Method for Image Informational Properties Exploitation in Pattern Recognition Environment

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Abstract. The problem of finding optimal image transformation according to informational image properties is considered. During the research, image informational properties that distinguish images from all other recognition objects were investigated. The notion of image equivalence was introduced. Notion of image equivalence as identity of images with respect to some transformation set was explored. The proposed equivalence definition allows decomposition of image set into subsets of a certain type and establishes correspondence between image equivalence classes and some subsets of operations. On this basis, the method for selecting efficient image recognition algorithm according to image informational nature was elaborated. The proposed method provides a possibility of improving efficiency of selecting image analysis algorithms and automation (partial or complete) of image processing. It allows taking into consideration internal information that image conveys, syntactic and semantic.

1 Introduction

Different types of images are more and more often used for representing input, intermediate, and output information in the applied tasks, at the same time the tools for selecting image analysis algorithm depending on the syntactic and semantic content of an image are yet poorly developed. Most computationally efficient image recognition algorithms are designed for the work with feature representations and image models. While constructing image representation, the essential part of information that image contains, can be lost. In order to use information contained in the image during its analysis, it is necessary to overcome the contradiction between the image nature and the image analysis methods that accept symbolic models only. Image analysis and recognition should be based on transformations that depend on specific informational image properties and reflect syntactic and semantic information contained in the image. The solution of this problem provides a possibility of improving efficiency of selection of image analysis algorithm and (partial) automation of image processing.

Since images are the objects with specific properties, they require special methods of processing, analysis, recognition, and understanding. The traditional approaches treat an image as a matrix of pixels with different levels of brightness; they do not take into account syntactic and semantic information of an image. An efficient algorithm of

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image analysis should consider what an image describes. The method for selecting an efficient image recognition algorithm according to image informational nature is presented in this paper.

In order to choose the optimal algorithm for image analysis, it is proposed to divide images into sets of similar images. This idea is supported by two facts: (a) images contain information that is redundant in some aspects; (b) not all information that an image contains is essential for solving image recognition task.

Thus, images appropriate for the task can be divided in the sets of "similar" ones. Assuming this "similarity" as equivalence, one obtains image equivalence classes.

The formalized concept of image equivalence is a basis for reducing the algorithmic complexity in image analysis. The equivalence provides a tool for the decomposition of the set of images into subsets of a certain type and puts into correspondence some subsets of operations. The search for the operations in subsets of a lower cardinality results in (partial) elimination of the exhaustive search during the optimization of complex procedures for solving the problem of finding the necessary transformation of images [1].

The method for selecting the efficient image recognition algorithm according to the informational nature of an image consists of five main stages:

1. image characterization - establishing of an input image equivalence class;
2. image model construction - image reducing to a recognizable form with the help of basic operations from corresponding class of transformations;
3. determination of a class of equivalence that image model belongs to;
4. image model classification – solving an image recognition task by using recognition operators that correspond to the equivalence class of image models;
5. checking whether the image characterization was correct – with the help of corresponding inverse transformations.

The proposed method considers image informational properties while choosing image analysis algorithm. It is aimed to ease the selection of appropriate image transformation algorithm depending on the image informational nature. Dividing images into sets of equivalent ones, the essential image properties are kept secure. Information essential for image recognition task will not be lost during different image transformations provided that image equivalence classes and corresponding transformations are determined correctly. Thus the method allows increasing efficiency of image analysis systems' functioning and partly automates the process of image analysis.

The principal topics of the article are: informational image properties, the notion of image equivalence, and the method taking into consideration image informational properties during image recognition. Section 2 provides a brief overview of basic image informational properties. Section 3 contains investigation into image equivalence notion. In section 4 the method for selecting efficient image recognition algorithm according to image informational nature is presented. In Conclusion, the paper results are summarized and the main directions of future research are outlined.

2 Image Informational Properties

Images have a set of specific informational characteristics that differentiate them from all other objects of recognition. These characteristics are informational capacity, compactness, obviousness, internal structure that reflects logical and physical relations of the external world, informational redundancy, consistency, and strong dependence on the conditions of their receiving, representing, and forming.

Images usually hold an extremely large amount of information that is redundant in the following aspects [4]:

- statistical redundancy (image elements that are close to each other have the similar level of brightness);
- psychovisual redundancy (a part of information that an image contains can be removed without change in image perception by a human);
- redundancy determined by the image recognition task (not all information that image contains is essential for solving image recognition task);
- semantic redundancy (the possibility of using context information compensates information losses due to the quality of analyzed image);
- interframe redundancy (the same objects of the image are repeated on the subsequent frames);
- invariant redundancy (images are invariant with respect to some classes of transformations).

The specificity of recognition task is that not all information that images contain is essential for successful solution of the problem, so image representation that partly reflects information contained in the image can be used. Application of such image model makes perfect reconstruction of the initial image impossible, though it is possible to classify the image correctly. This image property will be used further.

3 Equivalence in Image Recognition Environment

Solving the recognition problem requires availability of some image representation, presence of an efficient recognition algorithm, and accordance between image representation used and the requirements to the input data that the algorithm imposes. Most image recognition algorithms performing computational efficiency are devoted to the work with feature representations and image models only. As a result image analysis and recognition are based on transformations that don't depend on representation of the information being processed as an image.

The proposed principles of selecting image transformations in image recognition tasks are founded on descriptive approach to image analysis [1]. The following hypothesis is used:

- any image has a certain regularity or a mixture of regularities of different types;
- each class of equivalent images has corresponding class of transformations which being applied do not move the result of transformations out of the corresponding equivalence class.

The notion of equivalence is substantial in many sections of mathematics. It is a notion of fundamental importance in pattern recognition – pattern recognition task has no sense without equivalence on the sets of identifiable object given. Determining the notion of "image equivalence" is one of the crucial problems in mathematical theory of image analysis and recognition. Unlike classical pattern recognition theory when analyzing images the equivalence of objects of transformations is of a great interest, not the equivalence of transformations themselves, though generally speaking some correspondence can be established between these two kinds of equivalence.

The main purpose of introducing and using mathematical characteristics of image equivalence is to define and form classes of learning sample when solving the image recognition task. There are several ways to define the notion of equivalence.

1. An ideal way to introduce the notion of equivalence is to use certain image regularity (or a mixture of regularities of different types). This method should be based on specific semantic of corresponding images and it is connected with informational nature of an image.
2. From mathematical point of view, the notion of equivalence can be introduced as follows:
   - as a proximity according to some metric defined in the space of formal descriptions or features representing images (Definition 1);
   - as an identity regarding to some set of transformations (Definition 2).

Definition 1. Let {Z} be an image recognition problem. Two images I_1 and I_2 are *equivalent* with respect to this problem if their information n-dimensional vectors coincide, i.e.,

$$\forall j \in \{1,n\} \Rightarrow ||\alpha_j(I_1)|| = ||\alpha_j(I_2)||.$$

Definition 2. Let {Z} be an image recognition problem, {I} – class of equivalent images relevant to the problem {Z}, and {T} – a set of transformations corresponding to {I} (i.e. $\forall\ t' \in \{T\},\ \forall\ I' \in \{I\} \Rightarrow t'(I') \in \{I\}$). Two images I_1 and I_2 are *equivalent* with respect to the problem {Z} if

$$\forall t \in \{T\} \Rightarrow t\,(I_1) \in \{I\} \text{ and } t\,(I_2) \in \{I\}.$$

Any set of equivalent images composes an equivalence class in the set of images of the problem.

In this paper the notion of image equivalence is introduced as follows: images generated from some image-prototype (or a set of image-prototypes) with the help of a set of acceptable basic transformations are equivalent with regard to the basis of the above-mentioned operations [3].

The formalized concept of image equivalence is a basis for reducing the algorithmic complexity in image analysis. The equivalence provides a tool for the decomposition of the set of images into subsets of a certain type and puts into correspondence some subsets of operations. The search for the operations in subsets of a lower cardinality results in (partial) elimination of the exhaustive search in the optimization of complex procedures for solving the problem of finding the necessary transformation of images, if these procedures are represented by sequences of basic simple procedures [1].

4 Method for Image Transformation Selection

As a result of investigations, the method for selecting an efficient image recognition algorithm according to image informational nature was elaborated. It is based on the mathematical set-up of image recognition problem [1]. The proposed method exploits notions of image redundancy and image equivalence, and the hypothesis mentioned above.

It is given an image recognition problem Z. Let us define image equivalence set as an internal image class property, i.e. all images of the corresponding identifiable image set given are supposed to be equivalent (see Definition 2).

The following notions should be defined.

$\{I_1\}$ – images from the first class fixed in the image recognition problem Z that are supposed to be equivalent. The same for $\{I_2\}$.

$\{T_1\}$ – set of algorithms for image reducing to a recognizable form, i.e. algorithms for image model construction for images constituting $\{I_1\}$. The same for $\{T_2\}$.

$\{T_{acc}\}$ – set of acceptable transformations, i.e. transformations that being applied do not move the result of transformation out of the corresponding class of equivalent images.

$\{\Re(I_1)\},\{\Re(I_2)\}$ – classes of equivalent image models. $\{\Re(I_1)\}$ includes models of all images from $\{I_1\}$ and all models that can be obtained from images of $\{I_1\}$ by applying acceptable transformations $t_{acc} \in \{T_{acc}\}$. The same for $\{\Re(I_2)\}$.

$\{T_{inv}^1\}$ – the set if inverse transformations facilitating image equivalence class reconstruction from the result of recognition known. The same for $\{T_{inv}^2\}$.

Let *A* be recognition algorithm used and *a* – information vector that can take the following values $\{0,1,\Delta\}$. I* is an input image presented for recognition.

The following basic stages are distinguished in the method for image transformation selection according to image informational nature.

1.

$$P_{image\_characterization} = P(I^* \in \{I_1\})$$

Image characterization - establishing a class of equivalence that an input image belongs to. Classes of equivalent images strongly depend on the recognition task at hand, particularly, on transformations that do not move the image out of its equivalence class, and on the images that are supposed to be “similar”.

2.

$$\Re(I^*) = t(I^*)\text{, where } t \in \{T_1\}.$$

Image model construction - reducing image to a recognizable form with the help of basic operations from corresponding class of transformations. Note that there are no additional constraints imposed on $\{T_1\}$ (e.g. completeness, closeness, etc.), the only

constraint is: any transformation applied should not move the result of transformation out of the corresponding class of equivalent image models.
While constructing image model, information that image conveys can be partly lost. This makes perfect reconstruction of the input image impossible, though the class of image equivalence can be determined. At the same time, an image model should contain all information about the initial image that is essential for image classification.
3.

$$P_{image\_model\_characterization} = P(\Re(I^*) \in \{\Re(I_1^M)\}).$$

Determination of equivalence class image model belongs to.
If

$$P_{image\_model\_characterization} = 1,$$

then one have a set of recognition algorithms that solve the problem at hand in the best way. This step supports a choice of the optimal image recognition algorithm. Since different algorithms require different formats of input data, and the classes of equivalent images can differ according to the semantic properties of their members, it is necessary to choose an optimal algorithm among appropriate ones.
If

$$P_{image\_model\_charactarisation} = 0,$$

then it becomes apparent that the hypothesis agreed at step 1 was not correct. A new hypothesis about equivalence class input image belongs to should be put forward.
There are different ways for image model equivalence class determination. For example, decision rules can be fixed. These rules should reflect information that is essential for images from task at hand. Properties that allow distinguishing images belonging to one equivalence class from all other images should be taken into consideration.
4.

$$a = A(\Re(I^*)),$$

Image model classification. Here, the optimal image recognition algorithm *A* is chosen among recognition operators from the class of transformations that correspond to the class of equivalent image models. The problem is solved with a help of this algorithm.
5.

$$\Re'(I^*) = t_{inv}^1(a), \text{ where } t_{inv}^1 \in \{T_{inv}^1\}.$$

$$P_{class\_correct} = P(\Re'(I^*) \in \{\Re(I_1)\}).$$

Checking whether the image characterization was correct. Here, the equivalence class of the initial image is reconstructed by using the known result of recognition *a* and inverse transformations $\{T^1_{inv}\}$ that correspond to the equivalence class of images that was used.
If

$$P_{class\_correct} = 1,$$

then the problem was solved correctly. If

$$P_{class\_correct} = 0,$$

then image equivalence class was not determined correctly at the first stage. If the image was incorrectly characterized at the first stage, a new hypothesis is made about a class of equivalence the image belongs to. The problem is solved according to this hypothesis. The procedure stops as soon as the problem is efficiently solved.
There are different ways to set up inverse transformations:

? to compare typical image from corresponding equivalence class with input image;
? to compare the weighed some of several images characterizing equivalence class with input image.

The proposed method provides a possibility of improving efficiency of selection of image analysis algorithms and automation (partial or complete) of image processing. It allows treating image not as a matrix of pixels with different brightness but taking into consideration internal image information, syntactic and semantic.

Note that descriptive image algebras provide with convenient tools for such operations determination and presentation since they can operate both image models and their transformations. Specialized models of such algebras can be defined on the subsets of operations that correspond to the classes of equivalent images [2].

5 Conclusion

The method for selecting efficient image recognition algorithm according to image informational nature was elaborated. The method is based on the notions of image redundancy, and image equivalence, and the following hypothesis: each class of equivalent images has corresponding class of transformations which being applied do not move the result of transformations out of the corresponding equivalent class. The proposed method is aimed to facilitate the selection of appropriate image transformation depending on the image informational nature. It increases efficiency of image analysis system functioning and partly automates image analysis process. The method can be useful in many applications where image processing algorithm is to be selected among those available, e.g. applications in medicine, remote sensing, education, etc.

The main lines of future research are as follows:

1. Research on essential characteristics that determine an image.

2. Exploration of different examples of defining equivalence relation on the image set.
3. Investigation into correspondence between image processing, analysis, recognition and understanding algorithms and image equivalence classes.
4. Computer experiments on transformation selection with different methods for equivalence determination.

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