Granular Computing for Ontologies in Image Management

Zhengxin Chen and Qiuming Zhu

***Abstract*—Algorithms based on granular computing (GrC) have been developed for operations useful in image management. On the other hand, although granular computing has also been applied to development of ontologies, so far there has no well-known research work of using granular computing for development of ontologies in image management. In this paper, we examine this issue, and discuss important aspects need to be considered in a GrC-based approach for integrated ontology development and operations for image management. This examination leads us to further explore its potential *implications*; in particular, we pay attention to the role of image management as an enabling technology for smart city development, which results in our novel proposal on dual level study of ontologies for smart cities; i.e., macro and micro ontologies. Whereas the macro ontology emphasizes the study of smart cities directly at the infrastructure level, the micro-level ontology exploits features of enabling technologies (such as image management) to the development of smart cities in a more specific way.**

***Index Terms*—Ontology, granular computing, image management.**

I. Introduction

In a broad sense, *granular computing* (GrC) is the general term referring any computing theory/technology involves elements and granules, with granule, granulated view, granularity, and hierarchy as its key concepts. Algorithms based on granular computing (GrC) have been developed for operations useful in image processing and analysis. On the other hand, although granular computing has also been applied to development of ontologies, so far there has no well-known research work of using granular computing for development of ontologies in image management. In this paper, we examine this issue, discuss important aspects need to be considered in a GrC-based approach for integrated ontology development and operations for image management. In addition, this examination leads us to further explore its potential *implications;* in particular, we pay attention to the role of image management as an enabling technology for smart city development, which results in our novel proposal on *dual level study of ontologies* for smart cities; i.e., macro and micro ontologies.

Throughout this paper, we use the term *image management* to refer to all stages related to manipulating images, including image acquisition, processing, retrieval, analysis, etc. For now, it is just for convenience. However, as we will see later, the advantage of having this concept is we can use this term to denote integrated process of developing ontologies for conducting all activities at different stages of dealing with images.

The rest of this paper is organized as follows. In Section II we review basics of GrC and GrC-based approaches in image management. From this critical review we point out that existing work based on GrC for image management is largely computation based, rather than ontology or semantic based. In order to develop an ontology for image management using GrC, in Section III, we take a look on how GrC can be used to develop ontologies in general, and what ontologies can do for image management. Based on this discussion, in Section IV we present some key aspects for a GrC based approach of ontology development for image management. This direction of study leads us to further explore (in Section V) what GrC-based ontology can do beyond image management. In particular, we examine the importance of image management as an enabling technology for development of smart cities, and present our novel proposal on dual level study of ontologies for smart cities; i.e., micro and macro ontologies. We conclude this paper in Section VI.

II. Granular Computing for Image Management

A. Basics of Granular Computing (GrC)

We start with a quick review of important concepts in granular computing. A *granule* is a clump of elements drawn together by various criteria such as indisignuishability, equivalence, similarity, proximity or functionality. As such, a granule is an atom of uncertainty. *Granulation* refers to the process of forming granules. The granularity of a level refers to the collective properties of granules in a level with respect to their sizes. Granular structure is the collection of granules, in which the internal structure of each granule is visible. In a broad sense, *granular computing* (GrC) is the general term referring any computing theory/technology involves elements and granules, with granule, granulated view, granularity, and hierarchy as its key concepts. Since uncertainty plays an important role in the granulation process, fuzzy set theory, rough set theory and quotient space theory are three pillars for developing granule computing techniques [1,2,3]. See reference [4] for more on terminology in GrC.

B. Granular Computing and Image Management

Various approaches of using GrC for image management have been developed. For example, [5] presented issues related to image management and understanding from a GrC perspective. A basic concept *geometrical granules g* is defined with parameters x, y, z, w and h, where the point (x, y) defines the upper left corner of the granule and w and h defines the granule width and height respectively. From here, granulated universe can be defined, which is the union of all the geometrical granules. Applying rough set theory, a granulated image can be represented through upper and lower

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approximations. Approximation improvement is needed for human understanding, and maximal likelihood is used as an effective technique to achieve this. In another study, revising the work of [6], Anh *et al.* [7] proposed an approach using information granulation construction and representation strategies for classification in imbalanced data based on granular computing. In this approach, K-means algorithm is used for clustering each subclass in the training data set. In another work, Rizzi and Vescovo [8] described an automatic image classification method based on GrC.

Two related articles from Liu *et al.* [9], [10] addressed the issue of granular computing clustering through hypersphere representation of granule and the fuzzy inclusion measure compounded by the operation between two granules. A granule is composed by the data with the similar features, and the size of a granule is measured by the granularity defined by the maximal distance between data belonging to the same granule. In order to facilitate the study of granular computing, including operations between two granules, granules are represented as standard forms, such as a granule with the shape of circle in 2-dimensional space, as well as a granule with the shape of hypersphere in *N*-dimensional space. Algorithms for meet, join and clustering can then be developed.

Summarizing our discussion presented above, we may notice some commonalities shared by different authors and approaches: They are largely computational based, relying only on the very basic idea of granule. Each approach is basically standalone, without paying much attention to major developments in "mainstream" GrC. Each approach has its merit; yet each approach is developed in its own, somewhat *ad hoc* manner. In our view, there is a need for taking a look on the common semantics behind these approaches, namely, what GrC can offer for *ontologies* involved in image management. We will revisit this issue in a later section. But first, we have to take a brief look on what ontologies can do for image management.

III. Ontologies for Image Management

A. Basics of Ontologies and Its Importance to Image Management

In computer science, an ontology is a formal explicit description of concepts in a domain of discourse, properties of each concept describing various features and attributes of the concept, and restrictions on slots. An ontology together with a set of individual instances of classes constitutes a knowledge base [11]. It has been noted [12] that ontology is a collection of formal, machine-process-able and human interpretable representation of the entities, and the relations among those entities, within a defined application domain.

Formally, an ontology can be defined as the quintuple [13] of {I, C, R, F, A}, where I is the set of instances of the concepts; C is the set of concepts, R is the set of relationships, F is the set of functions defined on the set of concepts that return a concept, and A is a set of axioms, that is first order logic predicates which constrain the meaning of concepts, relationships and functions.

In order to develop an ontology for image management using GrC, there are two important issues to consider, namely, (1) In general, how GrC can be used to develop ontologies; and (2) What ontologies for image management means. These are examined in the next two subsections.

B. GrC and Ontologies

Ontological aspects have been studied by granular computer researchers, including the work on taxonomy of types of granularity [14]. In addition, granular computing can be used to aid the study of ontologies. One example is presented in [15] where the concepts of domain granule and domain granule lattice were introduced, and an algorithm of generating the lattice was proposed to capture the ontology. The relationship between granular computing and ontology can take the opposite direction as well; for example, [16] described a granular computing model based on ontology.

A specific rough-granular approach which incorporates domain knowledge is described in [17]. This additional knowledge, represented by ontology of concepts, is used to assist searching for features (condition attributes) relevant for the approximation of concepts on different levels of the concept hierarchy defined by a given ontology. Yet, the question of how ontologies of concepts can be discovered from sensory data remains as one of the greatest challenges for many interdisciplinary projects on learning of concepts.

Yan *et al.* [18] described an ontology concept hierarchy model to build an ontology based on GrC. On the other hand, [19] discussed how GrC can be *applied to* an *existing* ontology, starting from the observation that granularity is the act of representing and operating the information at different levels of detail. According to Keet [20], [21], granularity deals with organizing data, information, and knowledge in greater or lesser detail that resides in a granular level or level of granularity and which is granulated according to certain criteria, which thereby give a perspective also called view, context, or dimension on the subject domain, henceforth called granular perspective [21]. The granular information can be grouped in various levels made up of granules by following a different level of knowledge. As described in [19], in order to use the same ontology in different domains and by many people for different goals, it is needed to represent the ontology according to several granular perspectives. Four operations are defined to manage the structure of the ontology in different ways: elimination as the inverse of refinement and generalization as the inverse of splitting.

In an interesting review, [22] discussed the intrinsic connection between granular computing and clustering analysis. It presented the principle of granularity in clustering, presented granularity clustering theories involving fuzzy, rough set, quotient space and hybrid approaches. Although this paper does not directly address the issue of ontologies, the principle of granularity in clustering implies relationships, functions and axioms in the quintuple definition of an ontology. An applications of GrC on ontology for modeling a real world problem is described in Liu [23].

Summarizing, we have seen that GrC can make contribution to the research of ontologies in various ways, and methodologies developed in these studies may shed light to future research of GrC-based ontologies in image management.

C. Existing Work on Ontologies for Image Management

As a broad research area, ontologies of image management has been studied by researchers for years. It is important to note that ontologies have to be considered at all stages of image management, from *image acquisition*, *image processing*, to *image retrieval*, and finally, to *image analysis*. As an example of the ontologies for *image processing* is the work by Clouard *et al* [24]. Motivated by the question of what kinds of information are necessary and sufficient to design and evaluate image processing software programs, the aim of this work was to use existing algorithms for developing image processing applications. An image processing application is one component of the low level part of a more global image analysis and computer vision system. An ontology-based model for representing image processing application objectives using a computational language was proposed.

The importance of ontologies in image management at the stage of *retrieval* is exemplified in the work by Suriyakala *et al.* [25]. As noted by the authors, extracting knowledge from image database is challenging and requires a deep understanding of domain-specific knowledge especially in geospatial domain. An approach is proposed to allow semantic satellite image retrieval, capture the semantic image content and manage uncertain information using ontology model.

As an example of ontologies for *image analysis*, Town [26] presented an approach to designing and implementing extensible computational models for perceiving systems based on a knowledge-driven joint inference approach. These models can integrate different sources of information both horizontally (multi-modal and temporal fusion) and vertically (bottom-up, top-down) by incorporating prior hierarchical knowledge expressed as an extensible ontology.

Smith *et al.* [27] is a good example to show that when we talk about ontologies for image management, both generic (i.e., independent to any application domain) and domain-specific considerations are important. Ontologies are designed to be human-readable and also to allow automated reasoning over the domain. Ontology is one strategy for promoting interoperability of heterogeneous data through consistent tagging.

Ontologies of image management have shown significant effectiveness in operations of handling images. For example, Popescu [28] described the technical details of SemRetriev, a prototype system for image retrieval which combines the use of an ontology which structures an image repository and of Content-Based Image Retrieval (CBIR) techniques. Galiano *et al.* [11], [29] showed the use of scenario approach, based on subject domain ontology, allows to significantly simplify adaptation of image processing system to the peculiarities of subject domain without the restriction of the particular algorithms used. In another study, motivated by the question of what kinds of information are necessary and sufficient to design and evaluate image processing software programs, [8], [24] proposed a representation of these information elements using a computational language performable by vision systems and understandable by experts.

In addition, Shi [30] provided an overview of methodologies for image semantic analysis, including discriminative, generative, cognitive methodology. Discriminative methodology is data driven and uses classical machine learning, generative methodology is model driven and utilizes graphical models with text semantic analysis, and cognitive methodology can achieve four levels of generic computer vision functionalities: detection, localization, recognition, and understanding which are very useful for semantic knowledge exploration and image understanding. Note that even [30] does not talk about ontologies directly, all the methodologies mentioned above are directly related to ontologies.

IV. What GrC Can Do for Ontologies in Image Management

We can now summarize our discussion up to this point as follows. In Section II, we have reviewed basic concepts of granular computing, and examined what GrC has done for image management. In Section III, we have reviewed what ontologies can do for image management, and noted that although so far there is no well-known work of GrC for ontologies in image management, GrC can play an important role for ontology development. In this section, we discuss important aspects need to be considered for developing a GrC-based approach for ontologies in image management.

A full-fledged GrC-based ontology in image management takes time to develop. Yet based on our discussion presented in previous sections we can now present aspects need to be considered for developing a GrC-based approach for ontologies in image management.

(a) *Existing work in GrC can be extended to the study of ontologies in image management,* and this can be done in two ways. First, since GrC has been applied to ontologies, it is possible to apply developed ontologies to image management. For example, the rough set approach used in [19] to construct a specific granule view of an ontology could be explored for image management. Another example is implied in the work of [28] on automatic image classification by a granular computing approach, where the symbolic representation of images could be a good starting point for ontology-related study. Yet another direction of extending existing work in GrC is to provide a critical examination on GrC-based concepts and algorithms developed for image processing, identify key elements and develop ontologies from there. Recall earlier we have mentioned that clustering plays an important role in GrC for image management. Since there is an intrinsic connection between granular computing and clustering and since this connection implies ontologies (as discussed earlier), GrC has the potential of making contribution to image management through this direction of development.

(b) *Development of GrC-based ontologies covering all stages of image management*, from image acquisition and processing, to image retrieval, and to image analysis, as explained earlier.

(c) *Instead of developing a standalone GrC-focused ontology,* approaches which are useful for GrC (such as rough set theory or fuzzy set theory) can be *applied on existing ontologies* for image management. In fact, for the ontologies developed for image management, all things under consideration are usually crispy. CrC can be used to tackle uncertainty issues.

(d) *Ontologies developed from GrC can be combined or integrated with other ontologies*. Ontologies at lower, more detailed levels can be embedded into ontologies at higher levels.

(e) *Incorporating application domain knowledge for GrC-focused ontology development*. So far life science seems to be the domain in which ontologies have been well studied, so GrC may take advantage of this. Discussion on integrated studies on GrC, ontologies and bioinformatics can be found in [13], [27].

V. Advantages of Studying Ontologies: Image Management for Smart Cities

The advantage of studying GrC-based ontologies for image management may go far beyond image management itself. In particular, we would use this opportunity to call researchers' attention to the importance of image management for Smart Cities. In this section, after a brief review on the basics of smart cities and related ontologies, we discuss image management for smart cities, propose the dual level integrated study of GrC-based ontologies for image management in smart cities.

A. Smart Cities and Ontologies

The smart city concept is defined as an urban area that creates sustainable economic development and high quality of life by exceling in six key areas: economy, mobility, environment, people, living, and government [31]. Due to importance of smart cities, various approaches have been proposed for studying ontologies of smart cities. For example, Komninos *et al.* [32] argued that the impact of applications depends primarily on their ontology, and proposed building blocks of an ontology of smart cities. Abid *et al*. [33] showed an effort to exploit the concept of semantic Web for designing a new smart city ontology that is considered as a system of systems. Such ontology is beneficial for both the citizens and the administrators as it allows interoperability among different systems and frameworks. As a consequence of the significant amount of diverse ontologies for smart cities developed in the last decade, researchers have started efforts for interoperation and integration of these ontologies, as shown in the work by [34] and [35].

B. Image Management for Smart Cities

We can now take a look at image management for smart cities. A general discussion on enabling technologies can be found in [36]. In an editorial overview, [30] noted that the computer vision field is nowadays mature enough to demonstrate its possibilities beyond the surveillance and law enforcement purposes. From the autonomous car idea to the automatic interpretation of people interaction, groundbreaking applications open new ways to contribute to goals of this smart city concept. Examples include:

(a) An advanced driver assistance system implemented by a system on chip composed of a programmable logic that supports parallel processing necessary for a fast pixel-level analysis, and a microprocessor suited for serial decision making;

(b) A prototype based on line sensor cameras as a low-cost vehicle counter solution; the entire pipeline is a low-complexity design for an embedded hardware platform with very limited computational resources;

(c) A system architecture provides an automatic activity-dependent lighting environment as well as significant energy savings through the efficient integration of simplified computer vision strategies.

These examples clearly indicate that image management is becoming an important enabling technology for development of smart cities. Other related applications can be found in [37].

C. Dual Level Study of Ontologies for Smart Cities

Although importance of ontologies for both smart cities and image management has been recognized by IT researchers, they are largely studied separately. In addition, the integrated studies for ontologies of smart cities are mainly restricted to the notions directly related to smart cities, without taking considerations of enabling technologies such as image management. In order to make ontologies really useful, we now propose the exploration on the *relationship of ontologies of smart cities and ontologies of its enabling technologies.* The good news is that the need for exploration of studying relationships of ontologies of smart cities and its enabling technology has started being recognized, but much work is still needed. For example, Town [26] presented an approach to designing and implementing extensible computational models for perceiving systems based on a knowledge-driven joint inference approach. These models can integrate different sources of information both horizontally (multi-modal and temporal fusion) and vertically (bottom-up, top-down) by incorporating prior hierarchy. In our view, the hierarchy in the integration of vertical information could play a critical role of bridging the ontologies at higher (in our case, smart cities) and lower levels (in our case, enabling technologies). However, although Town's research may imply the need for studying ontologies beyond one single level, it does not directly address ontologies directly related to smart cities.

So far the only use case of relationship between ontologies of smart cities and its enabling technologies has drawn attention is [38]. Using detecting available parking spaces as an example, [38] discussed how to provide solutions to social problems by leveraging image analysis technology. The most interesting part of their work is the description of a *vertically integrated* approach, ranging from infrastructure to services based on the concept of open forum of software. However, [38] is largely an application-oriented paper, and no definition was given for the vertically integrated approach.

Based on our understanding of the two articles summarized above, we can now provide the following working definition: *Vertical integration of ontologies* refers to integrated ontologies from most general level to most specific level. In particular, *vertical integration of ontologies for smart cities* refers to integrated ontologies related to overall infrastructure of smart cities, along with ontologies of enabling technology at various levels for smart cities. For convenience of discussion, we also use the term *dual level* to distinguish ontologies studied at the main subject level, or *macro level* (in our case, smart cities), versus ontologies studied at the level(s) underneath it, or *micro level* (in our case, enabling technologies for supporting smart cities). We believe that this dual level approach of studying ontologies is much more realistic than directly studying a huge "universal" ontology, because the dual level approach makes our study more goal-oriented, so that micro level ontologies can be "plugged in" to the macro ontology whenever it is needed, to assure highest level of flexibility for integration of ontologies.

VI. Conclusion

Currently we are working on a sponsored project involving data fusion and visualization using multi-sensor NDE techniques. Image-based techniques have been used in road construction and public services, such as for concrete bridge inspection [39]. While we have focused on technical issues such as evaluation of algorithms on imbalanced data in image processing, we have also developed new interest on a larger scope of research perspective, particularly the relevance of image management to the development of smart cities, and the importance of ontologies in this big task. The approach presented in this paper is based on our previous research in granular computing (GrC). More work is needed for the proposed novel idea of dual level ontologies to accommodate vertical integration of various applications in smart cities.

A full-fledged GrC-based ontology in image management takes time to develop. Nevertheless, we can conclude this paper by summarizing the two most notable features of this paper, namely,

(a) We have reviewed GrC for ontology development in image management, described what GrC can do and what is yet to be accomplished; and

(b) We have presented the novel idea of dual level study of ontologies for smart cities. Although this is a general concept and is not necessarily restricted to GrC-based techniques, GrC can serve as the starting point to explore the proposed approach.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

The work was stimulated from an NRI Grant on data fusion and visualization. Both authors serve as co-PIs. This research is a continuation of ZC's previous work in GrC and ontologies and QZ's previous work in image processing and related areas. All authors had approved the final version. ZC is the corresponding author.

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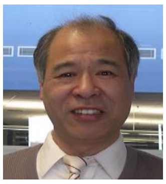

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