

# Activity prediction using hybrid generative/discriminative model

Lio Enrico 822861, Vasquez Alessandro 822569

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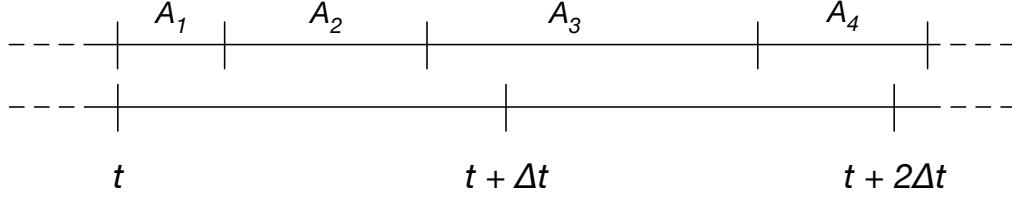


Figure 1: ADLs and intervals. The activity  $A_2$  being too short is considered noise and is dropped from the dataset. At the opposite,  $A_3$  is long enough to be detected in next interval.

## 1 Introduction

In this work we want to explore the power of a particular machine learning’s hybrid model, composed by a deep ANN (Artificial Neural Network) for the discriminative part and an HMM (Hidden Markov Model) for the generative part. In this hybrid model, the output of the ANN is used to refine the matrix of emission probabilities of the HMM so that the accuracy of the deep neural network is somehow “transmitted” to the HMM framework.

### 1.1 The setting

To train and test the hybrid model we used a dataset generated by a Wireless Sensor Network (WSN) which recorded the activation of almost a dozen sensors spread all over a user’s home for a couple of weeks. The first dataset is accompanied by another dataset created from the user’s annotations about which ADL (activity of daily living) was executing in which interval of time. By setting the sensors’ recordings as the features and the user’s ADL as the targets we can build a model that infer which sequence of ADL the user was executing by considering which sensors were activated during that period of time.

## 2 Data parsing, data alignment, data mapping

In order to get a discretized temporal format of the dataset, we sliced the data in regularly spaced intervals of time. The chosen length of those intervals is  $\Delta t = 60s$ . For each  $\Delta t$ , we consider the first ADL being executed in that interval, whereas for the sensors we consider all sensor that were activated at least once during the considered interval. The choice of excluding other ADLs that could possibly appears in the same  $\Delta t$ , was made by considering that if an ADL appears as the second activity during a given interval, two scenarios are possible: in the first one the ADL is so short that will not appear in the next time interval. In this case we assume that activity to be noise and do not consider it. In the second scenario the ADL is long enough to appear as the first ADL in the next interval, and will be associated to that interval. An example of these scenarios is illustrated in figure 1. We mapped each activity and each sensor into an integer number based on the order of appearance in the dataset, such

that the first activity/sensor to appear in the dataset is mapped as the 0-th activity/sensor. This means that the mapping differs for each different dataset. In our case, two datasets were used (*A* and *B*), thus two different mappings have been produced:

Map	Activity A	Map	Activity B
0	Sleeping	0	Spare Time/TV
1	Toileting	1	Grooming
2	Showering	2	Toileting
3	Breakfast	3	Sleeping
4	Grooming	4	Breakfast
5	Spare Time/TV	5	Showering
6	Leaving	6	Snack
7	Lunch	7	Lunch
8	Snack	8	Leaving
		9	Dinner

A *configuration* consists of a binary array in which the  $i$ -th element is set to 1 if the  $i$ -th sensor activated during the given interval of time, 0 otherwise. Each observation is associated with the ADL the user was executing during that interval of time.

## 3 Hybrid model

### 3.0.1 Neural Network

The neural network takes the configuration  $y_t$  associated to the time interval  $t$  as its input whereas the output, in accordance to our model, corresponds to the probability for the configuration  $y_t$  to be observed given the state  $x_{i_t}$ , i.e.  $p(y_t | x_{i_t}), \forall i$  at the time  $t^1$ . The neural network’s architecture is illustrated in figure 2. The activation function for the hidden and the output layer is the relu function:

$$relu(x) = \max(0, x).$$

The *softmax* function is the function  $\sigma$  that transforms the logits outputted by the network in a probability distribution:

$$\sigma(\mathbf{o})_j = \frac{e^{o_j}}{\sum_{k=1}^n e^{o_k}}, \text{ for } j \in 1, \dots, n.$$

We chose a feed-forward, 5-layered deep neural network that uses the back-propagation algorithm to learn. The loss function we chose is a classic for neural networks which implement multinomial logistic regression, the cross entropy:

$$cross\_entropy(\mathbf{t}, \mathbf{o}) = - \sum_i t_i * \log(o_i),$$

<sup>1</sup>In the original paper the author used the Bayes rule on the output of the softmax function since they considered it the probability  $p(\vec{x}_t | y_t)$ . We made a different choice in order to not “contaminate” the neural network’s result with the a priori probabilities of features and targets.

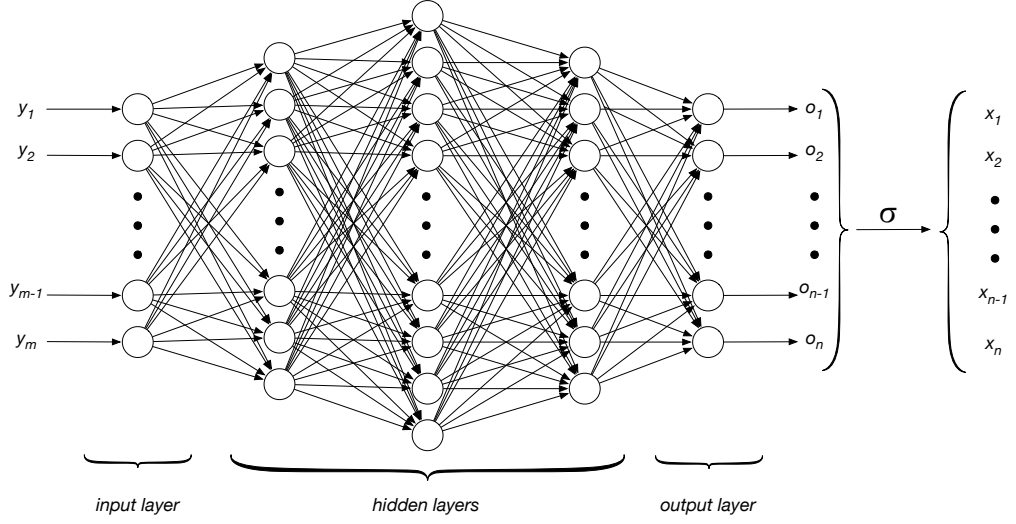


Figure 2: Architecture of the neural network:  $m$  is the number of sensors, i.e. the size of the observation's space, whereas  $n$  the number of the recorded activities, i.e. the state's space.

where  $\mathbf{t}$  is target array and  $\mathbf{o}$  is the neural network's output array. The target is *one-hot* encoded, since we know which activity is being executed by the user in the given interval of time.

### 3.0.2 HMM

The HMM structure is usually defined by three matrices:  $\pi$ , which provides the a-priori probabilities for each hidden state,  $T$ , which features the probabilities to transition from one hidden state to the other and  $O$ , the emission probabilities' matrix. In the hybrid model,  $\pi$  and  $T$  are generated by computing the frequencies of states and transitions in the training set, respectively.  $O$  is not defined since its columns are computed at each step by the neural network, when necessary.

## 4 Implementation details

### 4.1 System's architecture

### 4.2 Third-party libraries

We used `sklearn`, `numpy` and `pandas` for scientific computing matters. The neural network was developed with `keras`, a high-level API which uses `tensorflow` as its back-end.

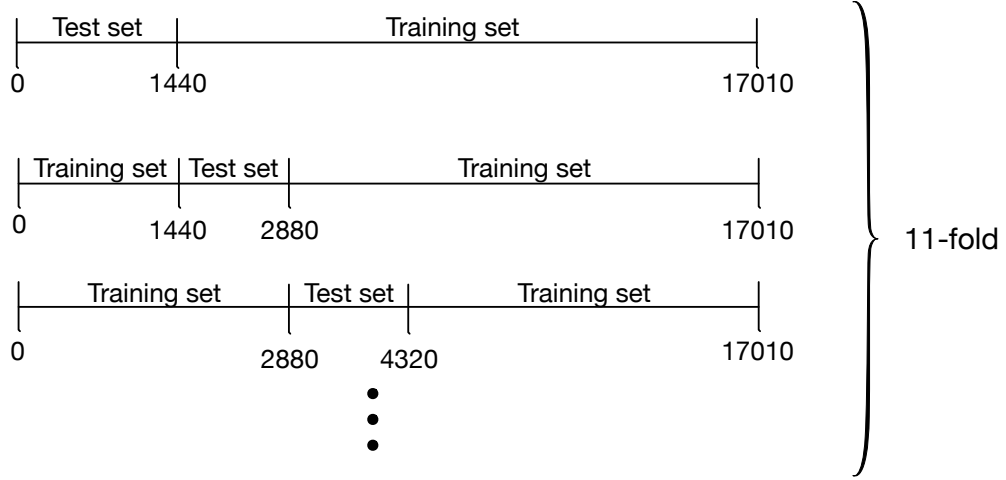


Figure 3: Cross validation of dataset A.

## 5 Results

### 5.1 Cross validation

In order to evaluate the performance of the hybrid model, we used the cross-validation technique: we splitted the whole dataset into  $k$  equal subsets and performed  $k$  rounds of learning and testing: on each round  $\frac{1}{k}$  of the data is held out as a test set and the rest of the dataset is used as training set. The basic idea is that each example plays a double role: both as test data and training data. We used a one-day  $k$ -fold cross validation, in which the test set consisted of a sequence of  $\sim 1440$  observations, the equivalent of an entire day divided by the time segments of 60 seconds. Figure 3 shows how the cross-validation was used with the dataset A: since 17010 samples were generated during the parsing, the number of folds will be  $k = \lfloor 17010/1440 \rfloor = 11$ .

### 5.2 Data results and conclusion

Thanks to the elimination of noise in the dataset and the deep neural network contribute, we obtained predictions with a pretty nice accuracy. We kept track of the average error of both the neural network and the hybrid model. Since the neural network works on single instances at a time, we suspected that it would have outputted more accurate predictions than the hybrid model, which works on sequences of  $\sim 1440$  elements at a time. As figure 4 shows, we weren't so much wrong. Here, the error was computed simply by dividing the not-matched states in the sequence by the sequence's length, for each of the  $\sim 10$  folds. The average error among all  $k$ -folds is:

	Avg hybrid error	Avg nn error
A	0.0403409090909	0.0324494949495
B	0.0527243589744	0.0520299145299

i.e. the hybrid model has an average accuracy that is greater than 90%.

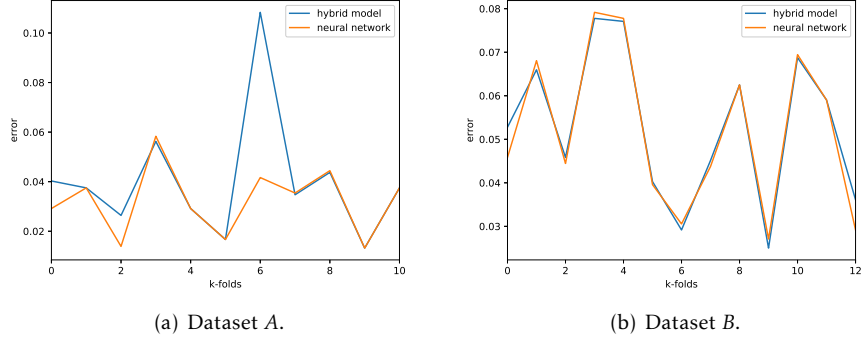
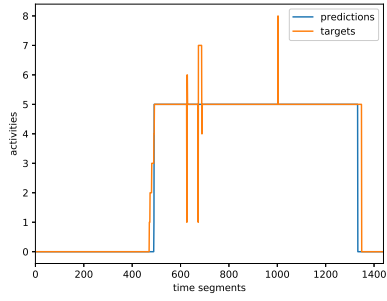


Figure 4: Mean error during testing.

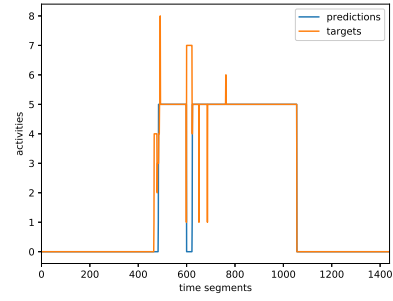
Figure 5 shows graphically the mismatches in the first two folds for both dataset A and B. If the prediction matches the target, the prediction's blue line is completely overlapped by the target's orange line. When a mismatch occurs, the blue line is not overlapped and can be seen.

### 5.3 Conclusion

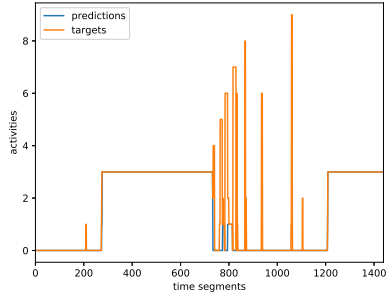
Hybrid models have been researched and used extensively in the field of machine learning. Even in a small project like this one, we had the chance to see with our own eyes the power of deep learning and hybridization. Hybrid machine learning models have a wide range of possible application from medical research, to social networks-related data analysis. Machine learning models are even used to predict the form of black holes by feeding images of celestial objects as training data: we are looking forward to see what new breakthroughs machine learning will lead to.



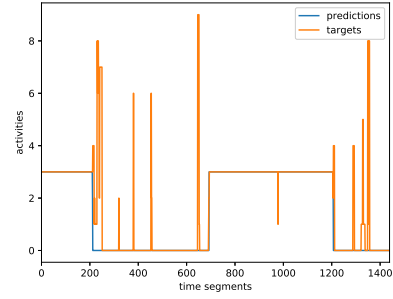
(a) 0-th fold, dataset A.



(b) 1-th fold, dataset A.



(c) 0-th fold, dataset B.



(d) 1-th fold, dataset B.

Figure 5: Prediction vs target mismatches.