GeoAgent-based Knowledge Acquisition, Representation, and Validation

Chaoqing Yu

Department of Geography, the Pennsylvania State University
302 Walker Building, University Park, PA 16802
Email: cxy164@psu.edu

GISystems have become essential tools for learning about and understanding Earth-related processes. Much evidence of these factors can be counted or otherwise measured in the landscape, and therefore also be quantified for representation in geospatial databases as observed facts. As such, we look upon the current GISystems as 'data-centered'. There are, however, many factors affecting the landscape, which cannot be directly seen, particularly when dealing with human-environment interactions. These include such things as political policies, plans, and laws; cultural elements such as religions, morals, and customs; and individual knowledge, beliefs, plans, goals, and skills. To gain better understanding of the highly complex, dynamic, linked, and scale-dependent human-environment relationships (Yarnal, 2001), we must be able to develop ways for representation of such things in a GIS context.

The research reported upon here introduces a concept of **GeoAgent** (geographic agent) for representing the human element of the Earth system. A GeoAgent is a spatially related software agent[1] embedded with knowledge that is acquired from one or a group of human individual(s), or institute(s) who inhabit(s) in and interact(s) with the dynamic

[1] An agent, here, is understood as an object with goals (Luck and d'Inverno, 2001). An agent is called as a software agent if and only if it communicates with other agents correctly in an expressive agent communication language (Genesereth and Ketchpel, 1994).

social and natural environment in the real world during a particular period of time. A GeoAgent is able to perform goal-driven actions, can memorize, learn and update its knowledge over time, is capable of "understanding" the information from spatial databases in order to respond the physical environmental changes, and can cooperate with other GeoAgents to achieve higher-level social goals. Together with the existing space-time studies in GIScience (Couclelis, 1992; Cova and Goodchild, 2002; Goodchild, 1989; Langran and Chrisman, 1988; Peuquet, 2001), this research considers *object, field, GeoAgent,* and *time* as the four fundamental representational components.

To integrate these four components at an implementational level, a conceptual representation framework, which is based on several previous work, including Mennis and Peuquet et al., 2000; Peuquet, 1988; and Peuquet, 1994, is introduced. The key challenge in implementation lies in how to technically bridge the gap between knowledge representation and spatial databases. A solution proposed in this research is to adopt two ways for representing geographic knowledge at the same time: *rule-based knowledge systems* and *graph-based concept maps*. Rule-based knowledge systems are used for encoding the social policies and laws to build GeoAgents' spatially distributed knowledge bases that determine GeoAgents' actions. The concept maps, which are graphic notations for representing knowledge in patterns of interconnected labeled nodes and arcs (Zaff and McNeese et al., 1993), are applied to visually construct and display geographical categories, objects, events, and GeoAgents, as well as their relationships. The GeoAgents can respond to the environmental changes by examining the status of their related geographic components on the concept maps, and then perform actions according to the stored rules in the knowledge systems. The mappable components on the concept maps are linked to GIS databases to indicate the related spatial information. Obviously, concept mapping acts as a pivotal technology to connect users, the stored geographic knowledge, and spatial databases together. Based on this strategy, implementation of a Java-based prototype is described. This prototype utilizes a combination of open source software packages, including Madkit (Multi-agent Development Kit), JESS (Java-based Expert System Shell) Touchgraph, and JTS (Java Topology Suite) and GeoTools for GIS. The major language for GeoAgents' communications applied in this project is ACL (Agent Communication Language).

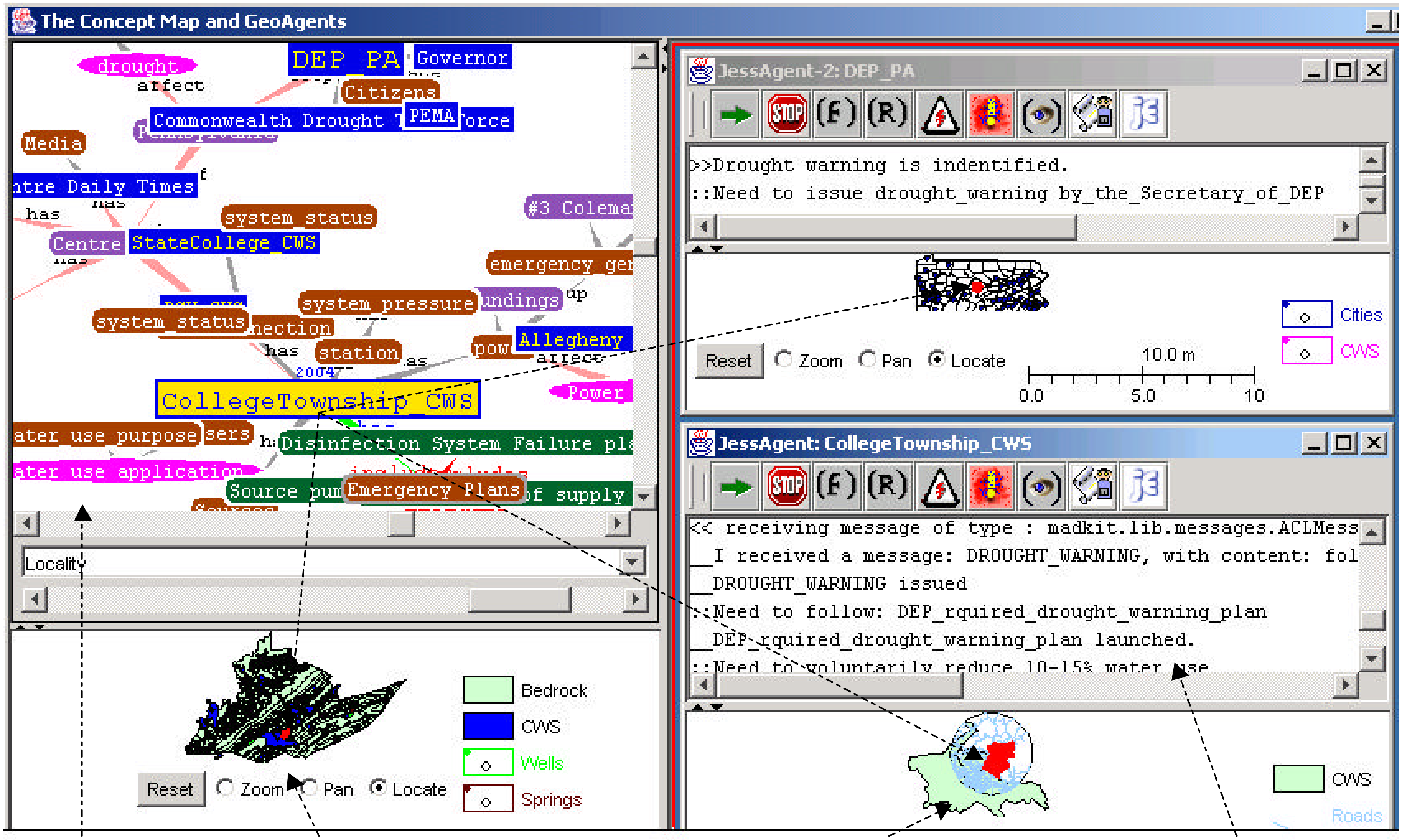
Employing this prototype software, case studies were conducted. Specifically, I demonstrate how human-environment interactions related to CWS (community water systems), especially in the hierarchical social process of drought management in Central Pennsylvania (PA), can be represented in the integrated spatial databases, concept maps, and GeoAgents knowledge bases (see Figure 1). In order to match what GeoAgents represent in the real world within the case studies, knowledge engineering, which is a process of capturing and formalizing the abstract knowledge into digital knowledge systems (McGraw and Harbison-Briggs, 1989; Schreiber and Akkermans et al., 2000; Morrison and Schaefer, 1991; Turban, 1993; Chorafas, 1990; Kasabov, 1996), is a crucial procedure for building GeoAgents. The focus of this paper is on a systematic way of GeoAgent-based geographic knowledge acquisition, representation, and validation.

Knowledge acquisition: Because a GeoAgent may represent a particular CWS, DEP, or local government agency in the case studies, *interviews* and interpretations of *pre-existing documents* are the two major approaches to geographic knowledge. For interviews, two different methods are applied: traditional interviews, and computer-based concept mapping. The method of traditional interviews is based on coding the transcripts of interviewees' oral answers to the pre-designed questions. The computer-based-concept-mapping approach is using the prototype software as a direct knowledge acquisition tool. During the interviews, the author was operating this software in a laptop; and the interviewees interactively worked with the operator to create, change, or delete concept nodes and their relationships on the laptop screen. In total, 15 traditional and 3 computer-based-concept-mapping interviews of local water managers are used as sources for geographic knowledge representation. In addition to interviews, another way is to interpret the pre-existing documents. In the demonstration case, this include the law of "Prohibition of Non-essential Water Use", the DEP (the Department of Environment Protection in PA)'s "Drought Management Plans", emergency plans and drought contingency plans of local CWS.

Knowledge representation: All of the acquired laws, regulations, and plan are converted to executable JESS rules in GeoAgents' knowledge bases. The acquired concept maps from interviews or documents are linked to geospatial databases. The GeoAgents then check the status on the concept maps, and can communicate with each other using ACL to perform actions in term of representing human-environment and social interactions (Figure 1). An important strategy to design the distributed GeoAgents is using the hierarchical goal inheritance and task specification to reduce redundancy of rules. For example, the DEP's drought management plans have general goals on how much water use should be reduced during a drought watch, warning, or emergency condition; and DEP's laws regulate the purposes of water usage during emergency conditions. Although these plans and laws are stored in the GeoAgent of DEP's knowledge bases, they can be inherited or shared by the GeoAgents of local CWS. According to their own local plans and specific environmental conditions, the CWS specify the state-level plans and laws in their actions for achieving the higher-level social goals.

Validation of GeoAgents' knowledge: In order to prove whether GeoAgents' actions are rational or not, knowledge validation is required. The approach is using experts' evaluations by re-interviewing some of the experienced water managers. When the GeoAgents' environmental settings are changed, the managers are asked to count how many actions taken by GeoAgents are wrong, missing, or incomplete. The results show that GeoAgents' behaviors in the case studies can perfectly match the water managers' opinions. After reviewing the performance of this prototype, the water managers, as well as local planners, believe that this GeoAgent-based system can be significantly valuable in supporting quick decision-makings in time-critical and regulation-rich situations.

Figure 1. An example of integrating geographic knowledge representation and spatial databases: the mappable concept nodes are simultaneously linked to multi-scale databases, and to GeoAgents' knowledge bases if applicable; GeoAgents respond to environmental changes by checking the status of the concept nodes



the concept map the study area: Centre County, PA the GeoAgent's natural environment the GeoAgent's knowledge-driven actions

Acknowledgement:
This research is supported by the NSF HERO project (http://hero.geog.psu.edu, under grant No. 9978052), led by Professor Brent Yarnal. I wish to acknowledge the help from Donna Peuquet, Brent Yarnal, Alan MacEachren, and the influence from David O'Sullivan, John Yen, Mark Gahegan, and other GeoVISTA and HERO team members.

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