THE DESCRIPTIVE TECHNIQUES FOR IMAGE ANALYSIS AND RECOGNITION

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Abstract: The presentation is devoted to the research of mathematical fundamentals for image analysis and recognition procedures. The final goal of this research is automated image mining: a) automated design, test and adaptation of techniques and algorithms for image recognition, estimation and understanding; b) automated selection of techniques and algorithms for image recognition, estimation and understanding; c) automated testing of the raw data quality and suitability for solving the image recognition problem. The main instrument is the Descriptive Approach to Image Analysis, which provides: 1) standardization of image analysis and recognition problems representation; 2) standardization of a descriptive language for image analysis and recognition procedures; 3) means to apply common mathematical apparatus for operations over image analysis and recognition algorithms, and over image models. It is shown also how and where to link theoretical results in the foundations of image analysis with the techniques used to solve application problems.

1 INTRODUCTION

Automation of image processing, analysis, estimating and understanding is one of the crucial points of theoretical computer science having decisive importance for applications, in particular, for diversification of solvable problem types and for increasing the efficiency of its solving.

The presentation is devoted to the research of mathematical fundamentals for image analysis and recognition procedures being conducted previously in the Scientific Council "Cybernetics" of the Russian Academy of Sciences, Moscow, Russian Federation, and currently in the Dorodnicyn Computing Centre of the Russian Academy of Sciences, Moscow, Russian Federation.

The final goal of this research is automated image mining. The main instrument is the Descriptive Approach to Image Analysis (Gurevich, 1989; 1991), which provides: 1) specialization of Zhuravlev's Algebra (Zhuravlev, 1998) for an image recognition case; 2) standardization of image analysis and recognition problems representations; 3) standardization of a descriptive language for image analysis and recognition procedures; 4) means to apply common mathematical apparatus for operations over image analysis and recognition algorithms, and over image models (Gurevich and Yashina, 2004).

Taking as a strategic goal the automated image mining it is necessary to provide image analysis professionals and final users with the following opportunities:

- automated design, test and adaptation of techniques and algorithms for image recognition, estimation and understanding;
- automated selection of techniques and algorithms for image recognition, estimation and understanding;
- automated testing of the raw data quality and suitability for solving the image recognition problem;
- standard technological schemes for image recognition, estimation, understanding and retrieval.

We shall outline the goals of theoretical development in the framework of the Descriptive Approach (and image analysis algebraization) ("What for"), the tool to achieve this goal ("How"), state of the art in the field (prospective trends), necessary steps to finalize the Descriptive Approach ("What to Do or What to be Done") and the global problem of an image reduction to a recognizable form. It will be shown also how and where to link theoretical results in the foundations of image

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analysis with the techniques used to solve application problems.

The structure of the paper is as follows:

1. What for
2. How
   - The Tool - Descriptive Approach
3. State of the Art:
   - Plurality and Fusion
   - Multialgorithmic Classifiers
   - Multimodel Representations
4. What to Do or What to be Done. Basic Steps:
   - Step 1. Mathematical Settings of an Image Recognition Problem
   - Step 2. Image Models
   - Step 3. Multimodel Representation of Images
   - Step 4. Image Equivalence
   - Step 5. Image Metrics
   - Step 6. Descriptive Image Algebras
5. Conclusion
   - Image Reduction to a Recognizable Form

2 WHAT FOR?

The image analysis and recognition techniques and tools are destined for solving of the following basic classes of applied image analysis problems:

1. Image matching for classification with an image, a set of images and a series of images.
2. Searching an image for some regularity/irregularity/object/token/fragment/primitive of arbitrary or prescribed type/form.
3. Clusterization of an image set.
4. Image segmentation (for homogeneous regions, groups of objects, selection of features).
5. Automatic selection of image primitives, specific objects, feature objects, logical and spatial relations.
6. Image reduction to a recognizable form.
7. Reconstruction and Restoration of missed frames in an image series and of images by fragments, primitives, generative procedures and context.
8. Image analysis problem decomposition and synthesis.

The most important – critical points of an applied image analysis problem solving are as follows:

- CPI. Precise setting of a problem (Step 1).
- CPII. Correct and "computable" representation of raw and processed data for each algorithm at each stage of processing (Step 2, Step 5).
- CPIII. Automated selection of an algorithm (Step 1, Step 3, Step 6):
  - CPIII-1. Decomposition of the solution process for main stages (Step 1, Step 6);
  - CPIII-2. Indication of the points of potential improvement of the solution ("branching points") (Step 1, Step 6);
  - CPIII-3. Collection and application of problem solving experience (Step 3, Knowledge Base);
  - CPIII-4. Selection for each problem solution stage of basic algorithms, basic operations and basic models (operands) (Step 6);
  - CPIII-5. Classification of the basic elements (Step 3, thesaurus).
- CPIV. Performance evaluation at each step of processing and of the solution (Step 2, Step 4, Step 6).
  - CPIV-1. Analysis, estimation and utilization of the raw data specificity (Step 2);
  - CPIV-2. Diversification of mathematical tools used for performance evaluation (Step 6);
  - CPIV-3. Reduction of raw data to the real requirements of the selected algorithms (Step 4).

The further development of the Descriptive Approach should provide necessary means for implementing of these steps. After each Critical Points in the brackets are indicated the corresponding "next steps" (the description of the steps see below).

So, the success of image mining in a whole is connected with overcoming of the Critical Points in a following way:

- automated design, test and adaptation of techniques and algorithms for image recognition, estimation and understanding (CPIV);
- automated selection of techniques and algorithms for image recognition, estimation and understanding (CPIII);
- automated testing of the raw data quality and suitability for solving the image recognition problem (CPII);
- standard technological schemes for image recognition, estimation, understanding and retrieval (CPI).

3 HOW?

Mathematical fundamentals for image processing and image analysis procedures are constructed in the framework of the Descriptive Approach to Image Analysis, which provides:

- specialization of Zhuravlev's Algebra for an image recognition case (CP1);

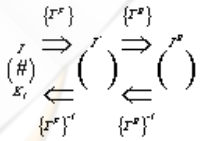
- standardization of image analysis and recognition problems representation (CP1);
- standardization of a descriptive language for image analysis and recognition procedures (CP2);
- means to apply common mathematical apparatus for operations over image analysis and recognition algorithms, and over image models (CPIV).
- The Descriptive Approach is based on:
- descriptive model of image recognition procedures (CPI);
- image reduction to a recognizable form (CPII);
- image models (CPII);
- algebraization of image mining (CPIII, CPIV);
- generative principle and bases of transforms and models.

The preliminary condition of algebraization of image mining is development of formal systems for image representation and transformation satisfying to the following conditions: a) each object is a hierarchical structure constructed by a set of operations of image algebra (Gurevich and Yashina, 2003) applied to the set of elements of images; b) the objects are points, sets, models, operations, morphisms; c) each transform is a hierarchical structure constructed by a set of operations of image algebra on the set of basic transforms.

The Descriptive Approach provides construction and application of two types of such formal systems - special versions of algebras - image algebras (CPIII, CPIV) (Ritter and Wilson, 2001) and descriptive image algebras (CPIII, CPIV) (Gurevich and Yashina, November 2003; 2003; Gurevich and Zhuravlev 2002).

Exploitation of the Generative principle and bases of transforms and models provides for decomposition of a problem into primitive tasks, establishing of the correspondence between basic primitive tasks and basic primitive transforms and combining of basic algorithms and models.

The corner-stone of the Descriptive Approach is a model of image recognition procedures (Figure 1).



$$J, J^*, J^R; T^S, T^R, T^S : J \Rightarrow J^*, T^R : J^* \Rightarrow J^R; \{J\} = \bigcup_j K_j.$$

Figure 1: Descriptive model of image recognition procedures.

4 STATE OF THE ART

The current trends in image recognition are connected with plurality and fusion of image recognition and image data, use of multiple classifiers and of multiple model representations of the images under processing. The classical and modern versions of image recognition schema are represented in Figure 2 and Figure 3.

5 WHAT TO DO OR WHAT TO BE DONE

In this section we shall outline the basic "next steps" necessary to finalize the Descriptive Approach and indicate what is done and what to be done for each of the steps. These steps are as follows:

- Step 1. Mathematical Settings of an Image Recognition Problem (CPI, CPIII-1, CPIII-2);
- Step 2. Image Models (CPII, CPIV-1);
- Step 3. Multiple Model Representation of Images CPIII-3, CPIII-5);
- Step 4. Image Equivalence (CPIV-3);
- Step 5. Image Metrics (CPII);
- Step 6. Descriptive Image Algebras (CPIII-1, CPIII-2, CPIII-4, CPIV-2).

5.1 Step 1. Mathematical Settings of an Image Recognition Problem

Done:

- CPIII-1 - Descriptive Model of Image Recognition Procedures;
- CPIII-1 - Mathematical Setting of an Image Recognition Problem. Image Equivalence Case.

To Be Done:

- CPIII-2 - Establishing of interrelations and mutual correspondence between image recognition problem classes and image equivalence classes;
- CPI - New mathematical settings of an image recognition problem connected with image equivalency;
- CPI - New mathematical settings of an image recognition problem connected with an image multiple model representation and image data fusion.

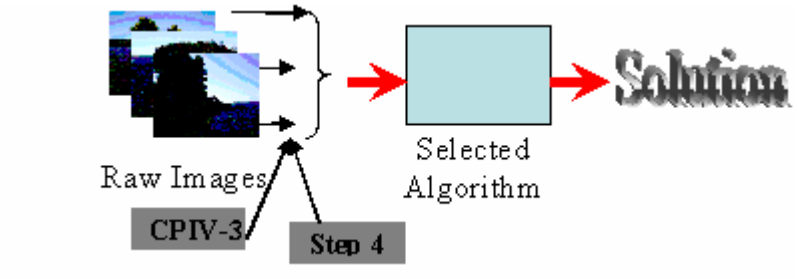


Figure 2: Image recognition. Classical case.

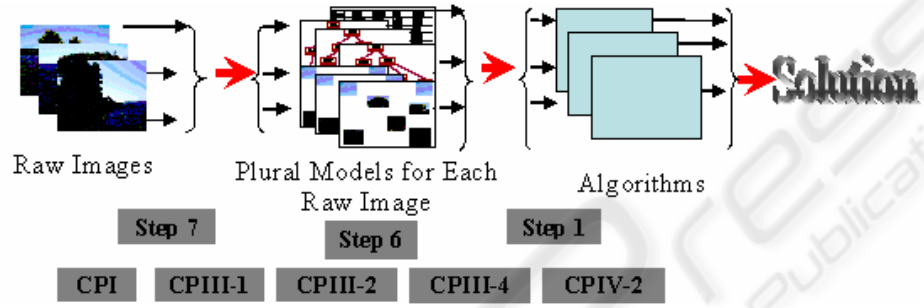


Figure 3: Image recognition. General case (multiple classifiers and model plurality).

5.2 Step 2. Image Models

Done:

- CPII - Main types of image models were introduced and defined;
- CPII - It was shown which types of image models are generated by the main versions of descriptive image algebras with one ring.

To Be Done:

- CPIV-1 - Creation of image models catalogue;
- CPIV-1 - Selection and study of basic operations on image models for different types of image models (including construction of bases of operations);
- CPIV-1 - Use of information properties of images in image models;
- CPIV-1 - Study of multiple model representations of images.

5.3 Step 3. Multiple Model Representation of Images

Done:

- CPIII-3 - Generating Descriptive Tree (GDT) - a new data structure for generation plural models of an image is introduced.

To Be Done:

- CPIII-5 - to define and to specify GDT;
- CPIII-5 - to set up image recognition problem using GDT;
- CPIII-5 - to define descriptive image algebra using GDT;
- CPIII-5 - to construct a descriptive model of image recognition procedures based on GDT using;
- CPIII-5 - to select image feature sets for construction of P-GDT;
- CPIII-5 - to select image transform sets for construction of T-GDT;
- CPIII-5 - to define and study of criteria for selection of GDT-primitives.
- An example of GDT is shown in Figure 4.

5.4 Step 4. Image Equivalence

Done:

There were introduced several types of image equivalence:

- image equivalence based on the groups of transformations;
- image equivalence directed at the image recognition task;
- image equivalence with respect to a metric.

To Be Done:

- CPIV-3 - to study image equivalence based on information properties of an image;

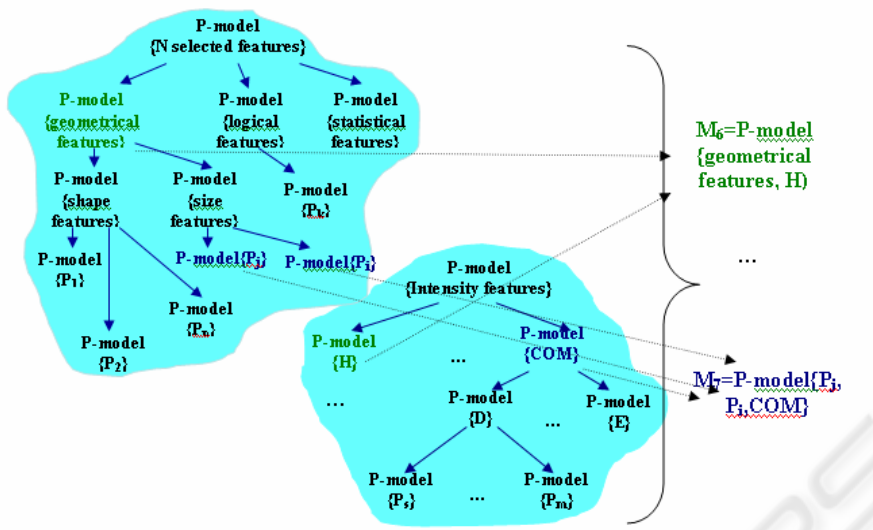


Figure 4: Generating Descriptive Trees.

- CPIV-3 - to define and construct image equivalence classes using template (generative) images and transform groups;
- CPIV-3 - to establish and to study links between image equivalence and image invariance;
- CPIV-3 - to establish and to study links between image equivalence and appropriate types of image models;
- CPIV-3 - to establish and to study links between image equivalence classes and sets of basic image transforms.

5.5 Step 5. Image Metrics

To Be Done:

- CPII - to study, to classify, to define competence domains of pattern recognition and image analysis metrics;
- CPII - to select workable pattern recognition and image analysis metrics;
- CPII - to construct and to study new image analysis-oriented metrics;
- CPII - to define an optimal image recognition-oriented metric;
- CPII - to construct new image recognition algorithms on the base of metrics generating specific image equivalence classes.

5.6 Step 6. Descriptive Image Algebras

Done:

- CPIII-1 - Descriptive Image Algebras (DIA) with a single ring were defined and studied (basic DIA);
- CPIII-2 - it was shown which types of image models are generated by main versions of DIA with a single ring (Table 1);
- CPIII-4 - the technique for defining and testing of the necessary and sufficient conditions for generating DIA with a single ring by a set of image processing operations were suggested;
- the necessary and sufficient conditions for generating basic DIA with a single ring were formulated;
- CPIV-2 - the hierarchical classification of image algebras was suggested (Figure 5);
- it was proved that the Ritter's algebra could be used for construction DIA without a "template object".

To Be Done:

- CPIII-1 - to study DIA with a single ring, whose elements are image models;
- CPIII-2 - to study DIA with several rings (super algebras);
- CPIII-2 - to define and study of DIA operation bases;
- CPIII-4 - to construct standardized algebraic schemes for solving image analysis and estimation problems on the DIA base;
- CPIV-2 - to generate DIA using equivalence and invariance properties in an explicit form;
- to demonstrate efficiency of using DIA in applied problems.

Table 1: Generation of image models by DIA.

	Elements of the Ring	Operations of the Ring	Result (type of a model)
1	Operations for computation of numerical features	Standard algebraic operations	P-models
2	Images	Standard algebraic operations	Images
3	Image algebra operations	Standard algebraic operations	G-, T-models, images, image fragments
4	Standard algebraic operations with parameters	Image algebra operations	G-, T-models, images, image fragments
5	Images and image representations	Image algebra operations	G-, T-models, images, image fragments

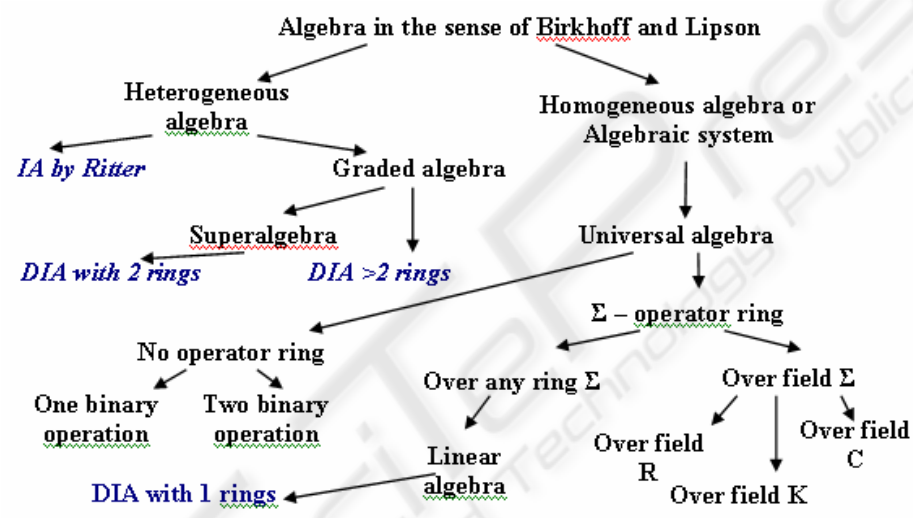


Figure 5: Hierarchy of algebras.

6 CONCLUSIONS

In principle, the success of image analysis and recognition problem solution depends mainly on the success of image reduction to a recognizable form, which could be accepted by an appropriate image analysis/recognition algorithm. All above mentioned steps contribute to the development techniques for this kind of image reduction/image modeling. It appeared that an image reduction to a recognizable form is a critical issue for image analysis applications, in particular for qualified decision making on the base of image mining. The main tasks and problems of an image reduction to a recognizable form are listed below:

1. Formal Description of Images: 1) study and construction of image models (Step 2); 2) study and construction of multiple model image representations (Step 3); 3) study and construction of metrics (Step 5).
2. Description of Image Classes Reducible to a Recognizable Form: 1) introduction of new mathematical settings of an image recognition problem (Step 1); 2) establishing and study of links between multiple model representation of images and image metrics (Steps 3, 5); 3) study and use of image equivalencies (Step 4).
3. Development, Study and Application of an Algebraic Language for Description of the Procedures of an Image Reduction to a Recognizable Form (Step 6).

After passing through the above mentioned steps it would be possible to formulate the axiomatics of the descriptive (mathematical) theory of image analysis.

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