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1 Introduction

In various domains, a geographically distributed team of people must work together, under time pressure, co-ordinating their actions with one another, to accomplish a shared goal. Examples are, an emergency response task force searching buildings and recovering victims after a natural or man-made disaster, and a military unit securing an area by checking it for explosive devices or enemy fighters.

The lower-level tasks, such as dealing with trapped victims or explosive devices, may be very different, but the functions of navigation, spatial awareness, scheduling, replanning, and communication between team members, share common features.

Voice-only communication, such as that provided by two-way radios, has long been the standard form of communication between distributed team members, but advances in networking and mobile computing will soon allow the voice channel to be joined by a visual channel on which all sorts of data may be shared.

Personnel located in the field will often be communicating with those in some type of fixed base. The difference in the roles of these two types of personnel will lead to differences in many aspects of their work. Previously the basic nature of the voice-only channel has meant that communicators have used their training and experience to modify their speech patterns to compensate for the asymmetry between them. However, the tight links that are becoming possible between devices used in different contexts require that now the technology must do its part in mitigating the differences between team members.

We are investigating how technology can be used to provide rich collaboration channels between geographically distributed team members with different roles, as described in the problem statement below.

1.1 Problem statement

We are addressing the issue of providing synchronous collaboration systems for geographically distributed teams working under time pressure to achieve a shared goal. We are using urban search and rescue (USAR) as an example of a domain requiring a team to navigate an area, perform physical tasks, monitor adherence to a schedule, respond to unexpected and changing situations, and replan if necessary.

We will assume various technological advances: tabletop displays for use in the base, handheld displays for use in the field, ubiquitous digital networks, location tracking, and access to online data.

A key feature of the domain is that personnel in the field will be in a different environment, using different equipment, and performing different tasks from those at the base. This means that the information required by the two classes of collaborators will be very different, as will the technology that can best support them. This gives rise to a very asymmetric form of distributed collaboration.

In this paper, we will describe the nature of the asymmetry inherent in hierarchies used to manage personnel in the field, highlight some issues for design of remote collaboration for this type of task, and suggest the combination of different display types and interfaces for creating a distributed synchronous collaboration system that supports the information needs and awareness of different classes of personnel.

The goals for our project that are covered in this document are as follows:

- Describe the advances in various technological fields that will enable, and shape, the type of asymmetric distributed collaboration we have introduced.
- Review relevant techniques that have been used to understand, enhance, and test other types of collaborative system.
- Describe urban search and rescue, and define a scenario to test the co-ordination of a team.

- Provide an analysis of urban search and rescue, from the point of view of the cognitive work that is required and must be supported by any remote collaboration system.

The following sections address these points. There are further goals for this project, which will be addressed in our future work (Section 4.1).

1.2 Distributed teams

We are specifically considering teams in which the members have different roles (Section 1.2.1) and are in different locations (Section 1.2.2).

1.2.1 Hierarchical organization

Teams are often organized in a hierarchy, to allow them to scale with the magnitude of a task. This is especially true of command and control organizations in the military, and emergency response in the civilian sector.

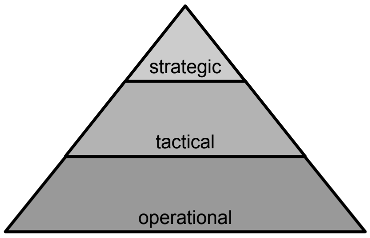

Figure 1: The three levels in the command hierarchy are referred to as strategic, tactical, and operational.

Levels in a command hierarchy are typically labelled *operational*, *tactical*, and *strategic* (Figure 1): operational units perform their duties in the field, the tactical level allows multiple operational units to be supervised, and the strategic level makes long-term decisions governing the mission. One can think of the levels as being roughly analogous to the levels in the army, where soldiers are at the bottom, officers in the middle, and generals and politicians at the top. These three levels correspond to *bronze*, *silver* and *gold* in British emergency services [Strategic Emergency Plan, p2.7].

Examples of such hierarchical organizations include military command and control organizations, and the Incident Command System [Bigley and Roberts, 2001] used in crisis response. In this work we are considering technological support for human actors at the lower levels of the hierarchy. That is, tactical and operational personnel who are either positioned in the field, or directly interacting with those that are. We will use the term *actors* to refer to humans in the organization.

In our USAR scenario the operational actors are those people responsible for searching buildings in the urban environment, and finding and extracting victims. The tactical actors will be those located in a base of operations, which may be a temporary facility set up close to the incident. Compared to the entire multi-agency force required to respond to a major incident, all of these personnel are at a relatively low level in the hierarchy, thus the the tasks they must perform are therefore fairly structured, and described in documents such as field operations guides. When the search gets underway, the role of the tactical actor is similar to that of a dispatcher in a train or ambulance service: monitoring the progress of the operation, and responding to deviations from the original plan. However, too much structure should not be imposed on the task: in crisis response novelty is the norm, so it must be possible for the actors to perceive and handle unforeseen circumstances.

1.2.2 Geographical distribution

It is often necessary to distribute a team geographically to accomplish a task. We are considering situations in which the operational personnel are positioned in the field and communicate remotely with tactical personnel, as shown in Figure 2. In particular, we are considering the remote collaboration links between personnel, which are the arrows in Figure 2 that cross the base-field boundary.

We are considering hierarchical organizations with distributed personnel that collaborate synchronously using voice and data channels, to operate in a dynamic domain. Previously, actors would communicate using voice channels (such as two-way radios). With advances in technology, digital networks can provide sharing of large amounts of information, as in the military's vision of *network centric operations*.

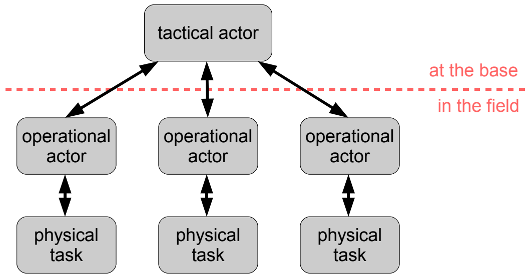

Figure 2: We consider situations where a tactical actor is situated in a base and is supervising operational actors in the field, thus there is a dividing line between them. Another line could be drawn between the operational actor and the physical task in cases where the physical task is preformed remotely using a robot.

Operational personnel are those people situated in the field, responsible for performing the physical work such as gathering information or material items, or providing services. Tactical personnel are those in a command centre coordinating the actions of multiple operational personnel. The difference between these roles leads to several forms of asymmetry.

1.3 Asymmetry

The human actors in an organization have different roles, which leads to different requirements for the technology used to support them.

1.3.1 Differing roles

Operational actors execute physical tasks (often while traversing the field setting), have detailed knowledge of the immediate situation around them, and receive information about new tasks from the tactical level. In contrast, tactical actors perform the higher-level functions of planning for future tasks, and coordinating the various operational personnel to ensure that the team satisfies the overall mission goals. They must remain aware of the state of all relevant personnel and resources, and consider information from many sources.

These different task activities and environmental constraints lead to different technological requirements for any support systems developed for these tasks.

Operational actors, who tend to be mobile and can experience physically demanding situations, would need an extremely portable and robust device, such as a small handheld computer. In contrast, tactical actors have few such environmental constraints, and thus can exploit stationary, large display systems.

1.3.2 Aspects of asymmetry

For our USAR scenario, there are various aspects that make the work of the operational and tactical actors very different (Table 1). The rows of the table are described in detail below.

Role. The roles are chosen for the actors according to their place in the hierarchy.

role	operational	tactical
function	execute task	plan, supervise operations
style of work	mainly physical	informational
environment	difficult, hazardous	controlled, safe
latency	negligible	significant
knowledge of world	local, detailed	global, coarse
knowledge of plans	individual, short-term	collective, long-term
computing	portable, limited	fixed, powerful
attention	intermittent	continuous

Table 1: Asymmetry due to the difference in operational and tactical roles.

Function. The operational actor is situated in the field where the physical task occurs. In contrast, the tactical actor's job is to supervise: she deals with planning, monitoring, and commanding.

Style of work. The operational actor is mainly performing a physical task, such as searching a damaged building. The tactical actor works solely with information.

Environment. The environment at the operational level presents various constraints because it is determined by external factors, may be restrictive in various ways, and may well require the operational actor to move from location to location. The environment in the base of operations for the tactical actor can be chosen to fit the needs of the task: we will assume it is fixed for the duration of the mission, is large enough to contain all the desired technology, and is protected from weather and other hazards.

Latency. Because the operational actor interacts directly with the external world, feedback will be fast, and the classical observe-orient-decide-act loop [Grant and Kooter, 2005] will occur rapidly. The tactical actor will work on longer timescales, and it may take some time to receive feedback on the effectiveness of a plan being executed.

Knowledge of world. An operational actor will possess detailed knowledge of the physical situation around him. The tactical actor will form a wider view that does not contain such fine detail, but does contain significantly more information from a wider variety of sources. Information must be aggregated as it is passed up from operational to tactical to avoid information overload, and similarly the tactical actor needs to select which information is useful before contacting any particular operational actor.

Knowledge of plans. The tactical actor is responsible for forming and maintaining a plan for the whole team, so she will have knowledge of the whole plan. An individual operational actor needs to know the details, only for the part corresponding to his own task. Also, the tactical actor will tend to work on a longer time scale than the operational. The tactical level should transmit updates to the plan to the operational level as needed.

Computing. The physical constraints at the operational level mean that any computing device must be small and portable, so the power of the device and the amount of information it can display will be limited compared to the tactical level. The tactical actor may be in a permanent command centre, or a mobile base of operations, but in either case state of the art computing and display facilities ought to be available.

Attention. The tactical actor does not interact directly with the physical environment, but interacts with other people through technology, so her primary task involves constant use of the technology. However, the physical nature of the operational actor's primary means that his continuous attention cannot be relied upon by any technological support.

1.4 Technology

Most remote synchronous collaboration technologies, such as video-conferencing and groupware [Grudin and Poltrock, 1997], assume that the situations and roles of the collaborators are fairly symmetric, and that the data they share is not subject to external influences. In contrast, as discussed below, we are considering a class of domains where significant asymmetry exists between collaborators, and where the situation is dynamic: it progresses independently of the collaborators and it causes time-pressure. The design of collaboration systems in such domains should be driven by the fundamental physical, organizational, and technological asymmetries.

Our hardware solution is to give a tabletop display to the tactical actor, a handheld display to the operational actor, and link the two with a digital network to provide *synchronous* remote collaboration (Figure 3). This is commensurate with the asymmetries in Table 1. At the base of operations there is space for a desk display to make sense of all the information. This can be linked to handhelds of personnel in the field to pass down commands and filtered information. We will support remote collaboration by supplementing the voice channel, the standard method of communication in emergency response (which will be provided using as voice-over-IP), with a shared visual space that can be used to send and discuss maps, information on resources, and updates to assignments.

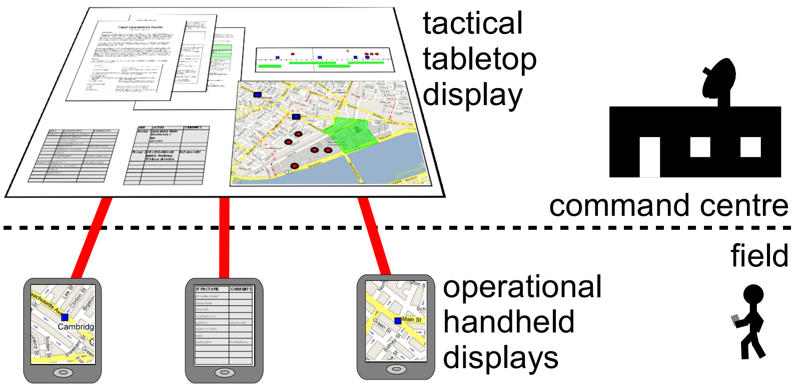

Figure 3: We will give a tabletop display to the tactical actor in the command centre, and a handheld display to the operational actor out in the field.

Once the hardware has been chosen, the challenge is to create a software infrastructure and human-computer interfaces for the people using the devices. We are designing interfaces for linked tabletop and handheld devices, to support real-time collaboration in a shared visual space. We will study how people collaborate in a test scenario to characterize the techniques they use and to inform design recommendations. In particular, we are interested in how the collaborators deal with the asymmetry in hardware and roles, which communication strategies they use to deal with the mismatch of information visibility, and how activity awareness between collaborators should be supported.

2 Background

In this section we describe the technological antecedents that enable the type of networked organization we are proposing. Then we review other methods for collaboration, with particular regard to asymmetry, and support for awareness, and finish with some design principles and evaluation techniques we intend to use.

2.1 New technology

Weiser's vision of ubiquitous computing included *tabs*, *pads*, and *boards* [Weiser, 1991]: display devices of very different sizes, for different situations and tasks (Figure 4). Standard computer screens are pad-sized, at 15-21 inches. The tab-sized, 2-4 inch displays of mobile phones and personal digital assistants have become popular, and recently there has been significant research interest in the board-sized displays, of 60-inches or more, that can now be constructed. The quantitative size differences between these devices entail qualitative differences in the activities they may support. At a fixed base a person can make use of a large display, but out in the field the user must settle for a the pad-sized display of handheld device in return for the portability it enables.

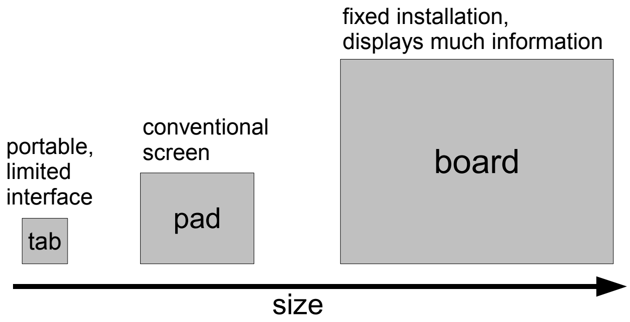

Figure 4: Most effort has gone into conventional display devices of the pad size. In our application, the tactical actor can exploit a board-sized display, and the operational actor is constrained to using a tab-sized one.

2.1.1 Tabletop displays

In the controlled environment of a base of operations, tactical actors will be free to exploit the benefits of the large display devices that are becoming available. Rather than the low-resolution shared wall displays that are often used in command centres, we mean large high-resolution personal displays.

Interface differences

The conventional computer interface with its small vertical screen and mouse input has remained mostly unchanged since the introduction of the Xerox Star around 30 years ago [Johnson et al., 1989]. Users have an appetite for screen space [Grudin, 2001] and multiple monitors are becoming popular. Improvements in display technology will make desk-sized displays feasible, and this will allow more information to be presented to operators, and in particular will support the viewing of GIS data and multiple documents. A tabletop system could display the maps, schedules, documents, and other information necessary to support the tactical role.

A large display is qualitatively different from a small one, and large displays have been shown to have benefits for cognition [Tan et al., 2003] and productivity [Czerwinski et al., 2003]. Swaminathan & Sato [Swaminathan and Sato, 1997] cite the ability to collaborate with several other people, and the ability to present a primary work object in context, as important benefits of such displays. They state that a large contiguous display, such as an interactive desk, is most useful for applications with the following characteristics:

- A large amount of interrelated information needs to be displayed, and
- any part of this information could, at any time, become the centre of user's attention and may need to be carefully studied or modified.

We will give the tactical actor a large desk display with pen input. There are various affordances this type of display that make it different to the conventional interface, so it should be designed differently. Large displays also pose new challenges for interface design, For instance, a mouse pointer can easily get lost, window management requires different mechanisms, and conventional menus are awkward to use when the menu bar is far away. A large display, even if technically homogenous, will not be used in a homogenous manner by the user, and the much larger space makes it possible to simultaneously display much more information, which enables more complex multitasking behaviour [Robertson et al., 2005].

The realization that the standard Window Icon Menu Pointer (WIMP) interface does not scale to very large displays has led to a series of modifications to the standard interface, and also to some radical re-inventions, including multi-touch finger and pen input, gesture recognition, arbitrarily rotated and scaled items placed in 'bins', user interface widgets that respond differently to each user, and physical objects used to control the digital content [Kurtenbach and Fitzmaurice, 2005, Scott and Carpendale, 2006].

Note that here we are assuming that the large display is controlled by a single user. Tabletop displays offer great potential for collocated collaboration, as has been the topic of much recent research, but here we are considering remote rather than collocated collaboration. Nevertheless, such a large display will be perceived as more public than a standard screen by people other than the actual user [Tan and Czerwinski, 2003], and can be a good focus for team attention during briefings [Dudfield et al., 2001], so it still has benefits for collocated personnel.

Existing systems

The Office of the Future [Raskar et al., 1998] pioneered the use of large displays in an office environment, using projectors to create displays on the walls of an office. Infrastructure for large displays has received considerable attention [Funkhouser and Li, 2000], and includes multi-projector calibration, and systems for visualization of large data sets. LambaVision [Leigh et al., 2006] is an architecture for combining an array of flat-panel monitors into a single large display; currently the seams between monitors are visible, but advances in hardware may soon allow them to disappear.

In recent years large display devices have become a popular topic for research. Most work on 'large displays' has used vertical cinema-style screens to display large data sets for scientific visualization. A related field, 'tabletop displays', where users directly interact with a horizontal interactive surface, has recently received much attention, particularly for collocated collaboration [Scott and Carpendale, 2006]. Recent developments in multi-touch sensing [Han, 2005] hold the promise of more fluid interfaces. Mostly, the tabletop systems support informal tasks like photo browsing, and there has been little work on performing time-critical tasks on such displays.

We will base our desk display on the Escritoire [Ashdown and Robinson, 2005], shown in Figure 5, which uses projectors to create a desk-sized display, and a large digitizer to allow accurate pen input over the entire area. The user of the desk will be presented with a large interface consisting of a spatial maps, temporal displays, and documents.

Figure 5: The Escritoire is a large horizontal display and interaction device that provides much more space than a normal computer monitor, and interaction that is more like using physical papers on a traditional desk.

Various recent projects have been exploring the possibilities of tabletop displays. Microsoft Surface[1] is a nicely packaged example of tabletop technology, allowing users to sit around a table and manipulate media items like photos. Research at the University of Calgary[2] has considered *bins* to group and scale content, *currents* to move it around the large area of the table, and new text entry methods. Direct-touch tabletops with multiple collocated users have been shown to create

[1] http://www.microsoft.com/surface/
[2] http://ilab.cpsc.ucalgary.ca/

new challenges for interface design [Shen et al., 2006]. The Tabletop workshops[3] have become an important forum for presenting the latest work on tabletop displays and interactive surfaces.

2.1.2 Handheld devices

Advances in technologies such as batteries, wireless networks, and small screen technology [Want and Borriello, 2000] are fuelling an upsurge in the use of portable computing devices, but Raghunath et al. [Raghunath et al., 2003] argue that "advances in technology will not significantly mitigate handhelds' limitations because human perceptual and motor systems—not the underlying technology—are the real limiting factors." These factors include human visual acuity, which limits the amount of information that can be displayed on a handheld, and size, which makes it impractical to use large data sets or handle many tasks.

The use of handheld devices for synchronous communication has been limited, but now that they are having wireless networking installed as standard, the potential is starting to be exploited. The Pebbles project[4] has provided several examples of useful collaboration from handheld devices, such as being able to annotate a shared PC screen from multiple handhelds. Handhelds have also been used successfully to share data in medical settings [Turner et al., 2005], and patients' personal screens have been exploited to display information in conjunction with a handheld [Alsos and Svanaes, 2006]. Pervasive games is one of the few applications where handheld devices distributed in the wider environment have been used for real-time communication [Benford et al., 2005].

Handheld devices and mobile phones are becoming more powerful, and are incorporating GPS, Bluetooth, web browsers, always-on high-capacity digital networking, and voice-over-IP. For reference, we are using a Sony Vaio UX micro PC, which has an Intel Core Solo U1500 1.33GHz processor, 1GB of RAM, a 4.5-inch 1024×600-pixel touch screen, and runs Windows Vista. It is at the high end of handheld devices now, but such features should be commonplace in a few years.

Soon the standard mobile network connection will be the internet protocol (IP), with voice communication and all other services implemented on top of that. With a general-purpose digital channel available, the question is how to best exploit the remaining communication capacity between devices. A video channel between collaborators can be provided to complement the audio channel, creating a videophone, but the 'talking heads' format provided by a pair of webcams is unlikely to be useful in many work domains. Often it is more useful to share a *task space*, a visual space where the users can collaborate over some shared information, rather than a *person space* [Buxton, 1992]. The challenge then is to design that task space, because its form is not self-evident as is the video channel created by pointing cameras at the users of the devices.

2.1.3 Networking

Advances are being made in wireless networking from the short to the long range. Table 2 shows a series of technologies that are either mature and widely available, or will be in the coming years. A combination or these technologies will be able to provide cheap and ubiquitous network access in urban areas, or areas where mobile network nodes have been specifically deployed.

Technology	Approximate range
passive RFID	1m
active RFID	10–100m
Bluetooth	10–100m
WiFi	100m
WiMAX	10km
mesh networks	city
internet	global

Table 2: Wireless networking technologies and their ranges.

[3] http://www.ieeetabletop2007.org/
[4] http://www.pebbles.hcii.cmu.edu/

On the small scale, soon most consumer products will contain RFID tags, which will link physical objects to the digital domain. This has been tried in emergency response by tagging equipment and also people, to associate information with them and track their location [Kristensen et al., 2006]. Short range networking like bluetooth is used to link multiple devices used by one person. WiFi is popular for networks the size of a building, and WiMAX promises to extend wireless networks to cover larger areas. Advances in mesh networks will allow robust ad hoc networks to cover large areas. The One Laptop Per Child project[5] is an example of future large-scale use of mesh networks. Finally these networks can be linked to the global internet. All this means that in the near future it will be possible to have a ubiquitous wireless digital network, even in disaster areas where normal infrastructure is not available.

The ubiquitous use of synchronous digital communication, including voice and data, that we are proposing, poses challenges for quality of service and security. These issues are beyond the scope of this report: they are the subject of ongoing work in networking. We will ignore the security requirements that would be required in a deployed system, and assume that quality of service factors such a latency are sufficient for our purposes, so that we can concentrate on our focus, which is the human factors of collaboration for distributed teams.

2.1.4 Tracking

The American Global Positioning System (GPS) is widely used to obtain location information, and can be used in combination with the similar Russian GLONASS system. The European Gallileo system, due to be completed by 2012, will provide better accuracy, and because it is a civilian rather than a military system it provides guarantees of service, making it more useful for applications such as emergency services.

Mobile phones will soon commonly have GPS receivers [Schreiner, 2007], and indeed, services to locate phones using triangulation from cell towers are already available. Various location-based services have appeared: parents can give their children a special, simplified mobile phone and track their position via a web site; social networking can be augmented to let you know when your friends are nearby; games involving visiting real-life locations are available; and sports and outdoor activities can be enhanced by automatic information updates such as weather reports.

The relevance for our emergency response application is that members of a distributed team will be able to stay aware of the locations of themselves and others, without any effort in communication. Integrated positioning systems and the ubiquitous network will mean information like this becomes automatically instantly available to all team members.

2.1.5 Digital databases

Various online mapping web sites such as Google Maps, Yahoo Maps, and Microsoft Virtual Earth have recently become popular. They are making geospatial data previously stored in hidden databases and only accessed through complex Geographic Information System (GIS) software available to the masses. The features of various online mapping sites are becoming more advanced [Geller, 2007] and Application Programming Interfaces (APIs) are being made available, allowing the data to be used in novel ways.

This type of data will be very useful for anyone navigating in an urban environment, and we will assume that it is available in our urban search and rescue scenario.

On the smaller scale, plans of individual buildings are now often submitted to government agencies in electronic form, so databases of plans must exist. Building plans are not generally available to the public in electronic form, partly because of security concerns, but one would hope that in an emergency situation, where lives are at stake, they could be made available.

Current practice in urban search and rescue teams, is to have a task force member responsible for acquiring and studying paper maps and building plans en route to an incident, but information

[5] http://laptop.org/

technology should be able to automate the task of acquiring this data. We will assume that plans are available for at least some of the buildings in our scenario.

Having assumed the existence of this spatial information, we must remember that after a large incident requiring emergency services, buildings are often damaged, infrastructure is destroyed, and there are hazards such as fire. A description of the situation on the ground may differ substantially from the normative data held in maps and building plans, so these types of data can only act as a guide to emergency responders. Updates to that static data will come from personnel in the field, so communication of changes to the data, such as annotations to a map, should be supported by the technology being used. Pushing data up from the lower to the higher levels in the hierarchy is often a challenge in emergency response organizations so care should be taken to make it easy for operational actors to communicate such first-hand observations up to the tactical level.

2.2 Remote collaboration

Powerful handheld computing devices and robust wireless networking will allow improvements in communication for emergency response organizations. Some projects have addressed remote collaboration in this domain (Section 2.2.1). Here we are particularly interested in the potential for this technology for synchronous collaboration over shared spatial and temporal information such as maps and schedules (Section 2.2.2), and a defining feature of our work is the extreme asymmetry between collaborating participants (Section 2.2.3).

2.2.1 Remote collaboration for emergency response

Researchers at NASA have been experimenting with giving first responders handheld computers (current generation personal digital assistants) [Betts et al., 2006]. They have considered one small part of the work of search and rescue personnel: getting the necessary lengths of timber for shoring up a building cut and transported to a rescue site where they are needed. This is a logistical problem, and providing a facility to remotely submit and queue requests to the people cutting the timber helps the operation.

Tomaszewski et al. present *geovisual analytics* as a method for supporting time-sensitive collaboration, analytical reasoning, problem solving, and decision making in domains such as crisis management [Tomaszewski et al., 2007]. It combines information retrieval, GIS, and visualization by providing information visualizations and search results linked to maps. Basically, users are able to use queries to search for information, and display the results on a map to visualize the spatial component of the problem. This should help decision making at higher organizational levels.

Johansson et al. found that in a simulated command and control task where subjects managed a fire fighting team, the use of a GIS with tracking of unit positions rather than a simple paper map improved the performance of the team and reduced communication volume [Johansson et al., 2007].

Much research work is being directed at multi-agent systems to automate higher-level reasoning and aid resource allocation (for example Wagner et al., 2004), but these are far removed from the real work of emergency responders, and address a long-term goal of automating the reasoning performed by humans. In contrast, here we are aiming to improve the availability and presentation of information to the human actors, and support the collaboration between them, so that they might do their jobs more effectively.

2.2.2 Sharing information

The standard audio channel used in many command and control situations may now be augmented with a digital channel that can transmit many types of data. This could be used to carry video of collaborators' faces to create a *person space*, but much more useful in many cases will be a *task space* [Buxton, 1992], a channel for sharing visual information that representing task status, planning, and actions. This will allow collaborators to transmit information more precisely than when speaking, ground their conversations on the information they share, and perform visual gestures that may be much simpler than their verbal equivalents.

Previous use of data channel

A data channel has been shown to benefit existing voice communications in various domains. These include air traffic controllers and pilots, where Data Link communications have reduced aircraft ground delay, flight time, and flight distance, and many messages, such as clearances, could be sent over the Data Link rather than by voice [Report DOT/FAA/CT-95/4]. Dispatch of vehicles such as taxis has benefited from the use of GPS and digital networking [Liao, 2001]. Railroad dispatchers have benefitted from combining voice and data link communication [Malsch et al., 2004], where the data link removed errors, and improved efficiency, safety, and situation awareness. That work showed that the voice channel was best for short, informal, time-sensitive messages. The data link was best for lengthy messages.

A geographic information system (GIS) displaying maps and GPS locations is a prime example of the type of large-scale dynamic data that can be displayed at the tactical level to aid in situation assessment and planning, and which would then be shared remotely. In our USAR example, a dynamic map might contain buildings to be searched, the locations of operational actors, and additional information useful for the planning activities. The tactical actor will want to view the whole map. During synchronous collaboration with an operational actor, a portion of the map may be shared between the two to allow deictic references: collaborators can point and annotate as they talk over the voice channel.

The challenge in creating a shared space is to define the way in which information will be shared. Mulgand et al. [Mulgand et al., 2005] consider data sharing at three distinct levels: *pixels*, *data*, or *recipes*. Sharing *pixels* creates a *what you see is what I see* system, provides common ground in the conversation, but restricts the collaborators to having identical views. Sharing *data* allows collaborators to see customized views of the same data. Sharing *recipes* is the most flexible because each collaborator can modify the recipe—this is essentially the database query used to generate the data. However, this means collaborators may end up viewing quite different representations of the same situation, so they will have to rely more heavily on the voice channel to resolve discrepancies.

In a task involving collaboration between participants with different roles and paper maps containing geospatial data [Carroll et al., 2007], participants relied on Post-it notes and directly annotating a shared map. They all used graphical annotations on the maps, including tracing routes and highlighting important information. They also extensively used pointing and gesturing over the map. When asked about the design for a computerized system, they requested sharing and transfer of data between maps, and information related to awareness and role differences, such as colour coding participants' roles, alerts of events, and an overview of the whole map. Convertino et al. [Convertino et al., 2005, 2007] recommend providing separate mechanisms for making private and public annotations, because the two fulfil different functions.

Information sharing in our system

Figure 6 is a depiction of the flow of information between the human actors, computer systems, and the physical world in our scenario. Arrows show the information channels, with the width of the arrows representing the capacity of the channels. The operational actor positioned in the real environment has detailed knowledge of, and possibilities for interaction with, the world around him. The tactical actor may make use of a large amount of digital data to form a model of the situation, and interact with it via a large device.

Information passes between base and field in three ways: the conventional voice channel between the actors; the shared workspace between the tabletop and handheld devices; and the automatic transfer of selected data, such as the GPS location of the operational actor which is transferred automatically to the tactical actor's display in real time.

2.2.3 Effects of asymmetry

Platform heterogeneity between remotely linked devices impacts collaboration [Velez et al., 2004]. Tremaine et al. [2005] had remote pairs of users collaborate synchronously on a puzzle task using either a conventional PC or a handheld computer, where the handheld offered a more restricted view of the problem. They found that the PC-handheld and PC-PC conditions produced better results than

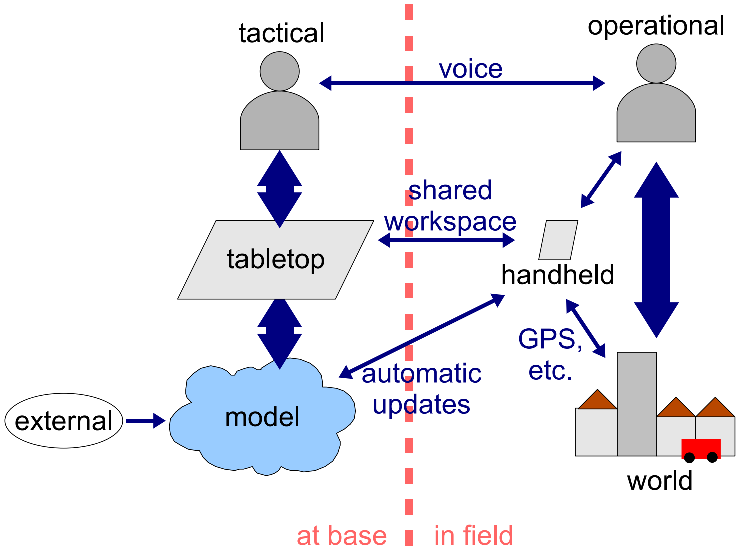

Figure 6: Flows of information in the distributed system. Thick arrow indicate large amounts of information transfer, and thin arrows, small amounts.

handheld-handheld, because if at least one person has a good view of the task, by using the PC, he could help the other person on the handheld with the restricted view. In that case the person on the PC had the situation awareness necessary for the team to succeed.

Krebs et al. (2004) consider this issue of asymmetry mostly from the perspective of how technological constraints, such as processing power and network bandwidth, cause asymmetry between collaborators. These limitations will be mitigated by the continuous progress of technology, but there are also other fundamental constraints that will not be solved by this progress, such as differences in display sizes, attention available from the user, and noisy challenging environments: the type of differences listed in Table 1. Screen size affects performance in tasks, for instance the lack of context when looking up items in a large table on a small screen reduces performance [Watters et al., 2003].

Another approach to asymmetry is taken by Drury and Williams [2002], who derive their assessment of how much information is available to different roles within a system by considering privacy concerns. This leads to a matrix showing who is allowed to know what about whom. They use a hospital example with doctors, nurses, and patients as the roles, which shows the importance of privacy, but in our USAR scenario the asymmetry is driven not by privacy, but by the factors listed in Table 1.

As an example of the issues created by asymmetry between collaborators and their technology, when using a shared view of a map, the tactical actor may share a map with an operational actor, and the tactical actor with the large display may be given control of the viewing parameters because she has the context necessary to make informed decisions about where to look. Exactly how this control is exercised is a matter for our continuing work. In general, the tactical actor may naturally assume much of the control of the shared data because this is the domain in which she works, while the operational actor is primarily dealing with his physical task. Thus the use of different display devices will complement the physical environments and organizational roles of the collaborators.

2.3 Awareness

In a dynamic domain where the situation in the external world is constantly evolving, support for awareness is important to let actors stay abreast of the situation. In collaborative systems, awareness is also important to allow each person to react to the actions each other is doing.

Gutwin and Greenberg [Gutwin and Greenberg, 2004] define four basic characteristics of awareness:

- Awareness is knowledge about the state of a particular environment.
- Environments change over time, so awareness must be kept up to date.
- People maintain their awareness by interacting with the environment.
- Awareness is usually a secondary goal—that is, the overall goal is not simply to maintain awareness but to complete some task in the environment.

Below we describe four awareness concepts, and note their relevance to the distributed collaboration system we are proposing: *common ground* is important in conversation; *situation awareness* allows the external world to be monitored; *workspace awareness* is useful when remote collaborators work synchronously on shared data; and *activity awareness* allows progress on tasks to be monitored, and tends to involve a longer-term view than workspace awareness.

2.3.1 Common ground

When people communicate with one another they must have common ground, which is a combination of mutual knowledge, mutual beliefs, and mutual assumptions [Clark and Brennan, 1991]. Common ground is established and maintained through a process called *grounding*, to "establish what has been said has been understood".

Each contribution a person makes to a conversation generally divides into two phases: *presentation* and *acceptance*. In the presentation phase, one person presents an utterance for the other to consider. In the acceptance phase, the second person gives evidence that she understands the original utterance.

Shared visual information between collaborators can help grounding by providing a potentially large and dynamic set of mutual knowledge that can be assumed to be known, or at least accessible, by all, and thus reducing the speech required to maintain grounding. Also, speech and interactions with the information can be interleaved, so for example, an action visible to both people in a conversation may act as a non-verbal acceptance phase.

Clark and Brennan [1991] list eight constraints on grounding. Two of them are not available to our distributed USAR team:

- *Copresence*: the people are in the same place.
- *Visibility*: the people can see each other.

Four of them are available:

- *Audibility*: they can hear each other.
- *Cotemporality*: low latency.
- *Simultaneity*: ability to send and receive at any time.
- *Sequentiality*: turns in the communication do not get out of order.

And two of them may be partially available:

- *Reviewability*: storage of a conversation history. Could conceivably be added for the visual part of the conversation.
- *Revisability*: messages can be altered before sending. Could be supported in some cases, for example with private map annotations that can be made public.

2.3.2 Workspace awareness

Workspace awareness [Gutwin and Greenberg, 2004] means knowing what other collaborators are doing in a shared workspace Gutwin and Greenberg define workspace awareness as:

> "the up-to-the-moment understanding of another person's interaction with the shared workspace."

They list three ways that workspace awareness is gathered:

- Conversation, gesture, and intentional communication

- Bodies and consequential communication
- Artifacts and feedthrough

In *intentional communication* a person explicitly sends a message to another. For example, she may point to an item visible to both people, and say something about it. *Consequential communication*, whereby one collaborator becomes aware of the actions of another by watching them happening, is also important. This happens automatically during collocated collaboration, but in a distributed system, features to support this type of communication must be explicitly added. *Feedthrough* is the process by which objects that are manipulated give indications about what is happening to them, for the benefit of remote observers. This must also be designed into a collaborative system. The MAUI toolkit [Hill and Gutwin, 2005] provides nice examples of feedthrough retro-fitted to standard graphical user interface widgets, such as menus and slider bars, so that a local user can watch what a remotely located user is doing.

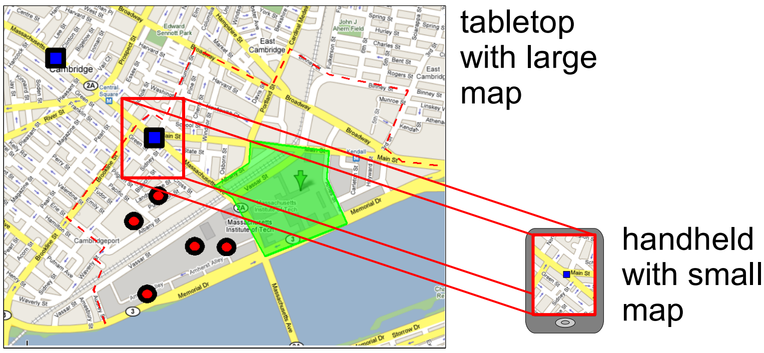

Figure 7: Ensuring participants remain aware of each other's actions when their views on the workspace are so asymmetric is a challenge.

For remote collaborators to remain aware of the actions of others using the techniques above they must first be able to see the relevant part of the shared workspace. *Visibility techniques* are used to ensure this happens. When collaborators are sharing visual information such as a map, different people may be working on different parts of the map, and the problem of awareness is exacerbated by the asymmetry in display sizes between a tabletop and a handheld display (Figure 7).

Three possible visibility techniques are [Gutwin and Greenberg, 2004]:

- Radar view
- Over-the-shoulder view
- Cursor's-eye view

The tabletop display has the space to provide over-the-shoulder views, that is, copies of the screens of each of the linked handheld devices. An example of this type of view is the 'document tracker' [Roth, 2000], where a small version of a remote user's view of a document is shown on the local user's screen. In that system, the local user can synchronize his own view of the document to the remote one whenever desired. A radar view could also be used, whereby the fields of view of the handheld displays would be indicated directly on the tabletop map.

2.3.3 Situation awareness

In a dynamic domain it is not just workspace awareness regarding shared digital data that is necessary, but also *situation awareness* [Endsley, 1995]: knowing what is going on in the external world. This consists of perceiving the elements of the world, comprehending what they mean, and predicting future states.

Generally it is a challenge to get information passed up from the operational to the tactical level, to allow perception of the situation at the higher level. Advances in portable computational devices and sensing technologies will allow much data on the state of operations to be automatically transmitted in real-time up to the tactical level. However, because the tactical actor is working at a higher level of abstraction, it will probably be necessary to distill the low-level data into a status visualization that can be rapidly assessed. The operational actor may be equipped with various sensing devices which would allow large amounts of information to be sent up to the tactical level, but visualizations should be devised that avoid cognitively overloading tactical personnel with information that is too detailed and voluminous.

2.3.4 Activity awareness

Activity awareness [Carroll et al., 2003] is a broader concept than workspace awareness, and involves knowing about the intentions of other actors in the system and their progress toward their goals. Collaborators must remain aware, not only of interactions with the shared information and of the external situation, but also of the plans of the actors in the system, and how well they are fulfilling them. This presumes that there are methods for specifying the plans for accomplishing the tasks of actors in the system, and for measuring progress against those plans. In our system this will be provided by schedules for the tasks of the operational actors.

3 Domain analysis

In this section we first give a general description of urban search and rescue (Section 3.1). We then define the scenario we will use for testing our collaborative system (Section 3.2). Finally we present the results of a cognitive task analysis to generate requirements for the design of our tabletop and handheld displays (Section 3.3).

Note that here we are not producing technology to find victims or extract them from collapsed buildings. Various researchers are working on that problem, particularly through the development of robots and interfaces for robots. Robots are used to aid with search and rescue operations [Murphy, 2004], and the human-computer interface is a crucial aspect [Yanco and Drury, 2007]. In this project we are developing technology to support the command and control task of co-ordinating the team, and thus our results are applicable to various other domains that involve distributed teams.

3.1 Urban search and rescue

The following description of urban search and rescue is based on US standards, primarily those defined in Federal Emergency Management Agency (FEMA) documents. The procedures are similar to those defined by other organizations that perform search and rescue operations.

3.1.1 Overview

The US Federal Emergency Management Agency (FEMA) has 28 USAR task forces (TFs) positioned around the US which are ready to deploy at an incident site within six hours. Each TF has a standard complement of 31 members that specialize in search, rescue, medicine, and technical tasks, with supporting members to perform logistics, communications, and work with heavy equipment. Each TF has an equipment cache containing $2.4 million worth of equipment, ranging from food and water that make the TF self-sufficient for the first 72 hours of deployment, to concrete cutting machinery used in the extraction of victims. TFs are deployed after events such as hurricanes, floods, earthquakes, accidents, hazardous material spills, and terrorist attacks (Figure 8).

3.1.2 USAR procedure

Emergency response operations generally divide areas into hot, warm, and cold zones [Murphy et al., 2000]. The *hot zone* is the inside of a building where a rescue is taking place. The *warm zone* is around it, and contains equipment and rest areas for the personnel. Elsewhere is the *cold zone*, which is open to the public and the media.

Figure 8: Following an incident such as a hurricane (left) the USAR task force is called in. They set up a base of operations (centre) then conduct search and rescue missions (right).

After an incident occurs, a FEMA USAR task force is called, and arrives in the area. It will set up a base of operations, then start the search. In our scenario we are assuming that the task force sets up a mobile base in the cold zone, or can use a fixed facility, which has the space and infrastructure to provide computing power, network access, and large displays to its tactical personnel. The operational personnel will be positioned in the warm and hot zones.

The TF has a series of tasks:

- Identify buildings and define a method for addressing them.
- Perform structural triage and assessment for hazardous materials (hazmat).
- Prioritize the search based on various factors: building function, occupancy, nature of the collapse, time of day, etc.
- Search: canine, electronic, physical.
- Prioritize rescues based on the available resources, and state of the victims.
- Rescue: set up operational work area, extract victim. This may involve heavy equipment/cranes which are handled by a specialist.
- Medical: treat patients in priority order: task force personnel, victims, others.

These tasks are performed under time pressure, and with incomplete information about the pre-incident layout and post-incident situation.

Task forces use the Incident Command System (ICS), widely used in the US, UK, and other countries, as a standard way to organize the command hierarchy. ICS mandates various procedures for the command structure, such as specifying that each commander have between three and seven subordinates, and communications be made in plain English to allow information to be passed between agencies.

3.2 Experimental scenario

In our scenario, a tactical actor in the base of operations co-ordinates the activities of several units in the field. The units perform a search and rescue task. Each unit may be a small team of people, but each team has one person, perhaps the team leader, holding a handheld computer and communicating with the tactical level.

3.2.1 Aspects to consider

Various aspects of the domain could be considered in this scenario. Table 3 shows a set of aspects, and the ones shaded in are the ones that we will consider in this project. For instance, we will consider the human resources—the allocation of tasks to people—but we will assume supplies such as fuel to be infinite.

Dimensions	Space	The locations of items in the environment.
	Time	The times of events.
Resources	People	The people who will perform tasks.
	Supplies	Supplies such as equipment, fuel, and food will be required in a real situation, but I will omit them from this scenario.
Activities	Past actions	A history of events that have happened, and the state of the system.
	Present state	The current physical situation, and what the actors in the system are doing now.
	Future schedule	The schedule of planned future actions.
Structure	Procedural	In real emergency response there will be official procedures that personnel should learn and follow, but in this project we will not be defining or testing procedures, so we will not impose them on users.
	Organizational	Real emergency response organizations scale with the incident and people move between roles, so organization awareness is important. In our scenario we will have only a small number of fixed roles.
	Technological	Technological limitations such as intermittent network and GPS coverage will, in practice, lead to styles of work designed to mitigate them. We will avoid this by assuming the technology works nominally.

Table 3: Aspects of the domain. The shaded cells indicate aspects considered in this work.

3.2.2 Simulation of the physical tasks

Our work is addressing team co-ordination rather than the lower-level tasks of USAR personnel, so we have chosen to simulate the tasks of moving to different buildings, and searching those buildings. There will be the option of changing to a more realistic arrangement, where subjects actually move around a real outdoor environment, at a later stage.

We will simulate the task of moving around the urban environment with RISK[6], a project at the D-CIS Lab[7], to create a simulation of emergency situations for testing human-computer interaction in such situations.

Figure 9 shows an example of a simple town created in RISK, and the perspective of a person walking around in that environment. The left image shows the it world editor, which allows the user to create a virtual environment containing buildings, human characters, and other entities. The right image shows the view of a person ‘walking around’ in the virtual environment.

We will implement a computerized task for the operational actors, to take the place of the actual searching of buildings. This will not be an accurate simulation of the low-level search task since that is not our focus in this project, but it will be exhibit similar features from the point of view of the tactical actor, such as being dependent on the features of the building being searched, taking a variable time to complete, having the possibility of finding victims, and possibly generating unforeseen events in the scenario which must be addressed.

[6] http://forge.decis.nl/projects/risk
[7] http://www.decis.nl/

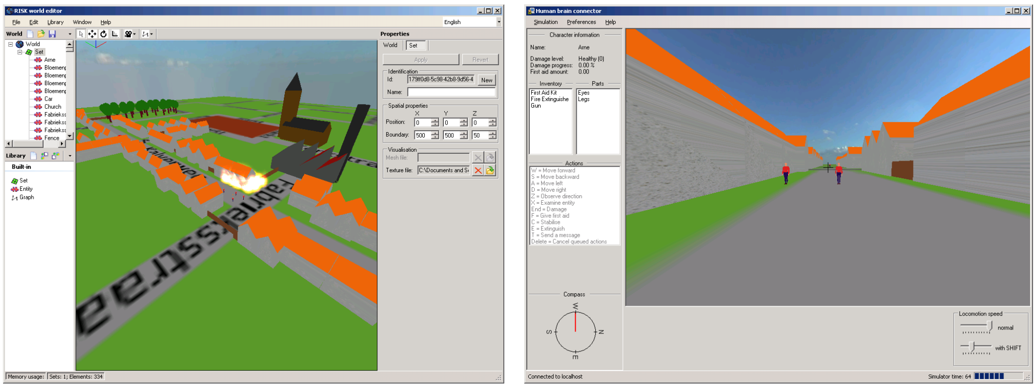

Figure 9: To simulate the movement of search units around a city we are using a virtual environment. The world editor (left) is used to create the city, then the experimental subject playing the role of the operational actor moves around the city from a first-person perspective.

3.2.3 Assumptions

In the experimental scenario we will have one tactical actor, and one or more operational actors representing search units. Currently, at the operational level only search units will be represented by human subjects. Rescue units will be simulated, and other types of personnel will be omitted in this simulation.

Below is a list of points that constrain our experimental scenario:

- People involved in the task.
  - There is one tactical actor in the base of operations using a large display.
  - There are one or two search units. The leader of each unit is using a handheld display.
  - Rescue units will be simulated.
  - Other units (medical, logistics, etc.) will be simulated or omitted
- Assumptions about the task.
  - No supplies, such as fuel, are necessary.
  - Units can be tracked (GPS) when they are outdoors, but not when inside buildings.
- Prior information.
  - The geographical zone of interest has been chosen.
  - A map of the area with roads and building outlines is available.
  - Information provided by other emergency services is available: no-go areas, blocked roads, etc.
  - Floor plans of (some) buildings are available.
  - Structure triage has been performed, so there is some information on all buildings that will be searched.
  - An initial search schedule has been made. The may be amended by the tactical actor as the scenario unfolds.

3.3 Cognitive task analysis

Before a user interface is created, the information that must be displayed and the functions that must be provided must be defined. We have performed a cognitive task analysis (CTA) to obtain these requirements, using a hybrid CTA method that has been developed at the Humans and Automation Lab at MIT for specifying futuristic human-computer interfaces [Nehme et al., 2006], that is, interfaces that are not simply an upgrade of an existing system.

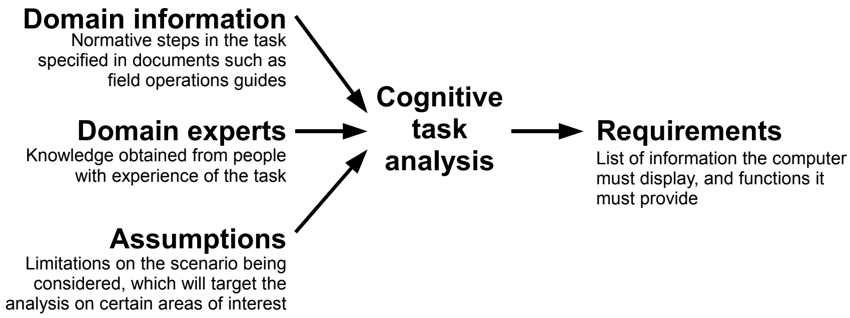

Figure 10: Overview of cognitive task analysis.

The purpose of cognitive task analysis is to take domain information, and assumptions which define the scope of the analysis, and create a list of requirements for the computer system that will be designed to support the task being analyzed. We are currently in the process of presenting our CTA to fire and rescue personnel in the UK, to obtain domain knowledge from domain experts as another form of input to the process. The inputs and outputs of the CTA process are depicted in Figure 10.

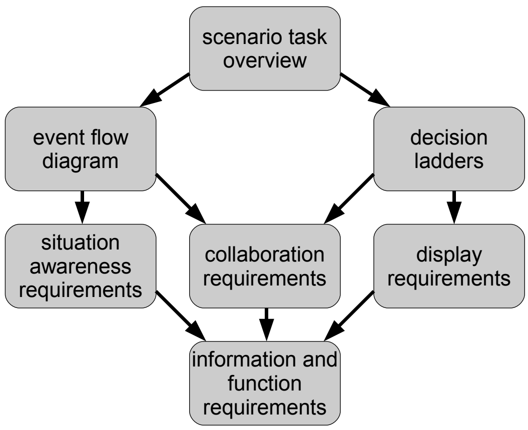

Figure 11: Steps in the hybrid CTA process.

After defining the domain in general, the hybrid CTA process consists of five phases:

- Scenario task overview
- Event flow diagram
- Situation awareness requirements
- Decision ladders, with display requirements
- Information and function requirements

The steps are depicted in Figure 11. We have added *collaboration requirements* to the previous method, because in our system there is more than one human, so the requirements for supporting collaboration between them should also be captured. The collaboration requirements are generated from the event flow diagram and decision ladders.

The final list of requirements is used as input to the design process for the computer interface presented to users. Each of the five steps is introduced in a section below, along with the result of applying it to our USAR scenario.

3.3.1 Scenario task overview

This scenario task overview defines the task that experimental subjects will be given. It is a hierarchical decomposition of the functions that must be performed by the actors. In our scenario we have identified three main phases—activation, operations, and demobilization. All three are listed in the tables below, but it is the operations phase that we will study, so it is given in most detail.

Activation

Activation	• USAR task force arrives at incident location • Set up base of operations • Brief teams on the incident action plan • Complete structure triage on all buildings • Create initial search schedule

Operations

Functions for the tactical actor:

Schedule (mostly temporal)	Search	• Monitor progress of search units in fulfilling the search schedule • Change search schedule – Reason for change: (a) search units not meeting the schedule (indicated either by passive monitoring or an active alert), (b) change to status of a structure, (c) external report – Rearrange the schedule, using static data, structure triage, and action history as inputs – Inform the units of the new schedule
	Rescue	• Monitor progress of rescue units in fulfilling the rescue schedule • Change rescue schedule – Reason for change: (a) rescue units not meeting schedule, (b) new victim found – Rearrange the schedule, using structure triage and victim reports as inputs – Inform units [automatic in this scenario]
Guide (mostly spatial)	Navigation (large scale)	• When a search unit discovers new information (blocked road, etc.) add it to the map • Ensure search units take good routes – Identify when a search unit is taking or may take a bad route – Generate a good route to the next structure in the schedule – Communicate the route to the search unit
	Structure access (small scale)	• Ensure units access structures easily – Identify when a unit may have trouble accessing a structure – Determine the best access point – Communicate the access method to the unit • If there is a report of a high-priority floor/room to search, inform the search unit

Functions for the search unit:

Search		• Perform search • Inform tactical level of any significant deviation from the schedule: search taking a long time, etc. • Report found victims • Report completion of search
Move	Navigation	• Move to each structure on the schedule in turn • Inform tactical of inaccuracies in the map resulting from difficulties in navigation
	Structure access	• Enter the structure • Move to each floor and room

Demobilization

Demobil-ization	• Review equipment • Dissassemble base of operations • Allow personnel to rest • Task force debriefing • Report on events, evaluation, and recommended changes

3.3.2 Event flow diagrams

Figures 13 and 14 (pages 24 and 25) contain the event flow diagrams. These are essentially flowcharts of the functions to be performed by the actors, showing the temporal relationships between the subtasks. Boxes symbolize processes; diamonds, decisions; and hexagons, loops. A difference between this application and previous uses of the Hybrid CTA method is that in this case some functions do not involve the computer (these are shaded in red) and some consist primarily of collaboration between people (these are shaded in green) rather than interaction between human and computer.

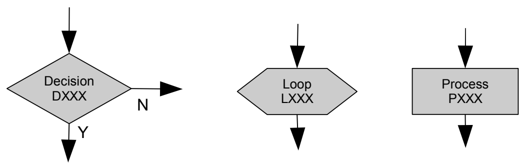

Figure 12: Symbols used in the event flow diagrams. Decisions have identifiers of the form DXXX, loops LXXX, and processes PXXX.

3.3.3 Situation awareness requirements

The situation awareness requirements are derived from the event flow diagram, and list information that should be present on the displays to support the functions in the diagram. They are listed in the table on page 26. The codes, (for example, P104) correspond to symbols in the event flow diagram.

The three columns for the three levels of situation awareness, as defined by Endsley [Endsley, 1995], are a standard part of the Hybrid CTA. We have added the fourth column for collaboration requirements, because many of the functions performed in this scenario consist primarily of collaboration with another person, rather than use of the computer.

3.3.4 Decision ladders

Key decisions that a person must make, as suggested by the event flow diagrams, are analyzed in decision ladders. The form of the decision ladders is taken from Rasmussen [Rasmussen, 1986]. Because the decision ladders require a significant amount of space we have moved them to Appendix A (page 31).

The ladders are annotated with information requirements (blue speech bubbles) which show the information needed by the person to complete each processing step.

Another addition over the standard decision ladders is the collaboration links, which show the stages in the information processing that rely on collaboration with another person. If the current actor initiates the collaboration, the decision ladder will be augmented with a two-way link: the actor will stop processing until the collaboration is completed. If the collaboration is initiated by someone else the decision ladder will have a pair of incoming and outgoing links, where the outgoing link is further along in the processing. In this case the decision ladder can be entered at the incoming collaboration link.

Because higher-level decisions may be better handled at the tactical level, decisions may be deferred up by the operational actor, and this is reflected by the upper parts of the decision ladder being bypassed in several of the decision ladders for the operational actor.

3.3.5 Information and function requirements

The situation awareness requirements table and the annotations on the decisions ladders together give rise to a list of information (computer output) and function (computer input and processing) requirements, which are listed in the information and function requirements tables on pages 27 and 28.

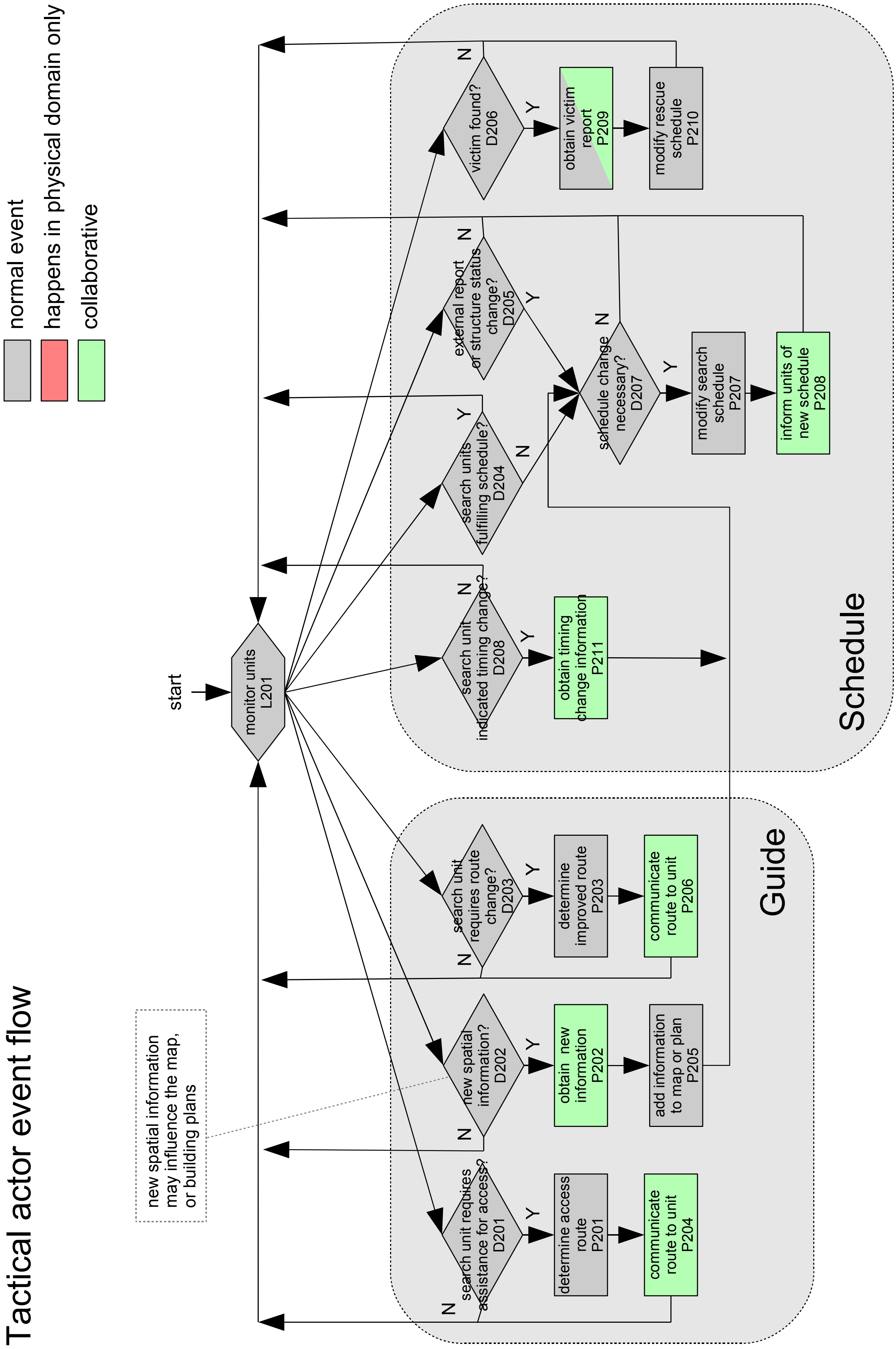

Figure 13: Event flow diagram for tactical actor

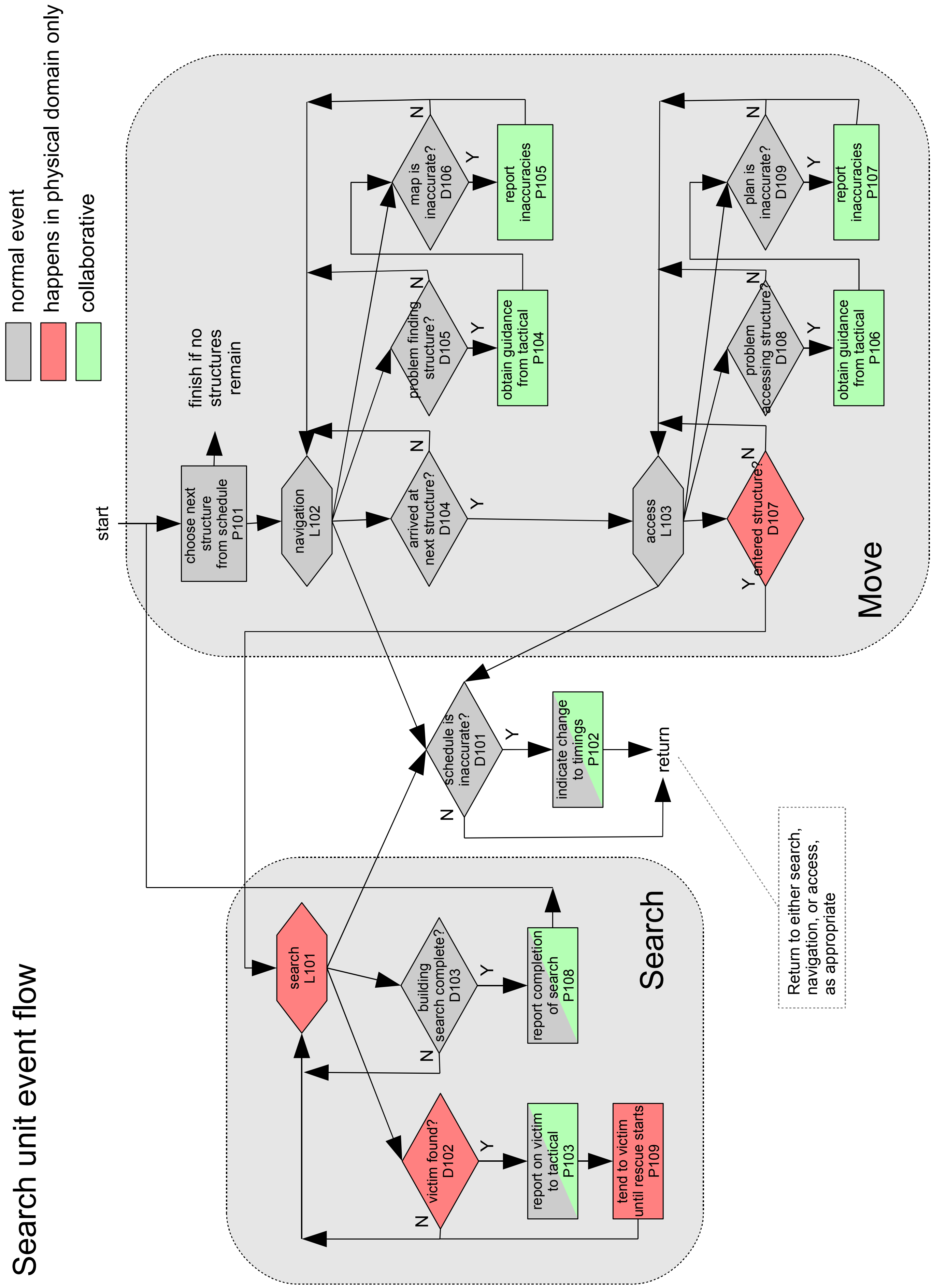

Figure 14: Event flow diagram for search unit

Task	Level I (perception)		Level II (comprehension)		Level III (projection)		Input/Collaboration	
Search Unit (Move)	Shared annotations on map	P104, D106	Highlight next structure in schedule	P101	Show future structures in schedule	P101	Shared annotations on map	P104, P105
	Map of current location	L102, D106	Show location of next structure on map	L102, D104, D105	Show other structures in schedule on map	D104, L102	Shared annotations on plans	P106, P107
			'You are here' marker on map	L102, D104, D105, D106				
			Items on map affecting navigation: no-go areas, annotations.	L102				
			Plans of buildings	L103, L101, D108, D109				
			Items on plan effecting access: blocked entrances, etc.	L103, D108				
Search Unit (Search)	Indicate early or late completion of search	D101	Show scheduled and actual times for previous searches	D101	Show scheduled times for future searches	D101	Victim report facility	P103
			List of floors/rooms in building	D103			Method for indicating updated timing for current search	P102
							Form for details of searched structure	P108
Tactical (Schedule)	Indicate when search times are significantly different to schedule	D204	Visualization of past search times versus schedule	D204, D207	Display of predicted future search times	D207, P207	Way to transmit modified schedule to teams	P208
	Alert of incoming reports	D205	Chronological list of external reports	D205	Display of predicted future rescue times	P210	Way to rearrange schedule	P207
	Alert of structure change	D205	Display data on structures	D205, P207			Shared display of victim report	P209
	Alert of new victim report	D206	Display victim report	P209				
	Alert of timing change report	D208	Display timing change report	P211				
			Visualization of past rescue times versus schedule	P210				
Tactical (Guide)	Map showing search units	D201, P201, D203	Items on map affecting navigation: no-go areas, annotations.	D203, P203	Show vector from teams to destinations	D201, D203, P203	Shared annotations on map	D202, P202, P206
	Plans of structures, with access points	D201, P201			Visualize future search locations on map	D203, P203	Shared annotations on plans	P202, P204
							Maps extra markers, etc.	P205
							Marking of routes with way points	P206

Figure 15: Situation awareness requirements.

Each requirement corresponds to one or more steps in the event flow diagrams of Section 3.3.2. Sometimes an information item is useful for multiple tasks; for example, building plans are listed in the 'Search Unit/Move' task, but are also used in the 'Search Unit/Search' task.

Decisions D202 and D208 are initiated from a search unit. No information requirements are provided for them because the information can be provided directly by another human (via the voice channel).

Requirements for the search unit display

Type	I/F	Description	Source
Map	I	Current location marker	SA, DL13
	I	Destination (next structure)	SA, DL13
	I	Other structures from schedule	SA
	I	Obstacles (No-go areas)	SA, DL13
	I	Annotations from tactical	SA
	I	Routes (way points) from tactical	DL13
	F	Allow annotations from search unit	SA, DL13, DL14
	F	Allow route from search unit	DL13, DL14
Structural Plans and Data	I	Plan of structure (if available)	SA
	I	Items on plan affecting access: blocked entrances etc.	SA
	I	Information on structure (number of floors etc.)	SA
	I	Annotations from tactical	SA
	F	Allow annotations from search unit	SA
Schedule	I	Ordered list of structures to search (past and future)	SA, DL11
	I	Scheduled time for each structure (past and future)	SA, DL11
	I	Actual times for completed structures	SA
	I	Highlight next structure in schedule	SA
	I	Alert if time for current task elapses	DL11
	F	Enter revised times (they will be highlighted for display to tactical)	SA, DL11
	F	Indicate search completion	DL12
	F	Victim report facility	SA, DL22
	F	Form for details of searched structure	SA
	F	Gesturing to tactical over schedule	DL11

Table 4: Information and function requirements for search unit.

Key for abbreviations:
I/F = Information (I) or function (F) requirement;
SA = derived from situation awareness requirements;
DLXX = Derived from decision ladder XX.

Requirements for the tactical actor display

Type	I/F	Description	Source
Map	I	Locations of search units	SA, DL23
	I	Histories of unit locations	DL23
	I	Obstacles (no-go areas, etc.)	SA, DL23
	I	Vectors from teams to destinations	SA
	I	Show future search locations	SA
	F	Shared annotations on map	SA, DL23
	F	Marking of routes with way points	SA, DL23
	F	Extra markers on map	SA
	F	Allow multiple routes to be entered, and rated on distance, time.	DL23
	F	Gesture with search unit over map	DL23
	F	Share way-point route with search unit	DL23
Structural Plans and Data	I	Plans of all structures with access points	SA
	I	Information on each structure (number of floors, etc.)	SA
	F	Shared annotations on plans	SA
Search Schedule	I	Indication of when search times are significantly different from the schedule	SA
	I	Alert of change to structure details	SA
	I	Alert of change to timing from search unit	SA
	I	Visualization of past and future scheduled search times	SA, DL21
	I	Visualization of past actual search times	SA, DL21
	I	Status displays for schedule fulfillment	DL21
	I	Show which schedule items can be moved	DL21
	I	Indicate changes made to schedule to aid collaboration with search unit	DL21
	F	Method of transmitting modified search schedule to teams	SA
	F	Ability to gesture on schedule during collaboration	DL21
	F	Allow search schedules to be rearranged, and show predicted results	SA, DL21
Victims	I	Alert of new victim report	SA, DL22
	I	Details of victim report	DL22
	I	Highlight important data in victim report	DL22
	F	Victim report shared between tactical actor and search unit. Shared highlighting and editing	SA, DL22
	F	Allow indication to search unit that victim report has been processed	DL22
Rescue Schedule	I	Visualization of past and future scheduled rescue times	SA, DL22
	I	Visualization of past actual rescue times	SA, DL22
	F	Allow rescue schedules to be rearranged, and show predicted results	DL22
External	I	Alert of incoming report	SA, DL21
	I	List of reports with details	SA, DL21

Table 5: Information and function requirements for tactical actor

4 Conclusion

Advances in wireless networking will allow voice communications to be joined by synchronous collaboration in many domains, and in particular in emergency response. Advances in interactive devices at both ends of the size scale—the small and the large—will provide devices more suited to the tasks of personnel in emergency response organizations, but the size difference will exacerbate the asymmetry inherent in the role differences. Collaboration will be very different to the conventional videoconference on desktop computers with webcams, keyboards, mice, and standard size screens.

In this document we have described the technological changes that will bring this issue to the fore, and reviewed previous work on the design, construction, and testing of collaborative systems. We have also described a domain which stands to benefit greatly from the new technology, and given a detailed analysis of tasks that could be enhanced by collaborative technology.

We are currently building a system to demonstrate the possibilities for supporting the analyzed tasks (navigation and scheduling of USAR teams), and will be conducting experiments to test how users react to the system, and determine which interface choices will best support the tasks.

4.1 Future work

We are currently designing the interfaces that will be used by the tactical and operational actors. There will be various technological challenges in creating working versions of these interfaces, and then we will use them in experiments to see how people use them, and the provide insights for improvements and recommendations.

4.1.1 Technology

We will address the information and function requirements identified in the CTA by creating tabletop and handheld interfaces for the tactical and operational actors, but the process of going from requirements to interface design is an ill-defined one, and requires ingenuity. We also have various technical constraints, so the implementation of the underlying technology will be interesting in itself.

In the coming months we will implement a distributed collaborative system between tabletop and handheld devices for supporting a distributed USAR team in their navigation and scheduling tasks. Our next report will be a description of the technical aspects of that system.

4.1.2 Research questions

By designing, implementing, and testing our proposed asymmetric collaboration system we will provide answers for several human factors research questions:

- How do collaborators deal with the asymmetry in hardware and roles?
  - How does this affect the aspects: space, time, plans, etc.?
- How do collaborators balance the use of information (regarding dimensions, resources, activities) between them?
  - Is this influenced by the complexity or accuracy of the shared model, that is, if the situation is more complex must the operational actor offload some information processing tasks onto the tactical actor?
- Workspace awareness. The actors will have very different display sizes: the operational actor's display will be very restricted
  - Is the asymmetry in views of the data a problem? Do collaborators remember that the asymmetry exists?
  - Should the tactical actor be given an indication of what the operational actor is seeing, and how should this be done, that is, which workspace awareness features are useful?

– What is the effect of showing on the desk what the operational actor is looking at, and what actions he is performing? How does this affect the different functions?

There are several other questions that we hope to answer along the way:

- Should status information on a large display be arranged to avoid items getting lost?
- How should unanticipated information be handled? For example, a map can be annotated if no adequate facilities exist to represent a new piece of spatial information.
- How should recency of geospatial and textual data be visualized?
- How should accuracy of geospatial and temporal data be visualized?

We will address these questions by performing experimental studies with groups of subjects representing members of a USAR team. There are various potential independent variables for these experiments:

- Complexity of spatial data.
- Complexity of the routes between buildings on the search schedule.
- How obvious the access to each building is.
- Accuracy of the match between static data and the world situation: how accurate the maps and building information is following the changes cause by the incident that caused the emergency.
- Complexity of scheduling required: the number of tasks to schedule, and the necessity to change the schedule during the scenario.
- Accuracy of timing: the match between predicted and actual timing, which will affect the ease of scheduling.

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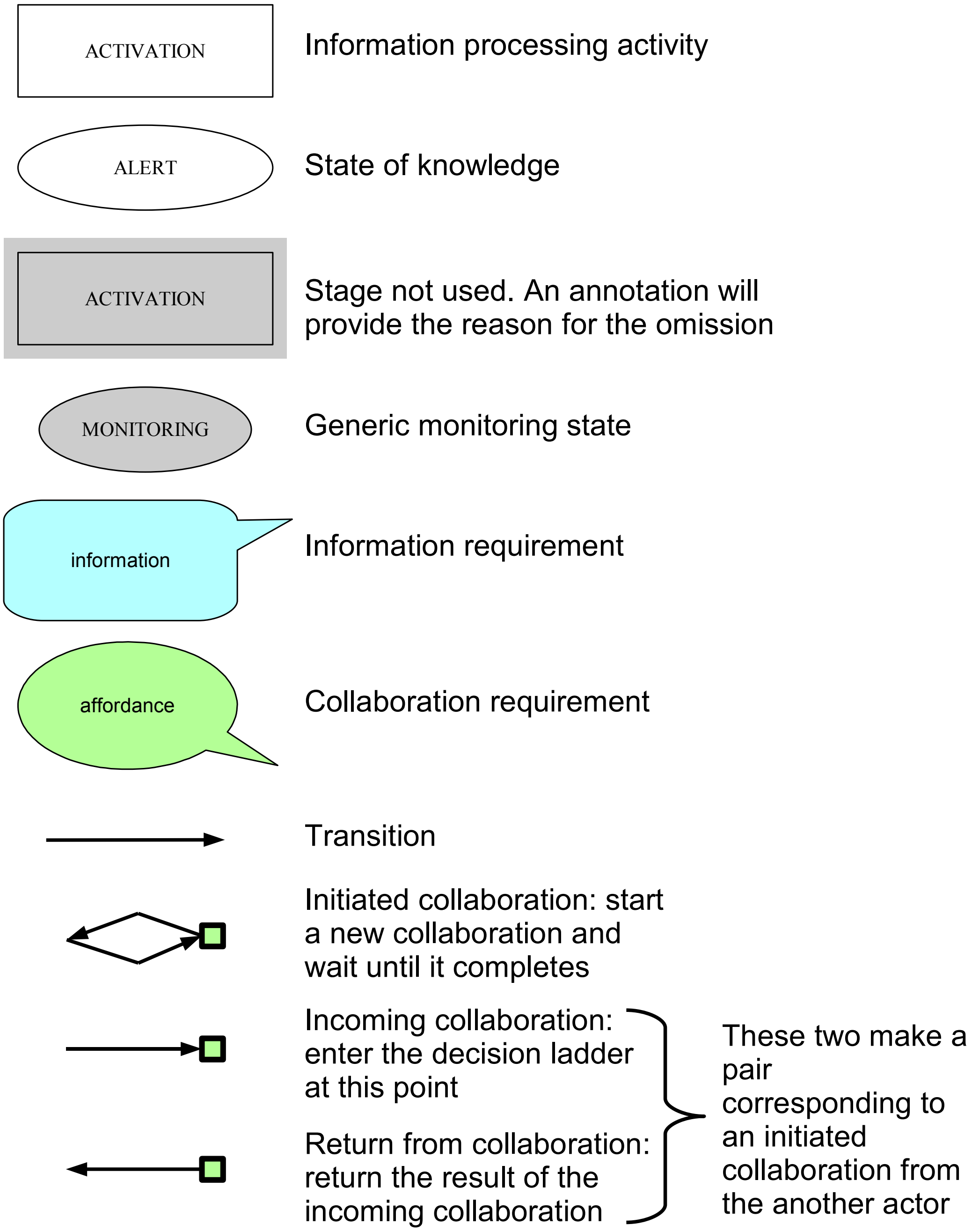
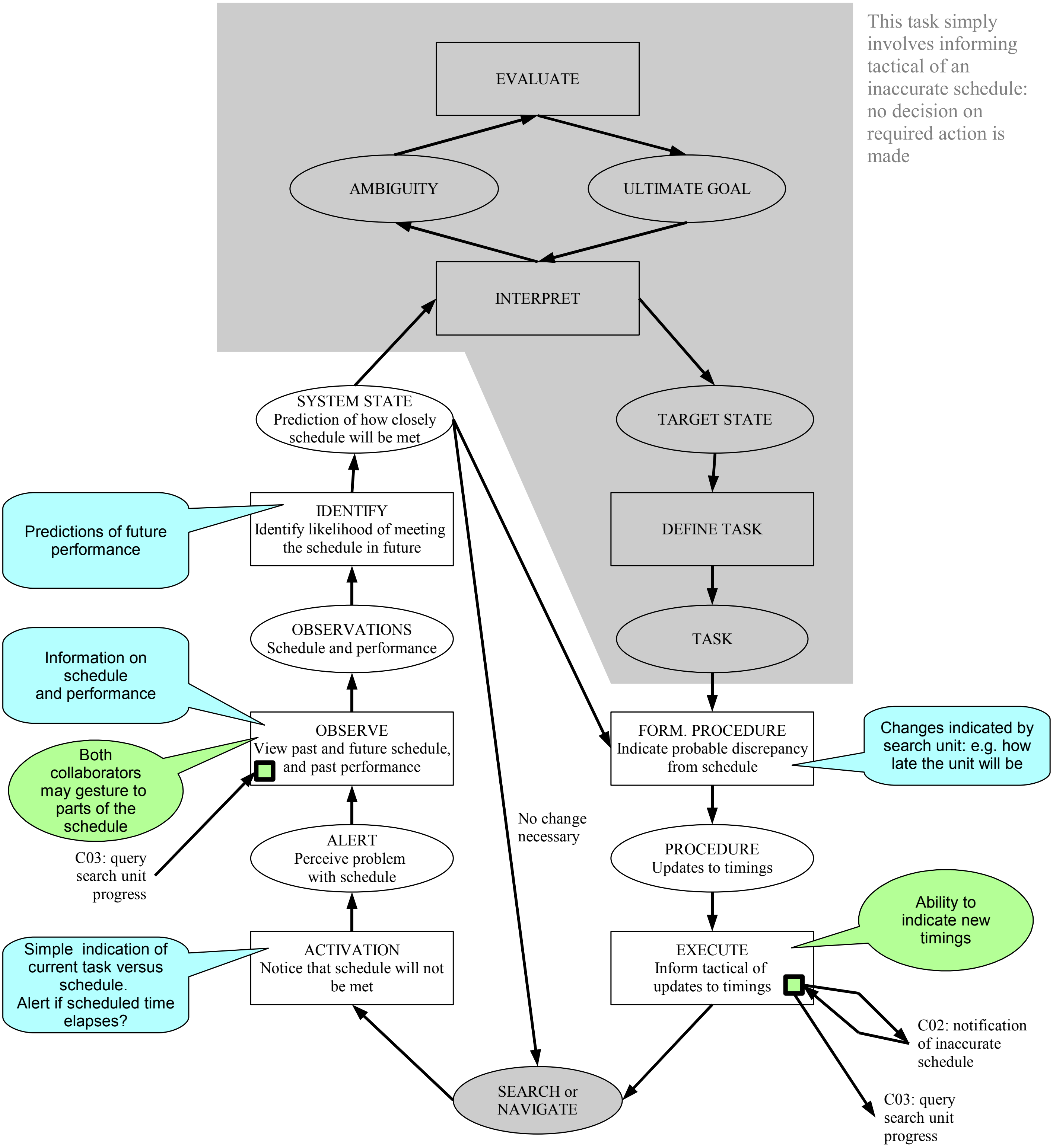
[8] http://web.mit.edu/aeroastro/www/labs/halab/

A Decision ladders

This appendix contains the decision ladders mentioned in Section 3.3.4. Each decision ladder has a code of the form of DL1X for the search unit and DL2X for the tactical actor. Under the title of each decision ladder is a list of the symbols in the event flow diagrams to which that decision ladder corresponds. Below is a key to the symbols used in the decision ladders.



DL11 Search: inaccurate schedule
(D101)

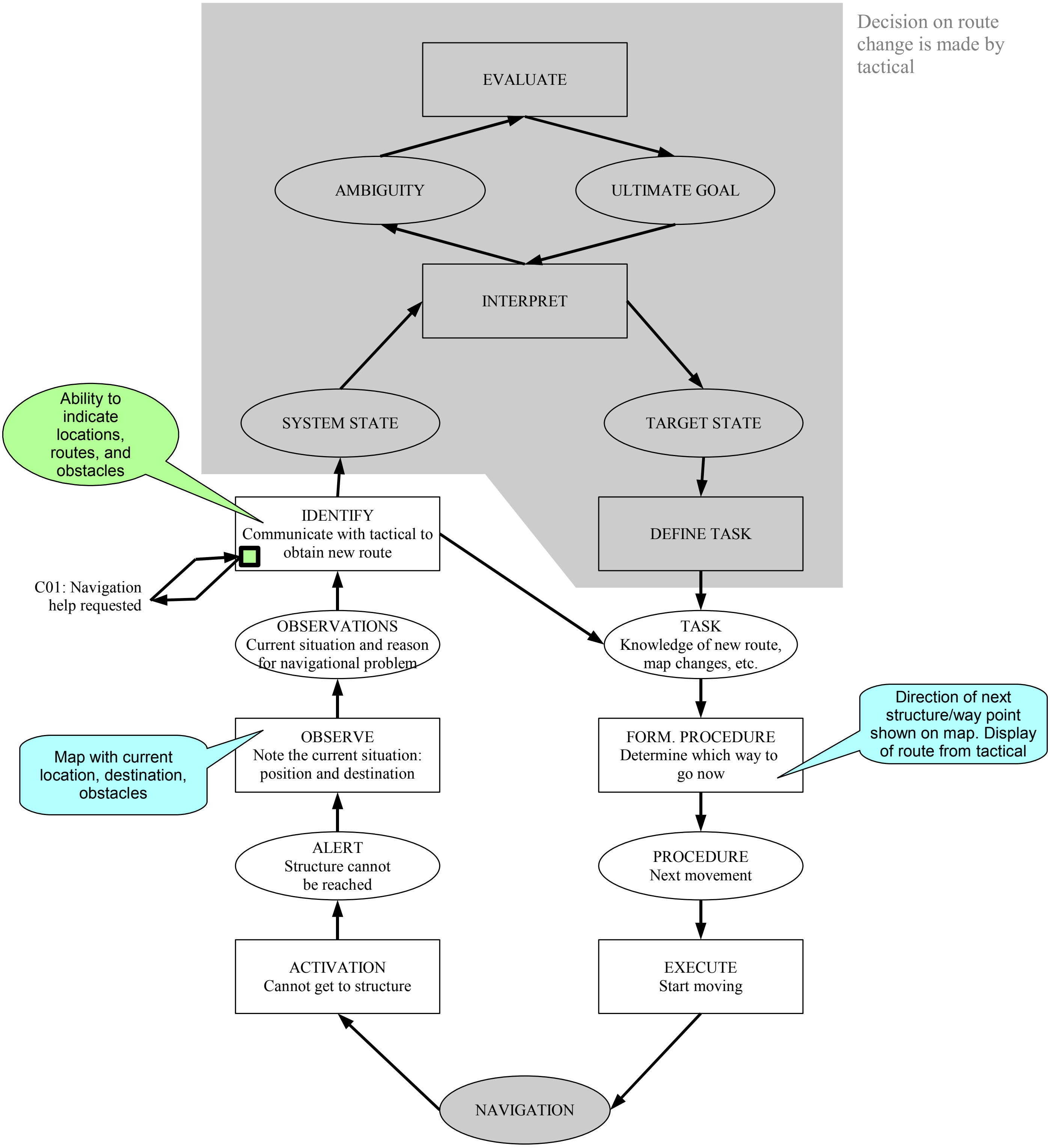


This task simply involves informing tactical of an inaccurate schedule: no decision on required action is made

DL13 Search: navigation (problem finding structure)

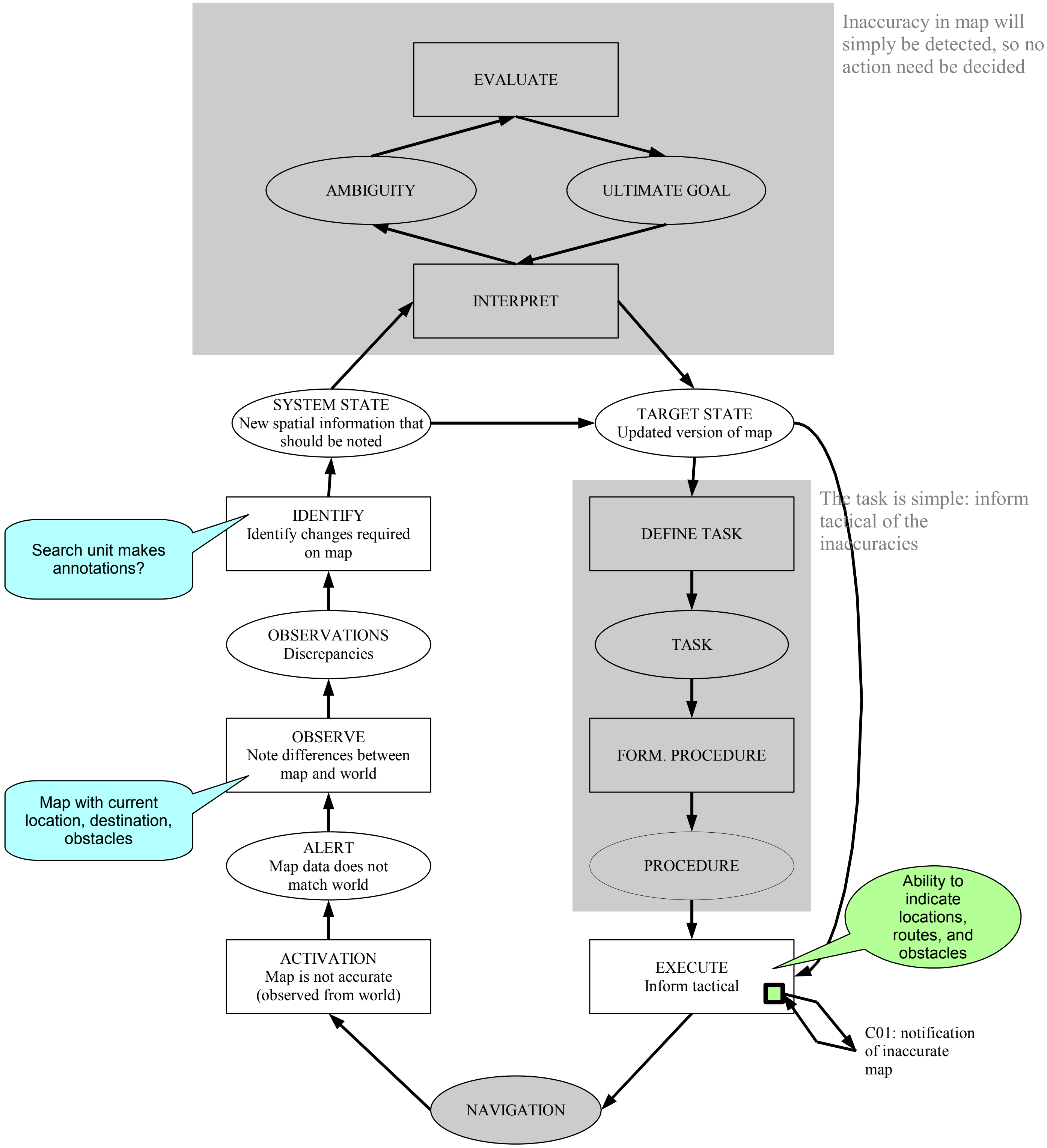
(L102, D105, P104)

(A similar ladder for L103, D108, P106 would address problems with obtaining access)



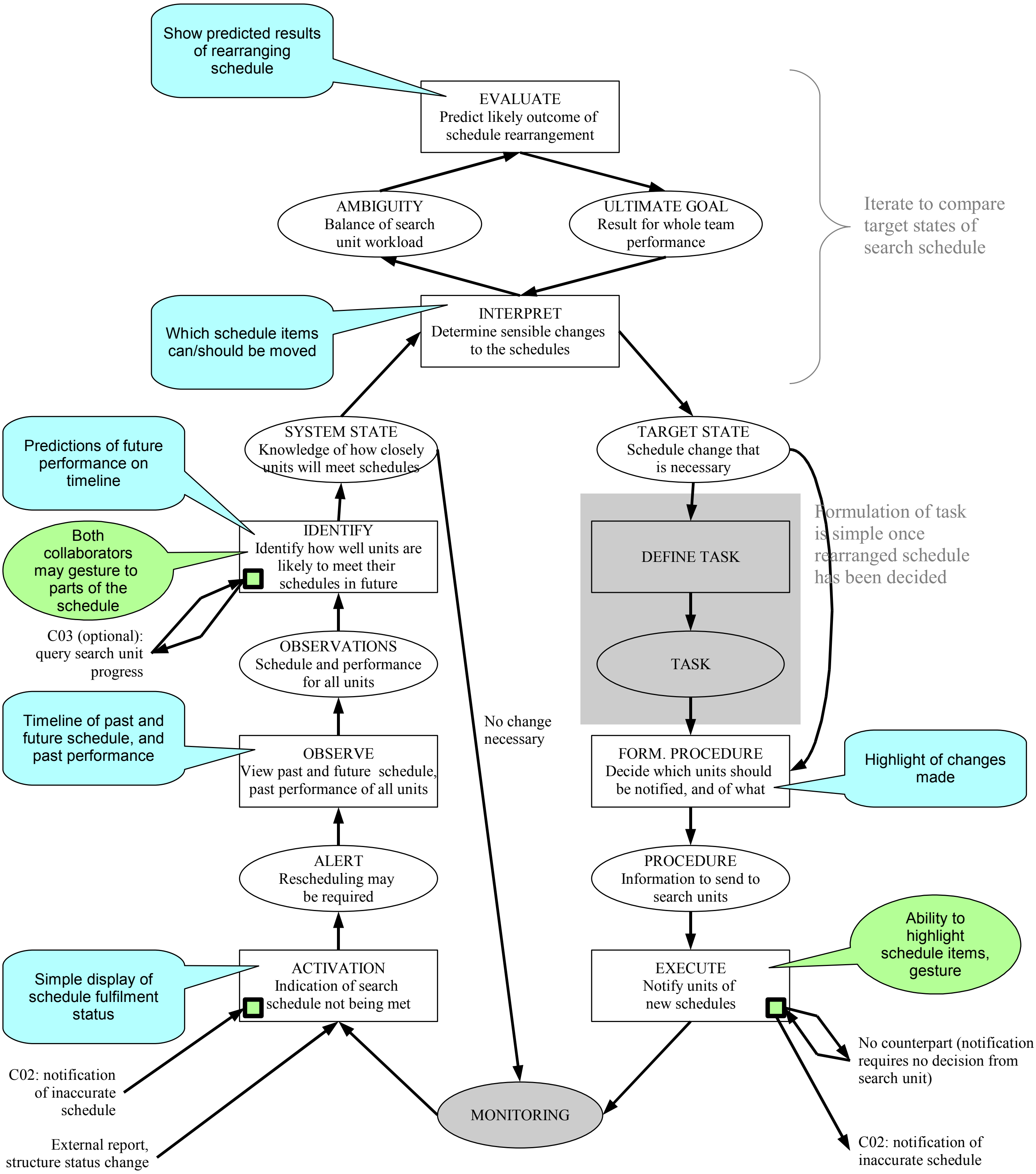
DL14 Search: navigation (inaccurate map)

(L102, D106, P105) (similar to L103, D109, P107)

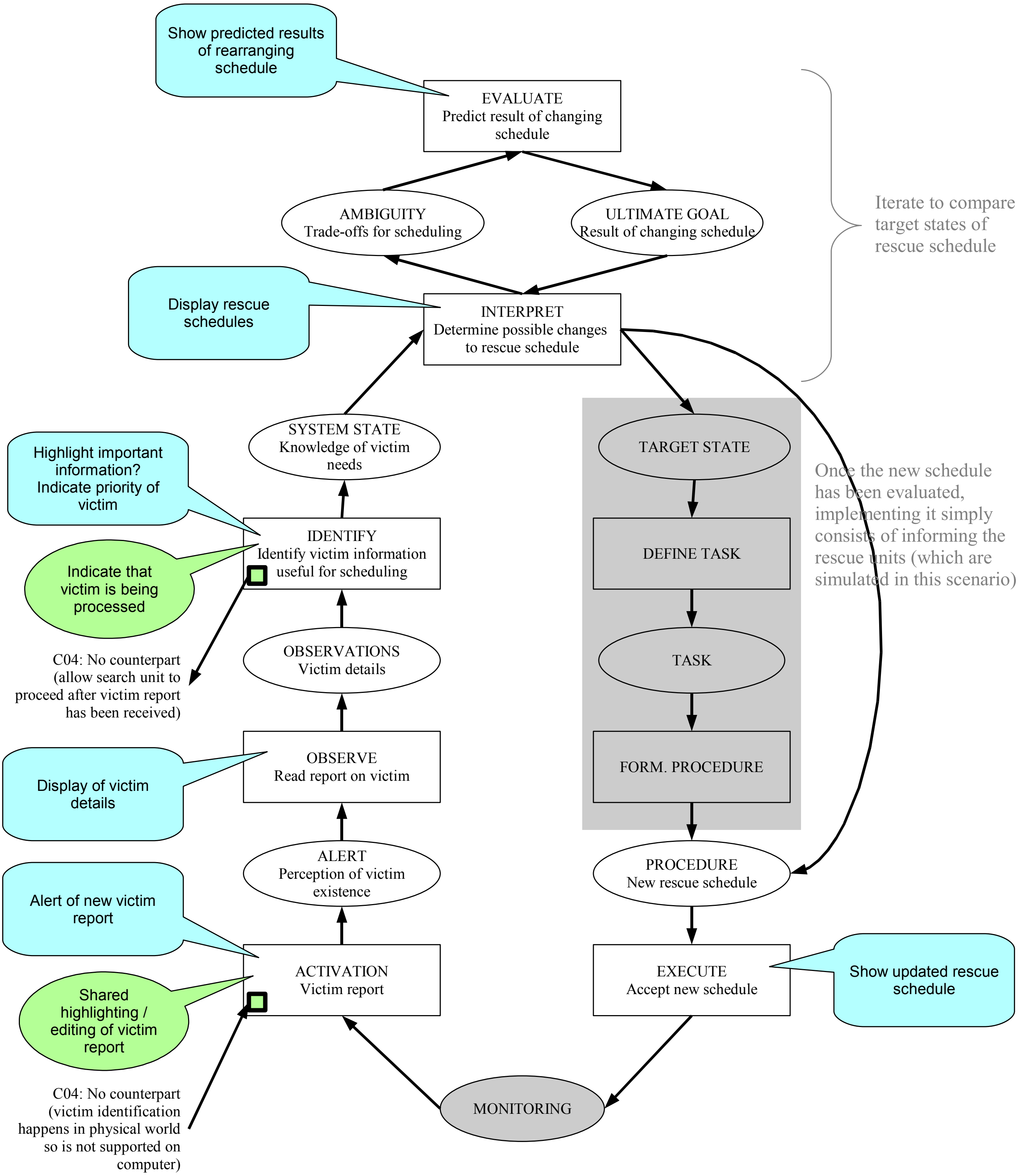


DL21 Tactical: search schedule change

(D204, D205, D207, P207, P208, D208, D211)

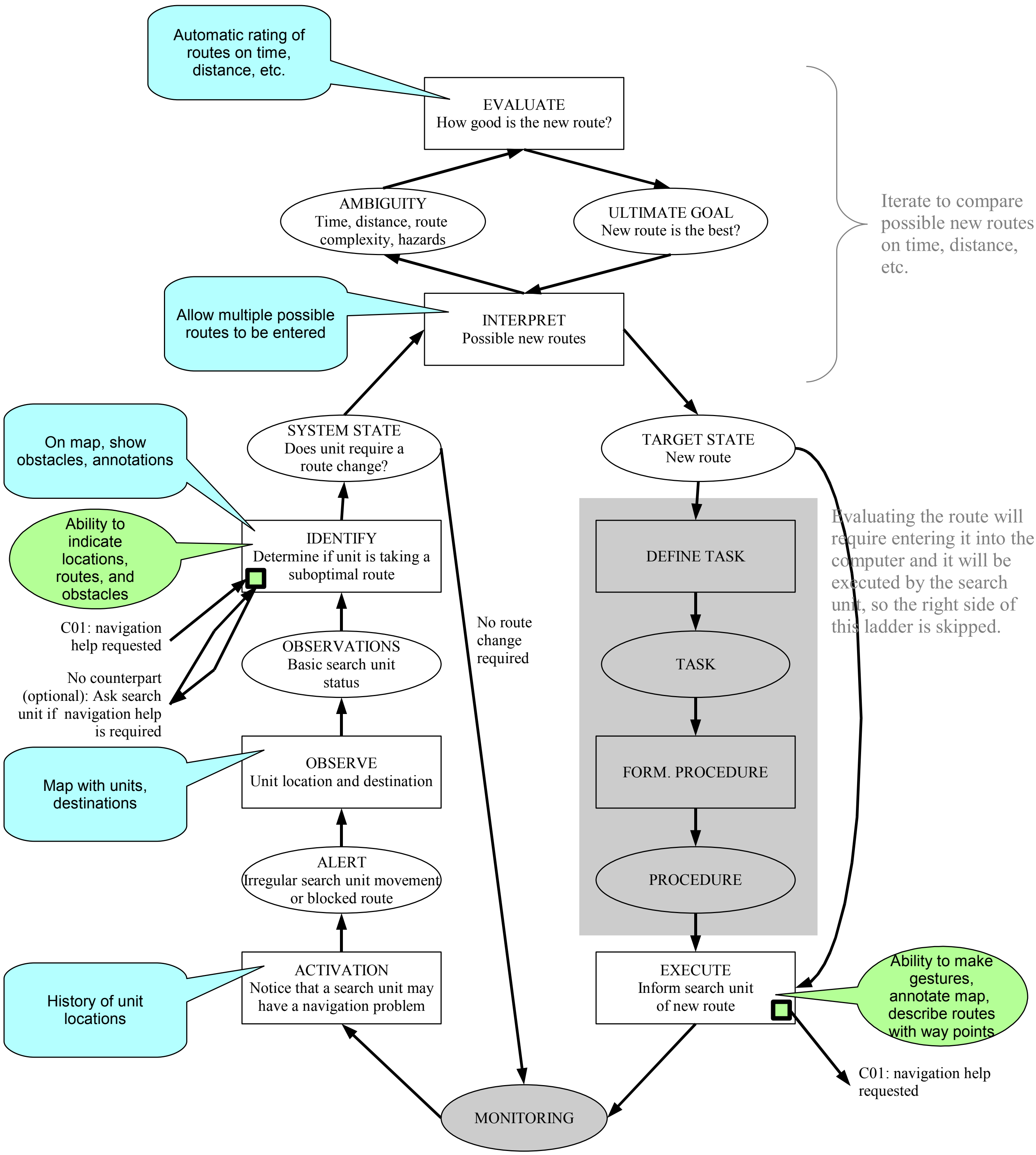


DL22 Tactical: victim found, update rescue schedule
(D206, P209, P210)



DL23 Tactical: route change

(D203, P203, P206) (similar to D201, P201, P204)



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