**GeoDialogue: A Software Agent Enabling Collaborative Dialogues between a User and a Conversational GIS**

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**Abstract**

A fundamental challenge that must be met to achieve a usable conversational interface to Geographic Information System (GIS) is how to enable a more natural interaction between the user and the system. This paper presents a design of an agent-based computational model, PlanGraph, and implementation of this model in a software agent, GeoDialogue, as a dialogue manager for a conversational GIS. This dialogue agent enables intelligent collaborative human-GIS dialogues. The capabilities of this agent are demonstrated through its performance in a conversational GIS, Dave_G.

1. Introduction

A Geographic Information System (GIS) is a computer-based information system for managing and processing geographically referenced data. Development of transparent interfaces is one of the long term goals for GIS, which leads to development of natural interfaces (human communication modalities enabled interfaces, e.g. speech and gesture enabled interfaces) for GIS. Development of natural interfaces for geographical information use has evolved from early systems enabling speech only and/or simple mouse-simulated gesture to current systems enabling speech and free-hand/pen gesture [1-5]. Most of these systems are conversational (speech enabled). One of the major challenges that must be faced for development of conversational GIS is how to enable a more natural human-GIS interaction (that is, more like human-human interaction [6]). The goal of this study is to facilitate more natural human-GIS interaction through enabling collaborative human-GIS dialogues. This study takes the Human Emulation (HE) approach to design the human-GIS interaction, considering its advantages over the Human Complementary (HC) approach [7].

An agent-based computational model, PlanGraph, is developed in this study to support the HE approach. A software agent, GeoDialogue, which implements this model, is implemented as a dialogue manager to enable collaborative human-computer dialogues. The capabilities of this agent are demonstrated through its performance in a conversational GIS, Dave_G [1, 3]. Our previous papers [1, 8] related to GeoDialogue focus on conceptual descriptions of this agent. This paper will focus on its implementation details.

2. PlanGraph

The design of the PlanGraph model is mainly based on two important theories, the computational collaborative discourse theory [9] and the SharedPlan theory [10, 11], together with the agent-based computational model, the RecipeGraph (Rgraph) model [12]. The assumption underlying our design of the PlanGraph model is that collaborative behavior between the GIS and the user underlying the collaborative human-GIS discourse is centered on a collaborative plan, SharedPlan [10, 11]. Both the system and the user contribute to this plan. The system agent needs to retain knowledge of the SharedPlan in order to reason about how to help the user during the communication. The PlanGraph models the dynamic knowledge that, at a given time during the human-GIS collaboration, the GIS agent adheres to the SharedPlan.

The PlanGraph (see its structure from our previous paper [1]) consists of the root plan representing the common goal of the system agent and the user and all its sub-plans for sub-goals. Each node in the PlanGraph is centered around a plan/subplan, a complex data structure which records an action...
together with a set of mental states that the GIS agent holds on that action at that given time. The PlanGraph also records the attention focus that the system agent holds on the SharedPlan at that given time.

This model also provides a set of reasoning algorithms associated with the PlanGraph. Upon receiving each user input, the GIS agent needs to react to the input with at least three steps, including interpreting the input, elaborating and executing the current SharedPlan toward its success, and sending out responses to the user. The design of the Interpretation Algorithms (IAs) in this model is based on and extends those in [12]. The designs of the Elaboration Algorithms (EAs) and Response Algorithms (RAs) follow the plan evolution process of a SharedPlan [11] and extend those in [13].


To illustrate how the PlanGraph model works, we have implemented this model in the prototype software agent, GeoDialogue, a human-GIS dialogue manager for the conversational GIS, Dave_G [1, 3].

3.1 Structure

The prototype software agent, GeoDialogue, includes five major modules (Figure 1), including Semantic Analysis, Interpretation, Dialogue Control, Elaboration, and Response Control. In addition, another two modules, Knowledge Base and GIS Component, are also included to support performance of the five major modules. The Dialogue Control module is the central intelligence module in the dialogue agent. Its sub component, PlanGraph, helps the agent to maintain the dynamic knowledge on the SharedPlan developed by the system and the user. Another sub component, Reasoning Engine, provides automated reasoning for the three modules, Interpretation, Elaboration and Response Control. This sub component also controls the dialogue process flow in the order shown in Figure 1.

3.2 Implementation of actions and recipes

The basic actions are implemented as public functions in GeoDialogue. Complex actions are elaborated after their recipes are decomposed in the PlanGraph. They are further executed as the basic actions involved in these complex actions are executed. The recipes are implemented in XML (see an example in Figure 2) and stored in Knowledge Base.

3.3 Implementation of mental states

For convenience in programming, a set of numerical labels (see Table 1), called Mental State Number (MSN), are implemented to represent mental states that the GIS agent holds on an action or a parameter in the PlanGraph.

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Figure 1. Structure of GeoDialogue

Figure 2. An example recipe, ShowMap1

3.4 Implementation of PlanGraph

The PlanGraph is implemented as a recursive dynamic data structure in GeoDialogue. The data structure itself defines the root plan and current attention focus only. Its recursive structure is achieved through the recursive structure of an action/parameter node (see the example PlanGraph in Section 4).
3.5 Implementation of reasoning algorithms

All individual reasoning algorithms associated with the PlanGraph are implemented as separate functions in GeoDialogue. These individual functions are organized in Reasoning Engine as three interleaved module functions for Interpretation, Elaboration and Response Control.

<table>
<thead>
<tr>
<th>MSN</th>
<th>Meaning of an MSN on an action α</th>
<th>Meaning of an MSN on a parameter p</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>The goal of α is proposed for α.</td>
<td>p is proposed in an action involved in the collaboration.</td>
</tr>
<tr>
<td>1</td>
<td>The goal of α is agreed by all agents in collaboration.</td>
<td>p is necessary for the collaboration and is waiting for instantiation.</td>
</tr>
<tr>
<td>2</td>
<td>α is a basic action ready to be executed.</td>
<td>p under the instantiation process is optional.</td>
</tr>
<tr>
<td>3</td>
<td>α is a complex action, and one plan is selected for this action.</td>
<td>p under the instantiation process is required.</td>
</tr>
<tr>
<td>4</td>
<td>The plan selected for α is successfully executed, and the plan execution result contains some uncertainties.</td>
<td>p is instantiated with a parameter value involving certain uncertainties.</td>
</tr>
<tr>
<td>5</td>
<td>The plan selected for α fails.</td>
<td>Instantiation of p fails.</td>
</tr>
<tr>
<td>6</td>
<td>The plan selected for α is successfully executed, and the plan execution result does not involve any uncertainties.</td>
<td>p is successfully instantiated with a parameter value without any uncertainties.</td>
</tr>
</tbody>
</table>

4. A sample human-GIS dialogue

A sample dialogue (Figure 3) between a human user and GeoDialogue is explained in this section to illustrate functionalities of PlanGraph and GeoDialogue. Figure 4 shows the final PlanGraph. The dotted section in this figure is added between U2 – U3, and all others are generated between U1 and G1.

After receiving the first recognized and parsed input, U1, GeoDialogue assigns semantic meanings to the input through Semantic Analysis and then sends the analysis results to Interpretation. By calling the IAs from Reasoning Engine, the agent initiates the PlanGraph with the user’s intention, See Map (with MSN 0), underlying U1 and focuses its attention on this action.

The dialogue begins with an empty map on the screen
U: The user; G: The dialogue agent, GeoDialogue
U1: Show me a map of Florida.
G1: {show a map with state boundaries and interstates in the area of Florida}. Is this OK?
U2: No, please also add major cities.
G2: {show a map with state boundaries, interstates and major cities in the area of Florida} Here it is.
U3: Thanks.

Figure 3. A sample human-GIS dialogue

Figure 4. The final PlanGraph
OK?” through executing the basic action, Generate Map.

Because Generate Map is a communicative action
done by the system, by calling RAs from Reasoning Engine, Response Control sends out all responses in
G1; the dialogue agent then focuses its attention on the
root action See Map (under the assumption that the user
usually can successfully execute the action Watch Map)
and waits for the user’s feedback on the collaboration
result—the map. Because the value of the parameter
node, Layers, is inferred, the MSNs on all its parent
nodes and the nodes that use the inferred value are
updated as 4, which indicates the existence of
uncertainties on these nodes. See the un-dotted section
of the PlanGraph in Figure 4 for the current
PlanGraph.

Upon receiving the user’s negative reply in U2,
GeoDialogue modifies its MSN on See Map as 3 and
re-elaborates this plan by tracing all its sub plans with
uncertainties. The agent interprets the second part of
U2 as Communicate Value by Informing (see the dotted
section in Figure 4), by which the user actively
provides modification information on the parameter
Layers. Then, the agent re-generates a new map by
adding another map layer, major cities, and a new
speech response, “Here it is,” in G2. The user’s positive
feedback in U3 confirms the success of human-GIS
collaboration for the user’s request, See Map (see the
final PlanGraph in Figure 4).

5. Conclusion and future work

In this paper, we offer two major contributions: 1)
the agent-based computational model, PlanGraph, can
help the system to keep track of the SharedPlan
developed during the human-computer communication
process; and 2) the prototype software agent,
GeoDialogue, can facilitate the conversational GIS to
have a more natural interaction with the user through
collaborative dialogues. The dialogue agent fails in
cases that 1) it can not interpret the recognized input,
and 2) all recipes of a focus action have been tried, and
all of them have failed. Future work will deal with
evaluating the naturality of human-GIS interaction
supported by GeoDialogue and improving the
knowledge of actions and recipes as dynamically
accumulated and updated during human-GIS
interaction.

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References

“Natural Conversational Interfaces to Geospatial Databases,”
interaction with single user applications through speech and
gestures on a multi-user tabletop,” Proc. The working
conference on Advanced visual interfaces, ACM New York,
Brewer, L. Bolelli, B. Shaparenko, S. Fuhrmann and H.
Wang, “Enabling Collaborative Geoinformation Access and
Decision-Making Through a Natural, Multimodal Interface,”
International Journal of Geographical Information Science,
Lynch, “Personalised maps in multimodal mobile GIS,”
International Journal of Web Engineering and Technology,
Directions: Do They Point to a New Avenue for Examining
Spatial Representations?,” Spatial Cognition & Computation,
“Towards human-like spoken dialogue systems,” Speech
collaboration,” Knowledge-based Systems, vol. 8, no. 2-3,
“Communicating Vague Spatial Concepts in Human-GIS
304-319.
structure of discourse,” Computational Linguistics, vol. 12,
no. 3, 1986, pp. 175--204.
complex group action,” Artificial Intelligence, vol. 86, no. 2,
1996, pp. 269-357.
SharedPlans,” Foundations and Theories of Rational Agency,
[12] K.E. Lochbaum, “A collaborative planning model of
requests and replies in a collaborative dialogue model,”
International Journal of Human-Computer Studies, vol. 53,
no. 6, 2000, pp. 915-968.