Behavioral Pattern Cluster Analysis System

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PREFACE

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Introduction

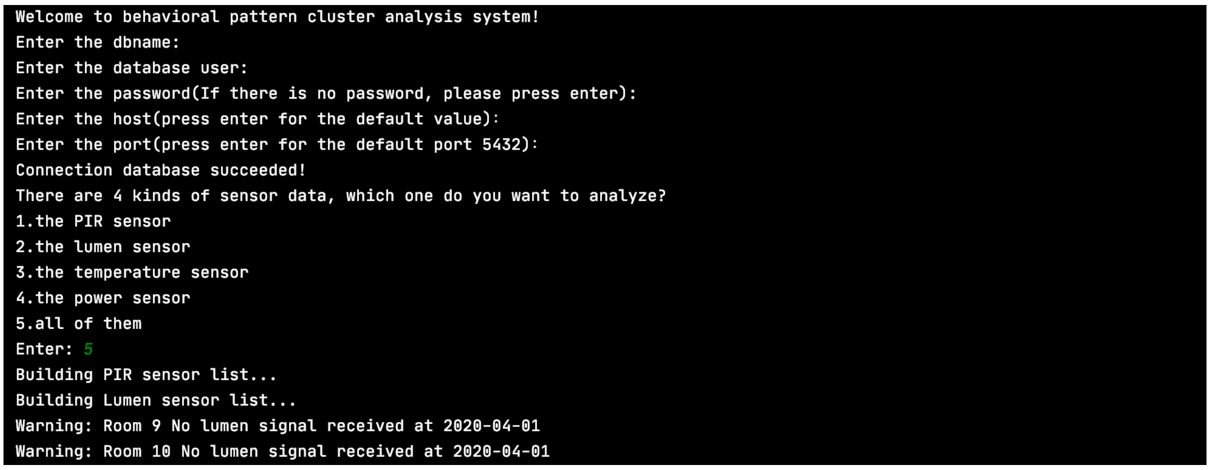
This is a python program to execute cluster analysis for people's daily living behavior at home, it used agglomerative hierarchical clustering to cluster which days are similar and present the common pattern for similar days.
We named this program as “Behavioral Pattern Cluster Analysis System (BPCAS)”, For user, it’s very user-friendly cause it has a Command-line Interface (CLI), this CLI will guide the user to execute the right input and present the program running log. For operator, the code is very readable and maintainable.
This documentation has two parts, Usage and Architecture of BPCAS.
For the first part, the usage is a guidebook for “getting started”, we recommend that you read this section carefully before using, especially the dataset part, because BPCAS is designed for the special dataset, “ensuring that the dataset is valid” is the key to the correct operation of this program.
For the second part, if you only care about how to use it and don’t care about the internal implementation, you can ignore this part directly. This part is the architecture of BPCAS, it details the architecture of the program, from execution process to algorithm details, from data extraction to data presentation, they will be illustrated and explained as clearly & simple as possible.
So, here we go.

Usage

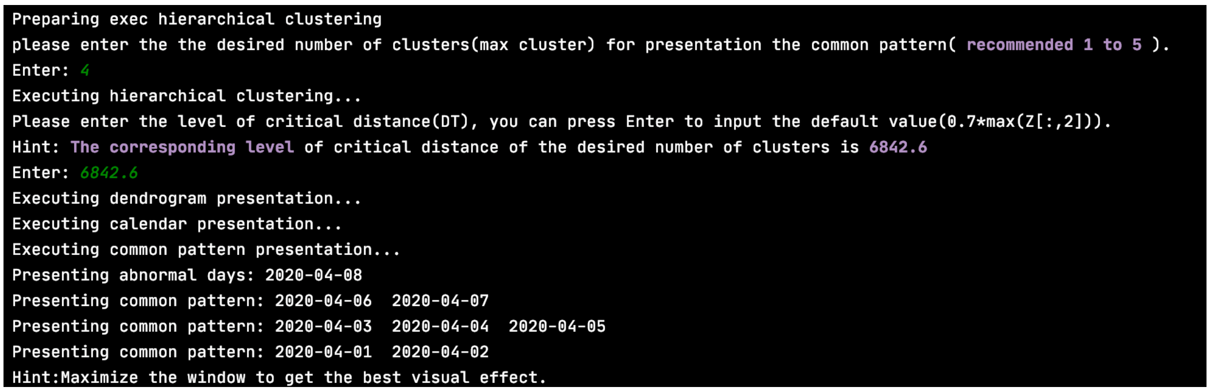
The source code is under the path src/main, first of all, build the third-party libraries, and then run " __init__.py " file with python 3.6. The src/test is unit test codes.

2.1 Command-line Interface (CLI)

The CLI is very user-friendly, you just have to insert the values following the instructions, and in case of an error, you'll be notified.



```
Welcome to behavioral pattern cluster analysis system!
Enter the dbname:
Enter the database user:
Enter the password(If there is no password, please press enter):
Enter the host(press enter for the default value):
Enter the port(press enter for the default port 5432):
Connection database succeeded!
There are 4 kinds of sensor data, which one do you want to analyze?
1.the PIR sensor
2.the lumen sensor
3.the temperature sensor
4.the power sensor
5.all of them
Enter: 5
Building PIR sensor list...
Building Lumen sensor list...
Warning: Room 9 No lumen signal received at 2020-04-01
Warning: Room 10 No lumen signal received at 2020-04-01
```



```
Preparing exec hierarchical clustering
please enter the the desired number of clusters(max cluster) for presentation the common pattern( recommended 1 to 5 ).
Enter: 4
Executing hierarchical clustering...
Please enter the level of critical distance(DT), you can press Enter to input the default value(0.7*max(Z[:,2])).
Hint: The corresponding level of critical distance of the desired number of clusters is 6842.6
Enter: 6842.6
Executing dendrogram presentation...
Executing calendar presentation...
Executing common pattern presentation...
Presenting abnormal days: 2020-04-08
Presenting common pattern: 2020-04-06  2020-04-07
Presenting common pattern: 2020-04-03  2020-04-04  2020-04-05
Presenting common pattern: 2020-04-01  2020-04-02
Hint:Maximize the window to get the best visual effect.
```

2.2 Input

2.2.1 Dataset

<u>Connection the database</u>

There are 5 arguments.

- dbname: compulsory, the name of database.
- database user: compulsory, the database administrator.
- password: optional, the database password, if there is no password, just press Enter.
- host: optional, the database host, press Enter for "localhost"
- port: optional, the database port, press Enter for default port 5432

If the input fields have some problems, the program will exit automatically, please check the connection info and run it again.

<u>Check if the dataset is applicable</u>

Three tables are necessaries.

- person_position: This table stored the PIR sensor's signals, we will extract dates from id_room, t_from, t_to attributes.
- sensor: This table stored configuration information of all sensors, we will extract dates from id_room, id_sensor, id_sensor_type, threshold attributes.
- stream_data: This table stored the Lumen Temperature and Power sensor's signals, we will extract dates from value, id_sensor, timestamp attributes.

Determine the id of these three sensors in "sensor_type" table like this

ID	NAME
3	Light
4	Temperature
5	Energy

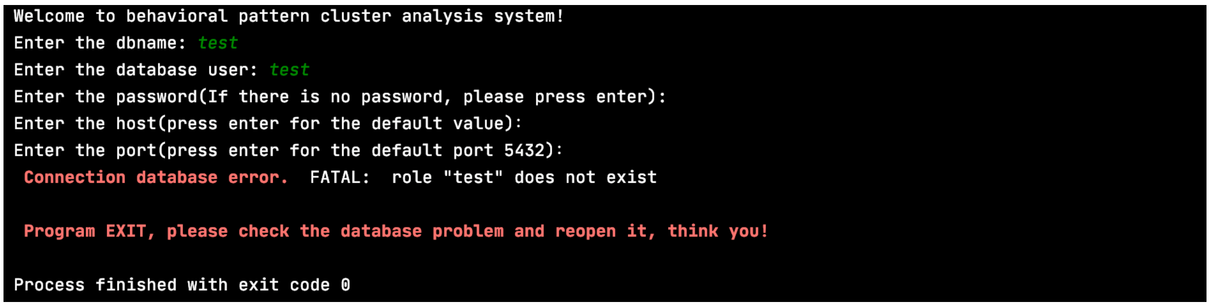
Be sure appliances' id in "sensor" table like this

ID_SENSOR	NAME
24	Microonde
26	Televisione
28	HC2 Power
32	Frigorifero
34	Forno
36	Lavatrici
45	Serra A
148	Lavastoviglie
150	PC

Dataset Error & Warning

-Error

In case of a failed access to the database, an error message will be showed, and the program will exit automatically.



```
Welcome to behavioral pattern cluster analysis system!
Enter the dbname: test
Enter the database user: test
Enter the password(If there is no password, please press enter):
Enter the host(press enter for the default value):
Enter the port(press enter for the default port 5432):
 Connection database error.  FATAL:  role "test" does not exist

 Program EXIT, please check the database problem and reopen it, think you!

Process finished with exit code 0
```

-Warning

Warning message will not cause the program to exit. There are two cases of warning

- Warning for appliance. In the dataset, there are 9 appliances. If other appliances appear, this warning will raise, you can ignore it if you don't care the new appliance.
- Warning for signals: if some sensor non has signals in the whole day, this warning will appear

For example:

```
Warning: Room 9 No lumen signal received at 2020-04-01
Warning: Room 10 No lumen signal received at 2020-04-01
Warning: Room 9 No lumen signal received at 2020-04-02
Warning: Room 10 No lumen signal received at 2020-04-02
```

It means that not have lumen signal at room 9 at whole day of 2020-04-01, maybe the sensor has not been installed on this day, so if you sure the dataset is right, you can ignore it.

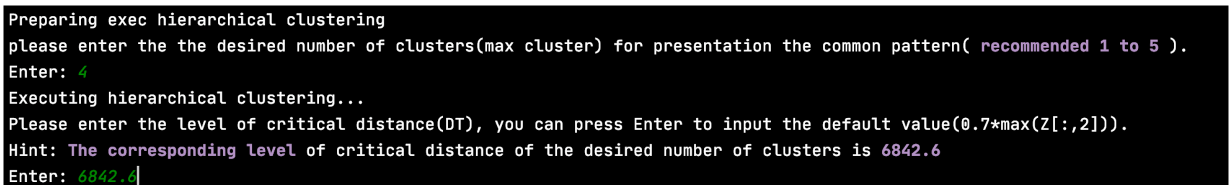
2.2.2 The desired number of clusters

This value also called max_cluster, it will decide the number of common patterns to present in the output.

2.2.3 The level of critical distance(DT)

This value will decide the final cluster in the dendrogram, the default value is 0.7*max (max distance of all cluster). Of course, we recommend using the corresponding value of max_cluater and the CLI will give you a hint.

For example:

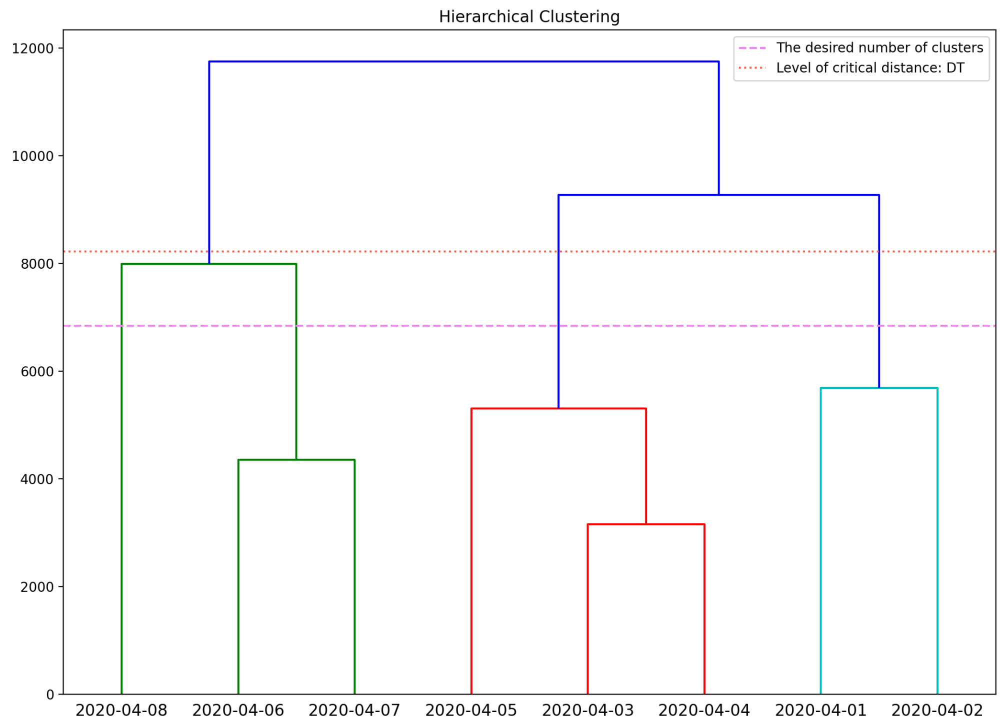


```
Preparing exec hierarchical clustering
please enter the the desired number of clusters(max cluster) for presentation the common pattern( recommended 1 to 5 ).
Enter: 4
Executing hierarchical clustering...
Please enter the level of critical distance(DT), you can press Enter to input the default value(0.7*max(Z[:,2])).
Hint: The corresponding level of critical distance of the desired number of clusters is 6842.6
Enter: 6842.6
```

2.3 Output

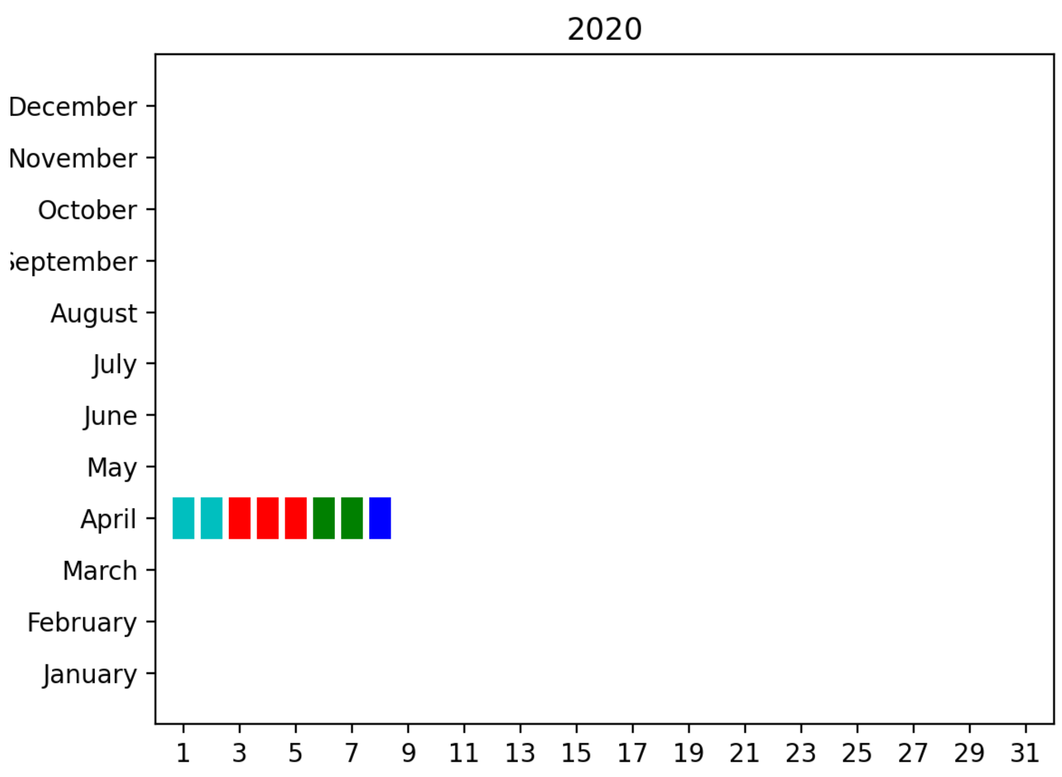
2.3.1 Dendrogram

In the dendrogram, except dendrogram, it also will present max_cluster and the level of critical distance(DT).
All days below the level of critical distance(DT) will be treated as same cluster,
And the desired number of clusters (max cluster) will present those cluster it passed.
For example:



As mentioned above, DT decides to dendrogram, and max_cluster decide the number of common pattern or abnormal day, if these two values are in a same interval, the common pattern and abnormal day will perfectly present the content of dendrogram.

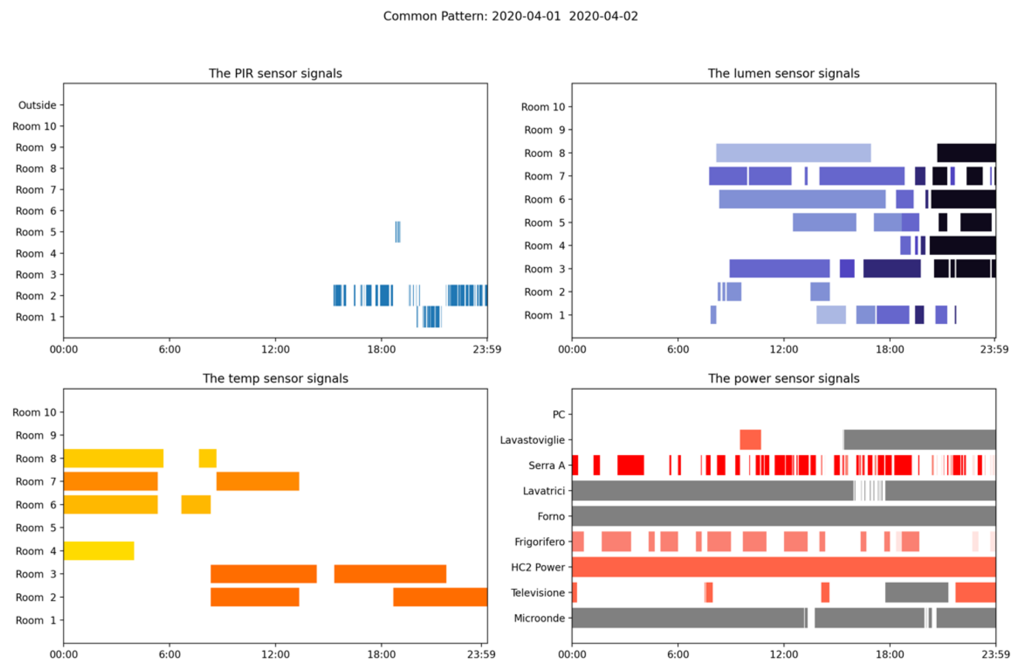
2.3.2 Calendar

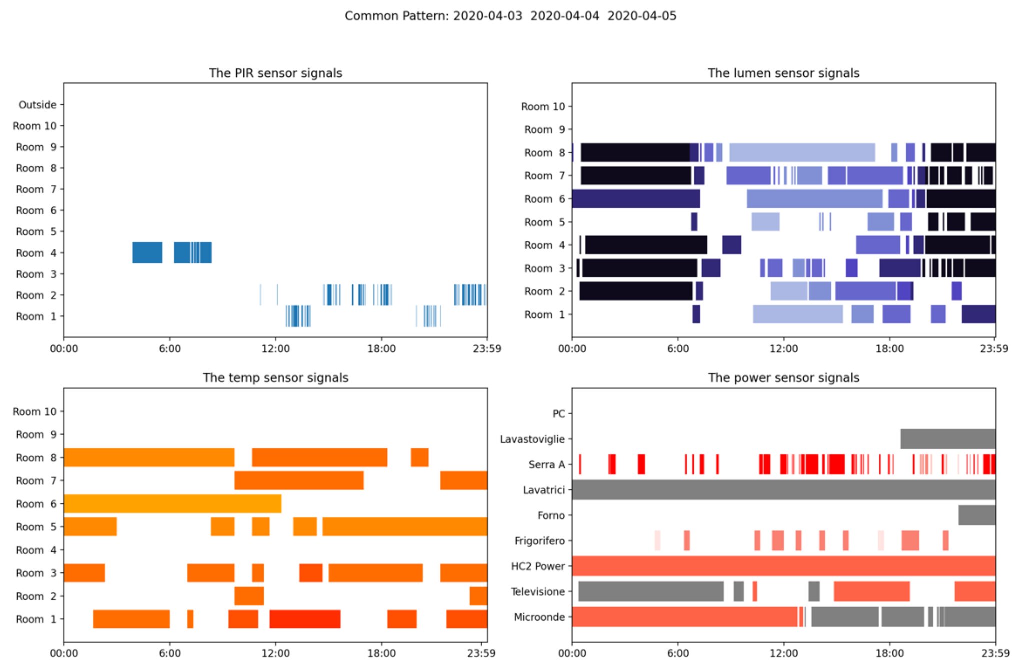


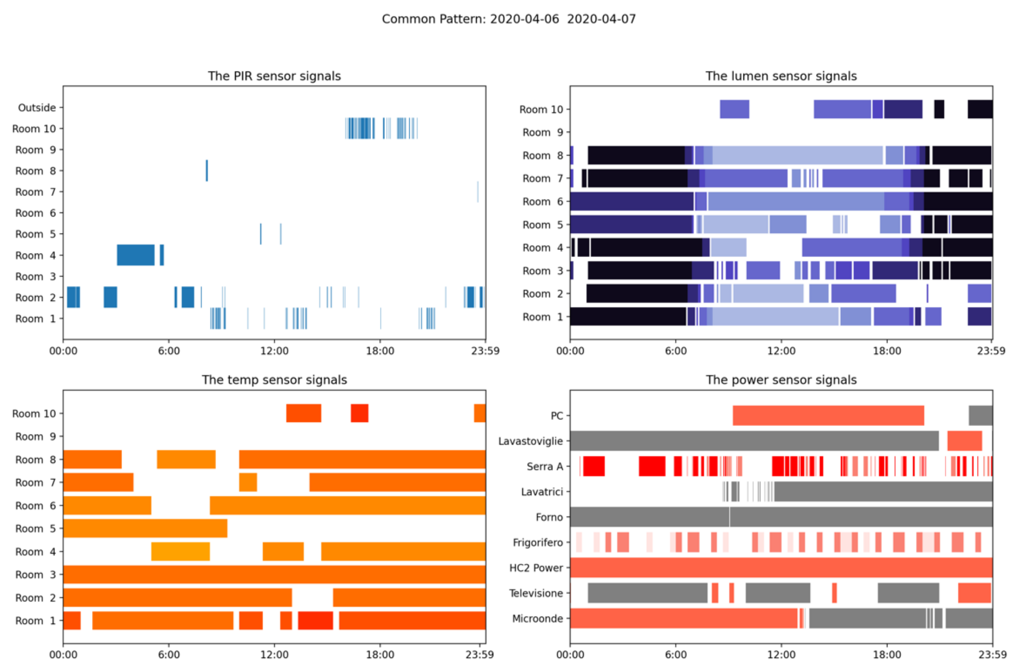
This figure will present which days in the same cluster, the color is same at dendrogram, the abnormal days will color in blue.

2.3.3 Common pattern

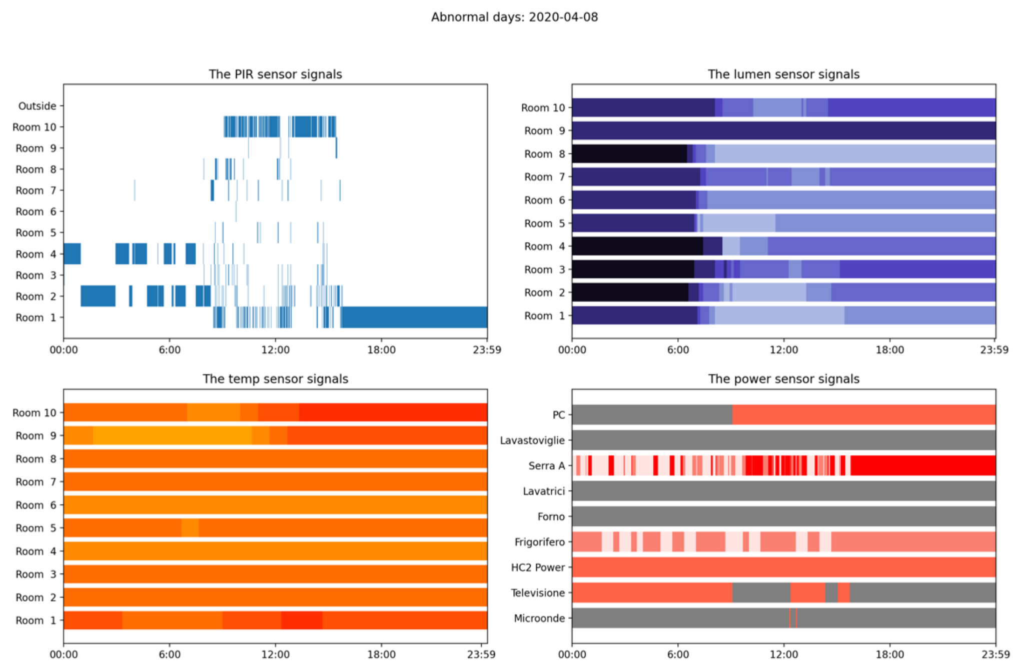
For lumen signals, the darker the color, the darker the light and vice versa.
For temperature signals, the redder color means higher temperature and vice versa.
For power signals, the red color means on, the gray means off. But for "Serra A" and "Frigorifero" the redder color means larger power and vice versa.







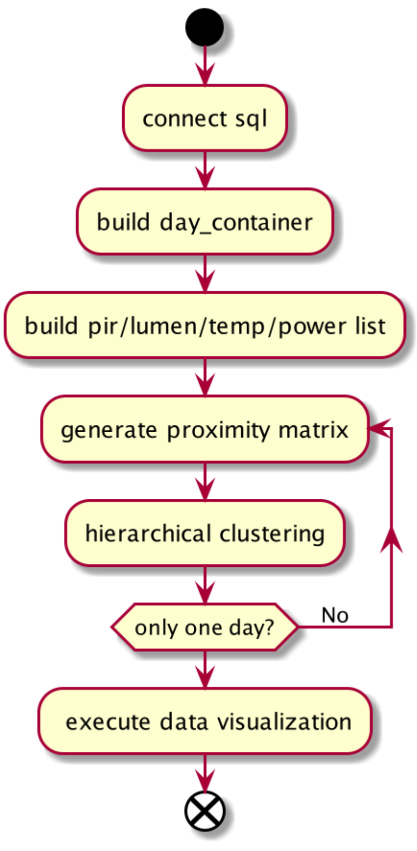
2.3.4 Abnormal day



Program Architecture

3.1 Dataset Connection

We used three-party library to handle database connection. About this part, please see code class SQLTool.


connect sql
build day_container
build pir/lumen/temp/power list
generate proximity matrix
hierarchical clustering
only one day?
No
execute data visualization

3.2 Build day container

In this step, we need to find all days from dataset. We used

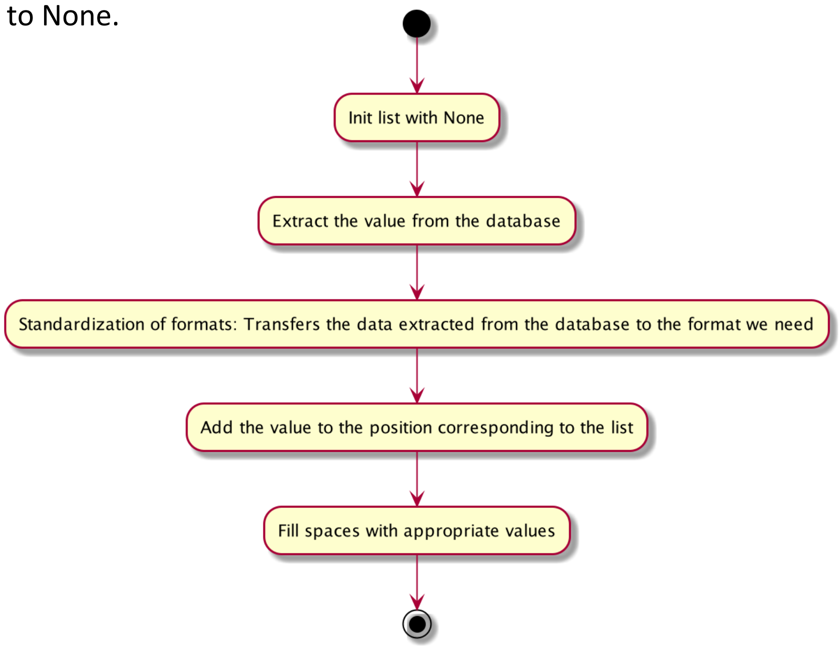
```
SELECT date(t_from) as date FROM person_position group by date order by date;
```

To query the database.
And build a class day_container for every day and stored them in list of class day_deck.

3.3 Build sensor list

The build sensor list process simulates the ETL (Extraction, Transformation e Loading) operation set, for every type of sensor list, we have to extract information from the dataset with a query statement and transform the formats according to the characteristics of each sensor. Finally, load them into the corresponding position. For every kind of sensor, we have a concept of sampling interval, it means that the interval time of the record. For each list, We initialize them to None.

Process:

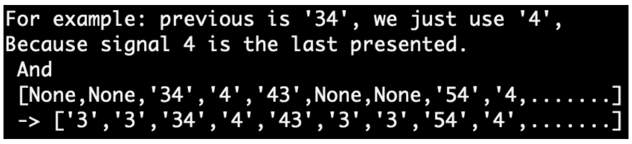

Init list with None
Extract the value from the database
Standardization of formats: Transfers the data extracted from the database to the format we need
Add the value to the position corresponding to the list
Fill spaces with appropriate values

3.3.1 Build PIR sensor list

- List format : 1-dimension list, length is 2880.
- Sampling interval : 30s once, 2880 times per day.
- Database query statement :

```
SELECT id_room, t_from, t_to FROM person_position  WHERE date(t_from)= + date_curr +  or date(t_to)= + date_curr
+ order by t_from, t_to, id_room;
```

- Standardization of formats : we use str to present PIR value, 1~9 for room 1~9, ‘a’ for room 10, ‘f’ for not at home (outside).
- Overlap problem : If multiple sensors are active at the same time, this means that the person is moving in multiple rooms, we handle this case like the example : If this person moves from room 4 and pass room 3 to room 5, we record string ‘435’.
- Fill spaces : After added all the values owned by the database, some parts may still blank. we have to fill them. The last char of the previous signal will use to be filler. if the first signal is black, fill with the first char of the following "not black signal". As left picture.



```
For example: previous is '34', we just use '4',
Because signal 4 is the last presented.
 And
 [None,None,'34','4','43',None,None,'54','4,.......]
 -> ['3','3','34','4','43','3','3','54','4',.......]
```

3.3.2 Build Lumen sensor list

- List format: 2-dimension list, length [10][288], 10 columns for each room, 288 rows for each signal.
- Sampling interval: 300s once, 288 times per room per day.
- Database query statement:

```
SELECT se.id_room, sd.value, sd.timestamp FROM sensor as se  join stream_data as sd on se.id_sensor = sd.id_sensor
WHERE se.id_sensor_type = 3 and date(timestamp) =  + date_curr + order by se.id_room, timestamp;
```

- Standardization of formats: we have to convert the signal value to lumen level, and we determine the lumen level according to sunrise and sunset, the sunrise and sunset times of Milan in April are from 6:30~20:00. So, lumen level is from 0 to 5 (which is from 'buio' to 'ottima')

  In table:

Sera			Giorno	
luminosità	Valutazione		luminosità	Valutazione
=0	Buio		=0	Buio
0 < x <= 5	SCARSA		0 < x <=20	SCARSA
5 < x <= 20	DISCRETA		20 < x <=40	DISCRETA
2 0< x <= 110	BUONA		40 < x <= 150	BUONA
110 < x <= 200	MOLTO BUONA		150 < x <= 300	MOLTO BUONA
200 < x	OTTIMA		300 < x	OTTIMA

- Fill space: we have to fill black space like PIR list, the previous signal will use to be filler. If the first signal is black, fill with the following "not black signal". For example, we will fill list from [None, None, '3', '4', '3', None, None, '5', '4, ...] to ['3', '3', '3', '4', '3', '3', '3', '5', '4',.......] and if the whole list is None(initial state), this function will print a warning in the CLI console.

3.3.3 Build temperature sensor list

- List format: 2-dimension list, [10][72], column 10 for every room, row 72 for every signal.
- Sampling interval: 1200s once, 72 times per room per day.
- Database query statement:

```
SELECT se.id_room, sd.value, sd.timestamp FROM sensor as se join stream_data as sd on se.id_sensor = sd.id_sensor
WHERE se.id_sensor_type = 4 and date(timestamp) =  + date_curr +  order by se.id_room, timestamp;
```

- Standardization of formats: We set the temperature to two degrees as a step.

  For example：

  18.5 -> 18

  19.5 -> 18

  They are regarded as no difference, because they are in the same step.

3.3.4 Build power sensor list

- List format: 2-dimension list, column 9 for every appliance, row variable length for every signal.
- Sampling interval:

There are 9 domestic appliances
1.Microonde: No.24, sampling interval is 30s
2.Televisione: No.26, sampling interval is 120s
3.HC2 Power: No.28, sampling interval is 300s
4.Frigorifero: No.32, sampling interval is 1200s,Power_level: 0w, 2w, 50w
5.Forno: No.34, sampling interval is 120s
6.Lavatrici: No.36, sampling interval is 120s
7.Serra A: No.45, sampling interval is 120s, Directly record the original value
8.Lavastoviglie: No.148, sampling interval is 120s
9.PC: No.150, sampling interval is 120s, threshold: 5w

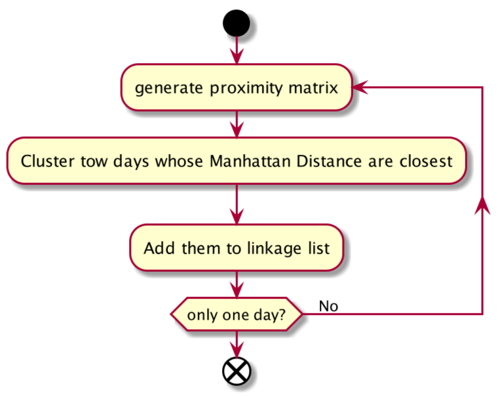
- Database query statement:

```
"SELECT se.id_sensor, sd.value, se.threshold, sd.timestamp FROM sensor as se join stream_data as sd on
se.id_sensor = sd.id_sensor WHERE se.id_sensor_type = 5  and date(timestamp) =  + date_curr + order by
se.id_sensor, timestamp;"
```

- Standardization of formats : For Microonde, Televisione, HC2 Power, Forno, Lavatrici, Lavastoviglie, PC, we record the on & off of these appliances according to the threshold, above the threshold is on (present with True), below the threshold is off (present with False). For Serra A, we just record the original value, and for Frigorifero, we record a power level. 0~2 is 0; 2~50 is 1, Above 50 is 2.

3.4 Execute hierarchical clustering

This picture is the steps of the program to execute the algorithm.

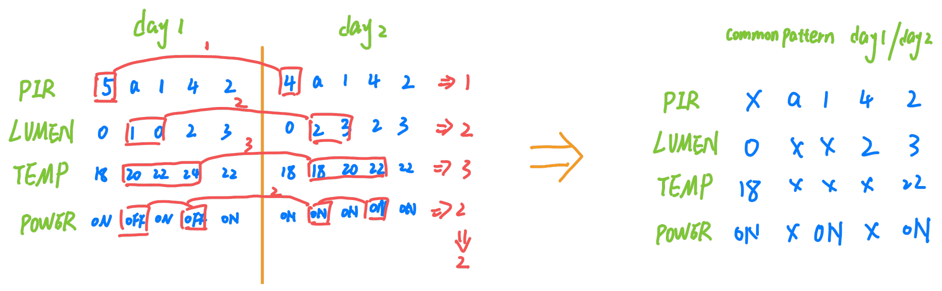

generate proximity matrix
Cluster tow days whose Manhattan Distance are closest
Add them to linkage list
only one day?
No

3.4.1 Defining Proximity between Clusters

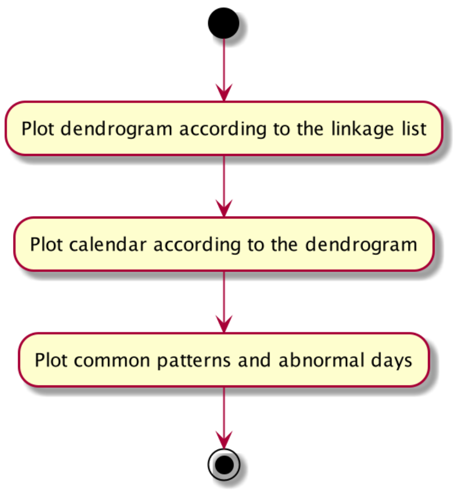
We use Manhattan Distance to define proximity.
For two list. We compare their elements from beginning to end, If the elements are the same, the distance is unchanged, if not equal, the distance is increased by one. Add up the distance of all available lists, which is the distance of two days.

3.4.2 Cluster two days

If the two days are closest, they will be clustered. Until clustered to only one day. So, in extreme cases, all elements are clustered, the maximum distance will be equal to the length of all lists. In this program, it will be 14040.



3.5 Execute data visualization


Plot dendrogram according to the linkage list
Plot calendar according to the dendrogram
Plot common patterns and abnormal days

Third-party libraries

- psycopg2 : To extract data from the database

  https://pypi.org/project/psycopg2/

- matplotlib.pyplot : To do data visualization

  https://matplotlib.org/index.html

- scipy.cluster.hierarchy: To plot dendrogram from linkage list

  https://docs.scipy.org/doc/scipy/reference/index.html