Non-Intrusive Load Monitoring

A way to reduce energy consumption

Rafael Teixeira

The importance of NILM

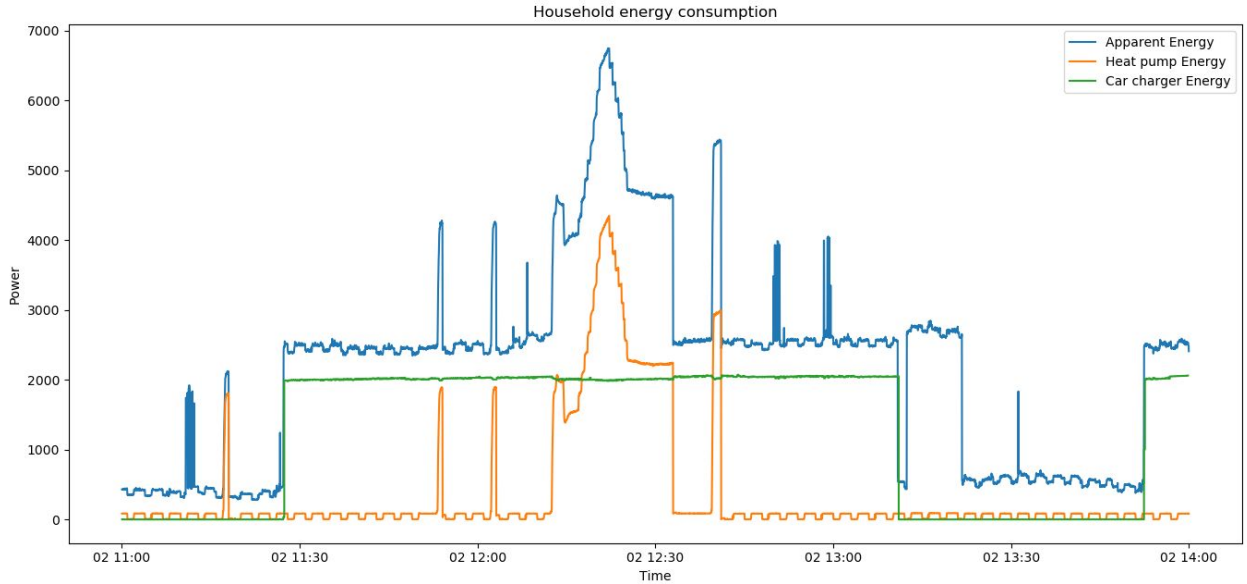
NILM's characteristics

Developed work

The final objective

What is NILM?

Non-Intrusive Load Monitoring (NILM) aims to desegregate the energy consumed by the entire household into the energy consumed by each appliance.



WIND ENERGY

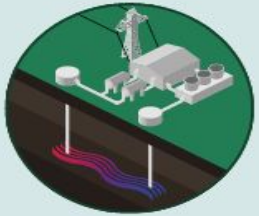
SOLAR ENERGY

HYDROELECTRICITY

WAVE POWER

TIDAL POWER

The importance of NILM



GEOTHERMAL ENERGY

BIOMASS ENERGY

COAL PLANT

GAS PLANT

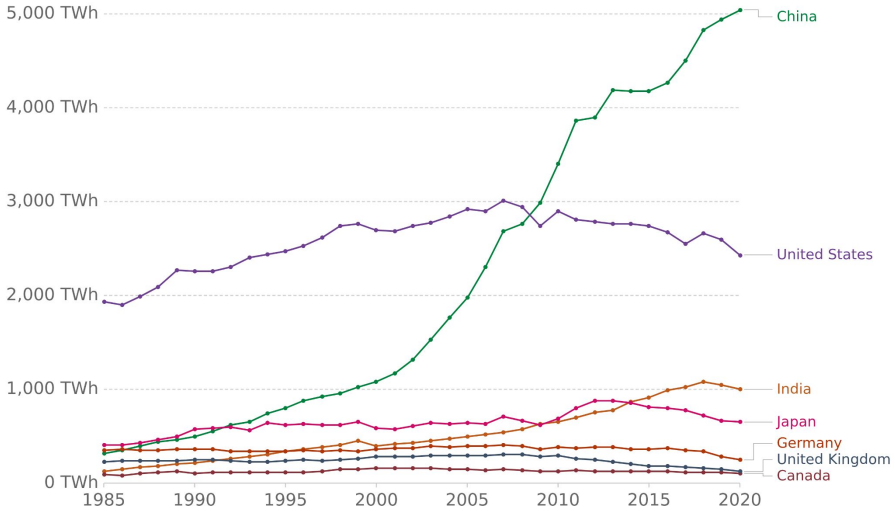
OIL PLATFORM

NUCLEAR PLANT

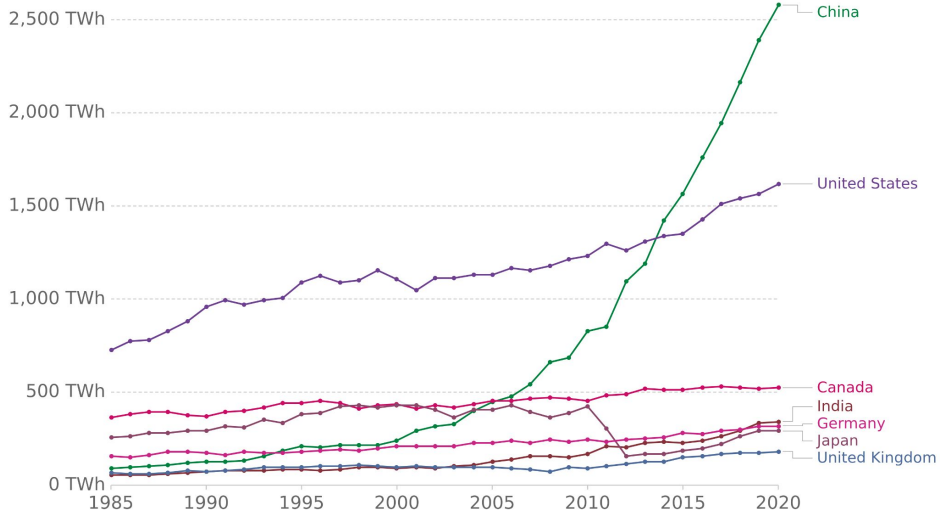
Energy Consumption and Potential Savings

Nowadays, **residential** energy consumption accounts for **30%** of the total energy consumption.

If households had proper feedback on the consumed energy, the **savings** could be up to **20%**.



Energy consumption from fossil fuels

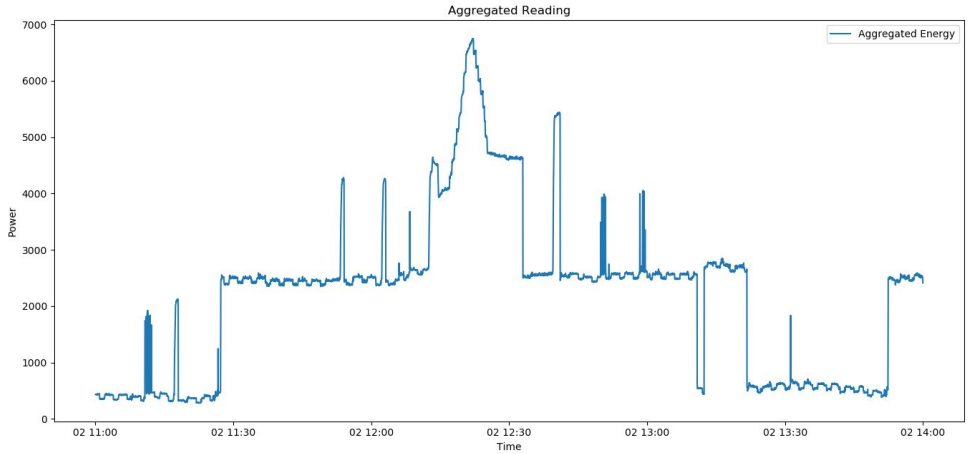


Energy consumption from low carbon emissions

The problem of existing solutions

There are solutions on the market that don't require NILM.

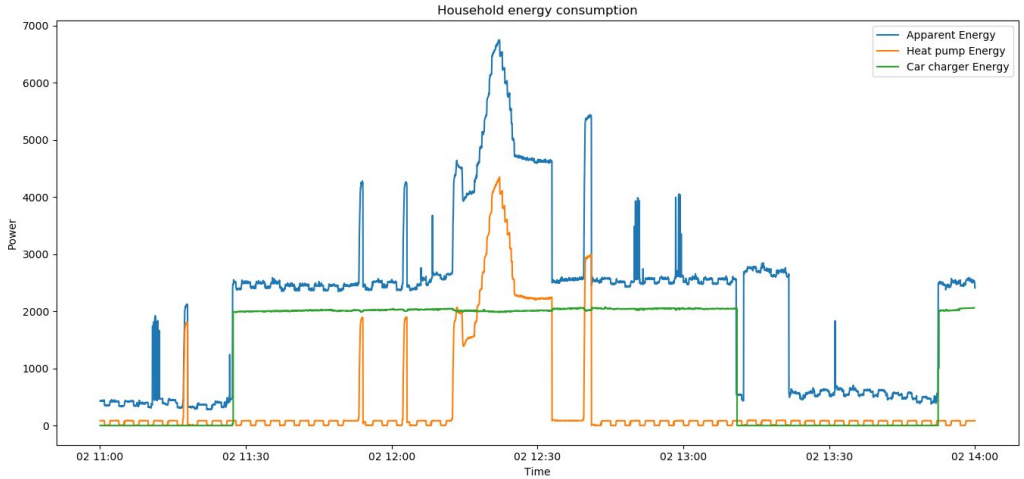
The ones with **lower installation and acquisition costs** can only provide feedback on the aggregated energy consumption.



https://marylandreporter.com/wp-content/uploads/2015/06/Pepco-smart-meter-1170x779.jpg

The problem of existing solutions

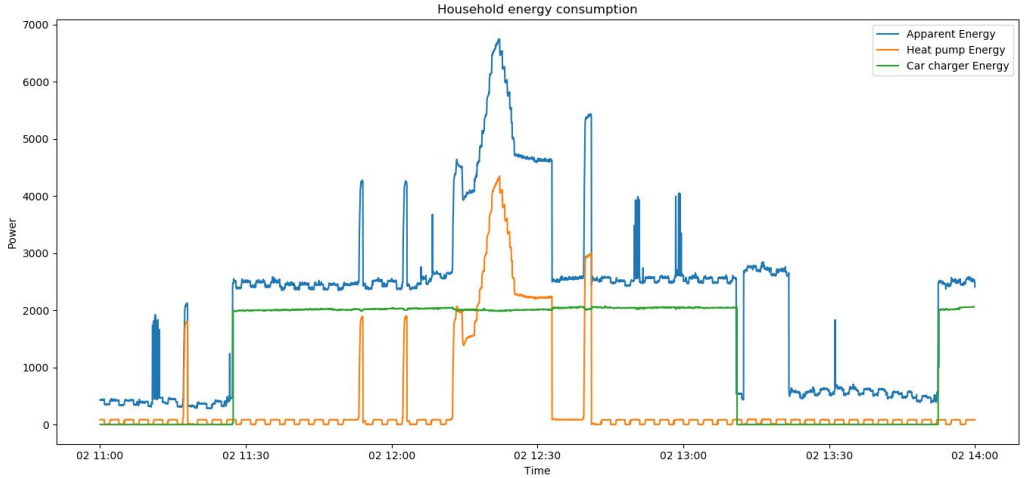
The ones with **high installation and acquisition costs** provide feedback on the appliance level, but the hassle caused makes adoption of the technology reduced.



https://ae01.alicdn.com/kf/HTB1QWduE4SYBuNjSsphxh6GvVXaC/2019-New-Convenient-WIFI-Smart-Plug-US-Plug-Smart-Timing-Socket-Wireless-Outlet-control-function-plug.jpeg

The ideal solution

The ideal solution must have low installation and acquisition costs and provide feedback on the appliance level.



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NILMs characteristics

Frequency of sampling and extracted features

The **amount of data extracted** from the readings is **dependent on the frequency** of the sampling.

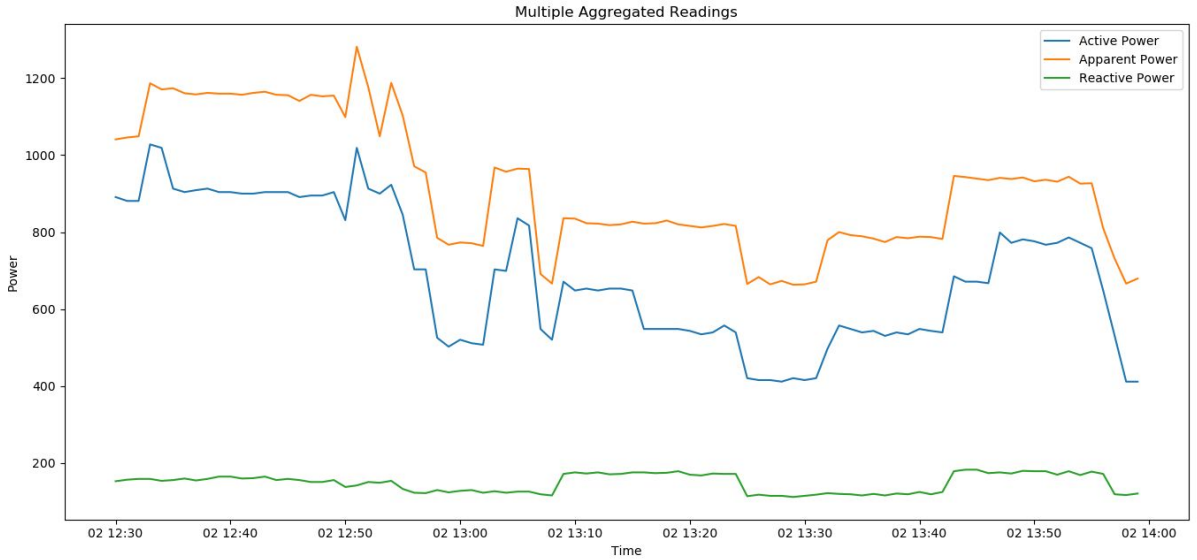
There are three categories of sampling frequencies:

- Low Frequency Sampling - ≤ 1Hz
- Medium Frequency Sampling -≥ 120Hz and ≤ 1kHz
- High Frequency Sampling - ≥ 1kHz

Low Frequency Sampling

Low-frequency sampling presents the **hardest** way to distinguish between appliances.

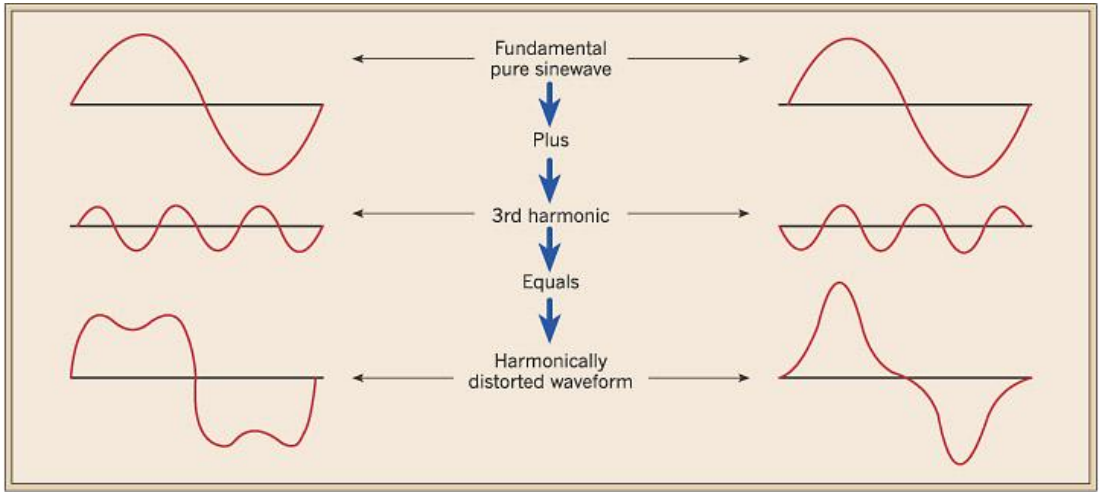
Its main advantage comes from the **low cost** of adoption.



Medium Frequency Sampling

Certain types of appliances, for example, power supplies, have non-sinusoidal consumptions called harmonics.

The medium frequency sampling allows us to **capture** the **harmonics** of the signal.



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High Frequency Sampling

Most appliances have a characteristic startup power draw.

These transient events last at most a couple of milliseconds but are able to **easily characterize** the appliance type.

It's the **most expensive** option.

Which Frequency to use?

Sampling Frequency	Pros	Cons
Low Frequency	The cheapest alternative. Allows the recording of more than just the aggregated power.	The less amount of features.
Medium Frequency	Improves the number of features.	Only relevant for a subset of appliances. Requires installation of new equipments.
High Frequency	The greatest amount of features.	The most expensive alternative. Requires specialized equipment.

Datasets

https://marylandreporter.com/wp-content/uploads/2015/06/Pepco-smart-meter-1170x779.jpg

https://ae01.alicdn.com/kf/HTB1QWduE4SYBuNjSsphxh6GvVXaC/2019-New-Convenient-WIFI-Smart-Plug-US-Plug-Smart-Timing-Socket-Wireless-Outlet-control-function-plug.jpeg

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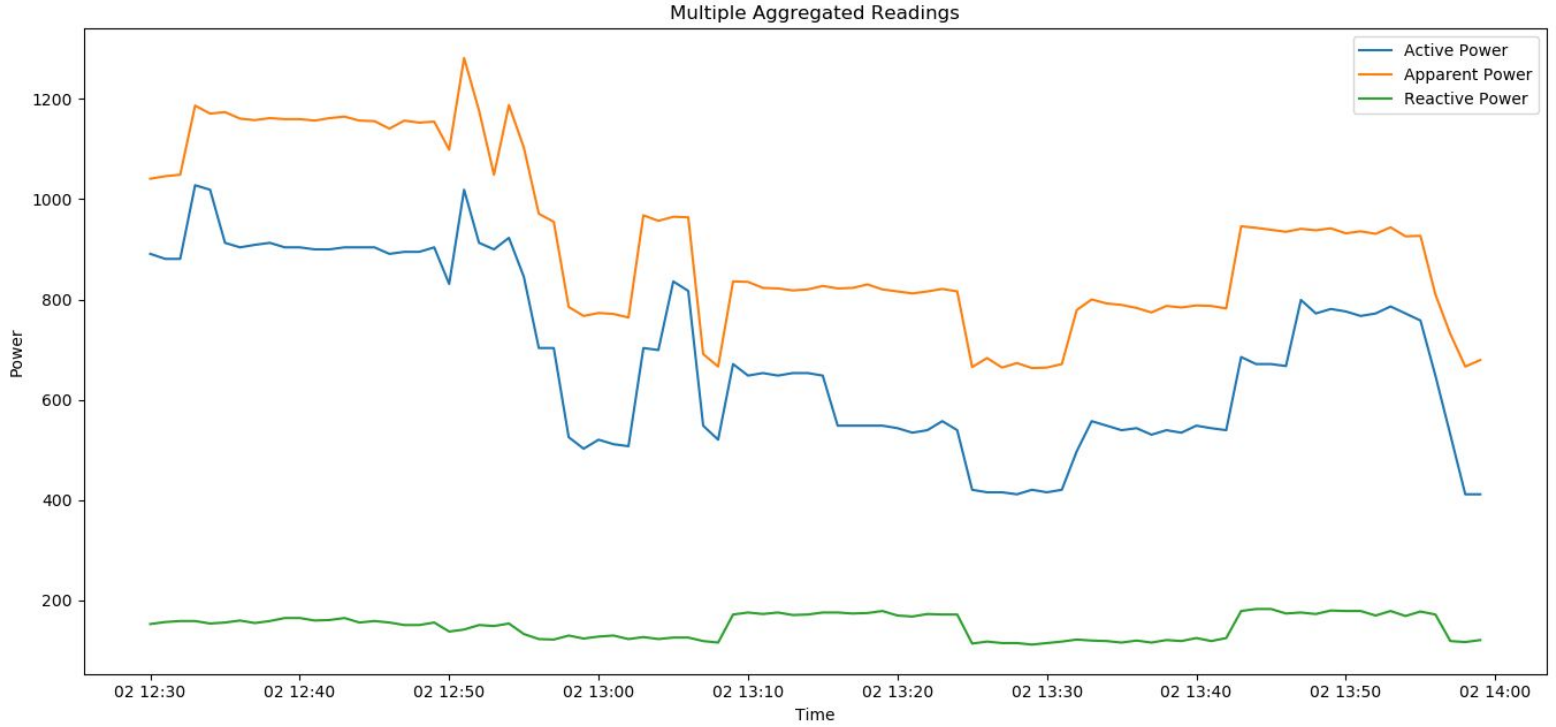
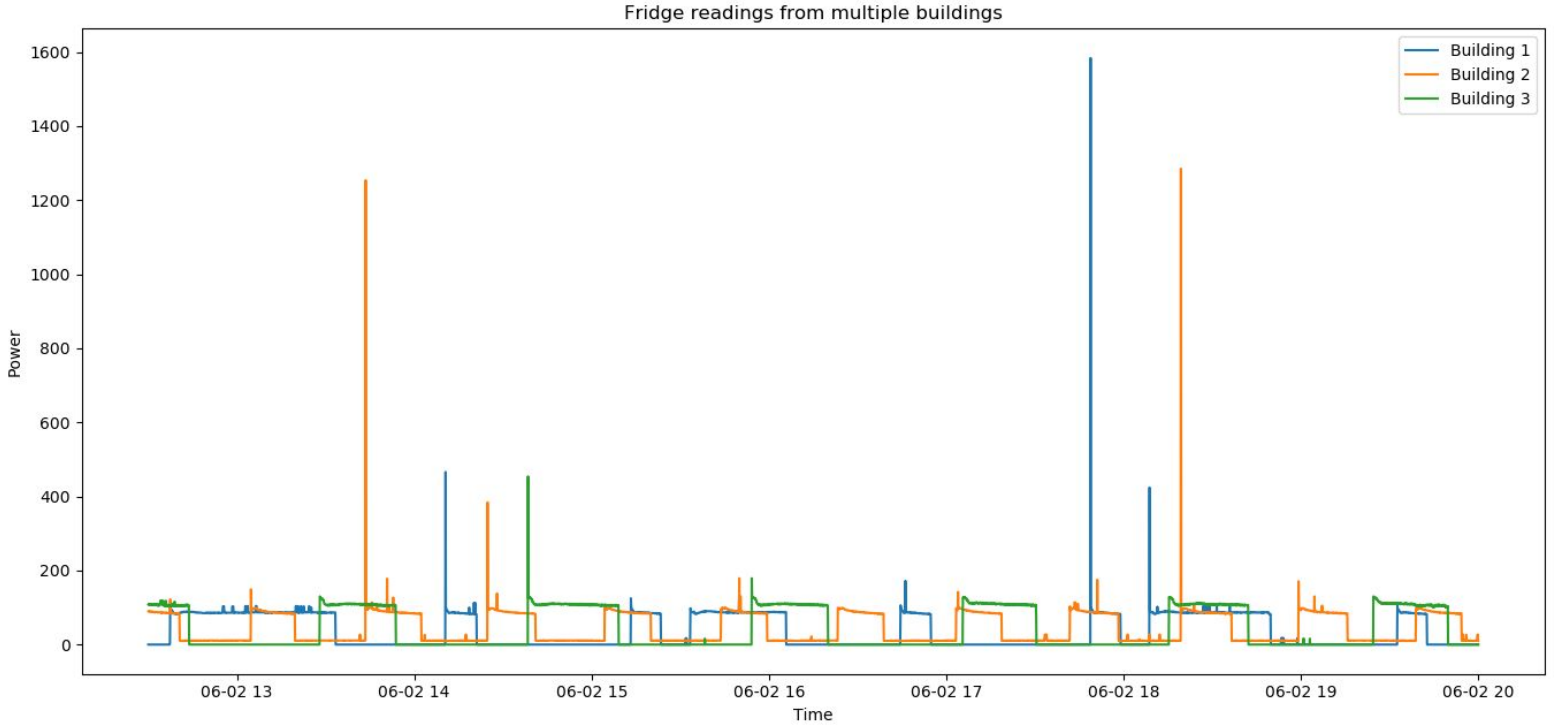
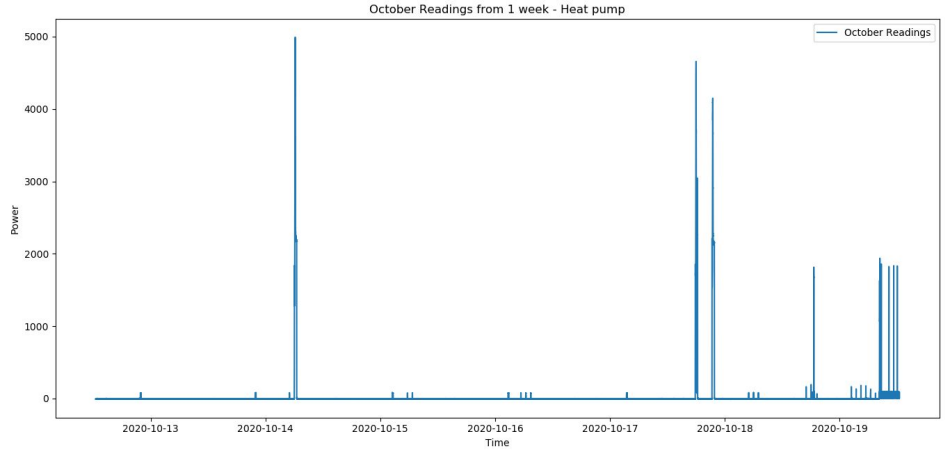
Datasets – Low Frequency Readings

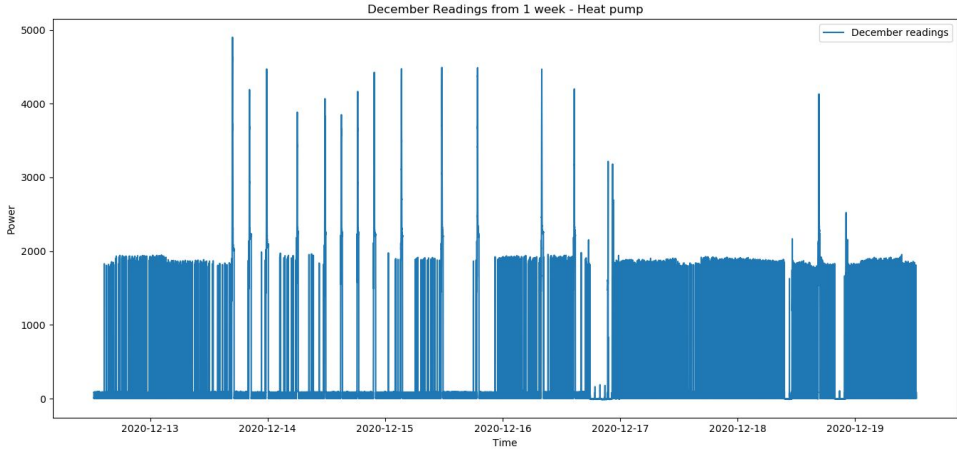


Datasets - Number of Houses

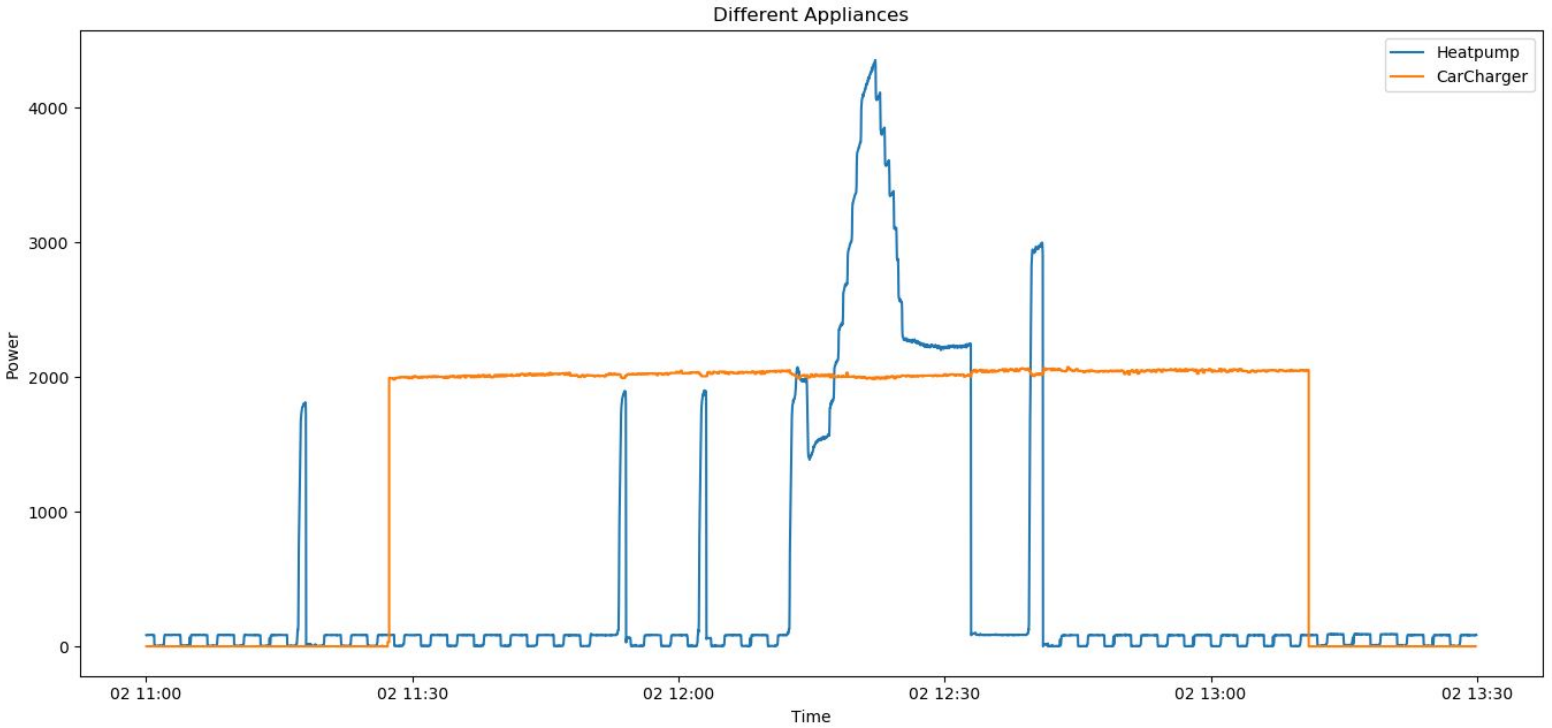


Datasets – Long recording period





Datasets – Variety of Appliances

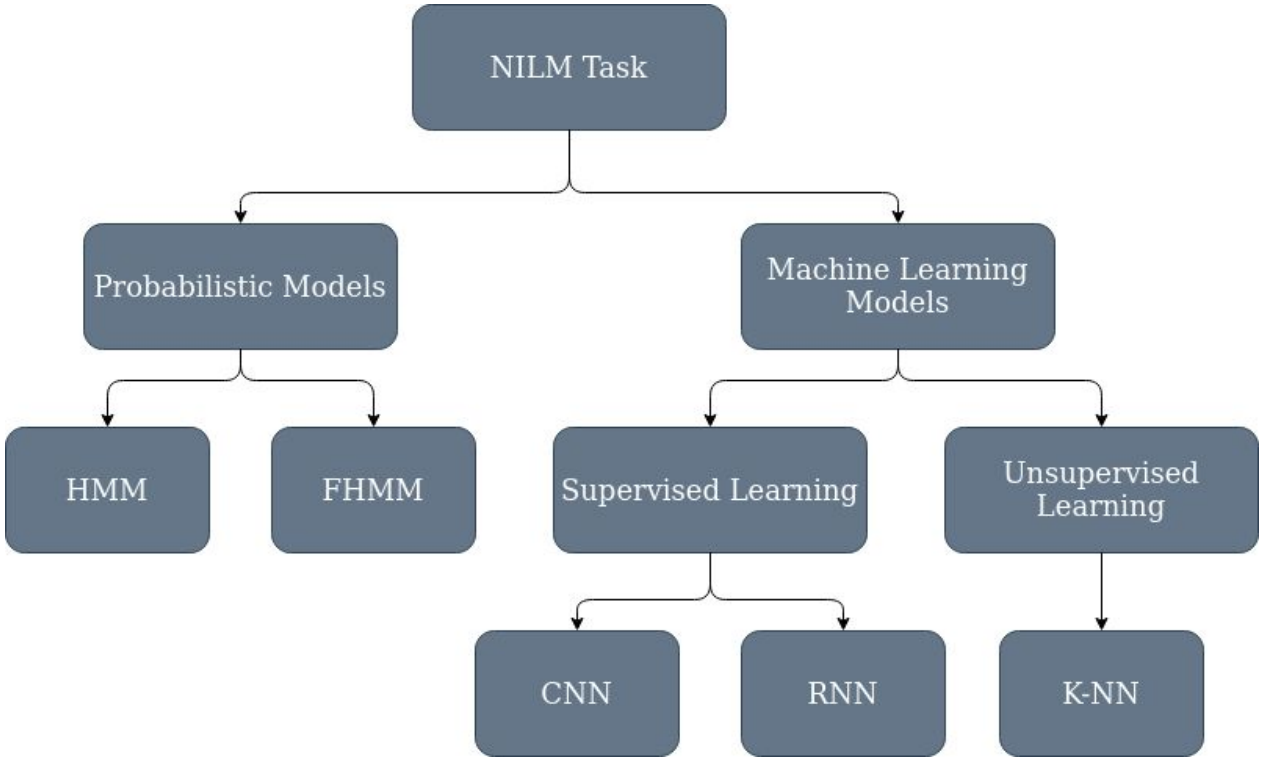


Datasets

Datasets	Flaws
REED	Only 3 to 19 days of recording the voltage and apparent power.
Dataport	Only records apparent power for large appliances on independent circuits
UK-DALE	Only records apparent power and some appliances are only present in one house.
AMPDs2	Only contains readings from 1 house.
DRED	Only 6 months of recording the apparent power..

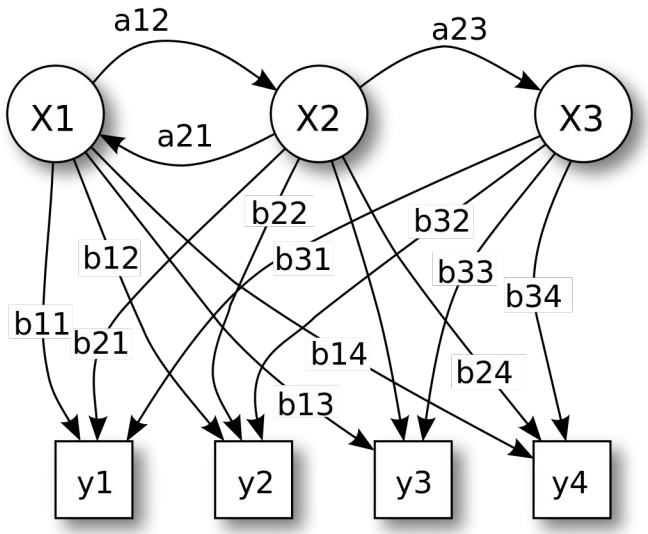
Subset of the most popular publicly available datasets for NILM

State-of-Art

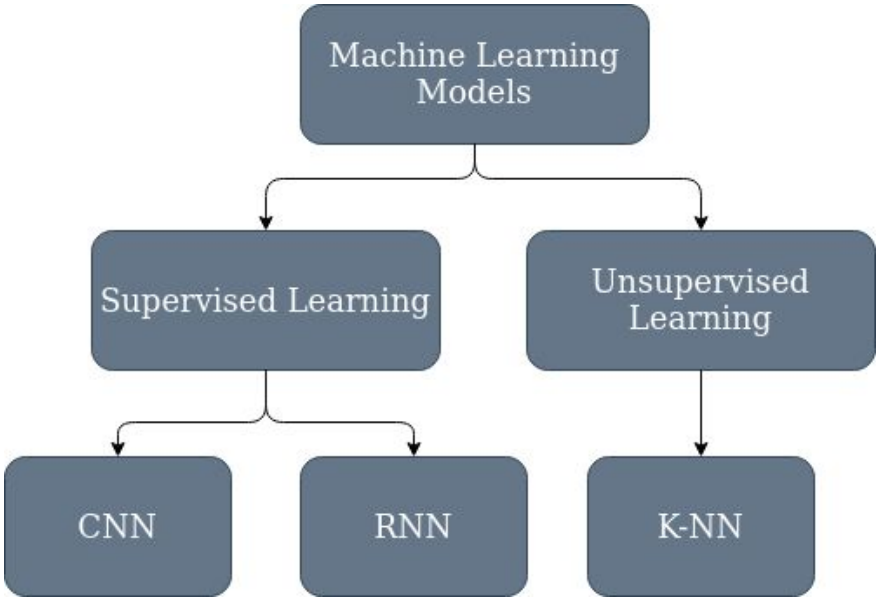

NILM Task
Probabilistic Models
Machine Learning Models
HMM
FHMM
Supervised Learning
Unsupervised Learning
CNN
RNN
K-NN

Probabilistic Models

They usually require expert knowledge about the appliances and are mostly either a Hidden Markov Model (HMM) or its variants.



Machine Learning Models

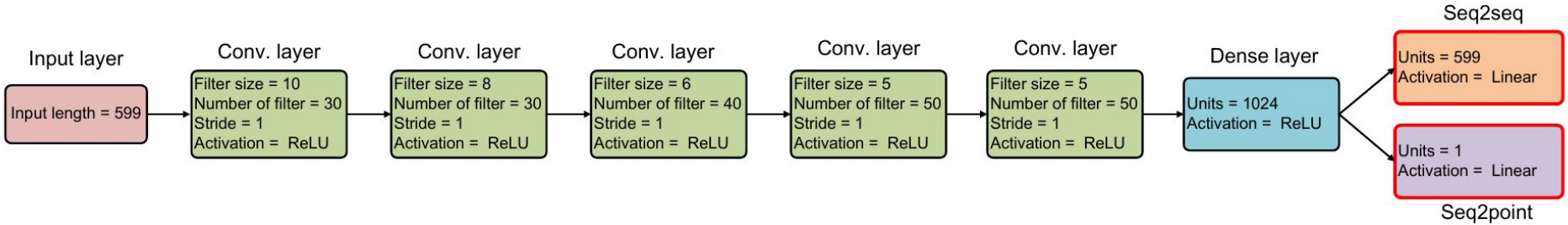


Machine Learning Models - Supervised Learning

The supervised solutions are the most explored and the ones that present the most promising results.

Some of the most popular models are:

- Seq2Point
- Seq2Seq
- WindowGRU
- BidirectionalLSTM

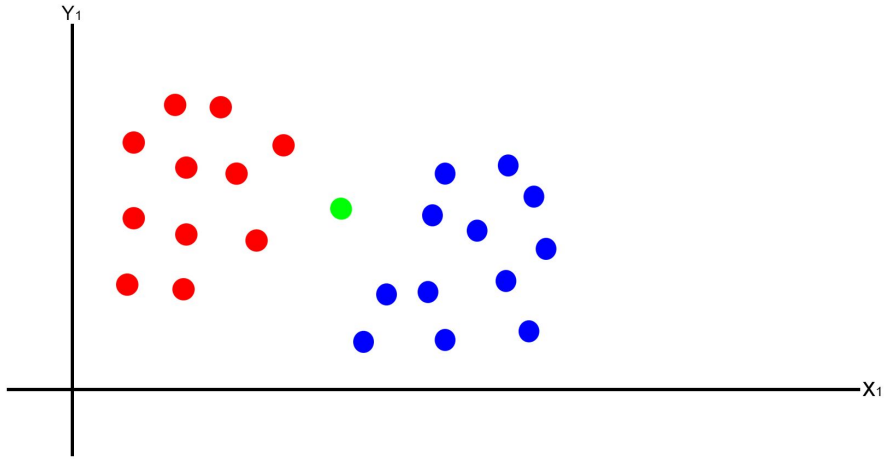


Chaoyun Zhang, Mingjun Zhong, Zongzuo Wang, Nigel Goddard, and Charles Sutton. 2018.
Sequence-to-Point Learning With Neural Networks for Non- Intrusive Load Monitoring. In Thirty-Second AAAI Conference on Artificial Intelligence.
https://www.aaai.org/ocs/index.php/AAAI/AAAI18/paper/view/16623

Machine Learning Models - Unsupervised Learning

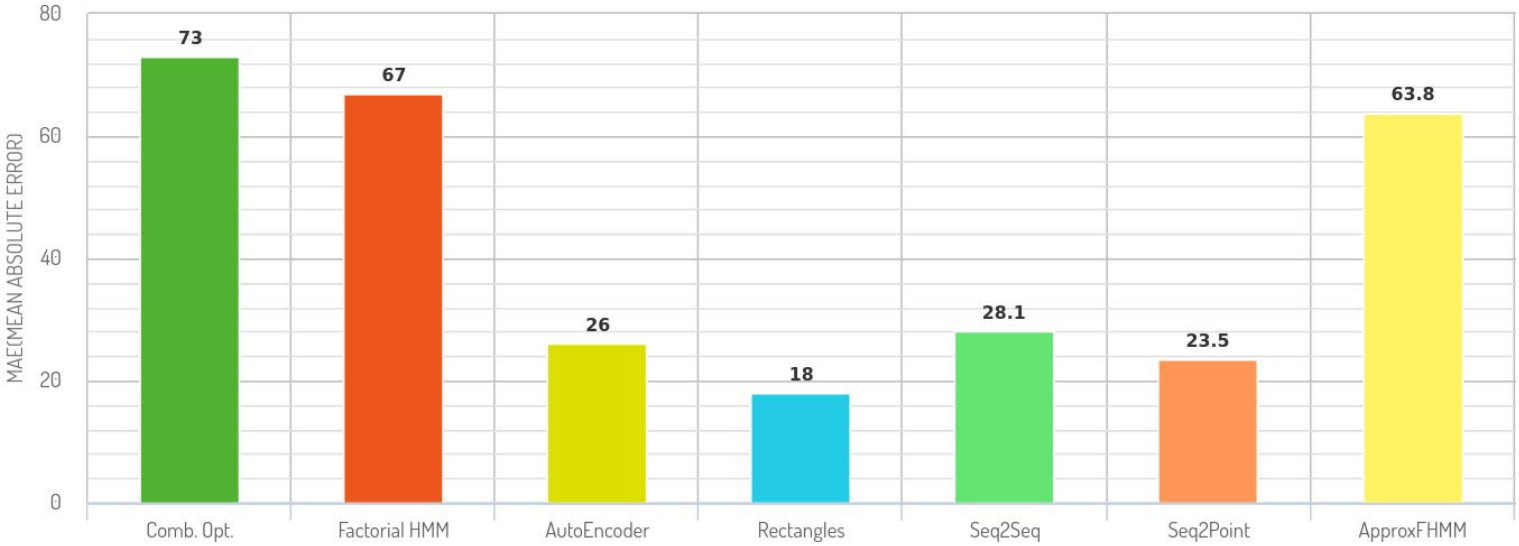
There is a **high interest** in these models since they don't need annotated data.

These models use clustering techniques, such as **K-NN**, as their predominant way to disaggregate the power consumption.



https://www.codershood.info/wp-content/uploads/2019/01/K-Nearest-Neighbors-K-NN-Classifier-using-python-with-example.png

State-of-Art



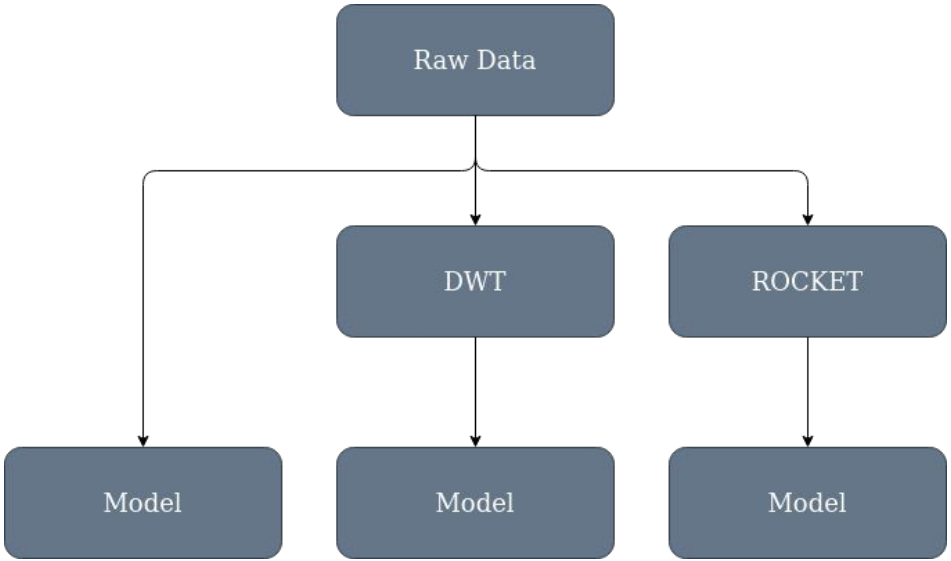
Classification results for a fridge

Developed Work

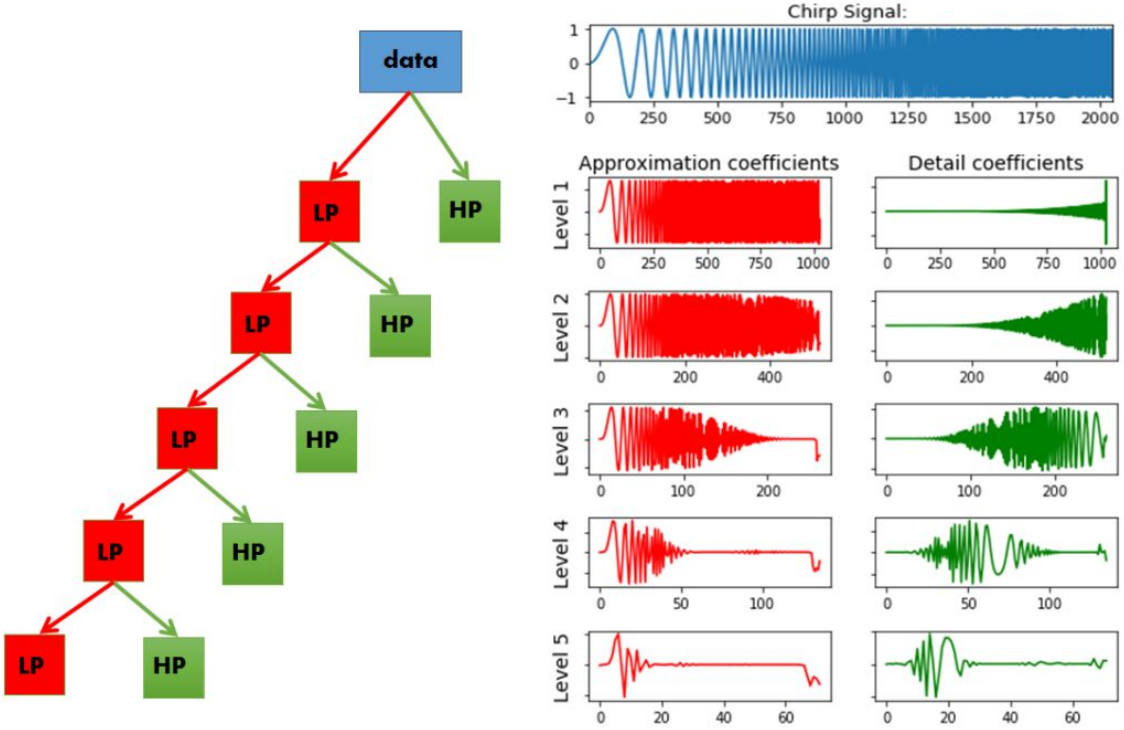
Novelty work

- Experiment with different feature extractors.
- Explore the implementation of a Deep RNN;
- Adapt a successful ResNet in other timeseries problems to NILM;

Feature Extraction

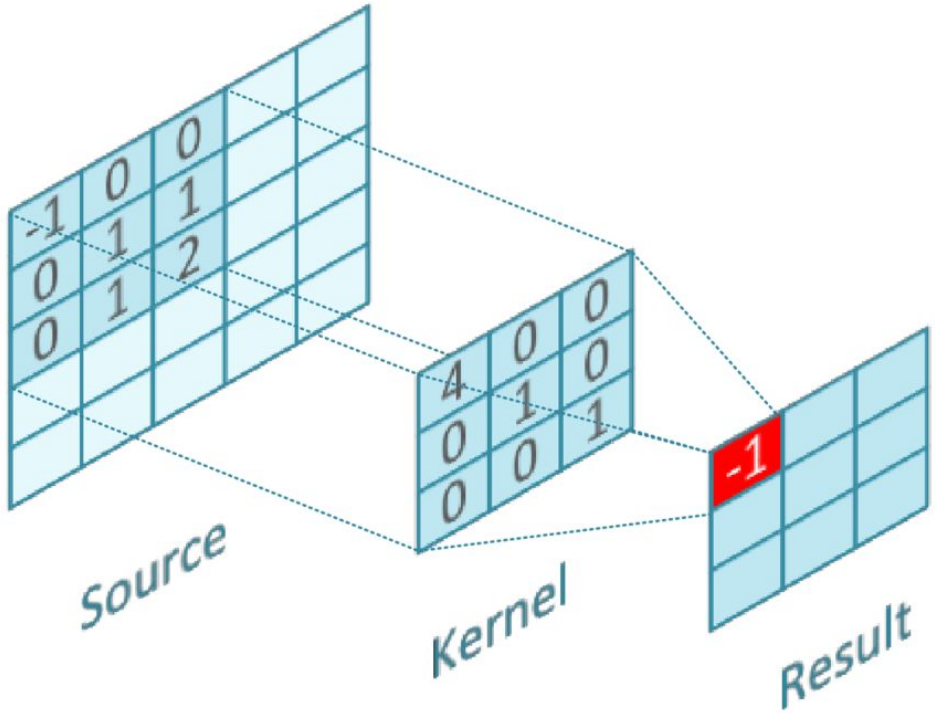


Feature Extraction – Discrete Wavelet Transforms



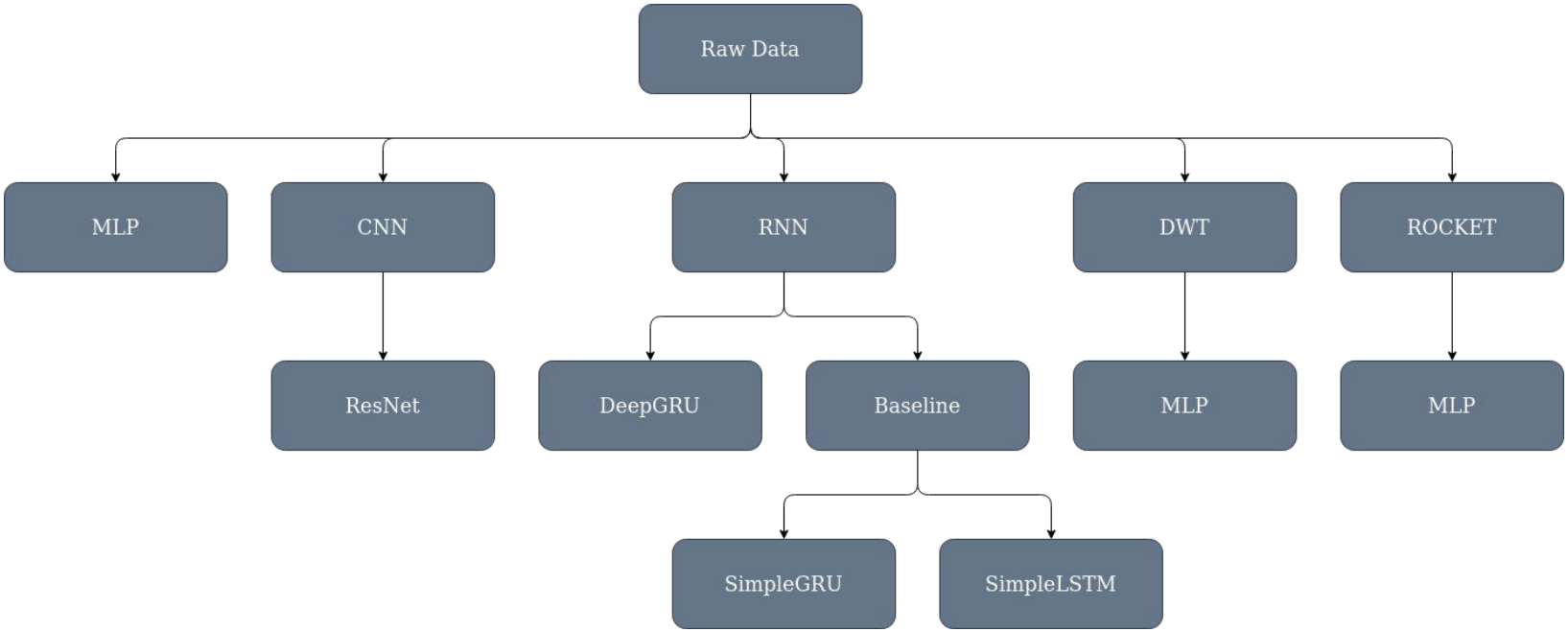
https://ataspinar.com/2018/12/21/a-guide-for-using-the-wavelet-transform-in-machine-learning/

Feature Extraction – Random Convolutional Kernels

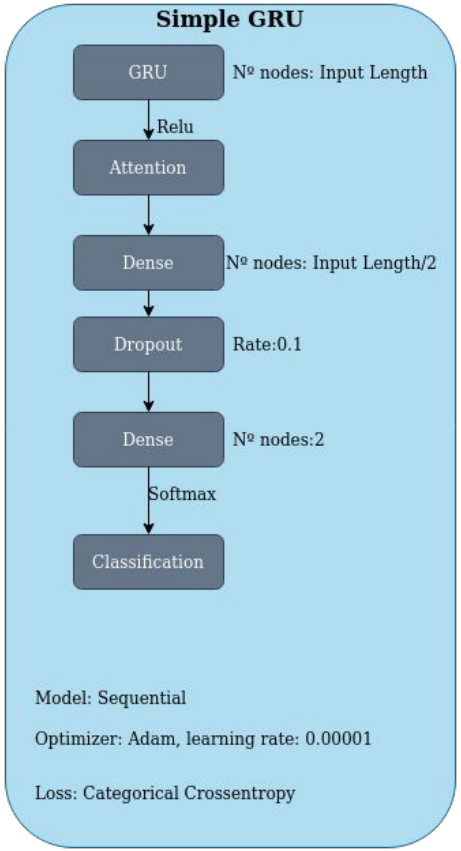


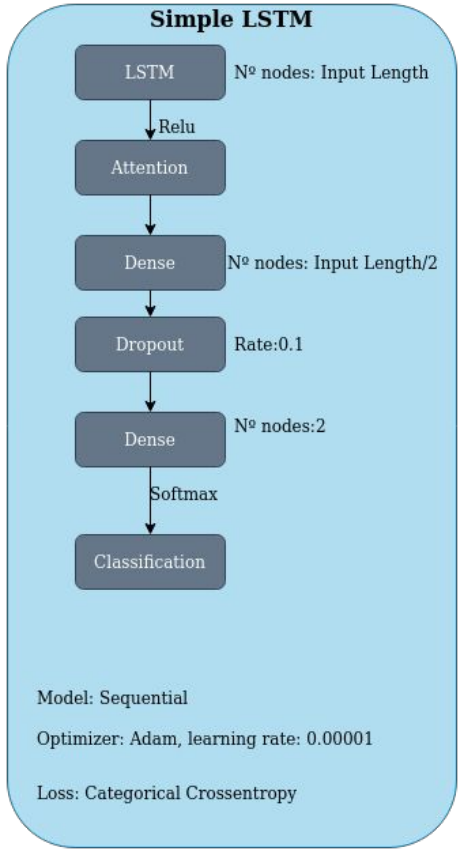
https://www.researchgate.net/profile/Baptiste-Wicht/publication/322505397/figure/fig5/AS:583063998308353@1516024698839/A-valid-convolution-of-a-5x5-image-with-a-3x3-kernel-The-kernel-will-be-applied-to.png

Proposed Models

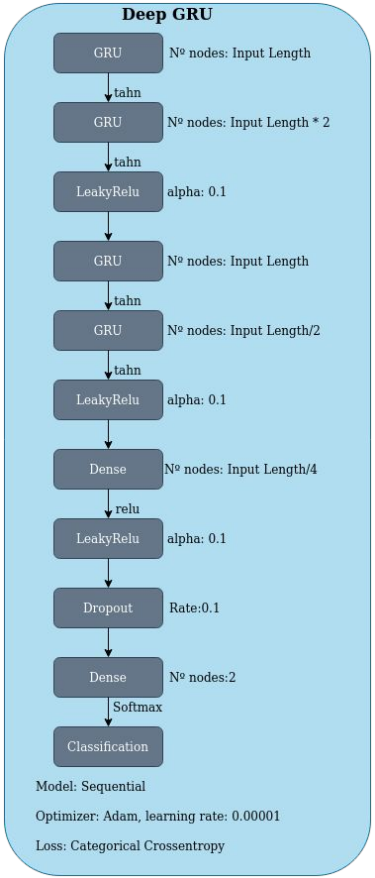


Proposed Models – Simple GRU & Simple LSTM



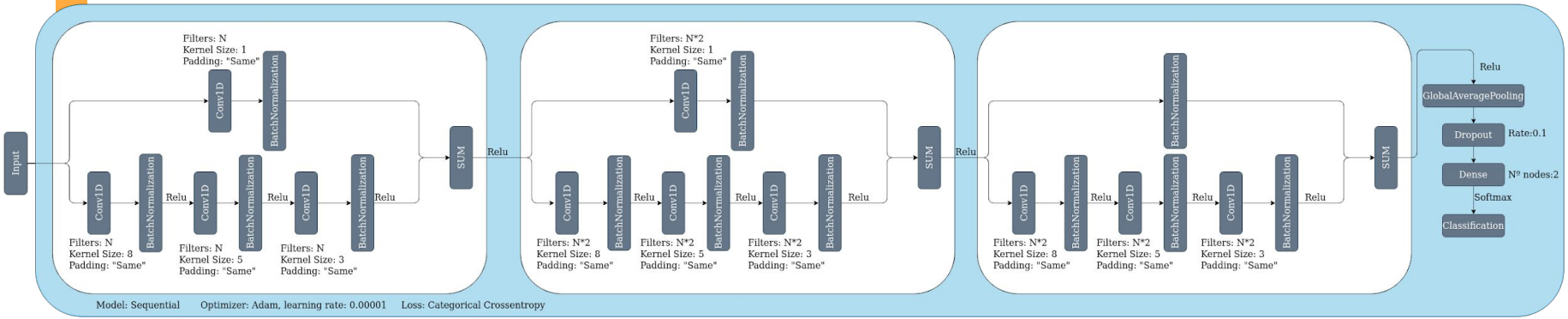


Proposed Models – DeepGRU

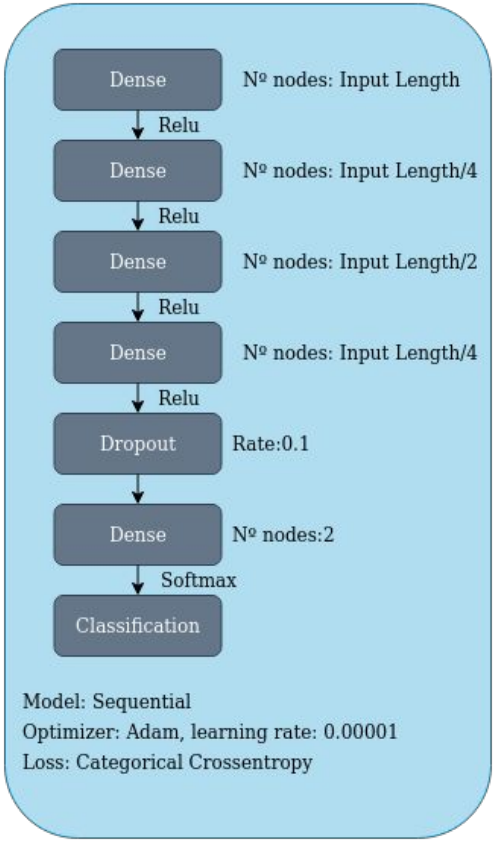


Proposed Models – Convolutional Neural Networks

The CNN we are using is a Residual Network proposed by Wang et al.



Proposed Models – Multilayer Perceptron



Preliminary Results

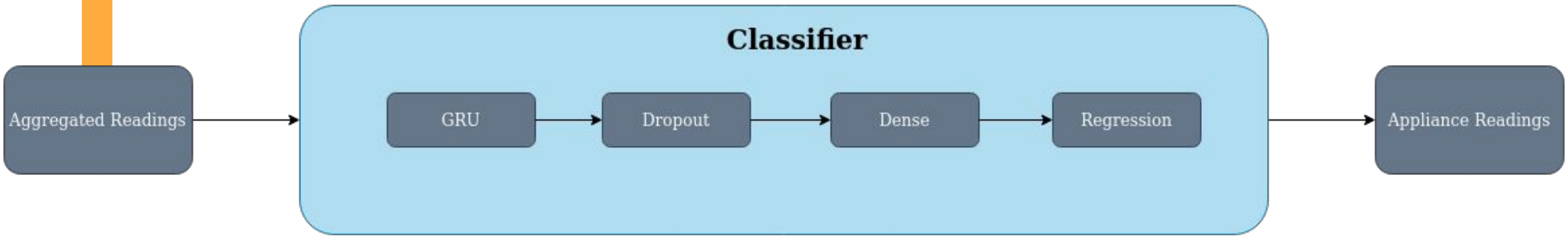
Network | Appliance	Heat Pump	Car Charger
SimpleGRU	0.22	0.14
SimpleLSTM	0.20	0.18
DeepGRU	0.83	0.5
ResNet	0.83	0.63
MLP_DWT	0.71	0.34

Matthews Correlation Coefficient obtained by the different models

The final objective

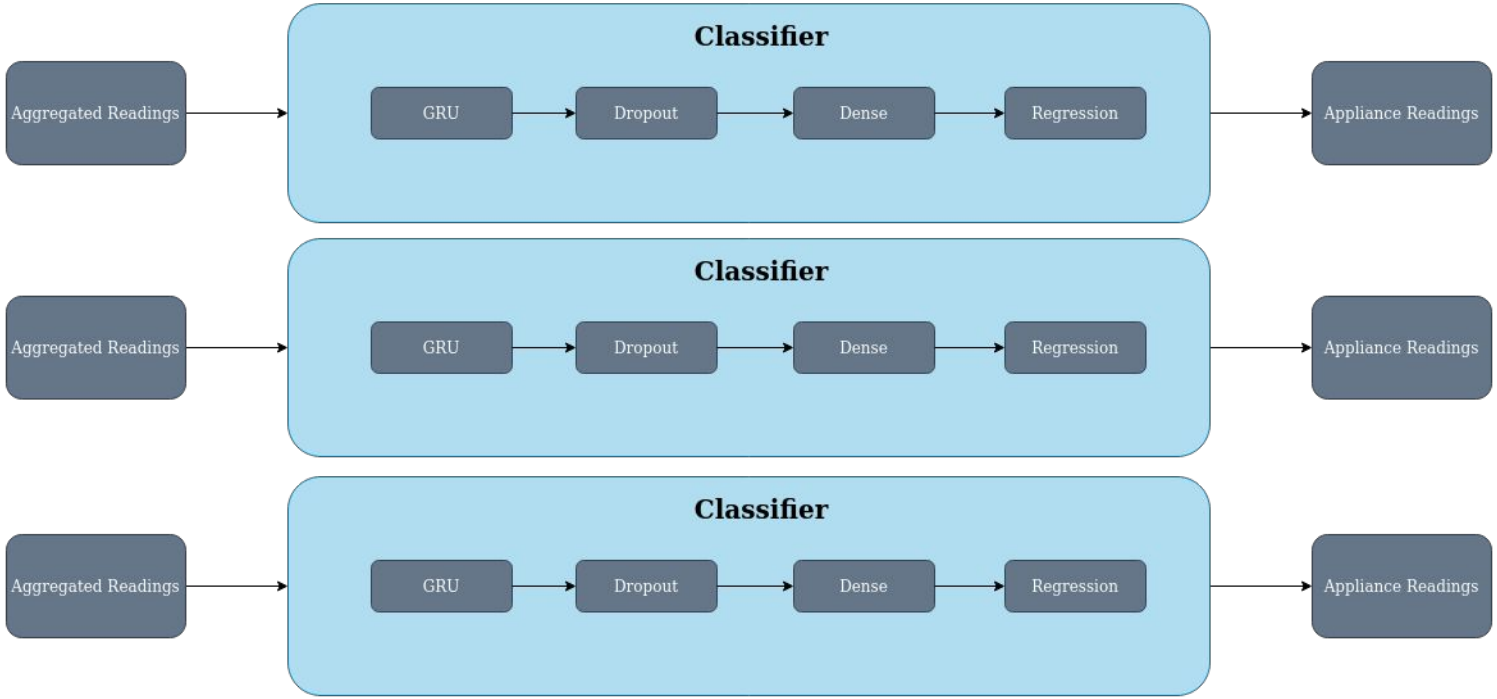
The final objective

The first step is to find a model capable of classifying a single appliance.



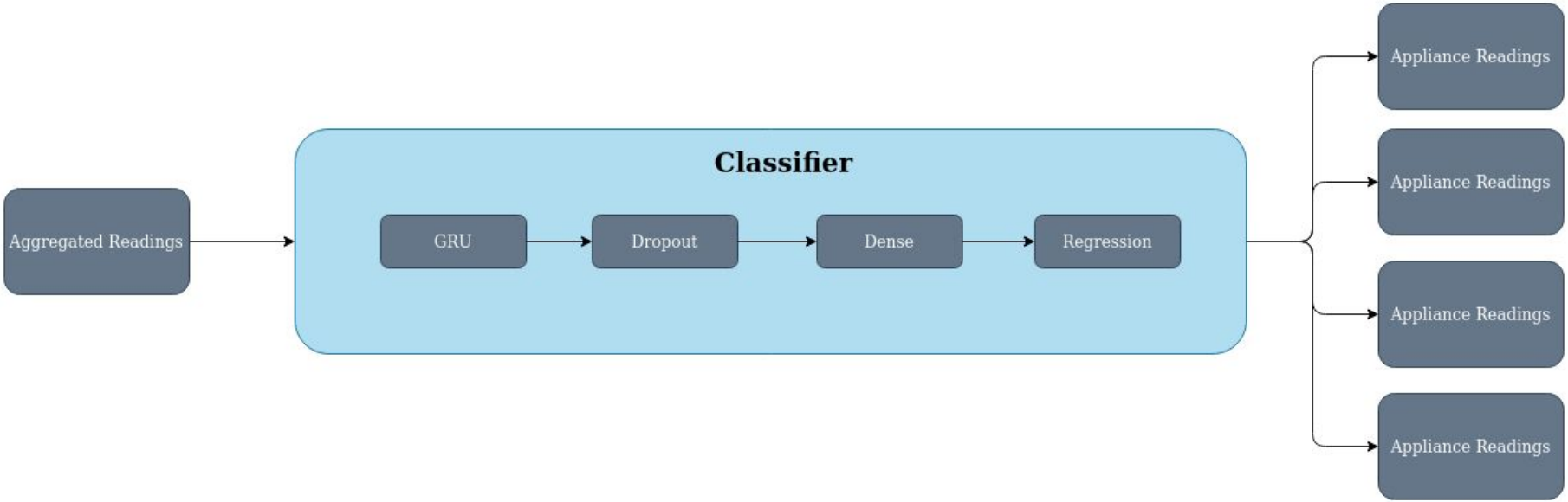
The final objective

After finding that model, the same model needs to be able to generalize to many appliances.



The final objective

The final step consists of a single model trained for all appliances.



Conclusion

As an ending note, I would like to state that, only **recently** the interest in NILM resurged, motivated by the advancements in machine learning.

Although the recent models show improvements compared to the previously presented solutions, the NILM problem is **far from being solved**.