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Activity Theory and its Applications in Software Engineering and Technology

Literature Search Results and Observations

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Introduction

This paper summarizes the results of a literature search on Activity Theory and its use in software engineering and other technology-related fields. There appears to be relatively little comprehensive use of activity theory by software engineers. The initial survey was therefore expanded to include the originators of the theory itself and also its use in cooperative work. A key point of interest is that the original theory introduces contradictions as sources of tension in an activity system and therefore as drivers of evolution. However there were only a few instances of contradiction analysis being used in software development. By contrast there are many examples of contradiction analysis in other fields such as education and the general situation of technology transfer. Several of these results are also included in this survey since they demonstrate how various types of contradictions are identified.

The first section of this report presents an overview of Activity Theory. Subsequent sections outline uses of activity theory in specific fields: education and organizational learning, cooperative work and technology transfers, human-computer interaction, and software development. The relevant references for each section are listed at the beginning of the section for convenience, and the name of the first author is bolded when it first appears in the discussion.

All sections describing the use of Activity Theory in different domains begin with a brief overview of the included research, followed by short paper summaries, and ending with general observations about the work. The observations highlight contradiction analysis and the time aspect of activity evolution since these are areas of the theory that seem quite interesting for systems development.

An Overview of Activity Theory

One of the main contributors of the theory is Yrjö Engström, and his work is comprehensive in terms of the history and evolution of the various concepts. Most of this section is taken from his papers. However, the work activity diagram as modified by Mikko Korpela et al., for application in collaborative work, is also included since it relates many of the same fundamental concepts. The two different presentations of the same concepts promote understanding of the original ideas.

Specifically, Mikko Korpela et al., present multiple means of coordination, communication, and work that are used, perhaps differently, by multiple people (subjects) performing some activity. The diagrams and notations associated with this view explicitly lay out the varying paths that may exist within a single activity system. By contrast, the Engström view shows a single subject, and a single set of rules and division of labor. Engström discusses the fact that there may be multiple subjects in an activity, but this isn't represented explicitly in the activity system diagram.

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Original Activity Theory Concepts

The main idea of Activity Theory is that all human activity is mediated. Further, the primary unit of any analysis must be the activity itself, not any one of its elements. There are four encompassing ideas in activity theory as described by **Engström**. These are:

- An activity system consists of multiple elements and their relations. The work that makes up an activity is hierarchical in nature.
- Activity systems make use of mediating artifacts, which are not restricted to any particular element making up the activity system.
- An activity system (elements, relations, and mediating artifacts) evolves over time.
- Contradictions within and between activities provide the tension that is required to effect evolution.

History

There is an in-depth discussion of the history of Activity Theory in Engström’s book published in 1987. The first work was done by the Russian Lev **Vygotsky** in the 1920’s and 30’s. This work introduced the notion of a mediated act. The focus was on an individual. The upper portion of the usual Engström activity system diagram incorporates these ideas. Alexei **Leont’ev** noted that human activity is never isolated – it always takes place within a context and is influenced by society. He moved the focus to the community in general, but did not extend the diagram. Engström is credited with the extended diagram. Many of Engström’s writings are focused on the learning that takes place over time and that drives the evolution of human activity. Contradictions are the source of such learning.

An Activity System

Figure 1 shows the general form of an activity system that Engström introduced.

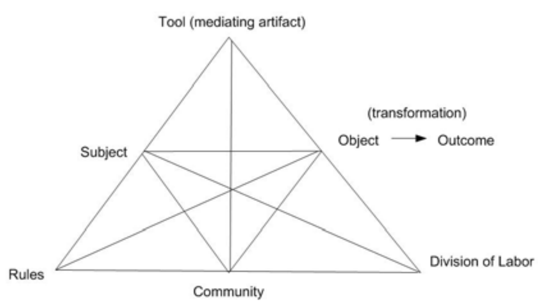

Figure 1. Engström’s activity system.

Structurally, the verticies of the triangle represent mediations: a tool mediates the interaction between a subject and object, while rules mediate interactions between the community and subject, and the division of labor mediates interactions between the community and object.

Briefly, the object is the object of the activity. It is transformed into the outcome by the subject, using the mediating tool. The object can be physical or conceptual, as can the tool. The subject can be an individual or a group. The community is anyone who shares the same object. The subject relation to the community is mediated by rules, which are implicit and explicit norms and conventions. The object and community relation is mediated by the division of labor, which tells how the task of achieving the object is divided up across the community. Division of labor also has a vertical component describing the power structure of the community as it relates to the activity object.

Most of the references in fields other than software use the *object* in the above diagram as the *object of the activity*, for example, the object of the activity *going to school*, for an elementary student may be to play with friends. Most of the software development discussions tend to interpret the object as something that is going to be transformed into the outcome. Engström notes that an object can be physical or conceptual, so both interpretations are reasonable.

The actual work that goes on in an activity is hierarchical in nature, as is shown in Figure 2.

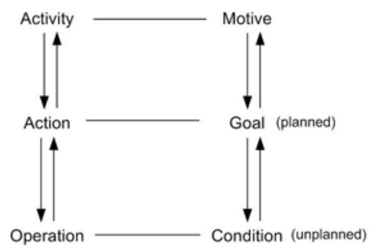

Figure 2. Hierarchical structure of activities.

A key point of this hierarchy is that actions are planned, and lead to some goal being completed. By contrast, operations are unplanned – they are simply put into motion as the result of some conditions. In the work on HCI, these are likened to interactions by novices (everything must be thought through when a person is learning a new system) and experts (experts tend to need shortcuts because they know what do to in a given circumstance without thinking about it much). Perhaps a more fundamental point is that while actions may become operations over time, if they are included in a new activity it is possible that they revert once more to actions that need planning to accomplish. Similarly, when viewed at a higher level of abstraction, an activity may be thought of as an action.

Engström included the idea of networks of activity systems even in his early work. He pointed out that all of the elements in an activity system can be thought of as being obtained from other activity systems, and the object or the outcome of the system can be thought of as being used in some other system to achieve its own object. This network is defined as a central activity system and its neighbors. There are 4 types of neighbors: i) activities where the *objects* and *outcomes* of the central activity are used, ii) activities that produce the *tool* for the central activity, iii) activities that "produce" the *subjects* of the central activity (e.g. education or training), and iv) activities such as administration or legislation that produce *rules* for the central activity.

Engström also presented 5 principles of activity theory that are referenced in many papers. These are i) an activity system is the primary unit of analysis, ii) activity systems always contain multiple "voices"; the viewpoints, traditions, and interests of the entire community, iii) "historicity" – an activity system is shaped over time and the objects, ideas, and tools all have history and all affect the activity system, iv) contradictions are the driving forces of change in the system, and v) expansive transformations occur when the object and motive change to accommodate much larger possibilities.

Mediating Artifacts

Engström doesn't talk much about mediating artifacts in his original work, but **Collins** et al., reference a later work (1990) of his that proposes a hierarchy of mediating artifacts. He evidently revised this over time, and the 2006 paper presents an alternate view. The later view is shown in Figure 3.

Figure 3. Engström's hierarchy of mediating artifacts

Engström points out that artifacts at the top of the hierarchy can be widely used, whereas artifacts at the bottom are applicable only in specific situations. Collins et al., used an earlier version of the hierarchy with only 4 levels in an analysis of a customer support environment. They explain the 4 level hierarchy as follows: **What** artifacts contribute to the means of achieving the object of an activity. These seem to be closely related to the *tool* portion of the activity system diagram. An example is a tool that is used to provide a customer support activity. **How** artifacts contribute to the understanding of how to achieve the object of the activity. These could possibly be associated with *division of labor* in the activity system. In customer support, informal coaching about how to create knowledge to be used by others in solving similar problems is such an artifact. **Why** artifacts motivate achieving the object. These seem to be related to the activity *motivation*. An example is decision rationale regarding why a support person approached a customer problem in a particular way. **Where-to** artifacts describe possible future states and possible evolution of the *object* of the activity system. An example in customer support is an analogy of software reuse to the knowledge captured regarding solving a particular customer problem.

Unfortunately, the additional 2 levels of the hierarchy shown in Figure 3 are not explained in the Engström paper, so the examples that were in the paper are also shown in the diagram. It is possible that 'In which location' is an organizing artifact, and that 'Who/What/When' artifacts are those which contain precisely this information. The latter are distinct from 'What' artifacts.

Activity System Evolution

Activity systems are dynamic. Engström states that they evolve over time, due to tensions/contradictions/conflicts within and between them. Engström associates this evolution with learning, and is especially interested in expansive transformations associated with collective or collaborative learning across the community involved in an activity system. His 2001 paper describes a case study where such an evolution of the activity of coordinated pediatric healthcare delivery in Helsinki took place. He describes a 7-step cycle involved in the evolution. It begins with a contradiction, either in the activity system or between it and other systems that affect it. This is followed by questioning of the activity itself, and also questioning whether the contradiction actually exists. Historical and empirical analyses follow this step, to refute or prove the contradiction. If proven, a new activity system "model" (i.e. a proposed new activity system), is developed. Additional contradictions or objections may be uncovered in the new model. A period of reflection and refinement occur with the new model, which finally lead to the evolved activity system. The final contradiction discovery may be met with what Engström terms *sideways* learning. Sideways learning means that rather than trying to adapt an idea to meet objections, the idea is pretty much cast aside for something new that meets the original goals and is thought to be able to also make the previous objections inapplicable.

Contradictions in Activity Systems

Engström uses the words contradiction, tension, and conflict interchangeably in his writing, as do many other authors. He presents a discussion, quoting Marx, which demonstrates the ideas of basic contradictions surrounding activity systems. In capitalistic societies basic contradiction comes about since the object of an activity has not only a use value, but can also have an exchange value in the society. It can become commoditized. In fact, Engeström notes that all the elements of an activity system can become commoditized and hence exhibit this contradiction; in the case of the subject and community this duality exists since these elements represent a labor force that can also be a commodity. (In a capitalistic society the labor force is mobile, so incentives must be present to persuade a subject to perform an activity. While these incentives are part of the activity system, they are usually not included unless they are germane to the activity system analysis.)

Collins et al., discuss a situation in their case study that shows this basic contradiction. They studied a customer support activity network where support engineers provided customer support in addition to creating reusable knowledge about customer problems. There was a use-value associated with the knowledge creation – anything that was documented that could help solve a similar problem at a future time had use-value. However, the customer support had an exchange-value; customers paid for support. Furthermore, support engineers were measured and rewarded for the volume of support problems they could resolve, rather than the quantity or quality of the reusable knowledge they created. The contradiction exists in the dual nature of the object of the activity network.

Webster defines a conflict as an "incompatibility or interference, as of one idea, desire, event, or activity with another". When viewed this way, conflicts may be seen as being caused by contradictions. Contradictions or conflicts can give rise to tensions in an activity system or activity system network. In the customer support system, the contradiction led to conflict in the activity network object, which in turn created tension that needed to be resolved through evolution of the activity system.

Engeström discusses external contradictions that result from use- and exchange-value contradictions. He defines 4 types of contradictions, using as an example the activity of a general practitioner doctor. Primary contradictions arise within any element of the activity system as a result of the internal differences between use value and exchange value. For example, the tools of the doctor include different medications. However, these are not just useful for treating patients; they also are commodities with prices, and are sold for profit.

Secondary contradictions occur between the elements of the activity system. For example, in Engeström's example a tool could be conceptual – classifying diseases and finding a correct diagnosis. There is a potential conflict between this tool and what might be the object of the activity – treating patients with a complex multitude of problems and symptoms. In this case there may not be a single diagnosis, and other things must be taken into consideration during the diagnostic process, such as the social and physical environment. There may not be a tool capable of integrating all the necessary information to determine correct diagnosis and treatment.

Tertiary contradictions occur between a more culturally advanced form of the activity object (and motive) that is not yet the dominant form of the activity. In Engeström's example, this might occur when administrators introduce new procedures that doctors are supposed to follow to achieve a more wholistic integrated approach, but the old form of the activity is still being generally used. There may be resistance to the new procedures. In another example from Engeström, the activity is going to school. An elementary student may pursue this with the object of playing with friends, while teachers and parents impose a more culturally advanced object of instilling the skills of lifelong learning.

Quaternary contradictions lie between the central activity system and its neighbors. An example of a quaternary contradiction is that a doctor strongly suggests that a patient modify some lifestyle characteristic as the outcome of the doctor's primary activity, while the patient resists the change. This is an example of a contradiction which occurs when the object of the central activity is used in another activity (in this case as the *tool* of the other activity). A key point to the discussion of contradictions is that any fundamental change in an activity system must first emerge as a deviation, and contradiction, in some form. Hence, contradictions are necessary to the evolution of the activity.

Cooperative Work Activity Systems

Korpela et al., modified the activity system proposed by Engeström in a way they claim is easier to understand, and that includes specific cooperative work elements. One extension is the explicit inclusion of a collective of actors and subjects all working toward an object. Multiple actors imply communication mediation and work distribution mediation. A core idea is that of the network of activities, as in the original activity system theory developed by Engeström. Korpela et al., discuss organizational boundaries, and how activities sometime cross such boundaries. They discuss identification of contradictions/conflicts across those boundaries, between activities in the network when activities are in the same organizational boundary, and also contradictions within elements of a single activity.

The main elements of Engeström's diagram appear in these adaptations, with the notable idea that there may be multiple mediating elements that are specific for specific subjects or work. All work is aimed at achieving the same object, as in Engeström's activity systems. The diagrams proposed by Korpela et al., for a single activity system and a network are shown in Figure 4.

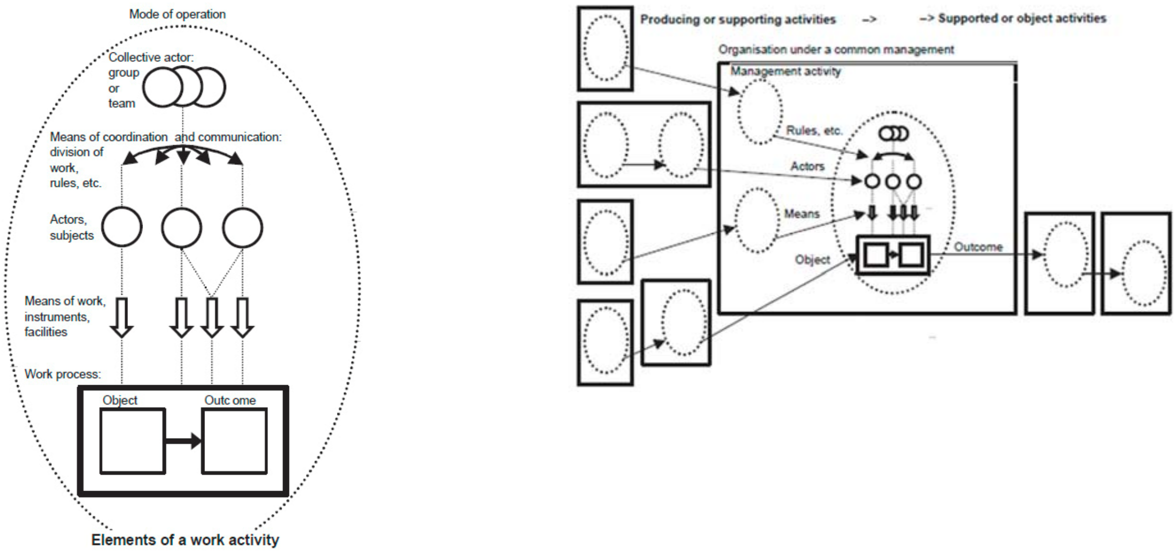

Figure 4. Work activity proposed by Korpela et al: Korpela, Mikko, Soriyan, H. Abimbola, and Olufokunbi, K. C. (2000). "Activity Analysis as a Method for Information System Development", Scandinavian Journal of Information Systems(12): 191-210.

The mode of operation noted at the top of the activity system model is a key source of contradiction when the activity is part of a network. Examples of modes are hierarchical and collaborative, which are discussed in various forms in the papers. For example, one version of a hierarchical mode of operation is technology-driven. Another is hierarchically driven by a doctor.

Observations

Mikko Korpela et al., present multiple means of coordination, communication, and work that are used, perhaps differently, by multiple people (subjects) performing some activity. The diagrams and notations associated with this view explicitly lay out the varying paths that may exist within a single activity system. By contrast, the Engström view shows a single subject, and a single set of rules and division of labor. Engström discusses the fact that there may be multiple subjects in an activity, but this isn't represented explicitly in the activity system diagram. The Korpela notation could therefore be better when there are multiple subjects, since the relations between the subjects and the means of coordination and communication and work are all represented explicitly. However, explicit mapping of Engström elements to the equivalent Korpela concepts could be difficult; the concept of community does not seem to exist in the Korpela model, and the concepts of rules and division of labor seem to be mixed in the Korpela notation. Ideally, a method to go back and forth between the notations would be ideal since more than likely a complex system can be described at a high level of abstraction using activities with many subjects, while at lower levels of abstraction the activities may have only a single subject.

Education and Organizational Learning

Activity theory has been applied in different domains to varying extents. Many applications are simple – merely identifying the elements of an activity system. However, in the field of education and organizational learning there are quite a few applications that identify contradictions and use them to suggest evolution, or at least point out why attempts at change have been only marginally successful.

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Overview

The papers described in this section are interesting because of their study of contradictions using activity theory. It appears that most of the studies are based on interviews and observations, and the researchers analyze this data. This data is used to create the activity system model. Then researchers then look for instances where the participants indicated conflict or tensions, and identify contradictions. Some researchers used the identification of a double-bind, or two forces pulling in opposite directions as being indicative of a contradiction. For the most part though, the process is rather ad-hoc from an algorithmic point of view. It is interesting that all of the types of contradictions discussed by Engeström are represented in these papers, sometimes all four in a single study. Two of the authors (Basharina and Murphy) studied networks of activity systems, and one (Núñez) proposed that analysis should be performed across a nested of hierarchy of activity systems. Basharina essentially did this with her study of a network of activity systems taking into account multiple cultural settings.

Paper Summaries

Basharina studied an international tele-collaboration between students of 3 different cultures (Japan, Mexico, and Russia), and analyzed contradictions using activity theory concepts. The study actually comprised a network of activity systems, one for each culture, sharing a work task. Interestingly, the object of the activity differed somewhat from culture to culture. Basharina identified 3 types of contradictions in the study. Intra-cultural contradictions occurred outside of the overall project activity system, while inter-cultural contradictions arose as the students worked together at the same task even while they actually participated in different activities. Technology was sometimes a hindrance as a result of unreliable tools. Basharina developed a diagram showing the intercultural impact on the overall network of activity systems. The overall outcome was supposed to be a "3rd place" where the students from each culture participated in a true collaboration. However, in reality, they often did not reach this place and instead remained just outside of it, within their local cultures.

Blackler writes about an organizational application of activity theory. In this case activity theory use was aimed at increasing the effectiveness of diverse working groups. Blackler proposes alternative terminology from that developed by Engeström, and also presents a slightly different diagram. The tool mediator is called Perspective Shaping, rules are called Perspective Taking, and division of labor is called Perspective Making. In this paper, PM is the central concept, and the other two elements influence and are influenced by it. Additional entities in these models are Information and Main Focus. These entities are influence and are influenced by PM. The organizational work process diagram for each of 3 different groups was constructed and analyzed to identify tensions. The tensions were used to develop a proposal for alternative rules and division of labor that could increase the group's effectiveness. No details were provided on a process for either identifying tensions or for modifying activity system elements to address them.

Dobson, **Murphy**, and **Núñez** each write about the use of activity theory in an educational setting. Most studies in this area are related to introducing some sort of technology into a learning activity. These papers all included contradiction identification using various examples.

Dobson presents 3 case studies, constructs activity systems from them, and identifies contradictions. Contradictions were found within elements, and between elements (tools and object, tools and community, division of labor and object, division of labor and community, division of labor and rules, and rules and object). Contradictions across the evolution of the object were not mentioned. Likewise, contradictions across neighboring activity systems were not mentioned, and neighboring activities were not identified.

Both Murphy et al. and Núñez survey previous studies. **Murphy** et al. describe contradiction analysis that was performed in several studies. They make the point that contradictions addressed by an individual subject usually do not lead to substantial and expansive transformations since the entire community is not involved in a collaborative transformation. Contradictions that are invisible (i.e. taken for granted or part of the culture) or cannot be discussed (i.e. embarrassing or culturally taboo) also do not lead to expansive evolution of an activity. The studies described found contradictions within and between elements of an activity system.

A study that was performed by the same authors studied contradictions across two interacting activity systems. That study also found an instance of a contradiction brought on by an emerging evolution of the activity object. Unfortunately the authors do not detail how contradictions were identified, other than by identifying a double-bind, or two forces pulling in opposite directions. This was done by first using an automation-assisted process to divide interview transcripts into units of meaning. These units were then analyzed by looking for "tension, contrast, denial, or opposition" between any two statements in a unit.

Núñez also surveys studies that discuss the use of AT in identifying and analyzing contradictions in the field of mathematics education. However, this paper also proposes a nested hierarchy across activities that can be used for additional analysis: i) a micro level of individual activity systems, for example in a classroom, ii) an institutional level that deals with a broader context of networks in, for example, schools, and iii) a cultural-historical level that deals with activities at a societal level. Examples of the last level are the concepts of numeracy and problem solving.

Núñez points out that most studies include data collected from needs analysis, evaluations, interviews, etc. This data is often categorized as belonging to one of the 6 elements of an activity system diagram as an initial starting point of the analysis. Instruments (tools) are further categorized as psychological (they help transform behavior) and material (they help transform the environment). The author states that contradictions are usually found when a new instrument or object is introduced into the activity system. Contradictions within the local activity system are identified in most of these studies. However, contradiction analysis across levels of systems (i.e. between micro and macro levels) does not occur very often. The author claims that completely identifying all elements of the activity system and completely analyzing it for contradictions within and across the hierarchical levels will increase the usefulness of activity theory analysis.

Observations

Contradiction identification is somewhat ad hoc in that it is based on interview and personal analysis by experts. Results are thus subject to experience of the experts and those conducting the interviews (which might be different persons), interview questions, etc. Nonetheless, primary (within elements) and secondary (between elements) contradictions as defined by Engström are identified by Basharina, Dobson, and Núñez. Murphy only identified secondary contradictions. Quaternary (across an activity network) contradictions were only found by Basharina and Murphy, while tertiary (with a more culturally advanced version of the activity) contradictions were identified by Murphy and perhaps Basharina. Basharina certainly identified a more culturally advanced version of the work activity in the "3rd place" she identified, but it was not clear whether contradictions she identified were a result of contradictions between this version and the original, or the result of other primary, secondary, and quaternary contradictions. Núñez describes contradictions across hierarchical levels of activities, but it is not clear that levels can be interpreted as more or less culturally advanced versions of the same activity, and thus be regarded as tertiary contradictions. Finally, Blackler identifies contradictions, but they seem to be either primary or secondary since they occur among the subjects of the activity, their interactions, and the contradictions with their backgrounds and how they interpreted the object of the activity.

Cooperative Work and Technology Transfers

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Salvioni, Carola, “Technology Communication: from Design to Use. Analysis of conflicts and possible mediation between technical approaches of design and situated practices of use within a well-defined institutional context”, Ph. D. dissertation, March 2010.

Overview

Most of the papers in this section describe contradictions rising from the introduction of a new technology into an activity system and the resulting changes in the system. However, one author (Bardram) only discusses the hierarchical view of activities/actions/operations and applies it to a cooperative work environment. Contradiction identification in the other papers occurs by analyzing interviews and observations, and is not described in any detail. All types of contradictions except the more culturally advanced object contradiction (Engeström’s tertiary conflict type) were found in these studies. The cooperative work papers generally involve a single activity system while the technology transfer papers deal with a network, where one system is that of developing the technology and the other is using it. Artifacts and mediation tools play prominent roles in these studies. One of the papers in this section (Korpela) describes a checklist to help identify elements in an activity system and also to identify neighboring systems.

Paper Summaries

Bardram, **Foot**, and **Korpela**, et al., discuss using activity theory in cooperative work, while **Hasu** and **Salvioni** specifically discuss it in terms of technology transfers from developers to users.

Bardram redefines some of the concepts of activity theory before applying it to cooperative work. He only uses the activity hierarchy: activity, action, and operation. It appears from the paper that coordinated work is at least similar to an operation, cooperative work is like an action, and co-constructive work seems to be similar to the concept of an activity. These definitions are attributed to work by Engeström, Brown, Christopher, and Gregory. The rest of the paper talks about the dynamic nature of the hierarchy through its transitions and applies the theory to a healthcare example. The cooperative work in this example is broken down along this hierarchy, and a tool is presented that was intended to support the cooperative work. Functionality of the tool is compared with the hierarchy analysis results, and the author describes changes that were suggested to help it better support the entire hierarchy and its dynamics.

Foot presents an activity theory analysis that identifies conflicts in a joint project between post-Soviet Russian states and US participants and funders. The project was aimed at cultural rebuilding and included ethnological aspects. Foot identified subjects and communities as being part of a larger group of interested parties oriented toward a common object. Since individuals could move in and out of the community/subject for any particular action of an activity, she used the term roles in these elements of the activity system.

Foot attributes the conflicts she identified to the use-value and exchange-value contradiction identified by Engeström. The project had a use-value object based on social-political issues (that is, to rebuild basic societal norms and culture), and at the same time, since the emergence of a more capitalistic view, there was an exchange-value object. The exchange value could take the form of saleable information, increased prestige across research, administration, and funding organizations, and also as loyalty to the project from the experienced members who were experiencing competition for their services.

Artifacts also provided a source of contradictions. Foot identified artifacts that functioned as mediators between the subject and community (i.e. rules dictated that reports be created by the subject as part of the activity, but they were not the orienting object of the activity) that had a dual functionality. On the one hand the report had a use-value that was in the ethnological monitoring it provided, while on the other there was an exchange-value since reports were essentially exchanged for membership in the network. The use-value and exchange-value contradiction led to the introduction of a new tool and eventually to a new form of the activity. It therefore provided the impetus for an evolutionary transformation of the activity. The paper continues with speculation on additional evolution that could be possible, as seen through the on-going fundamental contradiction in the system between the use- and exchange-values of the object.

The first section of this survey described most of the work by **Korpela** et al. However, the paper referenced for this section also includes a checklist of questions. The checklist can be used to identify elements of an individual activity system, and also other activity systems within its neighboring network. An example question is: "*Outcome*: What services or products do we produce?" A question used to identify neighbors is: "*Object*: From whom do we get our 'raw materials'? How do they produce what we need?" The authors state that answering these questions provides a snapshot of the activity in its network. Contradiction analysis can be performed across its elements, between the elements and the mode of operation (as evidenced by changes in the mode of operation over time in order to resolve these tensions), and across the network relations.

Hasu and Engeström describe the use of activity theory in analyzing a technology transfer. The particular case study is oriented around a complex piece of medical equipment that was developed by a research group and then transitioned into use in a hospital for research by staff doctors. The focus was on the dynamics of the interactions between the developers of the technology and its users. A detail of activity theory in this paper is the division of labor in two dimensions – horizontal division of tasks and vertical division of power and status. The authors also note that an artifact can be the object or the tool of an activity; there is nothing other than the activity at a particular moment that determines the meaning of the artifact. In this case study, the technology needed to be the tool of the users, but problems caused it to turn into the object of the activity.

The authors postulate two contradictions based on the history of the technology, then use observations and activity theory concepts to determine that these contradictions led to the actions they observed. The first contradiction was in the fact that a new activity emerged – using the technology in a clinical setting to make patient measurements whereas it had previously been used in an isolated producer community oriented toward research. The contradictions lay in the tools and rules of the activity. (It also seems possible that the new activity could really be a new object in the existing activity, which would result in an evolutionary type of contradiction.)

The second contradiction lay in the object (making a patient measurement) and the division of labor – a single person was responsible for the entire measurement, when in fact they needed assistance in performing it. The effect of this second contradiction was that the tool was transformed into the object of the activity, and troubleshooting the tool became the object of the activity rather than making the patient measurement. An interesting thing that was pointed out was that a doctor was in charge of making the measurement, and was in a control room, while a nurse was in charge of the patient and was in separated room. The doctor was alerted to a problem, but the nurse had physical observation capabilities. Hence both had part of the available information, but not all of it, so neither was able to actively help the other in the troubleshooting activity. The object was split between their two different activity systems due to the physical setting and the tools themselves (the control and physical machine).

The overall result of the analysis revealed contradictions in the hospital environment (the clinical application of the new technology) between the tool and both subject and object, and between the object and both the rules and division of labor. Contradictions in the development activity occurred between the tool and changing object (to use the tool in a clinical setting) and between that new object and both the existing rules and division of labor.

Salvioni uses activity theory and other means (situation action, distributed cognition, communities of practice, and argumentative theory) to explain low usage of an intranet in a cooperative work environment that is supported by a set of integrated web-based tools. The intranet was developed and is used within the same organization. Developers and users exchange roles sometimes due to work allocation. The context is a research institute at the University of Lugano in Switzerland. The institute offers masters programs in embedded systems, that combine formal classes with an industry-sponsored research projects. The courses are offered by international lecturers who travel to the institute for a short, intensive course time. Some of these people act as tutors later while the students are pursuing projects. They and the industrial sponsors must generally communicate with students in a remote setting. The internet tool was developed to support 2 issues: the need to retain information about the management of the workflows that occur from year to year, and the need to manage information about dynamic work that occurs as part of remote cooperative work. Work was begun in 2002, when few tools were available for such a situation, and the institute responded by building an internal intranet, complete with integrated tools.

This is an application of an activity theory analysis performed "by hand" by the practitioner. The author says activity theory identified a main contradiction between the development of the tool and its subsequent use. The subject element in the activity system is actually multiple subjects – the user and the developer, with the dual object of developing and using the intranet. The author identifies contradictions within each of the elements of the diagram and between some elements too (e.g. tool and community in terms of production and consumption – presumably of the tool). The author claims these contradictions helped identify areas for further research, however this process was not explained in the dissertation. There was a large section on the human interfaces of the integrated tools and an analysis of the issues in them, which doesn't seem to rely on the activity theory contradictions as a rationale. It appears that activity theory was used mainly to understand the general context of the system.

Observations

Contradictions are identified by these authors in the same way as the authors in the education world – through interviews and observations that are analyzed by experts. Bardram found secondary contradictions while Foot identified only primary contradictions. Foot however found changes to the activity based on the tensions rising from the primary contradictions. Korpela and Salvioni identified primary, secondary, and quaternary contradictions. Hasu identified secondary and quaternary contradictions. Tertiary contradictions were not identified by any of these authors, and the time-changing property of activity systems were not explored.

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Overview

The papers in this section deal with using activity theory in the field of HCI. Contradictions are discussed by Bertelsen in the context of analyzing how a user must shift their focus while interacting with a system. This paper is particularly interesting because of a conclusion that the contradictions found as part of activity theory analysis can lead to architectural changes in the software being developed. Another paper (Gay) attempts to add a hierarchical nesting to activity system analysis by using ecological theory. It was not clear from the paper how these ideas could be used. Two of the papers (Bertelsen and Kaptelinin) describe checklists that can be used to identify elements of an activity system. One of the papers (Uden) described a method to include temporal sequencing constraints in a task model, but this information is not used as part of any analysis.

Paper Summaries

Bertelsen and Bødker describe the use of activity theory in the re-design of a graphical editor for colored Petri nets (CPN). The paper uses activity theory to analyze the existing and future contexts of use of the editor, paying special attention to the role of artifacts in system use. The case study used is the design of alarm control systems, and sample artifacts are the CPN model within the tool that can be created and analyzed, and print-outs of the tool and reports of analysis that are used for communication and for recording changes. These items can be considered objects of the activity system.

The authors present previous work using activity theory concepts in design, specifically checklists by Korpela and Kaptelinin et al. The Korpela checklist aims to identify components of an activity system along with its surrounding network of activities. The Kaptelinin checklist is partitioned into 5 areas according to the principles of AT outlined by Engeström. The Kaptelinin checklist does not specifically identify the network, and neither does it lend itself to identifying contradictions in the system. The authors therefore supply their own checklist to aid HCI analysis. The authors perform a focus shift analysis on the user task of performing an exercise. A focus shift occurs when the user's focus shifts to different elements of the interface, or other distractions. The task in the case study was to create a CPN, and generate a report. During an observation of the task, the user's focus shifted between the exercise write-up, a printout of the CPN, and the interface elements of the application. The many changes in focus that were observed across the interface indicate that there are issues in the interface.

An interesting conclusion of this paper is that using activity theory concepts, especially the identification of alternate uses of the tool (i.e. for communication via printouts and for analysis via the internal representation of the CPN) produced a more complete activity network that could be analyzed. In fact, the results actually can influence the architecture of the tool – the CPN needs to be represented internally for analysis purposes, and the other use (printout) also needs to be directly represented in the system – thus layout is also a first-order concept. The authors point out that by focusing on the artifacts as they are used can move the HCI impact from just the interface to the way that work occurs, and also to the internal representation of the import concerns in the work in system function and architecture.

In another work, **Bertelsen** compares a cognitive walkthrough with some of the elements of activity theory, and suggests that activity theory may provide elements of context that are not contained in a walkthrough. The author points out that an important difference between walkthroughs and activities is that activities are dynamic, and their constituent actions and operations can change, unlike the tasks normally studied in a walkthrough. The author proposes a set of steps that integrate activity theory concepts into a cognitive walkthrough.

Constantine presents an integration of activity theory concepts with his usage-centered design methodology. The usage-centered design notation is extended with 4 new elements: players (i.e. activity theory community), artifact/tool, activity, and action. Usage-centered tasks are equivalent to activity theory actions, and usage-centered actors are equivalent to activity theory subjects. The word 'task' is used in the discussion, and the new notation element 'action' in example models. The models Constantine introduces are: Activity Context Model (new, has two parts – Activity Map and Activity Profiles), Participation Model (adaptation of existing User Role Model; includes Participation Map and Role Profiles), and Performance Model (adaptation of existing Task Model; seems to include an Activity-Task Map and task case elaborations – also called an Activity Model).

Constantine presents an overall process that has two sequential parts: activity modeling and solution modeling. Activity modeling in turn has three sequential parts: context (create activity map), participation (create participation map; focus is on roles), and performance (create performance map; focus is on task cases). Solution modeling has two parts: content (create navigation map and identify abstract prototypes) and design (create behavior).Constantine closes the paper with a discussion of the process and what activity theory offers. He claims that activity theory can help capture broad design implications in situations where activities are somewhat unconstrained and work may consist of relatively unpredictable combinations of those activities.

Gay and Hembrooke also describe applying activity theory in the context of HCI. Two insights mentioned in this paper are that psychological/social objects can be just as important as physical objects, and that artifacts/tools in one activity system can be objects in another that has the same subject. The example given is one where a word processing program is being used as a tool to write a paper, and because the subject has so many difficulties with the tool, it actually becomes the object of a different activity related to troubleshooting. The authors point out that inconsistencies/conflicts/tensions/disturbances can be used during design to discover why a disturbance occurs, why it did not previously exist, what effects it has, and how it can be resolved.

The authors propose integrating activity theory with an ecological theory of human development proposed by Urie Bronfenbrenner in 1979. There are 4 nested levels of hierarchy in this view: i) the micro level that consists of a single activity, ii) a meso level which consists of multiple activities with the same subject, iii) an exo level which consists of multiple settings, at least one of which does not contain the same subject but which influences the subject, and iv) the macro level that consists of the overarching patterns of social structure. An example given is that the micro level refers to an individual environment and its related function, the meso to interactions between micro environments, exo is an outer level that influences functionality of the environment, and macro defines the global context and operation of the entire system. The authors state that HCI issues are found in the interactions and interdependencies all levels, and also across time and space. The authors propose that an activity system outcome should be studied at a particular point in time in the context of all the interacting systems at the micro, meso, exo, and macro levels.

Kaptelinin et al., describe a checklist to identify the elements of an activity system in the context of HCI. The checklist has sections that are oriented around Engeström's 5 principles of activity theory. The tool mediation principle is assumed as the basic orientation of the checklist, so it has no specific section. Two versions of the checklist are presented; one for use in early design and the other for evaluation of an existing design. The two have major overlap. The design version has two parts; one relating to how the tool is expected to be used and the other relating to its actual design. The checklist is long, for example there are 13 items related to the hierarchical nature of activities in the evaluation checklist. The practitioner must develop questions that can uncover the instances of these items. Some sample questions related to each section are included in the paper. The authors state that the checklist is intended to be used in sections rather than as a whole-encompassing methodology. Further, the authors expect it to be tailored as needed to fit a specific situation. They also expect it to complement other HCI analysis tools, such as task analysis or contextual design.

Kuutti discusses the issues related to HCI research as it existed in the 1990's, and how the concepts of activity theory might be applied to address some of these issues. There was a critical need to include more system "context" into the design process, and no one existing method adequately addressed all aspects of this context. The author presents the basic elements of an activity, and the hierarchical nature of activities (with actions and operations), as well as their inherent dynamic features. Dynamics are discussed in terms of the movement between actions and operations, as in the HCI context where a novice action eventually becomes an expert operation. There is no discussion of the identifiable contradictions in an activity system or how these contradictions can be used in the design process.

Uden et al. propose a requirements specification methodology that is based on activity theory to address the need of capturing navigation requirements in Web applications. They look to activity theory concepts to provide a way to address organizational culture as it impacts web applications. They develop task models that include both activities and their context and extend these models to include navigation. Their goal is to understand interactions across an organization, not just within a single system. They claim that the task models can then be used to extract information useful in navigation structure specification.

The task model presented is based on the hierarchical decomposition of activities. The model has as its root an activity, which is decomposed into actions and then sub-actions. Temporal constraints among actions are shown as sequencing constraints (e.g. after, after with data passing, interruption and resumption, iteration, etc.) Each action has associated information about the goal(s), subject(s), and what the authors term contextual additional information, but what seems to be system or non-functional properties (e.g. frequency of execution, performance, security, availability, etc.) Actions are then broken down into sub-actions and modeled with a form of UML activity diagrams. Sub-actions are categorized as system operations (stereotyped as either functional or search), and interaction operations (information: input/output, or messages). The distinction between actions and operations in these diagrams seems to be in lack of sub-actions in operations.

The navigation of a web application is derived using guidelines from these activity diagrams. Each information exchange is interpreted as a web page. If two information exchanges are sequential then the web pages must be navigable so a link is needed between them. Search operations give rise to search engines that allow the user to start a search. Finally, other navigation information is obtained through the temporal constraints on the task model. E.g. interrupt/resume constraints across actions mean that navigation links must be available for the related web pages. The authors present an on-line music shopping web application as the vehicle to show their methodology. They use activity theory to explain the motive of a user of the application, and talk about historical use of the web, the difference between novice user motives and experienced user motives, etc. and how this will influence the application. They do not show how these factors can be used, but rather state that they should be taken into consideration. In addition, they explain Engeström's ideas about contradictions, but never use this information in their methodology or talk about how it could be used. Most of the social context concepts of activity theory seem to be missing (e.g. community, rules, and division of labor).

Observations

Papers in this section consisted of analysis papers and "tool" proposal papers. Bertelsen and Gay presented analysis that in Bertelsen's case identified primary contradictions, while the analysis in Gay's instance identified secondary contradictions. Bertelsen also proposes a tool approach that combines activity theory concepts with cognitive walkthroughs. He does acknowledge the time component of activities in this second paper. Constantine likewise proposes a tool approach that combines activity theory concepts with his usage-centered methodology, but he does not address analysis or activity evolution over time. Kaptelinin also proposes a tool in his checklist. It is strictly concerned with building an activity system diagram and does not address contradiction analysis or time evolution. Similarly Uden proposes a tool approach that uses some concepts of activity theory. Again, no contradiction analysis is detailed. The Kuutti paper proposes using the dynamic hierarchy of activity->action->operation to explain novice action and expert operation in the HCI context. While this is essentially an acknowledgement of time evolution from the user's perspective, no analysis is proposed, and the evolution of an activity as a whole is not addressed.

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Overview

There are several works describing the use of activity theory in software engineering, but relatively few take much advantage of the possible analysis that is offered by its concepts. Most authors use activity theory as a way to structure early requirements data, or to show "context" (Hassan, Kaenampronpan, Kirlidog, Liang, Martins, and Neto). Some discuss activity theory as part of a methodology of requirements elicitation and specification (de Souza, Fuentes, Martins, Mwanza, and Neto). Conflict analysis is also discussed by a few authors (Collins, Fiedler, Mwanza, and Neto).

Four works stand out in this section. First, the paper by Collins provides an in-depth discussion of activity theory analysis across a network to identify contradictions and eventually propose recommendations about tool design. Second, Fiedler discusses the use of activity theory in the context of software testing. Activity theory is used to provide testers with better knowledge of the context in which software will be used. Perhaps even more to the point, the paper gives several examples of possible ways to identify conflict. Also, the authors point out that there are many "correct" ways to apply activity theory to a given situation and all of them yield useful information. There are many papers by Fuentes et al., included in this survey, and this group seems to be among the only ones trying to apply activity theory in a semi-automated fashion. Their work includes conflict identification using structural patterns that are found using an automated tool. The concepts and tools were originally developed for multi-agent system development, and the group has more recently adapted these concepts to general requirements elicitation and to analysis of complex social networking interactions. Finally the work by Neto is interesting since it attempts to tie activity theory concepts to i*, and to use an activity theory system diagram to create strategic dependence and strategic rationale models.

Paper Summaries

Collins et al. describe a case study at Hewlett Packard in the customer support organization, specifically regarding creating knowledge that is used by support personnel to resolve customer issues. The research was undertaken to see if activity theory could contribute to understanding the work that occurs, and identify tensions related to knowledge creation. In addition, the use of artifacts was studied, in particular the hierarchy of mediating artifacts. The authors performed many interviews to create the primary data for the study. They identified the basic elements of an activity system by directly relating interview information with the various elements of an activity system diagram. They partitioned mediating artifacts according to Engeström's 4-level hierarchy discussed earlier in this paper.

The authors identified tensions within elements of the activity system, specifically in division of labor, rules, mediating artifacts, and even the object of the activity system. The object shift was toward maintaining, in addition to creating, knowledge. This shift can be related to an evolution of the activity object. The authors also identified tension between different elements of the system: between subject and mediating artifacts, between mediating artifacts and object, and between subject and rules. The knowledge creation activity system was identified as being part of a network that also includes a customer support activity and a knowledge maintenance activity. The authors identified tensions between these different systems: knowledge authoring and customer support (subjects and tools), and knowledge authoring and maintenance (object). This is the most in-depth study in the survey that identified all 4 types of contradictions discussed by Engeström.

The authors point out some requirements for the main support tool based on the artifact hierarchy (i.e. based on some of the *how*, *why* and *where-to* artifacts), and also based on the tensions they identified (within mediating artifacts and division of labor, between subjects and mediating artifacts, and between the knowledge authoring and customer support activity systems). The analysis thus helped identify opportunities for future "versions" of the network of activity systems and for the tools that support them. The authors note that while activity theory provided insights, other complementary models and concepts were needed to communicate with the study participants. Terminology was a big issue: e.g. "object". Also, the differences between the artifact hierarchy classes were difficult to communicate to the study participants. Finally, "activity" in activity theory is a noun, but to many participants the word is understood as a verb.

de Souza addresses the idea that activity theory can be viewed as a methodology. Four necessary components are required of a "methodology": a set of concepts, notation to represent them, process that guides model development, and heuristics to help the process. The claim is made that activity theory provides the first two, but the others still need to be developed. The Kaptelinin checklist is noted as relating to the process, and a reference to the Korpela work activity notation is noted as being a step toward bringing the notation closer to that of software engineering methodologies.

Fiedler and Kaner discuss using activity theory to more completely understand how a software product is used. The basic idea is to give software testing a more complete context, and to use contradiction analysis to think about possible limitations of a piece of software. The authors present several examples where the central activity system elements are explained, along with potential networked activities. Various problems with the software are described as resulting from contradictions across the activity network. All 4 types of contradictions outlined by Engeström are identified. Some examples are closely related to testing. The authors point out that choosing the elements of a system, and explaining a contradiction as one of the 4 types can often vary, depending on the perspective of the person creating the model and analyzing it. Such variations illustrate different things about an activity system. Since the use of activity theory in this situation is to gain an understanding of the context and ideas about how to explore the impact of a piece of software on it, each variation can be valuable.

Fuentes et al. have written several papers that relate to the use of activity theory in the design of multi-agent systems. Some papers present portions of a process where a multi-agent system is partially specified in a language such as INGENIAS. The group has a tool that maps these specifications into a UML profile called UML-AT. From here, they have developed a couple of libraries of patterns. Patterns in this and the other papers discussed here are presented as structural, requirements-level class diagrams. One set of patterns, called REG, is a refinement of the Kaptelinin checklist. It has a structure in UML-AT that consists of a question and an example structure that could "answer" the question. A practitioner chooses questions from REG to augment the existing UML-AT specification. The specification is automatically transformed back into the MAS specification language. The authors state that there are 170 questions in REG, but that only relevant ones should be used to augment a specification. They propose using contradiction analysis to find the related issues.

Contradiction analysis is the topic of other papers from this group. There is a website that has a library of the contradictions they have studied, but it was not available at the time of this writing. The papers included in this survey relate to 3 different conflicts: double bind (any possible action by a subject has some negative impact on some of its objectives), twofold meaning (an artifact is used for 2 different things within the same activity), and producer-user (the outcome of one activity is an artifact used as a tool in another activity). The contradictions are supplied in UML-AT, and pattern matching is performed to identify locations in a UML-AT specification where they might occur. Pattern matching is automated, and provided by a tool called ATA (AT Assistant). The practitioner is alerted when a match is found, and then must decide whether to "resolve" the contradiction. Patterns also exist for resolution. In the case of a double bind, the activity is decomposed into a set of activities, at least one of which has a positive impact on the outcome. For a twofold meaning, the solution is to add the artifact's contribution to the objectives of the activity. That is, the subject pursues an objective, to which the artifact contributes (it may be essential to achieving the objective or it could have a negative impact on the ability to achieve the objective). If there is no objective to which it contributes, the artifact use can be safely removed. Finally, the solution to the producer-user contradiction is to specify that each activity make a positive contribution to the other's objective.

One other work from this group is to use situational calculus to analyze abstract requirements. Predicates are defined that relate to activity theory concepts, and an activity theory extended version of situational calculus (SCAT) is used to find contradictions. A Prolog implementation of situational calculus called ConGolog was extended with operational capabilities, which allows searching for equilibrium (specific features do not change from state to state) or for constraint satisfaction in a state (existence of a particular property in a state). The purpose of this work was to provide an analysis for very abstract specifications that can be used prior to more in-depth work. The authors note that they have used transformations similar to those that transform UML-AT to INGENIAS to create INGENIAS specifications from SCAT programs, but they note that the SCAT programs are so abstract that the resulting specification are very incomplete.

Another paper from this group outlines a requirements engineering methodology based on their UML-AT patterns, ATA tool, and initial social properties. The social properties capture contextual information about the system being developed. The authors introduce the idea that these social properties take on different perspectives for social scientists (social), for engineers (requirements), and for customers (domain). They use UML-AT to specify the properties as patterns for each of the settings. Settings can have multiple views (UML-AT diagram and textual description), related properties (e.g. a "solution" to a conflict), and examples of their use (instantiations used in previous projects). The previously developed REG and library of contradiction patterns (ATCON) have been adapted to be used as sources for social properties. The process is described as iterative, looping around 1) picking social properties to investigate, 2) finding information about them, and 3) adding it back into the requirements. The ATA tool supports repository navigation, examining social properties, finding pattern matches, adding requirements, and transforming UML-AT requirements into other modeling languages (these other languages are not enumerated in the paper). A different contradiction described in this paper is a need-state. In this contradiction the outcome of an activity has changed and it is not clear if this will affect the ability of the subject to satisfy its objective. The solution is to add activities that will positively contribute to satisfying the objective.

There is also a paper by this group relating to partial analysis of individual interactions in social networks. The problem they address is that of easing the effort needed to analyze specific interaction for things like ethnographic studies or software evolution. Such studies require that individual user actions must be interpreted by multi-disciplinary teams. Using patterns that define what the authors call social properties can allow preliminary automated analysis to find interactions that can be studied in more depth. The patterns are quite complex and multidimensional. There are 3 different perspectives that are possible: activity theory-oriented, domain-oriented, and system-oriented. Within each of these perspectives, different settings can be specified. Each setting can have a UML-AT diagram specification, a textual explanation, a set of related properties, and bindings between variables in the various diagrams of the pattern. The example used in the paper is the exchange value pattern discussed in other work by these authors. An example AT setting shows a diagram of the conflict, and the related property section shows a potential solution.

The paper contains a lengthy description of how patterns are analyzed over time, and how their changing relevance is determined. Certainty degrees are assigned to instances of the patterns that are found in interaction data (e.g. low, certain, false, etc.). Relevance is tied to these certainty degrees. Pattern matching and relevance rating are accomplished using a modified version of the group's ATA tool, which also supports browsing instances of the patterns that are found. The example in the paper is used to point out that finding instances of the exchange value pattern can lead to using its solution in the software, thus resolving the original conflict. The authors conclude the paper with future work that includes extending UML-AT to incorporate unspecified AT concepts that were not originally included, and in being able to express semantics such as information state transitions (presumably this means the certainty degree transitions) and activity timeouts or triggering events.

Hassan and Gul use activity theory during requirements elicitation of a context-aware system that supports a mobile work force. The authors define context as having computing, user (includes preferences and skills, etc.), and physical (including location, time, weather, etc.) components. They map activity theory elements to these components as follows: the subject is related to personal context, the object is related to a task context, the community to spatio-temporal characteristics, the mediating artifact (tool) to the environment, rules also to the task context, and division of labor to the social context. The method proposed by the authors seems to concentrate on decomposition of activities into a hierarchy, and identifying artifacts used/produced during the activities. Context is used to develop scenarios that describe where/when a particular context is needed. This information leads to specific requirements, for example in a health application, when to use an emergency-driven, calendar-driven, or program-driven capability. This paper discussed activity theory concepts only the context of obtaining complete requirements regarding the conditions necessary for using particular contexts.

Kaenampronpan and O'Neil also discuss issues involved in context-aware systems, and the fact that these types of systems need to take into account many different kinds of context. The authors present the definitions of context used by various authors, and classify them according to what they cover, for example, location, time, or device characteristics. The authors propose to use the elements of an activity system diagram to discover all the important elements of a context. They note that there is no specific element related to time, or history in the basic activity system diagram, and this concept is needed in a context definition. Their solution is to track how the activity system changes at various points in time. This application of activity theory is related to the completeness of the definition of a context.

Kirlidog presents a proposal to use activity theory in the requirements elicitation of an information system in Turkey. The author claims that using activity theory will provide 3 benefits: i) the process itself is logical and hierarchical (this must refer to the hierarchy of activity/action/operation), ii) it promotes progress in that the practitioner is not lost in details, and iii) activity outcomes or deliverables can be measured to provide information regarding the activity success. Although the author mentions identifying conflicts (specifically within elements, between activity systems, and between different "phases" of an activity) they are not discussed as impacting the requirements elicitation and early design processes.

Liang et al. describe a multi-agent software system for education. They refer to a paper by Jonassen and Rohrer-Murphy from 1999 that outlines 6 steps to use activity theory in a learning environment. These are: i) identify the purpose of the activity system, its subject and relevant context, ii) define each of the elements of the activity system diagram, iii) define the activity hierarchy (activity/action/operation), iv) analyze and determine tools used for direct and indirect communication between the subject, community, and object, v) determine context bounds related to the subject that are required for the dynamics between the activity system elements (this concept is not defined or explained in the paper), and vi) analyze the overall dynamics or relations across the activity system elements. The authors identify the activity system elements for the software, and describe how it is used in a very general way. Unfortunately the paper does not include a discussion of how the system can be designed from the six steps except for a few obvious ones such as identifying agent goals from decomposing the purposes identified in the first step, and including agents that represent each of the subjects. Using contradictions/tensions in the activity system to aid design is not mentioned, nor is evolution of the activity system.

Martins et al. reported early work on requirements elicitation to create activity system diagrams for a simple example. Later Martins developed a requirements elicitation methodology that is described using a meta-model in the form of a UML diagram. The activity motivation is not part of the meta-model. The general structure of the activity system diagram is not directly visible in the meta-model. The relation between a subject and object is derived through the relation to a set of activities and the set of objects related to each of those activities. The meta-model is:

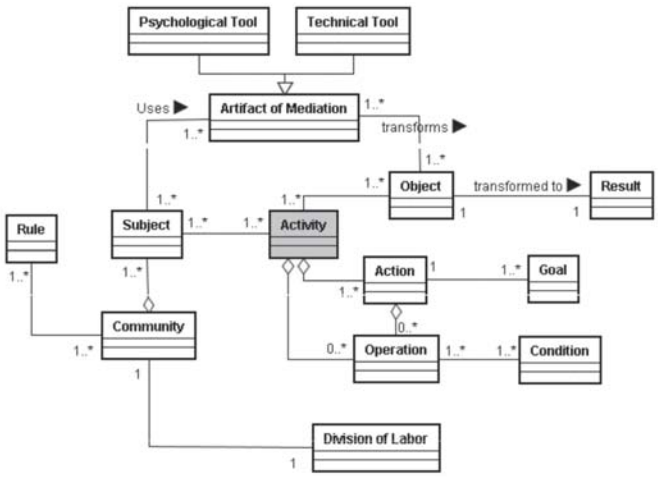

Figure 5. Meta-model for an activity system. Martins, Luiz Eduardo Galvão, "Activity Theory as a feasible model for requirements elicitation processes", Scientia Interdisciplinary Studies in Computer Science, 18(1): 33-40, January/June 2007.

Martins defines each of these elements, and also 'motive'. It is interesting that the only 'artifact' allowed is a tool. This is more restrictive than the general case described by Engström. Martins goes on to present a process to identify each of these elements during a requirements elicitation. The time relation is discussed (but it also is not represented in the meta-model) as being used to identify *original aspects of the activity*. It seems that this could be the basis for identifying *why things are done they way they are done*, and thus allow identification of rationale and constraints over time.

Once all the elements are identified, an activity system diagram is created. The diagram makes explicit Engström's intrinsic relationships (linking subject, object, and community). It also makes explicit the mediated relationships between these, as mediated by tools, rules, and division of labor. The rules and division of labor help identify the actions and operations hierarchically related to the activity, along with their associated goals and conditions.

Mwanza describes a methodology for requirements analysis that is based on activity theory. The methodology begins by the practitioner identifying the elements in an activity system diagram using some simple questions (e.g. to identify the activity: "What sort of activity am I interested in?"). These questions represent a very high-level checklist, and the answers allow the practitioner to construct an activity system. Mwanza says the basic purpose of this portion of the methodology is to allow the practitioner to obtain basic knowledge about the activity.

The next step is interesting – the practitioner considers both the external and the internal "lines" of the triangle diagram: the relations between Community and Object mediated by Tools and Division of Labor and Rules, and the relations between Subject and Object mediated by these same elements. Mwanza calls these *sub-activity triangles*. Another set of questions is created to explore these mediating elements, for example: "What Rules affect the way the Subjects achieve the Objective, and how?" These questions can be general, or they can be specific to the activity. A specific instance for a customer support activity is: "How does the rule of identifying and gathering FAQs while working affect the way the team/s share knowledge about work in order to provide better customer support?" Derivation of the specific questions used in the case study is not discussed.

Answers to the questions are used to guide further investigation through observation, interviews, questionnaires, etc. This additional data is used to identify contradictions. It appears that contradictions are not identified in a systematic way, such as using the idea of looking for contradictions within elements, between elements, between evolution of activity objects, and between neighboring activities, but rather in an ad hoc manner. The area of contradiction found using the question in the example customer support activity was: "Gathering FAQs". There is no discussion of how the identified contradictions are used to drive requirements.

Neto et al. describe how to integrate activity theory with the i* methodology for requirements engineering. They introduce the idea of a rapid ethnographical analysis that focuses on user activities and likely tensions in the activity systems. Multiple observation techniques are used, and this information is categorized into user activities, the activity theory elements of these activities, their hierarchical structure, and their tensions (all 4 types of contradictions discussed by Engeström are identified). The authors refer to another of their papers (described below) that discusses how to map this data into i* strategic dependence and rationale models. The proposed methodology then requires that stakeholders and developers jointly decide which tensions to use as the primary motivations for system development, and refine the system to relieve these tensions.

In another paper, Neto et al. propose a set of guidelines to derive i* models from activity theory diagrams during early requirements and propose using activity theory as a framework for context analysis in later stages of requirements specification. The process starts from ethnographical context analysis consisting of transcribed interviews, recorded interactions, and observational field notes. These are classified qualitatively using software (Nud*ist) and the classifications used to identify activities, actions, and operations. These are described with activity system diagrams. An intriguing point of this work is that diagrams are linked; that is the outcome of one diagram can become the objects of another.

The authors present a table of activities and decomposed actions. Although they do not explain this process, the actions appear to mainly come from the division of labor portion of the AT diagrams. They then show how an i* Strategic Dependence Model can be generated, using a set of guidelines. Actors are identified for every subject that i) depends on another "person" to participate in the activity, ii) depends on a resource provided by another activity, or iii) has a goal to produce something used by actors of other activities.

There are two dependencies between actors – those that are between subjects in a single activity, and those that are between subjects across a set of activities. In the first case, the activity is carried out by two subjects so a dependence relation is created between them. The authors do not discuss the case where there are more than two subjects. The authors assume that one subject will be more responsible than the other for the outcome, so the dependency is created with that actor being the 'depender'. The name of the relation is the same as the activity name. In the second case, the actor that uses something provided by the other actor is the 'depender'. The name of the relation is the same as the thing that is being received, pre-pended with the word 'Obtain'. In the case of the paper example, each of these names are the names of the outcomes of the previous activity.

Each dependence relation has a type: goal, task, resource, or soft-goal. If the dependee has autonomy to achieve the task the dependence relation is a goal relation, if not, then the dependence relation is a task relation. If the dependee must make an existing resource available, the dependence relation is a resource relation. If the dependee has autonomy to achieve the task but deciding whether or not the goal is actually achieved is subjective, then the dependence relation is a soft-goal relation.

The Strategic Rationale Model describes the reasons for the dependencies among actors, and the Strategic Dependence Model is augmented with this information. There are three guidelines associated with this augmentation. First, tasks are added to each actor as follows: if the dependence is within a single activity then a task is created for each actor and these are associated with the dependence relation. The name of the task is the activity name, pre-pended with "Participation in" If the dependence is across activities, and one subject produces something the other needs, the tasks that correspond to these activities are associated to the dependence relation between them.

Actions and sub-actions are added as follows: i) actions within an activity are created as sub-tasks for each actor who participates in executing them, ii) actions that are only executed by one subject are only included as sub-tasks in the relevant actor (note that the division of labor is used to help in this process), iii) sub-actions and operations are also transformed into sub-tasks for each actor involved.

The authors close with a discussion of future work that includes using tension analysis to guide late requirements phases. The paper does not specifically discuss how tool, community, or rules portions of activity system diagrams are used.

Observations

Collins, Fiedler, and Fuentes provide discussions and results of contradiction analysis. Neto briefly discusses such an analysis, and clearly uses it, but does not go into details regarding the process. Time evolution is also not part of Neto's work. The other three authors identify all four types of contradictions. Collins provides detail on a single system where all types of contradictions were found and also discusses activity evolution as it applies to future instances of the system, while Fiedler discusses many different systems that collectively demonstrate the four types. Fuentes' is the only group that attempts to identify contradictions in an automated manner. Specific instances of each type of conflict are described as patterns that can be structurally described and programmatically recognized. This group goes farther and modifies class structure to alleviate the contradiction, again in a single prescribed manner. However, their language for describing contradictions and mediating them is flexible and could no doubt be used to specify alternative solution patterns. However, only specific instances that can be described structurally are feasible for this method, and it is not evident that time evolution is included.

The de Souza paper is essentially a position paper. Hassan, Kaenampronpan, and Liang do not provide any discussion of analysis or time evolution. Kirlidog does not present any results of using activity theory, and while contradiction analysis is mentioned, time is not. Martins discusses time briefly but does not incorporate it into the work described, and no discussion of analysis is included. Mwanza discusses identifying contractions, but not in any systematic way. Time and evolution not included in this work.