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Human-GIS Interaction Issues in Crisis Response

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Abstract. Geospatial information systems (GIS) provide a central infrastructure for computer supported crisis management in terms of database, analytical models and visualization tools, but the user interfaces of such systems are still hard to use, and do not address the special needs of crisis managers who often work in teams and make judgments and decisions under stress. This paper articulates the overall challenges for effective GIS interfaces to support crisis management in three dimensions: *immediacy*, *relevancy*, and *sharing*. These three requirements are addressed by an integrated approach, taking a human-GIS interaction perspective. To demonstrate the feasibility of this approach, we cite our prototype system, DAVE_G (Dialogue-Assisted Visual Environment for Geoinformaton), as an example. DAVE_G uses a large screen display to create a shared workspace among team members, and allows risk managers to interact with a GIS through natural multimodal (speech/gesture) dialogues. This work highlights the design challenges and the required technical innovations towards the goal of making geographical information accessible to crisis management teams.

Keywords: geographical information systems, human-computer interaction, multimodal interface, speech and gesture, dialogue management, geovisualization

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1 Introduction

Human society is vulnerable to various crises, ranging from hazardous exposure, natural disasters (hurricanes and forest fires), to organized terrorist attacks threatening national security. These crisis events have overwhelming magnitude, are highly dynamic, and require immediate response [66]. Demands for resources are largely unpredictable in terms of time, location, and specific resources needed. Moreover, the urgency associated with crises implies that decisions must be made rapidly. To deal with the complexity and uncertainties while making decisions, crisis managers often work in teams, sharing information, knowledge, and judgment.

Much of the data, information, and knowledge that underpin critical decisions for emergency preparedness, response, recovery, and mitigation are geospatial in nature [55]. Crisis events happen in certain geographical context and their effects are mostly geographically distributed and location dependent. Crises require an extraordinary quantity of resources, such as search and rescue teams, medial assistance, food, and shelter. These resources are highly diverse and geographically dispersed as well. Emergency managers need tools to quickly identify, collect, and integrate crucial information about a fast developing situation.

Geographical information systems (GIS) have played significant roles in many past disasters and crisis events by providing critical risk analysis, characterization, and evaluation tools in support of decisions [15, 32, 36]. GIScientists, in collaboration with domain experts, have paid significant attention to the needs of crisis management professionals in terms of spatial data sources, data integration, network models and analysis, cartographical presentations, as well as coupling of GIS with risk simulation models[7, 13, 16, 30, 33, 72, 74] [22]. Practical issues related to the integration of the above component technologies into interactive decision-analysis tools have also started to be addressed [24, 25].

Despite the demonstrated value of geospatial information and the rapid increase in the volume and variety of geospatial information sources and analytical models, critical decision-relevant information is often inaccessible to crisis managers in real-time response situations. Recent field studies by Zerger and Smith [78] showed that crisis managers still prefer paper maps (made by GIS analysts prior to real events) rather than computer-based map displays. User perceptions and comments from their survey [78] have depicted desktop-based crisis management GIS as “cumbersome or difficult to be used by decision-makers directly”, “incapable of answering questions in acceptable time-frame”, “lack of spatial and temporal relevancy”, and “difficult to share information with others". These findings constitute a strong call for systematic attention to understand the unique operational constraints on human interaction with geospatial information inherent within the context of crisis response. For this purpose, we must first address the absence of a comprehensive framework for human-computer interaction in this domain [55]. Such a framework must be able to bridge the gap between our knowledge about human constraints and technological solutions. The work reported here fits to this goal, with a focus on real-time response of crisis management.

The objectives of this paper are two-fold. First, we develop a framework for understanding human interactions with geospatial information, which is structured around the notions of *immediacy*, *relevancy,* and *sharing* (see section 2). *Immediacy* refers to the timeliness constraint of crisis response. In order for the system-generated information to be useful, that information must be provided on-demand. *Relevancy* concerns how well the content and form of presented information fit the needs of the decision-makers. *Sharing* refers to the needs of collaborating team members to share workspace and awareness while dealing with complex emergency situations and coordinating actions. Although these requirements are not hard to meet individually, addressing all three requirements in one design solution can be extremely challenging, since they present competing design goals.

The second objective is to suggest a roadmap for radical innovations in human interactions with geospatial information in support of crisis response. This roadmap embraces multiple domains of research (interaction devices supporting human communication modalities, conversational dialogues, and large-screen visualizations) and their integration within a human-centered design paradigm (details are given in section 3). To explain the technical feasibility, design issues, and potential benefits of such an approach, we cite our own research prototype, DAVE_G (Dialogue-Assisted Virtual Environment for Geoinformation) [12, 49, 64] (see section 4). DAVE_G presents an integrated solution to address the needs for immediacy, relevancy, and sharing. User interaction with DAVE_G is supported by devices that sense human modalities (natural spoken language and free-hand gestures), and is mediated by a conversational dialogue agent. Functionally, DAVE_G plays the role of a human geospatial analyst who translates information needs of a crisis manager into formal GIS queries. To support team-based spatial decision-making, DAVE_G employs a large-screen display that serves as a shared workspace for group collaboration and communication.

2 Constraints on Human Interaction with Geospatial Information in Crisis Response

Crisis response activities are not 'business as usual'. In the crisis management continuum that ranges from mitigation, preparedness, response, to recovery, the response stage is both critical and immensely stressful. Crises require an immediate response and a coordinated application of resources, facilities, and efforts beyond those regularly available to handle routine problems. Typical activities of a response involve gathering available data and resources, a rapid assessment and characterization of the ongoing problem situation, and mobilizing and integrating resources to create an organization capable of managing and sustaining the required response and recovery [76]. Managers also need to disseminate information to the press and other affected parties to keep the public informed.

Although the value of geospatial information to crisis response is well-documented, evidence has shown [10, 42, 78] that people still prefer paper maps (instead of digital maps) and human knowledge (instead of computer delivered knowledge) in their rescue and relief works. However, it is exactly in this response stage that crisis managers have the greatest need of geographical information as they monitor and assess the dynamic situation and formulate plans for action.

There are clearly multiple impediments to GIS use for crisis response. One major distinction to make is between impediments related to (a) *operation* (associated with human-computer interaction, particularly learn-ability and usability) and (b) *interoperation* (associated with both data from diverse sources and tools from different vendors). Here, we focus on the former. Why is it so difficult to create geospatial information technologies that support of crises response? What is wrong with the current generation of commercial GIS that prevents acceptance by emergency managers? Answers to such questions require a clear understanding of the practical constraints on the utilization of geographical information by emergency management professionals in real crisis events. We organize our understanding of such constraints into three categories: *immediacy*, *relevancy*, and *sharing.*

2.1 Immediacy

Crisis response often means ‘life or death’[42]. When a crisis happens, usually the first 24-72 hours are the most critical period of information intensive activities [66]. The fast developing situation must be accurately diagnosed, analyzed, and characterized, and this has to be done quickly as new reports, observations, and judgment become available. The time span between the onset of an information need and map generation must be very short in order to be useful.

Existing, deployed geospatial information support tools for the crisis response context have not taken the level of immediacy needed into account, as evidenced in the event of World Trade Center Attack [42]. In a typical setting, emergency managers rarely interact with a GIS directly. Instead, their access to geographical information is mediated through a geospatial analyst who is trained on operating GIS to support various emergency response activities. In order to get an updated map, a crisis manager currently has to communicate such needs (together with requirements) to a geospatial analyst who will interpret and translate the needs into database queries and user interface operations. Some organizations often impose bureaucratic procedures (requesting, approval, charging) for using GIS technical assistance [15]. With this arrangement, immediacy is hardly possible since the human mediator (i.e. the GIS analyst) often becomes a barrier and bottleneck when quick information transfer is needed [18]. It usually takes a long time for the geospatial analyst to collect the relevant data, to extract, integrate and analyze them, and to display or print the information products before they can be used by crisis managers. Such delays interrupt human cognitive and communicative processes, and reduce the value of geographical information and the effectiveness of the decisions made. Even a five-minute elapse of GIS operation time in answering a spatial question can be too long for real-time evacuation planning [78].

2.2 Relevancy

The principle of relevancy in information access means that the system should deliver the right information content to the right people for the immediate tasks [56]. Relevancy in the context of spatial decision support for crisis has been mostly concerned with data and analytic issues aimed at characterizing crisis situation in a formal and scientific way. Attention has been given to the choice of spatial data sources, the understanding of their limitations, and the application of valid spatial and statistical methods for assessing potential risks of an ongoing crisis [13, 14]. The usefulness of computer generated maps is also affected by the amount of details, spatial scale, and the choice of spatial aggregation when the results of the geospatial analysis and simulation models are summarized and presented to the end users (see [73, 77, 78] for evidences).

Analytic and modeling support (as mentioned above) is necessary prerequisites, but is not sufficient for addressing the relevancy of geospatial information to crisis decisions. A recent National Research Council’s report [57] pointed out the potential danger of making decisions solely on the basis of analytic characterization of risks. First, models are not perfect and does not guarantee relevancy. Formal models often carry assumptions that may or may not be realistic for actual situations and these assumptions are rarely communicated to the users of such scientific information. The models may run on imperfect data that leads to a large degree of uncertainty in risk prediction. Even when the analysis is done correctly, the result of scientific models is often not directly interpretable, but needs to be translated into a form relevant to decision-makers' immediate concerns. Second, decision-makers in the early phases of crisis response also face the challenge of asking the right questions, making the right assumptions to compensate for the lack of knowledge (or information), and incorporating the perspectives and judgments of all the interested and affected parties. Geographical information systems that do not attend to such issues are unlikely to generate decision-relevant maps.

Approaches to improving relevancy of GIS-generated information can take many forms. Stein et al [71] suggested that relevance can be improved by increased interactivity between the decision-maker and the GIS, and interactivity can be achieved by better user interfaces, by allowing external information sources to be incorporated into risk analysis, and/or by user-directed change in the use of GIS. Gadomski et al [31] addressed the challenge of improving relevancy through incorporating an intelligent planning agent that acts on user's needs. The ultimate solution may require the integration of these approaches guided by good models of decision-making processes. A more radical approach is to open the process of risk assessment to a broad participation from all affected parties (crisis managers, citizens, government regulators) through an iterative analytic-deliberative process. Citing from a National Research Council's report [57]:

> *Analysis* and *deliberation* are considered as two complementary approaches to forming understanding of crisis situation and reaching agreement among people. *Analysis* helps answering factual questions using rigorous and replicable methods developed by scientific communities (natural, social, and decision sciences, as well as mathematics, logic, and law). *Deliberation* is the process of communication where 'participants discuss, ponder, exchange observations and views, reflect upon information and judgments concerning matters of mutual interests.

Our human-computer dialogue approach (to be detailed in section 4) fits to this category, since it opens the possibility of enabling iterative analytic-deliberative processes with direct citizens participation.

2.3 Sharing

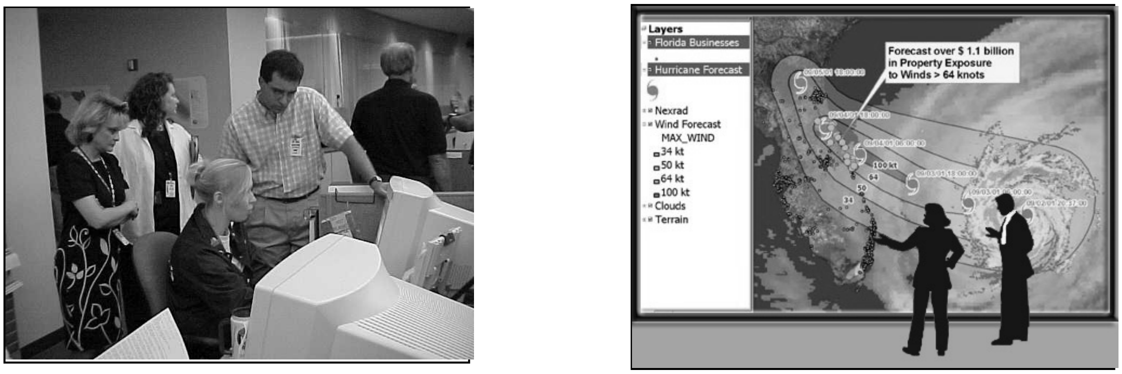
Maps encode spatial relationships in formal and structured representation. These representations enable shared understanding of spatial phenomena and their dependencies [46], and they play the roles of shared workspaces for visually complex tasks [43, 70, 75]. In group spatial decision making activities, a common map view can facilitate sharing of spatial context within which the spatial situation and associated problems can be collaboratively framed and characterized [17]. Shared map displays are often used when a team of responders, a group of officials, or the general public is to be briefed on a new situation. When dealing with a large scale crisis, visual displays encourage broader participation in the risk assessment process and allow consensus to be built among multiple affected parties [57].

The sharing requirements in a crisis management system may vary with multiple factors. First, a team may work together at the same-or-different time and at the same-or-different places [4, 21]. Sharing may also be affected by the kinds of tasks (risk analysis, or risk characterization, etc), group size, interaction control, intensity of interaction, and commonality of perspectives [48]. In the context of crisis management, a shared map display can be considered as the externalization of the shared mental models [54] among members of the management team. Zerger and Smith

[78] observed that emergency managers often gathered around a large scale paper map placed on a table as a shared workspace, and they rarely rely on a computer operator to display a map on a (small) computer monitor. Similar argument was made in the context of command post operations [52], where large-format paper maps were found to be preferred in collaborative use of geographical information. Consistent with such understanding, technologies that augment traditional paper and desktop with electronic support for annotation and collaboration, have been demonstrated by systems like Rasa (a digitally augmented paper system in military command posts application) [51] and EDC (Envisionment and Discovery Collaboratory) [3].

3 Beyond Desktop: Making GIS Interfaces Responsive to Crisis

The three principle constraints on human use of geographical information in crisis response (immediacy, relevancy and sharing) impose competing design requirements that are unlikely to be resolvable by adapting the traditional interface technologies of desktop GIS. To appreciate this human-technology dilemma, consider the setting of Figure 1*a*, which is typical in many emergency operation centers (EOC). Such an implementation (together with the capability of making large format paper maps) may be able to address one of the three human constraints, only at the price of compromising other ones.



(1*a*) Human-mediated information

(1*b*) Direct dialogue with map display

Figure 1 Current (left) and envisioned (right) environment for accessing crisis relevant spatial information

For example, the goal of immediacy can be achieved by anticipating all or most of the likely information needs and generating a set of maps before-hand (by GIS analysts). Then, the actual interaction will only involve fast presentation of these maps. However, a set of pre-designed maps may not be relevant when the user's information needs are dynamically changing at the time of use. No one can fully anticipate a crisis situation, and pre-created maps will probably fail to be decision-relevant without making changes. Conversely, the goal of relevancy can be reached by enlisting a GIS operator to create maps *on-the-fly* or by training emergency managers in GIS operations (so that they can control the map display as needed to fit the situation). Both options will destroy the immediacy principle due to added training and communication barriers. Large screen displays (as commonly found in emergency operation centers) make it easy to share information among collaborating members, but they are often limited to information presentation, and are rarely designed as a shared workspace for emergency managers to interact with geographical databases. In sum, it is the simultaneous presence of the three demanding requirements (immediacy, relevancy, and sharing) that creates a unique human-computer interaction problem.

In order to make GIS responsive and effective to crisis management demands, we are exploring advanced, human-centered interface technologies that may lead to a comprehensive solution to satisfy the requirements for immediacy, relevancy, and sharing. Initial attention has been focused on the challenges of geospatial information support in the Emergency Operation Centers (EOC). Our approach is to move human-GIS interactions beyond the traditional desktop paradigm, and towards a human-centered virtual environment as depicted by Figure 1*b*. Within this envisioned environment, crisis managers will interact with a wall-size display (instead of a desktop screen), using natural spoken language and free-hand gesture (instead of keyboard and mouse) to engage in cooperative dialogue with an intelligent information agent. This approach integrates advances in three primary domains: natural, multimodal interfaces; human-computer dialogue systems; and visually-mediated human-human collaboration and sharing.

3.1 From Computer Modalities to Human Modalities

During crisis events, emergency managers are fully occupied with the more pressing concerns of evacuation and resource allocation [78], and they are unlikely to have the time, the skills, and the extra cognitive capacity to deal with the frustrations of communicating with a computer system. Operating keyboards and mouse consumes human attentional resources and can interfere with the ongoing human problem-solving processes. In addition, desktop GIS forces human users to communicate information needs using computer modalities (keyboard and mouse) and machine languages (formal query languages). Spatial query languages and graphical user interfaces of GIS use terminologies that embed scientific views of geographical concepts and knowledge, which is quite different from naïve senses of space [20]. Metaphors and menu items are often confusing and have poor match to user’s mental models. These problems partially explain why people turn away from computer-based crisis support system and prefer paper maps in real-time crisis response.

With the advances of speech recognition, computers that understand human modalities become a reality. Crisis managers are most likely to benefit from such type of interfaces if the system is made to understand human geographical information requests expressed in natural spoken language. In fact, natural language forms of human-system interfaces have long been envisioned as the way towards transparent human-GIS interfaces [50]. However, spoken communication with a GIS is still far from being practical, due to the difficulties of understanding natural language in general and spatial concepts in particular. Verbal descriptions of geographic phenomena are often ambiguous, since language does not deal precisely with spatial relations [19]. To compensate for such problems, other authors have explored the use of gestures as a supplementary or alternative interface modality, either in the form of direct sketching on a map display [59, 60, 62] or through freehand gestures [27]. Complex spatial constraints (which are hard to interpret linguistically) can often be easily specified through simple pointing and circling. A more promising approach would be to integrate language and gesture [6, 28, 58, 79] to form multimodal interfaces.

3.2 From Queries to Dialogue-Assisted Interactions

Crisis managers not only need timely access to geographical information, but also more direct interaction with geographical information that is an integral part of their cognitive processes. Such applications are likely to create problems for the traditional query-based interfaces since the later require users to have a clear and complete knowledge about what information is needed, what data is available, and what operations are applicable and provided by the system. Query-and-answer based interfaces are designed to respond to fully specified requests. In reality, crisis managers is more likely to work in the mode of defining/refining information needs and exploring database contents while they interact with a GIS. This requires that information systems be more cooperative and helpful to human. Research on *spoken dialogue systems* [53] and *mixed-initiative* user interfaces [38] promise to make human interactions with information systems more flexible and engaging. Dialogue-assisted human-computer interfaces commonly borrow ideas from human-human conversational interactions. For example, the strategies of human dialogue repair, verification and clarification provide the basis for proper design of recovery processes [35, 45]. For crisis management applications, agent-based approaches that incorporate models of discourse, collaborative planning, and user's goals and intentions are particularly promising.

A dialogue agent facilitates information flows between users and information systems. It operates as a semantic translator that maps human's multimodal input into a series of database, analytical or cartographic actions executable by computers. At the same time, a dialogue agent maintains robust and consistent human-computer dialogues through graceful handling of recognition errors, misunderstandings, and ill-structured requests. There exist alternative dialogue control strategies (such as state-based, frame-based, and agent-based) (see [53, 61, 79] for recent survey). Recent trends in dialogue management are to incorporate discourse knowledge [29, 41] and user knowledge [26] in different degrees.

The design of dialogue assisted interactions must be based on sound theoretical foundations about agent collaboration and communication. Two promising alternatives are the conversational agency theory based on the BDI (Belief, Desire, and Intention) architecture of Bratman et al [8] and the collaborative planning framework of SharedPlan [34]. SharedPlan theory fits naturally to the modeling of intentional structures of collaborative discourse [45] and has been demonstrated by the Collagen system [65] to be a successful model for collaborative, mixed-initiative dialogues. Again, these theories and agent architectures have been partially tested in 'toy' applications, and we expect that crisis management systems require fuller implementation of the notion of cooperative problem-solving [2, 9, 37].

Incorporating dialogue assisted interactions into crisis management support systems has the additional benefit of enabling more decision-relevant system behavior. A spoken dialogue system for geospatial information can potentially be designed to support the iterative analytic-deliberative process in crisis characterization and decision-making under uncertainties. Dialogue is a way to encourage citizen participation in decision-making processes, and to communicate mutual awareness of crisis management teams on the crisis situations and action plans.

3.3 From Small Desktop Monitors to Large Screen Displays

Crisis response activities in emergency operation centers are often done by a group of professionals. Their collaboration requires a shared workspace, which was traditionally served by a large format paper map [78]. In such an application context, maps not only provide the spatial context for problem-solving, but also serve the role of mediator for human communication. MacEachren [47] identified three roles for maps in team collaboration: as the object of collaboration, as a support for dialogue, and as a support for coordinated work. This framework can be used to understand the roles of maps in GIS-supported crisis management. An EOC team might assess the crisis on a map-based display (as the *object of collaboration*) while interagency collaboration is supported through a complementary tool offering spatial annotation capabilities (providing *support for dialogue*). Simultaneously, by integrating GPS mobile technologies with the EOC display, EOC staff can monitor and manage activities of field personnel (providing *support for coordinated work*). GIS-enabled collaborative decision-making has been a research priority in GIScience [17], with seminal works done by Armstrong and colleagues [5] and Jankowski and Nyerges [39, 40].

The size of the map display has significant effect on the ability of a collocated team to share information and collaborate on a map representation. Zerger [78] reported, in his field study a emergency response exercise, that the size of the desktop computer screen does not allow necessary detail to be displayed for regional scale emergency management decision making, and that sharing information among multiple users was difficult over a small monitor. In contrast, large screen displays, such as the GIS WallBoard [27], support multiple spatial perspectives and experiences and allow multiple users to interact with the same or different parts of the map. People can move around the display area and easily gesture to any features or regions to make them part of conversation and collaboration.

4 DAVE_G: Dialogue-Assisted Virtual Environment for Geoinformation

The type of human-GIS interaction environment supporting crisis response, as we envisioned in Figure 1b, requires the integration of three component technologies mentioned in the last section. In order to further explain this new interface paradigm, we will discuss one of such systems, DAVE_G, that has been implemented by our research group. The principles and implementation details have been published elsewhere [12, 49, 64], but will be summarized in the next section, for the purpose of discussing how this technology addresses immediacy, relevancy, and sharing in an integrated fashion.

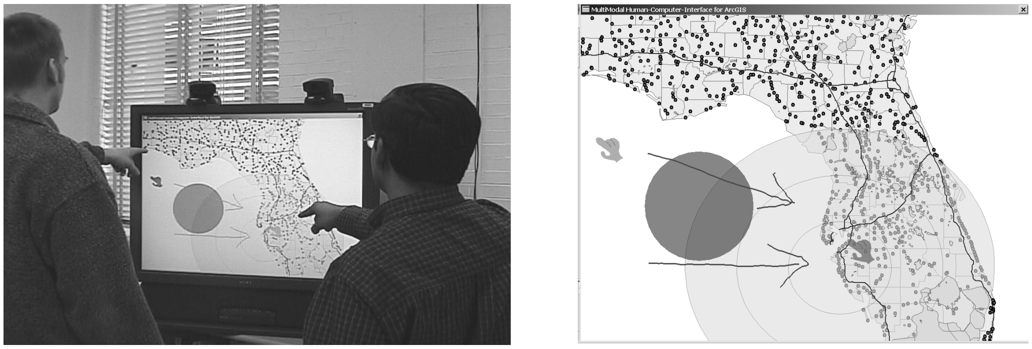


Figure.2 Two people interacting with DAVE_G (left) with actual snap shot (right). (Original source: Rauschert *et al* [64])

The primary design goal of DAVE_G is to provide a geographical information browsing and decision-support tool for crisis managers working in typical emergency operations centers (EOC). During crisis response, EOCs are centers of coordination, resource assembly, and strategic planning [63]. DAVE_G integrates solutions from natural language and speech processing, vision-based gesture recognition, and conversational dialogue technologies to enable multimodal dialogues with interactive maps served from geographical information systems [49, 64, 69]. In DAVE_G, natural hand gestures and spoken requests are recognized and semantic meanings are extracted, allowing completely device free interaction.

Figure 2 shows a snapshot of a user session where two users collaboratively work on a risk assessment for an ongoing hurricane, with geographical information accessed through spoken language and free-hand gestures. In this section, we will briefly explain relevant design and implementation details in support of later discussion.

4.1 DAVE_G Architecture

DAVE_G system is made of five functional modules that are cooperating with each other and share a common knowledge-base and a dialogue context (see Figure 3). In the user input module, one multimodal perception platform (consisting of a directional microphone and a video camera together with processing software)[1] is used for each user to capture human spoken and gesture input. The recognized message, encoded as a simple XML message, is forwarded to the dialogue management agent, *GeoDialogue*. The XML message structure is defined by a mutually understood protocol, called DAVE_G_XML. An example of such a message is given in Figure 4.

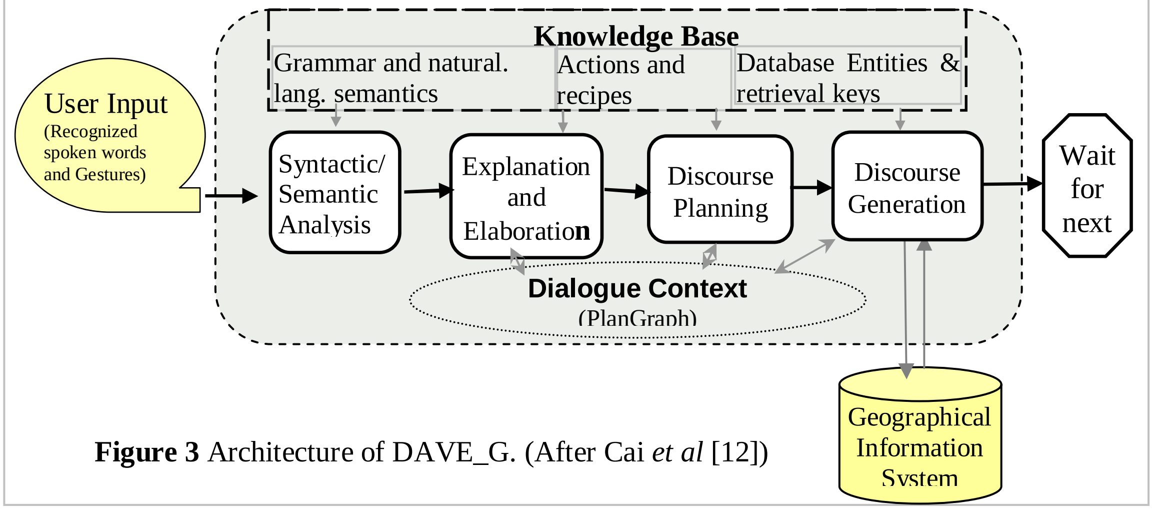


Figure 3 Architecture of DAVE_G. (After Cai *et al* [12])

```
<?xml version=”1.0”?>
<DAVE_GXML version=”0.0.2”>
<UTTERANCE speaker=“Ingmar“ time=82243.12>
   <PHRASE> <WORD start_time="82243.12" end_time="82244.2" x="123" y="456">Show </WORD>
                  <WORD start_time="82244.88" end_time="82245.1" x="123" y="456">me </WORD>
   </PHRASE>
   <PHRASE> <WORD start_time="82243.12" end_time="82244.2" x="123" y="456"> Palm </WORD>
                  <WORD start_time="82244.88" end_time="82245.1" x="123" y="456"> Beach </WORD>
   </PHRASE>
   <PHRASE> <WORD start_time="82243.12" end_time="82244.2" x="123" y="456">and </WORD> </PHRASE>
   <PHRASE> <WORD start_time="82243.12" end_time="82244.2" x="123" y="456">this </WORD> </PHRASE>
   <PHRASE><WORD start_time="82243.12" end_time="82244.2" x="123" y="456">county</WORD></PHRASE>
   <PHRASE><WORD start_time="82243.12" end_time="82244.2" x="123" y="456"> here </WORD> </PHRASE>
</UTTERANCE>

<GESTUREs>
   <gesture type="CIRCLE" start_time="82243.12" end_time="82244.2"> <POINT x="123" y="456" />
        <RADIUS r="789" /> </gesture>
   <gesture type="SELECT" start_time="82243.12" end_time="82244.2"> <POINT x="123" y="456" /></gesture>
   <gesture type="LINE" start_time="82243.12" end_time="82244.2"> <POINT x="123" y="456" />
              <POINT x="123" y="456" /> </gesture>
</GESTUREs>
</DAVE_GXML>
```

Figure 4 A multimodal utterance encoded as DAVE_G_XML message

A recognized input from the user will go through four stages of processing. *First*, the ‘*syntactic and Semantic Analysis*’ module parses the input based on pre-defined grammar that groups recognized words into phrases. For each phrase, a meaning is assigned, which can be a concept referencing an action or a concept referencing database entities. This stage of processing requires accessing grammatical and semantic knowledge available from the system’s knowledgebase. The ‘*Explanation and Elaboration*’ module will iterate through the set of meaning units (as derived from the previous module) and attempt to relate them with the current dialogue context. The ‘*Discourse Planning*’ module reasons the current status of the interaction, generates a list of potential action items (called agenda), and decides next dialogue move according to the agenda and associated priority rules. Central to the function of this module is the discourse context represented as a PlanGraph [12]. It corresponds to the intentional structure of the human-computer dialogue [44]. Finally, the '*Discourse Generation*' module decides what response messages are sent back to the user. If a map is to be generated, it will formulate a GIS executable command based on the discourse knowledge recorded in the PlanGraph. This command is sent as a query to a GIS server. Successful execution of this command will result in return of a map. In our experimental system, we use ArcIMS [23] as the geospatial information server to provide both cartographic and database functions.

Next, we provide more details on some of these modules.

4.2 Speech Components

Speech Recognition in DAVE_G utilizes a speaker dependent voice recognition engine (ViaVoice from IBM or Microsoft Speech from Microsoft) that allows reliable speech acquisition after a short speaker training procedure. The set of all possible utterances is defined in a context free grammar. The grammars constrain the system's vocabulary for better recognition while retaining flexibility in how speech commands can be formulated. The speech recognition module of the system reports time-stamped words and phrases, which are to be fused with other modalities.

4.3 Gesture Recognition

Gesture recognition is accomplished through a number of vision components (face detection, palm detection, head and hand tracking) that work together cooperatively under tight resource constraints. The main challenge here is the recognition of continuous hand gestures and the gesture segmentation into such meaningful units like pointing, circling, and contour. The acquisition of continuous gesture observations is through the use of trained Hidden Markov Models. In order to detect boundaries of gesture units, a simple token-passing model is employed. For more detail, see [68].

4.4 Modality Fusion

Recognizing a user's communicative intents requires the appropriate fusion of partial meanings embedded in different modalities. Investigation of human-map interaction during Weather Narration showed that the deictic word occurred during or after the gesture in 97% of the cases for large screen display systems [67]. On this basis, DAVE_G uses a time-stamp approach (detecting temporal co-occurrence between deictic phrases and gestures) in fusing spoken and gesture inputs. When the time-stamp approach fails to find a match, semantic information (tasks, actions, and parameters) are used to generate best guesses.

4.5 Semantic Interpretation of User's Actions

As a human-computer dialogue environment, DAVE_G keeps track of the human interaction history and dynamically maintains a representation of the dialogue context. This context includes a record of the contributions of each utterance, gesture, and participant to the intentional structure of the dialogue (see Figure 5 for an example). Each incoming message (multimodal utterance) from the user is understood within the current dialogue context. Since the system recognizes the user's intention rather than simply recognizing GIS commands, it is capable of understanding user's domain specific language (in addition to common GIS commands), as long as the relevant knowledge is captured in its recipe library. When the intention of the incoming utterance is fully explained (i.e. contributing to the advancement of existing action plans in the dialogue context), we say that the meaning of the human input is successfully grounded with the system.

Translating the user's speech and gesture input into GIS commands is done through the execution of basic actions corresponding to the plan node currently under the focus of the dialogue. For example, a request "place a 1-mile buffer around these[circle gesture] facilities" will invoke the system's knowledge about buffer generation in the form of a recipe for this action. The recipe consists of two parameters 'buffer distance' and 'features'; these parameters can be filled by interpreting the verbal phrase '1-mile' and the multimodal phrase 'these[circle gesture] facilities'. Then the subaction 'Generate' becomes immediately executable.

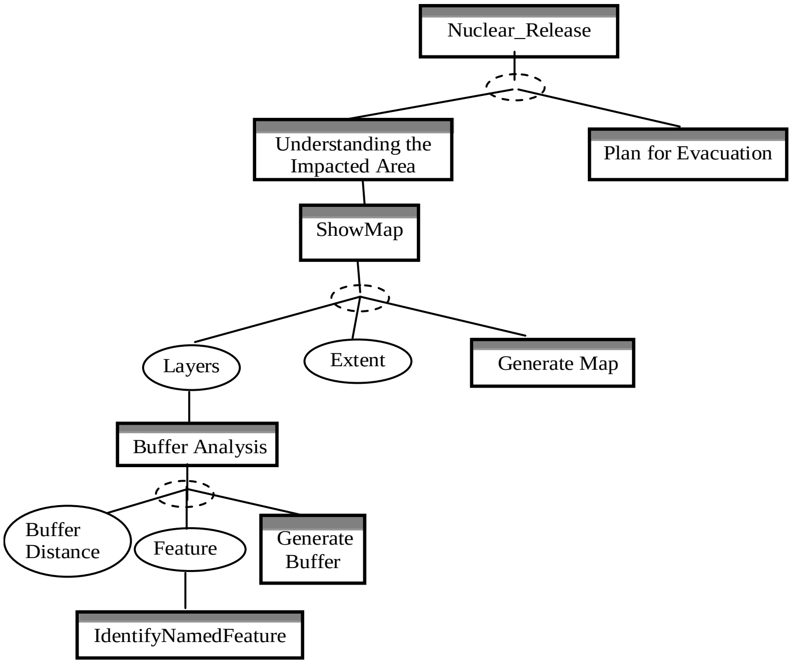


Figure 5. An example of dialogue context represented as a PlanGraph

4.6 Cooperative Dialogues

The ability for DAVE_G to interact with the users in a mixed-initiative and cooperative fashion originates from its reasoning capability to form its own intention. This reasoning process follows Bratman's cooperative principles [9]. The system deliberates on the user's current intention, and attempts to help the user by either auto-completing details of action plans, negotiating the meaning of vague concepts [11], or contacting external information sources. Cooperation involves the act of giving and taking dialogue initiatives under the overall principle of advancing user's goal. More detail is given in [12].

5 Discussion and Conclusion

We have looked into reasons that underlie low utility of GIS tools in real time response to crisis situations, and drawn attention to three special requirements of GIS for crisis response that have not been addressed adequately by the GIS research community: immediacy, relevance, and sharing. This paper has focused particularly on human-computer interaction issues related to these three requirements. We have suggested potential innovations to human-GIS interfaces that require the integration of advances in three technical domains – multimodal interfaces, human-computer dialogue system, and visually-mediated human-human collaboration and sharing. Such work should be guided by deep understanding of geographical information use in crisis management context, and be informed by the principles of human collaboration and communication. We described the progress we have made so far on our research prototype system, DAVE_G. The current functionalities of DAVE_G are still relatively primitive compared with what we have envisioned, but this is taken as the first step towards a new paradigm of interacting with geographical information.

Table 1. Comparison of DAVE_G and desktop GIS environment

	DAVE_G	Desktop GIS
Immediacy	**High**. Users express their needs in natural human modalities, which are directly intercepted by computers for automated interpretation and query processing. No need to know GIS commands and database contents. Response is fast and errors are handled gracefully.	**Low**. Large delays due to the cognitive load of translating information needs into user interface actions and queries, as well as physical load of operating input devices (mouse/keyboard). It is also error-prone and stressful to users. The use of a GIS operator may also become a bottleneck.
Relevancy	**High**. Responses are planned in real time by the dialogue agent that employs various knowledge sources (user models, task state, and discourse history) to make each response relevant to the current concerns of the user. Human interaction with DAVE_G is mixed-initiative, allowing users to guide the system to create relevant information output.	**Low**. Response to information requests is likely to be pre-programmed to deal with typical events and expected needs. No chance to allow users to direct the generation of map display to deal with novel situations and controversial decisions.
Sharing	**High**. Large screen display allowing multiple people to share a large workspace at the same time. The screen presents only relevant information. Selection and reference to objects on the screen is easy and immediately viewable by other participants in the room. There is no need to switch modalities when communication activities interleave between human-human and human-computer.	**Low**. Information is only available from small screens viewable by single users. Collaborative team members do not have equal (and same time) access to the map display, resulting in a lower degree of sharing of spatial contexts of the tasks. The screen is likely to be cluttered with a large number of interface objects (menus, tools, icons) that may or may not be relevant to the current stage of interaction.

As a summary of the advances made by DAVE_G system, Table 1 presents a speculative comparison of DAVE_G and traditional GUI-based GIS interfaces (such as ArcView 3.1), linking back to our initial goal of designing for immediacy, relevancy, and sharing. We believe that the power of GIS in visualizing and characterizing crisis and risks should be made (and can be made) accessible to emergency managers during real-time crisis response, and our work on DAVE_G flagged the kinds of innovation needed toward that important goal.

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