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Knowledge sharing in Web-based collaborative multicriteria spatial decision analysis: An ontology-based multi-agent approach

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ABSTRACT

The Web-based Multicriteria Spatial Decision Support Systems (MC-SDSS) enhance the collaborative/participatory spatial decision making by providing the relevant GIS-based MCDA (Multicriteria Decision Analysis) tools for active participation/collaboration. Typically, regular/novice decision makers need to acquire knowledge from expert decision makers in a participatory decision making process. Over the last decade or so, significant research efforts have been made to use Web-based GIS-MCDA tools for collaborative spatial decision making. However, these efforts as the collaborative decision making tools lack a knowledge sharing mechanism or framework that allow for exchange and sharing of decision knowledge between decision makers (decision makers' agents). In the case of providing knowledge sharing capabilities by these tools, exchange of decision knowledge relies on decision makers' common sense to manually interpret the meanings of each other's knowledge and use the right ones. To address these limitations, this study proposes an ontology-based multi-agents approach for knowledge sharing in a collaborative MC-SDSS. The decision makers' agents committed to the ontology can interoperate and exchange decision knowledge with intended and unambiguous meanings.

1. Introduction

It has been recognized that spatial decisions made collectively tend to be more effective than decisions made by an individual decision maker. Previous studies suggest that spatial decision making paradigm should move from the traditional, centralized, bureaucratic, and top-down approach to a holistic, participatory, communicative, and collaborative decision making practice (e.g., Bugs, Granell, Fonts, Huerta, & Painho, 2010; Gorsevski, Cathcart, Mirzaei, Jamali, & Ye, 2013; Jelokhani-Niaraki & Malczewski, 2014, 2015a; Simão, Densham, & Haklay, 2009). Decision makers including urban planners, experts and analysts could potentially communicate with each other to share and exchange knowledge, and provide a collective solution during spatial decision making processes (e.g., site selection and land use suitability assessment processes). With different expertise levels, experience, domain knowledge and analytical abilities, decision makers range across experts to novices in defining decision knowledge and using spatial decision support tools.

The concept of Web-based GIS has been proposed as an effective tool for participatory/collaborative/group spatial planning or decision making. The Web can be used as an information infrastructure for delivering spatial data and GIS functionalities to the general public. The integration of Web-based GIS and MCDA (Multicriteria Decision Analysis) techniques can provide appropriate MC-SDSS (Multicriteria Spatial Decision Support Systems) for direct involvement of people in a collaborative spatial planning process (Malczewski & Rinner, 2015). The tools integrate GIS capabilities (spatial databases and analyses) and MCDA techniques into Web platform to support a user or a group of users in making better spatial decisions (Boroushaki & Malczewski, 2010a; Jankowski & Nyerges, 2001; Jelokhani-Niaraki & Malczewski, 2014, 2015a; Kordi & Brandt, 2012). The GIS-MCDA approaches can be effectively used to support a wide variety of land use decisions and assessments problems according to multiple criteria and decision makers' preferences (Chen & Paydar, 2012; Chen, Yu, & Khan, 2013; Ebrahimian Ghajari et al., 2018; Musakwa, Tshesane, & Kangethe, 2017). Web technologies open new possibilities for the use of GIS-MCDA in a participatory environment, shifting the paradigm of participatory decision making processes from a closed, place-based (fixed time and location), and synchronous process to open, asynchronous, distributed, and active processes. Access to the relevant GIS-MCDA data and tools anywhere (any location that has the Internet access), anytime (24 h a day, seven days a week), by anybody and through any PCs or handheld devices (e.g., PDA, smart phones) and networks has remarkably enhanced the level of participation in spatial planning.

Jelokhani-Niaraki and Malczewski (2012a) suggest that Web-based collaborative GIS-MCDA processes should move toward being user-

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driven, where the processes provide decision participants (i.e., decision makers) with a choice or definition of their own decision model (knowledge) during a multicriteria spatial decision making process. They suggest that the collaborative GIS-based MCDA methods as the participatory spatial decision making tools need to provide a more flexible and adaptive decision making framework in which each participant can define his/her knowledge such as constraints, criteria (i.e., objectives, sub-objectives, and attributes), alternatives, and preferences. Malczewski and Rinner (2015) argue that the primary aim of the GIS-MCDA is to improve the effectiveness of decision making by incorporating decision makers' knowledge into computer-based procedures. Scheuer, Haase, and Meyer (2013) place emphasis on integrating knowledge into a multicriteria spatial assessment approach, where they propose to put stakeholders' preferences into operation in form of a knowledge-base, thereby making it accessible and reusable in multicriteria assessment. There have been a number of studies highlighting and demonstrating integration of knowledge into spatial decision making processes (Arciniegas & Janssen, 2012; Cheung et al., 2016; Debolini, Marraccini, Rizzo, Galli, & Bonari, 2013; Giordano & Liersch, 2012; Natarajan, 2017; Rodela, Bregt, Ligtenberg, Pérez-Soba, & Verweij, 2017; Scheuer et al., 2013; Wei, Xu, & Tang, 2011; Zhu et al., 2014). For instance, Arciniegas and Janssen (2012) implemented a collaborative workshop for land use planning using GIS-MCDA, in which stakeholders used drawing tools on the Touch table in order to transfer and process local knowledge. Natarajan (2017) coined the term “Socio-spatial learning”, where spatial planning knowledge is framed upon community engagement. They described a case study of incorporating community knowledge in participatory spatial planning and decision making process. Rodela et al. (2017) investigated two key social sides of spatial decision support systems: knowledge integration and learning. Their study focused on the extent that current SDSS research considers and accommodates knowledge integration and learning.

In a knowledge-driven collaborative GIS-MCDA environment, decision makers with various level of knowledge, expertise, and experience may need to share and exchange their decision knowledge regarding the decision problem at hand. Usually, regular/novice decision makers need to acquire knowledge from expert decision makers. The knowledge sharing of people representing diverse areas of information and potentials provide a compromise and consensus solution. Over the last decade or so, significant research efforts have been made to use Web-based GIS-MCDA tools for collaborative spatial decision making (Boroushaki, 2010; Boroushaki & Malczewski, 2010b; Chen, Jiang, & Li, 2007; Dragićević & Balram, 2004; Evans, Kingston, & Carver, 2004; Hall & Leahy, 2006; Hamilton et al., 2016; HaryPrasetyo, Muhamad, & Fauzi, 2016; Jankowski, Zielinska, & Swobodzinski, 2008; Jelokhani & Malczewski, 2014; Jelokhani-Niaraki & Malczewski, 2014; Jelokhani-Niaraki & Malczewski, 2015a; Karnatak, Saran, Bhatia, & Roy, 2007; Mekonnen & Gorsevski, 2015; Mirmohammadi, Jelokhani Niaraki, & Alavipanah, 2016; Rao et al., 2007; Silva, Alçada-Almeida, & Dias, 2014; Simão et al., 2009; Taranu, 2009; Voss et al., 2004; Yalew, van Griensven, & van der Zaag, 2016). A number of Web-based GIS-MCDA tools have used knowledge sharing tools such as forums, blogs, argumentation maps, etc. (e.g., Arciniegas & Janssen, 2012; Boroushaki & Malczewski, 2010b; Ferretti, 2016; Jelokhani & Malczewski, 2014; Simão et al., 2009). However, these efforts as the Web-based participatory decision making tools lack a knowledge sharing mechanism or framework that allow for automatic interpretation as well as exchange and sharing of GIS-MCDA knowledge elements between decision makers (or decision makers' agents). In these tools, exchange of decision knowledge relies on decision makers' common sense to manually interpret the meanings of each other's knowledge and use the right ones. Conventionally, decision maker A needs to manually examine the meanings/semantics of knowledge terms specified by decision maker B based on his/her experience and, if appropriate, use it in his/her decision. In other words, when decision maker A needs to use knowledge of decision maker B, it specifically requires the decision maker A to interpret and understand the meaning of knowledge terms used by decision maker B. In such cases, exchange of knowledge between decision makers mainly requires human mediator intervention to mediate meanings and appropriately transmit them. This is due to the fact that the semantics/meanings of decision knowledge are not explicitly organized; they are in the form of informal and implicit assumptions in decision makers' minds. In other words, the burden of semantic interpretations and mediations of knowledge terms is on the shoulders of decision makers (Jelokhani-Niaraki, Sadeghi-Niaraki, & Choi, 2018; Peachavanish, Karimi, Akinci, & Boukamp, 2006).

Collaborative GIS-MCDA tools need to provide the capabilities to exchange knowledge with intended and unambiguous meanings. Certainly, only if the semantics of decision knowledge are defined and shared between the two decision makers, the knowledge transmitted would be automatically recognized and processed. There is, therefore, a need for research to facilitate semantic knowledge sharing among decision makers, where decision knowledge/information can automatically be reasoned and shared with intended meanings. Ontologies are considered as an enabling technology for semantic knowledge sharing (Fonseca, Egenhofer, Davis Jr, & Borges, 2000; Jelokhani-Niaraki et al., 2018; López-Cuadrado, Colomo-Palacios, González-Carrasco, García-Crespo, & Ruiz-Mezcua, 2012; Morente-Molinera, Pérez, Ureña, & Herrera-Viedma, 2016; Yoo & No, 2014). Swartout and Tate (1999) define ontology as a basic structure or framework around which a knowledge-base can be built. Formally, the ontology of a particular domain covers its terminology (domain vocabulary), all essential concepts and their instances (individuals) in the domain, their classification, taxonomy, and relations (Gaševic, Djuric, & Devedžic, 2009).

Jung, Sun, and Yuan (2013) discuss that ontologies provide knowledge-bases for domain experts to formalize geospatial semantics and conceptually model geospatial problems for semantic inferences (see also Lee, Lee, & Kwan, 2017; Mignard & Nicolle, 2014; van den Brink, Janssen, Quak, & Stoter, 2017). A knowledge-base can be defined as an ontology that has been populated with instances (Buckner, Niepert, & Allen, 2011). Evangelou, Karacapilidis, and Khaled (2005) argue that a well-defined ontology-based knowledge model facilitates sharing and reuse of bodies of knowledge across groups by providing a shared understanding of decision model. The ontology is needed to express the collaborative GIS-MCDA knowledge in a shared, unified, structured, meaningful, and machine-interpretable form, ready for software agents and people to interpret, process, communicate, share, and reuse (Jelokhani-Niaraki & Malczewski, 2012b; López-Cuadrado et al., 2012; Jelokhani-Niaraki et al., 2018). In addition, agents can be used to carry out some set of knowledge sharing operations on behalf of a decision maker, with some degree of independence or autonomy, and in so doing, employ some knowledge or representation of user's goals and desires (Obitko, 2007). The agents have been widely used in the context of group decision making in general and group spatial decision making in particular (e.g., Malczewski & Rinner, 2015; Pooyandeh & Marceau, 2013). The purpose of this paper is to address the need for knowledge sharing in collaborative GIS-MCDA setting by developing a GIS-MCDA knowledge sharing framework based on a collaborative GIS-MCDA ontology and multi-agents paradigm. It involves processing and assessing the similarity of knowledge inputs using Natural Language Processing (NPL) measures for spatial knowledge matching and sharing purposes (Chen, 2014; Lampoltshammer, 2012; Wang, Du, Feng, Zhang, & Zhang, 2018). A prototype implementation of knowledge-based collaborative GIS-MCDA was developed for tackling a parking site selection problem.

2. Knowledge sharing and collaborative GIS-MCDA

The collaborative GIS-MCDA methods should provide ways to support knowledge exchange and acquisition process in a collaborative