Pattern Recognition Letters 112 (2018) 118–124

Contents lists available at ScienceDirect

Pattern Recognition Letters

journal homepage: www.elsevier.com/locate/patrec

Subgraph spotting in graph representations of comic book images

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ARTICLE INFO

Article history:
Received 22 December 2017
Available online 20 June 2018

Keywords:
Attributed graph
Region adjacency graph
Graph matching
Graph isomorphism
Subgraph isomorphism
Subgraph spotting
Graph indexing
Graph retrieval
Query by example
Dataset and comic book images

ABSTRACT

Graph-based representations are the most powerful data structures for extracting, representing and preserving the structural information of underlying data. Subgraph spotting is an interesting research problem, especially for studying and investigating the structural information based content-based image retrieval (CBIR) and query by example (QBE) in image databases. In this paper we address the problem of lack of freely available ground-truthed datasets for subgraph spotting and present a new dataset for subgraph spotting in graph representations of comic book images (SSGCI) with its ground-truth and evaluation protocol. Experimental results of two state-of-the-art methods of subgraph spotting are presented on the new SSGCI dataset.

1. Introduction

Graphs are widely used for representing the structure, topology and attributes of underlying information in various application domains of pattern recognition. Information retrieval based on the structural and topological similarity between query and retrieval candidates can be best modeled by an attributed graph retrieval problem [1], which thus is a very important research problem especially for the application domains of structural pattern recognition, computer vision, image analysis, data mining and machine learning [2,3]. This research problem becomes more challenging if the graphs contain attributes on their nodes and arcs. The research problem of searching a query graph in a database of graphs is termed as subgraph spotting [4].

The lack of freely available ground-truthed datasets makes it difficult to test and compare the methods of subgraph spotting. In this paper we present our recent work on the research problem of subgraph spotting. This work was initiated for organizing a competition for the 23rd International Conference on Pattern Recognition (ICPR 2016)[3]. The competition is a joint effort from the members of the IAPR Technical Committees[4] on "GRAPHICS RECOGNITION (TC10)" and on "GRAPH BASED REPRESENTATIONS (TC15)". The competition has been named SSGCI (subgraph spotting in graph-representation of comic book images) and is focused on the research problem of subgraph spotting in a database of attributed graphs. The idea of content-based comic book images retrieval via subgraph spotting stems from the fact that a graph is capable of representing and preserving the structural information extracted from comic books images. The goal of the SSGCI competition is to spot a query attributed graph in a database of attributed graphs i.e. for a given query attributed graph the goal is to retrieve every graph in the database which contains this query graph and to provide node correspondences between the query and each of the result graphs. This main challenge of the SSGCI competition represents an open research problem in graph-based structural pattern recognition. The problems of matching, indexing and retrieval of graph-based representations of underlying data are

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[3] http://www.icpr2016.org/site/at-glance/.
[4] http://www.iapr.org/committees/committees.php?id=6.

https://doi.org/10.1016/j.patrec.2018.06.017
0167-8655/

actively researched into by the community employing exact as well as in-exact methods.

There are two important new contributions of this paper. First, this paper presents our recent work on the problem of subgraph spotting in graph-representation of comic book images (SSGCI). The paper presents a new dataset, which is freely available[5] for academic research so that the researchers can benchmark their methods with respect to the other state of the art methods. Second, this paper presents new unpublished results of two state-of-the-art methods on this new SSGCI dataset.

This paper is organized as follows. In Section 2 we present related work. In Section 3 we describe two state-of-the-art methods of subgraph spotting. In Section 4 we present details about the new SSGCI dataset, its groundtruth and the associated evaluation protocol. In Section 5 we present the experimental results and discussion. The paper concludes in Section 6 with some future lines of work.

2. Related work

The use of relational models that allow to represent visual objects in terms of relations among different components has gained huge interest among the research community [2,3]. At the heart of these structural techniques, *graphs* have been used over decades as robust and theoretically grounded representation paradigm. With graph-based methods, underlying patterns are first modeled with graphs, where nodes correspond to local primitives, and edges describe their spatial and geometric relationships. Then a form of graph matching technique, such as, *graph isomorphism, graph embedding* etc, is applied for subsequent recognition, classification tasks. This general framework has been successfully applied to many computer vision and pattern recognition problems [5–7]. However, graph matching is a very well known but challenging task, which is classified as a *GI-complete* problem [8]. A particular class of algorithms resulting from the consideration of outliers is called *subgraph matching*. Roughly, it can be defined as matching one graph (pattern graph) as part of the other (target graph or result graph). Among the earlier works, a group of methods worked with *tree search with backtracking* [9], which gave birth of the popular *graph edit distance*. In these papers, the authors introduced the *graph edit costs i.e.* the costs for substituting, deleting, inserting and merging nodes and edges to define a distance between two graphs [10]. In general, the problem of computing graph edit distance being NP-complete, many have come out with approximate solutions [11]. However, most of the modern methods address the inexact matching problem and focus on the relaxation of permutation constraints. Based on the approximation strategy and the applied methodology, these methods can be broadly classified into three categories: (1) *spectral decomposition* [12], (2) *semidefinite programming (SDP) relaxation* [13] and (3) *convex relaxation* [14].

Content-based image retrieval (CBIR), which makes the use of the representation of visual content to identify relevant images, has attracted sustained attention in the last two decades [15,16]. In early CBIR algorithms and systems, global features are commonly used to describe image content by color, shape, texture, and local structure. As representation of structured visual content, visual features are correlated by spatial context in terms of orientation, scale, and key point distance in the image plane. By including the contextual information, the discriminating capability of visual codebook can be greatly enhanced [17]. Graph-based information spotting has also received huge attention by the research community. These methods, on one hand, take advantage of graph representation for delineating the structural information of underlying object, and on the other hand, use the power of indexing techniques for fast processing the information. In [18], Rusiñol et al. proposed a symbol spotting method based on the decomposition of line drawings into primitives of closed regions. An efficient indexing methodology was used to organize the attributed strings of primitives. Lately, Luqman et al. [4] also proposed a method based on fuzzy graph embedding for symbol spotting. In [19], Dutta et al. proposed a method based on indexing the serialized subgraphs for symbol spotting on line drawing documents. Riba et al. proposed a word spotting method by indexing the graphs of handwritten words, where the convex parts of the words act as the nodes of the graph [20]. Le et al. [21] proposed a content-based comic book image retrieval system by using a multi-layer graph representation and frequent graph mining techniques.

To the best of our knowledge there is no freely available dataset which is readily available for the problem of subgraph spotting. Most of the works in literature (including the ones that have been cited above) have used their home-built datasets for reporting the results. Some of the datasets that have been used by different graph-based methods for some closely relevant tasks include the following datasets. The CMU house and hotel image sequences are among the most popular datasets to test the performance of graph matching algorithms. It consists of 111 frames of a toy house and 101 frames of a toy hotel, each of which had been manually labelled with 30 landmark points. The car and motorbike image dataset [22] consists of 30 pairs of car images and 20 pairs of motorbike images that were taken from the dataset of PASCAL challenges. Each pair of images consists of 15 to 52 true correspondences. The IAM graph dataset [23] and the GREYC Chemistry dataset are two graph repositories containing many sets of graphs with class information. These graphs are useful for testing the performance of graph classification algorithm. Graphical symbols are often converted to graphs, and have been frequently used for symbol spotting and classification task [19]. The SESYD [24] and FPLAN-POLY [18] datasets have become very popular for that purpose. Similar to the graphical symbols, handwritten words converted to graphs have also become important, HistoGraph dataset can be considered as one of the many efforts. Among the others, IAM handwriting database and Washington database have been used by many researchers.

Even after having quite a few datasets that are somehow useful for testing graph-based methods, there is no dataset that is freely available for the subgraph spotting task. This fact motivates us to create the new SSGCI dataset and to make is freely available for facilitating the research community to investigate new subgraph spotting techniques and the use of structural information for CBIR and QBE.

3. Two state-of-the-art methods of subgraph spotting

This section presents detailed description of two state-of-the-art methods of subgraph spotting which participated in the SSGCI competition of the 23rd International Conference on Pattern Recognition (ICPR 2016).

3.1. Method 1: Tensor Product Graph for Inexact Subgraph Matching

The main motivation of this method is the use of contextual information of nodes (*i.e.* neighbouring structures) to make subgraph matching more robust and efficient in large scale visual recognition scenarios. A second key component is the formulation of subgraph matching with approximate algorithms. Therefore, in this work, the authors proposed an inexact subgraph matching methodology based on *tensor product graph* (TPG). Given two attributed graphs, it is quite straight forward to get the pairwise similarities and assign them as weights on the edges of TPG. Next, one can think of

[5] http://icpr2016-ssgci.univ-lr.fr.