Toward An Ontology of Geo-Reasoning to Aid Response to Weapons of Mass Destruction

David Kirsh[1], PhD. Nicole Peterson[2], Leslie Lenert[3], MD
[1]Dept of Cognitive Science, University of California, San Diego, CA
[2]Dept of Anthropology, University of California, San Diego, CA
[3]California Institute for Telecommunications and Information Technology and the School of Medicine, [3]Dept of Veterans Affairs San Diego Healthcare System, San Diego, CA

We study how Metropolitan Medical Response System units conceptualize the physical space of a disaster and their organized response. Using a variety of ethnographic methods before, during, and after a disaster drill, we have developed an initial ontology for geospatial and context-aware technology. The conceptual map of first responders is far more complex than a geographical map. Zones *and* Areas *are used to describe documented concepts critical to MMRS operations.* Ad hoc *locations also play a critical role, helping first responders communicate tactics in spatial terms. Such distinctions play an important role in the way our experts think about their activity. Successful geoaware alerting systems must incorporate these notions if they are to seamlessly fit into the work flow of first responders.*

INTRODUCTION AND BACKGROUND

Mass casualty events are chaotic and dynamic. Personnel, victims, hazards and equipment are in constant motion, and despite the best efforts by the incident command center (ICC) and their field staff no one has a complete picture of what is happening. To improve the 'situation awareness' of the ICC we have been developing small wireless devices to attach to personnel, victims and equipment. These continuously send location information back to the ICC for evaluation. With two hundred or more such devices distributed around a site the ICC is in danger of being overwhelmed with data. The solution is to present data in terms of the spatial concepts and reference points which incident commanders use to understand what is going on. This paper reflects our initial attempt at understanding the concepts and ontology of disasters and emergency response that incident commanders and medical response experts have developed.

The context of this activity is the Wireless Internet Information System for Medical Response in Disasters (WIISARD) project. This project is one of the National Library of Medicine's Internet II research projects, and aims to study the role of advanced location-aware networks as tools for response to disasters. The WIISARD project focuses on developing technology to aid Metropolitan Medical Response System units in mitigating the impact of attacks with weapons of mass destruction (WMD), particularly WMD attacks that use chemical, biological, nuclear or radiological weapons (CBRN). By lowering the cost of geospatial awareness we believe it will be possible to reduce error, increase coordination, and improve the efficiency of response.

Our theoretical perspective is inspired by work in cognitive science under the topics of distributed cognition (1, 2), situated cognition (3), and participatory design (4). Such theories suggest that to understand a complex process such as the response of first responders to an WMD attack it is necessary to recognize that different responders have different perspectives on disasters partly because of their roles and partly because of the information reaching them. No one has a comprehensive vision of everything going on, nor need they, since response is a distributed activity with different agents requiring awareness of different aspects of the event and at different levels of detail. Police need one sort of information to move their agents into position, the FBI another sort, the firemen another, and medical response teams yet a further sort. The type of information and awareness required by each group depends on the specific decisions they must make. Previous research has shown that information is more usable if it is presented in a form that fits decisions and situated needs (3). This has encouraged designers of information systems to spend time understanding the way information should be represented. Here we present our initial studies of how responders conceptualize disasters and emergency response. Our goal is to create an ontology of geospatial concepts for MMRS operations. This is a necessary step in creating a cognitively efficient geospatial alerting system to help medical response.

Response to Weapons of Mass Destruction

When a weapon of mass destruction is released response units arrive on the scene and organize themselves in accordance with the protocol of the Incident Command System (ICS). The incident command system is a hierarchical organization with an Incident Commander (IC) at the top of the chain of command, directing several lines of response (6). Because information dissemination capabilities are limited within a disaster, the ICS is organized specifically to support *gathering of information* to the IC for decision making and *dissemination of orders* from the IC. Medical response for all types of incidents using the ICS model has three care stations at geographically distinct locations: *Triage station:* where patients are sorted into categories for treatment; *Treatment station:* where medical care is delivered on site; *Transport station:* where victims are readied for transport to hospital. Activities at the three stations are overseen in the *Command Center,* which should be in the cold zone, a region that is a safe distance from the release and the hot zone.

METHODOLOGY

To collect data on the spatial understanding of incident commanders and responders, we conducted observations and interviews before, during and after an MMRS drill. The drill took place in Carlsbad, CA, in May of 2004 and brought together responders from local police and fire departments, fire and county SWAT teams, FBI, and area hospitals. The event simulated a bomb explosion at an office building, with about 100 wounded victims within the building. As the first group of local firefighters arrived and deployed outside the buildings, a secondary device with radiological components (i.e., a dirty bomb) was set off, which killed most of those firemen and contaminated part of the local area.

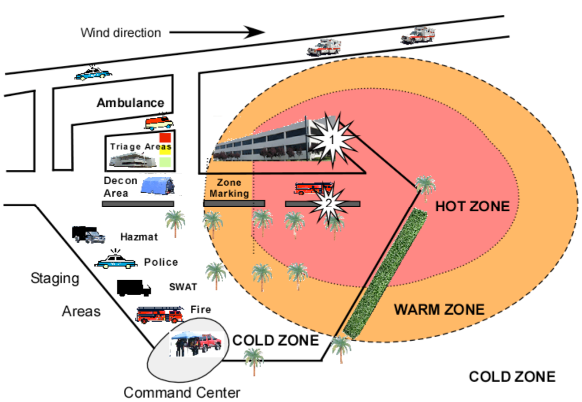

Figure 1: **WMD drill site schematic**

The ethnographic materials we collected in the context of this drill included:

Pre-drill interviews and simulations: We videotaped our live interviews with various experts from different groups involved in the drill, some of whom had 20 years of experience in incident command during emergencies. Our experts occupy key positions in emergency response, including medical, hazardous materials, fire and paramedic, and evaluation. Interviews consisted of prepared questions that elicited open-ended responses and follow-up queries, following Spradley's suggestion that the ethnographer discover both the questions and the answers through interviews (7). We also used a novel hand simulation in which our domain experts walked through the movements and locations of response teams and the sequence of events and activities during the drill. These simulations assisted in eliciting narratives (8, 9), and giving the "grand tour" of the situation (7). We collected five two-hour pre-interviews.

Interviews began with an introduction to the project and a request for each participant to describe what they thought would happen in the drill. Participants were asked to narrate the event using props we provided consisting of paper fire trucks, victims, and so on, and large poster board on which to draw the buildings and access routes (see Figure 2 below). In addition, the interviewer often asked for clarification, elaboration, or information about specific topics, like zones or response activities (e.g. "You talked about the radiation pagers being used to describe where the safe zone is. What other kinds of zones are going to be set up and who's going to set them up?" Answer: "Basically the same zones… There's hot zone, warm zone, cold zone. You could have a large zone downwind that you may start to isolate to prevent [automobile] traffic in something like this…" [Vent pre-interview 5/9/04]).

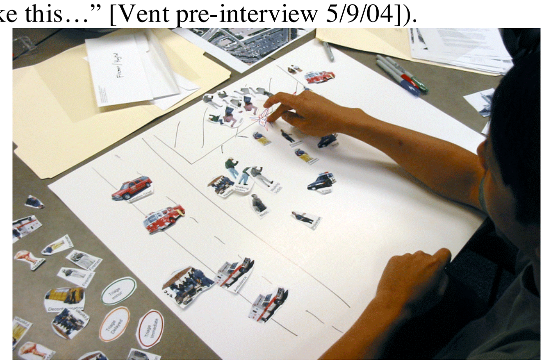

Figure 2: Hand simulation of drill expectations

Drill observation: The disaster drill itself was videotaped using five video cameras. Two cameras were dedicated to an overhead view of the entire event. One camera focused primarily on the incident command center, and two others recorded medical activities and decontamination of victims. In total, we collected over 20 hours of video.

Event debriefing: Immediately following the drill, we attended and took notes of a post-event debriefing, where different agencies discussed successes and problems of the drill.

Post-event follow-up interviews: After the drill, we were able to follow-up with the experts from our pre-drill interviews, repeating our use of our "hand simulator" to prompt recall of the events of the drill. In addition, we used our videos to elicit more detailed narration about specific events at the drill. We completed four two-hour post-interviews.

Coding interviews and drill footage: We transcribed and coded the large amount of video from interviews and the drill iself, focusing on the different interview topics and the different events observed during the drill. Inter-coder reliability was assured through joint coding; two to four coders worked simultaneously on the same footage to ensure completeness and agreement. For interviews, coders met to discuss their ideas for each category, and reviewed others' coding. The goal of our ethnographic analysis was to learn to see a disaster the way our different experts do. This means learning how they conceptualize the disaster space and how they think about the activities and responsibilities of their teams. To grasp these conceptualizations we reviewed the language they used to discuss coordination, errors and team activity, and we observed their gestures, pointing and drawing as they recreated our specific drill as well as other drills and real events they have participated in. We then encoded this expertise around a rough ontology of site management entities, attributes and processes.

RESULTS

Geospatial thinking was an integral part of thinking and activity of emergency responders. Incident commanders and other personnel use both detailed and highly abstracted maps to organize information and convey orders in a precise manner. However, the nature of maps changes depending on the situation and the need.

The treatment of geographic information in documents and interview data led us to identify three different concepts of space utilized by the responders in discussions: *zones, areas,* and *ad-hoc regions*. The distinction between these three conceptualizations of space is not hard and fast and illustrates differences in how experts reason about space when managing an incident response.

Zones: When hazardous material or shooters are present, it is obviously vital to define areas of greater or lesser safety. A site can be divided into three zones: hot (contaminated to a degree that responders require special protection), warm (minor contamination that is not hazardous without special equipment or the threat of contamination) and cold (safe) zones: In some diagrams they are called the exclusion, contamination reduction and support zones, and law enforcement uses a different term for the zone demarcated by the range of a terrorist with a weapon. Because the boundaries of a zone have to do with physical parameters, such as the concentration of pathogens, wind velocity, topography, gun or bomb range, and other biophysical facts, better boundaries can be determined as better biophysical information flows into the incident command: "Radiation pagers will go off at that point and HazMat will say we have to clear out farther back and establish a true cold, hot" (Chan pre-interview 4/8/04).

Areas: Whereas determination of zones depends on facts, the location and dimensions of areas depends on the type of activities they will support. For instance, in the exclusion zone, there may be a *refuge area* where victims can queue before being carried through a decontamination tent, or before they are escorted out of the hot zone. Typically, this will be as safe a place in the hot zone as can be found and a short distance away from it; in the warm zone, there will be a safe refuge area. Teams too need areas to queue, set up or do their work: "Optimally, we'd be looking at a secondary triage there and the three areas set up. Geographically, an engine between them or something between them. We have colored banner tape that says immediate, delayed, so we tape it off. We would tape tarps on the ground. And now a patient goes, dirty, clean, triaged, right into one of these areas (pointing to minor, delayed, immediate) and then filtered out to ambulances" (Heiser pre-interview 5/6/04). Typically each team will set up in a *staging area*, identified by their equipment and trucks. They may have control over other areas. For instance, the fire or MMST will triage victims and then dispatch them to walking wounded, delayed, and immediate care *treatment areas*. From there they are taken to ambulances. Because of this focus on task and activity, there are many more areas than zones.

Ad hoc regions: The third type of spatial region is less permanent than *zones* and *areas*, but important in the moment-to-moment management of a disaster site. We have found in discussions with experts that many of the tactical decisions taken during response have a spatial focus. A SWAT team leader when directing the sweep in a building to check for a shooter will often designate specific places as *grouping* or *secure areas,* places where his or her team can regroup after a quick search, or where advance groups should wait for the rest of the team. When a room has been checked, it should be marked as secure, although in the heat of activity explicit labeling may not occur and it is the fact that the team has proceeded beyond those rooms that implicitly marks them as in the '"safe" region: "Most SWAT teams historically when they're searching a building or moving through are so rigid that anything that's behind them is clear and anything in front of them is not. So they're not worried about marking" (Heiser post-interview 6/24/04). Although obvious to tactical thinkers, ad hoc spaces are rarely discussed or formally taught. In addition, ad-hoc regions include grouping places for equipment or other resources. Like *zones* and *areas*, *ad hoc* regions give rise to errors of coordination and planning that can have long-term implications for the effectiveness of a response.

Attributes of Spaces: In working toward an ontology of the major spaces in an incident we believe we are finding the pressure points where errors occur and where better information will improve coordination. A conceptual model of the attributes of spaces is shown in Figure 3.

Another set of errors are associated with questions of *permissions* and *rules of entry* and *exit*. For instance, not everyone has the right to be in or near certain areas. Some regions are off limits, such as forensic areas, some are 'full' and so have no vacancy, some have time limits and so on. Some allow stock piling of certain resources and prohibit certain others. Examples of errors arising from permissions and rules may be easy to fix when all personnel and victims wear identifiers, and all resources are tagged. But until such time there will be occasions when unauthorized personnel approach the ICC, when resources are dropped in inappropriate areas, when walking victims leave the site perimeter without signing out, or 'delayed' victims are led to the 'immediate' treatment area instead of their own area, and decontaminated victims walk through contaminated areas and are recontaminated.

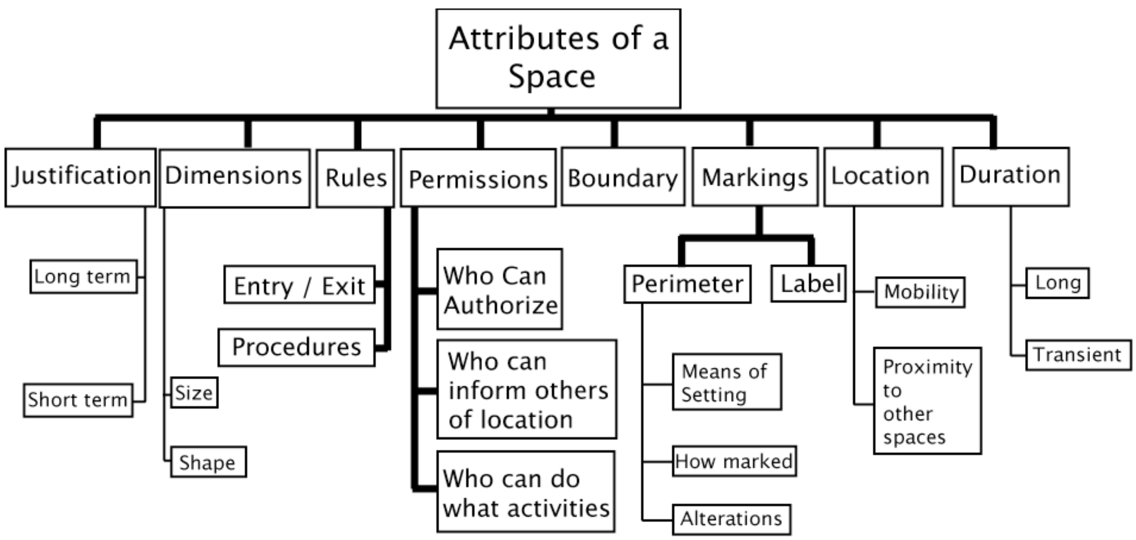

Figure 3.

For instance, spatial regions have *dimensions*, whether they are well known or not, and whether they are precise or not. Responders may get these dimensions wrong and not know of their mistake. For example, the hot zone from a contaminant is typically assumed to be an ellipse, while the hazard area from a suspect sniper in a window is an arc and a radius. But hot zones needn't be ellipses, especially if the wind has changed its shape.

A second set of attributes and values relates to the *markings* used to identify spaces. For example, yellow plastic tape is often associated with *perimeters*. However, because it is hard to lay tape vertically the vertical contours of a space are often unmarked, leading other responders to believe that a zone's edge is the same two stories up as at ground level. *Labels* are another type of marking. Flags are often used to mark the center of an area or station; vehicles are often used to mark a staging area.

The concept of *boundary* refers to whether violation of *rules* or *permissions* is actionable. A fireman may be in a SWAT owned space and rules may suggest that this is not appropriate for him, but his presence would not be perceived as an actionable problem. A contaminated victim in the command center is an actionable problem that is a *boundary* violation. During the debriefing after the drill, several people commented that the incident command center was not "buffered" enough from non-necessary personnel, preventing efficient completion of tasks.
Other attributes that need to be considered include temporal properties, and proximity to other spaces.

Not every space lasts the duration of an event. Ad hoc spaces, in particular, can become stale, as when the SWAT team changes its rendezvous place with changes in the shooter's position. Proximity becomes significant when contamination is a concern or when space is limited and teams are just arriving and need stake out a staging area that will be accessible given

	Justification	Perimeter defined	Perimeter marked	Perimeter moves	Center marked	Duration	Shape	Nested spaces?
Zones	Factual	Yes	Yes	Yes	No	Event	3D	Yes
Areas	Long-term requirements of activity	Often	Sometimes	Sometimes	Yes	Event	2D	Yes
Ad hoc	Short-term requirements specific to one activity	No	Sometimes	No (expires)	No	Phase of activity	2D/1D	Other ad hoc

Table 1. Geolocation attributes of space types

the other staging areas being claimed by other teams.

Differences between types of spaces: The distinctions between the types of spaces become more clear when we compare how the values of attributes are determined. One area of distinction is in how space is defined. For example, the perimeter of the space is defined, marked, and characterized differently, reflecting the characteristics of the different spaces. The dimensions of areas, such as staging areas is more arbitrary and changes with the needs of the team involved. The same applies to ad hoc spaces. Further differences in basic attributes are summarized in Table 1.

A further area of difference between zones, areas and ad hoc regions lies in the permissions and procedures associated with entering and exiting spaces. Zones and areas, unlike ad hoc regions often have specific entry points through which entry is managed. These are coupled with entry procedures, such as those required for entering contaminated space, moving within range of the shooter. Permissions too distinguish spaces. Only the incident commander officially creates hot, warm and cold zones, only authorized responders can announce when a zone boundary has been moved. By contrast entry into a treatment area can be from any opening, it does not require special procedures, and anyone can tell anyone where it is.

DISCUSSION

Our objective has been to show how responders conceptualize and organize the space of a disaster. Using a variety of ethnographic methods before, during and after a disaster drill, we have developed an initial ontology for geospatial and context-aware technology. The conceptual map of first responders organization is far more complex than a geographical map. *Zones* and *Areas* are used to describe documented concepts critical to MMRS operations. *Ad hoc* locations also play a critical role, helping first responders communicate tactics with geography. This type of space often represents the working but undocumented geolocation knowledge of first responders. As the networked geoaware WMD response team becomes a reality, these conceptions of space will become increasingly important to achieve the kind of global situational awareness that is needed to enhance disaster response using location aware technologies.

For example, by recognizing the differences between permissions, boundaries, and shapes of regions, we can suggest how monitoring systems can alert responders to wandering patients, changes in zones, and potential overfill situations in triage areas. Geoaware alerting systems based on such principles will play an important role in allowing first responders to concentrate on critical issues like rescue and containment, while technological systems enforce more mundane rules ensuring safety and correct procedures.

ACKNOWLEDGEMENTS

This work was supported by a contract (N01-LM-3-3511) from the National Library of Medicine.

REFERENCES

1. Hutchins E. Cognition in the Wild, MIT Press, Cambridge, MA; 1995.

2. Kirsh D. Distributed Cognition, Coordination and Environment Design, *Proceedings of the European conference on Cognitive Science*. 2001; pp 1-11.

3. Clancy WJ. *Situated Cognition*. Cambridge: Cambridge University Press, 1997.

4. Sperschneider W, Bagger, K. Ethnographic fieldwork under industrial constraints: Towards design-in-context. NordiCHI2000 Proceedings;2000.

5. Schultz CH, Koenig KL, Noji EK. A medical disaster response to reduce immediate mortality after an earthquake. N Engl J Med 1996;334(7):438-44.

6. Spradley J. *The Ethnographic Interview* .New York: Holt, Rinehart and Winston. 1979.

7. Jackson B. *Fieldwork*. Urbana: University of Illinois Press. 1987.

8. Agar, M. The Simulated Situation: A Methodological Note. Human Organization 1969;28: 322-329.