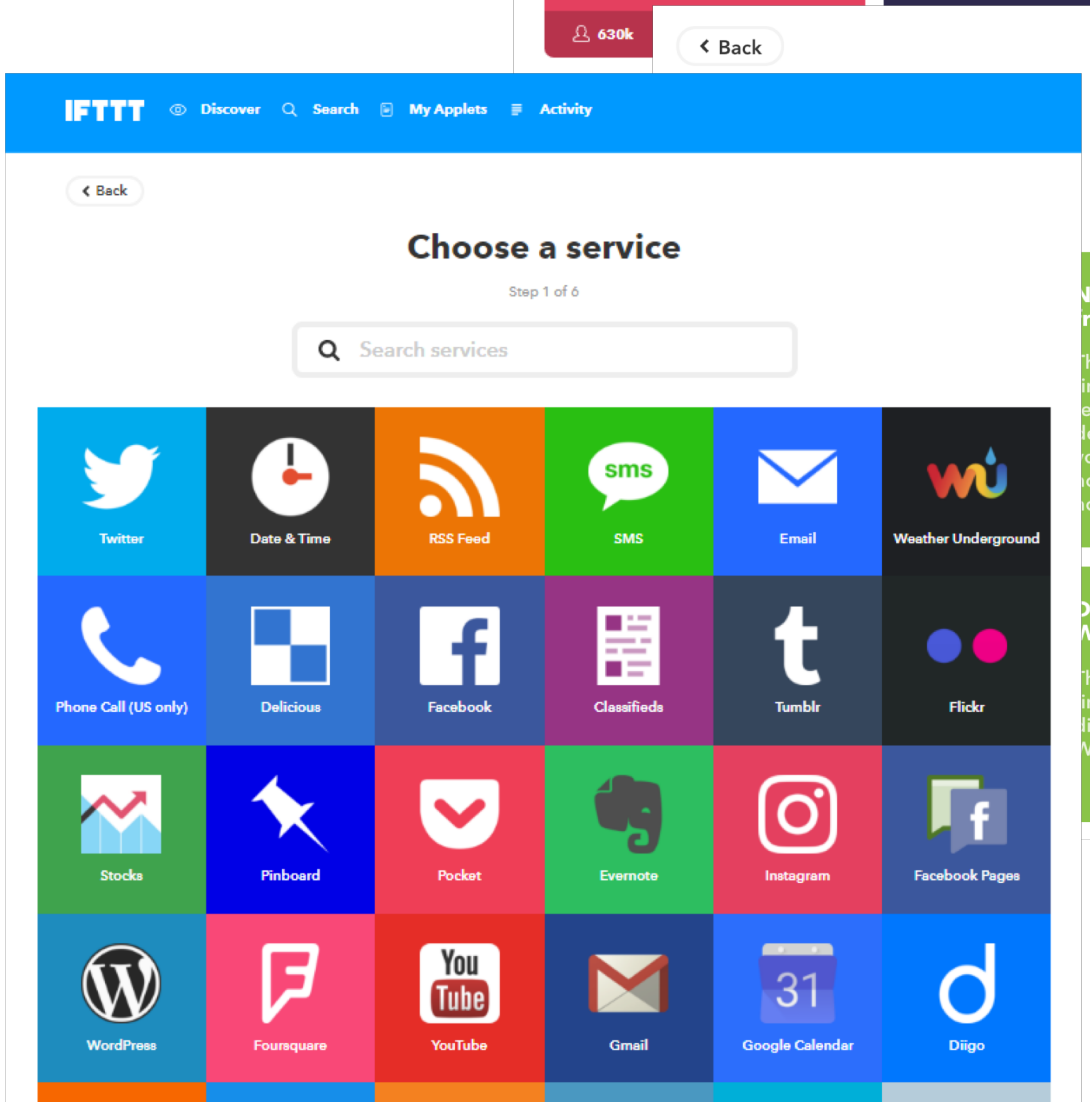


In the context of the Internet of Things, End User Development empowers end-users with and without programming skills to customize their own IoT devices and service on the basis of their personal needs.

Typically, third-party EUD interfaces allow users to define simple TRIGGER-ACTION rules

if this then that


Tweet your Instagrams as native photos on Twitter
by Instagram
Get an email with NASA's astronomy pic of the day
by IFTTT
Sync your new Instagrams to a Pinterest board
by Instagram
630k


IFTTT
Discover
Search
My Applets
Activity
Back
Choose a service
Step 1 of 6
Search services
Twitter
Date & Time
RSS Feed
SMS
Email
Weather Underground
Phone Call (US only)
Delicious
Facebook
Classifieds
Tumblr
Flickr
Stocks
Pinboard
Pocket
Evernote
Instagram
Facebook Pages
WordPress
Foursquare
YouTube
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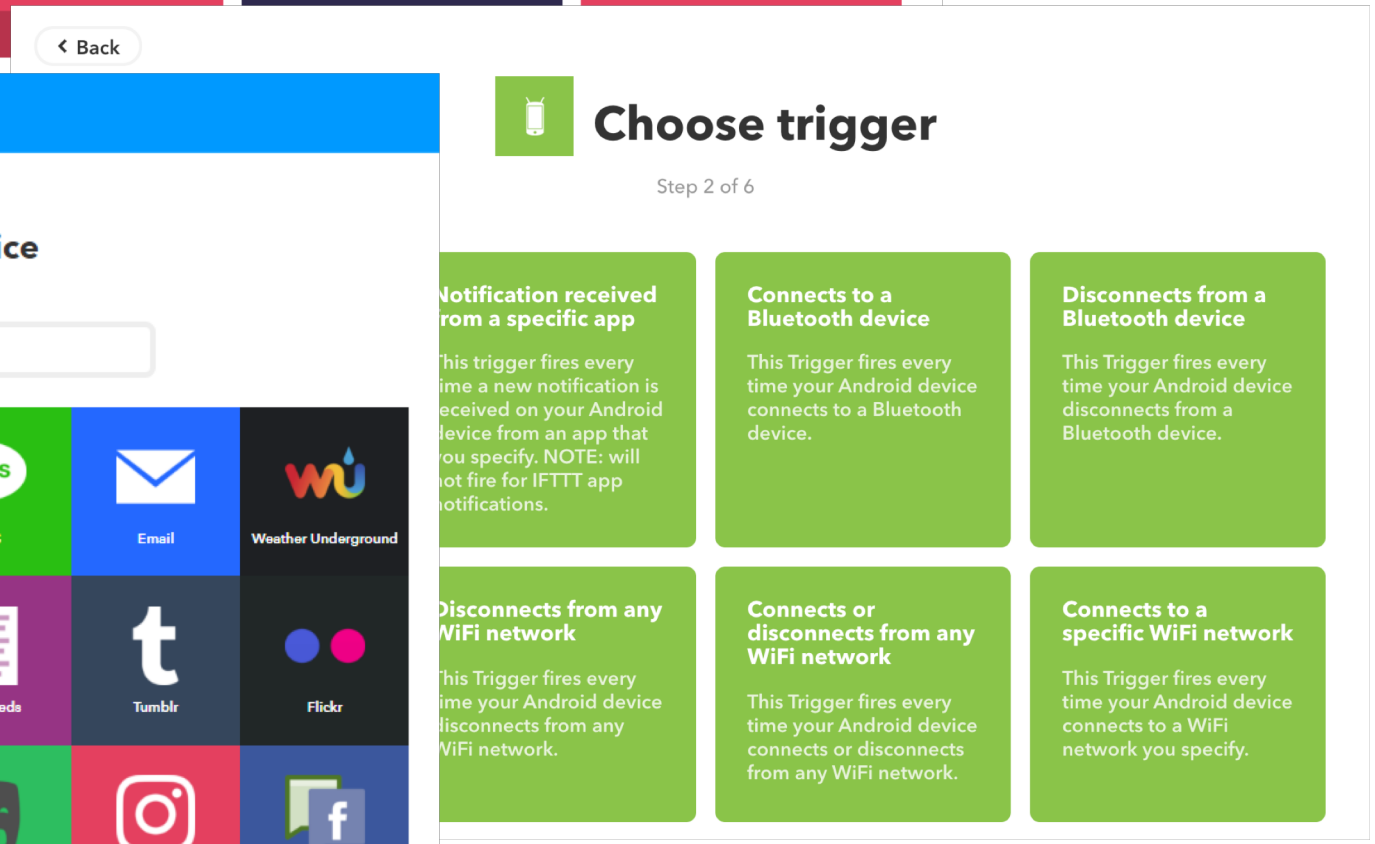

Back
Choose trigger
Step 2 of 6
Notification received from a specific app
This trigger fires every time a new notification is received on your Android device from an app that you specify. NOTE: will not fire for IFTTT app notifications.
Connects to a Bluetooth device
This Trigger fires every time your Android device connects to a Bluetooth device.
Disconnects from a Bluetooth device
This Trigger fires every time your Android device disconnects from a Bluetooth device.
Disconnects from any WiFi network
This Trigger fires every time your Android device disconnects from any WiFi network.
Connects or disconnects from any WiFi network
This Trigger fires every time your Android device connects or disconnects from any WiFi network.
Connects to a specific WiFi network
This Trigger fires every time your Android device connects to a WiFi network you specify.

ISSUES

John, a manager of an important company, is always hot, especially in summer. He loves air conditioning, and he would like to set a low temperature wherever it is possible.

At home, John has an intelligent Nest thermostat, that he controls through his Android smartphone. John goes to work by his BMW smart car. There, all the offices are equipped with a Samsung air conditioner.

- 😒 Too many rules
- 😒 Too many technologies
- 😒 Too many contexts

Abstraction

Two IoT devices that provide equivalent or identical functions (e.g., set the indoor temperature) but differ in brands are treated like separated entities.

Adaptation

Contemporary end-user programming environments work only with well-know IoT devices and services, associated to a specific user.

Context-Awareness

User Preferences

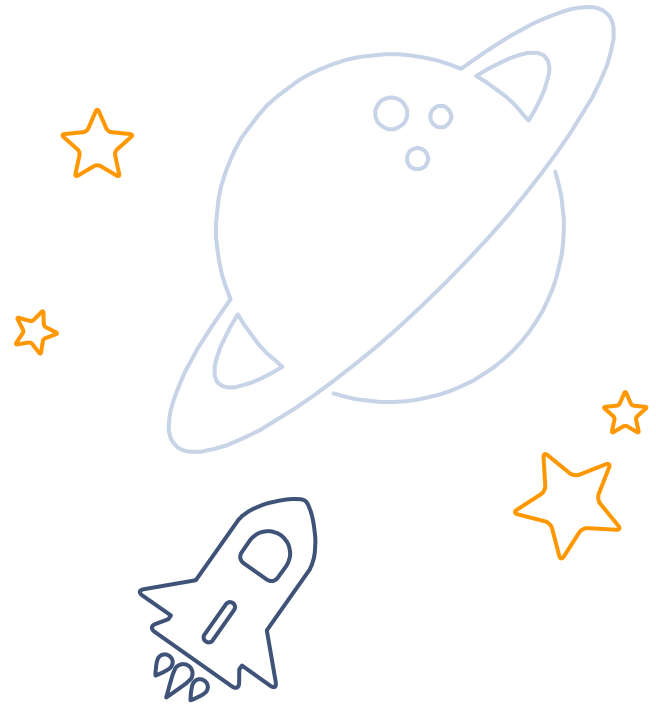
User Centered Design

Semantic Web

Optimization Methods

High Level of Abstraction

End-User Development



RESEARCH GOAL

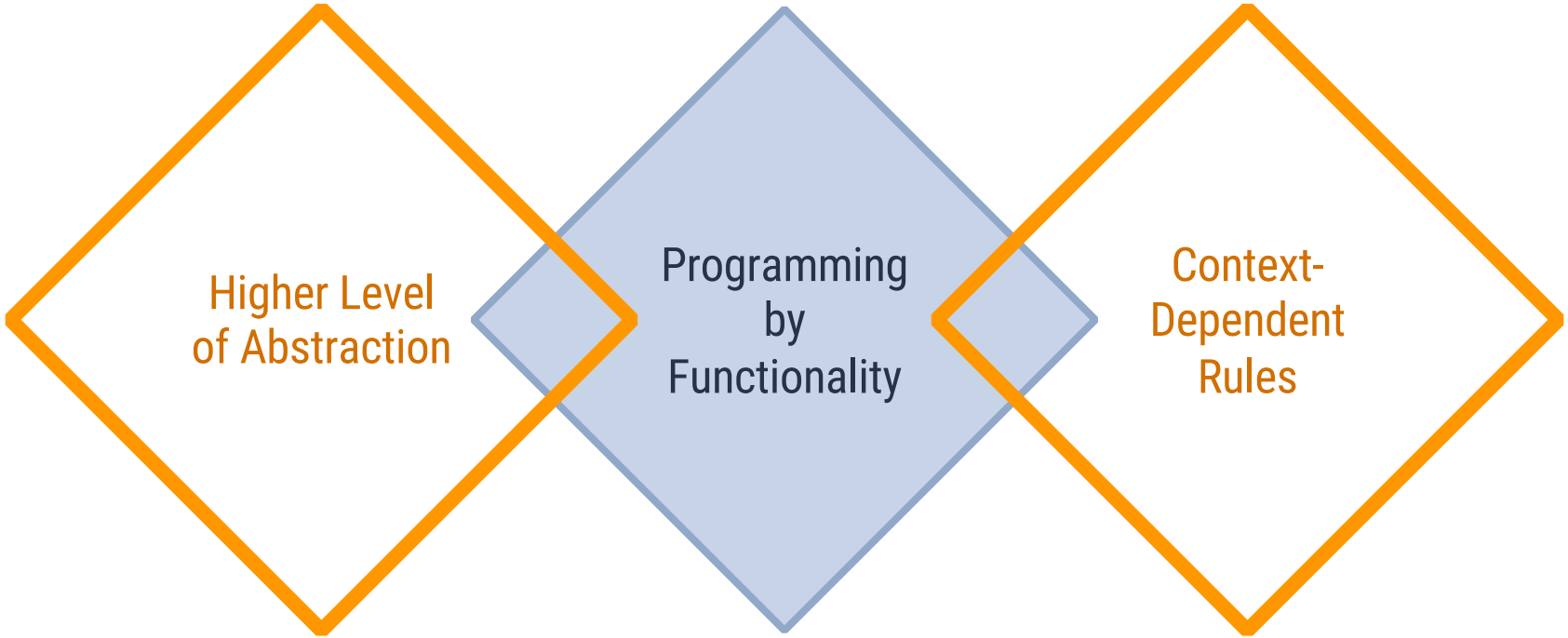
Using the Sematic Web to assist end-users in customizing their **Internet of Things** systems and services, with a particular focus on End-User Development solutions for **Trigger-Action Programming**.

2

EUPont

A High-Level Approach Towards End User Development in the IoT

HOW CAN WE HELP JOHN?



IF

I enter any defined location,

THEN

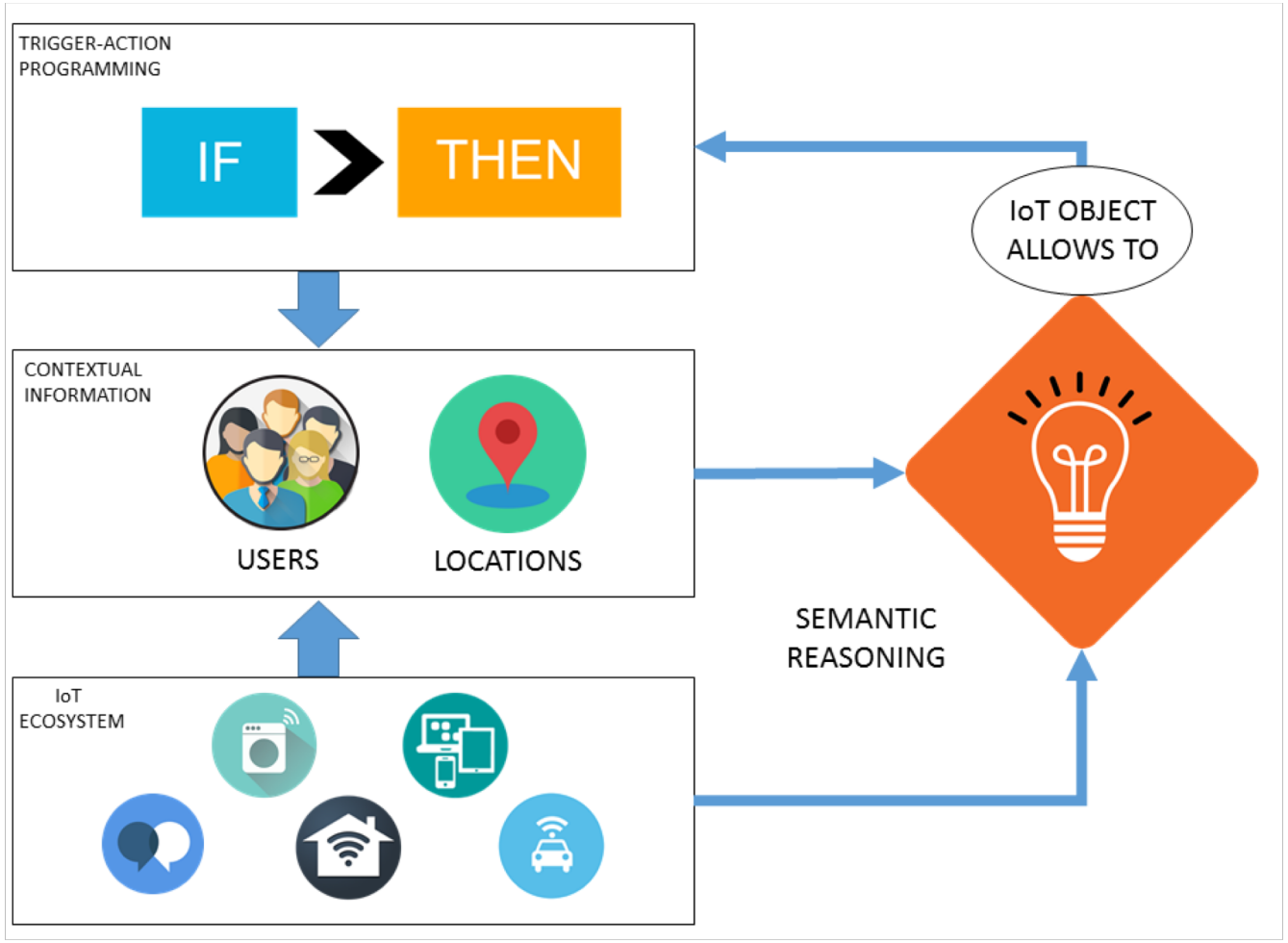
set its temperature to 20 Celsius degree

EUPont

End User Programming Ontology

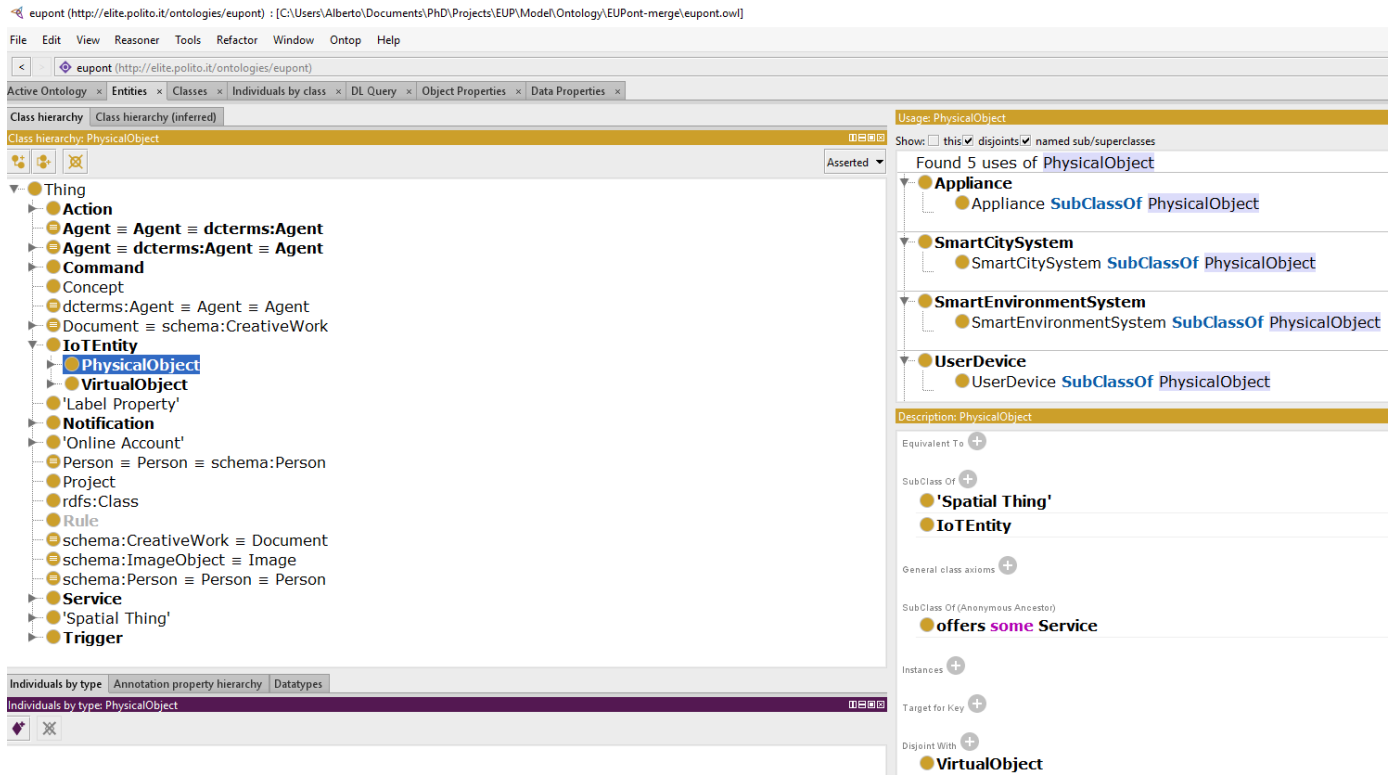
GOALS:

- Higher level of abstraction
- Programming by functionality
- Context dependent rules



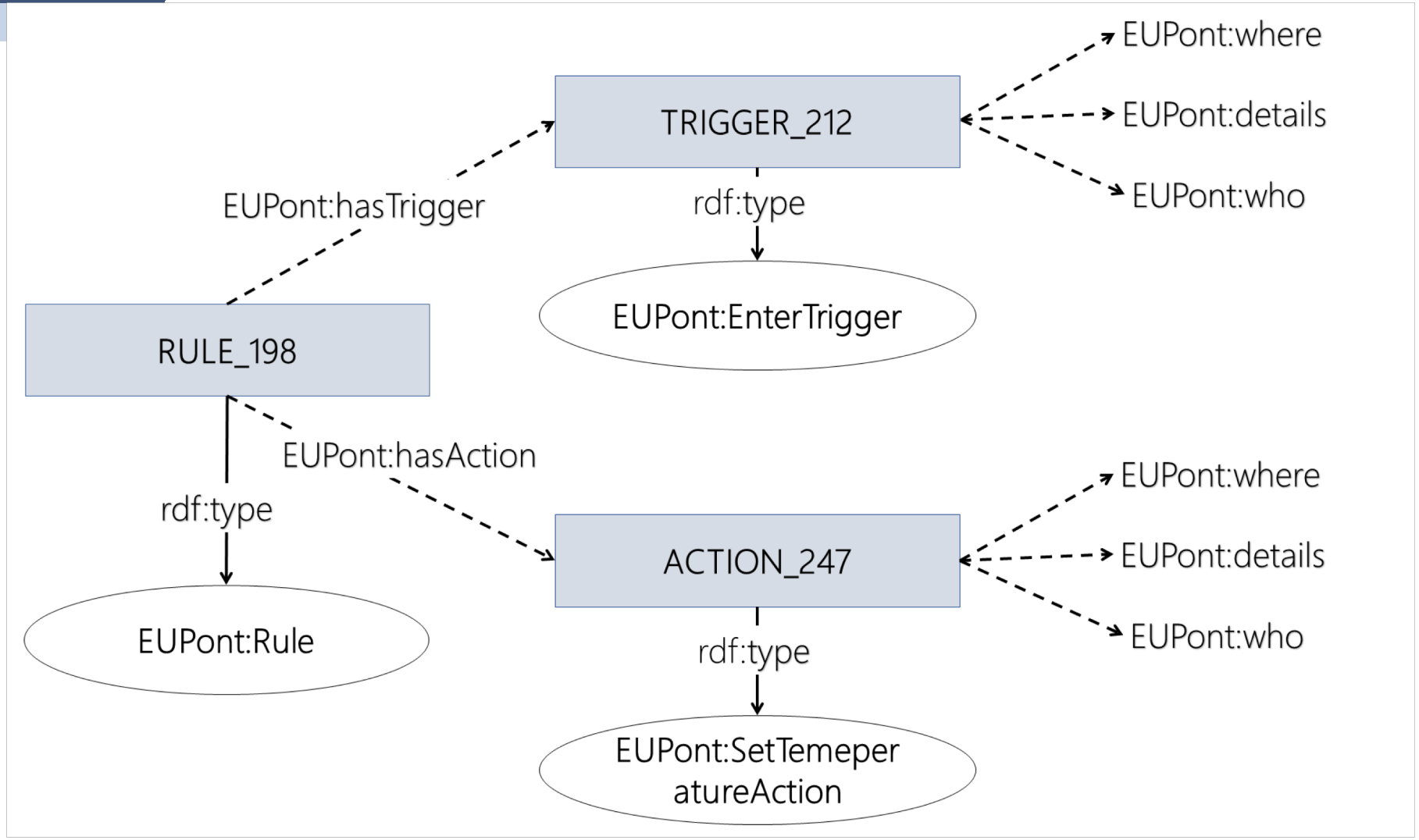
EUPont is available at http://elite.polito.it/ontologies/eupont.owl

It has been integrated in a user interface for composing trigger-action rules, and has been evaluated in multiple user studies.

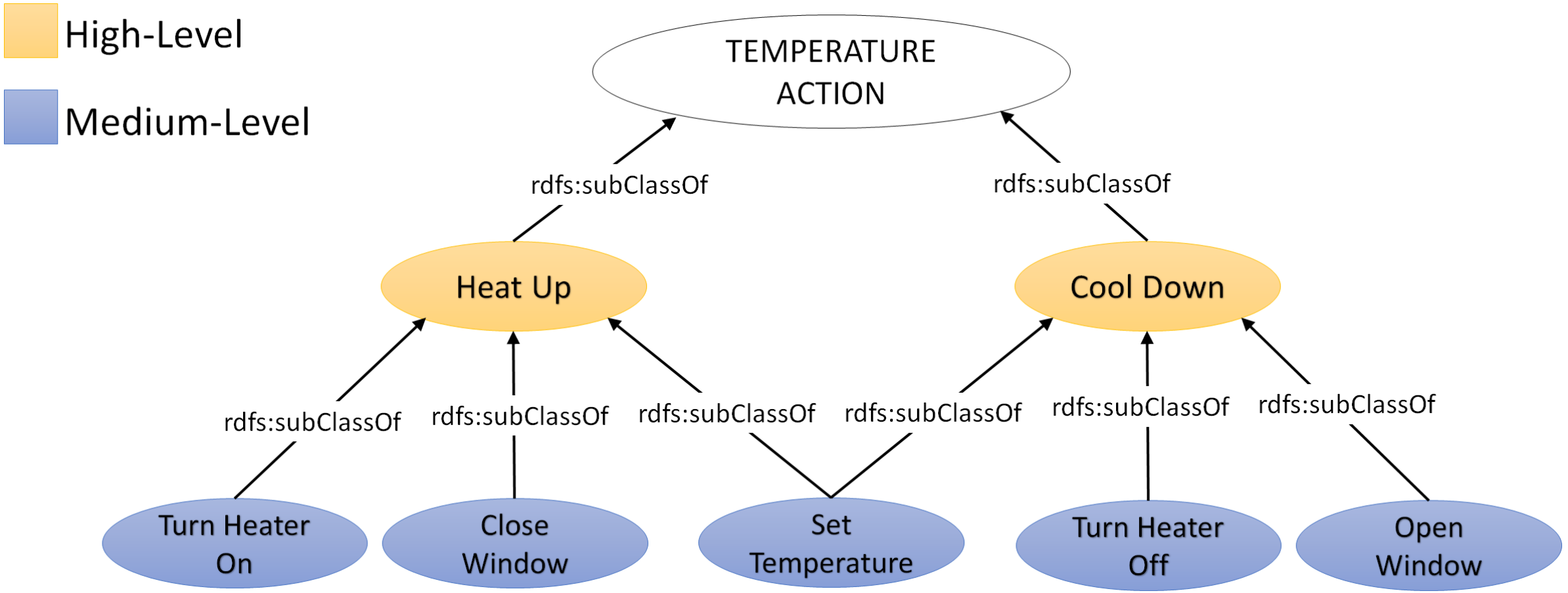


[1] F.Corno, L. De Russis, A. Monge Roffarello, «A High-Level Approach Towards End User Development in the IoT», CHI 2017: The 35th Annual CHI Conference on Human Factors in Computing Systems
[2] F.Corno, L. De Russis, A. Monge Roffarello, «A Semantic Web Approach to Simplifying Trigger-Action Programming in the IoT», IEEE Computer, 2017
[4] F.Corno, L. De Russis, A. Monge Roffarello, «A High-Level Semantic Approach to End-User Development in the Internet of Things», International Journal of Human-Computer Studies, 2018

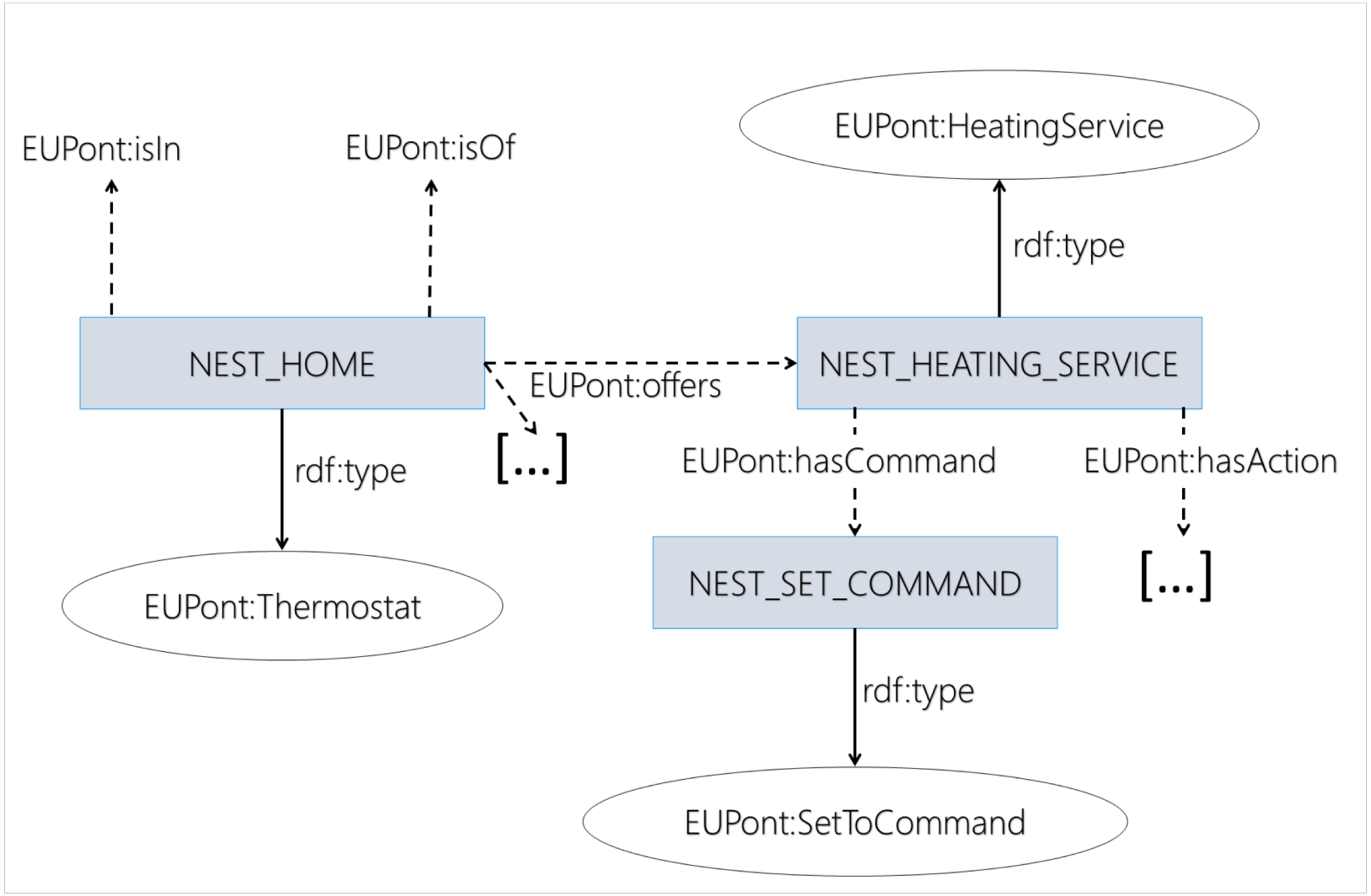
IF I enter any defined location, **THEN** set its temperature to 20 Celsius degree



Trigger-Action Programming Layer



Trigger-Action Programming Layer



IoT Ecosystem Layer

SWRL RULE

```
SetTemperatureAction (?action) ^ IoTEntity(?entity) ^
offers(?entity,?service) ^ HeatingService(?service) ^
hasCommand(?service,?command) ^
SetToCommand(?command) -> allowTo(?IoTEntity, ?action)
```

REASONING

3

EUPont in Practice

Enriching Contemporary EUD Solutions with Semantic Features

RecRules: Recommending IF-THEN Rules to End Users

The goal is to **recommend by functionality** , i.e., suggesting trigger-action rules on the basis of the final behaviors users would like to define, thus abstracting any technological details such as brands or manufactures.

Top-N

RecRules recommends a list of valuable trigger-action rules to the end-user

Content-Based

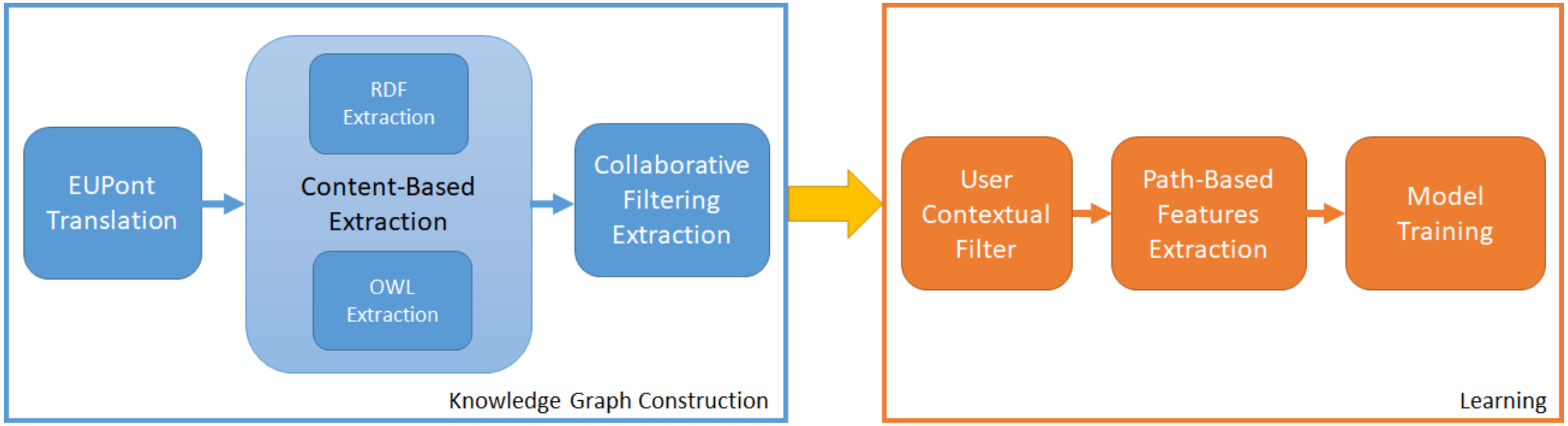
Recommendations are computed on the basis of the rules already created or reused by the user

Collaborative

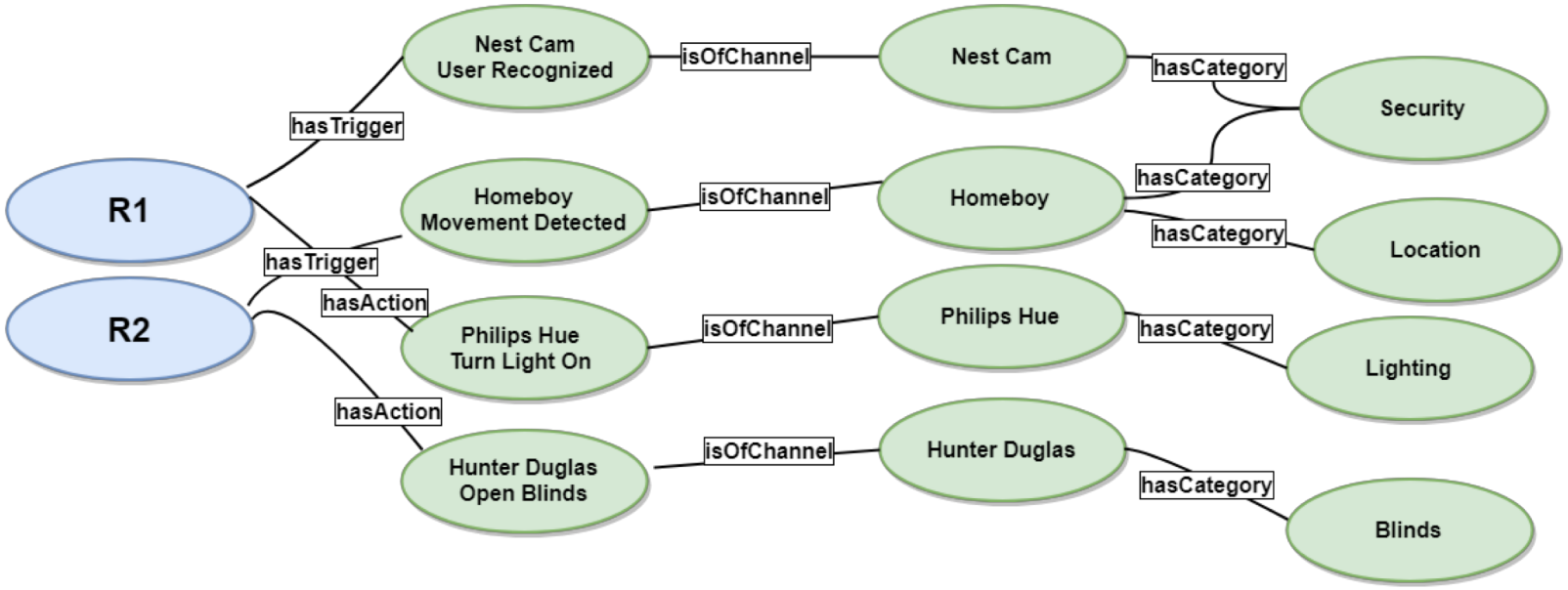
Recommendations are computed on the basis of the rules created or reused by other users

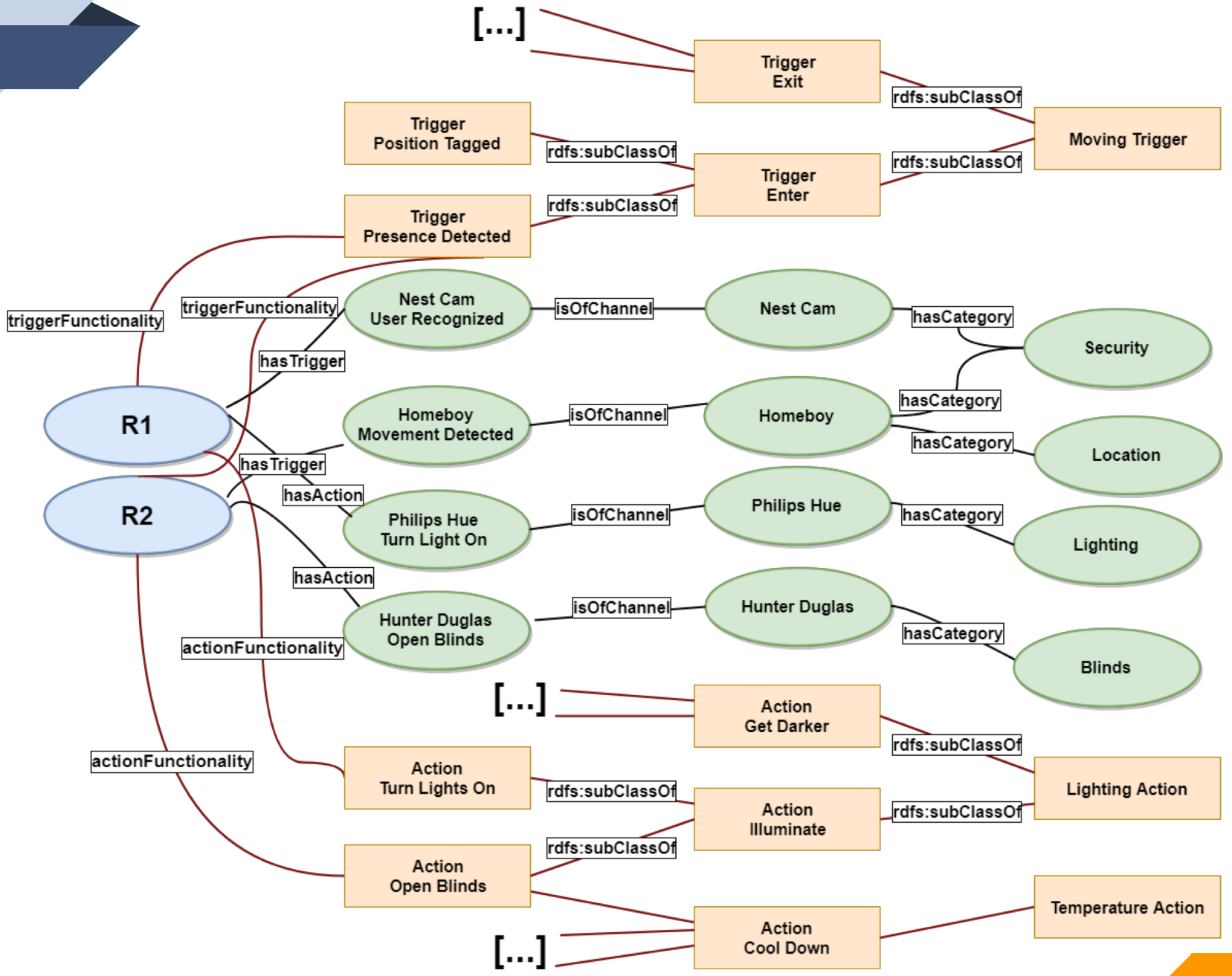
Implicit

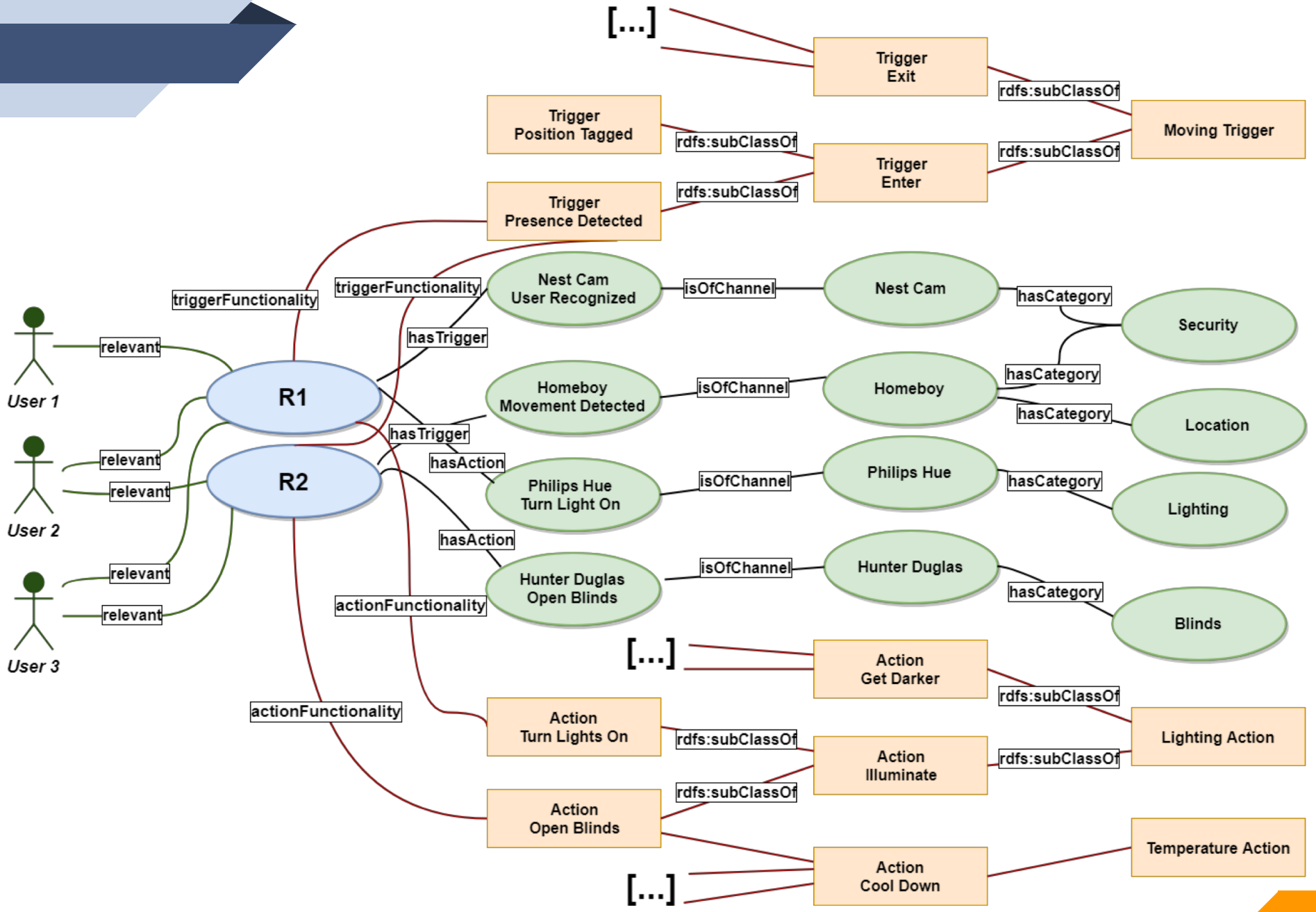
RecRules only exploits implicit feedback, e.g., the rule creation and the rule reusing

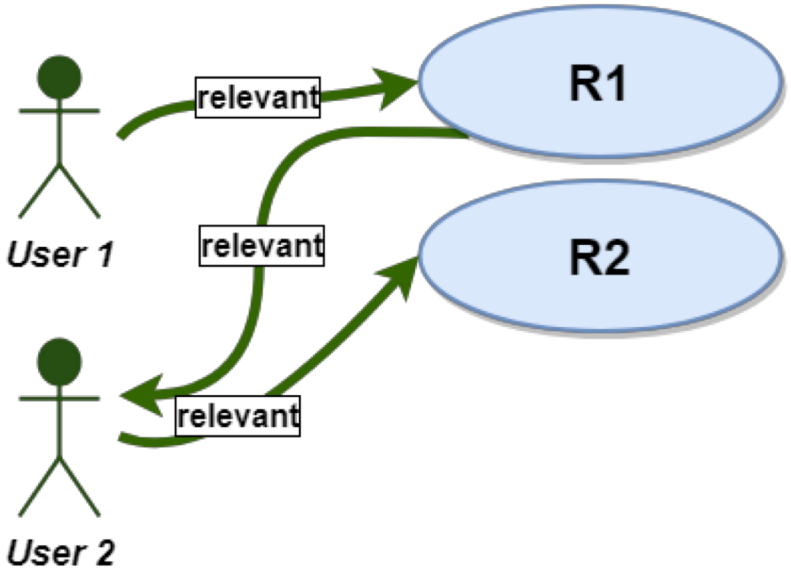

EUPont Translation
RDF Extraction
Content-Based Extraction
OWL Extraction
Collaborative Filtering Extraction
Knowledge Graph Construction
User Contextual Filter
Path-Based Features Extraction
Model Training
Learning


R1
R2

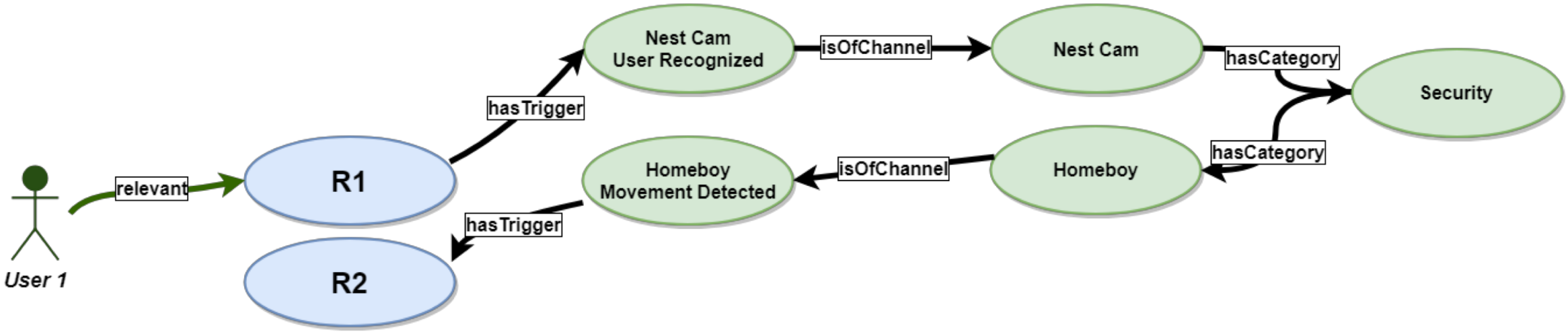

R1
R2
hasTrigger
hasTrigger
hasAction
hasAction
Nest Cam
User Recognized
Homeboy
Movement Detected
Philips Hue
Turn Light On
Hunter Duglas
Open Blinds
isOfChannel
isOfChannel
isOfChannel
isOfChannel
Nest Cam
Homeboy
Philips Hue
Hunter Duglas
hasCategory
hasCategory
hasCategory
hasCategory
hasCategory
Security
Location
Lighting
Blinds


[...]
Trigger Exit
rdfs:subClassOf
Moving Trigger
Trigger Position Tagged
rdfs:subClassOf
Trigger Enter
rdfs:subClassOf
Trigger Presence Detected
rdfs:subClassOf
triggerFunctionality
triggerFunctionality
Nest Cam User Recognized
isOfChannel
Nest Cam
hasCategory
Security
hasTrigger
R1
Homeboy Movement Detected
isOfChannel
Homeboy
hasCategory
hasCategory
Location
hasTrigger
hasAction
R2
Philips Hue Turn Light On
isOfChannel
Philips Hue
hasCategory
Lighting
hasAction
Hunter Duglas Open Blinds
isOfChannel
Hunter Duglas
hasCategory
Blinds
actionFunctionality
[...]
Action Get Darker
rdfs:subClassOf
Lighting Action
actionFunctionality
Action Turn Lights On
rdfs:subClassOf
Action Illuminate
rdfs:subClassOf
rdfs:subClassOf
Action Open Blinds
Action Cool Down
Temperature Action
[...]

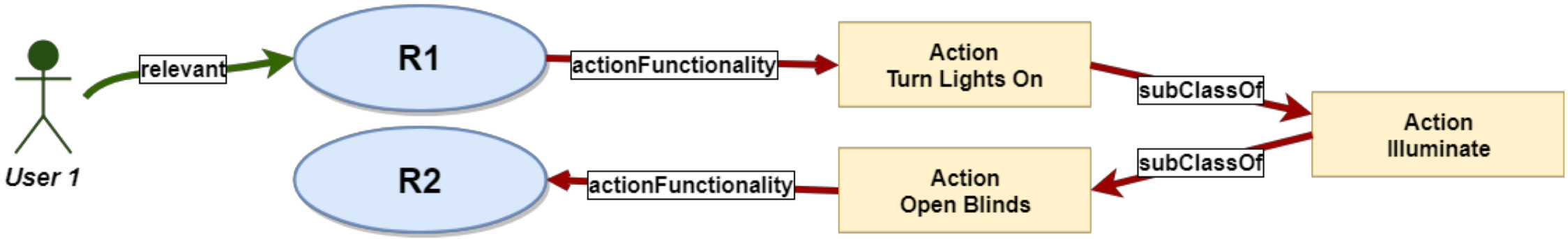

[...]
Trigger Exit
rdfs:subClassOf
Moving Trigger
Trigger Position Tagged
rdfs:subClassOf
Trigger Enter
rdfs:subClassOf
Trigger Presence Detected
rdfs:subClassOf
triggerFunctionality
triggerFunctionality
Nest Cam User Recognized
isOfChannel
Nest Cam
hasCategory
Security
hasTrigger
relevant
User 1
R1
Homeboy Movement Detected
isOfChannel
Homeboy
hasCategory
hasCategory
Location
hasTrigger
relevant
relevant
User 2
R2
hasAction
Philips Hue Turn Light On
isOfChannel
Philips Hue
hasCategory
Lighting
hasAction
relevant
relevant
User 3
Hunter Duglas Open Blinds
isOfChannel
Hunter Duglas
hasCategory
Blinds
actionFunctionality
[...]
Action Get Darker
rdfs:subClassOf
Lighting Action
actionFunctionality
Action Turn Lights On
rdfs:subClassOf
Action Illuminate
rdfs:subClassOf
rdfs:subClassOf
Action Open Blinds
Temperature Action
Action Cool Down
[...]



Collaborative Path

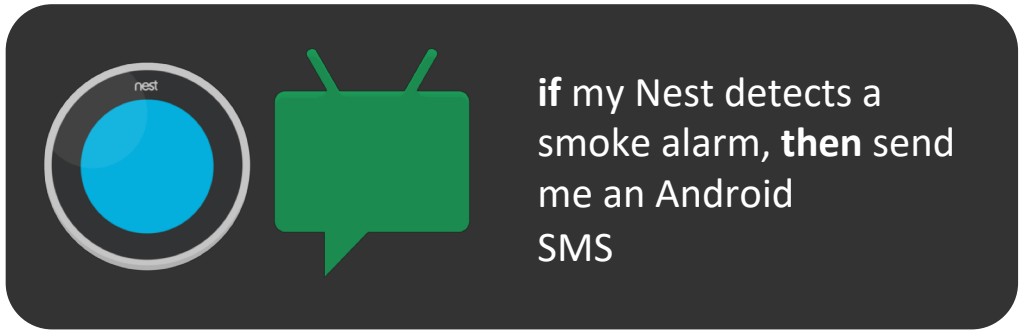


Technology Path

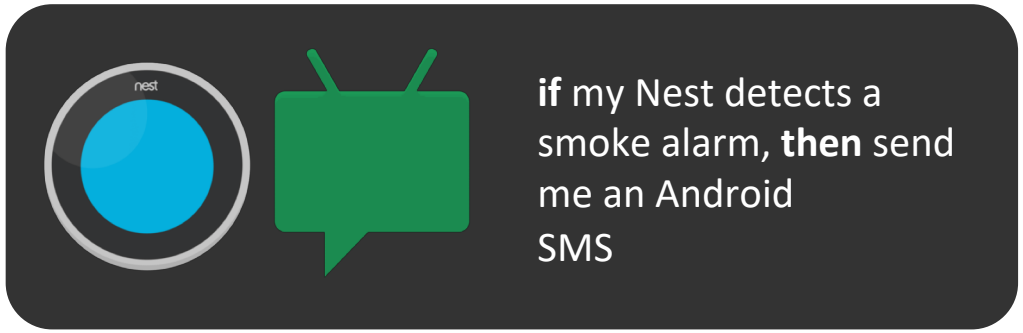


Functionality Path

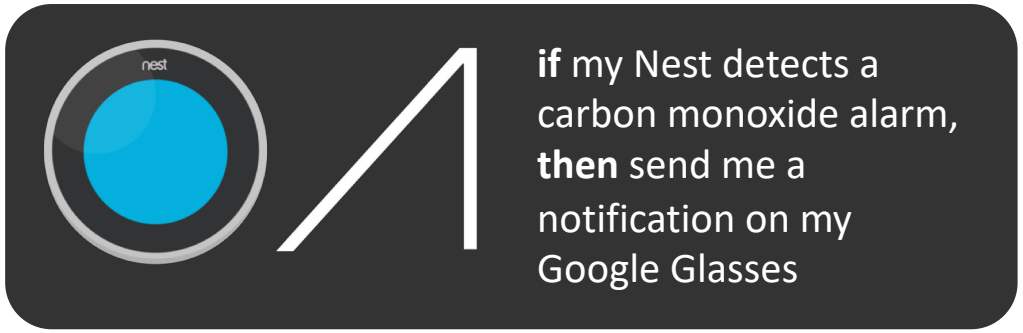
Training Set



Training Set

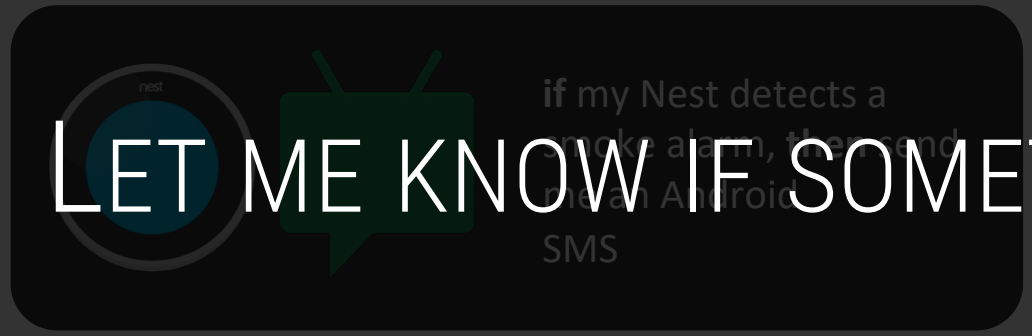


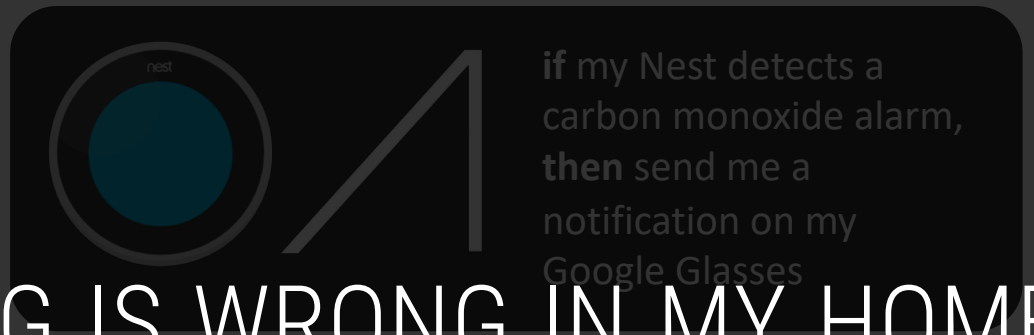
Recommendation Set

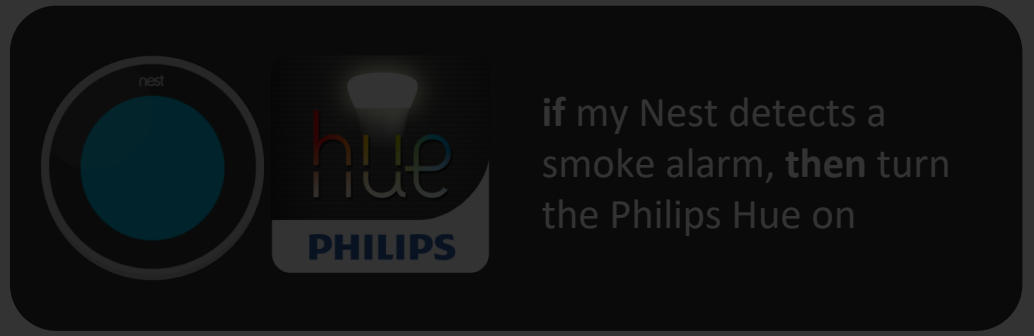


Recommendation Set

Training Set



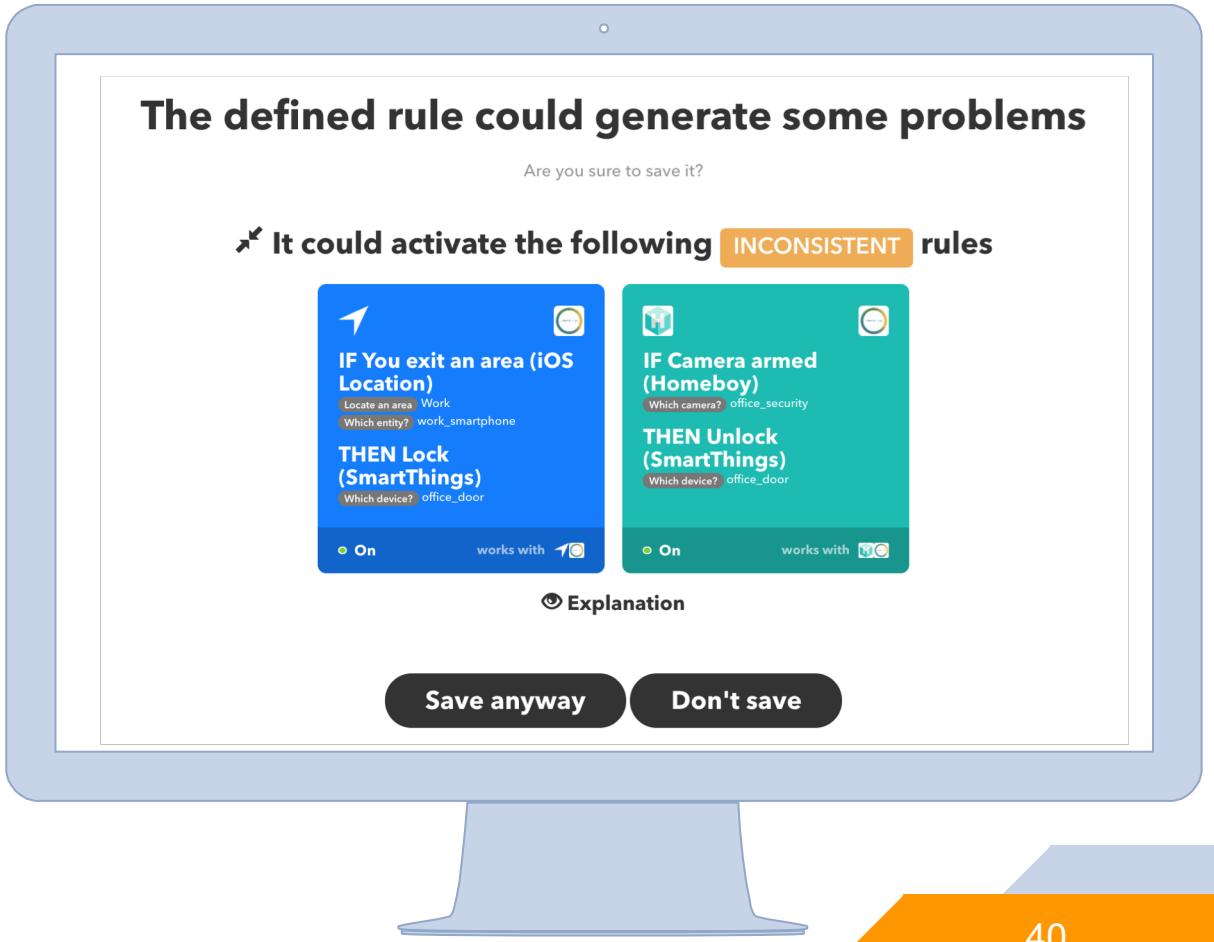


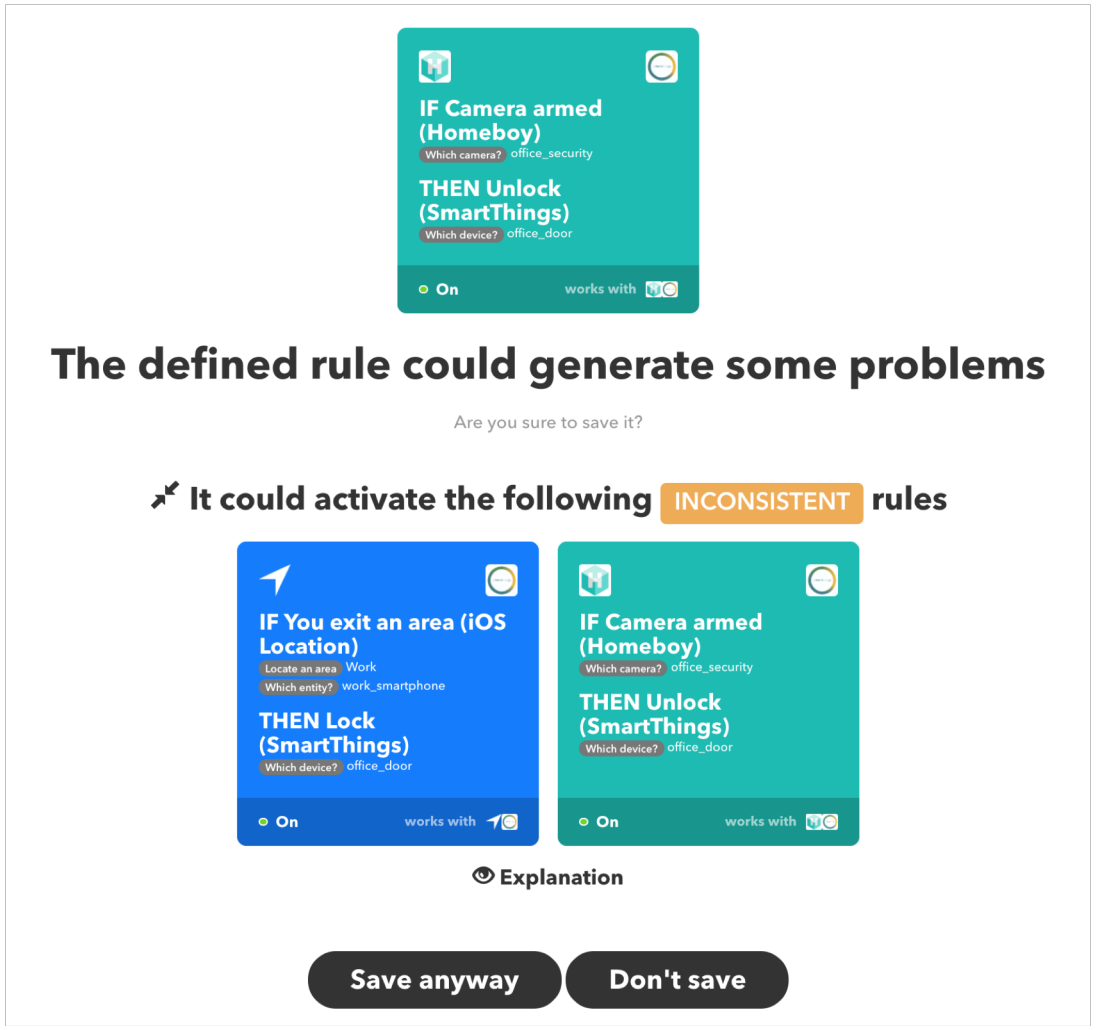


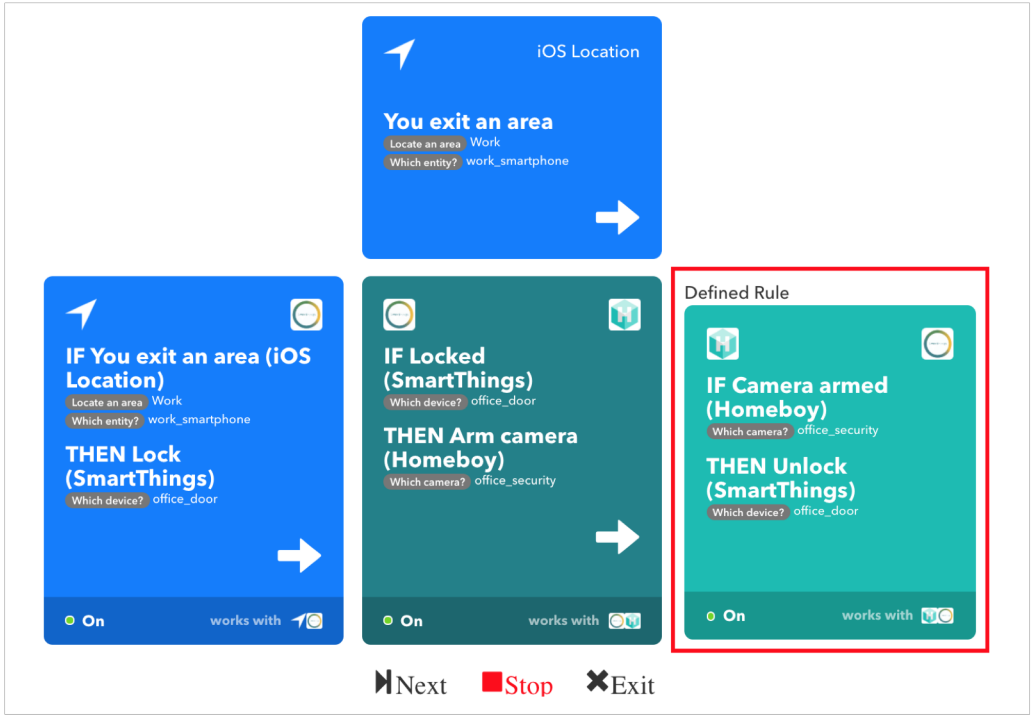
LET ME KNOW IF SOMETHING IS WRONG IN MY HOME...

EUDdebug: Empowering End Users to Debug IF-THEN Rules

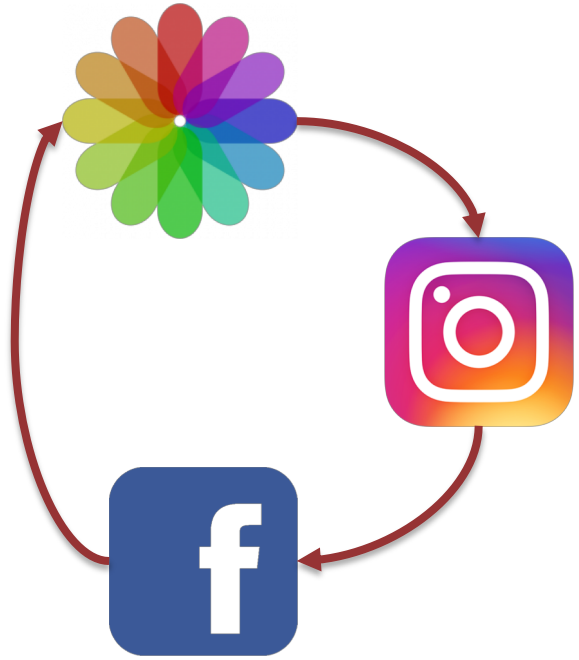
The goal is to properly **warn** users when they are defining any troublesome or potentially dangerous behavior, (i) by assisting them in **identifying rule conflicts**, and (ii) by helping them **simulate and foresee** the run-time behavior of their rules.




IF Camera armed (Homeboy)
Which camera? office_security
THEN Unlock (SmartThings)
Which device? office_door
On
works with
The defined rule could generate some problems
Are you sure to save it?
It could activate the following INCONSISTENT rules
IF You exit an area (iOS Location)
Locate an area Work
Which entity? work_smartphone
THEN Lock (SmartThings)
Which device? office_door
On
works with
IF Camera armed (Homeboy)
Which camera? office_security
THEN Unlock (SmartThings)
Which device? office_door
On
works with
Explanation
Save anyway
Don't save


iOS Location
You exit an area
Locate an area Work
Which entity? work_smartphone
IF You exit an area (iOS Location)
Locate an area Work
Which entity? work_smartphone
THEN Lock (SmartThings)
Which device? office_door
On
works with
IF Locked (SmartThings)
Which device? office_door
THEN Arm camera (Homeboy)
Which camera? office_security
On
works with
Defined Rule
IF Camera armed (Homeboy)
Which camera? office_security
THEN Unlock (SmartThings)
Which device? office_door
On
works with
Next
Stop
Exit

- IF I post a photo on Facebook, THEN save the photo on my iOS library
- IF I add a new photo on my iOS library, THEN post the photo on Instagram
- IF I post a photo on Instagram, THEN post the photo on Facebook



Loops

- IF I play a new song on my Amazon Alexa, THEN post a tweet on Twitter
- IF I play a new song on my Amazon Alexa, THEN save the track on Spotify
- IF I save a track on Spotify, THEN post a tweet on Twitter

Redundancies

- **IF** my Android GPS detects that I exit home, **THEN** lock the SmartThings entrance door
- **IF** my Android GPS detects that I exit home, **THEN** set the Nest thermostat to Away mode
- **IF** the SmartThings entrance door is locked, **THEN** set the Nest thermostat to Manual mode

Inconsistencies

if this then that

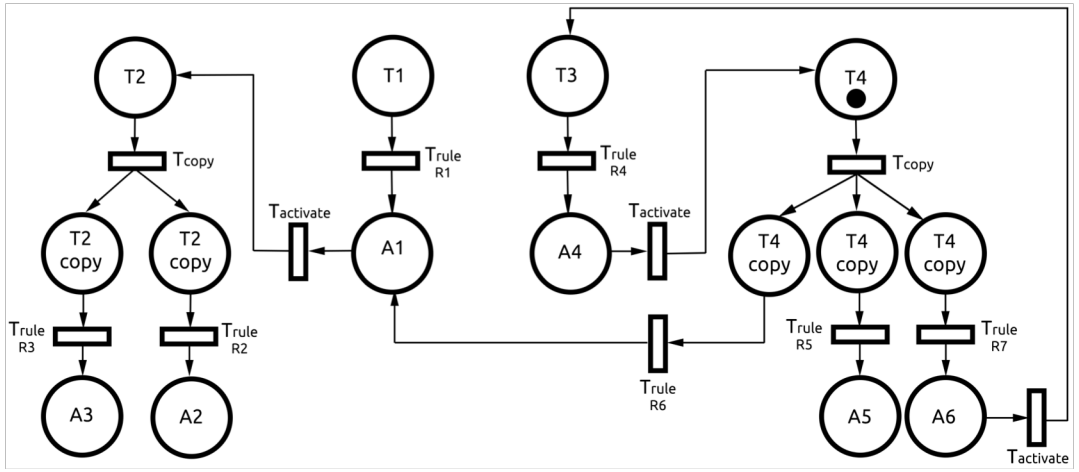
REDUNDANCIES

LOOPS

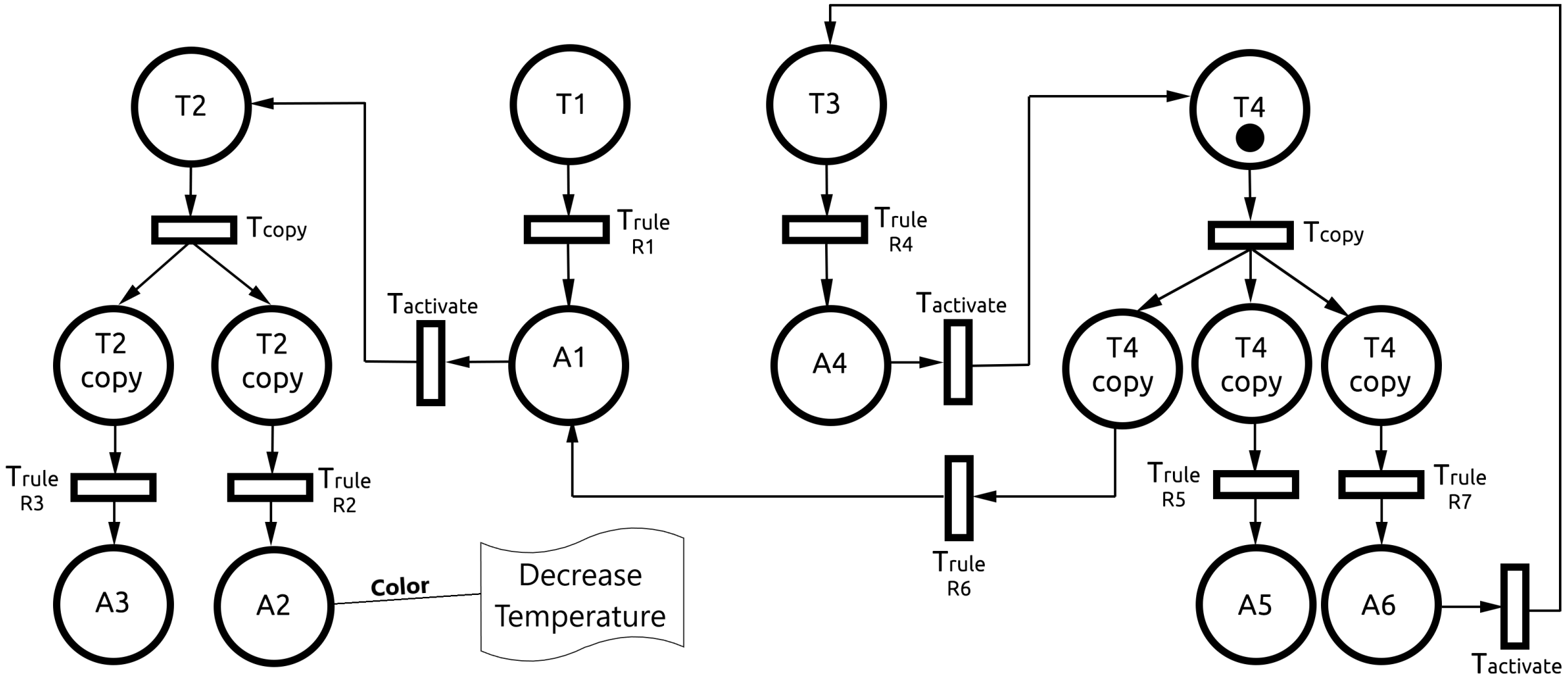
INCONSISTENCIES

Client

EUPont Ontolgy



Server


T2
T1
T3
T4
Tcopy
Trule R1
Trule R4
Tcopy
Tactivate
Tactivate
T2 copy
T2 copy
A1
A4
T4 copy
T4 copy
T4 copy
Trule R3
Trule R2
Trule R5
Trule R7
Trule R6
A3
A2
Color
Decrease Temperature
A5
A6
Tactivate

THANK YOU!

e-Lite

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