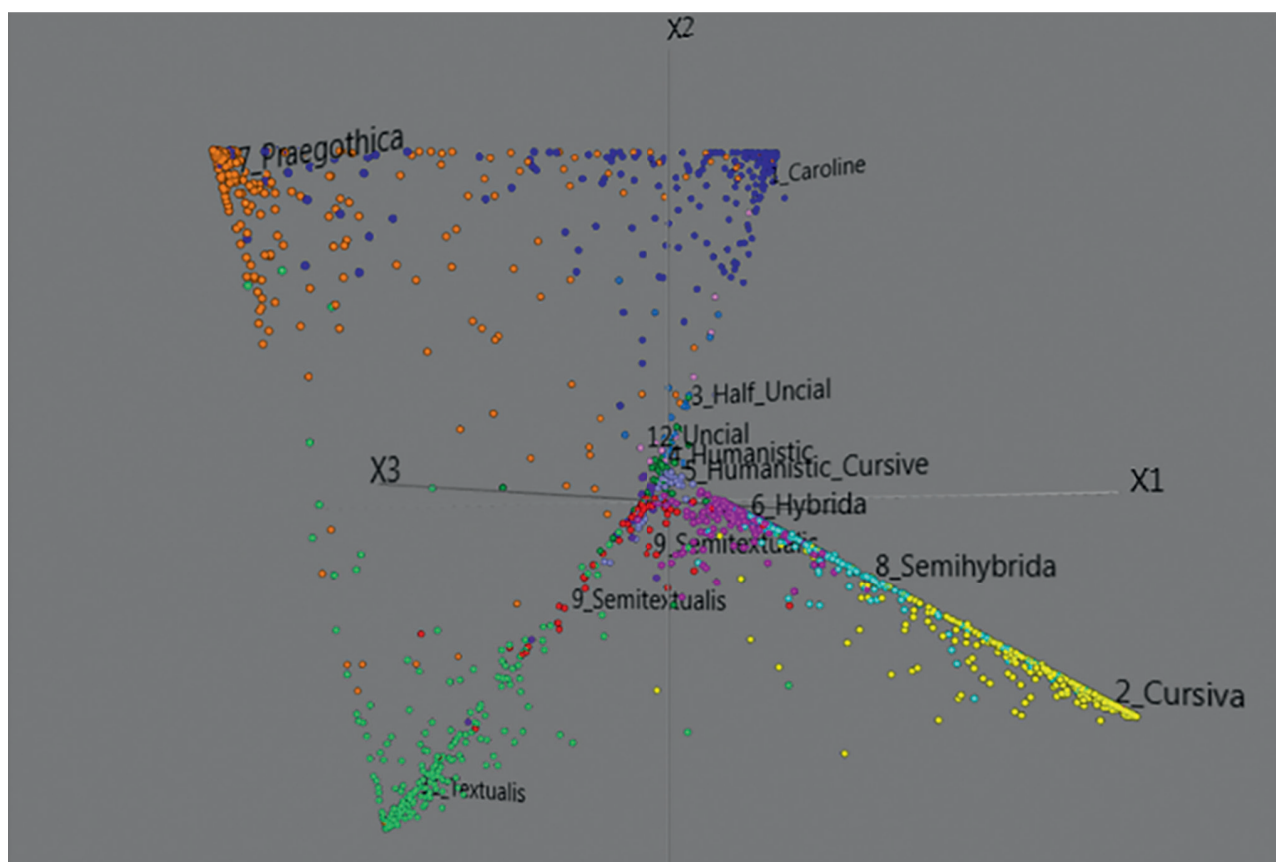


# manuscript cultures

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**Article**

# On Avoiding Segmentation in Handwritten Keyword Spotting: Overview and Perspectives

**Marçal Rusiñol | Barcelona**

## Abstract

In this paper we focus on the problem of handwritten keyword spotting when we want to avoid a layout segmentation step. We strongly believe that bypassing the segmentation step is a must in the context of historical document collections where achieving a perfect word or text line segmentation is unfeasible. So, architectures that dismiss the segmentation step are a clear asset in the context of historical documents. We will provide an overview of the various state-of-the-art approaches and conclude by discussing the promising results in the field and the remaining challenges.

## 1. Introduction

Nowadays, in order to provide access to the contents of digital document collections, their textual contents are stored in electronic format so that any search engine is able to index the data corpus and users are able to perform textual searches. When dealing with large collections, automatic transcription processes are used, since manual transcription is not a feasible solution. In the context of digital collections of historical manuscripts, handwriting recognition strategies are applied to achieve an automatic transcription of the handwritten text. However, handwriting recognition often does not perform satisfactorily enough in the context of historical documents. Documents with severe degradations or using ancient glyphs can make recognizing individual characters difficult, and the lexicon definition and language modelling steps are not straightforwardly solved in such a context. In such a scenario, the particular application of handwritten keyword spotting gained attention.

Handwritten keyword spotting is defined as the pattern recognition task aimed at locating and retrieving, from a collection of manuscript images, a particular keyword requested by the user, without explicitly transcribing the whole corpus or having the text in electronic format at hand. Such an application is thus particularly interesting in scenarios in which an automatic text transcription is deemed

likely to fail by resulting in too many errors and when budget restrictions make manual transcription of the corpus' contents unfeasible.

In fact, the term *keyword spotting* was not coined in the context of historical manuscripts, but first appeared in the speech analysis community in the early seventies (Vintsyuk 1971). For its purposes, the application focused on locating the timestamps in audio signals in which a specific keyword might be uttered. Today, such technology is used by personal digital assistants such as Alexa, Siri, and Google's Home device, but, of course, national security agencies have employed keyword spotting systems to search through hours and hours of recorded conversations and isolate utterances of suspicious keywords.

In the early nineties, some preliminary works that used the term spotting in document images appeared, for instance the papers by Chen et al. 1993 and by Kuo and Agazzi 1994. Those works focused on dealing with typewritten text. At that time, however, the performance of OCR engines was already starting to be good enough to be used reliably. So, the only interest in using spotting techniques instead of recognition pipelines was computational efficiency. But, in the mid-nineties, Manmatha et al. (1996 and 1997) and Keaton et al. (1997) first used the term in the context of handwritten document images. Here, the recognition approaches were far from successful, and there was strong motivation to use spotting techniques. It was clearly an exciting research line that might have an important cultural impact. Handwritten keyword spotting systems will provide accessibility to tons of digitized manuscripts that were previously doomed to stay locked in vaults.

## 2. The conventional pipeline

From those early works until the end of the first decade of the 2000s, all the proposed approaches followed the same pipeline. First, a layout analysis step was needed to

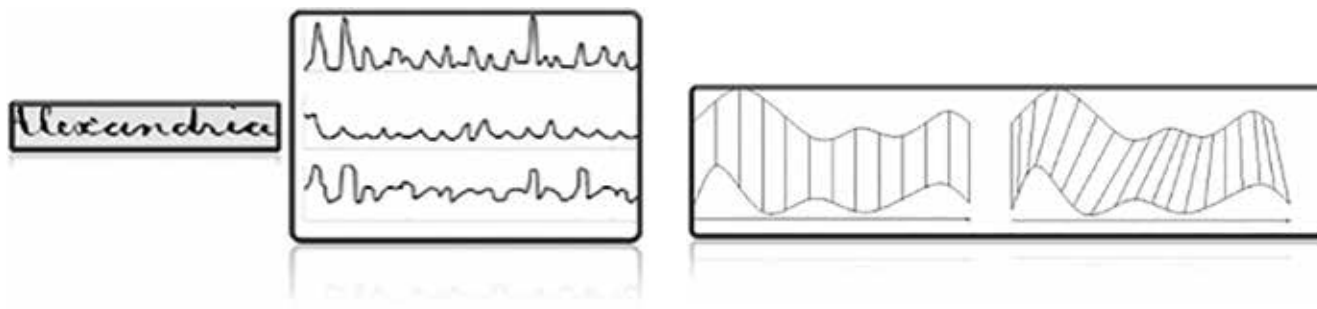


Fig. 1: Projection profiles and DTW for matching individual words, presented in 2007 by Rath and Manmatha.

segment the document pages into physical elements such as paragraphs, text lines or words. At that time, most of the approaches worked at the level of the word. In a second stage, a descriptor was computed for each of the already segmented words. Such a descriptor encoded the word's shape. Finally, when the system's user made a query, giving an example of the keyword he was looking for, a distance between the query descriptor and all the descriptors from the dataset was computed to yield the final ranked list.

This pipeline presents several drawbacks. On the one hand, the segmentation step is not always straightforward and is usually error-prone. In fact, although word and text line segmentation is a quite mature research topic, it is far from being a solved problem in critical scenarios dealing with handwritten text and highly degraded documents. Any segmentation errors will affect the subsequent word representations and matching steps. On the other hand, working with the query-by-example paradigm forces the user to already browse the document pages searching for an instance of the keyword he wants to query. Finally, such an approach is hardly scalable to large collections, because, at the retrieval stage, one has to compute the distances between the query and all the words in the collection.

The team of Rath, Manmatha et al. continued to work on the idea of handwritten keyword spotting, specifically on the manuscript letters of George Washington (Rath, Manmatha et al. 2002). But it was the seminal work by Kolcz et al. (2000) that achieved a breakthrough in the handwritten keyword-spotting domain by proposing the use of the Dynamic Time Warping (DTW) method (often used in speech analysis) for nonlinear sequence alignment. The use of DTW together with profile features was later popularized by the well-known works by Rath and Manmatha (2003 and 2007), and many flavours of DTW-based handwritten keyword spotting methods have appeared since their publications. However, the use of DTW-based solutions was

extremely computationally demanding, and thus many other authors devoted their efforts to proposing less-demanding feature-vector representations and matching schemes, for instance, the binary representation proposed by Zhang et al. in 2003.

In this paper, we will focus on the segmentation issue, provide an overview of the various state-of-the-art approaches, and conclude by discussing the promising results in the field and the remaining challenges.

### 3. First attempts at producing segmentation-free systems

Dependence on good word segmentation motivated the researchers of the keyword-spotting domain to move recently towards completely segmentation-free methods. One of the first groups of researchers to approach this problem, Leydier et al., in 2005, 2007 and 2009, proposed a keyword spotting methodology based on local keypoints. For a given query image, interest points were extracted and encoded by a simple descriptor based on gradient information. The keyword spotting was then performed by trying to locate zones in the document images with similar interest points. These retrieved zones were then filtered and only the ones sharing the same spatial configuration as the query model were returned.

The same idea was also used early by Rothfeder et al. in 2003 using corner features, and by Rusiñol and Lladós in



Fig. 2: Matching local features from handwritten words, from the work by Rothfeder et al. 2003.

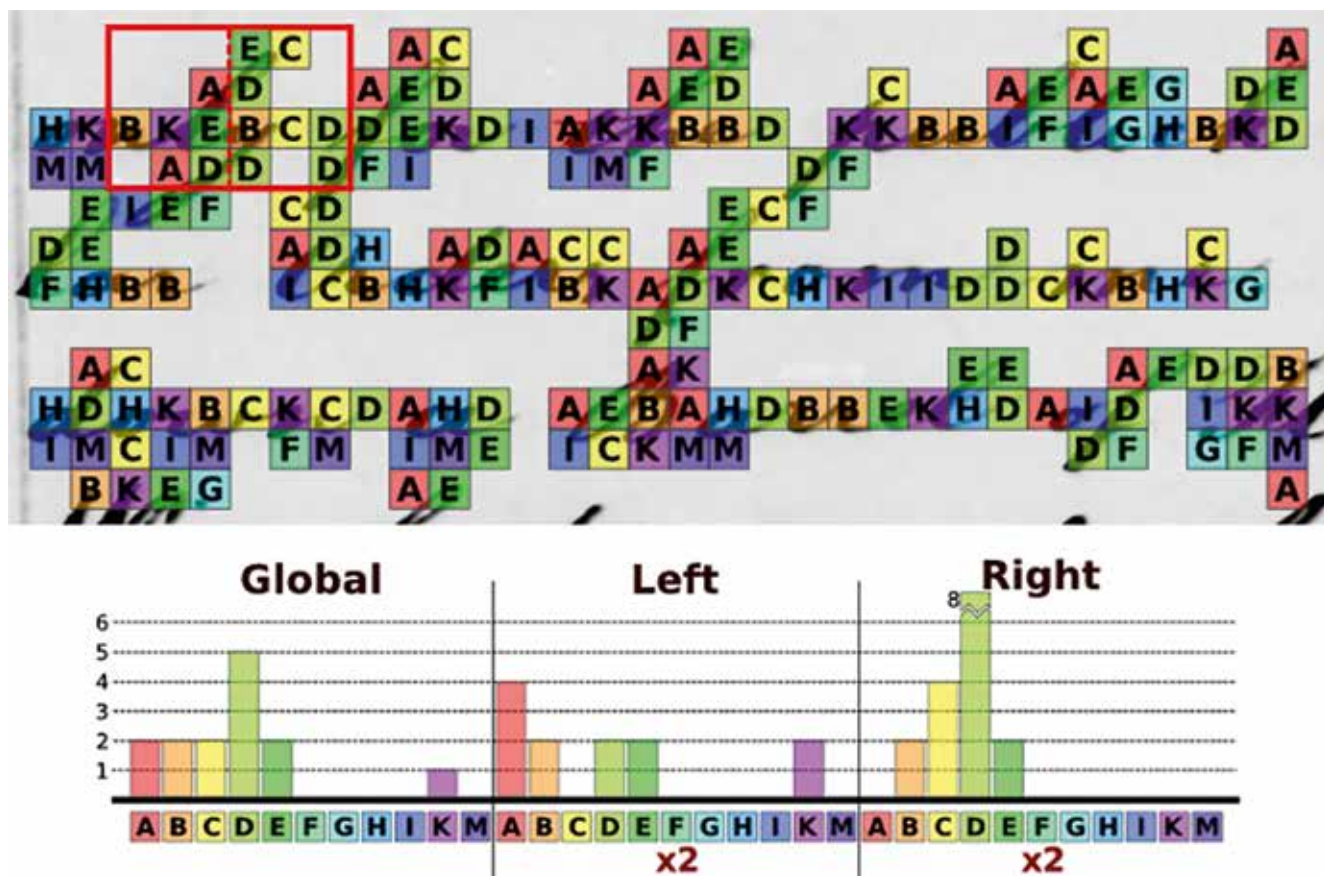


Fig. 3: Sliding window approach over a bag of visual words from Rusiñol et al. 2015.

2008 as well as by Zhang et al. in 2013 using well-known local descriptors such as SIFT or shape context to spot handwritten text.

However, directly matching local keypoints might be too computationally expensive when dealing with large datasets. A single page would easily yield tens of thousands of local descriptors that have to be matched with the query keyword snippet. Even though indexing and approximate-nearest-neighbours algorithms can help to deal with billions of such distances, it is clear that such approaches do not scale well. Thus, researchers started to apply other approaches, inspired by the latest developments in computer vision for problems such like facial and traffic sign recognition.

#### 4. Sliding window methods

The term segmentation-free handwritten keyword spotting started to gain momentum around 2010 with the appearance of methods that used sliding window approaches over bag-of-visual-words (BoVW) descriptions. Usually, local shape features are computed densely over the whole page, and later a sliding window with a fixed geometry defines the different

patches where such local descriptors are to be aggregated. The zones where the sliding window overlaps with the queried word should have a slightly more similar description than the perfectly segmented word. Examples of such an approach to handwritten keyword spotting include the works by Rusiñol et al. in 2011 and 2015, which used SIFT-powered BoVW descriptors over sliding windows; by Rothacker et al. in 2013, 2014 and 2015, which proposed to compute a HMM that sequentially analysed BoVW features; by Almazán et al. in 2014, which used a sliding window-approach based on HOG descriptors; by Ghosh and Valveny in 2015, which used a sliding window over Fisher Vector descriptors; and by Ghorbel et al., who proposed in 2015 the use of Haar-like features like those used for facial recognition in commodity cameras.

Such methods had an important advantage over the methods that tried to directly match local descriptors. By holistically describing image regions, the process of matching was drastically consolidated. The contents of the sliding windows were encoded with powerfully performant descriptors at that time, and, when combined with quantization and indexing schemes, the methods did scale up and were able to tackle large collections.

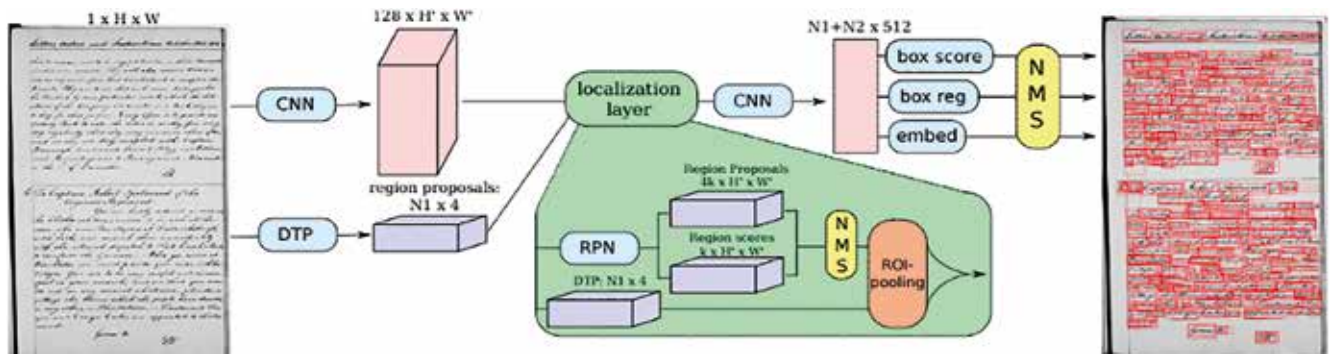


Fig. 4: End-to-end deep learning architecture for proposing and spotting word locations, by Wilkinson et al. 2017.

One might argue that using a sliding window *is* in fact some sort of very naïve word segmentation. Indeed it is, but the strength of such methods was that they were already engineered and designed from this point of view, and thus they assumed from the start that the word segmentation that they would have to process was inherently noisy.

Though in the first such proposed methods we saw that sliding windows struggled with either very long or very short words, the subsequent approaches, which either used multi-scale sliding windows (Rusiñol et al. 2015) or worked directly on an over-segmentation of the pages (Kovalchuk et al. 2014), started to be powerfully performant in such aspects.

At that point, the document image community started to address yet another important aspect that had scarcely been addressed before: performing queries by inputting typewritten electronic text, instead of querying the system by example. To deal with this problem, completely unsupervised methods were no longer fruitful, and the community started to use methods based on machine learning. At that time, deep learning re-emerged with the appearance of AlexNet, which competed in the ImageNet Large Scale Visual Recognition Challenge in 2012. The network achieved an error rate of 15%, almost 11 percentage points lower than that of the runner-up. The document image analysis community started to shift to methods based on deep learning, as well.

### 5. Methods based on Deep Learning

Like in other computer vision applications, the use of deep learning approaches completely superseded previous methods, notoriously improving retrieval performances on standard public datasets. Although most of the contributions in the literature still focus on segmentation-based pipelines, some works like the ones proposed by Rothacker et al. in 2017, Wilkinson et al. in 2017 and Ghosh and Valveny in 2017 have started to tackle the segmentation-free scenario.

In such cases, either a neural network is trained to provide likely locations to find words – which, again, the punctilious reader might argue *is not* strictly speaking segmentation-free. Or the systems are trained end-to-end and are able to provide directly the locations of good examples of the words that the user has queried.

But, even though the results of methods based on deep learning are amazingly good, there is no such thing as a free lunch. Such methods *do* need a significant amount of annotated data to be trained properly. Even though researchers have started to apply synthetic text and data augmentation strategies (Krishnan and Jawahar 2016), they still need a significant amount of real data to fine-tune the system. This need for annotated data might be a strong deterrent to using such methods in real archival environments.

### 6. Discussion

First, note that most publications on handwritten keyword spotting that are based on a previous step of word segmentation are overly optimistic about their presented results. It is a common practice in our field to use the ‘perfect’ ground-truth segmentation provided by public datasets such as the George Washington letters or the IAM datasets (e.g. Aldavert et al. 2015). In that sense, we argue that the results provided by segmentation-free methods are usually closer to the reality than those provided by segmentation-based methods (Dey et al. 2016).

The second aspect we would like to highlight is the appropriate use of learning-based methods. Indeed, their performance is astonishing, and nowadays they have completely outperformed the rest of the state-of-the-art. But, in keyword spotting applications for libraries or archives, one can hardly assume that the users or owners of the system will be eager to provide hundreds of thousands of manually transcribed words in order to properly train the spotting system. In such



scenarios, we believe that it is best to avoid learning-based methods, and that sliding-window methods offer the important advantage that they can be used off the shelf.

But, should learning-based methods really be ruled out? So far, other aspects of handwritten keyword spotting are solved solely by learning-based methods. To provide the ability to query a system by strings instead of examples or to deal with different writers can be addressed only with machine learning systems. So the question remains.

Finally, we would like to also highlight that in recent years, public datasets such as the George Washington letters and the IAM database can be regarded as almost solved. Recent methods already claim average precision rates above ninety per cent in such datasets. In the near future, we will need larger and more challenging public annotated datasets in order to keep the handwritten keyword-spotting field alive and progressing.

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# Written Artefacts as Cultural Heritage

Ed. by Michael Friedrich and Doreen Schröter

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**NO 1**



# manuscript cultures (mc)

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## manuscript cultures 8



## manuscript cultures 7



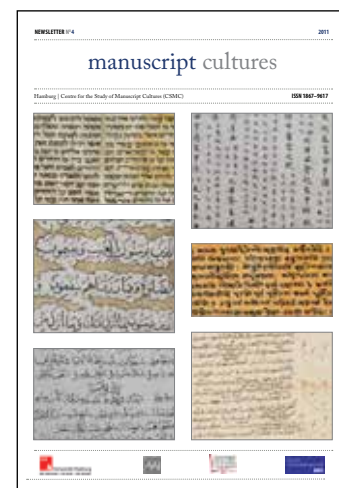
## manuscript cultures 6



## manuscript cultures 5



## manuscript cultures 4



# Studies in Manuscript Cultures (SMC)

Ed. by Michael Friedrich, Harunaga Isaacson, and Jörg B. Quenzer

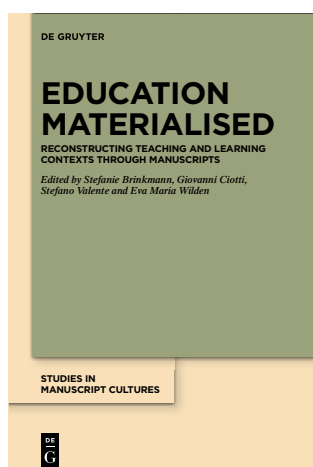
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Forthcoming



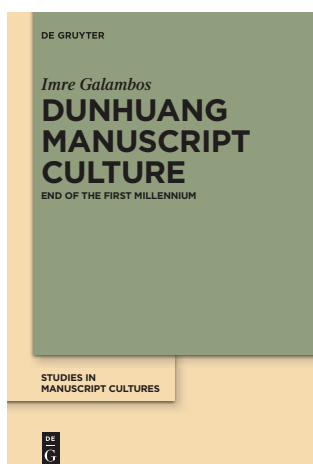
23 – *Education Materialised: Reconstructing Teaching and Learning Contexts through Manuscripts*, edited by Stefanie Brinkmann, Giovanni Ciotti, Stefano Valente and Eva Maria Wilden

Manuscripts have played a crucial role in the educational practices of virtually all cultures that have a history of using them. As learning and teaching tools, manuscripts become primary witnesses for reconstructing and studying didactic and research activities and methodologies from elementary levels to the most advanced.

The present volume investigates the relation between manuscripts and educational practices focusing on four particular research topics: educational settings: teachers, students and their manuscripts; organising knowledge: syllabi; exegetical practices: annotations; modifying tradition: adaptations.

The volume offers a number of case studies stretching across geophysical boundaries from Western Europe to South-East Asia, with a time span ranging from the second millennium BCE to the twentieth century CE.

New release



22 – *Dunhuang Manuscript Culture: End of the First Millennium*, by Imre Galambos

*Dunhuang Manuscript Culture* explores the world of Chinese manuscripts from ninth–tenth century Dunhuang, an oasis city along the network of pre-modern routes known today collectively as the Silk Roads. The manuscripts have been discovered in 1900 in a sealed-off side-chamber of a Buddhist cave temple, where they had lain undisturbed for almost nine hundred years. The discovery comprised tens of thousands of texts, written in over twenty different languages and scripts, including Chinese, Tibetan, Old Uighur, Khotanese, Sogdian and Sanskrit. This study centres around four groups of manuscripts from the mid-ninth to the late tenth centuries, a period when the region was an independent kingdom ruled by local families. The central argument is that the manuscripts attest to the unique cultural diversity of the region during this period, exhibiting – alongside obvious Chinese elements – the heavy influence of Central Asian cultures. As a result, it was much less ‘Chinese’ than commonly portrayed in modern scholarship. The book makes a contribution to the study of cultural and linguistic interaction along the Silk Roads.

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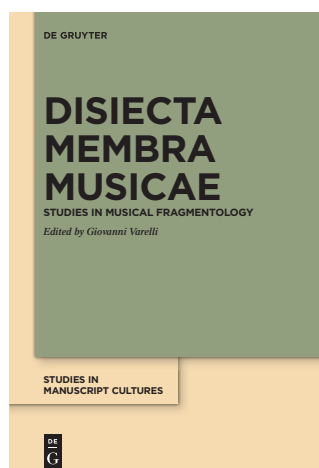
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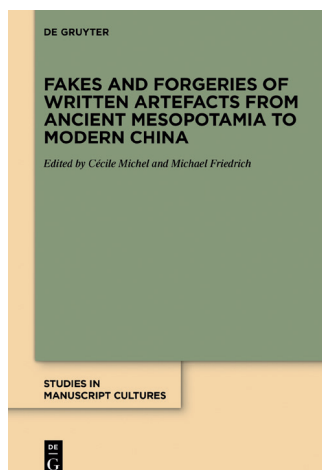
New release



21 – *Disiecta Membra Musicae: Studies in Musical Fragmentology*, edited by Giovanni Varelli

Although fragments from music manuscripts have occupied a place of considerable importance since the very early days of modern musicology, a collective, up-to-date, and comprehensive discussion of the various techniques and approaches for their study was lacking. On-line resources have also become increasingly crucial for the identification, study, and textual/musical reconstruction of fragmentary sources. *Disiecta Membra Musicae. Studies in Musical Fragmentology* aims at reviewing the state of the art in the study of medieval music fragments in Europe, the variety of methodologies for studying the repertory and its transmission, musical palaeography, codicology, liturgy, historical and cultural contexts, etc. This collection of essays provides an opportunity to reflect also on broader issues, such as the role of fragments in last century's musicology, how fragmentary material shaped our conception of the written transmission of early European music, and how new fragments are being discovered in the digital age. Known fragments and new technology, new discoveries and traditional methodology alternate in this collection of essays, whose topics range from plainchant to *ars nova* and fifteenth- to sixteenth-century polyphony.

New release



20 – *Fakes and Forgeries of Written Artefacts from Ancient*

*Mesopotamia to Modern China*, edited by Cécile Michel and Michael Friedrich

Fakes and forgeries are objects of fascination. This volume contains a series of thirteen articles devoted to fakes and forgeries of written artefacts from the beginnings of writing in Mesopotamia to modern China. The studies emphasise the subtle distinctions conveyed by an established vocabulary relating to the reproduction of ancient artefacts and production of artefacts claiming to be ancient: from copies, replicas and imitations to fakes and forgeries. Fakes are often a response to a demand from the public or scholarly milieu, or even both. The motives behind their production may be economic, political, religious or personal – aspiring to fame or simply playing a joke. Fakes may be revealed by combining the study of their contents, codicological, epigraphic and palaeographic analyses, and scientific investigations. However, certain famous unsolved cases still continue to defy technology today, no matter how advanced it is. Nowadays, one can find fakes in museums and private collections alike; they abound on the antique market, mixed with real artefacts that have often been looted. The scientific community's attitude to such objects calls for ethical reflection.

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