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The Radial Wavelet Frame Density Estimator[1]

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Abstract

The estimation of probability densities is one of the fundamental problems in scientific research. It has been shown that Wavelet Density Estimators, which are a well-documented nonparametric approach, outperform other nonparametric estimators in problems involving densities with discontinuities and local features. However, the use of this type of estimators is not widely extended in the scientific community mainly because of their heavy computational complexity and their difficult algorithmic implementation. A novel multidimensional Wavelet Density Estimator approach based on new multidimensional scaling functions with analytic closed-form expressions is proposed. The key advantages of the proposed estimator are its simpler multidimensional algorithmic implementation and its significant reduction in computational complexity. Algorithmic formulations for four different data analysis scenarios are presented: (1) batch processing of input data, (2) online estimation for stationary process, (3) online estimation for non-stationary contexts and (4) batch estimation of high-dimensional data. The assessment results show that the proposed approach reduces the computational time of the estimation process while maintaining competitive estimation errors.

Keywords: Density Estimation, Wavelet Density Estimators, Radial Wavelet Frame Density Estimator, Multidimensional Density Estimation, Online Density Estimation, Data Streams Analysis.

1. Introduction

The estimation of probability densities, which has been thoroughly studied in the literature, is one of the fundamental problems in statistics and a key building block in many facets of scientific research (Scott, 2015). While histograms, Kernel Density Estimators (KDE) and Finite Gaussian Mixtures are the most popular non-parametric density estimation methods, Orthogonal Series Estimators (Céncov, 1962), that encompass a set methods based on the idea that a given density can be expressed as a convergent series of orthogonal basis functions, are rarely applied. The main reason for this is their inability to estimate local properties of the underlying density (Vannucci, 1995). This drawback is solved with Wavelet Density Estimators (WDEs), which are a type of Orthogonal Series Estimator intensively investigated in the literature, that offer more flexibility in terms of convergence, approximation of local features and smoothness. In general, wavelet-based estimators are superior to other orthogonal estimators since they inherit the advantages of wavelets and multiresolution analysis (Safavi et al., 2004).

The seminal works in the context of WDEs can be traced back to the study of density estimation in Besov spaces presented in Kerkyacharian and Picard (1992) and the investigation of the approximation of delta functions using wavelets reported in Walter (1992). Multidimensional extensions for this type of estimators, which can be constructed using tensor products of one-dimensional wavelets, have been investigated by Walter (1995) and Vannucci (1995). Some authors have explored the improvements in the approximation properties of WDEs that can be obtained by applying thresholding or shrinkage strategies to wavelet coefficients. Relevant work regarding this approach is the

[1]Supplementary material related to this article, including the R code for all the proposed algorithms, can be found in the online version of the paper as well as in https://doi.org/10.5281/zenodo.1400850

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