Communicating Spatial Uncertainty using Geospatial Reasoning

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BIOGRAPHY OF PRESENTER

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ABSTRACT

Users of remotely sensed imagery need to know about the spatial uncertainty in their image data in order to make sound decisions using their imagery. As a minimum, the user should understand the presence and level of spatial uncertainty in their data.

This paper proposes the use of intelligent software agents as a means of assisting users to understand the spatial uncertainty in their images. These agents incorporate geospatial-reasoning capabilities and participate in a multi-agent architecture that enables them to identify and communicate the uncertainty present in imagery. The reasoning model used by the agents is based on the Belief Desire Intention (BDI) model often used in artificial intelligence.

The reasoning required by the agents to communicate spatial uncertainty was modelled using beliefs, desires and intentions. The modelling involved identifying the types of agents, their roles and applying BDI concepts to define behaviour that allowed the agents to achieve defined goals.

A prototype was developed that includes a multi-agent architecture, techniques for visualising uncertainty and an interaction diagram to allow the user and agent system to communicate and provide feedback to each other.

Imagery of the Point Wilson coastal area in Victoria, Australia was used in this study. Four existing images that had been classified based on land use were overlaid to create a composite image containing spatial uncertainty. The prototype was tested using the composite image.

This study has demonstrated that software agents with geospatial reasoning capabilities are able to assist users to understand uncertainty in their image data. An interaction diagram that maps the users goals to the agent reasoning capability allows

a user to communicate to the agent system. The agents are able to modify their behaviour in response to advice from the user, so that the user's goal of understanding the uncertainty in their image data can be achieved.

INTRODUCTION

Digital imagery is now widely available to the general public and is used is a range of applications. These applications can include the use of imagery to provide background context for GIS projects, the use of images to provide map content in web pages and the use of images in the construction of surfaces for 3-dimensional visualisations.

One of the main issues with the wide availability of imagery is that non-specialist users may be unaware that their images and other spatial products can contain errors, be inaccurate and contain information that is far from certain. These users have this misconception because they are typically non-image specialists and assume that the images can be accepted at face value and used without any consideration of the consequences of their use. However, such users can be provided with assistance to gain an understanding of the properties of their data sets.

This paper proposes the use of *intelligent software agents* to assist users to reach a satisfactory level of understanding about the spatial uncertainty in their classified imagery so that they can make informed decisions. Agents with geospatial reasoning capability can be incorporated in software tools that can be used to analyse image data sets and provide feedback to users about the uncertainty in the data.

SPATIAL UNCERTAINTY

Though the GIS community uses the terms spatial accuracy, error, quality and uncertainty interchangeable, this work is focussed on spatial uncertainty. The reader can refer to work by Hunter and Goodchild (1994) for a discussion of accuracy, error and quality in a spatial context.

Spatial uncertainty exists when we have a lack of knowledge about the differences (and the reasons for their occurrence) between the observation or results that are obtained and the truth to which they pertain (Hunter and Goodchild, 1994). Allan (1998) has shown that spatial uncertainty exists in classified remotely sensed imagery in the form of *geometric* and/or *semantic* uncertainty.

Geometric and spatial uncertainty is discussed in-terms of land use. If the location of the boundary of a polygon representing a given instance of a land-use class is either defined incorrectly or is unknown, then the polygon has geometric uncertainty. Semantic uncertainty is defined with respects to the non-spatial characteristics of the land-use classes of an image. There are two cases of semantic uncertainty for land-use classes:

1. Uncertainty in land-use that has been assigned to a region within the image
2. Uncertainty in attribute values of the land-use type assigned to a region.

The uncertainty in an image can be included in the meta-data descriptions associated with an image. However, though meta-data may include uncertainty descriptions, non-specialist users may not be able to interpret the meaning of these descriptors. In addition, software agents can use these descriptors and/or analyse the data to communicate the uncertainty to users. This paper follows on from work performed by Darragh & Allan (2002).

THE AGENT CONCEPT

Intelligent software agents (Busetta et al, 1999; Gilbert, 1997) are a field of study of artificial intelligence (AI) (Jackson, 2002). Other fields of AI study include neuroscience, computational vision, machine learning and statistical pattern recognition, knowledge-based systems/knowledge representation, knowledge management, expert systems and Intelligence Computer-Aided Instruction (Jackson, 2002).

Agent Characteristics

Franklin & Graesser (1997) identify the characteristics of software agents that distinguish them from computer programs. Gilbert (1997) also identifies these characteristics, which are autonomous, goal-driven, reactive and continue to run.

Agents are *autonomous*. When an agent is delegated to perform a task, it has independence to perform the task. Maes (1995) notes that if computers are to become more widely used then the direct manipulation metaphor common to desktop and mobile computers will have to be replaced by delegation where tasks are delegated to the software.

Agents are *goal-driven* because they have a purpose and act in accordance with that purpose. Agents are *reactive* as they are able to sense changes in their environment. Agents *continue to run,* as they do not have a limited lifetime. In addition to the above characteristics, some agents can also be social, customised or adaptive, mobile and/or believable.

Some agents are *social* as they can interact and communicate with other agents. Agents that ate *customisable* or *adaptive* learn and change their behaviour based on past experiences. Some agents are able to move within a network and as such are *mobile*. Agents that strive to be *believable* are visible and/or audible to the user.

Franklin & Graesser (1997) provide a taxonomy of autonomous agents that includes software agents. Software agents are a subclass of computational agents. Classes of software agents include task-specific agents, entertainment agents and viruses. The agents used in this study are task-specific agents.

Multiple Agents

In agent-based systems, multiple agents exist and each agent has a specific role to perform. The role an agent performs within the system is based on the *type* of the agent - each agent is a specific type of agent. For example, an agent may have a role to present information to the user or query datasets searching for patterns in the data.

Agent Communication

Each agent performs the tasks associated with its role. An agent will perform a task when a request is made to the agent. Requests are typically from other agents but they can also be from *objects* or *programs* that may exist in the system. Agents have a mechanism to communicate so that they can receive requests and provide feedback with the outcome of a request. The mechanism used by agents is typically a message-based protocol. The kinds of communication include agent-to-agent and human-to-agent.

AGENT REASONING

Reasoning is defined as the *"intellectual faculty by which conclusions are drawn from premises"* (The Australian Pocket Oxford Dictionary, 1981). A key differentiator of agents from other software constructs such as objects and programs is that they have the ability to reason. As previously mentioned, one of the characteristics of agents is that they are goal-driven. Agents are able to achieve goals because they contain a reasoning model that supports goal-oriented behaviour. Such a model is the *Belief Desire Intention* (BDI) model.

Goal-directed Reasoning

The *Belief Desired Intention* (BDI) framework enables simple rational behaviours (Howden et al, 2001). The BDI model has it foundation is folk psychology which is the way people think that they think, as opposed to the actual mechanism of the brain (Norling, 2004). The framework consists of three elements: beliefs, desires and intentions.

A *belief* is what is held to be true. A *desire* is a need for something to happen. A desire is analogous to an objective or a goal. The term goal is used in this study. Each desire has an *intention*. An intention is a plan of action to achieve a desire. Each plan consists of a series of activities that need to be performed to reach a goal.

Geospatial Reasoning

This study uses the terminology of *geospatial reasoning* to describe the ability of agents to reason about spatial uncertainty in classified remotely sensed imagery using the BDI model.

AGENT APPLICATIONS

Agents have been used in a range of software applications. Prior to the application of agent technology, AI techniques have been used in GIS such as the work performed by Egenhofer & Frank (1990). Though agents have been applied in the geospatial domain, one application area that has not been investigated and has promise is the application of agents to communicate spatial uncertainty in imagery.

Non-spatial Application of Agents

The Microsoft® Agent in the form of the Office assistant is a well-known example of the use of agents in commercial software applications. The assistant can provide help based on the current task performed by the user or provide help for requests from the user.

Geospatial Agents

The concept of using and applying agents in the geospatial domain has been varied. Examples include map production and map use (Frank, 2000), generalisation of map data (Galanda & Weibel, 2002), interpretation of 3-dimensional scientific data (Gallimore et al, 1998), Internet mapping and distributed GIS services (Luo et al, 2004; Nolan, 2003; Tsou, 2002), simulation of human recreation activities (Itami & Gimblett, 2001) and providing specialist advice on geography and the environment (Cartwright et al, 2003).

THE CASE STUDY

A case study was performed to investigate the application of software agents to communicate spatial uncertainty to image users. The case study involved:

	Step
1	Preparation of image data sets
2	Design of the geospatial reasoning model
3	Development of the prototype
4	Implementation of the reasoning model
5	Testing of the model
6	Evaluation of the model

Table 1: Case Study Method.

Preparation of Image Data Sets

Classified imagery used by Allan (1998) was used in this study. Four ArcInfo™ Grid files were overlaid to create a composite image. Overlaying the images resulted in a raster data structure with four digital values per pixel. Each value corresponding to one of seven land uses: bare ground, irrigated pasture, pasture, sand, salt marsh, trees and water.

A software program (*Img2RasPoly*) written for this study was used to polygonise the composite image. This involved aggregating pixels with the same four values into polygons, resulting in a polygon data set consisting of 25635 polygons.

Design of the Geospatial Reasoning Model

As part of the study, the BDI concepts were applied to produce a reasoning model to communicate spatial uncertainty. This involved defining a set of beliefs, desires (goals) and intentions (plans) so that the user can obtain their overall objective, which is to gain knowledge about the uncertainty in their data so that they can make an informed decision whether or not the uncertainty in the data is allowable in their work.

Beliefs of the User
Table 2 lists the beliefs identified for the user. The beliefs are categorised as presence, level, distribution and classification.