**Models (TO DO: ensembles)**

We experimented with models of every kind. We tried using convolutional and dense models. We tried also putting layers with recurrent neurons, like the LSTM layer and the GRU layer. These layers were shown to be more effective when placed in a bidirectional structure. We also tried using the attention layer, which was effective when placed after the bidirectional GRU layers. In the end, our best-performing model was a combination of everything: it is composed of a series of convolutions, 2 bidirectional GRU layers, and an attention layer.

**Scaling**

We applied standard scaling, min-max scaling (between 0 and 1, and between -1 and 1), and robust scaling. We discovered in our tests that these scaling helped increase the accuracy, but there wasn’t a specific scaling that worked well for every model. In some models, such as the convolutional networks, the standard scaling was enough, while in models containing recurrent nodes (like LSTM and GRU), standard scaling after a min-max scaler (the range was not so important) gave better results.

We tested 2 scaling strategies: feature-wise and with respect to each pair (timestamp, feature). The first solution provided better results in all our models.

**Class weights**

We tried implementing the class weights for the training, but it showed bad results and an accuracy decrease of several percentage points for every model tested. This is probably due to the very strong imbalance of the data samples among the classes, especially the classes that have a very limited number of samples available. We eventually did not use any class weighting in our trainings of the models.

**Data augmentation techniques**

All the augmentation techniques used were applied to the dataset in an offline fashion. This means that the dataset is augmented before training, and it doesn’t change at every epoch (like a training dataset generator would do).

The first method used for data augmentation was **data oversampling** for the classes with the least number of samples available. This method takes every sample and copies it multiple times so that eventually all classes will have more or less the same number of samples. The class with the highest number of samples is not oversampled at all. This approach aims at balancing the dataset as much as possible. When each sample is copied, a random gaussian white noise is added to the time series (feature-wise) so that the samples are not exactly equal but they differ slightly one from the other.

The second method used for data augmentation was the **cubic interpolation with 1d splines** of the time series. This approach serves for getting a higher resolution time series that is as accurate as possible, considering the number of points available for the time series. Our code takes each sample and increases its resolution of the time series by 3x. So we trained models that take an input shape of size (108, 6) instead of (36, 6). We also tried with different resolution multipliers, but the best-performing ones were 3x and 5x.

Chart, line chart

Description automatically generated

This plot shows the effect of the cubic interpolation of a randomly drawn time series. The blue dots represent the original time series points, while the red dots the interpolated time series. The blue dots are distanced 1 timestamp between each other, while the red dots are 3 times denser in space.

This increase in the resolution of the time series did not show significant improvements in our models, as we expected, so we used another technique to exploit the cubic splines interpolation differently.

**Cubic splines interpolation for the creation of artificial samples**

The **final method** for data augmentation is based on the computed interpolated time series of the entire dataset **without increasing the resolution of the samples.** The previous approach created a dataset of 2429 samples with shape (108, 6). Now, instead of training models on time series with higher resolution, we decided to try to train the models on time series with the original resolution, but on a dataset with more samples. So, the final technique creates **artificial samples**, using the interpolated time series, to create a training set with more samples than the original one. The algorithm takes every interpolated time series from every sample. Then, given a time series with 3x resolution, for example, it extracts 3 different time series that are 36 timestamps long (the original time series length). For each extracted time series, a gaussian white noise is added too, so to create samples that differ as much as possible.

The way for which new artificial time series are extracted from an interpolated one is by taking the points that are 3 timestamps apart and saving the sequence in 3 time series. For example, if the resolution multiplier was set to 3, the length of the interpolated time series is 108 and the first sequence is obtained by the points at the timestamps [0 3 6 9 12 … 105]. The second sequence is obtained by the points at [ 1 4 7 10 13 … 106], and the third sequence is obtained by the points at [ 2 5 8 11 14 … 107]. This way 3 new sequences with length 36 are created and correspond to the artificial samples of the dataset. The new sequences will be very similar one from each other, and similar also to the original sample. The resulting dataset will contain a number of samples that is 4 times bigger than the original one, because, for each original sample, the augmented dataset will contain the original sample and the 3 artificial samples. This technique proved to be effective in our tests, providing an accuracy increase of several percentage points.

**Cross-validation, handling the window, feature selection and PCA**

Given the small training time of our models, we decided to select our models with a cross-validation technique. We used the StratifiedKFold cross-validator from sklearn, with k ranging from 7 to 10. The stratification was important as the original dataset was very imbalanced.

It’s important to note that we preferred not to modify the original window provided with the dataset. Indeed, we had no idea whether consecutive time-series samples in the original dataset were in temporal-dependent order. Additionally, we had no clue that at test time (on Codalab) samples were fed with the same order.

In this way, we considered every sample independent from each other and were able to implement the cross-validation in a straightaway manner. The cross-validation has been used to also test the splines augmentation, learning rates related parameters, PCA, features drop and all combination of scalers.

We tried removing 1 feature at-a-time, but it seemed not so beneficial. Better results were achieved with PCA, projecting features over 5 or 6 components, just before applying the scalers.

The use of cross-validation turned out to be very important as the performance of models in this problem setting appeared strongly influenced by the train-test split. In this way, we selected the models that had high average accuracy and low fluctuations among all the splits, discarding models that reached very high accuracy due to a “lucky” split.

**Tsaug library for augmentation**

We also tested the tsaug library, which provides augmentation for timeseries data. The results were worse than our splines augmentation implementation. Moreover, it slowed out too much our trainings, as the augmentation is computed by the CPU, so testing many augmentation combinations inside the cross-validation was not affordable. Therefore, we decided not to use it.

**Learning rates**

**Other possible techniques**

Reshape the samples as an image and use 2D convolutions with augmentation applied at training time by the network layers.

Outline

* models with
  + convolution and dense layers
  + lstm and gru layers
  + bidirectional lstm and gru
  + attention layer
  + a combination of everything
* cross validation
* oversampling not useful
* data augmentation with splines interpolation
* data augmentation with gaussian noise
* data augmentation with artificial samples from splines interpolation
* scaling: robust, minmax, standard
* class weights not useful
* removal of “difficult” features not useful
* pca
* tsaug --> guast