# Ontology-based Framework to Image Mining

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**Abstract.** A novel knowledge-based approach for supporting image processing and analysis is presented as well as its use within a framework for image mining. Modern approaches to knowledge representation, ontologies and reasoning, have been combined with techniques for image processing, analysis and understanding within a semantic framework able to support the extraction of novel knowledge for image collections.

## 1 Introduction

Due to the pervasive diffusion of imagery data and their central role in many key problems of socially and industrially relevant domains, the need for automated applications able to support image analysis tasks has been attracting and absorbing the increasing interest and effort of the research community for the last decades. Furthermore, the possibility of using large image collections to extract novel, relevant and significant knowledge for solving specific tasks has demonstrated to assure an even higher added-value to image processing applications.

Usually, image processing (IP) specialists address each specific problem they are asked to solve by wisely integrating their knowledge about image processing and analysis techniques with the necessary domain knowledge, acquired by elicitation from domain experts and the analysis of all the processes related to image formation, acquisition and interpretation. Once understood the problem, IP expertise is employed in finding out the most suitable techniques that apply to the kind of images and problem at hand. This usually results in a multi-step procedure devoted to solve commonly identified sub-problems, which correspond to main IP issues such as image enhancement, relevant structures extraction and analysis, content categorization and interpretation. The results of this IP chain can be passed as input for an image mining process for being employed into a virtuous loop of knowledge representation and extraction.

In the last years, a big effort has been spent for defining general-purpose computerized applications able to interpret automatically image content, but very

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little has been done for aiding at high level the development of IP applications by systematically defining IP processes and their recording for re-use, evaluation and integration. Indeed, a formal and sound description of IP algorithms can help building applications able to support non-expert users in the choice of the correct algorithms and/or procedures to apply to their particular image instance.

Actually, there are a number of reasons why a clear, formal description of processes, algorithms or methods applied to images can be useful if not necessary. More precisely, clear definitions of algorithms, with explicit references to the problem they solve, the data they manipulate and the parameters they require, can be helpful for building:

- a library or catalogue of IP algorithms suitable for re-use by storage, retrieve and sharing mechanisms, e.g., the formal definition can be easily exploited for automated retrieval of algorithms that satisfy expressed requirements;
- a repository of developed procedures, with the corresponding addressed problems, which can be used as references for similar cases, e.g., via *case-based reasoning*;
- a framework able to support the development of IP applications by suggesting the most suitable algorithms for solving a specific problem. Suggestions can be obtained by reasoning on both the *syntactic* (e.g., input types and parameters) and *semantic* features (e.g., constraints and requirements or high-level description of the results);
- a framework for knowledge extraction able to integrate a library of data mining algorithms tuned on image applications

In the most complex visions, algorithms and information about their applications should be maintained in an appropriate *Knowledge Base*, which formalizes the expertise of IP domain

Ontologies have emerged in the last years as a knowledge representation formalism Ontologies specify reusable conceptualizations which can be shared by multiple reasoning components communicating during a problem solving process.

So far, a variety of methodologies and algorithmic resources have been designed and developed to solve particular tasks, focusing on the specific application problem, but attempts to standardize different approaches and methodologies are still rare.

In this paper, an ontology-based framework to image analysis is discussed and its extension to address image mining tasks is discussed. The approach combines techniques for image processing, analysis and understanding with modern approaches to knowledge representation, ontologies and reasoning, to support intellectual decision making in image understanding tasks. The paper is organized as follows. Section 2 overviews works devoted to the usage of ontologies for solving image-based tasks. Section 3 presents basic ideas of the ontology-based approach to image mining. In Section 4 the description of the ontology on image analysis is presented. In Conclusion the directions of future work are discussed.

## 2 Related Works

Ontologies as an effective way for knowledge representation became very popular last years. Different works related to usage of ontologies for solving image-based tasks have been reported. For example, in [3] an approach for solving the symbol grounding problem involved in semantic image interpretation is presented. The method is based on using the image processing ontology to reduce the gap between the image processing level and the visual level. Authors note that the proposed ontology is not complete and should be considered as a basis for further extension. In [5] a platform dedicated to the knowledge extraction and management for image processing applications is proposed. It includes a system that automatically generates image processing applications on the basis of goal formulations given by a user who is inexperienced in image processing domain. The user defines the goal of processing in terms of his/her application domain and then the system translates this information into image processing terms taken from the image processing ontology. The result of this translation is an image processing request which is sent to the planning system to generate the program that responds to this request.

The main contribution of our work is the development of a sufficiently detailed and well-structured ontology which will cover all important aspects of image processing, analysis and understanding (main categories of concepts, their properties and relations). The proposed ontology can be used as a base for the construction of specialized knowledge bases for supporting image analysis and, then, image mining.

## 3 Ontology-based Image Analysis

In solving problems of image analysis, one must make complex decisions at different levels of processing. To obtain the required solution, usually, several processes and stages of processing should be combined. At each stage, the problem of choosing the most appropriate method and specification of its parameters may arise.

The automation of image analysis assumes that researchers and users of different qualifications have at their disposal not only a standardized technology of automation, but also a system supporting this technology, which accumulates and uses knowledge on image processing, analysis and evaluation and provides adequate structural and functional possibilities for supporting the more intelligent choice and synthesis of methods and algorithms.

The automated system (AS) for image analysis must provide a formal and precise representation of the qualification of the IP specialist and include tools for emulating choice strategies and applying known processing methods used by specialists in solving such problems. The AS must combine the possibilities of the instrumental environment for image processing and analysis and a knowledge-based system. Therefore, one of its main components is a knowledge base. Knowledge bases usually contain modules of universal knowledge, which are not related to any subject domain (knowledge necessary for scheduling and control of the processing, result mappings, estimation of the processing quality, object recognition, and conflict resolution, as well as knowledge about methods of image processing and analysis) and knowledge modules related to a certain subject domain (segmentation strategies, object descriptions, and specialized strategies for feature extraction and object identification). The AS must provide software implementation of the hierarchies of classes of the main objects used in image analysis, have a specialized user interface, contain a library of algorithms that allow one to solve the main problems of image analysis and understanding with the help of efficient computational procedures, and provide accumulation and structuring of knowledge and experience in the area of image analysis and understanding. The need of efficient knowledge representation facilities can be fulfilled by using a suite of ontologies and thesauri. Ontology-based knowledge representation provides: 1) explicit formal description of semantics; 2) shared understanding of a given domain; 3) re-use of knowledge. Ontologies can be considered as a skeleton of knowledge bases for supporting image analysis. Thesauri can help users to create requests to the AS. They can assist in choosing appropriate keywords for specifying a goal to be achieved, data to be processed and results to be obtained (see Fig.1). More detailed description of the proposed approach can be found in our previous work [1].

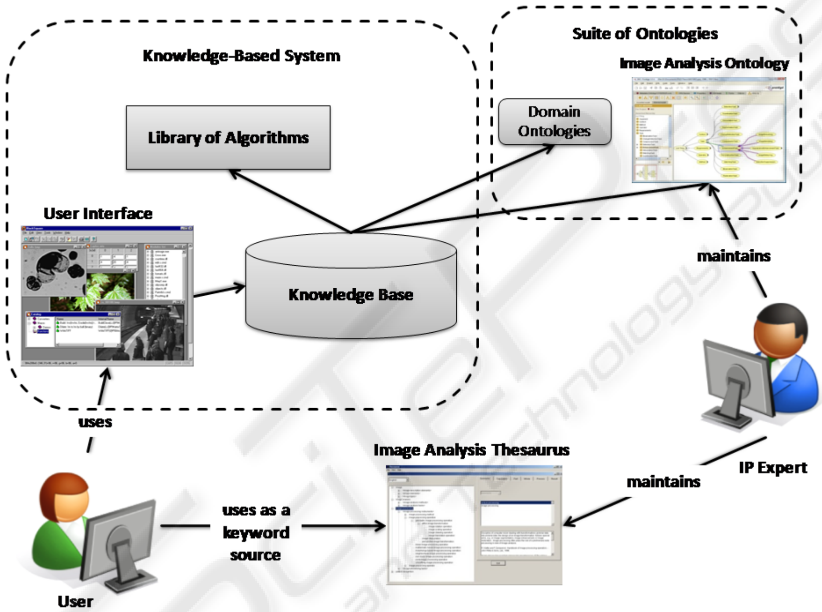


**Fig.1**.Ontology-based methodology.

## 4 Image Analysis Ontology

The Image Analysis Ontology (IAO) is needed for solving the following tasks: 1) construction of unified description and representation of image-based tasks and methods for solving these tasks; 2) automation of image analysis methods combination on the base of semantic integration; 3) automation of navigation and retrieval in knowledge bases on image analysis.

Below the description of the current version of the IAO is presented.

### 4.1 Scope and Sources

The IAO is aimed at representing domain independent knowledge used for solving image processing and analysis tasks. The IAO codifies:

- knowledge about general image-based tasks and their decomposition into sub-tasks;
- knowledge about methods (approaches, algorithms, techniques, operators, etc.) for image processing, analysis, recognition and understanding.

The first step of the ontology development process is to define main classes of concepts of a given domain. As a main source of the information about concepts (including term definitions and basic relationships between terms) the Image Analysis Thesaurus (IAT) [2] is used. IAT is being developed at the Scientific Council "Cybernetics" of the Russian Academy of Sciences and detailed later at the Dorodnicyn Computing Centre of the Russian Academy of Sciences. It contains more than 2000 terms related to image processing, analysis and recognition. The IAT reflects a current state of a given domain. The information about new concepts is being added regularly.

### 4.2 Tools and Languages

The Ontology Web Language (OWL) [6] has been chosen to build the IAO. Today OWL is one of the most commonly used formal language for ontology description. OWL has more facilities for expressing meaning and semantics than XML, RDF, and RDF-S. OWL is intended to provide a language that can be used to:

- formalize a domain by defining classes and properties of those classes,
- define domains and ranges for properties,
- define individuals and assert properties about them,
- reason about these classes and individuals .

For editing the ontology we are using the Protégé ontology editor (version 3.2.1) developed by the Stanford Medical Informatics at the Stanford University School of Medicine [4]. The editor implements a rich set of knowledge-modeling structures and actions that support the creation, visualization, and manipulation of ontologies in various representation formats.

### 4.3 Main Classes and Class Hierarchy

The behavior of an IP expert can be efficiently described in terms of tasks to be solved and methods for solving these tasks.

In general, image processing and analysis tasks are characterized by a final goal to be reached, input data and requirements to a result. The formal definition of the concept «task» is as follows.

**Definition 1.** *Task* $T(G_T, I_T, R_T, C_T)$ is defined by its *goal* $G_T$, *input data* $I_T$, *requirements* $R_T$ and *context* $C_T$ , where

- *goal* $G_T$ – the desired result;

- $I_T$ – the description of input data;
- $R_T$ – requirements to a final result;
- *context* $C_T$ - any useful information.

**Definition 2.** *Method* is an algorithmic procedure or a set of algorithmic procedures characterized by the following:

- its competence (tasks that can be solved by this method);
- input and output data;
- a set of subtasks to be solved (i.e. *complex method*) or an operator (primitive or compose one) (i.e. *primitive method*) to be applied.

Usually, the same task can be solved by several methods. $\{M_T\}$ is a set of *methods* for solving a *task* $T(G_T, I_T, R_T, C_T,)$, if $M_T$: $(I_T,R_T,C_T)$=>$G_T$.

OWL-ontologies consist of the following components: classes (of concepts), properties of classes and individuals (instances of classes). A class defines a group of individuals that belong together because they share some properties. Classes can be organized in a specialization hierarchy using *subClassOf*. There is a built-in most general class named `Thing` that is the class of all individuals and is a superclass of all OWL classes [6].

In accordance to the definitions presented above the following IAO classes were defined: `Task`, `Method`, `Data`, `Context и Requirements`. The hierarchy of subclasses is based on term relations fixed in the IAT.

Current version of the IAO contains the following subclasses of the class `Task`: class `BinarizationTask`, class `CompressionTask`, class `DetectionTask`, class `EnhancementTask`, class `InterpolationTask`, class `MatchingTask`, class `QuantizationTask`, class `ReconstructionTask`, class `RestorationTask` and class `SegmentationTask`. Some of these classes, in turn, also include subclasses. For example, class `ContrastEnhancementTask` and class `NoiseReductionTask` are subclasses of the class `EnhancementTask`. The current version of the IAO contains 24 subclasses of the class `Task`.

It should be noted, that the proposed task hierarchy is a preliminary one. It requires more detailed investigation with involving of experts on every specific subsection of the domain, for example, experts in image compression, image segmentation, etc.

The hierarchy of `Method` subclasses classifies different types of methods in accordance with a task they solve. For example, the class `SegmentationTask` has the corresponding class `SegmentationMethod`, which describes existing methods for image segmentation.

The class `Data` includes the following subclasses: class `Image`, class `ImagePart` and class `ImageSequence`.

The class `Context` includes the following 6 subclasses: class `AcquisitionContext` (context related to image acquisition, for example, camera type and location, acquisition date, etc.), class `ApplicationContext` (context describing a subject domain of a task, for example, biology, medicine, etc.), class `FunctionalContext` (context describing an application of results, for example, diagnostics in the case of a medical task), class `ObjectFeaturesContext` (context related to the description of image objects, for example, geometrical object characteristics, object location, etc.), class PhysicalContext (context describing technical characteristics of an image to be processed, for example, image format, image illumination, image quality, etc.) and class ProblemTypesContext (context describing a type of a task, for example, analysis, processing, recognition, understanding or reducing an image to a recognizable form). This list of subclasses of the class Context is open. New subclasses can be added in the future if it will be needed.

The class Requirements includes the following 2 subclasses: class PerformanceCriteria, which includes the following 2 subclasses: class AlgorithmPerformanceRequirements (algorithm performance requirements, for example, calculation accuracy, computational complexity, etc.) and TechnicalRequirements (technical requirements, for example, CPU characteristics, platform type, etc.) and class QualityRequirements, which describes result quality requirements.

Fig.2 shows relations between main IAO classes.

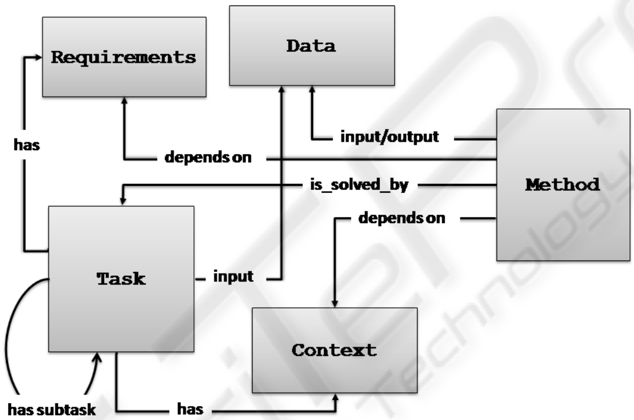


**Fig.2**. Main IAO classes and relations between them.

### 4.4 Properties of Classes

OWL-properties is characteristics of classes. Properties can be used to state relationships between individuals (*owl:ObjectProperty*) or from individuals to data values (*owl:DatatypeProperty*). Property hierarchies may be created by making one or more statements that a property is a subproperty of one or more other properties. A property has a domain (*rdfs:domain*) and a range (*rdfs:range*). A domain of a property limits the individuals to which the property can be applied. The range of a property limits the individuals that the property may have as its value. Properties may be of the following types: inverse, transitive, symmetric, functional or inverse functional. Table 1 shows some examples of different IAO properties.

**Table 1.** Examples of IAO properties.

| *rdf:Property* | *rdfs: domain* | *rdfs: range* | Allowed values | Examples |
|---|---|---|---|---|
| ***is_solved_by*** | `SmoothingTask` | `SmoothingMethod` | Instances | |
| ***num_of_bits*** | `Image` | Integer | 1,4,8,16,24, ... | 8-bit image |
| ***edge_type*** | `Edge` | String | “roof”, “step”,.. | step edge |
| ***linearity*** | `ImageFilter` | Boolean | true, false | linear filter |

Let us consider the property ***is_solved_by*** (see Table). The property is an example of *owl:ObjectProperty* property. Its domain is the class `SmoothingTask`, its range is the class `SmoothingMethod`. The property has an inverse property ***is_appled_for***. Other properties listed in the Table are examples of *owl:DatatypeProperty* properties.

In addition to specific properties, all defined IAO classes have standard OWL-properties such as - *rdfs:comment* and *rdfs:label*. The former property has value in a form of concept definitions extracted from the IAT while the latter property has value in a form of concept names (terms) extracted from the IAT as well.

## 5 Conclusions and Future Work

An ontology-based approach to image analysis has been presented. The description of the ontology on image analysis has been presented. It is important to note, that the ontology is not completed. It requires more detailed investigation of the given domain. We are planning to revise and refine the proposed ontology to extend its applicability by mean of introducing more precise information on tasks and methods.

The work on the ontology opens a straightforward direction for the development of an integrated and advanced framework for mining new information from large collections of images. By integrating the ontology with algorithms for image representation and understanding, high-level semantic information can be extracted from images and data mining algorithms can be applied to it for obtaining novel knowledge about specific domain problems. Such an integration is under design and will be the subject of future research.

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