Wavelet Transform in De-noising Geophysical Data

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Abstract: - Shallow depth geophysical data from archaeological sites contain various levels and types of noise that hinters the valuable information of the subsurface architectural relics. Wavelet transform techniques were tested as a method for decomposition of the original geophysical data in order to eliminate the noise levels inherent to the geophysical measurements. In addition to the above, unsupervised classification techniques were employed for the final fusion of different datasets, originating from various survey or processing procedures. The resulting images were able to enhance the subsurface targets, eliminating the noise levels and exploiting fully the properties of the geophysical techniques used.

Key-Words: - wavelets, classification, fusion, geophysical prospection, archaeological data, Sikyon, Greece.

1. Introduction

Geophysical methods offer great insights about the subsurface of the archaeological sites because each one can yield information about relatively different aspects of the subsurface. The image constructed from these data, through different graphics and processing techniques, makes it easier to detect the location of a monument and visualize its extent within the subsurface. However, the interpretation of the geophysical data is a difficult task as they are masked by cultural noise originating by either the diachronic usage of the landscape or the modern agricultural or the construction activities in an area of cultural interest. As a result of the above processes, the image resulting by the interpolation of the geophysical measurements is often of poor quality, containing high percentages of random or systematic noise which hinder the valuable information related to the subsurface targets. Therefore, the suppression of the noise levels and the enhancement of the signals carrying the useful information is an important process in any processing approach.

In denoising, traditional spatial filters can usually smooth the data and reduce the noise, but at the same time they blur the data to some extent [1]. More recently, new denoising techniques, such as wavelet-based approaches [2], non-negative sparse coding (NNSC) shrinkage techniques [3], principal components analysis (PCA) [4] and sparse coding (SC) shrinkage [5], are explored and applied to a variety of measurements in various fields, such as astrophysics, geophysics, medical signal analysis, a.o. These methods have been proven to have a relatively successful impact in denoising images by using different skills and strategies. More recently, Tsivouraki and Tsokas [6] investigated a wavelet denoising scheme for magnetic archaeological prospecting data.

The noise in geophysical data usually has high frequency content, a random distribution and characteristic frequencies depending on the causing sources. Sometimes, the noise from the micro relief of the ground surface is coherent and pseudorandom and thus can be separated from other sources of noise [7]. Still, denoising just by conventional filtering is difficult without affecting the signal's sharp variations and even harder to separate the different components of noise in the signals. Because of that, denoising and fusion processes in wavelet domain was employed in an experimental basis to enhance geophysical data obtained from shallow depth surveys of archaeological sites.

In this paper, all of the geophysical data, originating from different types of measurements (resistivity tomography, resistivity, magnetics, a.o.), were pre-processed by calculating the different directional derivatives and constructing the corresponding image in Surfer 8.0. Similarly, the original images were classified utilizing an ISODATA unsupervised classification within ERDAS software package. Then, the discrete wavelet transformation was used for denoising purposes and fusing the different datasets to separate the noise levels from the useful signal.

2. Wavelets

The wavelet transformation is a practical signal analysis tool having application in a variety of scientific and engineering areas including Geophysics. Wavelets are mathematical functions with special properties that enable processing and analysis of data distributions at different resolutions at the same time. The main properties of the wavelets include the ability to concentrate the energy of a smooth signal in a few wavelet coefficients while at the same time the transformation of white noise still has the attributes of white noise [8, 9]. Therefore, it is reasonable to assume that small coefficients represent the noise and can be set to zero, while the large ones contain the signal's energy and should be kept for further processing. Moreover, the decomposition and reconstruction of wavelets makes possible an efficient fusion of different signals by calculating the low frequency approximations of these signals. The former in combination to the reconstruction with the high frequency detailed signals can lead to a reduction or minimization of the noise levels. The wavelet transform is a linear transform and as such, wavelet algorithms are faster and more efficient than conventional algorithms. On the other hand, the performance of the method is affected by the choice of the wavelet functions. There are no unique denoising and fusion recipes covering all data types, especially the wide range and complicated nature of geophysical data. Each data type needs an empirical selection of the proper combination of the above mentioned filters.

3. The Archaeological Site of Sikyon and Geophysical Approaches

The Sikyon survey project was initiated in 2004 consisting of different research modules, including surface surveys and geophysical prospection techniques. The project is carried out under the collaboration of the University of Thessaly, the Institute for Mediterranean Studies – FORTH and the 37th Ephoreia of Prehistoric and Classical Antiquities of Corinth, with the participation of the American School of Classical Studies and the Universities of Cambridge and York. During the last three years of investigations, various sections of the site focusing in the area of the ancient Agora have been surveyed through a multi-component geophysical approach. The ancient Agora is located to the south of the Roman Baths and contains a number of monumental architectural structures, such as the Bouleuterion, the Gymnasium, the temple of Artemis Limnaia and a large Stoa structure limiting the Agora to the South (Fig. 1). Most of the structural remains of the site span from the Classical-Hellenistic period to the Byzantine times.

Fig. 1. The wider region of the Agora of ancient Sikyon. The map indicates the main architectural relics of the site, most of which were excavated in the past, but remain still under the current surface of the ground.

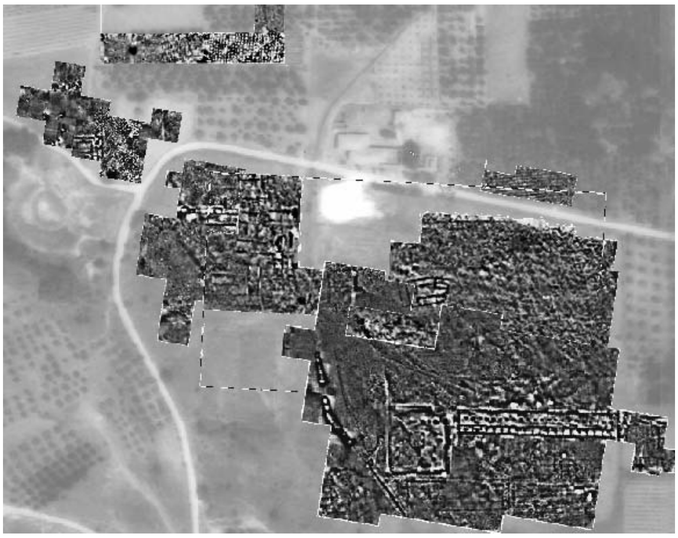

Fig. 2. The integrated results of the magnetic survey in the area of Sikyon. Magnetic data were collected through 3 different seasons employing a Bardington GRAD 601 and a Geoscan Research FM256 fluxgate gradiometer, using a 0.5m sampling strategy.

Until today, more than 50,000m^2 of the wider region of the Agora have been covered through magnetic (Fig. 2), resistivity, resistivity tomography and ground penetrating radar (GPR) techniques. Resistivity surveying was carried out with multiplexer instrumentation allowing the mapping of different depths. Furthermore, electrical resistivity tomography (ERT) and GPR techniques provided detailed information of specific sections of the site through different depth layers, allowing a 3D reconstruction of the subsurface relics. The specific experiments were carried out systematically above a three-aisled basilica, which was located to the south of the temple of Artemis Limnaia. ERT measurements were conducted with SYSCAL Pro and multiplexer along 28 parallel profiles, 1m apart, using the Dipole-Dipole electrode configuration. A 450MHz antenna and an EKKO 1000 GPR unit were employed to obtain stratigraphic information along 55 parallel transects, 0.5m apart, above the region of basilica. Horizontal slices were created for different depths allowing the 3D mapping of the basilica ruins, which are suggested to extend at a depth less than 150-160cm below the current surface of the ground. In the particular paper, two slices of the electrical tomography data were used, corresponding to depths of 0.35-0.75m (ERT2) and 0.75-1.22m (ERT3) respectively.

4. Data Processing

Interpolation algorithms were employed in order to create maps of the corresponding geophysical data using Surfer 8.0. The images were further processed through the calculation of the first directional derivatives for directions of 30^0, 45^0 and 90^0. Some of the original data images and directional derivative images are illustrated in Figure 3.

The above images collectively indicate aspects of the study area. The signals are corrupted with normal white noise with different standard deviation. The signal to noise ratio (SNR) is within the range of 12 to 14. To extract the useful signal from the particular images, the wavelet method was firstly used for denoising the resistivity and magnetic data and their corresponding first directional derivatives. Then, the original denoised images were fused with their corresponding directional derivatives by using wavelet decomposition and reconstruction functions. Different combinations of the original data with their directional derivatives were tried: The popular sym4 wavelet basis was employed first to decompose the original data images and their directional derivatives. The sub-image, composed of the low frequency components, is called an approximated image. The remaining images, containing high frequency components, are termed detail images. The original images were fused with the directional derivative images through simple map algebra computations (addition or subtraction of images) of their approximated images originating from wavelet decomposition. The new image was created by reconstructing the above result (computed sum or difference) with the detail image from either the original images or directional derivatives. All possible combinations of the original resistivity and magnetic images with their directional derivative images in 30^0, 45^0 and 90^0 were tested using the same wavelet basis sym4, together with other wavelet functions such as Db1, Db2, Db4. The results suggest that the fusion by subtracting the approximated image of directional derivative image of 90^0 from that of the original magnetic image and then reconstructing with the detail image of original magnetic image can better preserve the characteristics of the signal and reduce the noise at the same time (Figure 4). The rest of the geophysical data were also processed by performing the same denoising and fusion approaches, the outcome of which offers new and complementary information of the study area.

Successful geophysical interpretations of cultural features rely on expertise in the local archaeology and knowledge of corresponding archaeological signatures in geophysical data, based on a combination of subjective insights and deductive reasoning. In an effort to acquire detail information of the archaeological site from the geophysical data, the corresponding images were classified using ISODATA unsupervised classification techniques. The performance of unsupervised classification was evaluated based on a fixed classification scheme (six different classes) for each one of the geophysical datasets (Fig..5). The classified images presented the geophysical information clustered within different ranges that can be used for visualization purposes.

The wavelet method was also used for fusing the denoised geophysical data with the corresponding classified images. The wavelet basic function used was still Sym4 and fusion method was LR_fusion in approximation and Max in detail parts respectively. Furthermore, the resistivity and magnetic data were integrated by fusing the classified resistivity image with the denoised magnetic image and the classified magnetic image with the denoised resistivity image (Figure 6).

Figures 4 and 6 suggest that more detail information is available after the fusion of the classified image with the denoised image of ERT data, whereas the integration of magnetic and resisitivity data via wavelet fusion made the outline of the structural remains more clearly defined. The suppression of small noisy artifacts is obvious.

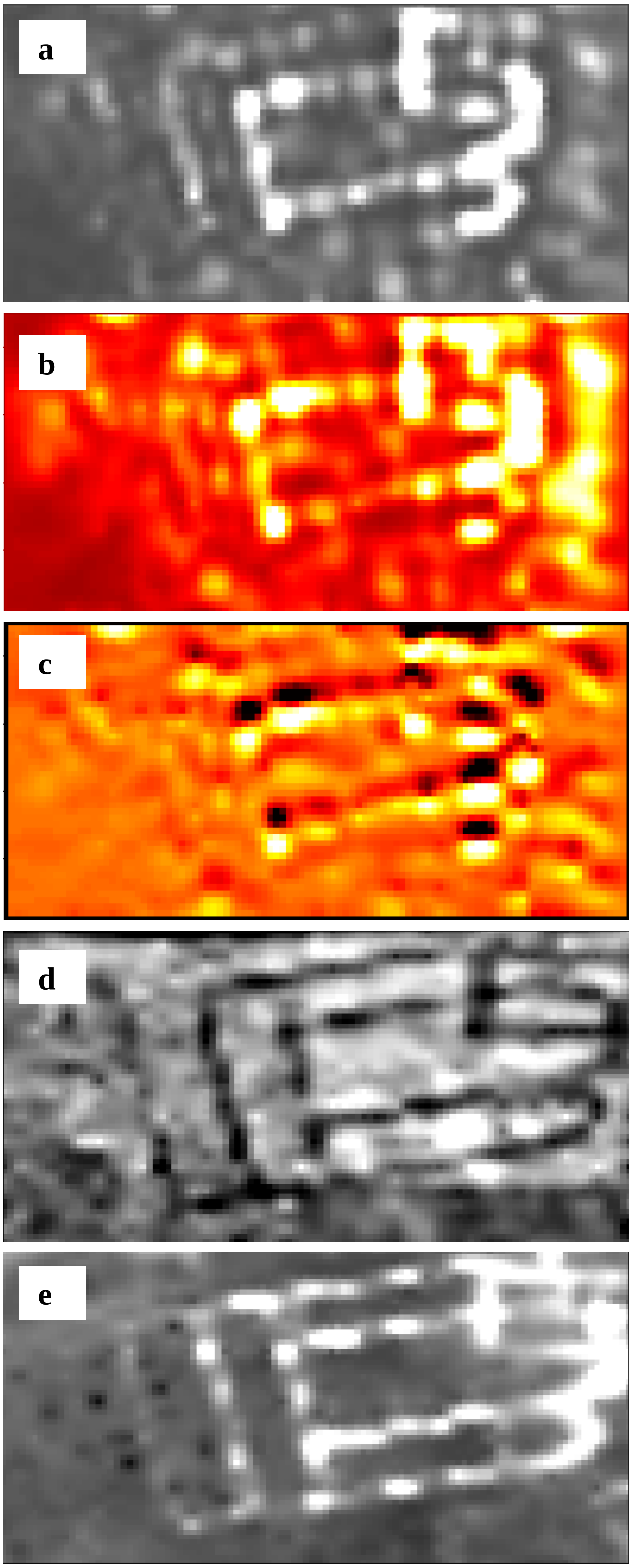

Fig. 3. Original datasets, consisting of a) ERT 2, b) ERT 3, c) ERT 3 directional derivatives at 90^0, d) magnetics and e) resistivity measurements.

The quality of the denoised images was evaluated through the computation of the normalized mean squared error (MSE), which is defined as follows [10]:

$$MSE_n = \frac{\sum_{i=1}^{N}\sum_{J=1}^{M}(X_{ij} - \bar{X}_{IJ})^2}{\sum_{i=1}^{N}\sum_{j=1}^{M}(X_{ij})^2} \qquad (1)$$

Where, parameters M and N denote the original image's size, X and $\bar{X}$ denote respectively the input data set and its mean matrix. Using Equation (1) the calculated MSE_n of ERT2, ERT3, magnetic and resistivity images are 0.31, 0.42, 0.24 and 0.23 respectively.

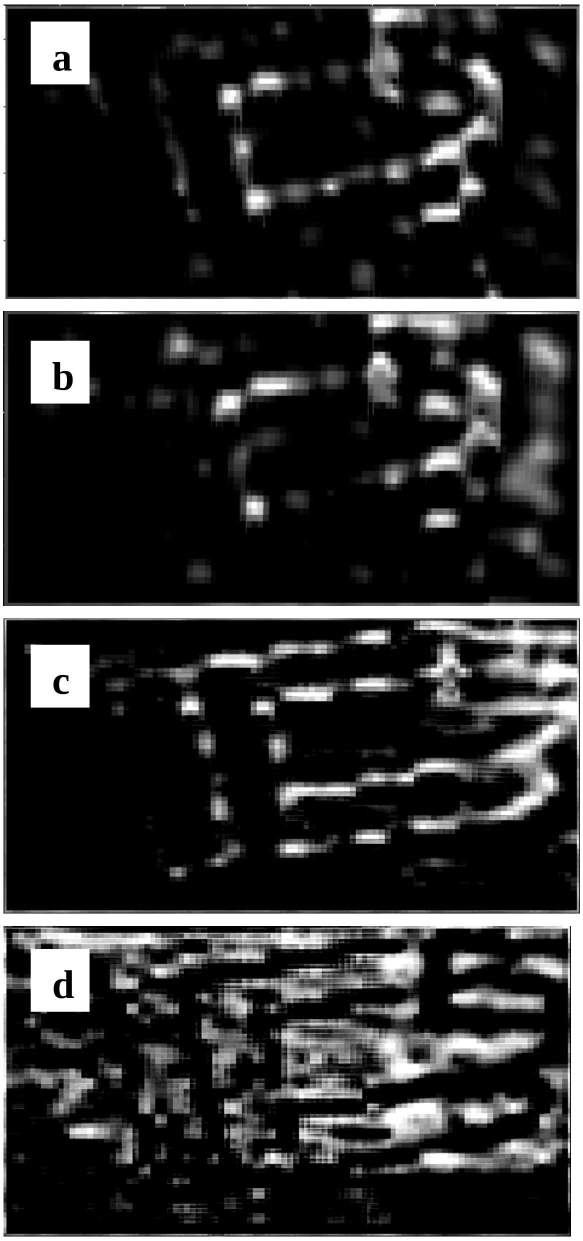

Fig. 4. Denoised images by fusing the original data with the directional derivative image of 90^0: a) ERT2, b) ERT3, c) resistivity, d) magnetics

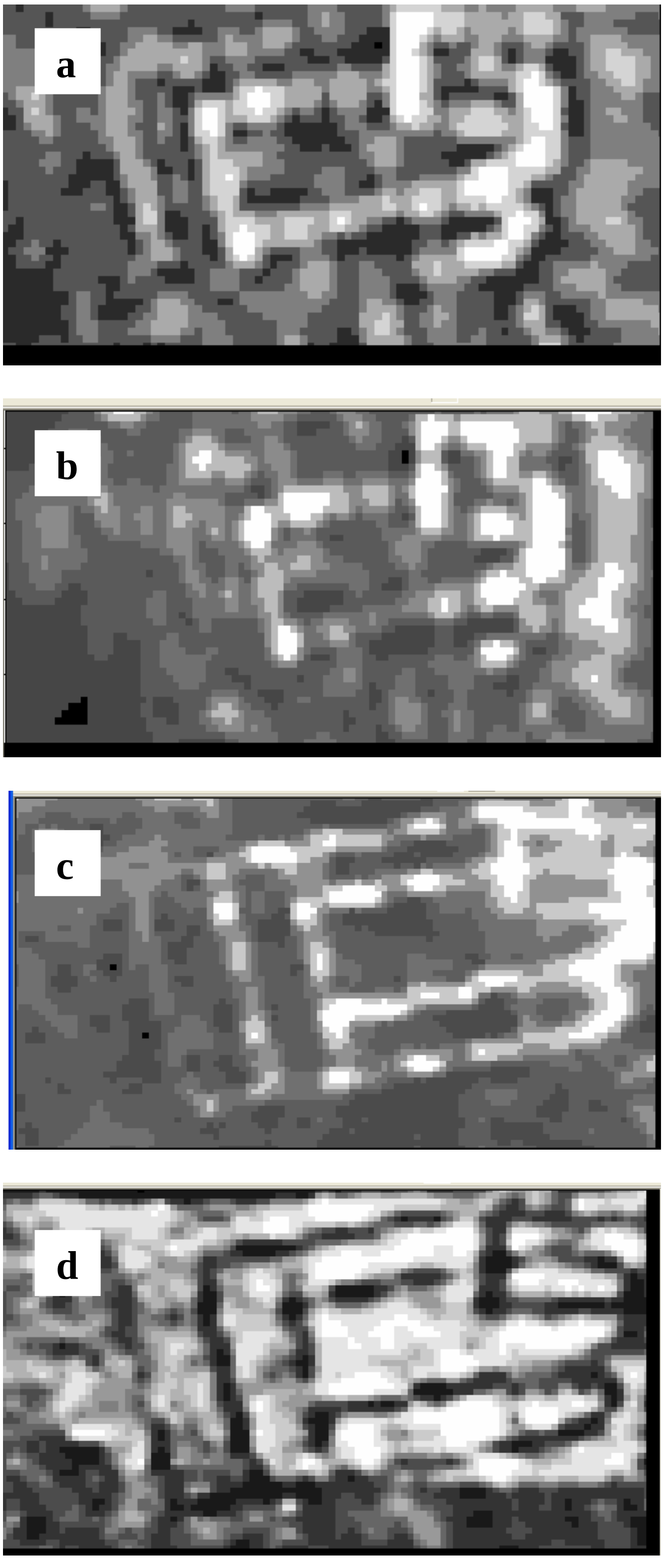

Fig. 5. Classified datasets, consisting of a) ERT 2, b) ERT 3, c) resistivity and d) magnetics.

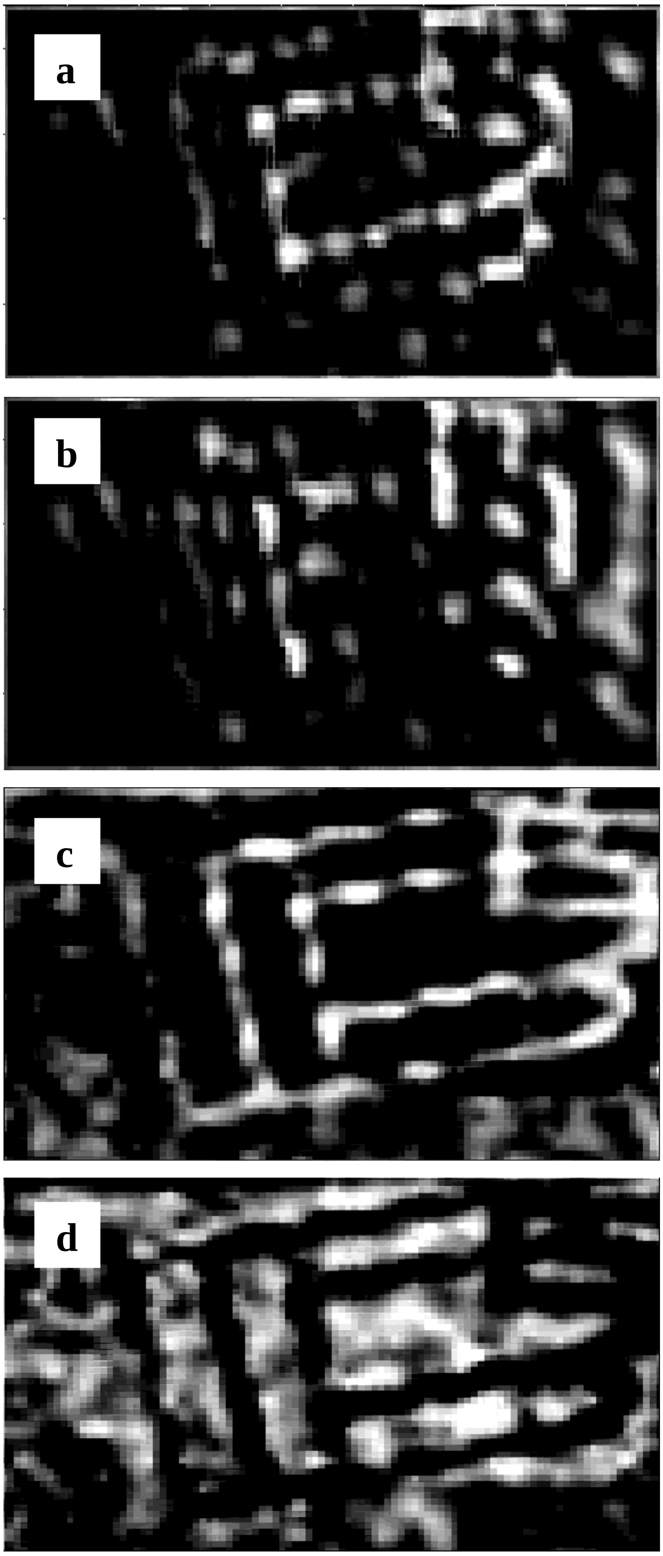

Fig. 6. Processing results. a) ERT2, b) ERT3, c) integration by fusing classified resistivity image with the denoised magnetic image, d) integration by fusing classified magnetic image with the denoised resistivity image.

5. Discussion & Conclusions

According to the experimental results, it can be suggested that the denoising method combining the wavelet transform with image classification is of practical use in outlining shallow depth geophysical targets. Integrating multiple geophysical data sets offers large potential for improving our understanding of the subsurface. Moreover, integrated data may simultaneously show relationships between the conductive, magnetic and electromagnetic properties of the underground targets, improving our knowledge of the features, exploiting multiple sensor attributes and enhancing overall interpretation. The advantage of the method is based on the fact that the wavelet decomposition, reconstruction and image classification as an intermediate step of processing, retains the useful information within both spatial and spectral domains. It exploits fully the information context of multiple geophysical datasets and provides a significant suppression of the white noise and the coherent one caused by the systematic undulations of the ground surface. Image processing with wavelet transform was easily implemented and performed in Matlab. The suitable mother wavelet has to be chosen at the onset of the procedure, which is based to the user's experience and level of training with the process. Further evaluation of the above process is under way and is based on different datasets from various archaeological sites that contain targets of different attributes (dimensions, depth extent, a.o.).

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