An Activity Theory Framework for DSS for Extreme Events

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Abstract. Usage of activity theory has emerged in other applications in computer science, including human computer interfaces. This paper applies activity theory as a theoretical framework for the analysis of DSS for extreme events. An example, based on computer support on the web for hurricane response, is used to illustrate how activity theory might be applied to extreme events in a decision support system environment.

Keywords. Activity Theory, Extreme Events, Decision Support Systems

Introduction

Activity theory recently has emerged in some applications of computer science. The purpose of this paper is to present activity theory as a framework for examining decision support systems (DSS) for extreme events. Activity theory provides a template-based theory that enables us to assess particular factors that influence performance of an activity, and the interaction of those factors. Activity theory is found to facilitate understanding some of the key issues associated with extreme events, in particular hurricanes. Further, activity theory provides a general "context" for the use of decision support systems (DSS). As will be seen below, one of the interacting factors in the template-based theory, is the set of "tools" that are used in an activity. Clearly, some of the most important tools are computer-based systems designed to support a range of decision makers.

This paper proceeds in the following manner. Section 2 reviews activity theory, and section 3 discusses some of the computer science applications of activity theory. Section 4 applies activity theory to DSS systems developed for extreme events, using web – based information as an example. Section 5 briefly summarizes the paper and reviews some extensions.

1. Background: Activity Theory

Activity theory resulted from the efforts of Russian psychologists trying to develop a psychological theory based on Marxist philosophy and thinking. Historically, activity theory was initiated by the Russian Psychologist Lev Vygotsky in the 1920's and 1930's. His work is summarized in Vygotsky (1978). That work was extended by S. L.

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Rubenstein, A. N. Leontjev (1978) and others. Rubenstein apparently was the first who formulated the notion of human action as a unit of psychological analysis (e.g. Rajkumar (no date)).

Although activity theory was founded by Russians, perhaps its most active researchers have been from Scandinavia. For example, one of the key sets of structures used to explain activity theory was developed by Engestrom (e.g., 1987). Engestrom (1987) generated generic templates for activity theory with wide spread application.

Activity theory differentiates between people and things (e.g. Nardi 1996). People are not characterized only as "nodes" or "agents" in a system. Only people have motive and consciousness. Activity theory emphasizes context factors and the interaction between people and their environment. As a result, tools, e.g., computer systems, play an important role in the theory. Activity theory suggests that some context must be accounted for in the analysis of human action. The key entities in the theory are the subject, object and community, while tools, rules and divisions of labor constitute the artifacts used in the activities to establish the context. In an activity, the subject modifies an object to generate an outcome, while using a tool, in the context of a community with its corresponding rules and division of labor, as seen in figure 1. The remainder of this section investigates the components of that basic model, and concludes with a comprehensive example to illustrate the concepts.

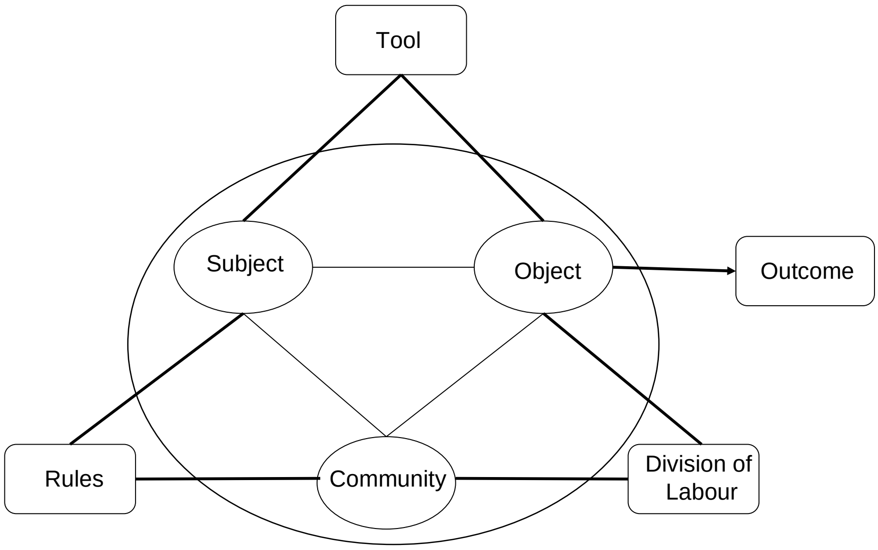

Figure 1 -Structure of an Activity (Engestrom 1987)

Although the activity theory literature is substantial and continues to emerge, activity theory does not provide any explicit or cookbook methodologies. As a result, it is not strictly a theory, but instead, provides a template-like approach to facilitate analysis. For example, a use of activity theory, often is focused on gathering and analyzing information based on figure 1. However, some "checklists" for different environmental settings have been generated (e.g., Kaptelinin et al. 1999).

1.1. Activity and Tasks

The main object of study of activity theory is human work activity. An activity is a form of "doing" directed to an object (e.g., Kuutti 1996). Activity theory uses the notion of an activity as the basis and unit of analysis. An activity is motivated towards transforming an object into an outcome (Barthelmess and Anderson 2002). Activities have an object and are defined by that object, while transformation of the object motivates the existence of the activity (Kuuti and Arvonen 1992). Accordingly, Bedny and Harris (2005, p. 130) define an activity as " … a goal directed system where cognition, behavior, and motivation are integrated and organized by a mechanism of self regulation toward achieving a conscious goal."

Activities may have more than a single step. As a result, there may be more than one activity and each activity can be made up of a number of related tasks. Accordingly, the analysis can be broken down to the task level in order to generate more detail. However, there are no firm barriers as to what is a task or activity. Further, activities may or may not be independent of each other or sequentially related.

Kuutti (1996) offers some examples of activities, including a software team programming a system for a client. Clancey et al. (1998) note that activities can include reading mail, going to workshops or answering phone calls, so the notion and detail of activities can be very general. As another example, activities could include a preparation activity for an extreme event or a sequence of events. Articulation of the detail of the level of activity can vary based on the analysis.

1.2. Object and Goal

The object of an activity is that which is modified and explored by a subject, according to the goal of the activity (Bedny and Harris 2005). Objects can be material things. Engstrom (2004, p. 6) defined an object as " … a heterogeneous and internally contradictory, yet enduring, constantly reproduced purpose of a *collective activity system* that motivates and defines the horizon of possible goals and actions." As seen later in the paper one example object is "useable knowledge." Another example could be a set of actions produced by a system for a joint human and system response to an event.

Some researchers (e.g., Bedny and Harris 2005) have suggested that between the object and outcome in the template of figure 1, there should be a goal to facilitate understanding activity theory. Bedny and Harris (2005) call the goal a conscious cognitive representation of the desired result of the particular activity. Goals can be established at any point during task performance. Goals are mental representations of a desired future state. Further, goals may be modified during the course of the activity. Since goals are not a generally acceptable component of activity theory, we will not consider them further.

1.3. Outcome and Subject

The outcome of an activity may or may not be one that accomplishes the object or goal, if there is one in the representation. For a decision support system, an outcome could be a potential set of actions, and possibly the relationship between the potential set of actions and what occurred when they took those actions.

A subject typically is a person that undertakes an activity. Subjects are people in different roles (e.g., blue collar workers and white collar workers) that transform materials and use information. Subjects are part of a collective effort, and so subjects could be part of a group using a decision support system. Different subjects need to be accounted for accordingly.

1.4. Community

Community refers to all of the people involved in the activity. If the activity relates to a system, then the community will relate to the specific activity and its location in the life cycle of the system. For example, a system in steady state use will have a particular organizational community that includes those putting data into the system and those responsible for maintenance of the system. A system in design and development can be a largely different community from a system in steady state, and include others from the community, including designers and top management from functional areas. Community for an extreme event can include a range of people, including those from government who are supporting emergency preparedness.

1.5. Tools

Tools can be either physical or mental tools (Kaptelinin et al. 1999). Tools shape the way that people interact with reality. In addition, tools are shaped by the experience of other people who have tried to solve similar problems, and thus tried to make the tool more useful or efficient. Ultimately, the use of tools is an evolutionary capture and use of knowledge that influences not only external behavior, but also the mental functioning of the individual.

Tools are both enabling and limiting (Kuutti 1996). On the one hand, tools provide the subject with enhanced capabilities. On the other hand, tools restrict interaction to be from the perspective of the particular tool being used. Some example tools include decision support systems, analytical models, databases, scanners and even spreadsheets, depending on the level of detail of concern in the analysis.

It is in the tools portion of the model that the role of decision support systems becomes most clear and where the key relationships to context are defined for decision support systems. Activity theory suggests that DSS do not exist in an independent setting but must account for a clearly specified set of factors listed in figure 1. As a result, the approach provided here is not just aimed at extreme events but can be generalized to a broad range of events and to DSS in general.

1.6. Rules

Rules refer to any guidelines, codes, heuristics or conventions that guide activities and behaviors. Rules can refer to what it means to be a member of the community. Rules also can refer to production rules for the activity. Rules can be established at the particular organization or by outside agencies, e.g., any group that is a part of the community. Rules could include emergency preparedness rules or organizational policies.

1.7. Division of Labor

Division of labor refers to balancing activities and parts of activities between different people and artifacts. Division of labor also refers to the hierarchical structure of organizations that support the activities. As a result, organizational relationships in or between emergency preparedness organizations, could be included in the analysis of the division of labor.

1.8. Example

In one of the most complete and clearest discussions of applications of activity theory, Collins et al. (2002) addressed the issue of documenting solutions to customer problems within Hewlett – Packard, focusing on the knowledge authoring activity. They had found that support knowledge about application software had become more difficult to capture in a reusable way because the software had complex dependencies on contextual and environmental variables that were unique to each customer. Ultimately, they argued that their results could be used to provide input for tool requirements and authoring, and to provide value by aligning customer support and knowledge authoring tools. Their discussion of the issue was based around the activity theory element. Some of their findings are summarized in an activity theory template in figure 2.

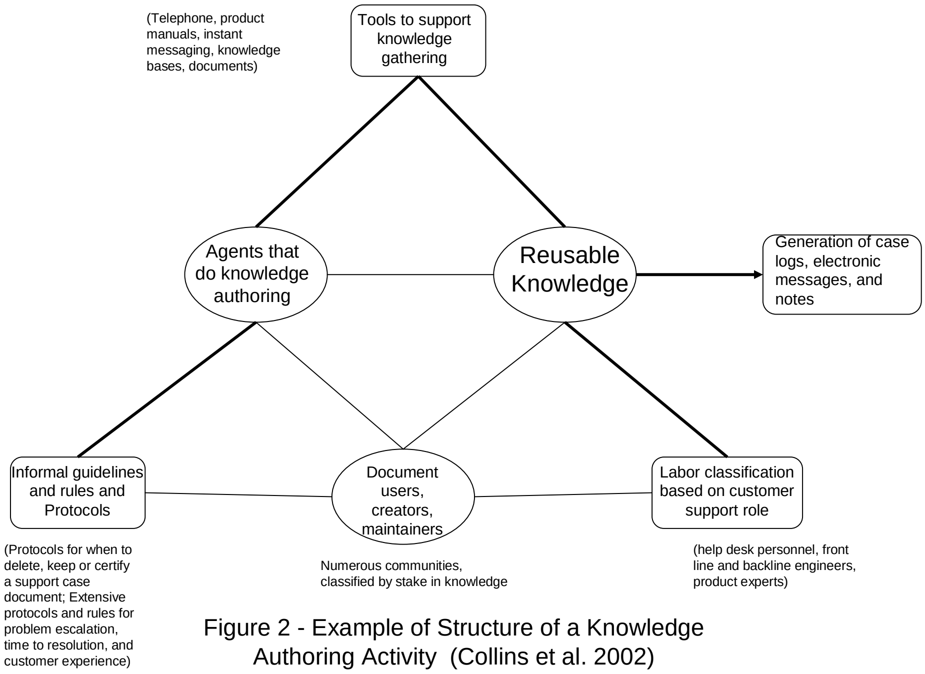

Figure 2 - Example of Structure of a Knowledge Authoring Activity (Collins et al. 2002)

2. Previous Research: System Applications of Activity Theory

So far there have been a number of system applications of activity theory in human computer interaction, computer supported cooperative work, modeling work processes and systems design and software engineering. However, activity theory has received limited analysis in the investigation of extreme events.

2.1. Human Computer Interaction (HCI)

During the late 1980's and early 1990's there was a debate against the use of information processing psychology and cognitive science as the foundation of human-computer interaction. Bodaker (1989), Engestrom (1987) and Nardi (1996) were among the first to bring activity theory to the analysis of computer interfaces. Activity theory was proposed as an alternative to cognitive science for human computer interaction (HCI) by a number of researchers, including Kuutti (1992) and others. For example, Kuutti (1992) argued that although there is a perception that HCI is based on cognitive science few practical HCI solutions ultimately make use of that theoretical structure. As a result, there is a gap between theory and practice of HCI. Kuutti (1992) agrees with Henderson (1991, p. 257) who argues that "… starting with a focus on interface, the subject matter inevitably expands to encompass the complete working circumstances that occasion and motivate the human interaction with the machine." A number of other research studies in activity theory have addressed HCI, e.g., Bannon (1991), Fjeld et al (2004), Uden and Willis (2001) and Verenikina and Gould (1997).

2.2. Computer Support Cooperative Work (CSCW)/Knowledge Management

Kuutti and Arvonen (1992) used activity theory to help identify CSCW applications. In the application discussed above in figure 2, Collins et al. (p. 58, 2002) used the model in figure 1 as a basis of the interviews. In addition to information about the particular nodes (tools, subject, etc.), they focused on interactions between pairs of the nodes, as a basis to "… provide rich insights into system dynamics and opportunities for evolution of the system."

2.3. Modeling Work Processes and Interacting Agents

Clancey et al. (1998) and Sierhaus and Clancey (2002) developed software designed to facilitate the simulation of activities, using an activity theory model of human interaction. They developed a multi-agent simulation tool designed to understand how contextual variables influence how people accomplish collaboration in real work environments. Using this approach, Sierhaus et al. (2000) model activity behavior of APOLLO 12, creating models with named agents (e.g., Pete Conrad). As part of the findings of their models they structure activities in a hierarchical manner, where a person can be involved in multiple activities and activities can be subsumed by other activities. Activity theory templates seem almost "made" for artificial intelligence modeling with their network structure, their focus on subjects/agents, the fact that subjects have objects guide efforts, and the notion that rules guide subjects.

3. Activity Theory and Selected Hurricane Web Resources

The purpose of this section is to apply activity theory to an extreme event setting, that of hurricanes. A number of web-based resources on which the discussion is based, support a range of decision makers. The set of resources on which the discussion is based are summarized in the appendix.

3.1. Subject

Subjects are likely to be anyone who may have to experience the hurricane, anyone who knows someone who has to experience a hurricane, or someone who has responsibility for facilitating action or response to the hurricane, while at the same time using a computer-based support approach to respond to the event. Subjects also may include system developers and maintenance workers responsible for developing systems that are used for supporting response to extreme events. A complete real world application would choose a specific subject or group of subjects.

3.2. Subject and Object

One perspective is that a DSS-based system has an object of generating actionable knowledge. Based on the available web-based information, that actionable knowledge could range from matching those affected by the extreme event to those who would like to help, to determining policy based on the likelihood that the hurricane will impact a particular area. As a result we would expect that the object is not one specific object, but something that meets the needs of a particular subject/context. Further, we may see that a plan ultimately is matched to what happened when the actions occurred. Ultimately, the object could be a useable plan to respond to a hurricane event.

3.3. Community

The community of extreme events, such as hurricanes is heterogeneous and potentially world-wide. After analyzing some of the resources on the web, that community includes, individuals affected by hurricanes, governments of countries affected by hurricanes, individuals responsible for marshalling or creating resources for response to extreme events, academic communities interested in attacking extreme event problems and others. In some cases the community includes outsiders, such as when hurricane Dean got a “holy cow” from an astronaut as part of a Youtube video, in response to viewing the hurricane from space. Jamaica’s government’s response to hurricane Dean is also chronicled on Youtube. Based on the particular subject(s) chosen the corresponding community would be matched up. The breadth and depth of analysis of community might vary based on a number of concerns, such as, subject.

3.4. Tools

There are a number of computer-based tools that facilitate understanding extreme events. This is where the role of decision support systems plays a critical role in many different forms. There are a range of different systems that can support decision makers. In addition, making those tools available in a web environment can further facilitate use. For example, videos and the ability to post videos for general access, potentially brings into broader analysis, more information about what actually happened before, during and after a storm. As seen with the recent Indonesian tidal wave, even home movie videos by those at the scene, allowed experts to better understand and explain the events. Accordingly, those videos may lead to changes in the way that we respond to these events. Blogs allow users and a broad-based range of commentators to try and tease meaning out of what has happened, and out of any evidence from the events, such as videos. Web users can examine the outcome of sophisticated models presented on the web. Information about individual expert predictions about hurricanes is available on the web. Further, computer archive data available on the web allows anyone to use the data to generate models of hurricanes from the past and in the future. Another set of issues is to what extent do the individuals being analyzed have access to the necessary tools. Again, the tools analyzed depend on the subject, community and other variables.

3.5. Rules, Division of Labor and Outcome

Rules for dealing with hurricanes and extreme events can come from a number of sources. For example, video clips clearly illustrate that during hurricanes, governments of countries affected by the hurricane immediately put into place “emergency preparedness” rules. These rules might include, “no one on the streets …” etc.

Other sources of rules are available. Analytical models include formal mathematical rules that are then used to forecast the movement, etc. of the hurricane. Organizational policies provide additional rules. Findings from scientific analysis of hurricanes provide guidelines as to hurricane behavior also could be viewed as rules.

Division of labor relates to a number of aspects of hurricane events. For example, generating information about the hurricane comes from multiple sources, some compensated, some not (e.g., see the videos on Youtube). Data is summarized on one site, while analytical models are summarized on others. The task of matching those affected by the hurricane and those who want to help, is done by others. Satellite photos are available, as are other photo sets. Specific sites each provide specific niches. The outcome can refer to generation of logs of recommendations or answers to questions or actions taken. Ultimately, what happened when those recommended actions were actualized, and the relationship the actions had to what actually occurred also can be captured to match a plan against expectations.

3.6. More Details

The “activity is the context,” the particular activities, and the corresponding templates that we investigate drive the context. Accordingly, let’s examine some potential examples in greater detail to illustrate further use of the theory. Table 1 contains an example with three potential subjects: a home owner in an affected area, a first responder entering a hurricane impacted area and a government bureaucrat responsible for resource allocation. These examples are only designed to illustrate, and in practice would be in greater detail.

Table 1 - Example Activity Templates

Subject	Government Bureaucrat	Home Owner	First Responder
Object	Resource Deployment	Safety, Home Protection	Depends on their task and activity responsibility
Community	Government	Can include family and neighborhood	Other first responders, fire departments, police etc.
Outcome	How well were resources deployed?	What happened to the property?	Were operations a success?
Tool	Information flows from official sources. Web pages matching up resources and resource users.	News Feeds, blogs, official knowledge resources on preparing for a hurricane.	Information flows from official sources, posted videos from hurricane, blogs from those affected, weather information.
Rules	Government rules for disaster areas, etc.	Rules governing evacuation, insurance, etc.	Employment rules, firefighting, emergency rescue, etc. rules.
Division of Labour	Generally, each bureaucrat has a specific role	May have family perform different roles, e.g., board up windows	Team members each have a role

4. Contribution and Extensions

This paper applied activity theory to the use of DSS for extreme events, in particular hurricanes. It found that the activity theory framework provides a useful vehicle for the investigation of extreme events by eliciting key features associated with the activities. In particular, the "activity is the context," where the particular activities, and the corresponding templates that we investigated drive the context.

Brezillion (1999, 2003) and Brezillion and Pomerol (2001) have investigated context in computing and problem solving. Thus, this research into activity theory provides an alternative and theory-based approach to providing a context for understanding the role of DSS.

The discussion presented here can be extended to other extreme event settings, such as earthquakes, plane crashes, etc. In addition, much of the discussion here directly relates to understanding general context related issues, associated with decision support and other types of systems that drive the notion of "tools" in activity theory.

Appendix – Selected Web Resources About Hurricanes

The purpose of this appendix is to summarize some of kinds of web resources available about hurricanes and other extreme events. Those resources are placed in the context of activity theory in section 3.

Computer Archive Data About Hurricanes
http://www.wunderground.com/hurricane/at2007.asp
Computer Models of Hurricanes
http://www.nhc.noaa.gov/aboutmodels.shtml
http://www.wunderground.com/tropical/tracking/at200706_model.html
Expert Prediction
http://www.palmbeachpost.com/storm/content/weather/
During the Storm: Videos from Space
http://www.youtube.com/watch?v=FxFOm8BC4GE
http://www.youtube.com/watch?v=2CZNfC-imj8
After the Storm: Post Videos
http://www.youtube.com/watch?v=Jma6QR5gWEo
After the Storm: Match Victims and Helpers
http://www.katrina.com/americanangels/guidelines.htm
After/Before the Storm: News Coverage
http://www.washingtonpost.com/wp-dyn/content/nation/special/10/
http://video.ap.org/v/Legacy.aspx?f=FLWPP&g=0986454d-3fb2-4533-8d88-f5359565c273&p=ENAPus_ENAPus&t=m1180634924143&rf=http%3a%2f%2fwww.palmbeachpost.com%2fstorm%2fcontent%2fstorm%2fhomepage%2findex.html&fg=tool&partner=en-ap

After/Before the Storm: Blogs
http://www.palmbeachpost.com/storm/content/shared-blogs/palmbeach/stormblog/

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