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A new proposal for graph-based image classification using frequent approximate subgraphs

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ABSTRACT

Graph-based data representations are an important research topic due to the suitability of this kind of data structure to model entities and the complex relations among them. In computer vision, graphs have been used to model images in order to add some high level information (relations) to the low-level representation of individual parts. How to deal with these representations for specific tasks is not easy due to the complexity of the data structure itself. In this paper we propose to use a graph mining technique for image classification, introducing approximate patterns discovery in the mining process in order to allow certain distortions in the data being modeled. We are proposing to combine a powerful graph-based image representation adapted to this specific task and frequent approximate subgraph (FAS) mining algorithms in order to classify images. In the case of image representation we are proposing to use more robust descriptors than our previous approach in this topic, and we also suggest a criterion to select the isomorphism threshold for the graph mining step. This proposal is tested in two well-known collections to show the improvement with respect to the previous related works.

1. Introduction

In many research fields, graphs have been largely used to model data due to their representation expressiveness and their suitability for applications where some kind of entities and their relationships must be encoded within some data structure. Also, a vast graph theory has been developed in order to work with graphs and process the information they represent. In this paper, we intend to explore and combine two research fields where graphs are involved, in order to exploit both their advantages.

The first field is related to Computer Vision. Our intention is to classify images using a graph-based representation. The first step for image classification is to extract low-level features that will encode relevant information for the task, but it has been shown that low-level information by itself cannot provide the high-level perception cues that exist in human minds to describe objects or images in general (this is the well-known semantic gap problem) [16]. Within the range of low-level features developed so far, graphs are one of the representations that can provide some kind of high-level information implicitly, making them a desirable representation choice for researchers to find new solutions. Many works have represented images as graphs (see Section 2) with this purpose, and have developed methods for classification using this type of data structure. One major concern in this area is that although graphs are powerful representational tools, they are hard to work with, leading usually to algorithms with high computational costs, or simplifying the data structure, thus losing some of the embedded information. Having a collection of images represented as graphs rises the question of whether graph mining techniques can be used to discover beneficial information and to perform certain tasks such as image classification.

Now we will approach the other research field that we are aiming to explore: Data Mining. Several authors have developed graph-based techniques and methods for satisfying the need to convert large volumes of data into useful information [4,24,45]. Frequent subgraph discovery is an example of such techniques [15]. An important problem in graph mining tasks is classifying information, such as image [2,13,25,35,36], text [26], and molecular [11,23] datasets. Although using graph mining for classification purposes has been widely explored, these approaches may not always produce the optimal results in all applications and several authors [22,27,7] have expressed the necessity to use approximate graph matching for frequent subgraph mining. These authors defend the idea that, by using approximation, more interesting subgraphs can be found for many applications, for instance, when processing graph databases that have distortions (in terms of

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different geometric, topological or semantic variations) of similar structures in several objects [2,23]. Distortion in data is one of the challenges for developing classifiers based on frequent subgraphs in several domains of science [2,9,19,23,29,40,42,43,46,47]. Frequent approximate subgraph (FAS) mining is an important problem in graph mining, where the mined patterns are detected taking into account such semantic distortions. Thus, such approximate solutions achieve classification results which are different from the other graph mining methods.

As mentioned before, in this paper we aim at combining and exploiting both research fields (image classification and frequent approximate subgraph mining) by proposing an image representation that can be used in a classification framework. Although graph mining techniques for image classification have been explored before (see Section 2.3), our main contribution resides precisely in the approximation part of the subject. This work is, in fact, an extension of a previous work [3] where we make use of a powerful graph-based representation adapted to the conditions of the problem. The new contributions and changes with respect to that work are the following:

- We use a different visual description of the regions in order to add context information to it. We employ a visual descriptor already reported in the literature, making some changes to take advantage of the structure of irregular pyramids.
- We propose a criterion to obtain the isomorphism threshold needed in the FAS mining step, which is the parameter employed to determine whether two graphs are similar enough to be considered in the frequency count.

We performed new experiments to show how these improvements largely and positively influence the classification results, while comparing it also with other state-of-the-art methods in image classification.

The remainder of the paper is distributed as follows. Section 2 is a summary of related works in the fields of graph-based image classification, graph mining and the combination of both. Section 3 presents some basic notions regarding graph mining techniques and some specific details of the FAS mining process. The graph-based image representation used in our proposal is described in Section 4. Section 5 depicts the classification framework, where both topics discussed in Section 3 and 4 are combined. In order to validate our approach, we present experimental results in Section 6 and conclusions are given finally in Section 7.

2. Related work

In this section, we start by providing a brief on classification methods using graph-based representations. Next, we present a review of previous works related to approximate graph mining and finally, we present a brief on classification using frequent patterns, which is the subject of this paper.

2.1. Brief overview of image classification using graph-based representations

Representing images as graphs has become popular because they are powerful tools to encode different types of information, and may provide a robust and rich representation for many applications. How to exploit this information is the main issue in the graph-based classification scope. A popular graph-based image representation is the Region Adjacency Graph (RAG) [6] where each vertex represents a region in the image and an edge exists between two vertices if the underlying regions are adjacent.

Different methods have been developed to use graphs for classification tasks, for instance, graph matching algorithms [21,12,32,18,17], which use distances (ex. graph edit distance), greedy matching techniques or matching kernels in order to compare graphs. Another way to perform classification is by using graph embedding methods [8,20], which, in general terms, map graphs to a vector space and then perform regular classification operations with the resulting vectors.

Although graphs are considered to be a powerful representation, they have a major drawback, which is the lack of suitable classification methods where they can be used. Graph matching techniques usually have the problem of the computational complexity involved in the process and graph embedding methods usually tend to suppress part of the information encoded by the graphs. Graph mining techniques used for classification purposes could be considered a halfway between graph matching and graph embedding methods, thus using the strength of both and reducing their individual disadvantages.

2.2. Summary of approximate graph mining

Traditional exact graph mining has become an important topic of research in recent years [7,15,34,44]. However, there are concrete problems where these solutions could not be applicable with positive outcomes [19]. Sometimes, the interesting subgraphs show slight differences throughout the data. An example of these differences can be seen on image processing, where these differences may be due to noise and distortion, or may just illustrate slight spatial differences between instances of the same objects. This means that we should tolerate slight semantic variations or some mismatches of vertices (and edges) in frequent subgraph pattern search.

In the last years, some approximate graph mining algorithms have been published where several similarity functions are used. For example, the algorithms SUBDUE [19] and RNGV [42] are based on graph edit distance; Monkey [46] is based on β-edge sub-isomorphism; UGRAP [40] and MUSE [47] are based on sub-isomorphism on uncertain graph collections; GREW [29] is based on sub-isomorphism employing ideas of edge contraction and graph rewriting; CSMiner [43] uses node/edge disjoint sub-homeomorfismo; gApprox [9], APGM [23] and VEAM [2] are based on substitution probabilities.

gApprox, *APGM* and *VEAM* algorithms defend the idea that a vertex label or an edge label cannot always be replaced by any other. Therefore, these algorithms specify which vertices, edges or labels can replace others using substitution matrices to perform frequent subgraph mining. However, only APGM and VEAM perform frequent approximate subgraph mining on graph collections and we are interested in this kind of mining. APGM only deals with the variations between the vertex labels, while VEAM performs the mining process using both the vertex and edge label sets.

In this paper, the last two algorithms are applied in order to create an image representation that will be used for classification purposes. This is due to the need of an algorithm that allows some variations in the data using substitution probabilities and keeping at the same time the topology of the graphs.

2.3. Brief review of classification using frequent patterns

As mentioned before, frequent subgraph patterns have been successfully used for classification tasks in different domains of science [2,11,13,23,26,35,36]. However, among these solutions, there are only two that use frequent approximate subgraphs in classification tasks [2,23]. These methods perform feature (subgraph) selection taking into account semantic distortions. APGM algorithm [23] allows these distortions only between vertices of