Dynamic Barycenter Averaging Kernel in RBF Networks for Time Series Classification

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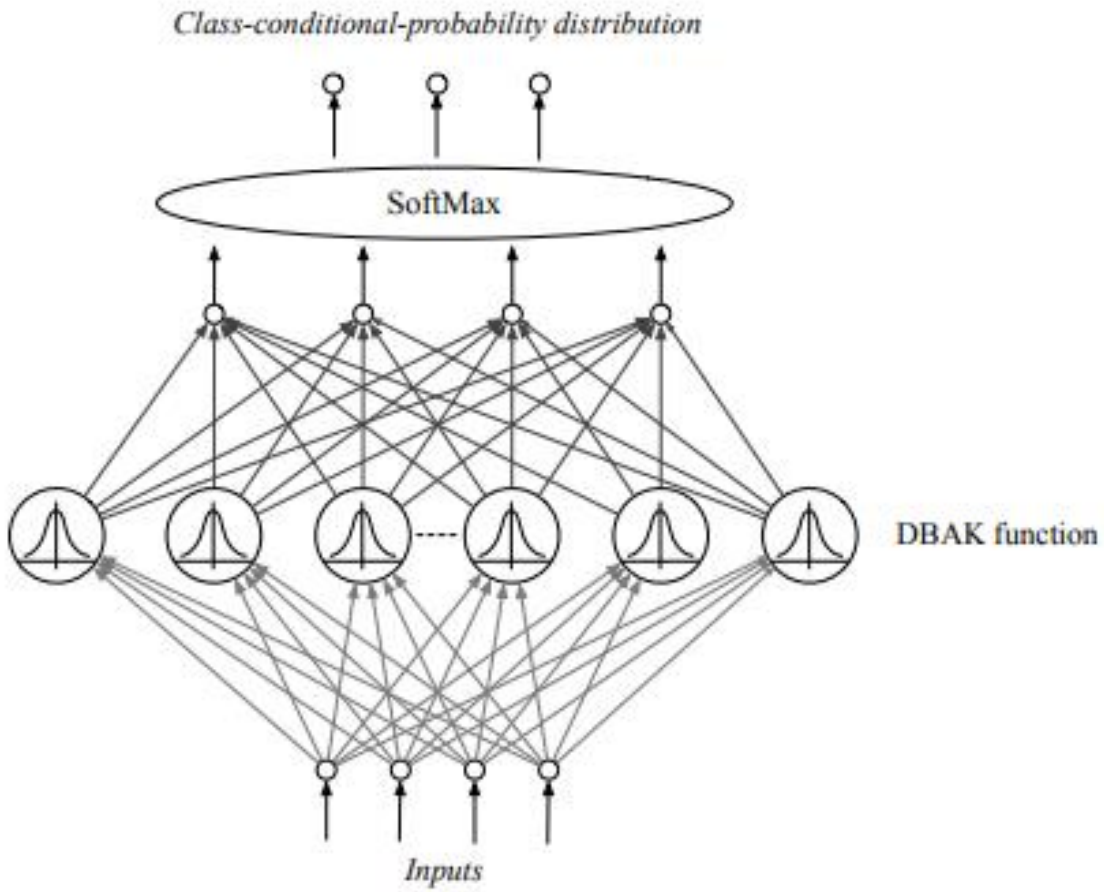
Introduction

Dynamic Barycenter Averaging Kernel Radial basis function

- First, we combine k-means clustering with a dynamic time warping (DTW) based averaging algorithm called DTW barycenter averaging (DBA) to determine the center of DBAK.
- Then, in order to facilitate the stable gradient-training process in the whole network, a normalization term is added into the kernel formulation.
- By integrating the information of the whole time warping path, our DBAK based RBF network (DBAK-RBF) performs efficiently for TSC tasks.

Method

The general structure of RBF Network with DBAK



Algorithm

Algorithm 1 DBA

Require: c the initial average sequence
Require: $\mathcal{S} = \{T_1, \cdots, T_N\}$ a set of N sequence
Require: $Maxiter$

for iter = 1 **to** Maxiter **do**
  $\hat{c}$ is a set to store aligment for each dimension for all signal in $\mathcal{S}$
  for each T in $\mathcal{S}$ **do**
    Compute DTW warping path i and j for T and c.
      //So $T(i_k)$ and $c(j_k)$ are aligned points.
    Add all aligned $T(i_k)$ to its associated subset $\hat{c}(j_k)$

      //$\hat{c}(j_k)$ is a subset of aligned points
      //$\hat{c}$ is a set of subsets.
  end for

  //Compute new average
  for each subset $\hat{c}$(j) **in** $\hat{c}$ **do**
    c(j) = barycenter($\hat{c}$(j))
  end for
end for

return c

Algorithm 2 DBAK-RBF

Require: $\mathcal{D} = \{T_1, \cdots, T_{N_D}\}$: a set of time series; $\mathcal{Y} = \{y_1, \cdots, y_{N_D}\}$ corresponding labels of $\mathcal{D}$; C: the number of kernel's centers.

1. Clustering the given data $\mathcal{D}$ by k-means;
2. Using DBA algorithm to obtain the medoid of time series in each cluster;
3. Initialize parameters $\{\sigma_p\}$, $\{w_{p,c}\}$, and $\{b_c\}$;
4. Forward-propagation

5. Back-propagation by using gradients formulated

return the centers $\{C_p\}$; the optimized width $\{\sigma_p\}$, the weights $\{w_{p,c}\}$ and the biases $\{b_c\}$.

Result

Accuracy of 13 mainstream TSC classifiers and our DBAK-RBF

DATASETS	DTW_{1NN}	DD_{DTW}	ST	LS	BOSS	TSF	TSBF	EE	Flat -COTE	HIVE -COTE	MLP	FCN	ResNet	DBAK-RBF
ArrowHead	0.703	0.789	0.737	0.846	0.834	0.726	0.754	0.811	0.811	**0.863**	0.778	0.843	0.845	0.750
Beef	0.633	0.667	0.900	0.867	0.800	0.767	0.567	0.633	0.867	**0.933**	0.720	0.697	0.753	0.767
BeetleFly	0.700	0.650	0.900	0.800	0.900	0.750	0.800	0.750	0.800	**0.950**	0.870	0.860	0.850	0.850
BirdChicken	0.750	0.850	0.800	0.800	0.950	0.800	0.900	0.800	0.900	0.850	0.775	**0.955**	0.885	0.900
Car	0.733	0.800	0.917	0.767	0.833	0.767	0.783	0.833	0.900	0.867	0.767	0.905	**0.925**	0.667
CBF	0.997	0.997	0.974	0.991	0.998	0.994	0.988	0.998	0.996	**0.999**	0.872	0.994	0.995	0.996
CinCECGtorso	0.651	0.725	0.954	0.870	0.887	0.983	0.712	0.942	0.995	**0.996**	0.840	0.824	0.826	0.675
Coffee	**1.000**	**1.000**	0.964	**1.000**	**1.000**	0.964	**1.000**	**1.000**	**1.000**	**1.000**	0.996	**1.000**	**1.000**	**1.000**
DiatomSizeReduction	0.967	0.967	0.925	0.980	0.931	0.931	0.899	0.944	0.928	0.941	0.910	0.313	0.301	**0.996**
DistalPhalanxOutlineCorrect	0.717	0.732	0.775	0.779	0.728	0.772	0.783	0.728	0.761	0.772	0.726	0.760	0.771	**0.860**
DistalPhalanxTW	0.590	0.612	0.662	0.626	0.676	0.669	0.676	0.647	0.698	0.683	0.617	0.690	0.665	**0.800**
Earthquakes	0.719	0.705	0.741	0.741	0.748	0.748	0.748	0.741	0.748	0.748	0.717	0.727	0.712	**0.835**
ECG200	0.770	0.830	0.830	0.880	0.870	0.870	0.840	0.880	0.880	0.850	**0.916**	0.889	0.874	0.880
ECGFiveDays	0.768	0.769	0.984	**1.000**	**1.000**	0.956	0.877	0.820	0.999	**1.000**	0.970	0.987	0.975	0.826
FaceFour	0.830	0.830	0.852	0.966	**1.000**	0.932	**1.000**	0.909	0.898	0.955	0.840	0.928	0.955	0.966
FacesUCR	0.905	0.904	0.906	0.939	0.957	0.883	0.867	0.945	0.942	**0.963**	0.833	0.946	0.955	0.824
Fish	0.823	0.943	**0.989**	0.960	**0.989**	0.794	0.834	0.966	0.983	**0.989**	0.848	0.958	0.979	0.829
GunPoint	0.907	0.980	**1.000**	**1.000**	**1.000**	0.973	0.987	0.993	**1.000**	**1.000**	0.927	**1.000**	0.991	0.927
Ham	0.467	0.476	0.686	0.667	0.667	0.743	**0.762**	0.571	0.648	0.667	0.691	0.718	0.757	0.714
Haptics	0.377	0.399	0.523	0.468	0.461	0.445	0.490	0.393	**0.523**	0.519	0.433	0.480	0.519	0.477
Herring	0.531	0.547	0.672	0.625	0.547	0.609	0.641	0.578	0.625	**0.688**	0.528	0.608	0.619	0.641
InlineSkate	0.384	**0.562**	0.373	0.438	0.516	0.376	0.385	0.460	0.495	0.500	0.337	0.339	0.373	0.307
ItalyPowerDemand	0.950	0.950	0.948	0.960	0.909	0.960	0.883	0.962	0.961	0.963	0.954	0.961	**0.963**	0.955
Lightning2	0.869	0.869	0.738	0.820	0.836	0.803	0.738	**0.885**	0.869	0.820	0.670	0.739	0.770	0.883

Accuracy of 13 mainstream TSC classifiers and our DBAK-RBF

Lightning7	0.726	0.671	0.726	0.795	0.685	0.753	0.726	0.767	0.808	0.740	0.630	0.827	0.845	**0.863**
Mallat	0.934	0.949	0.964	0.950	0.938	0.919	0.960	0.940	0.954	0.962	0.918	0.967	0.972	**0.982**
Meat	0.933	0.933	0.850	0.733	0.900	0.933	0.933	0.933	0.917	0.933	0.897	0.853	**0.968**	0.933
MiddlePhalanxOutlineCorrect	0.698	0.732	0.794	0.780	0.780	0.828	0.814	0.784	0.804	**0.832**	0.770	0.801	0.809	0.683
MiddlePhalanxTW	0.506	0.487	0.519	0.506	0.545	0.565	0.597	0.513	0.571	0.571	0.534	0.512	0.484	**0.647**
MoteStrain	0.835	0.833	0.897	0.883	0.879	0.869	0.903	0.883	**0.937**	0.933	0.858	**0.937**	0.928	0.890
OliveOil	0.833	0.833	0.900	0.167	0.867	0.867	0.833	0.867	0.900	0.900	0.667	0.723	0.830	**0.933**
OSULeaf	0.591	0.880	0.967	0.777	0.955	0.583	0.760	0.806	0.967	**0.979**	0.557	0.977	**0.979**	0.607
Plane	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	0.978	**1.000**	**1.000**	**1.000**
ShapeletSim	0.650	0.611	0.956	0.950	**1.000**	0.478	0.961	0.817	0.961	**1.000**	0.503	0.724	0.779	0.672
SonyAIBORobotSurface1	0.725	0.742	0.844	0.810	0.632	0.787	0.795	0.704	0.845	0.765	0.672	**0.960**	0.958	0.933
SonyAIBORobotSurface2	0.831	0.892	0.934	0.875	0.859	0.810	0.778	0.878	0.952	0.928	0.834	**0.979**	0.978	0.845
Symbols	0.950	0.953	0.882	0.932	0.967	0.915	0.946	0.960	0.964	0.974	0.832	0.955	0.906	**0.975**
ToeSegmentation1	0.772	0.807	0.965	0.934	0.939	0.741	0.781	0.829	0.974	**0.982**	0.583	0.961	0.963	0.943
ToeSegmentation2	0.838	0.746	0.908	0.915	0.962	0.815	0.800	0.892	0.915	**0.954**	0.745	0.880	0.906	0.907
Trace	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	0.990	0.980	0.990	**1.000**	**1.000**	0.807	**1.000**	**1.000**	**1.000**
TwoPatterns	**1.000**	**1.000**	0.955	0.993	0.993	0.991	0.976	**1.000**	**1.000**	**1.000**	0.946	0.871	**1.000**	0.997
Wine	0.574	0.574	0.796	0.500	0.741	0.630	0.611	0.574	0.648	0.778	0.565	0.587	0.744	**0.907**
Worms	0.584	0.584	0.740	0.610	0.558	0.610	0.688	0.662	0.623	0.558	0.457	0.765	**0.791**	0.624
WormsTwoClass	0.623	0.649	**0.831**	0.727	**0.831**	0.623	0.753	0.688	0.805	0.779	0.601	0.726	0.747	0.735
Avg.Rank	10.784	9.534	6.841	7.398	6.375	9.045	8.000	7.739	4.909	**4.045**	11.523	6.568	5.943	6.295
p-value	0.000	0.006	0.754	0.628	0.655	0.003	0.142	0.273	0.230	0.138	0.000	0.791	0.253	-
cor-p-value	0.000	0.060	1.965	2.512	2.512	0.033	1.242	1.518	1.610	1.242	0.000	1.508	1.610	-

Conclusion

The performance of DBAK-RBF and RBF with different number of centers