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# Analysing Situated Interaction Hazards: An Activity-Based Awareness Approach

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**Abstract:** This paper presents a case for the usefulness of Activity Theory for the analysis of situated interaction hazards in safety-related systems. It is suggested here that situation awareness is a safety critical attribute that is acquired and maintained through situated activity or actions. We introduce an Activity-Based Awareness model based on this fundamental premise and we show how the model is consistent with the principles of Activity Theory. We also provide an example of the usefulness of activity theory as a theoretical and practical foundation for the analysis of situated interaction hazards in complex, safety-related systems. Specifically, we describe how the Activity-Based Awareness model and activity theory principles were applied to an investigation of situation awareness in a military air traffic control system. We show how this approach can also be used to support analyses of general interactive systems use. We suggest that this general approach can be used to support analyses of interactive system use to inform system design and mitigate against the situated interaction hazards inherent in safety-related systems, and that this provides evidence that Activity Theory can be a useful way of looking at situational hazards in safety-related systems use.

**Keywords:** Activity theory; Situated action, Situation awareness.

## 1. SITUATED ACTIVITY AND SAFETY-RELATED SYSTEMS

The starting point for any systematic analysis of human-computer interaction is an understanding of *how* and *why* users perform activities. Task analysis techniques are often used within the Human-Computer Interaction (HCI) community to capture *how* an activity is performed. The general purpose of task analysis is to observe the entirety of a user's interaction within a particular system, including both social and individual activities, and to produce a description containing all of the information necessary to conduct a particular task. However, it is often difficult - if not impossible - to provide a complete description of human activity as task analysis techniques and methods cannot capture either the *tacit* knowledge or the fluent action in the actual work process that are often required in skilled activities (Bannon and Bodker 1991).

To understand *why* an activity is performed it is necessary to consider both individual and collective cognition in a specific context. However, the dominant cognitive paradigm in HCI research has been based on the human information processor (as characterised by Card, Moran and Newell 1983) that explains individual cognitive processes isolated from their context. Although the human information processing model has been extremely useful, there is a growing awareness of the limitations associated with this paradigm for human cognition (see for example Nardi 1996a; Hutchins 1995; Suchman 1987; Winograd and Flores 1986). A key limitation of this model is that it has neglected the importance of how people work when using computer systems situated in the real world, suggesting that a consideration of cognition requires a holistic approach through careful consideration of the social, organisational and political aspects of HCI in context.

Understanding the 'how' and 'why' of activity in context becomes even more important when considering how people must work within complex systems as both direct and indirect human actions are repeatedly mentioned as major contributing factors to incidents or accidents (Hollnagel 1993). This was clearly the case, for example, when the crew of the USS Vincennes incorrectly interpreted the information presented by their system and a fatal decision was taken to shoot down a commercial airliner killing 290 passengers (Rochlin 1997). While this may be an extreme example taken from a military context, other command and control systems such as this are increasingly being integrated into social contexts where their correct design and operation is essential to ensure the safety of the general public and the environment. Systems such as these are often referred to as safety-related systems. By their nature, safety-related systems present unique hazards arising from the interactions between the user and the system. Studies of similar safety-related systems have shown that human factors have contributed significantly to accidents and incidents (see Sandom 1999; Heath and Luff 1991).

To help eliminate or mitigate such hazards we require new theories and models of work for capturing the richness of human activity in context and for framing analyses of how and why activities are performed – particularly when safety is an issue. A number of alternative theories have emerged and Activity Theory is one promising research method for studies of work. There are, of course, other approaches, many of which consider awareness and related issues from stances that are not explicitly related to Activity Theory (see, inter alios, Luff and Heath 2000; Heath and Luff 1991; Whalen 1995; Klein 1991; Artman and Wærn 1995; Artman and Wærn 1996; Artman and Wærn 1999; Garbis and Wærn 1999). This range of research has the potential to inform studies of human task performance, but to retain focus, this paper will limit itself to a consideration of Activity Theory, exploring its potential by briefly introducing the theory and the key principles which it embodies.

The paper aims to bridge between a theoretical treatment of Activity Theory and the development of models/techniques that can aid in the study of safety-related systems. As such, providing a detailed practical study is beyond the scope of the paper – rather the aim is to establish a position on the practical value of Activity Theory in relation to the study (and subsequent development/improvement) of systems of this type. This paper will therefore explore the potential of Activity Theory, briefly introducing the theory and the key principles that it embodies. We will then consider how Activity Theory might be used to gain an improved understanding of the use of a particular safety-related interactive system. We will use Activity Theory to analyse the user-system interactions with respect to the awareness that the user builds of the work situation, and present an 'Activity-Based Awareness' model that we are using to inform the design of a safety-related system. This will lead us to argue that Activity Theory offers a useful way of looking at situational hazards in safety-related systems use and that approaches informed by a Activity Theory perspective, such as the model presented in this paper, may be useful to those involved in this area.

## 2. AN INTRODUCTION TO ACTIVITY THEORY

Activity Theory (AT) can be broadly defined as a philosophical framework, drawn from Soviet psychology, for understanding the richness of human activity in social contexts. AT has its own terminology, which can initially be hard to penetrate, and it is tempting to try to alleviate the problem by using more familiar terms; however, this approach has generally been resisted unless clarity is affected. Before we describe how AT has been applied in a specific context for the study of work, it is necessary to provide a brief introduction to the theory (however, an in-depth explanation of the philosophical foundations of AT is beyond the scope of this paper and readers are directed to the work of Leontiev (1978; 1981) and Vygotsky (1978) for more detailed discussions). It should also be recognised that there are numerous different interpretations of AT and our explanation is primarily informed by the work of Engeström (1987), Bodker (1991) and Nardi (1996b).

The basic unit of analysis in AT is the activity and we will therefore examine a model of the structure of activity as proposed and adapted by numerous activity theorists (Kuutti 1996; Engeström 1987). An examination of this activity structure model provides a basis for discussing the principles of AT and an appreciation of these key principles will later enable us to consider the applicability of AT for analysing safety-related systems.

### 2.1 The Structure of Activity

AT deals with the activity of transforming something to achieve an objective while avoiding the dichotomies between thought and action or between individuals and society which are prevalent in western philosophy (Blackler 1993). The basic unit of analysis in AT is human activity which is motivated by the need to achieve an objective. In AT terminology, the term *activity* is intended to convey the essential connotation of physically or mentally ‘doing in order to transform something’ and the term *object* is used in the sense of an objective (Kuutti 1996).

An influential model of activity (Fig. 1), based on the conceptualisation by Engeström (1987), can be used to show the structure of activity and to highlight the key principles of AT.

**Fig. 1. Structure of Activity (adapted from Engeström 1987)**

Fig. 1 depicts the three main relationships between the individual (subject of the activity), objective (object of the activity) and social group (community) involved in an activity. It should be noted that all the elements of the activity are related; however for the sake of clarity not all of these connections are shown in Fig. 1. From this model we can see that the object of an activity is transformed by the participants through a transformation process. The model also depicts the reciprocal relationship between the subject and the object of an activity and it shows that this relationship is mediated by an artefact or tool.

Specifically, this model illustrates that an individual’s actions towards an objective will be mediated not only by the tools used - but also by the rules and division of labour of the community to which the subject belongs. It is also vital to realise that in AT the two-way nature of these relationships depicts the fundamental principle that the tools, rules and division of labour involved in the activity will in turn affect the cognitive processes of an individual.

The activity structure model in Fig. 1 shows that AT is based on a number of fundamental, philosophical principles, which we will briefly consider here. These key principles (based on the prevalent characterisation of AT by Kaptelinin 1996 and Nardi 1996b) provides us with a framework with which to consider the applicability of AT for analysing, in the following section, the awareness that users of systems develop through their interactions.

### 2.2 Principles of Activity Theory

AT may be presented through six basic principles that will be introduced in this section.

### *I. Unity of Consciousness and Activity*

Perhaps the most contentious principle of AT is the perspective that consciousness and activity cannot be meaningfully separated at either the individual or the social level. The conscious action of an individual engaged in an activity is recognised by AT as a person inevitably possesses a number of biases based on personality, experience or training that will affect their actions. AT also contends that consciousness is a major determinant of human activity at the social level and that it is not simply a theoretical construct found in the head – consciousness couldn't meaningfully exist without activity involving other people and artefacts. Instead, according to AT, consciousness exists in everyday practice and the 'social theory of consciousness' (Vygotsky 1978) is a fundamental principle of AT. It is an axiom of AT that tools mediate human consciousness and it follows that the introduction of new tools into an activity will affect both the social and individual processes that develop. The corollary of this is that the existing social processes of the community in which the activity takes place will affect the consciousness of the individual involved in the activity.

### *II. Object-Orientedness*

The term *object-orientedness* as used in AT should not be confused with the use of the same phrase in software engineering. In AT, object-orientedness refers to a perspective that the environment in which we interact plays an important role in our basic activities. Activity theorists contend that we are situated in an environment that combines many different physical or abstract objects that influence how people act. Activity theorists consider social and cultural properties of the environment to be as important an object as physical ones. This principle contrasts sharply with the cognitive psychology approach and the human information processor model where human cognition is deemed to be based entirely upon low-level sensorimotor functions. Object-orientedness however has much in common with the perception - action cycle espoused by Neisser (1976) where perception is deemed to be an active activity.

### *III. Hierarchy of Activity*

Many psychological theories use human action as the principal unit of analysis without considering the context within which these actions are situated. In AT the basic unit of analysis is the activity which is considered to be the *minimal meaningful context* required to understand situated actions. Consider for example the activity of providing airport services where there are many different specialists involved including air traffic controllers, operations managers and engineers. One operations sub-specialisation is provided by the Bird Control Unit (BCU) whose goal is to ensure that birds do not present a hazard to aircraft in the vicinity of the airfield. To achieve this goal, BCU staff drive around the airfield playing loud tape recordings of birds in distress to frighten other birds away. On their own, the actions of these people may seem irrational and even bizarre. However, viewed within the context of providing an airport service, the individual actions of the BCU become rational and can be understood.

A key principle in AT is the discrimination between a hierarchy of processes as shown in Table 1.

| **Process** | **Motivation** | **Relative Duration** | **Characteristics** |
|---|---|---|---|
| *Activity* | Objective | Long | Minimal Meaningful Context for Actions |
| *Action* | Goal | Short | Planned and Conscious |
| *Operation* | Conditions | Short | Reactive and Automatic |

**Table 1. Hierarchy of Activity**

Table 1 shows that human activity is considered a relatively long-term process and activities are typically accomplished through shorter-term *actions* and *operations* involving different levels of awareness or consciousness. Participating in an activity requires a subject to perform conscious actions which have defined goals. In turn, actions require an individual to perform automatic operations that are initiated by certain environmental conditions. Typically, each conscious action is planned. With practice however, a conscious action can become an automatic operation. Conversely, an automatic operation can regress into a conscious action.

### *IV. Internalization/Externalization*

Vygotsky (1978) asserted that human mental activity is derived from external action through a process of internalization. In AT internalization is the transformation of external actions into internal mental processes. For example, we usually learn to count as an external action using our fingers; however, we generally internalize the activity of counting on our fingers into a process of internal mental arithmetic. The principle of internalisation has much in common with the ubiquitous, but ill-defined 'mental models' in HCI studies which are purported to enable mental simulations to be performed before external action is taken (Kuutti 1996). Externalization is the opposite of internalization where mental processes manifest themselves as verifiable and observable behaviour. For example, checking the result of mental arithmetic using a calculator. This idea of internalization in AT is a powerful concept since it includes the notion of embodiment of knowledge and production of new knowledge that can be used in other contexts or activities.

### *V. Mediation*

Artefacts (both physical and abstract) often mediate human activity and the principle of mediation is a core concept in AT. The design of an artefact mediates the way that people can interact with the real world in the sense that it simultaneously limits and enables activity. An artefact also encapsulates the practices of its users through its physical properties and through the knowledge of how it should be used. An AT concept underlying artefact mediation is the formation of *functional organs* (Leontiev 1981) where an artefact's physical and abstract properties and human abilities combine to produce a more effective system. In Fig. 1, the tools, rules and the division of labour involved in an activity perform mediation.

### *VI. Development*

Finally, AT contends that activity cannot be fully understood unless we know how it developed into its existing form. For example, it may be revealing to learn when particular conscious actions developed into automatic operations when undertaking a specific activity. The principle of development in AT concerns the analysis of the continuously evolving practice of an activity rather than taking a simplified snapshot at one particular instant thus introducing the concept of dynamism.

These six principles constitute an integrated theory; and a systematic application of an AT approach must include the interaction between these principles. A common reply to the call for a richer understanding of human activity has been to complain that ‘human factors’ are too complicated to understand in context and we must therefore adopt a reductionist view to decompose problems and enable experimental methods to be brought to bear. From this perspective it is often assumed that the mental processes that underpin human behaviour in the laboratory can later be extended to real-world activities. AT rejects this reductionist view and it provides a wider basis for studies that equally address the individual and social interactions, cultural factors and developmental aspects of human activity.

## 2.3 Activity Theory and Situation Awareness

AT is not a new approach and it has been applied by Soviet psychologists and social scientists since the 1920s; however, attempts to apply AT to other fields, including HCI, have only recently been made. The AT perspective suggests a radically reformed framework for the study of human-computer interaction from that provided by the human information processor perspective. In AT the basic unit of analysis is the activity which is considered to be the *minimal meaningful context* required to understand situated actions. Perhaps the most fundamental implication of this shift in perspective is the explicit realisation that computer-mediated activity deals with two interfaces: the human-computer interface and the human/computer-environment interface.

Using AT as an analytical framework broadens the system view as it leads us to examine system users and the social setting in which they operate the system. A particular area in which this perspective might be useful is in the design and evaluation of safety-related systems, where researchers have begun to consider hazards that might arise through the design of the interactions between the system, its users and the work context in which they operate. These situated interaction hazards are very different from those which have historically been the concern of safety-related systems since they arise directly from the *use* of the system and require some understanding of the cognition of users *in situ*.

There are several human-centred constructs that may help us to understand these issues, an important one being the idea that people have an awareness of what is going on with respect to their interaction with the system and its environment - often referred to as the user's 'Situation Awareness' (SA). A fundamental difficulty in safety-related systems design is in providing interfaces that enable accurate assessments of situations and facilitate the prediction of future system states based on user awareness of a situation (Storrs 1997). Finding ways of assessing and understanding the human activity involved in acquiring and maintaining SA is important in helping identify areas where users form incorrect awareness and where, as a result, there are interaction hazards. Given the nature of the problem, AT is a strong theoretical candidate to help us understand these 'Activity-Based Awareness' issues. If this is the case, AT-based analyses of the operation of such systems will help to inform the design of safety-related systems.

In order to consider the usefulness of AT in this area, we will introduce and discuss a model of SA developed through our use of AT in analysing aspects of safety-related systems.

## 3. AWARENESS THROUGH ACTIVITY

SA has been characterised as a critical but ill-defined phenomenon in complex interactive systems (Sarter and Woods 1991). One of the problems in making use of SA is the conflicting theoretical perspectives from which this phenomenon has been described and researched. In the context of human-machine interaction, current definitions of SA are generally based on opposing views of SA as either a cognitive phenomenon or as an observer construct. This is similar to developments within the field of HCI where context and situated action are increasingly acknowledged as important. A detailed discussion of SA is beyond the scope of this paper and a comprehensive review can be found in Sandom (2002).

Whilst theoretical debate is both healthy and necessary, a pragmatic stance that synthesises elements from the different perspectives may be a more immediate way of contributing to systems design. The outcome of this approach would be a synthetic model that helps designers understand SA and its usefulness in designing interfaces, interaction sequences and dialogues within safety-related systems. A model of SA was proposed (Fig. 2, and described in detail in Sandom 2002) based on the basic principle that awareness is acquired through human activity. This Activity-Based Awareness model of SA is underpinned by the philosophy and principles of AT and we will briefly introduce it here before describing how AT analysis may be brought to bear on our perspective of SA in interactive systems.

**Fig. 2. Activity-Based Awareness Model (adapted from Neisser 1976)**

The Activity-Based Awareness Model of SA (Fig. 2) is adapted from Neisser's Perception-Action Cycle (1976) which portrays the adaptive, interactive relationship between an actor and the environment. Neisser's (1976) model is used as a basis for conceptualising and developing the Activity-Based Awareness Model because of its nature as being concerned with this relationship between an actor and his/her environment. Similarly, the Activity-based awareness model of SA also depicts how awareness information is continuously extracted from a real-world situation and how this is integrated into an individual’s awareness to form a mental representation upon which decisions are based and situated actions are undertaken. This model of SA addresses some of the key conflicts between opposing views of SA as either process or product as it encompasses both views. The model shows the inseparability of the SA acquisition process and the resulting (product) state of awareness that recursively direct the selection of relevant situation information in a continuous cycle.

In Fig. 2, the three terms sample, modify and direct are used. In Neisser’s model, these terms are related to the environment, knowledge and action respectively. In the adapted model of Fig. 2 the terms relate directly to the areas of situation, awareness, and situated action. For the purpose of using Neisser’s model in the context of SA, the terms ‘situation’ and ‘awareness’ are substituted for ‘environment’ and ‘knowledge’ to imply that only a subset of elements of the environment and knowledge relevant to a specific task are considered. This view is consistent with the well cited definition of SA espoused by Endsley (1995).

As the individual begins to interact in their environment, they can be considered as moving along the spiral in the model from the central point. An individual may start anywhere in the cycle as, for example, a routine may take over to provoke initial action. Starting arbitrarily, the individual will *sample* the situation, building a perception of it by extracting and interpreting information content. This may lead the individual to *modify* their awareness, developing their subjective mental representation of the situation in which they are interacting. Changes in the individual's interpretation of the situation cause them to consciously *direct* their action (including what/where to sample next), anticipating future states in which they might find themselves and acting accordingly.

The lines between each sample-modify-direct actions in Fig. 2 show a distinction between the actions; however in practice it is asserted that there is not a clean, sequential transition between the different actions and these boundaries may be indistinct. The ‘sample–modify–direct’ cycle which the individual can be thought of as having passed through will have developed their awareness in a particular way. As time progresses the individual will cycle through these phases building an integrated awareness that grows with each iteration. The integrated SA line in Fig. 2 is intended to imply that an individual will develop **an** integrated awareness of a situation not necessarily **the** awareness that accurately reflects the actual situation. We argue that an individual will develop a subjective mental representation of the situation in which they are interacting and that the accuracy of the acquired awareness will be affected by (among other things) consciousness and interaction breakdowns. These important issues will be examined in more detail throughout the paper.

This Activity-Based Awareness model is intended to capture the dynamic nature of human activity in the process of acquiring and maintaining awareness of a situation. We can see from the following summary that the theoretical foundations of this model are underpinned by the six basic principles of AT introduced in Section 2.2.

### *I. Unity of Consciousness and Activity*

The contribution of consciousness to the overall activity of proactive extraction is explicit in this model that encapsulates consciousness based upon both internal cognitive and external social resources in the system environment. Thus the model acknowledges the existence of social consciousness and also reflects the view that an individual's awareness of an objective situation consciously affects the process of acquiring and interpreting new awareness in a continuous, proactive extraction cycle.

### *II. Object-Orientedness*

The model recognises the principle that many different physical or abstract objects are present as the objective situation is sampled to influence the modification of the subjective awareness held by the user. The subject's consciousness then directs the sampling action to relevant objects in the situation based on their awareness and also on social factors which provide the objective for the activity and goals for individual actions.

### *III. Hierarchy of Activity*

At one level, the model represents the longer-term activity of acquiring and maintaining SA in a dynamic environment. The model also encapsulates the hierarchical aspect of this activity by subdividing the activity into the shorter-term actions and operations that are involved in the sample-modify-direct cycle. The model intentionally does not specify the conscious level of these sub-activities as this will depend upon the context of the interaction.

### *IV. Internalization/Externalization*

The model directs the researcher to observe the process of acquiring and maintaining SA while encouraging the identification of what aspects of the external, situation objects become internalized as part of the subject's awareness. Analysis of the internalized information can indicate aspects where the information presented to the subject is deficient for acquiring appropriate levels of awareness. The externalisation of this awareness can be observed through the sampling strategy adopted.

### *V. Mediation*

The model synthesises aspects of the objective situation as presented to the participants and the awareness held by the subject. The objective situation may be presented to the subject through interaction with an artefact, such as a computer-based system, that simultaneously limits and enables the activity-based awareness. Thus the model encompasses the concept of tool mediation and the formation of a functional organ of machine and man through the interface. In the sense that SA is the fit between a subjective interpretation of a situation and the objective situation as represented by a tool (HCI), the Activity-Based Awareness model represents the mediating relationship between the subject and the artefact.

### *VI. Development*

Finally, the model recognises that situation samples must be integrated with a current ‘picture’ to form a subjective awareness of a situation. Therefore, it suggests the importance of analysing how awareness is developed in order to fully understand the activity under observation. An analysis of the development of awareness should encompass both short-term adaptations to an environment and the longer-term, continuously evolving practice of an activity which influences a participant’s consciousness.

The Activity-Based Awareness model provides a framework for analyses of situated activity in safety-related systems. Specifically, the model can be used to identify difficulties that affect the continuity of the actions, such as interaction breakdowns. Interaction breakdowns (or mediation breakdowns) are defined here as any interruption to the continuity of the actions in the ‘sample–modify–direct’ cycle.

The division of this activity of updating or acquiring awareness into separate actions (sample–modify–direct) provides a structure for researchers to analyse and categorise SA problems. For example, the model could be used to question where the problems in particular situations might have arisen: what information did the individual sample from their environment?; how did this lead them to modify their awareness (what was available through the interface)?; and how, subsequently, did this direct their actions and operations.

The structure of the model partitions different areas of interest to allow researchers to concentrate on each as a distinct dimension contributing to awareness which can bring its own set of potential problems. It also allows us to consider the boundaries between these partitions, which is where we believe that many SA difficulties might arise. For example, as users integrate sampled information, the modification of their awareness may loosen the coupling between subjective interpretation and the objective situation leading to a reduction in SA.

So far we have only considered the theoretical advantages of applying the principles of AT and the Activity-Based Awareness model to help us to understand work in safety-related systems. Empirical evidence is also required to help us to assess the potential of AT in this area and evidence from a practical study will be integrated into the following section to highlight key issues related to the model. In the practical study, the focus was on the activity-based evaluation of an interactive system that relies on high levels of SA for safe operation, with the overall goal being to use the Activity-Based Awareness model to undertake analysis which would inform the design of a replacement system. The initial findings presented here are oriented towards providing a perspective on the applicability of AT and our Activity-based awareness model in the work context in question. A detailed discussion of method and the results from this empirical study will not be undertaken as it is beyond the scope of this paper. Instead, the paper includes reference to, and discussion of, elements of the study that we undertook; the elements chosen are those that reflect what we see (and our practical experience suggests) are key possibilities offered by taking an Activity Theory-based stance (as reflected in the model presented in the paper and used in the practical study to study SA)

## 4. OBSERVING ACTIVITY-BASED AWARENESS

The United Kingdom Air Defence Ground Environment (UKADGE) system provides ground-based command and control services to military aircraft within the UK Air Defence Region (UKADR). The core capability of the UKADGE system is provided by the Air Traffic Control activity of Air Defence Fighter Controllers and also by the hardware and software of an information system known as the Integrated Command and Control System (ICCS) which, together with data from other information systems and numerous sensors, can compile a recognised air picture of the UKADR.

The existing ICCS hardware is becoming obsolete and expensive to maintain and a project is being undertaken to replace the system with more modern, commercial off-the-shelf components. Many of the system changes will be transparent to the Fighter Controllers; however, a major tangible change will occur with the replacement of the existing ICCS HCI, which will impact significantly on system interactions and activities.

From an operational safety perspective, the proposed changes to the system interface have been recognised as a major area of risk and a pragmatic method of assessing the relative functional safety of the replacement system was required. As part of this process, an empirical study of the UKADGE system was undertaken to provide a benchmark assessment of the safety of the existing HCI against which a replacement could be evaluated. It was also hoped that the findings from this study would inform the specification and subsequent design of the replacement HCI.

A preliminary survey was conducted at all UK Air Defence sites using semi-structured interviews with a representative sample of Fighter Controllers and a questionnaire was distributed to all Fighter Controllers to identify representative air traffic control activities (Air Defence missions) to be used for analysis. Significantly, the preliminary survey revealed that an overwhelming majority of operational Fighter Controllers regarded SA as the major safety concern for operators of this safety-related system. The survey also revealed that the major changes proposed to the existing HCI would affect both individual and social command and control activities within the system, therefore an AT approach was considered appropriate for the data collection and analysis phases of the field study.

To focus on the structure of Air Defence as an activity, a high-level activity diagram (Fig. 3) was constructed and validated with assistance from numerous Fighter Controllers. This diagram was used as the activity-based framework within which the UKADGE system was initially analysed.

**Fig. 3. Air Defence Activity Structure**

Our initial observations and subsequent video analysis of Fighter Controller activity during a number of representative Air Defence missions confirmed our expectation that SA in Air Defence (in the sense of a high coupling between an objective situation and the subjective awareness of the operator) is acquired and maintained through individual and social activity. However, it was also apparent that the high-level activity diagram (Fig. 3) could not provide us with sufficient detail to structure an examination of the mediating properties of the activity. Specifically, in this case, we were interested in the mediating properties of the situation presented by the ICCS HCI and the subsequent effect upon the Fighter Controller's awareness. The Air Defence Control activity was therefore characterised and analysed further using the 'sample-modify-direct' cycle of the Activity-Based Awareness model of SA as a framework.

The major contribution of the Activity-Based Awareness model to the field study was that, through providing an analytical framework to organise our investigation of SA, it enabled us to target our efforts and it helped us to develop an improved understanding of the SA problems that Fighter Controllers encountered during system use. There are two specific ways in which AT and the Activity-Based Awareness model have informed the analysis of the existing interactions and the design of the replacement interface: identifying and understanding situated interaction hazards in the form of *interaction breakdowns* and *automatic operations* - both of which are key to SA and thus safe system operation. The following discussion of these issues is not intended to be exhaustive; rather it aims only to highlight the contributions of AT and the Activity-Based Awareness model in the analysis.

### 4.1 Interaction Breakdowns and Automatic Operations

Consistent with the 'hierarchy of activity' principle of AT, Bodker (1996) maintains that experience enables conscious actions to become automatic operations and interaction breakdowns occur when automatic operations regress into conscious action. Before the UKADGE field study commenced, it was expected that interaction breakdowns would cause Fighter Controllers to apply a proportion of their finite cognitive resources to the interaction and not to the system objective. Therefore, the initial expectation was that interaction breakdowns would be hazardous in a safety-related system such as UKADGE as the Fighter Controller must suspend aircraft control in order to interact with the system. Based on this intuitive understanding, it was perceived that an aim of the ICCS HCI design should be to eliminate any potential interaction breakdowns and to develop a *transparent* interface that required minimal conscious cognition. This sentiment is prevalent within the HCI literature which often equates transparency with system usability (see for example Hasan 1998; Nardi 1996a; Norman 1993).

Having speculated that interaction breakdowns would be significant events in terms of operator SA, observations and subsequent video analyses of Fighter Controllers were undertaken and the Activity-Based Awareness model was used to identify interaction breakdowns during the analysis of many hours of video data. However, subsequent analysis of the data revealed that a major hazard to SA in the UKADGE system is associated with the Fighter Controller performing automatic processing when conscious thought is required and therefore - contrary to our initial expectation - transparency was not considered conducive to safety in this context.

Through video analysis involving the subject controllers in post-task walkthroughs, it was revealed that a Fighter Controller’s awareness of a situation was often not updated following automatic operations and their awareness was therefore inaccurate. This raised a tension between moves to remove interaction breakdowns by making interactions transparent (and interfaces usable) and the problems caused by the emphasis this places on automatic cognition. This suggests to us that there are situations when usability and safety are mutually exclusive and automatic cognition is to be avoided in favour of conscious cognition, with the implication that usability of the system is decreased if the operator is consciously engaged.

## 5. AN ACTIVITY THEORY-DRIVEN CONTRIBUTION

The example in the previous section is one illustration of the way in which AT and our derivative Activity-Based Awareness model can contribute to the analysis of the existing system use and inform system re-design. We can now describe a general approach that evolved through the analysis of the ICCS system use using data from videotape of actual use and through post-task analysis with system users to identify situated interaction hazards. Our approach uses the six principles of AT as a guiding framework and draws on the Activity-Based Awareness model as an analytical tool at appropriate points. The approach is presented as a four-stage model in Fig. 4, and the stages are discussed in the remainder of this section. We believe that the general applicability of this activity-based approach to the analysis of situated interaction activity addresses a major criticism that AT offers only abstract guidance to practitioners and that there is little help in AT’s practical use in real and complex technological work contexts. The approach suggests that a strong understanding of AT and the work context can lead relatively simply to framing more targeted AT-oriented support for practitioners.

**Fig. 4. A Four-Stage Model for Investigating Situation Awareness**

### *Stage I. Structure High-Level Activity*

The aim of this stage is to produce and validate high-level activity structure diagram(s) (Fig. 3). The diagrams can then be used as a framework for categorising the initial data collected through, in our case, interviews and questionnaires with domain experts.

### *Stage II. Identify Interaction Breakdowns*

In this stage initial problem actions and operations resulting from interaction breakdowns are identified. Subject-Computer-Object mediation breakdowns can be identified and categorised using the Activity-Based Awareness model of SA and applying the principles of AT to direct the observation.

### *Stage III. Analyse Breakdowns using AT Principles*

The aim of this stage is to analyse and describe the observed in-use mediation breakdowns using the Activity-Based Awareness model of SA and applying the AT principles as a guiding framework.

### *Stage IV. Interpret Results and Suggest Safe Design Solutions*

In this final stage, the findings from the preceding stages are interpreted from an AT perspective (drawing on the AT principles). An understanding of the situated interaction breakdowns and their associated hazards will lead to informed re-design solutions which can be justified from a system safety perspective.

Generally, an AT approach to interaction analysis can be useful to HCI researchers in a number of ways:

Development through System Use. Modern interactive systems can provide users with a means of adapting the interface to suit their individual preferences. Paradoxically, studies have shown that many users do not take advantage of these adaptation facilities. Kaptelinin (1996) argues that the cognitive approach does not provide a way of solving this problem. AT however distinguishes between the status of a particular process using the AT hierarchy of activity principle as described in Table 1. An understanding of the level of a process within this hierarchy can help the researcher to anticipate the direction of developmental changes. If the change relates to an automatic operation then the associated problems may be technical ones that relate to the conditions for interaction. If safety is an issue, hazardous interactions may be identified using the process outlined in this paper and design solution can be proposed that anticipate developmental changes that may occur with system use.

The Social Context of Activity. With the exception of new cognitive approaches such as Distributed Cognition (Hutchins 1995) most cognitive approaches have been developed specifically to deal with the individual as the unit of analysis. Although AT initially dealt with the individual (Leontiev 1978) it has since been extended, most notably by Engestrom (1987), to encompass the social context of activity to include the subject, object and community as depicted in Fig. 1. The approach used in this paper would be useful to researchers trying to bridge the conceptual gap between traditional HCI approaches and Computer Supported Cooperative Work (CSCW) issues.

## 6. CONCLUSIONS

This paper has made a case for the potential of Activity Theory (AT) as a effective research method for the analysis of activity-based awareness that can inform the design of a particular type of technology-mediated work – that involving the use of safety-related systems. We have explained the role of AT for analysing work within this context, have examined the role of Situation Awareness (SA) within the argument and we have suggested that AT may be particularly useful for exploring situational hazards in safety-related systems use and subsequently informing the design of safety-related systems that rely on high levels of SA.

We have presented aspects of a field-study of a military air defence system and indicated how an AT-based analysis of computer-mediated activity was undertaken to inform our understanding of activity-based awareness. The initial findings of the UKADGE system study have already directed us to specify SA as a critical design parameter for the replacement interface. The safety requirements for the replacement system now specify that the replacement system must balance the requirements of both SA and usability in the design of interfaces and interactions. The study is on-going and our initial experiences lead us to believe that AT has the potential for further contribution to the design of the UKADGE system and interactive systems in general.

The aim of this paper, however, has not been to provide a detailed field-study with specific findings; rather we have been concerned with making a contribution to the methodological debate surrounding AT and its applicability to studies of technology-mediated work. The nature of the work with which we have been concerned – interactions between a safety-related interactive system, its users and the environment in which they are situated – lends itself to activity analysis and we have been able to use AT to identify and argue the relevance of SA as a critical design parameter for the system. This also led us to draw together AT and SA to provide an Activity-Based Awareness model which we have used as an analytical tool to help make sense of the awareness that a user has, and develops, of their work situation.

Using AT as a guiding framework alongside the model led us to rationalise a four-stage investigative approach for use in studies on mediation breakdowns in safety-related systems. We are applying this in on-going empirical work and see it as a example of how methodological constructs can be developed from an integration of AT and domain or context specific constructs, in our case SA. We feel that criticism of AT as too abstract a framework to support the investigation of work can be countered by its potential value when integrated with existing context specific constructs. We do not however argue for the superiority of AT and we recognise that other, equally important, methods within HCI with dissimilar perspectives are also likely to be useful when the focus of investigation is different. Taking a less dogmatic stance than has been prevalent in HCI studies may lead us to choose methods and constructs based on a more pluralistic view where pragmatism drives our choice of method and provides multiple viewpoints.

In future work we will also look at AT in different contexts for example non-safety related systems where SA may still be an important construct. Any real-time application where the updating of the user’s awareness of the situation through the integration of environmental information is a context where the approach might be useful in analysing the system and making recommendations for its re-design.

Application areas which particularly interest us include share dealing and commodity trading.

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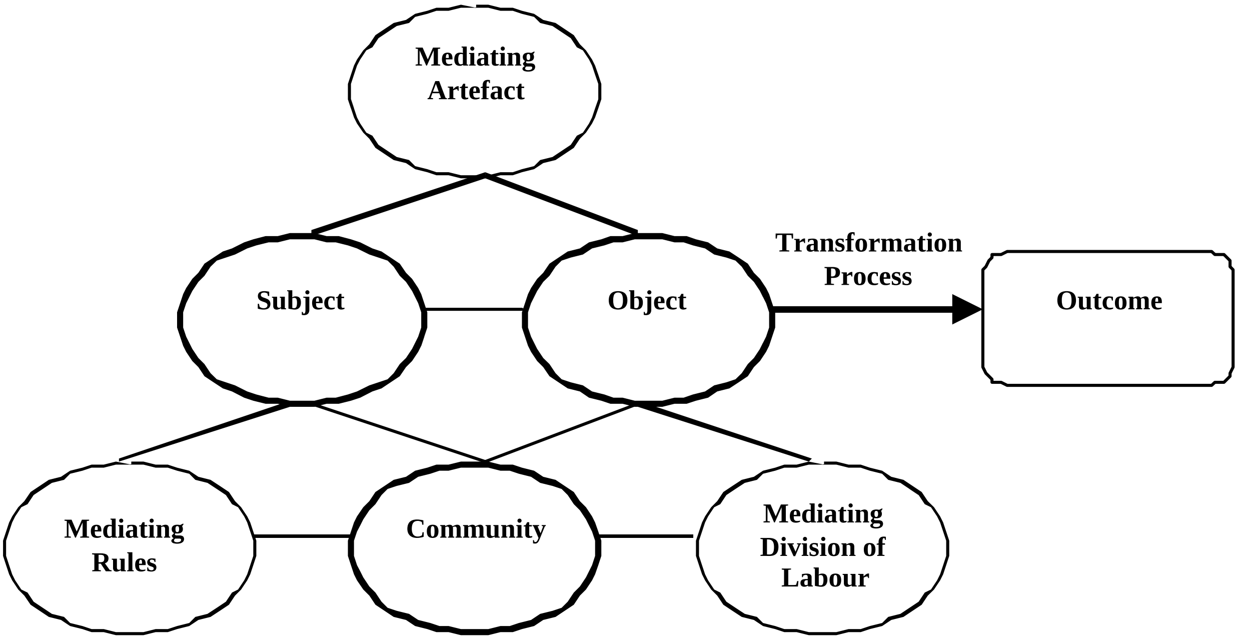

**Fig. 1. Structure of Activity (adapted from Engeström 1987)**

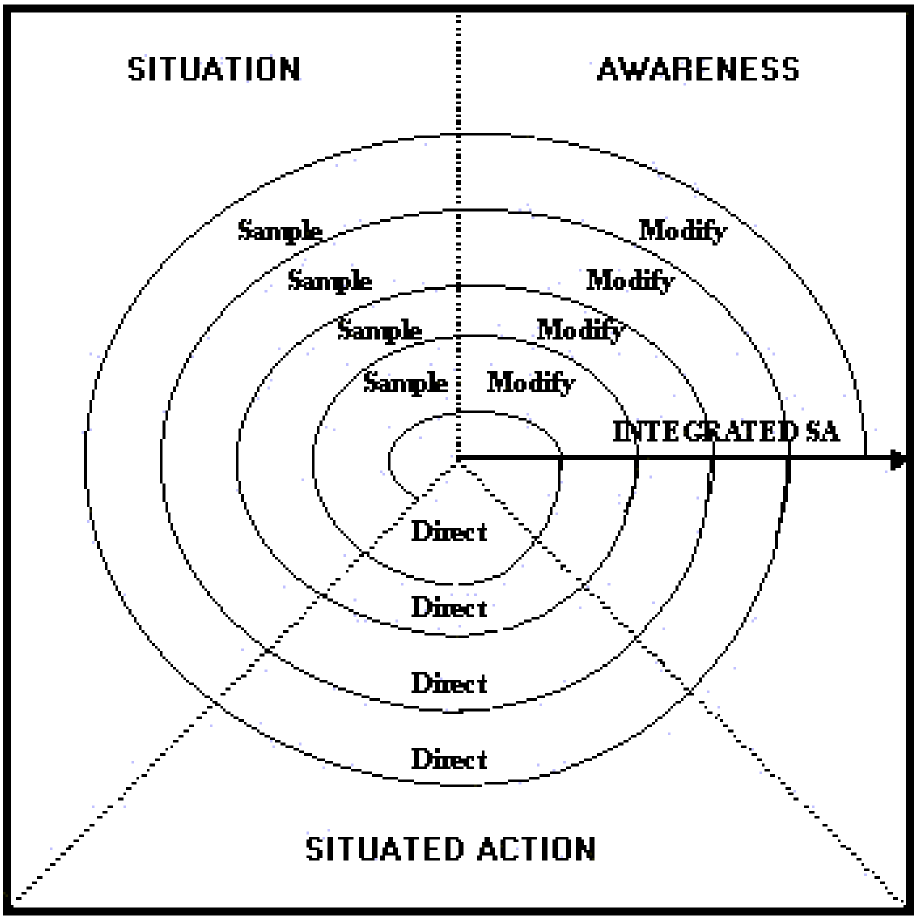

**Fig. 2. Activity-Based Awareness Model (adapted from Neisser 1976)**

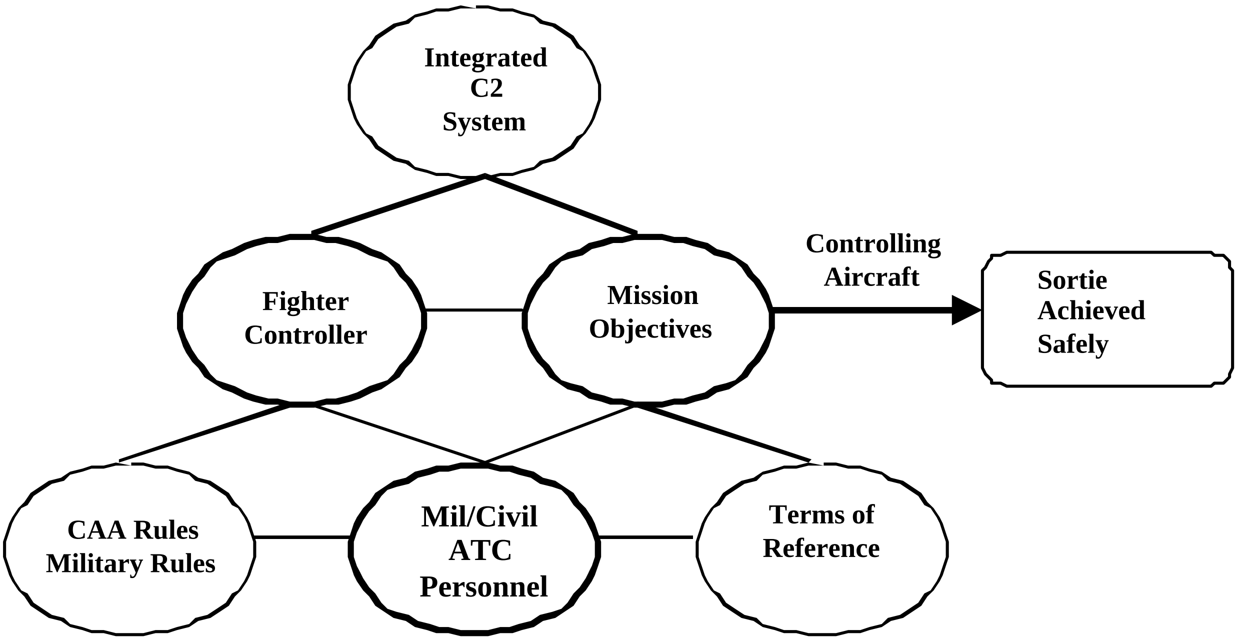

**Fig. 3. Air Defence Activity Structure**

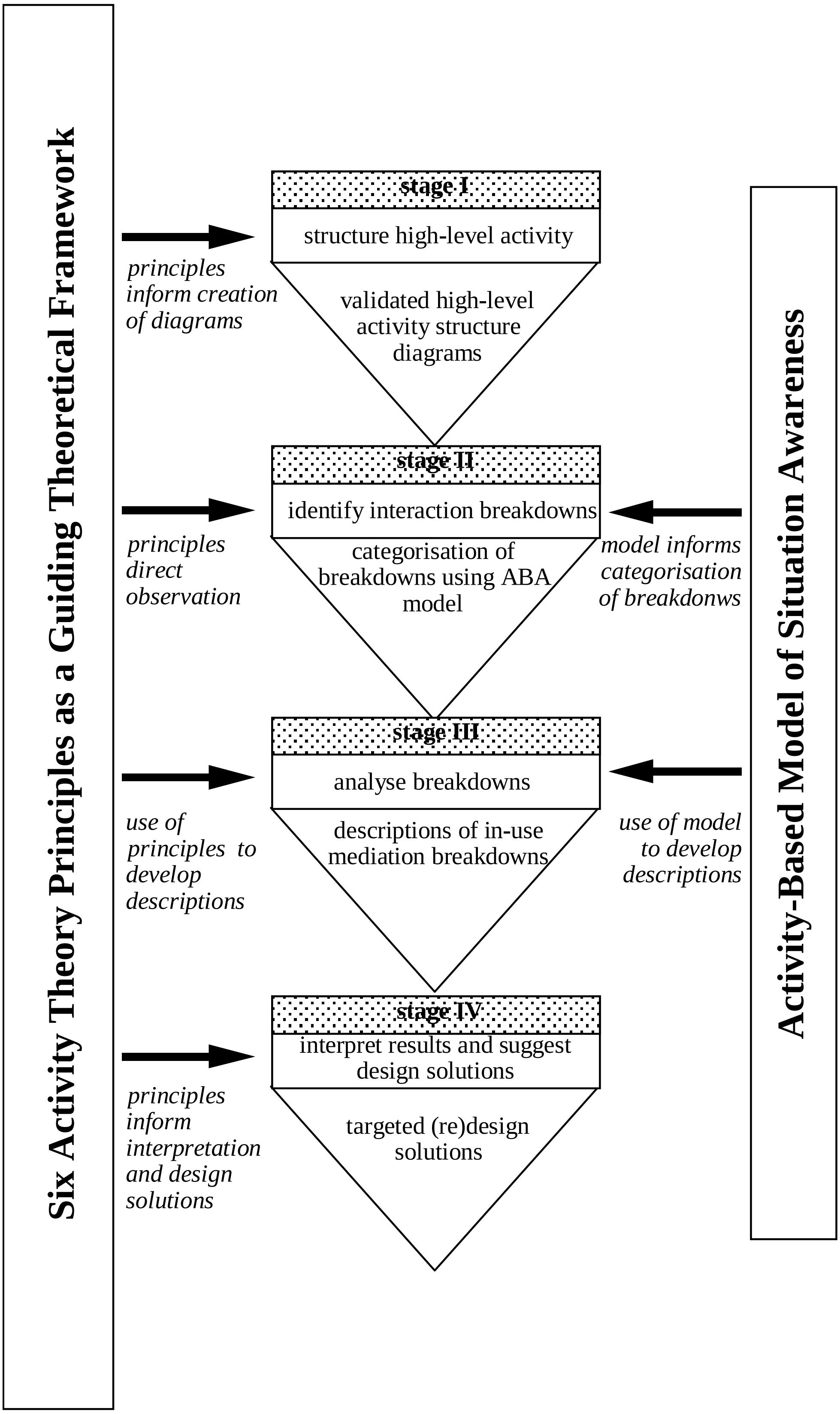

**Fig. 4. The Four-Stage Model for Investigating Situation Awareness**