Federal University of Amazonas
Institute of Computing
Graduate Program in Informatics
Interest Group on Embedded Systems

EMBEDDED MINING CORRELATIONS BETWEEN DISTRIBUTED DEVICES

Prof. Dr. Raimundo Barreto
Márcio André da Costa Alencar

Salvador-BA, November 07th 2018

PRESENTATION SCHEDULE

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INTRODUCTION	I	Contextualization
PROBLEMATIC	II	Definition of main and specifics goals
PROPOSED METHOD	III	Components specifications and its interactions
EXPERIMENTS	IV	Experiments and results
FINAL CONSIDERATIONS	V	Important notes

INTRODUCTION

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Contextualization

- What is *"Internet of Things"* ?

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Contextualization

- What is *“Internet of Things”* ? There’s no global definition but, a simplistic concept, could be as the scenario where **things** are connected!

Source: https://news.fiu.edu/2017/06/fiu-to-offer-first-internet-of-things-degree-in-u-s/112824

INTRODUCTION

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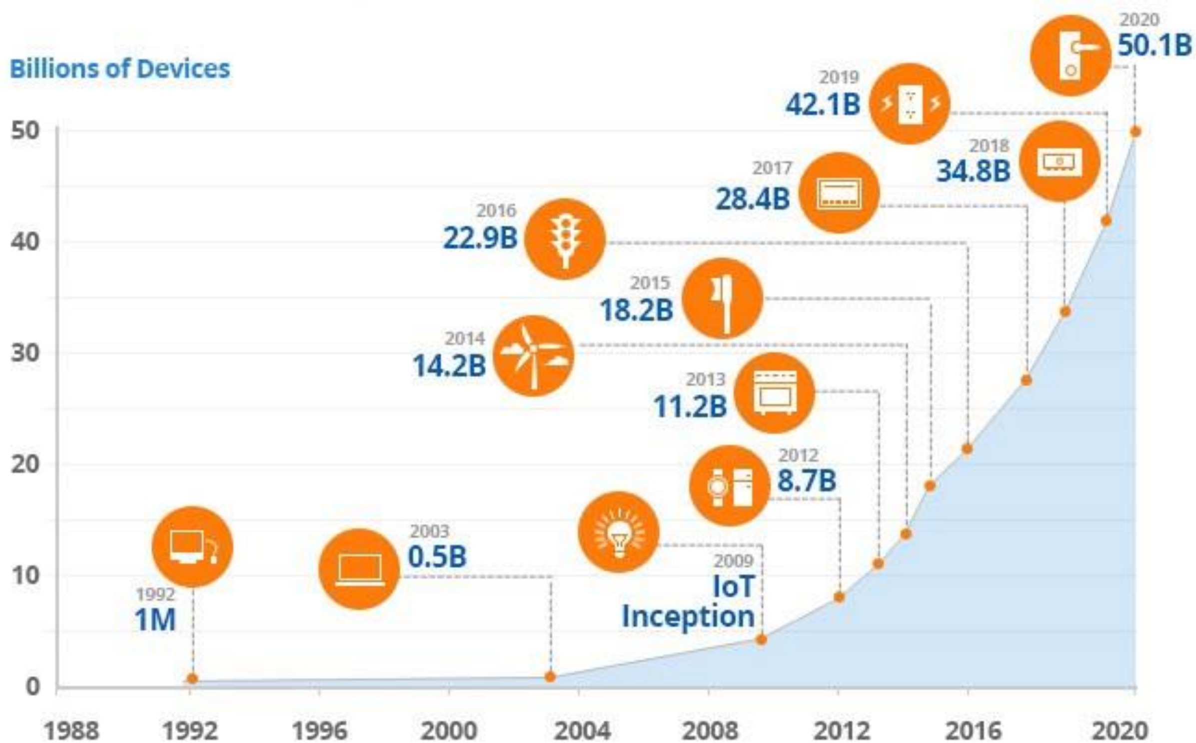
Contextualization

- Until 2020 will be over 50 Bi devices (IDC - 2011)



Source: https://hackernoon.com/the-most-promising-internet-of-things-trends-for-2018-10a852ccd189

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Contextualization

- Many of them will be in your home;

Source: https://www.liefner.de/smarthome/

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Contextualization

- Many of them will be in your home;
- Be connected is not enough. **IoT demands intelligence!**

Source: *https://www.liefner.de/smarthome/*

PROBLEMATIC

How to provide intelligence to IoT devices?

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PROBLEMATIC

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How to provide intelligence to IoT devices?

The ability to provide intelligence and autonomy in IoT relies primarily on the need to identify activities, patterns and correlations implicit in the activity records of each device that composes it.

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How to provide intelligence to IoT devices?

The ability to provide intelligence and autonomy in IoT relies primarily on the need to identify activities, patterns and correlations implicit in the activity records of each device that composes it.

Some points must be considered before that:

- **Architecture**: Centralized / Decentralized
- **Kind of intelligence**: What information extract
- **Devices Limitations**: Much / Few Resources
- **Cost/Benefit:** Expensive or cheap solution

PROBLEMATIC

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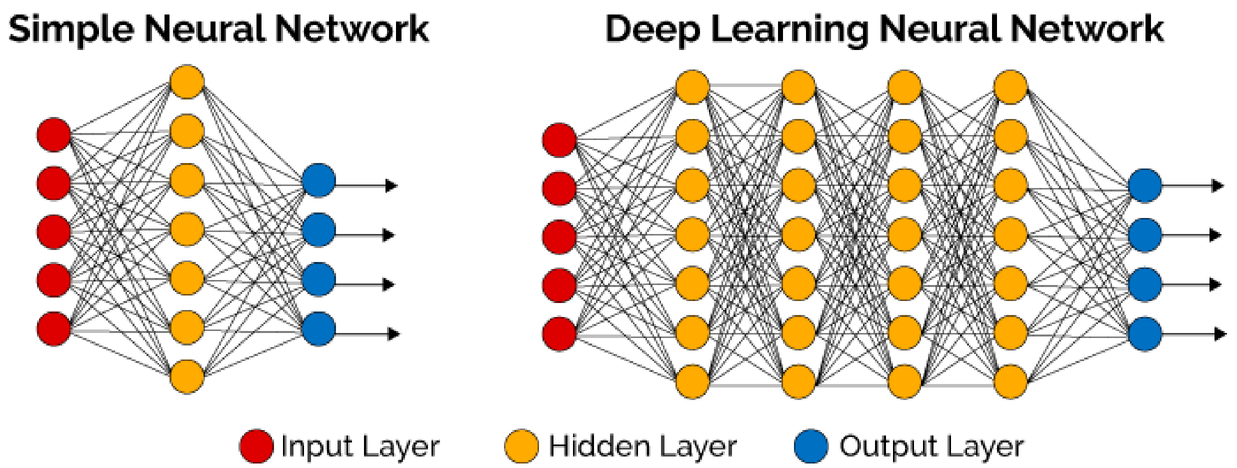
State of art in Machine Learning

- Neural Network(Deep learning)



Source: https://becominghuman.ai/deep-learning-made-easy-with-deep-cognition-403fbe445351?gi=35630fc87e88

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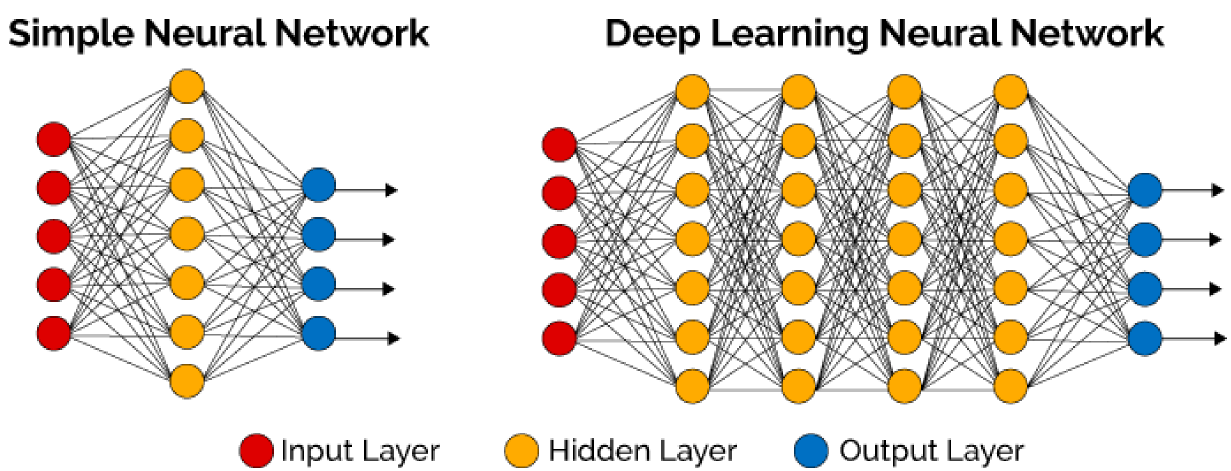
State of art in Machine Learning

- Neural Network(Deep learning)
- High computational cost (storage/processing)

(CHEN *et al*., 2015; MOONS e VERHELST, 2017)



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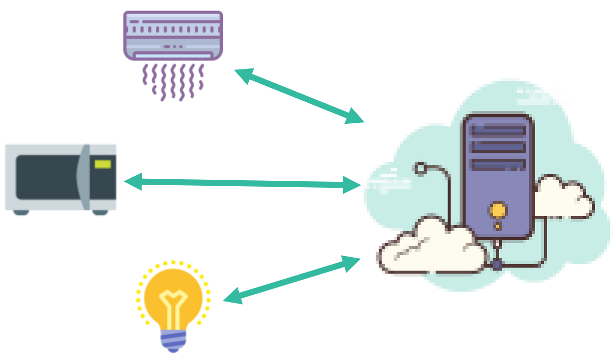

Source: https://icons8.com/

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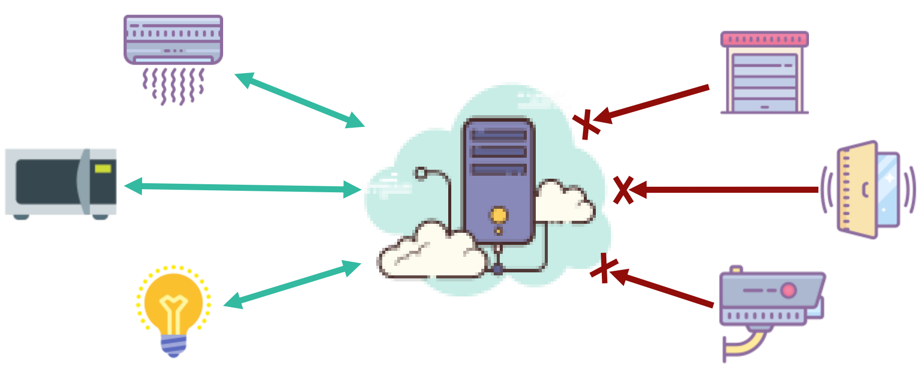

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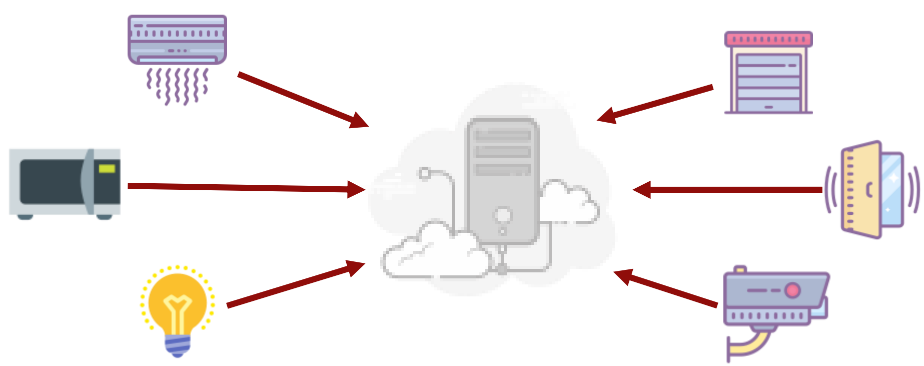

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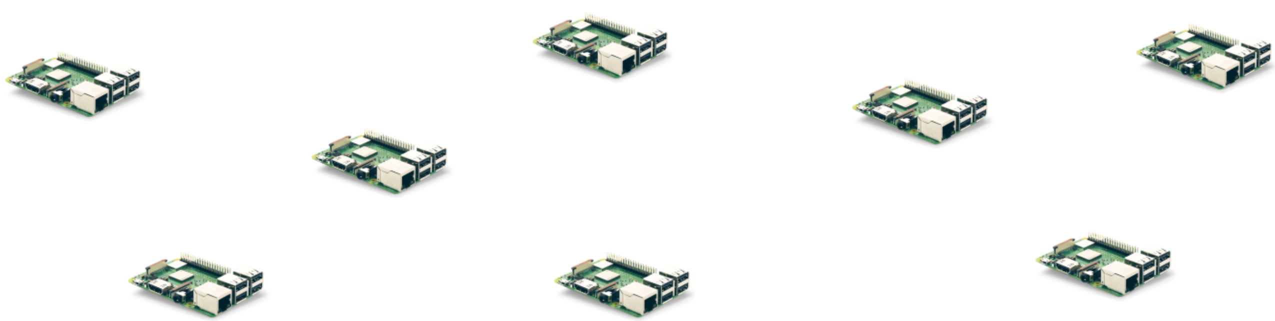
PROBLEMATIC

State of art in Machine Learning

- Neural Network(Deep learning)
- High computational cost (storage/processing)

(CHEN *et al.*, 2015; MOONS e VERHELST, 2017)

- Centralization / Dependency
- Devices with many resources (expensive / waste of resource)



Source: https://icons8.com/

PROBLEMATIC

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How to provide intelligence to IoT devices...

Considering:

- Decentralized environment
- Devices autonomy
- Limited processing and storage resources
- Extract knowledge from limited amount of data

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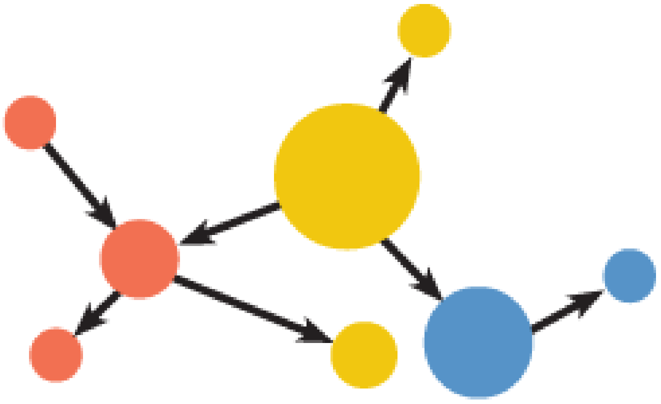
Data mining!

A strategy to circumvent such adversities is the use of data mining techniques, but specifically of **association rules**, which seek to identify frequent patterns in a dataset so that it meets minimum support and confidence criteria.

(CHEN *et al*., 2015; TAN *et al*., 2006)



Source: https://community.powerbi.com/t5/R-Script-Showcase/Association-Rules/td-p/58491

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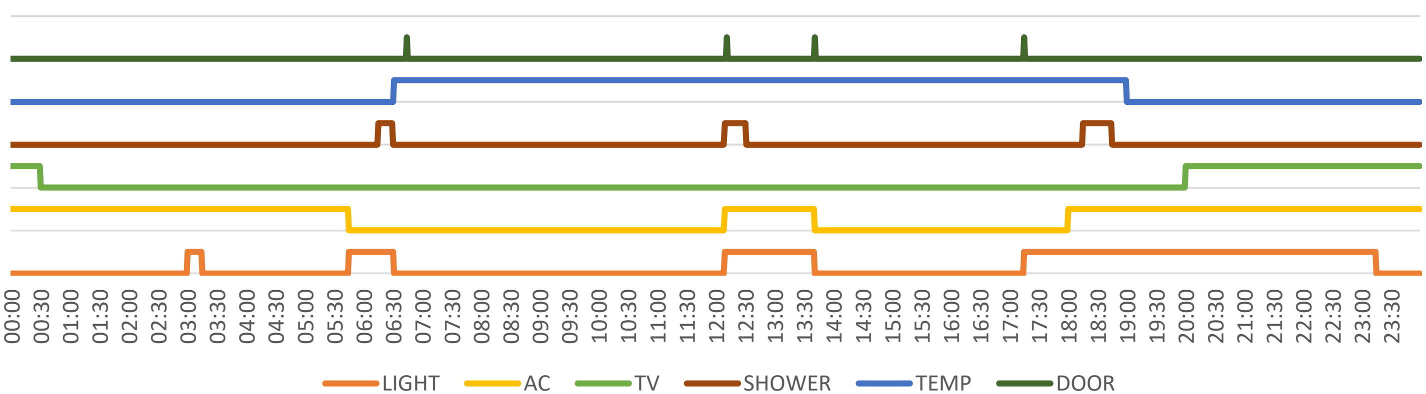
Data mining!

Although **each device has a unique usage pattern, some** devices have **similar characteristics** of use, that **could be used to correlate** them.

(PAL *et al.*, 2017; GONZALES e AMFT, 2015; CHEN *et al.*, 2012; HEIERMAN *et al.*, 2003).



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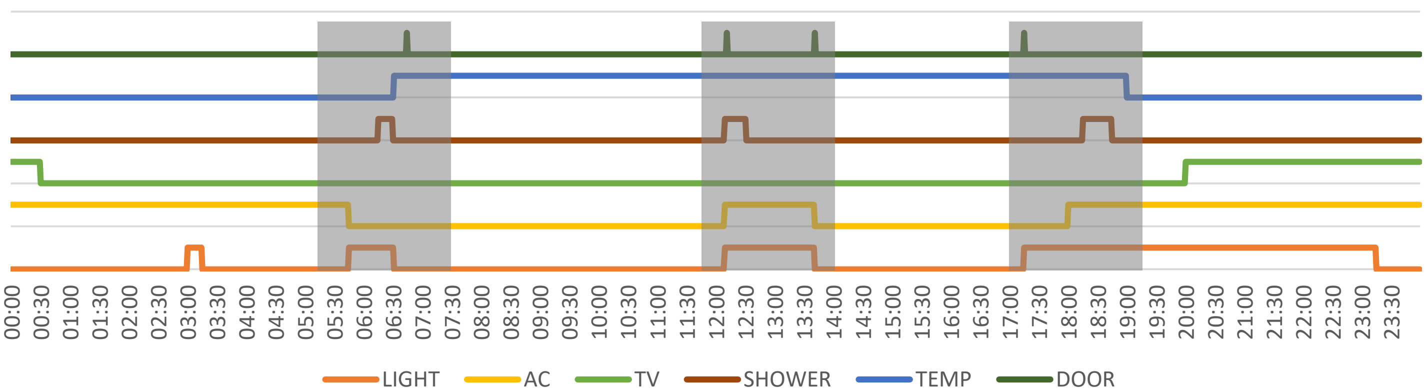
Main Goal

Demonstrate the ability of intelligent integration between devices in the internet of things, through a decentralized mining of implicit correlations between their **patterns of state changes.**



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Preliminary information

It is important to comprehend some components and specifications before a general architecture overview

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Preliminary information

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Keep that in mind:

- We want to work with devices that have severe restrictions of processing, storage and memory (Like: ESP8266-01)

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Preliminary information

It is important to comprehend some components and specifications before a general architecture overview

Keep that in mind:

- We want to work with devices that have severe restrictions of processing, storage and memory (Like: ESP8266-01)
- All storage and processing must be performed into each device, there’s no storage server or cloud services.

PROPOSED METHOD

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Preliminary information

It is important to comprehend some components and specifications before a general architecture overview

Keep that in mind:

- We want to work with devices that have severe restrictions of processing, storage and memory (Like: ESP8266-01)
- All storage and processing must be performed into each device, there's no storage server or cloud services.
- The devices must talk to each other (http requests) and obtain a global knowledge based on local decisions.

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Devices behavior

Each device must be specified as a Finite State Machine, composed by a set of well defined (discrete) states ($S = \{s_1, s_2, \ldots s_i\}$) which represents its interactions with environment. It also has a set of actions ($A = \{a_1, a_2, \ldots, a_i\}$) which allow to transit among the |S| states;

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Example: Lamp/Light/Binary Device

S={“on”,”off”}

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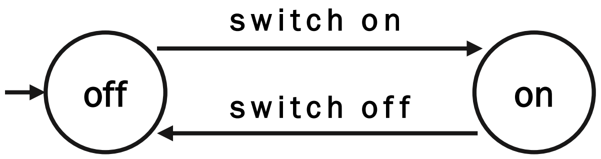
Example: Lamp/Light/Binary Device

S={“on”,”off”}

A={“switch on”,”switch off”}



Embedded data storage

Based on this FSM and assuming a finite set of discretized time interval(slots) as $T = \{t_1, t_2, \dots t_j\}$ it is possible to define a embedded database as a counters matrix $M_{ij} = A \times T$ where each element $c_{nm} \in M_{ij}$ is a counter associated to the action $a_n \in A$ at the time $t_m \in T$;

$$M_{ij} = \begin{bmatrix} c_{11} & \cdots & c_{1j} \\ \vdots & \ddots & \vdots \\ c_{i1} & \cdots & c_{ij} \end{bmatrix}$$

$i: num\ of\ items\ in\ A\ (\ |A|\ );$
$j: num\ of\ items\ in\ T\ (\ |T|\ );$
$c_{nm}: counter\ for\ each\ action\ a_n\ at\ slot\ t_m;$

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Pattern of changes

The devices' pattern of changes could be extracted from the embedded dataset by comparing the counters that belongs to the same slots(column in matrix).

Embedded Database(M_{ij})

	00:00	01:00	02:00	...	21:00	22:00	23:00
switch off	10	2	0		26	14	12
switch on	2	2	0		34	17	7

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	00:00	01:00	02:00	...	21:00	22:00	23:00
switch off	<u>10</u>	2	0		26	14	<u>12</u>
switch on	2	2	0		<u>34</u>	<u>17</u>	7

Pattern of change (P)

00:00	01:00	02:00	...	21:00	22:00	23:00
SWITCH OFF	-	-	...	SWITCH ON	SWITCH ON	SWITCH OFF

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Mining correlations

Once that each devices satisfies the previously specifications is possible to identify implicit correlations between its actions by the frequency of a pair of actions that shows together when two patterns are compared slot by slot.

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Once that each devices satisfies the previously specifications is possible to identify implicit correlations between its actions by the frequency of a pair of actions that shows together when two patterns are compared slot by slot.

Pattern of change form Device 01	00:00	01:00	02:00	...	21:00	22:00	23:00
	SWITCH OFF	-	-	...	SWITCH ON	SWITCH ON	SWITCH OFF

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Pattern of change form Device 01

00:00	01:00	02:00	...	21:00	22:00	23:00
SWITCH OFF	-	-	...	SWITCH ON	SWITCH ON	SWITCH OFF

Pattern of change form Device 02

00:00	01:00	02:00	...	21:00	22:00	23:00
DOOR CLOSE	DOOR CLOSE	-	...	DOOR OPEN	DOOR CLOSE	DOOR CLOSE

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Mining correlations

Once that each devices satisfies the previously specifications is possible to identify implicit correlations between its actions by the frequency of a pair of actions that shows together when two patterns are compared slot by slot.

Transaction Dataset(D)

00:00	01:00	02:00	...	21:00	22:00	23:00
SWITCH OFF	-	-	...	SWITCH ON	SWITCH ON	SWITCH OFF
DOOR CLOSE	DOOR CLOSE	-	...	DOOR OPEN	DOOR CLOSE	DOOR CLOSE

Mining correlations

Once that each devices satisfies the previously specifications is possible to identify implicit correlations between its actions by the frequency of a pair of actions that shows together when two patterns are compared slot by slot.

Transaction Dataset(D)

00:00	01:00	02:00	...	21:00	22:00	23:00
SWITCH OFF	-	-	...	SWITCH ON	SWITCH ON	SWITCH OFF
DOOR CLOSE	DOOR CLOSE	-	...	DOOR OPEN	DOOR CLOSE	DOOR CLOSE

Possible Rules

SWITCH OFF ⇒ DOOR CLOSE
SWITCH OFF ⇒ DOOR OPEN
SWITCH ON ⇒ DOOR CLOSE
SWITCH ON ⇒ DOOR OPEN

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Mining correlations

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Transaction Dataset(D)

00:00	01:00	02:00	...	21:00	22:00	23:00
SWITCH OFF	-	-	...	SWITCH ON	SWITCH ON	SWITCH OFF
DOOR CLOSE	DOOR CLOSE	-	...	DOOR OPEN	DOOR CLOSE	DOOR CLOSE

Possible Rules

SWITCH OFF ⇒ DOOR CLOSE
SWITCH OFF ⇒ DOOR OPEN
SWITCH ON ⇒ DOOR CLOSE
SWITCH ON ⇒ DOOR OPEN

Which rule(s) is(are) more frequent?

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Mining correlations

Association Rules correlate an "Action X" from "Device 01" with an "Action Y" from "Device 02" and give an importance to that rule based on:

$$\textbf{Device 01}(\textbf{Action } \boldsymbol{X}) \Rightarrow \textbf{Device 02}(\textbf{Action } \boldsymbol{Y})$$

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Mining correlations

Association Rules correlate an "Action X" from "Device 01" with an "Action Y" from "Device 02" and give an importance to that rule based on:

- **Support:** How frequent is this rule in transactions dataset(D);
- **Confidence:** How reliable is this rule.
- **Lift:** How dependent are antecedent and consequent;

$$\textbf{Device 01}(\textbf{Action } \boldsymbol{X}) \Rightarrow \textbf{Device 02}(\textbf{Action } \boldsymbol{Y})$$

$$[\,sup{:}\,80\%, lift{:}\,4.3, conf{:}\,96\%]$$

PROPOSED METHOD

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Mining correlations

Put in other words, those metrics are:

$$Rule: \; X \Rightarrow Y$$

$$Support = \frac{frq(X,Y)}{N}$$

$$Confidence = \frac{frq(X,Y)}{frq(X)}$$

$$Lift = \frac{Support}{Supp(X) \times Supp(Y)}$$

*N = Size of dataset transaction

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Mining correlations

Minimum Thresholds must be defined to avoid unnecessary processing of non-frequent itemsets:

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Mining correlations

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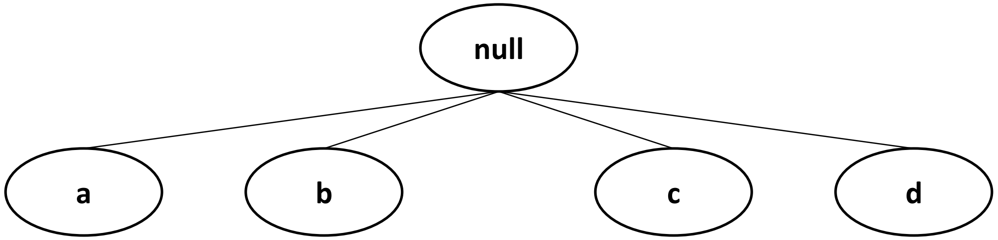
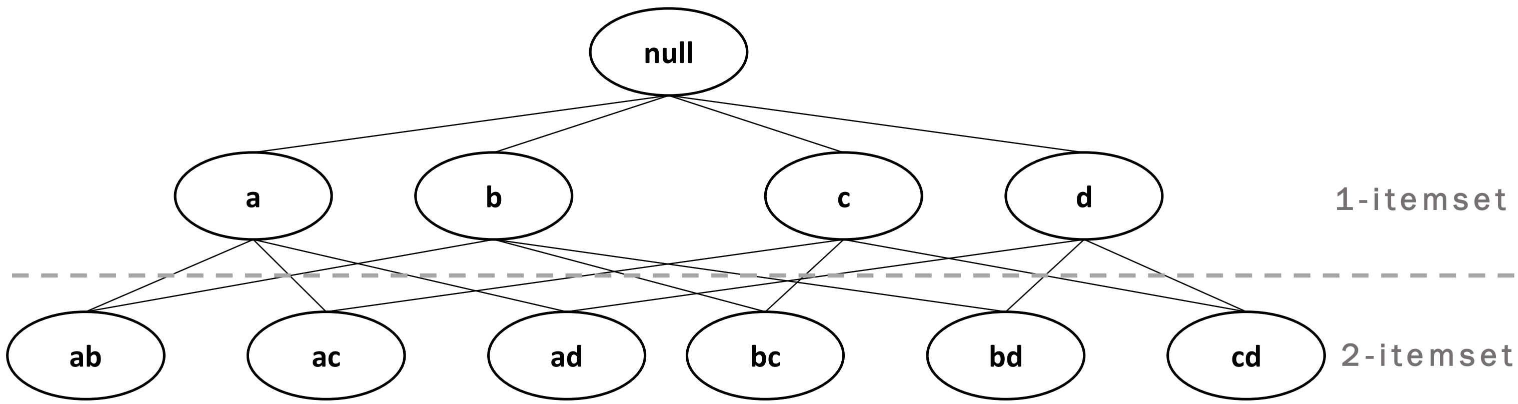


1-itemset

Mining correlations

Minimum Thresholds must be defined to avoid unnecessary processing of non-frequent itemsets:



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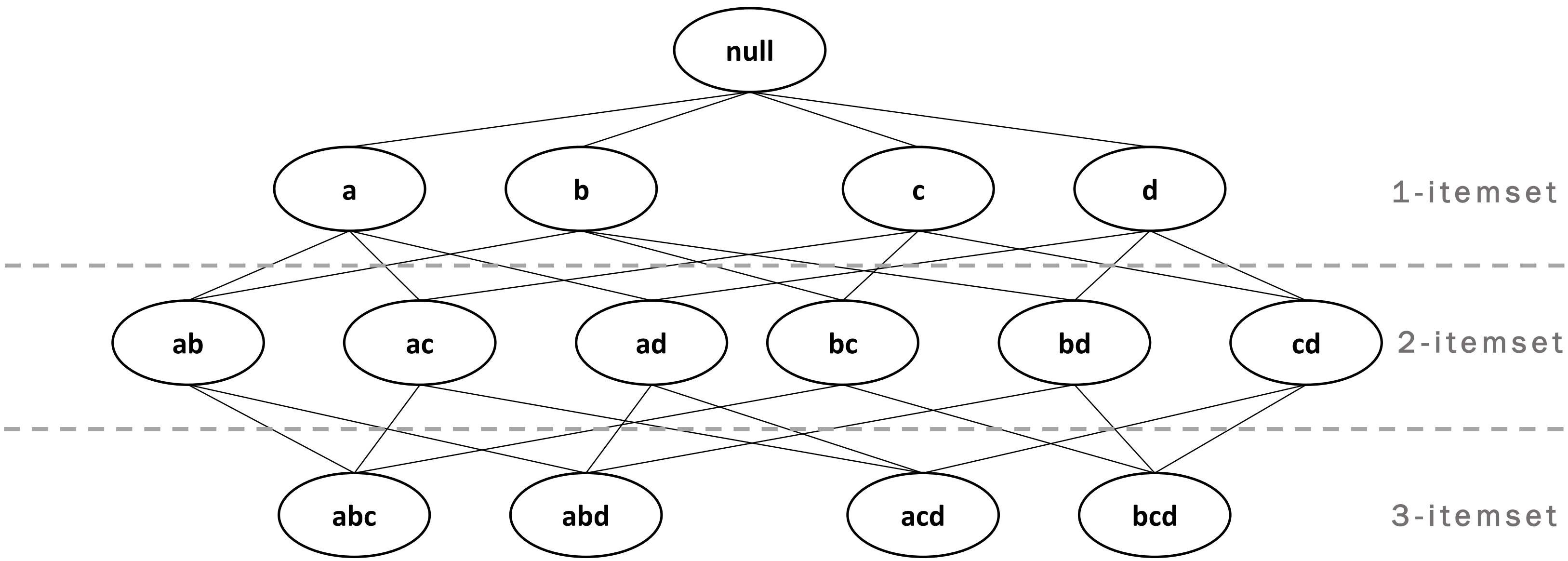

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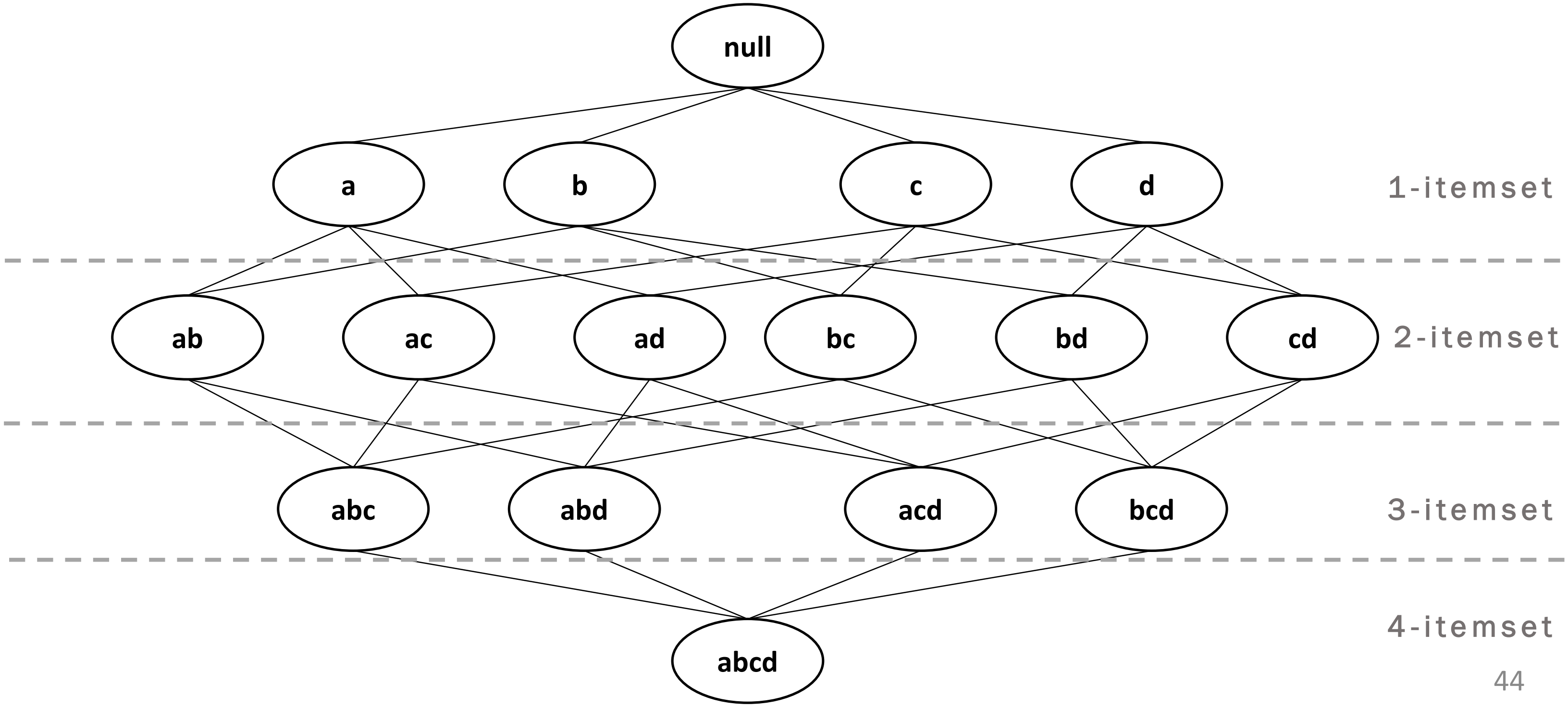

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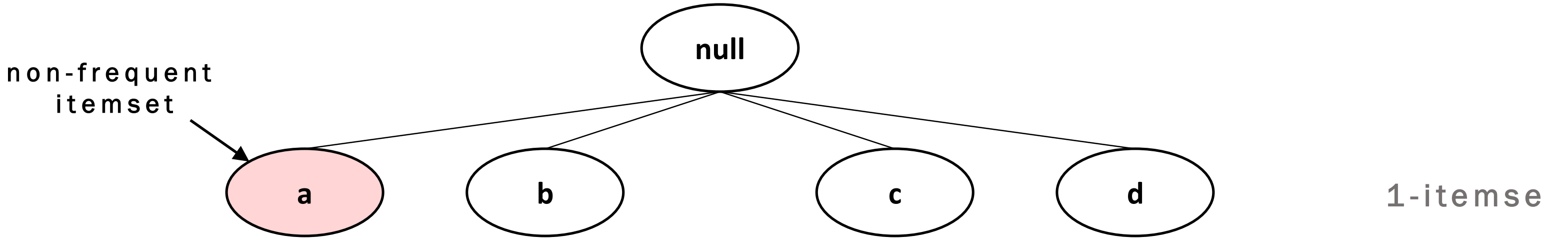

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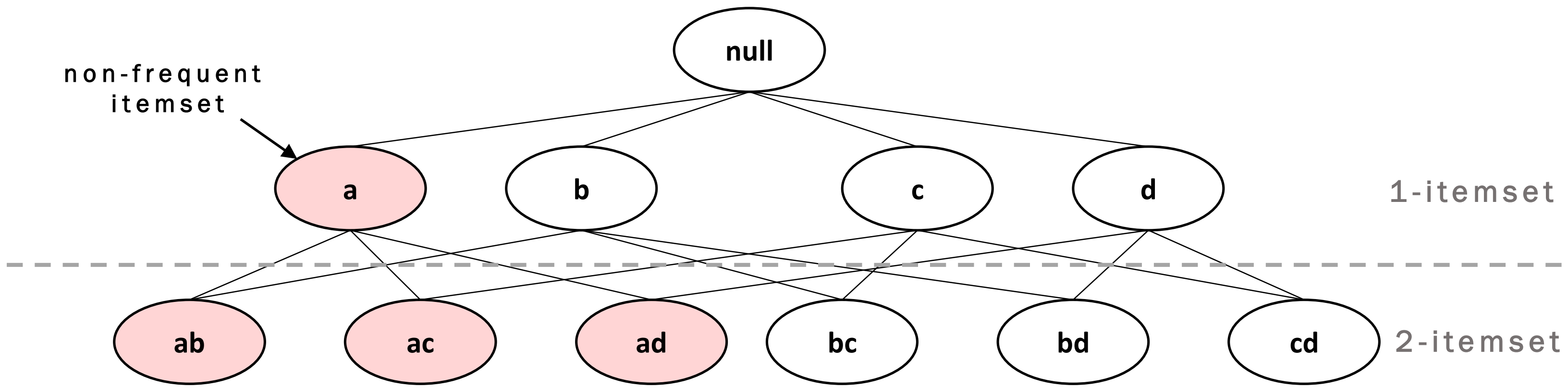

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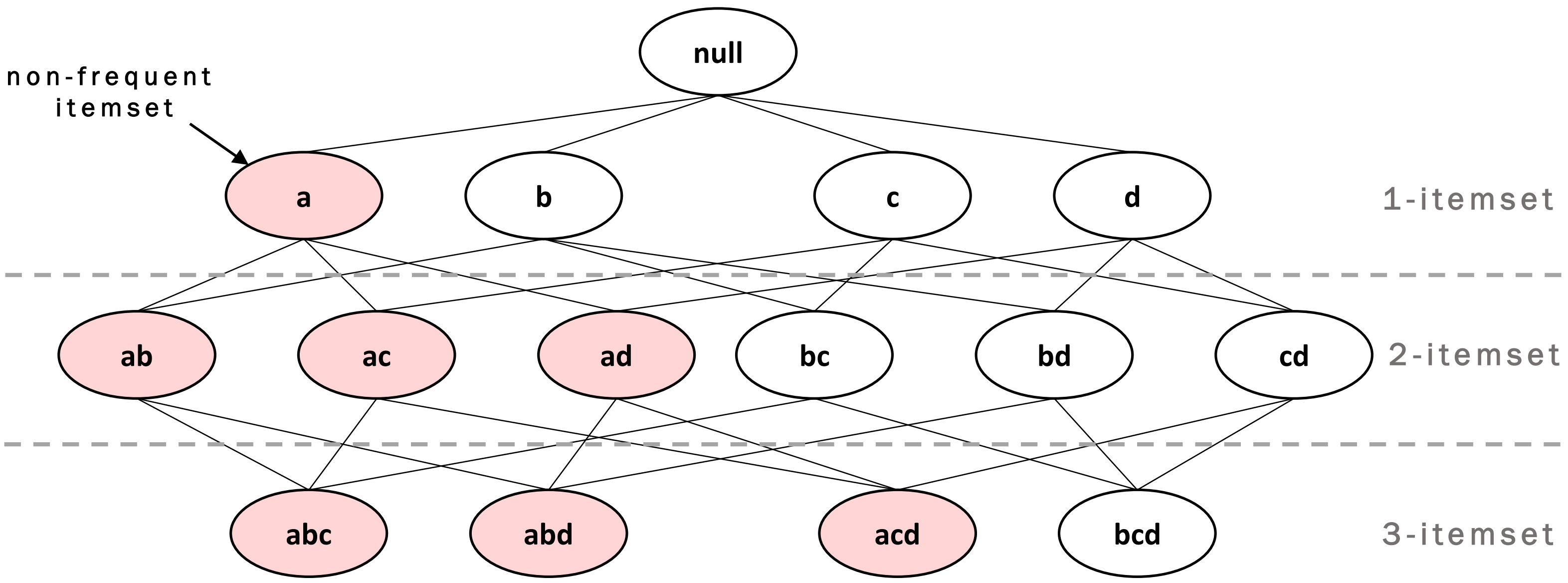

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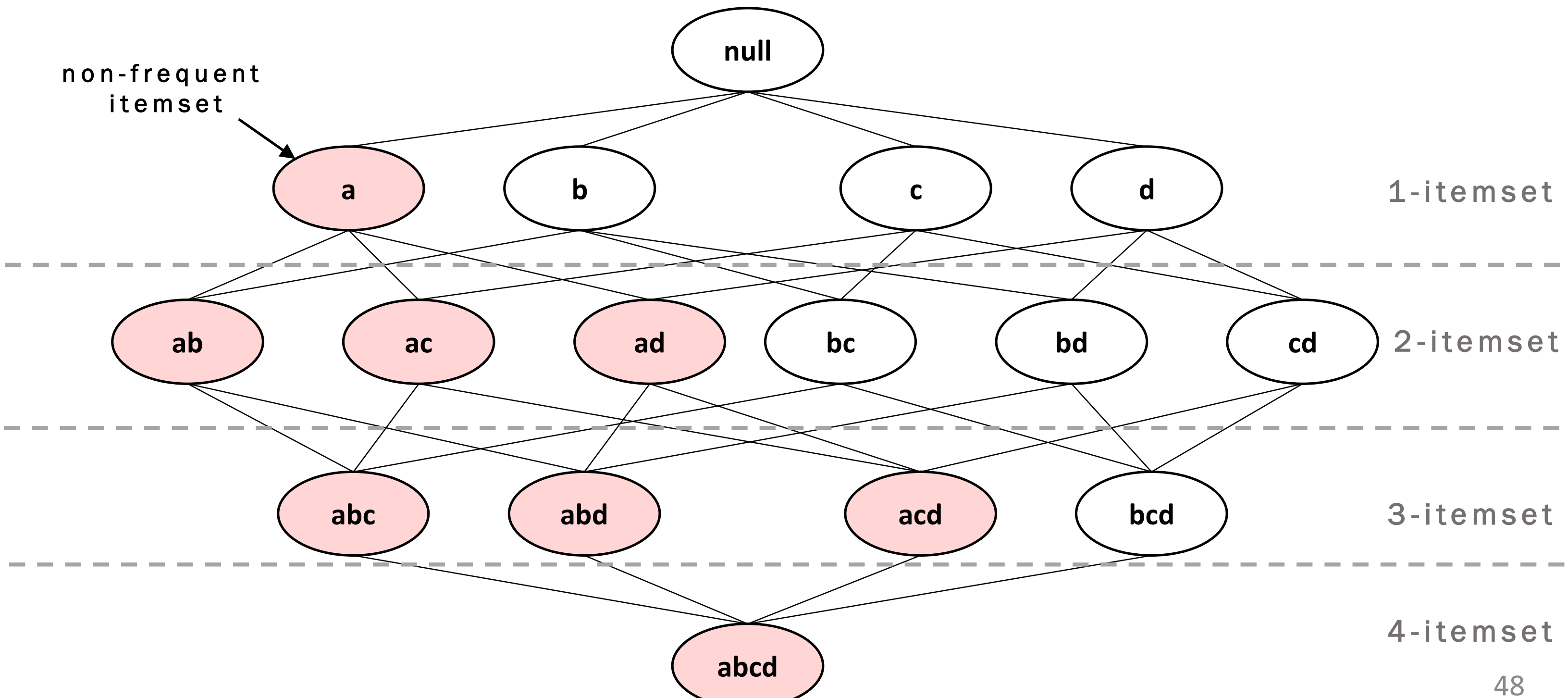
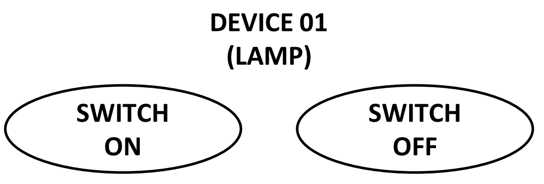


PROPOSED METHOD

Mining correlations

This approach does not combine actions from the same device. Also is not necessary to create itemsets greater than 2;



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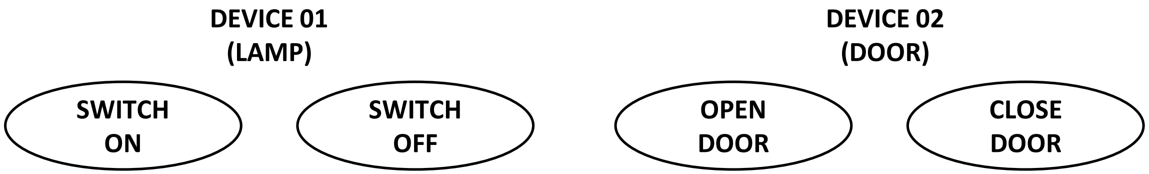

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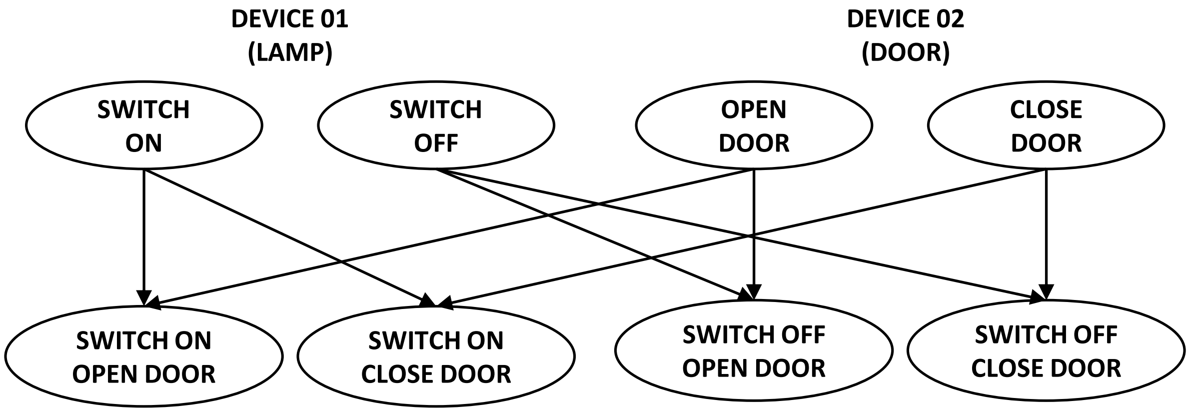

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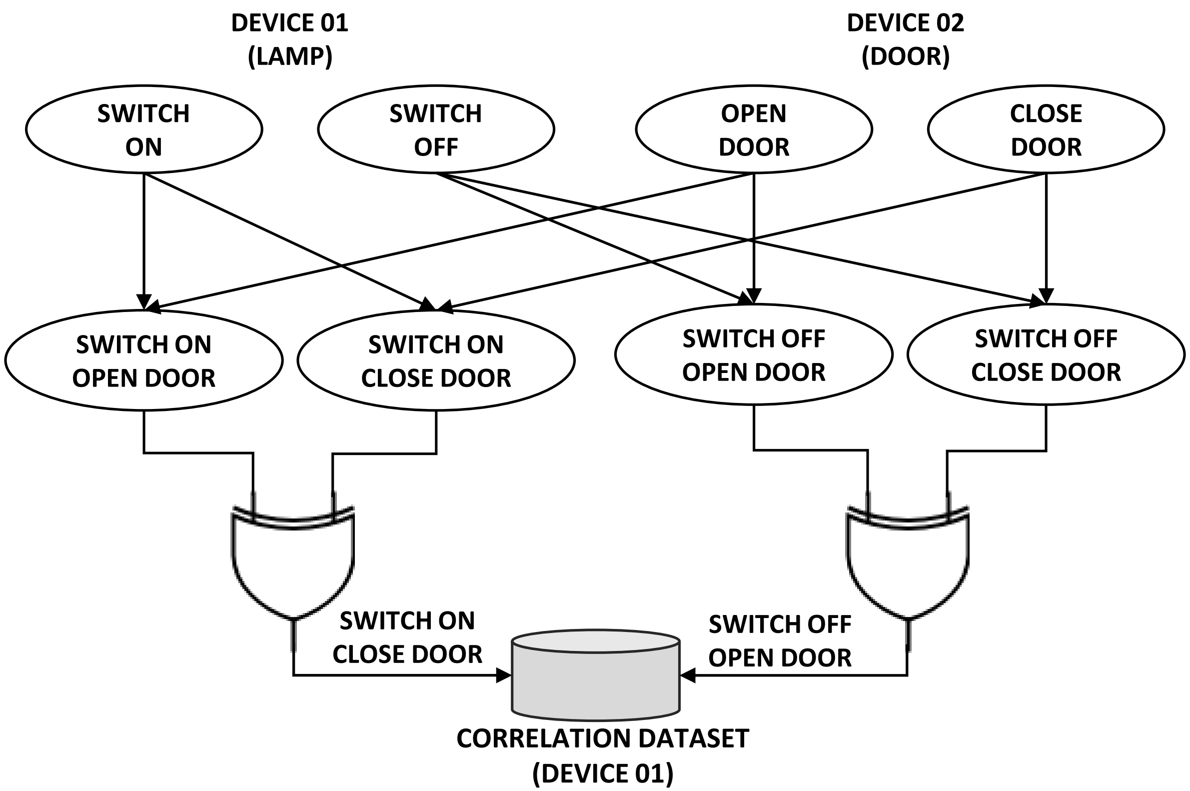

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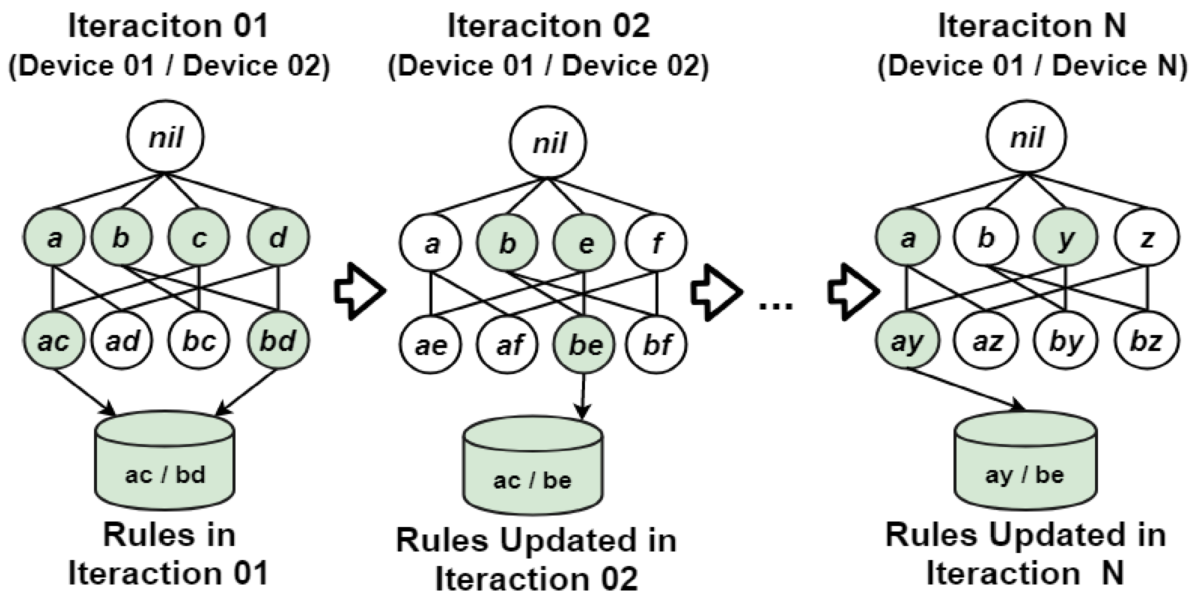
Mining correlations

This process repeats to each device in network updating the most relevant rules in correlation dataset



PROPOSED METHOD

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What should I do now!?

Based on those rules it is possible to Device 01 perform a request to Device 02 change its states to satisfy the rule;

PROPOSED METHOD

What should I do now!?

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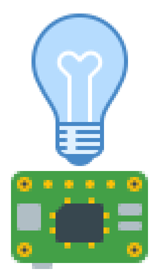
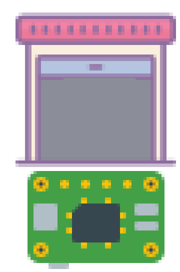
RULES IN DEVICE 01

SWITCH ON ⇒ CLOSE DOOR

SWITCH OFF ⇒ OPEN DOOR



DEVICE 01



DEVICE 02

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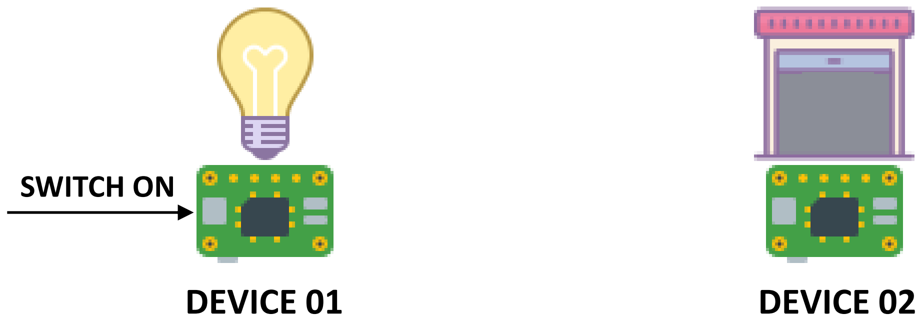
What should I do now!?

Based on those rules it is possible to Device 01 perform a request to Device 02 change its states to satisfy the rule;

RULES IN DEVICE 01

SWITCH ON ⇒ CLOSE DOOR

SWITCH OFF ⇒ OPEN DOOR



PROPOSED METHOD

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What should I do now!?

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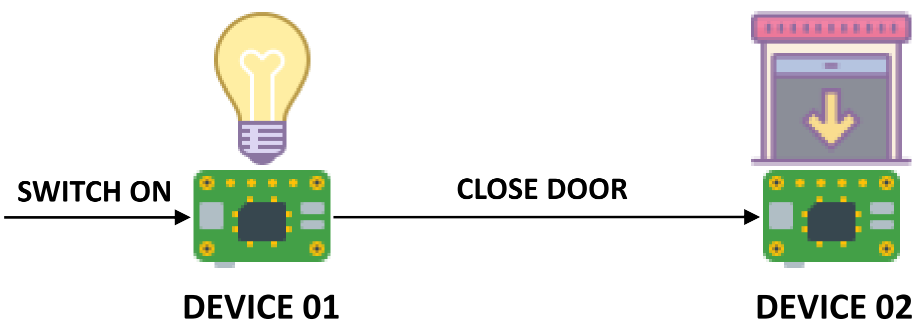
RULES IN DEVICE 01

SWITCH ON ⇒ CLOSE DOOR

SWITCH OFF ⇒ OPEN DOOR



PROPOSED METHOD

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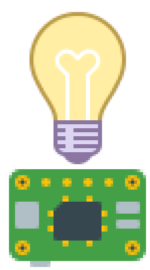
What should I do now!?

Based on those rules it is possible to Device 01 perform a request to Device 02 change its states to satisfy the rule;

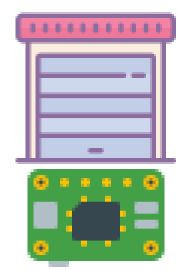
RULES IN DEVICE 01

SWITCH ON ⇒ CLOSE DOOR

SWITCH OFF ⇒ OPEN DOOR



DEVICE 01



DEVICE 02

PROPOSED METHOD

I

II

III

IV

V

What should I do now!?

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RULES IN DEVICE 01

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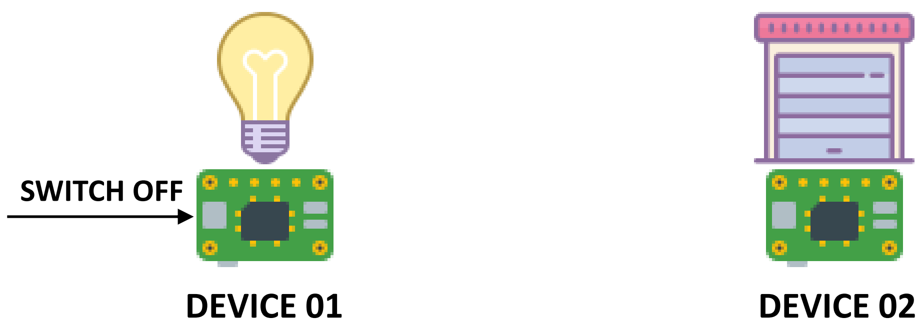
SWITCH OFF ⇒ OPEN DOOR



PROPOSED METHOD

I
II
III
IV
V

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RULES IN DEVICE 01

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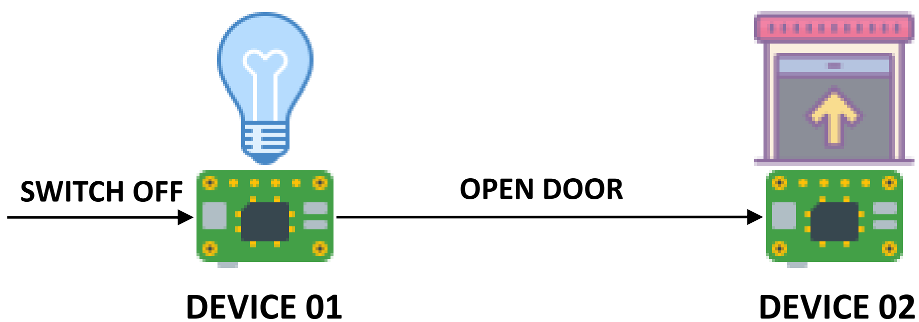

PROPOSED METHOD

What should I do now!?

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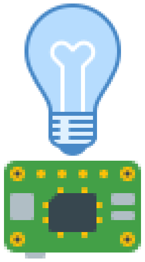
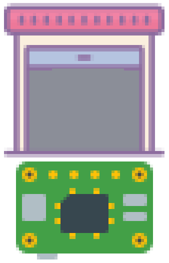
SWITCH ON ⇒ CLOSE DOOR

SWITCH OFF ⇒ OPEN DOOR



DEVICE 01



DEVICE 02

ALWAYS!?

THAT'S SOUND ~~STUPID~~ DANGEROUS

Slot restrictions

To avoid unusual integrations the trigger is fire only if the input action were the most probable to occur at the current slot.

Slot restrictions

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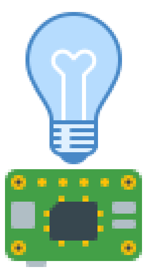
RULES IN DEVICE 01

SWITCH ON ⇒ CLOSE DOOR

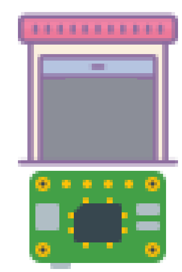
SWITCH OFF ⇒ OPEN DOOR



DEVICE 01

00:00	SWITCH OFF
01:00	-
02:00	-
...	...
21:00	SWITCH ON
22:00	SWITCH ON
23:00	SWITCH OFF

00:00	CLOSE DOOR
01:00	CLOSE DOOR
02:00	-
...	...
21:00	OPEN DOOR
22:00	CLOSE DOOR
23:00	CLOSE DOOR



DEVICE 02

UFAM

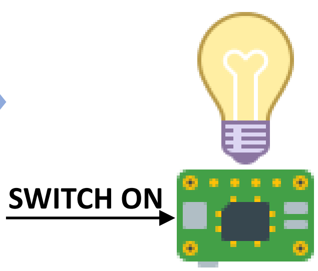
Slot restrictions

To avoid unusual integrations the trigger is fire only if the input action were the most probable to occur at the current slot.

RULES IN DEVICE 01

SWITCH ON ⇒ CLOSE DOOR

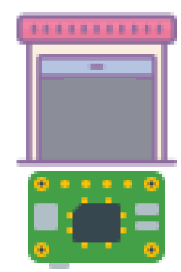
SWITCH OFF ⇒ OPEN DOOR



DEVICE 01

00:00	SWITCH OFF
01:00	-
02:00	-
...	...
21:00	SWITCH ON
22:00	SWITCH ON
23:00	SWITCH OFF

00:00	CLOSE DOOR
01:00	CLOSE DOOR
02:00	-
...	...
21:00	OPEN DOOR
22:00	CLOSE DOOR
23:00	CLOSE DOOR



DEVICE 02

PROPOSED METHOD

UFAM

Slot restrictions

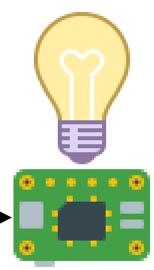
To avoid unusual integrations the trigger is fire only if the input action were the most probable to occur at the current slot.

RULES IN DEVICE 01

SWITCH ON ⇒ CLOSE DOOR

SWITCH OFF ⇒ OPEN DOOR

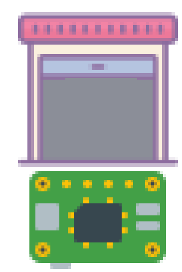
SWITCH ON



DEVICE 01

00:00	SWITCH OFF ✗
01:00	-
02:00	-
...	...
21:00	SWITCH ON
22:00	SWITCH ON
23:00	SWITCH OFF ✗

00:00	CLOSE DOOR
01:00	CLOSE DOOR
02:00	-
...	...
21:00	OPEN DOOR
22:00	CLOSE DOOR
23:00	CLOSE DOOR



DEVICE 02

UFAM

I
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Slot restrictions

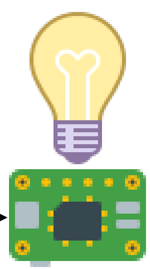
To avoid unusual integrations the trigger is fire only if the input action were the most probable to occur at the current slot.

RULES IN DEVICE 01

SWITCH ON ⇒ CLOSE DOOR

SWITCH OFF ⇒ OPEN DOOR

SWITCH ON

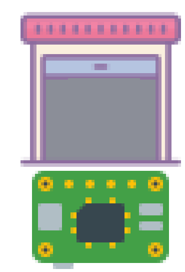


DEVICE 01

00:00	SWITCH OFF
01:00	-
02:00	-
...	...
21:00	SWITCH ON
22:00	SWITCH ON
23:00	SWITCH OFF

CLOSE DOOR

00:00	CLOSE DOOR
01:00	CLOSE DOOR
02:00	-
...	...
21:00	OPEN DOOR ✗
22:00	CLOSE DOOR
23:00	CLOSE DOOR



DEVICE 02

PROPOSED METHOD

UFAM

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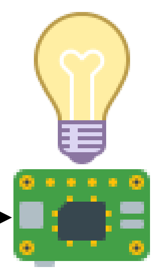
RULES IN DEVICE 01

SWITCH ON ⇒ CLOSE DOOR

SWITCH OFF ⇒ OPEN DOOR



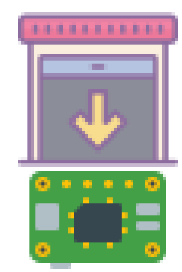
SWITCH ON

DEVICE 01

00:00	SWITCH OFF
01:00	-
02:00	-
...	...
21:00	SWITCH ON
22:00	SWITCH ON
23:00	SWITCH OFF

CLOSE DOOR

00:00	CLOSE DOOR
01:00	CLOSE DOOR
02:00	-
...	...
21:00	OPEN DOOR
22:00	CLOSE DOOR
23:00	CLOSE DOOR



DEVICE 02

PROPOSED METHOD

UFAM

I

II

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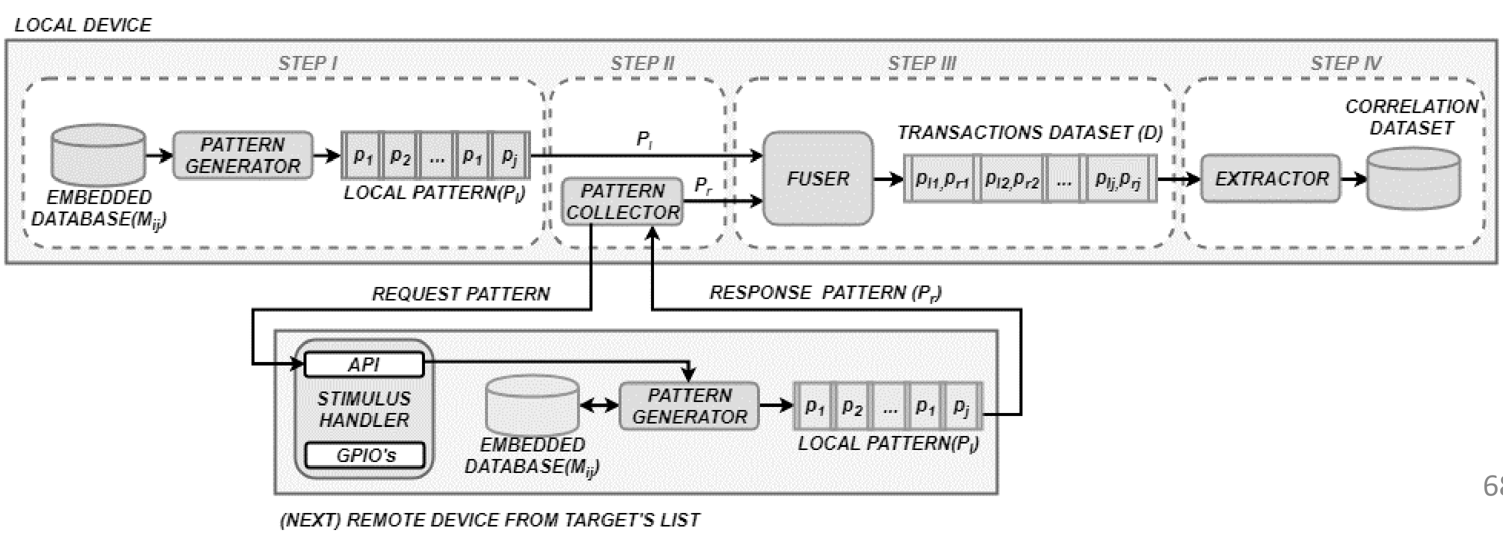
Process Overview

Once that each devices satisfies the previously specifications is possible to identify implicit correlations between its actions.



UFAM

I

II

III

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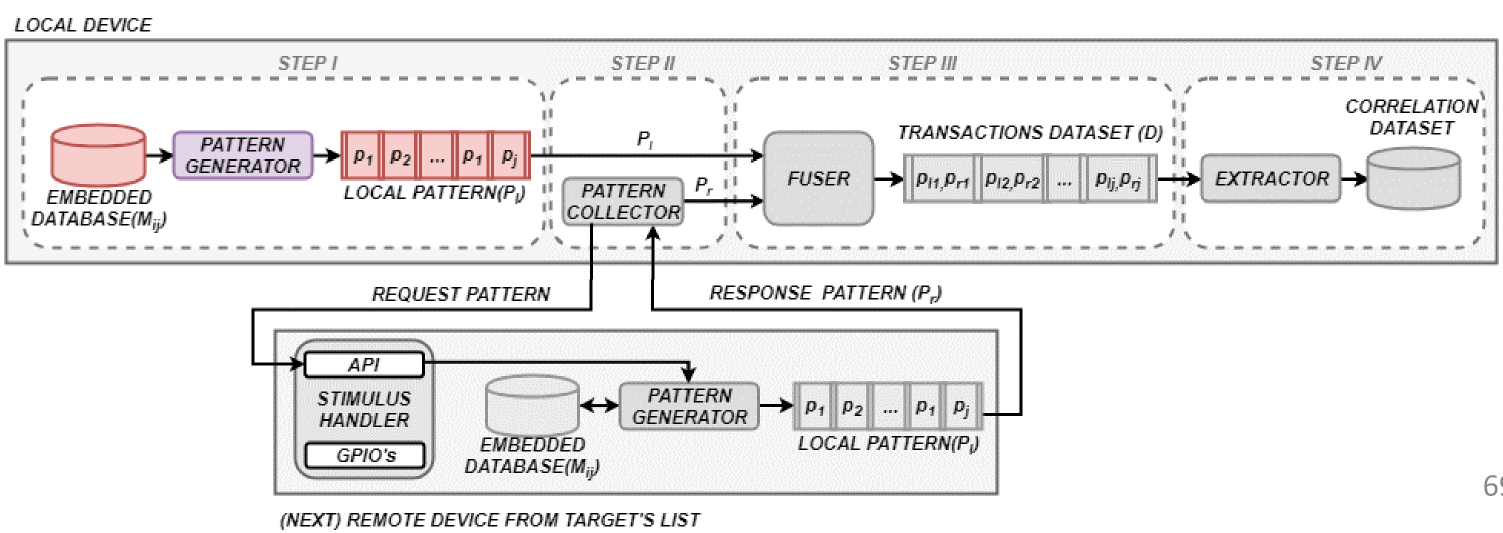
V

Process Overview

Once that each devices satisfies the previously specifications is possible to identify implicit correlations between its actions.

- **Step I:** Identify the local pattern



PROPOSED METHOD

UFAM

I

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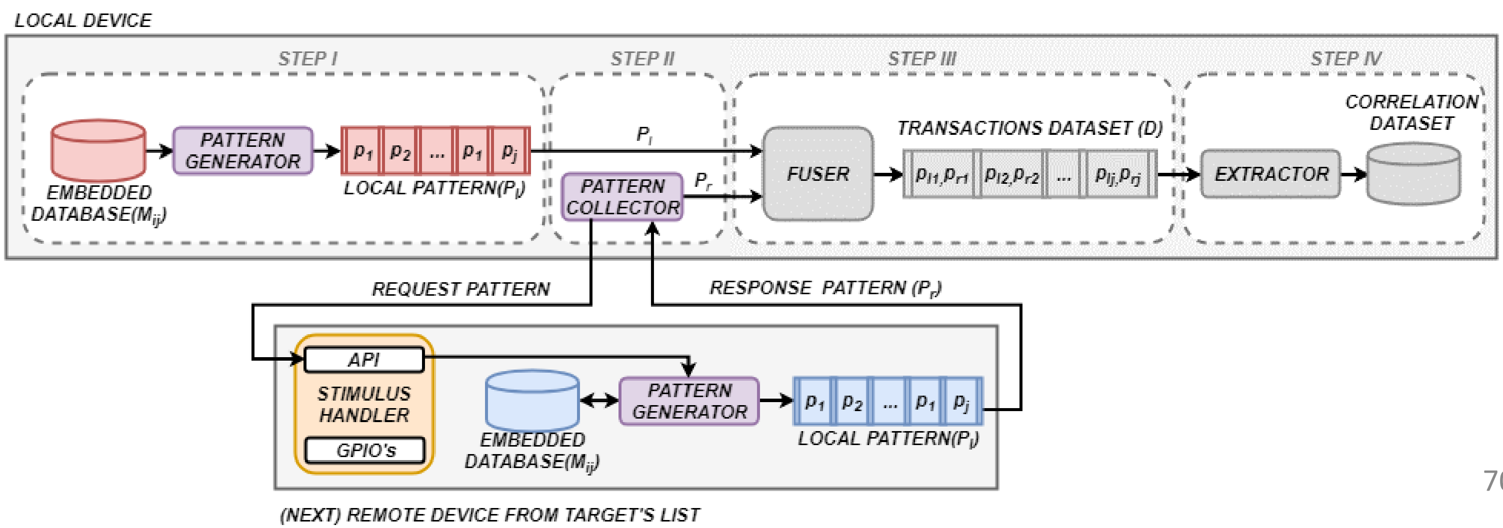
V

Process Overview

Once that each devices satisfies the previously specifications is possible to identify implicit correlations between its actions.

- **Step I**: Identify the local pattern
- **Step II**: Obtain the (next)remote pattern (http request/response)



PROPOSED METHOD

UFAM

I

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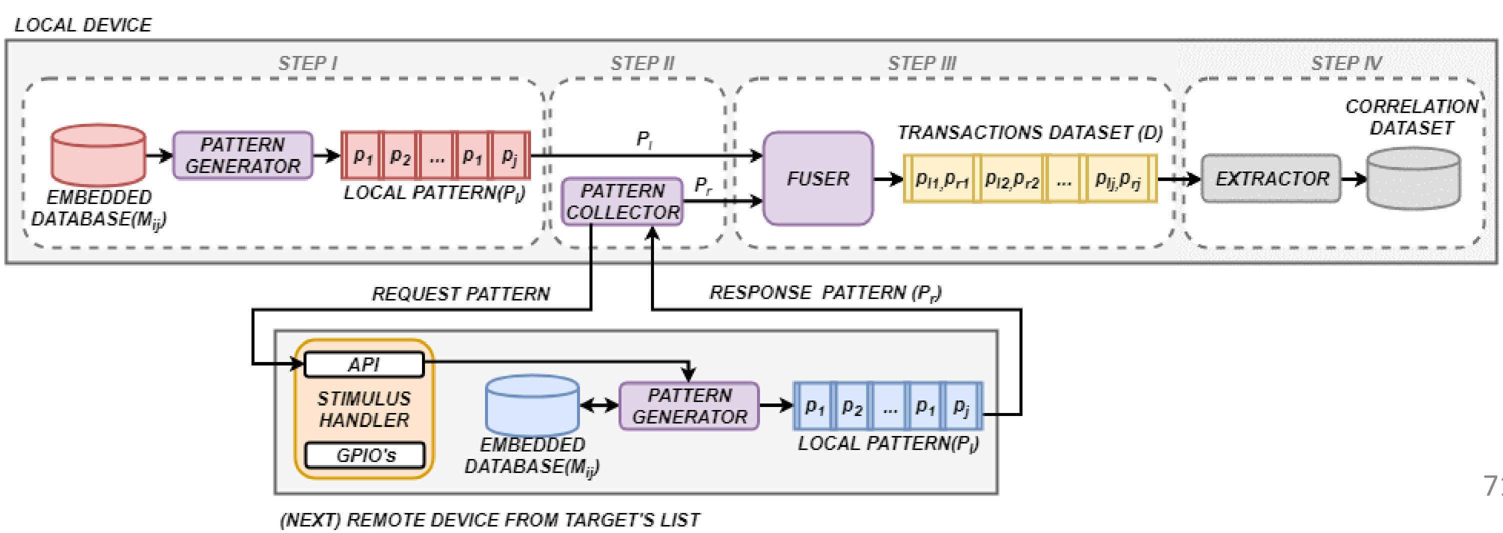
V

VI

Process Overview

Once that each devices satisfies the previously specifications is possible to identify implicit correlations between its actions.

- **Step I**: Identify the local pattern
- **Step II**: Obtain the (next)remote pattern (http request/response)
- **Step III**: Fusion the patterns (create a transaction dataset)



PROPOSED METHOD

I

II

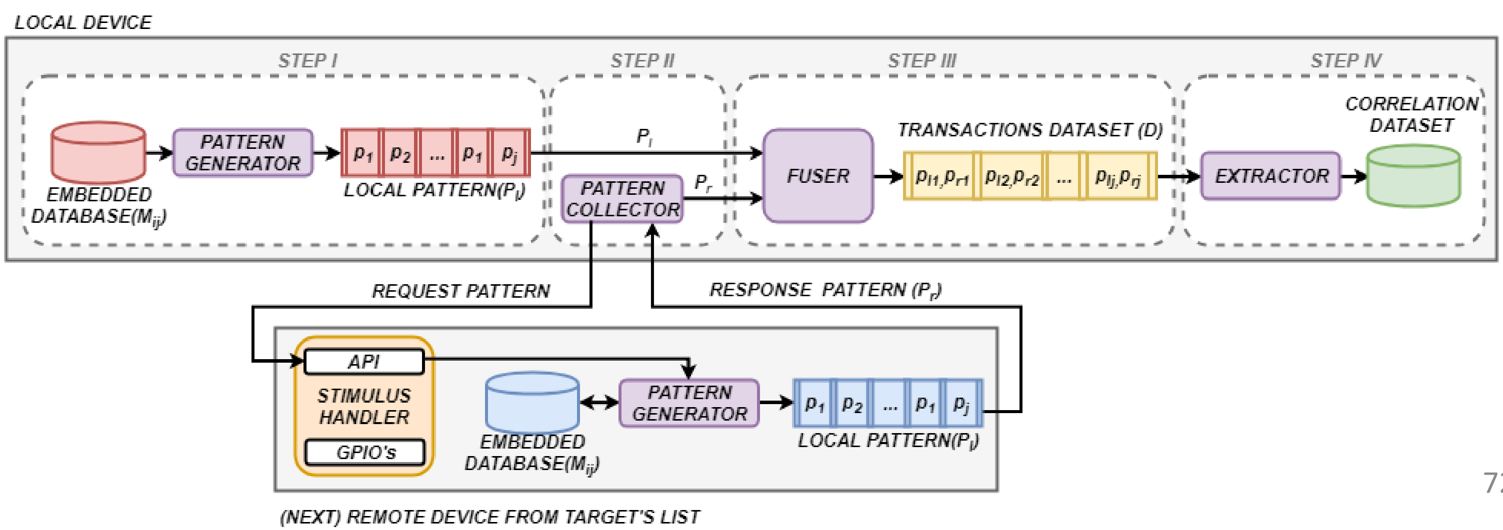
III

IV

Process Overview

Once that each devices satisfies the previously specifications is possible to identify implicit correlations between its actions..

- **Step I**: Identify the local pattern
- **Step II**: Obtain the (next)remote pattern (http request/response)
- **Step III**: Fusion the patterns (create a transaction dataset)
- **Step IV**: Extract the correlations (Associative rule mining)(*Back to II)



EXPERIMENTS

Experiment

Identify correlations between two devices.

Teste the integration between their actions (if exists).

Implemented in Lua (https://nodemcu-build.com/)

FINAL CONSIDERATIONS

UFAM

I

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Important Notes

Dataset dimensionality (|A|x|T|): The database dimensionality grows proportionally to the number of actions and the numeber of slots. (The higher is the number of states/slots, The higher will be the memory consumption)

FINAL CONSIDERATIONS

UFAM

I

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Important Notes

Dataset dimensionality (|A|x|T|): The database dimensionality grows proportionally to the number of actions and the numeber of slots. (The higher is the number of states/slots, The higher will be the memory consumption)

Pattern sharing: All devices must be abble to handle its own pattens and dataset AND a remote device's pattern.(patterns fusion and associative analysis)

FINAL CONSIDERATIONS

UFAM

I

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III

IV

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Important Notes

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Slots Interval: The slot interval must be the same for all devices. That implies in equal |T| for all devices.

FINAL CONSIDERATIONS

I

II

III

IV

V

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Slots Interval: The slot interval must be the same for all devices. That implies in equal |T| for all devices.

Device discovery: Multicast uses UDP!

Federal University of Amazonas

Institute of Computing

Graduate Program in Informatics

Interest Group on Embedded Systems

QUESTIONS?

Manaus, July 13th 2018

Federal University of Amazonas
Institute of Computing
Graduate Program in Informatics
Interest Group on Embedded Systems

THANK YOU

Manaus, July 13th 2018

TRIGGERS CORRELATIONS

UFAM

Associative Analysis Metrics

- **Support:** Number of elements in a set

CENTRALIZED

PAO	LEITE	CAFÉ
1	1	1
1	1	1
1	0	1
0	1	1
1	1	0
0	1	0

(BREAD->MILK): 3/6
(BREAD->COFFEE): 3/6
(MILK->COFFEE): 3/6

DECENTRALIZED

PAO	LEITE
1	1
1	1
1	0
0	1
1	1
0	1

(BREAD->MILK)
3/6

PAO	CAFÉ
1	1
1	1
1	1
0	1
1	0

(BREAD->COFFEE)
3/5

LEITE	CAFÉ
1	1
1	1
0	1
1	1
1	0
1	0

(BREAD->COFFEE)
3/6

TRIGGERS CORRELATIONS

UFAM

Associative Analysis Metrics

- **Support:** Number of elements in a set
- Define Max Transaction Value (|T| = 7)

CENTRALIZED

PAO	LEITE	CAFÉ
1	1	1
1	1	1
1	0	1
0	1	1
1	1	0
0	1	0

(BREAD->MILK): 2/6
(BREAD->COFFEE): 2/6
(MILK->COFFEE): 3/6

DECENTRALIZED

PAO	LEITE
1	1
1	1
1	0
0	1
1	1
0	1
-	-

(BREAD->MILK)
2/7

PAO	CAFÉ
1	1
1	1
1	1
0	1
1	0
-	-
-	-

(BREAD->COFFEE)
2/7

LEITE	CAFÉ
1	1
1	1
0	1
1	1
1	0
1	0
-	-

(BREAD->COFFEE)
3/7