COMPARISON AND COOPERATION OF SEVERAL CLASSIFIERS

Xavier DRIANCOURT, Léon BOTTOU, Patrick GALLINARI

<xd@lri.lri.fr> or <xd@FRLRI61.BITNET>
L.RI. Bat 490 • Université Paris Sud • 94450 Orsay • FRANCE

This paper presents the comparison of several methods on a multi-speaker isolated word small vocabulary problem. A sub-optimal cooperation between Time Delay Neural Networks and other algorithms is proposed and successfully tested on the problem. An optimal cooperation method between Dynamic Programming and some other algorithms is proposed.

We use the following abbreviations: Dynamic Programming (DP), Multi-Layer Perceptron (MLP), Time Delay Neural Network (TDNN), Recurrent Neural Network (RNN), Learning Vector Quantization (LVQ), Isolated Word Recognition (IWR), Hidden Markov Models (HMM).

1 INTRODUCTION

Speech can be considered as a sequence of local phonetic events. Consequently, speech recognition should integrate both sequence and phonetic events detection aspects. From this point of view, many already popularized speech recognition methods are not satisfying. Many methods use global recognition of whole patterns (e.g. classical MLP, LVQ, K-Means ...), some methods perform local events detection (e.g. TDNNs, Shift-Tolerant LVQ or K-Means ...). Dynamic Programming performs sequence detection by using some simple distance to match frames. Two popular methods partially integrate the two aspects: Hidden Markov Models which try to reduce the weakness of local detection performed by DP and Recurrent Networks which learn to perform some kind of sequence detection. Cooperation between HMM or DP for time alignement and Neural Networks for local events detection seems especially interesting. Such cooperative models have been recently introduced [2], [3], [4].

In §2 we detail a problem of speech recognition. Then we compare the efficiency of several methods to solve this problem in §3. In §4, we explain and test a sub-optimal algorithm of cooperation between TDNN and other classifiers, especially DP. Finally, we introduce an optimal algorithm of cooperation between DP and TDNN, K-Means or LVQ.

2 A MULTI-SPEAKER ISOLATED WORD RECOGNITION PROBLEM

The French database used for the experiment reported here is made of *thirty words* uttered *ten times* by each of *ten speakers*. It was sampled at 10 KHz. In all the experiments reported here, we have used a bark-scale *filterbank* signal preprocessing. The result is a condensed spectrogram, made of 100 frames of 16 coefficients per second; the overlap between two consecutive frames is 1/200 second.

The database was recorded in an *office environment*. The words selected for the database are the ten digits and twenty text editor command words.

Half of the database was used for training and the other half for testing. The test set had about 1500 examples, so for instance the 95% confidence interval at 96% correct classification is 1.1%.

3 COMPARISON OF SEVERAL METHODS

We give herein some details about the versions of the different methods we have employed, as well as the recognition rates they obtained on the test base.

Dynamic Programming (DP)

Our Dynamic Programming algorithm is quite simple and uses as references the examples from the training base. This DP obtained *86.7%* recognition.

Adaline

Adaline gave a baseline performance of *74%*.

Time Delay Neural Network (TDNN)

Our version of TDNN [7] is stochastic. Figure 1 shows our most efficient architecture, called IWR2.

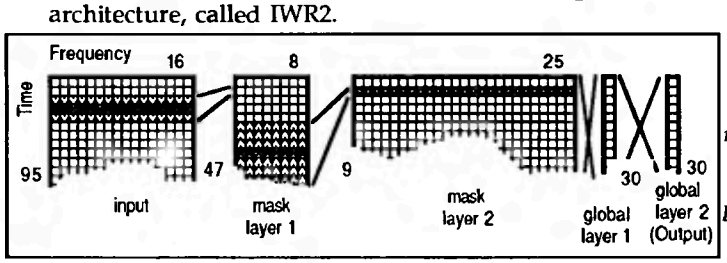

Figure 1 : IWR2

This figure shows the most efficient classical TDNN architecture.

Each square stands for a neuron

Many architectures were tested. We mention here two modifications of IWR2: IWR1 where the layer *"global layer 1"* has been deleted and IWR1-16 where *global layer 1* has been deleted and where *mask layer 1* uses 16 hidden units per frame (instead of 8 in IWR2). IWR2 gave a *96,5%* recognition rate, IWR1-16 *96.5%*, and IWR1 *94.5%*.

Frequentialy Connected TDNN (F-TDNN)

In common TDNN, masks (i.e. quasi-linear filters) are local along the temporal dimension, but global in the frequential dimension. It is possible to use masks which use local connections in both dimensions. Then "expert" knowledge can be introduced in the design of these connections, which can improve performance and speed. A first attempt with this method, gave *97%* recognition. This F-TDNN is a restriction of the architecture of TDNN IWR1.

Recurrent Neural Networks (RNN)

We used a special kind of Recurrent Neural Network where the recurrent part of the RNN is implemented with shared weights, by unfolding the recurrent network along time. Consequently, the RNN has a finite temporal extension.

We faced problems in conditionning the algorithm. Our best recurrent network obtained *96%* success.

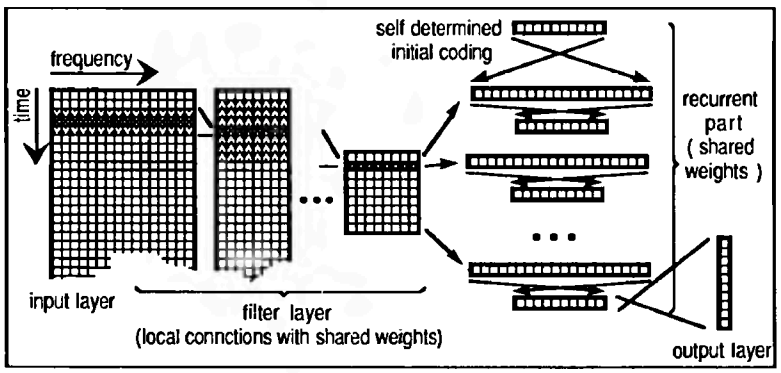

Figure 2: Recurrent Network

This recurrent network has a finite temporal extension; the iterative part is implemented with shared weights

K-Means

K-Means is a *stochastic* algorithm: we adapt references after presentation of each example and the database is presented several times. K-Means can be used as an efficient classification method. To do this, we *supervise* the algorithm by applying a K-Means independently to the different classes. Furthermore, we use a *shift-*

tolerant version, based on the same principle as the shift-tolerant LVQ algorithm [5]: during training, K-Means is applied to temporal windows over the input samples. For classification, each word is scanned and the decision is obtained through the vote of all temporal windows. This sophisticated version obtained *82%* success.

Learning Vector Quantization (LVQ)

We used a *shift-tolerant* LVQ2 [5] [4] (see above *K-Means* for more details on shift-tolerance), modified the following way [1]: we consider the *nearest reference of the good class* instead of the second closest reference. We initialized LVQ with K-Means. The best LVQ of this kind had 11 references for each class, and obtained *83%* success; with 16 references per class, the learning rate was better, but the test was not as good: *79%*.

The following table sums up all results mentionned in §3:

DP	Shift K-Means	Shift LVQ-16	Shift LVQ-32	Adaline	TDNN IWR1	TDNN IWR2	TDNN IWR1-16	F-IWR1	RNN
86.7	82	83	79	74	94.5	96.5	96.5	97	96

Table 1: % of correct answers on the test set for the different classifiers

4 A SIMPLE SUB-OPTIMAL COOPERATION METHOD: FEATURE EXTRACTION

The method we propose here consists in using the lower layers of a TDNN to provide a preprocessing. Then any classifier can be used on the preprocessed data. More precisely, we build a two module architecture. First module is a TDNN, which will be used to code the data in one of its hidden layer H. The top of the TDNN (i.e.. layers above H) is then exchanged with another classifier which will receive as input the output of H which is called *extracted features*.. Speech data will be processed sequentially by the two modules. Training is performed as follows: we first train the TDNN and then use the outputs of H, as training data for the second module. Figure 3 illustrates the method.

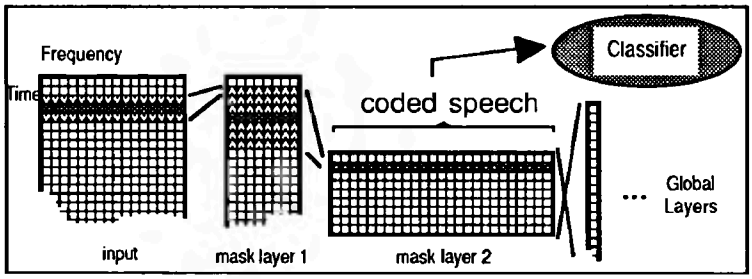

Figure 3: Feature Extraction

Propagation through the network is redirected after last mask layer towards another classifier.

We have tested various combinations of TDNN architectures and classifiers. The results are given below:

Top classifier / Feat. extractor	DP	MLP1	MLP2	LVQ-LBG	LVQ KM16	LVQ KM32	RNN
TDNN IWR1	98.8	94.5	96.5	97.75	97.12	97.25	96.5
TDNN IWR2	92	86	95	KM stands for K-Means; LBG is another clustering algorithm used to initialize LVQ; MLP1 and 2 are MLPs with 0 and 1 hidden layer.			
TDNN IWR1 16	94						
F-TDNN IWR1	98.8						

Further experiments should be made for a complete understanding of these first results. We can already make some remarks:

- The best scores are clearly obtained by combining DP and TDNN IWR1 or F-TDNN IWR1,

- The architecture of the upper layers of a TDNN influence the training of the lower layers. A two layers top is more complex than a single layer top. Therefore, codes from IWR2 may be more complex than codes from IWR1.
- These cooperative systems are clearly sub-optimal: the code obtained by feature extraction may be not especially adapted to the top classifier. It is especially critical for DP, which is not adaptive and uses simple distances (Euclidean, Manhattan...) to match frames.
- A further advantage of feature extraction is the reduction of dimensionality which allows to spare a large amount of time for training adaptative top classifiers (LVQ, ...) or for using matching algorithms (DP); in the case of DP, there is a ratio of about 8 to 1.

This cooperation is said *sub-optimal* because nothing guaranties that the TDNN trained in a first step on the IWR problem will provide a preprocessing which fits the classifier used afterwards. In order to get an optimal algorithm, the two modules should be *trained* together.

5 OPTIMAL COOPERATION WITH DYNAMIC PROGRAMMING

Encouraged by the good results given by the sub-optimal cooperation methods, we have worked on a familly of optimal cooperation algorithms, based on the frame to frame matching operated by DP. We are going to build an optimal two module architecture combining TDNN and DP. Like in §4, the first module will be the first layers of a TDNN and the second a DP. These two modules will now be trained together using an adaptive gradient algorithm. For purpose of simplicity, we introduce and detail these algorithms for isolated word recognition only. We first describe an algorithm for training the DP module and then discuss the global architecture.

5.1 Gradient Back-Propagation through a DP Module

Dynamic Programming computes a dissimilarity measure between two sequences of frames. By the way, a path is found in the grid of frame to frame matching. This path is a sequence of frame to frame correspondance. We can then build a *K-Means-DP*: given a training word, the closest DP reference W among the set of references Ω can be adapted by applying an attraction (like k-means) from each frame of the training word on each corresponding frame of W.

Actually, this system is an original application of gradient back-propagation. Let us call Q the measure of dissimilarity between a training example $X = x_1,\ldots, x_{P_X}$ and its most similar reference. We call $W = w_1,\ldots, w_{P_W}$ a reference and $c_1 \ldots c_M$ the frames of <u>all</u> reference words together: $c_{W1} = w_1, \ldots, c_{WP} = w_P$ are the frames of word W. A path which matches X to W is written: $p_{XW} = (l_{XW}, \sigma_{XW}, \hat{\sigma}_{WX})$, where l_{XW} is the length of the path and $\sigma_{XW}(i)$ (resp. $\hat{\sigma}_{WX}(i)$) the coordinates of X (resp. W) for the i^{th} step of the path. We can write Q as follows:

$$Q(X,c_1,c_2,\ldots,c_M) = \underset{\substack{\text{words} W \\ \text{in set } \Omega}}{\text{Min}} \left(\underset{\substack{\text{paths } p_{XW}(l_{XW}, \sigma_{XW}, \hat{\sigma}_{WX}) \\ \text{which match X to W}}}{\text{Min}} \sum_{i=1}^{l_{XW}} d(x_{\sigma_{XW}(i)}, w_{\hat{\sigma}_{WX}(i)}) \right) \quad (1)$$

Equation (1) means that the dissimilarity is the addition of all frame-to-frame distances along the best path generated while matching X to its most similar reference W.

Actually, we use Q as the cost function (error) back propagated. Given the closest reference W and the best path p_{XW} which matches W to X, we can write the gradient of Q, using twice the property: $[\nabla_y \text{Min}\, Z = \nabla_y Z_{min}]$. We obtain:

$$\nabla_{c_j} Q = \sum_{i \text{ such that: } \hat{\sigma}_{WX}(i) = w_j} \nabla_{w_{\hat{\sigma}_{XW}(i)}} d(x_{\sigma_{XW}(i)}, w_{\hat{\sigma}_{WX}(i)}) \; ; \text{ reminding that for any j: } w_{w_j} = c_j . \quad (2)$$

We can remark a consequence of equation (2):

$$\nabla_{cj} Q = 0 \quad \text{for} \quad j \notin \{w1,\ldots, wp\}, \text{ i.e. only the frames of the closest reference W will be modified.} \quad (3)$$

Equation (2) means that the components $\nabla_{cj} Q$ of the gradient ∇Q are themselves the sum of gradients of the frame-to-frame distance computed on all couples (j, w_{wj}) in the best path generated while matching X to its most similar reference W.

The same method works to build a LVQ2-DP; compared to K-Means-DP, we must make two modifications. First, nothing happens when the classification is good. Second, when a classification is bad, the frames of closest reference word W are repulsed, while the frames of closest good reference V are attracted by the corresponding frames of training exemple X.

We can notice that this DP training algorithm allows to build artificial references, when it is used alone.

5.2 Global Gradient Systems integrating DP

Our two module TDNN-DP architecture can now be trained in an optimal way. Input speech is first processed sequentially by the two modules. We then compute the output error function Q (1) and back propagate the gradient through the DP module using (2), these values can then be used to compute the gradient for the weights of the TDNN module. The resulting adaptative systems are then called TDNN-K-Means-DP and TDNN-LVQ2-DP.

6 CONCLUSION

We have compared many popular methods of speech recognition on a real-size simple problem. We have tested a sub-optimal cooperation method between TDNN and other classifiers, and found that cooperation between Dynamic Programming and Time Delay Neural Network was especially efficient. We have introduced a familly of optimal algorithms, based on error back-propagation and which makes DP cooperate with K-Means, LVQ and TDNN.

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