Event-based Awareness Promotion For Distributed Collaborative Activities

Guoray Cai
College of Information Sciences and Technology
Pennsylvania State University
University Park, PA 16802 USA
Email: cai@ist.psu.edu

Bo Yu
College of Information Sciences and Technology
Pennsylvania State University
University Park, PA 16802 USA
Email: byu@ist.psu.edu

***Abstract*— Maintaining awareness is central to effective coordination and collaboration in complex human activities, but pervasive computing environment has not adequately addressed this requirement from a formal design perspective. Existing awareness solutions work only for relatively small-scale collaboration in traditional workplace, and they suffer from either inflexibility or lack of scalability if applied to pervasive computing environment. Based on our analysis of awareness life cycle, we propose a model of event-based awareness promotion mechanism. Our model extends focus-nimbus model and reaction-diffusion model with computational reasoning of dependencies and diffusion paths. The model is partially validated through implementation of our experimental environment, DACE (Dependency-based Awareness and Coordination Environment), which supports belief tracking, updates, and reasoning tasks and enhance the cognitive capability in awareness interpretation and use. Key principles of the DACE system are explained through a hypothetical scenario of search and rescue exercise typical in emergency response applications.**

Keywords-awareness; Awareness; coordination; activity modeling; dependencies

I. INTRODUCTION

Support for awareness is one of the most active research areas in computer-supported collaboration [1-3]. One general design concern for collaborative systems is that awareness must be achieved with minimal attention and effort from the participants of teamwork [4]. Awareness falls into the category of articulation work that is required for coordination but not the primary goals for collaboration [5]. Taking extra time and effort to achieve awareness can interrupt the current line of action, and therefore damage team performance [6]. As a result, a large number of awareness mechanisms and tools have been proposed in the literature, aiming at promoting awareness in a relatively effortless way [7].

Although much progress has been made in designing awareness mechanisms to support team activity at relatively small and medium scales [7], it becomes a much more difficult task to promote awareness in complex and highly distributed activities [8]. With the advent of ubiquitous devices and pervasive computing environment, awareness must be built into the system in a formal and explicit fashion. Our interest in supporting awareness is motivated by the need for coordinating large-scale distributed collaboration in geocollaborative crisis management [9-14]. Crisis response usually involves multiple, distributed individuals and organizations (first responders, search and rescue workers, medical staff, transportation coordinators, and others) to mitigate the impact of incidents that threaten public safety and the environment. Coordination among teams are normally driven by critical events, such as discovering a trapped or wounded victim, reported contamination, extreme medical condition of a survivors.

***A Motivating Scenario**:* A chemical factory near an urban area was exploded and caused a major pollution. To respond to this critical incident, task force is formed that includes search and rescue teams, decontamination teams, medical treatment teams, and transportation teams. Teams are dispatched and configured geographically to cover the impacted area. Each team covers a functional area of the overall mission. **Search and rescue** teams patrol the incident area to search for victims and report their locations and status. Discovered victims are first decontaminated (by one of the **Decontamination teams)** before they can be moved to other facilities. If a victim is wounded, he or she will be scheduled and transported to a **medical station** for treatment. The **transportation team** handles all transportation needs for moving victims to treatment stations and the transportation team handles shelters. Although teams are working autonomously on their local tasks, they must coordinate their capacity, schedule, and priority to deal with emerging and unexpected situations in order to save and protect all the victims in an efficient fashion. *Figure 1 shows a hypothetical distribution of tasks and teams in relation to the disaster area.*

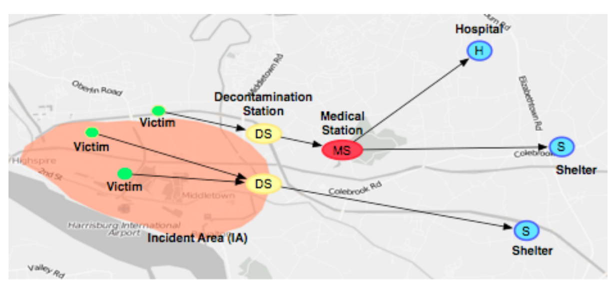

Figure 1. An emergency scenario

Such applications have a few unique aspects that make the awareness problem difficult. *First*, the 'field of work' is highly distributed (EOC, mobile command-and-control posts, first responders, medical stations, etc), with extremely low mutual visibility, intelligibility, and common frame of references among sites. Few have the time and energy to keep up with the changing global picture of operation. *Second*, there are potentially a large number of events (internal and external) that may have varying degree of relevance to different actors at any given time, and they compete for attention and cause information overload [15]. *Third*, coordination in response to events is complicated by the contingent and semi-specified course of actions that are subject to re-planning in response to the volatile environment. The combination of the above three characteristics leads to magnitudes more complexity than what can be handled by the existing awareness methods and tools developed so far [16, 17].

Awareness in collaborative work is unlikely to be effortless and failure of coordination may lead to negative consequences. Managing awareness adds cognitive load to human agents. Large-scale collaboration can benefit from the use of computational artifacts that actively promote awareness. This paper proposes a framework for articulating and supporting awareness promotion. We conceptualize awareness promotion as a collaborative process that involves the division of work among all the human participants and the computational systems in a large, distributed activity. Within this framework, the system plays the role as a mediator to facilitate the interpretation and propagation of awareness information. At the center of our computational model is a situational representation of activities and dependencies, which enables the system to provide several mediation functions: (1) It provides the visual and interactive support that allow the users to interpret awareness information within their local scope of work. (2) It supports the relay of awareness information across local scopes. (3) It can play a even more proactive role to automate the reasoning on how certain awareness information impact the states of activities as its effects propagate across multiple activities. To validate our design methods, we implemented a prototype system DACE as a proof of concept artifact.

After reviewing related work in the following section, we will present our conceptualization of the collaborative awareness process, followed by a description of our computational framework for supporting such awareness processes. Finally, we discuss the advantages as well as limitations of our method, using a concrete emergency response scenario.

II. Related Work

Our method for awareness promotion is informed by the theories of collaborative awareness in the literature [2, 18]. Among many alternatives approaches for supporting awareness, 'event propagation mechanisms' have been in favor, due to the advances in awareness representation and computational environments [19-21]. The benefits of adopting event-based approaches include (1) allowing recipients of awareness information to decide when they attend to, and (2) opening up opportunities for computational mediation and *active promotion* of awareness.

Despite the popularity of event-based awareness research and the maturity of event processing technologies [22], the benefit of introducing computational support to awareness in collaborative system has not been materialized. Early conceptualization of awareness as events propagating through some kinds of semantic network (such as GroupDesk [20] and PoLIAwaC [23]) turns out to be far from adequate. Among more elaborated models of awareness, the most influential ones are the *focus-nimbus* model [24, 25] and the *reaction-diffusion* Model [21, 26].

The *focus-nimbus* model uses the spatial metaphor of "focus-nimbus" to capture the communicational and social aspects of using awareness and provides a way to compute mutual awareness. It allows one to compute different measures of awareness between objects. It merely focuses on how awareness information is produced and perceived but not on how it affects the behavior of the objects.

The *reaction-diffusion* model organizes awareness space as a distributed set of entities, each with ability to react on events (with different sensitivities depending on sources) and diffuse the effects to other neighbors based on diffusion rules. Both models were intended to be general and extensible, and can be tailored to specific applications. While they apply to awareness phenomena in pervasive computing context, both must address two sharp critics imposed by Schmidt [2].

One is the artificial dichotomy of awareness concept (between attention and peripheral awareness, and between by-product awareness and add-on awareness), which does not exist in practice. The second is the separation between awareness model and the activity model of the cooperative work. Schmidt argued that awareness should be described in reference to activities, practices or phenomena or object that a person is made aware of. In addition, both models were motivated by small scale collaboration and have not been tested in large-scale, highly distributed collaboration[26].

In summary, none of the existing models of awareness captures the full awareness cycle as we discussed in section II-C. They could not deal with highly distributed activities because their representations do not include formal representation of activities as we do in our model.

The model we propose here advances our understanding of awareness phenomena in two ways:

(1) It extends the focus-nimbus model [25] of awareness space with a concept of "local scope." The basic rationale is that, even though various activities can be identified in a collaborative setting, each actor usually only engages in a small part that is pertinent to his/her specific role in the overall team goal. Within these local scopes of work, human actors are responsible for perceiving and interpreting important events and awareness information. Meanwhile, the system will maintain the global picture of the whole

collaboration, and propagate the awareness information to relevant actors. By distributing the overhead for awareness promotion among all the participants, the effort for each individual participant can be constrained to a manageable level.

(2) It extends the reaction-diffusion model with a middle step of "re-planning" which couples the awareness promotion cycle with the main activity through computational reasoning. The revised model can be called "reaction-*replanning*-diffusion" model.

III. CONCEPTUALIZING AWARENESS

In collaborative applications, awareness describes a mode of coordination [27]. Awareness is not as simple as picking up stimuli from the environment, but represents active interpretation, documentation, and dissemination of the interpreted event.

A. Events

In collaboration, there are potentially a very large number of events that may or may not be relevant to an actor at any given time. Following Shipley and Zacks [33], we define events as happening related to things. Events occur when objects change or interact. An event could be associated with either physical or mental objects. An apple is not an event, but "an apple is falling" is an event. "A person changed his/her intention/belief on …" is also an event.

We separate the concept of event as real world happenings from the notion of event as one's psychological experience of a real world happening. It is particularly useful to differentiate them for the purpose of awareness studies. It is human perception and experience of events that generate awareness.

B. Awareness

To be aware is a state of mind generally described as being 'cognizant,' 'mindful' or 'heedful' (as detailed by Schmidt[2]). While carrying out local activities, members of the teams must also attend to new events happening elsewhere that may affect their work, and be prepared to adjust their activities accordingly. In an event-driven collaborative system, a*wareness refers to the human consciousness about the happening of events and their relevance to ongoing or future human activities*. This definition emphasizes that *awareness is inherently an interpretive, inferential, and predicative phenomena operated on the relationship between the happenings (events) and the ongoing work*. Awareness information is interpreted and re-interpreted at every step it propagates.

C. Awareness Lifecycle

Awareness as a state of mind can be gained through one's own perception or by means of receiving and interpreting information from other sources. The process of achieving consciousness about some events of importance is called "*awareness lifecycle*" and has a number of recognizable stages (Figure 2).

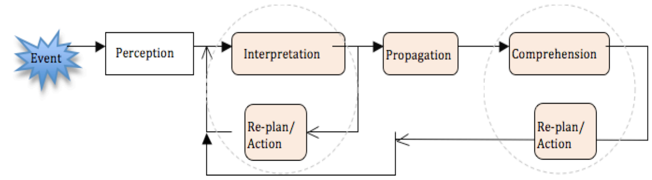

Figure 2 Event-based Awareness cycle

For example, the accident could block a segment of the road that a person 'John' has to travel to a meeting. Being aware of this traffic accident enables the person to re-plan his/her travel and decide what to do next. Continuing the story, if John cannot arrive the meeting on time due to the accident, it could mean that the meeting needs to be rescheduled or postponed. This in turn affects other participants who may also be interested in knowing the event and adjust their travel plans correspondingly. The relay of initial awareness knowledge to other agents within the awareness system is called *awareness propagation*. When another agent (say Kim) received the notification, he will need to analyze the source and the significance of the message in relation to his local activity. This stage is given a name "*comprehension*." When implications of the event is clear, an agent will need to make adjustment to his activity plan (also known as re-plan), which is likely to change the state of work. Such change in state-of-work is also an event that may be of interest to other agents in the same ongoing activity.

An agent who perceives an event will actively interpret the event into clear implications in terms of how it changes in the state of collaborative work. Since interpretation takes activity contexts into account, it is important to make that context explicit. To organize such complexity, we use the following notations:

(1) e: the original event,

(2) D(e): description of e by its source, location, and other measurable properties.

(3) I(e, C; p): an interpretation of an event e by an interpreter, p, using a context C. I(x, C; p) is usually a conclusion on how event e causes immediate or future state change on some part of the activity. In some cases, the event to be interpreted could be D(e) instead of e.

It worth note that one piece of awareness information may be derived from interpreting multiple events. For example, a 'rain' event and a 'temperature drop below zero' event together could trigger an awareness notification to a potential traveller that the road could be icy and dangerous. The impacts of events on activities can differ from simply providing a piece of context information to more decisive events, such as triggering a new activity, delaying, disabling or causing re-planning of an ongoing activity.

D. *Awareness Promotion*

Following the process of awareness lifecycle (see the section above), promoting awareness involves four phases (roughly correspond to those in Figure 2):

- Aid on the *perception* (e.g., strengthening the stimulus);
- Support *interpretation* (e.g., including information about the context where the interpretation has to be performed).
- *Awareness propagation* and notification. The system should notify those (and only those) who need to be aware. This requires reasoning on dependencies across roles, which could be costly to human if without computational support.
- Supporting the *comprehension* of a notification when it is received.

These four types of awareness promotion require different methods for system mediation, not only at the user interface level but also in terms of augmenting human knowledge and reasoning. Since each phase in awareness promotion lifecycle is cognitively demanding, it is an important goal of CSCW research to discover better formal models of awareness promotion processes so that we can offload some of the cognitive load to computational systems. We will contribute to this effort by proposing a framework of awareness promotion.

IV. A Framework For Awareness Promotion

Based on the requirements for awareness promotion, we specify the formal constructs of our awareness promotion model.

A. *Activity as SharedPlan*

We follow the activity theory [28] to consider activities as the basic unit of understanding collaboration. An *activity* specifies a particular way of doing something. An *activity* can be either a basic operation, or a complex action that needs to be decomposed into subsidiary ones. A *resource* can be anything that is used in activities, including both physical and informational objects, such as rescue vehicles, and traffic information. A *goal* is a state of affairs in the world that the actors would like to achieve. How the goal is to be achieved is not specified, allowing alternatives to be considered. In order to capture the dynamics of activities, we adopt a SharedPlan view of collaborative activities, following the collaborative plan theory of Grosz and Sidner [29, 30]. It emphasizes a mental state view of collaborative plans that allow re-planning and reasoning on contingencies. Figure 3 shows an example of the model that captures a portion of major activities and dependencies in an emergency response scenario.

Our *SharedPlans* model of the activity [30-33] is a collaborative plan that captures a moment-to-moment representation of an unfolding activity and includes not only a hierarchy of actions but also the set of mental states (beliefs, intentions, and commitments) that the participating actors have established towards the plan and its sub-plans.

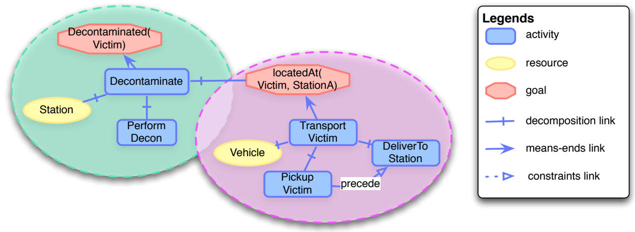

Figure 3. Modeling activities and dependencies

A plan can be partial, meaning that the activity is still ongoing and unfolding. During the performance of an activity, its plan representation is updated to reflect the changes. By representing a collaborative activity as shared plans, the major components (*activity*, *resource*, *goals*) of collaborative activities can be matched to corresponding elements in a shared plan (*action*, *parameter*, *pre-condition*). A shared plan reflects various relationships between its elements. A *means-ends* relationship indicates a relationship between an *end* – which can be a goal to achieve, or a resource to be produced – and a *means* - in the form of an activity - for attaining it. A *decomposition* relationship indicates a relationship between an activity and its subsidiary components.

B. *Dependencies*

By representing a collaborative activity as shared plans, various types of dependency relationships (as discussed in the theories of coordination [34, 35]) can be inferred from the hierarchical structure of the plan, recipes, and constraints. In particular,

(1) A *shared-resource* dependency can be inferred from two decomposition relationships that start from two different activities, but point to the same resource.

(2) A *producer-consumer* dependency is represented as a combination of a means-ends relationship and a decomposition relationship, where one activity uses a resource that is attained by another activity.

(3) A *common-output* dependency is two means-ends relationships through which one resource is produced by two activities.

(4) *Goal-related* dependencies refer to the cases where one activity depends on the other activity because the latter is a means to achieve a subsidiary goal. This type of dependencies occurs when a large activity is decomposed into a number of sub-activities. Goal-related dependencies can be indirect and mediated by an intermediate goal. In this case, there exist a decomposition relationship between an activity and a subsidiary goal and a means-ends relationship from the goal to another activity.

(5) *Temporal* and *spatial dependencies* are represented as constraint relationships between activities.

C. *Field of Work*

The awareness system of a collaborative activity must cover the whole field of work of the activity. However, this field of work is too large for individuals to monitor. On the other hand, each actor usually only engages in a small set of them that are pertinent to his/her specific role that feeds in the overall team goal. This is due to the reason that collaborators are motivated to ease their management by decoupling a complex problem into a set of smaller ones. The result of this division of responsibilities is that each actor is only responsible for the *local scope of work.* Within their local scope of work, team members actively monitor the part of the environment that is directly related to their activities, and they are most knowledgeable in the processes and the issues related to their local activities. They know what probably will happen and what they expect to happen. When things happen within the local scope of an agent, awareness is relatively easy through direct observation. In contrast, awareness of an agent on events that occur remotely must depend on other agent's observation that can be captured by the awareness system[2].

Any dependencies that run across two local scopes define the dependency between two local scopes. They serve as the bridges between local scopes of multiple actors to propagate awareness information. Although an actor is only responsible for and interested in the activities within her/his local scope of work, the activities outside the local scope can still potentially impact her/his work through dependencies. Figure 4 demonstrates how the awareness process works on top of the three constructs. In the beginning, Actor 1 perceives some unexpected event happening in the environment, and attempts to interpret it as whether and how it can impact the activities within her local scope of work. After interpreting the event, she associates it with a state change of Activity 1.

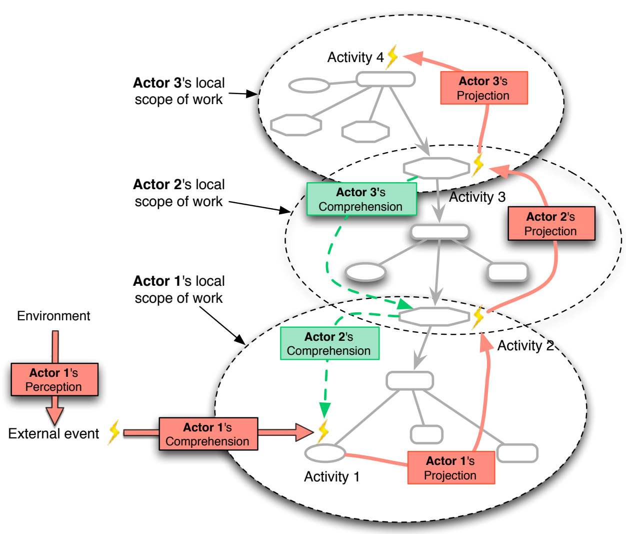

Figure 4. Activity-oriented awareness process

Furthermore, she predicts how the state change of this activity will impact other activities because of the dependencies among them. After Actor 1's projection, the event is likely to impact another activity (Activity 2), which also falls into Actor 2's local scope of work. Upon receiving this projection from Actor 1, Actor 2 first needs to understand where this projected event comes from by backtracking the interpretation, and evaluate how this event will impact his own line of work, which leads to a new projected state change of Activity 3. The similar process then is propagated to Actor 3's local scope of work. In this way, the team's awareness of the initial external event is collaborative developed as the relevant actors gradually attach their interpretations to it.

D. *Tools Mediation for Awareness Promotion*

The above understanding of awareness patterns and processes motivated our design of computer-supported awareness promotion focuses on the mediation roles that the system can play to support awareness development. In this paper, we focus on three specific roles of mediation:

(1) *Promoting awareness propogation.* When an event happens, there is need to promote the awareness of that event to those actors who are likely to be interested or affected. Such process is often a hard one when awareness is to be propogated across multiple local scopes. By Maintaining a computational model of the ongoing activities as a network of interdependent local scopes, the system can reason about plans to pass and relay the awareness informaton to other actors.

(2) *Promoting awareness comprehension*. It provides the visual and interactive support that allow the users to interpret awareness information within their local scope of work. As the awareness information is propagated across multiple actors, the chain of reasoning can become very lengthy. By visualizing the event propagation chains with context information about activities, the users can backtrack how the awareness information is developed from the origins.

With the situated knowledge about activities and their dependencies, the system can play a even more proactive role to automate the reasoning on how certain awareness information impact the states of activities as its effects propagate across multiple activities. In this way, the system can offload some of the interpretation effort from the human actors. Meanwhile, the human actors should have the capability to revise the system's interpretation.

We operationize these mediation roles within an event notification system to promote awareness. Events are basic units of awareness information, representing changes concerning the environment, resources, goals, and activities in a collaborative setting. We make distinctions between *external* (in the environment) and *internal* events (in the activities). *External* events are changes in the physical environment that have impact on the performance of activities. *Internal* events are state changes on any resources, goals, and activities involved in the collaboration.

By adopting the event-driven approach [22], the mediation roles of the system to support transitive awareness process can be illustrated in Figure 5.

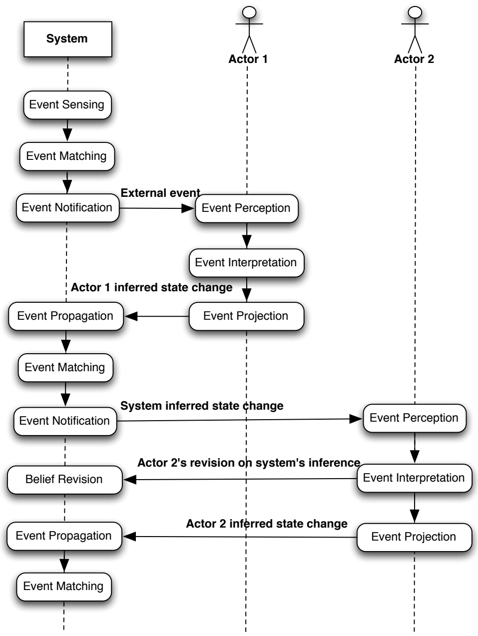

Figure 5. Mediating the event-driven awareness process

Whenever an external event is sensed by the system, it first matches the events with all the users' predefined local scope of work and their subscriptions. If a match is found, the system notified the matched user (e.g. Actor 1) about the external event. Then upon perceiving the event, Actor 1 interprets the direct impacts of this event on his/her current activities and predicts future changes to other activities within his/her local scope of work. The inferred state changes represented as internal events are then sent back to the system. The system reasons about how these predicted changes by Actor 1 may impact other actors due to the dependencies among activities, and notify the projected state changes to other relevant users (e.g. Actor 2). Upon receiving the notification about the projected state change, Actor 2 needs to interpret the change by backtracking where this state change comes from and relating it to the activities within his/her local scope of work. Actor 2 may reject the system inference by revising the belief about the projected state change, or predict further changes due to this change, which leads to a new cycle of reasoning.

To fulfill these mediation roles, the system entails a computational and a visualization subsystem. The computational subsystem maintains a representational model of the ongoing activities and their dependencies based on SharedPlan theory [30], and automates the reasoning on how certain state change propagate across multiple activities using a Bayesian network [36]. The visualization subsystem provides the visual and interactive support to the human cognitive process, which allows the users to backtrack where an inferred state change come from and allow them to reason about and predict new changes from the interpretation of current events.

E. *Awareness propagation*

Propagation of awareness messages is accomplished by reasoning on who should be notified according to activity dependencies. We represent a complex and distributed activity into a set of interrelated sub-activities using network-based representational model, where the nodes represent the basic elements of activities, and the links represent the dependency relationships between them. This network-based model of dependencies allows us to automatically reason about how an event happened on one part of the activity is related to other agents who are likely to be affected. In this study, we employ a Bayesian network method to perform dependency reasoning and awareness propagation [36]. Bayesian networks are directed acyclic graphs in which the nodes represent multi-valued variables, and the arcs signify direct dependencies between the linked variables and the strength of these dependencies are quantified by conditional probabilities. The purpose of the Bayesian network is to give a belief in each possible value for each node after some evidence arrives.

In the context of our model, the nodes are basic elements of activities, and possible values for each node variable are states of the represented activity, resource, or goal. The evidence fed into the network includes certain state changes on some activities. Thus, the purpose of the Bayesian network is to update the system's belief in the states for every other node after some state change occurs on a node.

To operationalize the Bayesian network, we follow a three-step process: (a) construct the Bayesian network, (b) assign the conditional probabilities for each link, (c) and perform the belief updating when some events arrive. Detailed design of awareness propagation is given below.

V. VISUAL SUPPORT FOR EVENT COMPREHENSION

Event interpretation denotes the cognitive process of a user to understand the meaning of an event notified to him/her, and relates it to the activities in his/her local scope of work. When the event is an external one or a direct change on an activity of the user's own, it is a relatively easy job. However, when an agent receives an event notification, it is often hard to make sense of it because the notification message is the result of a chain of reasoning by other users and the system, and the details of such reasoning were not packaged into the message.

Because the system keeps track of the reasoning process, the system can help the users to interpret events by providing a visual representation of the event propagation chain. Such a visual representation provides an overview of the whole reasoning process, allow the users to understand where an event comes from, and check details on each step of the reasoning.

Figure 6 shows an example of the visual implementation of the event propagation chain. Some design considerations are summarized as follow:

(1) We use shapes to indicate the types of nodes (i.e. activity, resource, condition, external events). Arrows connecting the nodes indicate the directions of dependency relationships
(2) Each node is associated with a quick preview indicating the state change on that node
(3) We use colors to indicate the strength of system's beliefs on each step of the chain (e.g. definitely, likely, maybe, not sure)
(4) Mouse over on a node will show the detail information about the node, as well as the notes made by other actors when they generate that state change
(5) We show the boundary between nodes in the current user's local scope and these outside, so that the user can clearly see when the propagation enters their work territory.

As the users interpret an event, they may decide on certain state change in the reasoning chain is inaccurate based on their knowledge. Hence, we allow the users to modify their beliefs on existing changes by clicking on each node. The user can modify the strength of beliefs on the changes, along with the free-text notes to record their rationales for making the modification. We limit the modification to only the nodes within the current user's local scope as the users have best knowledge about their own activities.

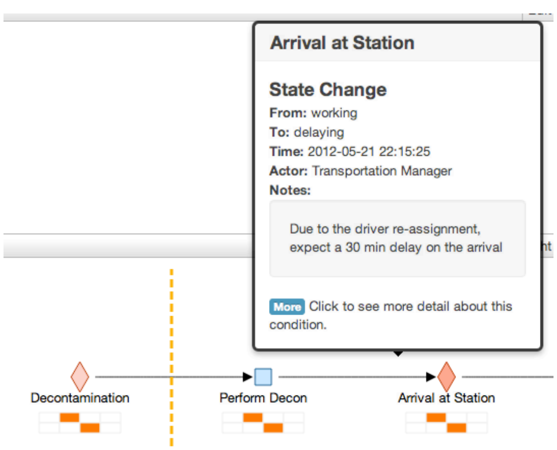

Figure 6. Visualization of the event propagation chain

VI. Visual Support for Event Projection

After the user interprets an event, he/she has the opportunity to project the current state change to other activities within his/her local scope because of the dependencies may exist among these activities. To support the event projection process, the system provides an overview of all the activities and their dependencies within the user's local scope, so that the user can infer how the perceived existing state change may impact other activities.

Figure 7 shows an example of the interface that allows the users to check detailed information on each activity node, predict the possible changes on the node, set the levels of confidence on the change, along with the free-text notes to record their rationales for making the prediction. The user's prediction will be sent to the system to relay the propagation process, and the notes made by this user will be visible when other actors check the state change in their interpretation.

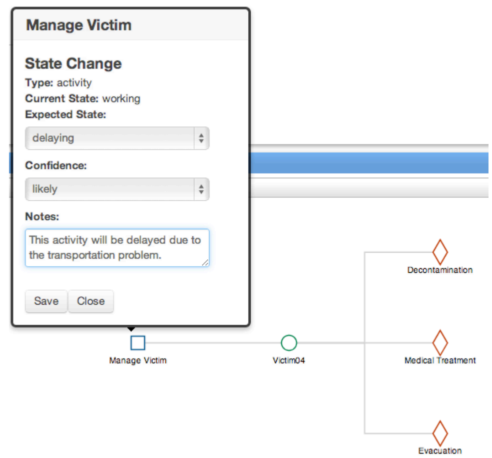

Figure 7. The event comprehension interface

VII. Discussions

So far we have developed a model of event-based awareness promotion for distributed collaborative activities (Section III). We also suggested how computational systems in pervasive environment could play a role in awareness promotion if formal representations of activities and dependencies of cooperative work are established (section V). This is a broad agenda of research requiring much more details to be developed. In the same time, it is important to test and validate the model through implementation and evaluation. We have been working on initial implementation of a system that can support the full awareness cycle and computational mechanisms of awareness promotion, and the details of such implementation effort will be reported separately.

Future work is planned to validate the key conceptual constructs (such as the forms and nature of local scopes, the mechanism of selective notification, and cognitive load of awareness interpretation and comprehension). Deeper understanding of awareness phenomena in distributed collaboration will provide better conceptual foundation upon which computational models and systems can be constructed.

Acknowledgment

This work is partially funded by the National Science Foundation under award IIS-1211059.

REFERENCES

[1] P. Dourish and V. Belotti, "Awareness and coordination in shared workspaces," in *Proceedings of the 1992 ACM Conference on Computer Supported Cooperative Work*, New York, 1992, pp. 107-115.

[2] K. Schmidt, "The Problem with `Awareness': Introductory Remarks on `Awareness in CSCW'," *Computer Supported Cooperative Work (CSCW),* vol. 11, pp. 285-298, 2002.

[3] M. Rittenbruch and G. McEwan, "An Historical Reflection of Awareness in Collaboration," in *Awareness Systems*, J. Karat, et al Eds.: Springer London, 2009, pp. 3-48.

[4] P. Markopoulos, "A Design Framework for Awareness Systems," in *Awareness Systems*, J. Karat, et al. Eds.: Springer London, 2009, pp. 49-72.

[5] K. Schmidt and L. Bannon, "Taking CSCW seriously," *Computer Supported Cooperative Work (CSCW),* vol. 1, pp. 7-40, 1992.

[6] J. M. Carroll, M. B. Rosson, G. Convertino, and C. H. Ganoe, "Awareness and teamwork in computer-supported collaborations," *Interacting with Computers,* vol. 18, pp. 21-46, 2006/1 2006.

[7] P. Antunes, C. Sapateiro, J. A. Pino, V. Herskovic, and S. F. Ochoa, "Awareness Checklist: Reviewing the Quality of Awareness Support in Collaborative Applications," in *Collaboration and Technology*. vol. 6257, G. H. T. L. S. Kolfschoten, Ed., ed, 2010, pp. 202-217.

[8] F. Cabitza, M. P. Locatelli, C. Simone, D. Ardagna, M. Mecella, and J. Yang, "Promoting Process-Based Collaboration Awareness to Integrate Care Teams," in *Business Process Management Workshops 2008*, 2009, pp. 385-396.

[9] G. Cai, L. Bolelli, A. M. MacEachren, R. Sharma, S. Fuhrmann, and M. McNeese, "GeoCollaborative Crisis Management: Using Maps to Mediate EOC-Mobile Team Collaboration," in *Proceedings of DG.O2004 - the 5th annual conference on digital government research*, Seattle, WA, 2004.

[10] G. Cai, A. M. MacEachren, I. Brewer, M. McNeese, R. Sharma, and S. Fuhrmann, "Map-Mediated GeoCollaborative Crisis Management," in *LNCS 3495: Proceedings of the IEEE International Conference on Intelligence and Security Informatics (ISI 2005), Atlanta, GA, USA, May 19-20, 2005*, P. Kantor, G. Muresan, F. Roberts, and e. al., Eds., ed Atlanta, Georgia: Springer, 2005, pp. 429-435.

[11] S. Fuhrmann, A. MacEachren, and G. Cai, "Geoinformation Technologies to Support Collaborative Emergency Management," in *Digital Government - E-Government Research, Case Studies, and Implementation*. vol. II, H. Chen, L. Brandt, V. Gregg, R. Traunmüller, S. Dawes, E. Hovy, A. Macintosh, and C. A. Larson, Eds., ed, 2008, pp. 395-420.

[12] R. Sharma, M. Yeasin, N. Krahnstoever, Rauschert, G. Cai, I. Brewer, A. MacEachren, and K. Sengupta, "Speech-gesture driven multimodal interfaces for crisis management," *Proceedings of the IEEE,* vol. 91, pp. 1327-1354, 2003.

[13] G. Cai, R. Sharma, A. M. MacEachren, and I. Brewer, "Human-GIS Interaction Issues in Crisis Response," *International Journal of Risk Assessment and Management,* vol. 6, pp. 388-407, 2006.

[14] A. M. MacEachren and G. Cai, "Supporting Group Work in Crisis Management: Visually mediated human-GIS-human dialogue," *Environment and Planning B-Planning & Design,* vol. 33, pp. 435-456, 2006.

[15] S. R. Fussell, R. E. Kraut, F. J. Lerch, W. L. Scherlis, M. M. McNally, and J. J. Cadiz, "Coordination, overload and team performance: effects of team communication strategies," presented at the Proceedings of the 1998 ACM conference on Computer supported cooperative work, Seattle, Washington, United States, 1998.

[16] K. Schmidt, "Riding a tiger, or computer supported cooperative work," presented at the Proceedings of the second conference on European Conference on Computer-Supported Cooperative Work, Amsterdam, The Netherlands, 1991.

[17] K. Schmidt, "The Concept of 'Work' in CSCW," *Computer Supported Cooperative Work (CSCW),* vol. 20, pp. 341-401, 2011.

[18] C. Simone and K. Schmidt, "Taking the distributed nature of cooperative work seriously," in *Parallel and Distributed Processing, 1998. PDP '98. Proceedings of the Sixth Euromicro Workshop on*, 1998, pp. 295-301.

[19] W. Prinz, "NESSIE: an awareness environment for cooperative settings," presented at the Proceedings of the sixth conference on European Conference on Computer Supported Cooperative Work, Copenhagen, Denmark, 1999.

[20] L. Fuchs, U. Pankoke-Babatz, and W. Prinz, "Supporting cooperative awareness with local event mechanisms: the groupdesk system," presented at the Proceedings of the fourth conference on European Conference on Computer-Supported Cooperative Work, Stockholm, Sweden, 1995.

[21] C. Simone and S. Bandini, "Compositional features for promoting awareness within and across cooperative applications," presented at the Proceedings of the international ACM SIGGROUP conference on Supporting group work: the integration challenge, Phoenix, Arizona, United States, 1997.

[22] O. Etzion and P. Niblett, *Event Processing in Action*: Manning Publications Co., 2010.

[23] M. Sohlenkamp, W. Prinz, and L. Fuchs, "PoLIAwaC: design and evaluation of an awareness-enhanced groupware client," *AI & Society,* vol. 14, pp. 31-47, 2000.

[24] T. Rodden, "Populating the application: a model of awareness for cooperative applications," presented at the Proceedings of the 1996 ACM conference on Computer supported cooperative work, Boston, Massachusetts, United States, 1996.

[25] J. Gulliksen, M. Harning, P. Palanque, G. van der Veer, J. Wesson, G. Metaxas, and P. Markopoulos, "'Aware of What?' A Formal Model of Awareness Systems That Extends the Focus-Nimbus Model," in *Engineering Interactive Systems*. vol. 4940, ed: Springer Berlin / Heidelberg, 2008, pp. 429-446.

[26] C. Simone and S. Bandini, "Integrating Awareness in Cooperative Applications through the Reaction-Diffusion Metaphor," *Computer Supported Cooperative Work,* vol. 11, pp. 495-530, 2002.

[27] A. Svirskas, J. Isachenkova, and R. Molva, "Towards secure and trusted collaboration environment for European public sector," in *CollaborateCom 2007. International Conference on Collaborative Computing: Networking, Applications and Worksharing, 2007.*, 2007, pp. 49-56.

[28] B. A. Nardi, "Studying Context: A Comparison of Activity Theory, Situated Action Models, and Distributed Cognition.," in *Context and Consciousness: Activity Theory and Human-computer Interaction*, B. A. Nardi, Ed., ed Cambridge, MA: The MIT Press, 1996.

[29] B. J. Grosz and C. L. Sidner, "Attention, intentions, and the structure of discourse," *Computational Linguistics,* vol. 12, pp. 175-204, 1986.

[30] B. J. Grosz and S. Kraus, "Collaborative plans for complex group action," *Artificial Intelligence,* vol. 86, pp. 269-357, 1996.

[31] K. E. Lochbaum, "A collaborative planning model of intentional structure," *Computational Linguistics,* vol. 24, pp. 525-572, 1998.

[32] G. Cai and Y. Xue, "Activity-oriented Context-aware Adaptation Assisting Mobile Geo-spatial Activities," in *Proceedings of the ACM IUI 2006: International Conference on Intelligent User Interfaces*, Sydney, Australia, 2006, pp. 354-356.

[33] B. Yu and G. Cai, "Coordination of Emergency Response Operations via Event-Based Awareness Mechanism," presented at the Proceedings of the 9th International Conference on Information Systems for Crisis Response and Management, Vancouver, Canada, 2012.

[34] K. Schmidt and C. Simonee, "Coordination mechanisms: Towards a conceptual foundation of CSCW systems design," *Computer Supported Cooperative Work (CSCW),* vol. 5, pp. 155-200, 1996.

[35] T. W. Malone and K. Crowston, "The interdisciplinary study of coordination," *Acm Computing Surveys,* vol. 26, pp. 87-119, 1994.

[36] J. Pearl, *Probabilistic reasoning in intelligent systems: networks of plausible inference,* vol. 28: Morgan Kaufmann, 1988.