AN APPLICATION OF THE 5-S ACTIVITY THEORETIC REQUIREMENTS METHOD

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Abstract: Requirements analysis in highly interactive systems necessarily involves eliciting and analysing informal and complex stakeholder utterances. We investigate if Activity Theory may provide a useful basis for a new method. Preliminary results indicate that Activity Theory may cope well with problems of this kind, and may indeed offer some improvements.

1 INTRODUCTION

One of the most crucial aspects of highly interactive, multi-user, organisational systems is the interface. The Human Computer Interaction (HCI) community has not adopted rigorous Formal Methods with open arms (Paterno, 1996). However, the HCI community has widely adopted Usability Engineering approaches (Corporate Solutions 2006), such as Nielsen's (1994), which offers considerable formality. There remains, however, scope for user interface (UI) design to adopt a theoretical framework to enhance consistency across the whole design and development lifecycle.

A theoretically-consistent framework from initial conceptual elicitation to evaluation of the finished product may prove useful. Since the aim of UI design is to produce interfaces that assist users to carry out their day-to-day activities, particularly in an organisational setting, a psychological and sociological theory could be a serious candidate for the informing theoretical framework. We suggest that Activity Theory (AT) would be a useful framework and could serve as the basis for an end-to-end system analysis and design method for highly interactive, multi-user systems. In this paper, we present an AT-based analysis and design method (called the 5-S Method) and a preliminary test example, used to test the method and explore the suitability of AT.

2 SCOPE

This research focuses on highly interactive systems (Brown, 2005) where the UI itself underpins a large proportion of the system's functionality. AT is an appropriate theoretical framework for highly interactive systems for three reasons: 1) it is focussed on understanding real life activities, 2) in its classic formulation it provides a method of task decomposition and 3) in its latest versions it has been used to describe networks of inter-related activities. Because AT provides a mechanism for describing networks of goal-directed human activity, it could be useful in understanding those systems that have many users, with multiple roles, whose activities are highly interrelated e.g. most organisational information systems.

Table 1: An Extended Activity Theory Taxonomy.

AT layer	Doing	Facilitator	Driver	Product	Protagonist
4	Activity Network	System	Agenda	Process	Group
3	Activity	Tool/ScreenSet	Motive/Object	Outcome	Subject
2	Action	~ Screen	Goal	Transaction	Actor
1	Operation	Switch	Condition	Change	Operator

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So the scope of our research is to develop an AT-based analysis and design method specifically for highly interactive, multi-user, information systems.
The concept of an Activity Network and the task decomposition inherent in AT i.e. Activity > Action > Operation, allows the proposed method to focus on many different levels of the interaction process. At the higher levels i.e. Activity Network and individual Activities, the method would support more experienced designers who could draw on their own experience to provide solutions to lower level design issues. At the lower levels i.e. Action and Operation, the method would guide neophyte analysts and designers, even to the selection of suitable widgets. So, while our method is at times highly prescriptive, it is also intrinsically flexible, allowing analysts and designers to select those parts of the method which are appropriate to their level of expertise.

3 ADAPTING AT

AT identifies an Activity as the smallest meaningful task carried out by a human subject. Vygotsky states that all human Activity is carried out by a Subject, using physical or psychological Tools to achieve some Object which may result in a physical Outcome (Vygotsky, 1978).
Engström (1987) expanded the conception to include a social context. Figure 1 shows the seven node Engström matrix.
To adapt AT to a system design role, it is necessary to shift focus to the facilitating Tool(s) of an Activity, as these Tools include the computer system to be specified. Ultimately, the analyst is seeking to identify and describe some common set of Tools, at least part of which resides in the Tool node of each member Activity in the Activity network, thus describing a useful computer system.

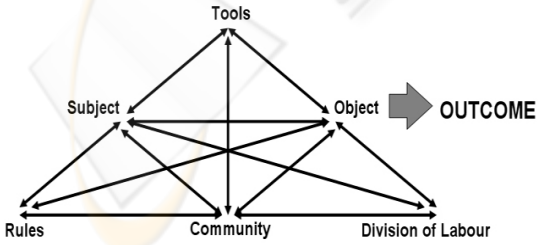

Figure 1: Engström's Activity Matrix (Engström, 1987).

Leont'ev (1978) proposed a three layer hierarchic structure: Activity, Action and Operation to represent different levels of intellectual "engagement" of the Subject, with an Activity requiring deep engagement while an Operation is virtually autonomic. Kuutti (1991) included a fourth and topmost abstraction: the Activity Network, being that related cluster of Activities that are carried out by a community of Subjects working on some common task or process.
As described (Brown, 2006), we have extended the AT taxonomy to avoid confusion between the four layers. This extended taxonomy is shown in Table 1.
English lacks a common collective noun for the abstract notion of 'verb', so we employ an atypical definition of 'Doing' in the singular (OED). The collective terms 'Facilitator', 'Driver', 'Product' and 'Protagonist' were adopted for other AT aspects.

4 AN AT ANALYSIS AND DESIGN METHOD

The 5-S method elicits and decomposes stakeholder utterances, in accordance with AT principles. Starting at layer 4, the Activity Network is identified, layer 3 then identifies Activities. Layer 2 identifies Goal driven Actions and layer 1 atomic Operations. Conditions which drive Operations are then mapped to Switches, a term we employ generically for UI elements. These are recomposed and grouped into the following UI structures:

1. System: The computer tool(s) which best facilitate the Network of Activities.
2. Station: Activities grouped according to Roles within the stakeholder organisation.
3. ScreenSet: Groups of Screens associated
4. Screen: Interface groupings of Switches closely related to Actions within the Activity.
5. Switch: Unitary elements of the UI.

Careful analysis of the requirements gathered at each layer should permit recomposition of the Facilitators at each layer until ultimately a System (the most abstract Facilitator) is described. The description of the System would, for all practical purposes, form a feasible, defensible and consistent Requirements Specification.
As Figure 2 shows, the 5-S workflow passes downwards through the AT layers from abstract to refined, before passing back up through the layers in recomposition. The boundaries of the seven phases are porous in both dimensions.
Horizontally, there are links between the decompositional analyses at any given layer and the

guidance they give to the recomposition in the upwards pass. Vertically, each of the phases tends to confirm the results of the previous, and yield candidate solutions to the next.
Starting at the most abstract fourth layer, 5-S elicits clues from stakeholders to the Activities. This requires some degree of iterative consultation akin to Business Process Modelling, which serves to confirm and amalgamate the Stakeholders' consensus view of the process in hand.
Further details of AT and the informing principles of our method have been presented elsewhere (Brown, 2006).

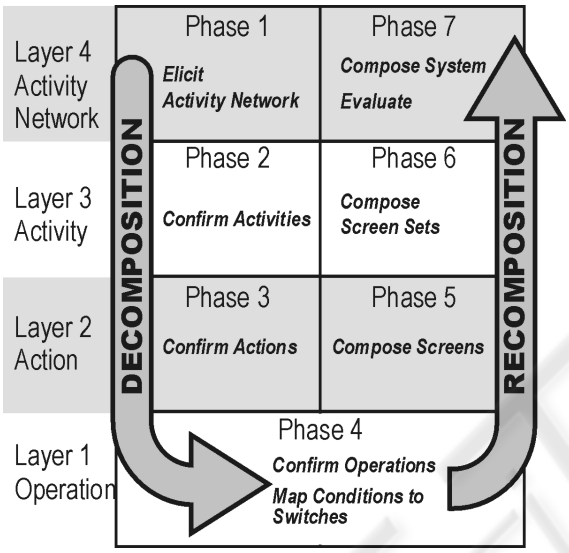

Figure 2: The 5-S Workflow Concept.

5 TEST EXAMPLE

To facilitate easy access to genuine stakeholders and a general familiarity with the Group, Process and Agenda (Table 1), a routine academic process was chosen for the test example, namely: "Academic Administers an Assessment Task".
This matched the scoping of the project and could be designed and built by neophytes using common graphical user interface (GUI) elements.
This Process involved Academics who each direct one or more Tutors. Academics design assessment tasks for Students to complete. The Tutor(s) may distribute, collect and mark them. The Academic must collate and centrally register the results.
To investigate the methods ability to cope with different interpretations of Process, two different Academics were interviewed, together with Students and Tutors of each.

6 PRELIMINARY RESULTS

To explore the suitability of AT in Requirements Analysis, we have run the method as it exists against the test example described above. We present below an indicative selection of preliminary results in the early phases of the method.

6.1 Phase 1 – Activity Network

An Activity Network is a related set of Activities which contains and describes the hierarchic component Doings of a Group Process.
We are interested in the requirements for a System that best Facilitates the Group Process. This System comprises computer based Tools which Facilitate and in some instances Automate the Group Doings. To this end, we are interested in those Activities whose Tools could include some element of the System. The user interfaces of the included computer based Tool(s) define a boundary surface for the conceptual space where the System resides. Activities whose Tool nodes do not connect to this surface are not considered.
During initial elicitation, this System does not yet exist and iterative consultation with the stakeholders is advised prior to automating or altering any Doing. These early phases comprise a Business Process Modelling (BPM) exercise. Interestingly, Martins and Daltrini (Martins 1999) have observed that AT precepts are compatible with Yu's i* BPM method.

Table 2: Phase 1 Elicitation Questions.

1	What is the purpose of the Process? (Agenda – layer 4)
2	Who is involved in this Group? (Subjects – layer 3)
3	What classes/roles of people are involved? (Roles – layer 4)
4	What does this Group do? (Process – layer 4)
5	What do each of these people/classes/roles intend to achieve? (Object – layer 3)
6	What do each of these people/ classes/ roles produce? What is their result? (Outcome – layer 3)
7	Why do each of these people/classes/roles carry out their Activity? (Motive – layer 3)

As the scope of the System remains unknown, in the early Phases of the method, heuristics are required by which to accept or reject Activities from the

Activity Network and its Process before the System can be described.

In this informal analysis, commonalities of several forms between Activities are identified. Generally these are neither necessary nor sufficient conditions. Commonalities we specifically examine include:

People: A Subject in one Activity may be the same person as the Subject in another. A Subject of one Activity may be a Community member of another. It is also important to understand Roles played by individuals, subsets of whom have a part-whole relation with the Subjects of identified Activities.

Motive/Object: if several people express the same Motivation or Object, then they are likely to be Subject members of the one Activity. If these are consistent with a group Agenda and contribute to some group Process, then membership of the Activity network may be strongly indicated.

Outcome: The outcome of one Activity may become a Tool or Rule of another. One Activity may determine the Subject of another (Vrazalic, 2004).

We conduct elicitation of these informal diagnostic characteristics using Phase 1 questions shown in Table 2. Actual interviews are somewhat flexible of course, and these questions serve more as a guideline than as any kind of script. Collection and analysis of these Phase 1 indicators necessarily generates a list of strong candidate Activities, to be confirmed in Phase 2.

Our preliminary results include:

Agenda: Students must demonstrate their learning and skills by completing indicative assessment tasks to a measurable standard without cheating.

Subjects: S1 Academic; S2 Student(s); and S3 Tutor(s). If Subjects are in a part-whole relationship (eg: some differences between an Activity conducted by a single Tutor, or by the Group of Tutors), there are three likely consequences:

Firstly, if the Doing of the Subject subset can be conducted in the absence of the rest of the Subject group, then the Actions within the Activity must be designed to allow for some or all or the Subject(s) to conduct the Doings individually as required.

Secondly, If the Doing of the subset must be conducted in the absence of the rest of the Subject group, then the Activity needs to be split into two or more, one in which the Activity is conducted by the entire Subject group, other(s) conducted by some subset of the group.

Or finally, it may be necessary to create an entirely new Subject, consisting of some part-whole subset of the previous Subject group (and possibly others), essentially a new Role, for this Activity and/or related Activities.

Roles: Subject Co-Ordinator, the highest appeal, records grades etc; Expert Authority, who set assessment, define questions, define answers; Head Tutor, a possible liaison between lower grade tutors and the Academic; Normal Tutor, who distributes, collects, possibly marks and reports; Low-Grade Tutor, who only distributes and collects, no marking; and Student, who must complete assessment on time, without cheating.

Table 3: Candidate Academic Activities.

Subject 1A (S1A) = Academic A	
S1A.01	Create assessment questions
S1A.02	Post assessment questions to FTP site
S1A.03	Post assessment questions and marking guide to Tutors
S1A.04	Field clarifications from Tutors and Students
S1A.05	Pre-process combined answers from all submitting students
S1A.06	Facilitate negotiation of marking scheme with Tutors
S1A.07	Conflate all marks from Tutor(s) to a Spreadsheet
S1A.08	Anonymize Spreadsheet to PDF document
S1A.09	Upload PDF to FTP site
S1A.10	Field student appeals and complaints
S1A.11	Transfer Spreadsheet totals to new Spreadsheet for personal archiving
S1A.12	End of semester processing of totals to Campus Administration system.
Subject 1B (S1B) = Academic B	
S1B.01	Create assessment questions
S1B.02	Create marking guide
S1B.03	Distribute assessment questions and marking guide to Tutor(s)
S1B.04	Distribute hardcopies of Assessment questions to Students in lecture class
S1B.05	Field clarifications from Tutor(s) and Students
S1B.06	Conflate marks from Tutor(s) to personal archive Spreadsheet
S1B.07	Upload marks to central Website
S1B.08	Field Student appeals and complaints
S1B.09	End of semester processing of totals to Campus Administration system.

Identification of people, motives and outcomes informed the choice of individuals to be interviewed. Interviews with Academics A and B, and some Students and Tutors of each produced candidate Activities. Different individuals expressed different personal interpretations of the process, which

resulted in multiple sets of responses. Table 3 shows the candidate Activities elicited from the Academics. The System is being designed to facilitate the Group Process and so iterative elicitation of stakeholders is required to reduce these two sets to a single consistent list of Activities. This occurs in Phase 2.
Except in so far as their effects are reflected in the Division of Labour, description of Roles plays no direct part in AT, and as such the term does not appear in our extended AT taxonomy. Whilst in this example eliciting Roles proved necessary for a consistent Activity list, it may not always be necessary to elicit Roles simply to move on to Phase 2. We anticipate however, that a clear mapping of the coincidence of Roles in Subjects will prove necessary for recomposition into System Requirements in Phase 7. Further, there may be times during decomposition of Group Doings that an analyst is tempted to restructure the Group Process by collapsing or conflating Doings. Consideration of Roles however should reveal that some near-equivalent and seemingly repetitive or redundant Doings probably must be retained for reasons of the Agenda and the Group's cultural-historical structure.

6.2 Phase 2 – Activities

The primary unit of analysis in AT is the Activity itself, usually visualised as the seven node Engström matrix (Figure 1). For our purposes we specify what each node contains for a systems design context.
SUBJ: the Subject is the group or individual who conducts a particular Activity. An individual can be the Subject of any number of Activities, which indicates that individuals' unique organisational Role.

Table 4: Academic Activities.

Subject 1 (S1) = Academic(s)	
S1.01	Create assessment questions
S1.02	Create marking guide
S1.03	Make assessment questions available to Students
S1.04	Distribute assessment questions and marking guide to Tutor(s)
S1.05	Field clarifications from Tutors (S3) and Students (S2)
S1.06	Conflate all marks to a personal archive Spreadsheet
S1.07	Advise Students of marks
S1.08	Field Student appeals and complaints
S1.09	Semester processing of totals to Campus Administration system.

COMM: the Community comprises all other parties involved in transactions associated with the Activity. Subjects of one Activity are often Community members of another, as the Network of Activities at layer four indicates that the Activities are related, if only by use of some common Tool.

Table 5: Student Activities.

Subject 2 (S2) = Student (s)	
S2.01	Get assessment questions
S2.02	Submit assessment answers and validate submission
S2.03	Check marks
S2.04	Appeal results

Identification of the Community indicates how the UI elements of the System need to be grouped, such that all parties have the appropriate capability to interact and conduct their normal transactions.
TOOL: the Tool(s) comprise all physical, virtual and psychological facilitating mechanisms used by the Subject and or Community members. Tools include not just sophisticated artefacts and softwares, but also seemingly mundane facilitators such as clocks, telephones, notepads and personal conversation. The analyst must consider all Tools, as the final System may subsume, imitate or compliment any number of them.
RULE: the Rules node for our purposes contains primarily Temporal constraints, including ordinal ranking of Actions where appropriate.
DivLAB: the Division of Labour for our purposes contains primarily Deontic constraints. Issues of obligation, permission, denial and the like, indicate 'who does what'.
OBJ: the Object is crucial analytical node for classical AT, but for our purposes may be conflated with the driving Motive. It effectively contains that which the Activity hopes to achieve.
The identification of Objects in early phases of elicitation serves as strong indicators that Activities have been identified. Ultimately, Activities are defined and differentiated by these Motives.
OUT: The Outcome node contains that which actually results from the Activity. Classical AT pays strong attention to the tension between Object and Outcome. For our purposes the Outcome can contain interesting linkages. As observed by Kuutti (Kuutti, 1991), the outcome of one Activity may appear in any node of another: in RULE as a Temporal constraint, in DivLAB as a Deontic constraint, in TOOL as some process, device or document, in SUBJ or COMM as some individual whose Role has changed or most interestingly, in OBJ as a new

motive which thus can instantiate a whole new Activity.
In our test example we elicited different candidate Activities from two Academics, their Tutors and Students.
Since the Role(s) played by different members of S1 are equivalent, we assume that there should be a consistent common set of S1 Activities. We returned to the individuals and produced a consensus Activity set which is shown in Table 4. Achieving consensual agreement is not a deterministic process however, though by following AT principles it was possible to facilitate negotiations by presenting all options within a common framework.
Some Activities have been subsumed into others, for example S1A.06 "facilitate negotiation of marking scheme with tutors" becomes simply one means of achieving S1.02 "create marking guide". Other Activities may have been relegated to the Action layer.
Should it prove impossible to produce a consensus Activity set, then perhaps there has been some confusion regarding Roles. The Activity Network needs re-examination and perhaps a new category of Subject(s) is required. Thus, following AT principles prompts and facilitates resolution whenever analysis fails to capture the Group Process properly.
By a similar process a consensus Activity set was produced for the Students and Tutors. We present the Student Activities in Table 5.

Table 6: Node Entries for Activity S2.01. "Get assessment questions"

SUBJ	Student enrolled in correct course
COMM	Academic &/or Tutor of that course
OBJ	Obtain a correct and complete version of the assessment questions
RULE	• Assessment questions only become available after notification. • There may be a deadline after which the questions become unavailable
DivLAB	• Only a Student enrolled in that course should be able to obtain the assessment questions • The Academic or Tutor must provide notification on time • The Academic or Tutor must provide a correct and complete version
TOOL	• Some means of receiving notification • Network account and/or ID card • Networked access
OUT-COME	Student now has a TOOL and the RULE and DivLAB details for Activity S2.02

Each Activity can be represented on an Engström matrix. We tabulated the Activity details, and details of the sample Activity S2.01 "get assessment questions" is presented below in Table 6. Observe that until the System has been designed, the TOOL node can only reflect currently used or speculative Tools.
The OUTCOME reflects that this Activity is linked to another in the Activity Network. Whilst not shown here, DivLAB constraints in Activity S1.01 "academic creates assessment questions" required that the assessment contain correct instructions and deadline information for the Students. According to AT, the actual Outcome may be quite unexpected and final deployment of the System may produce variance.

6.3 Phase 3 – Actions

Actions are Goal driven Doings, subsidiary to Activities. The Actions comprising any one Activity should all serve the Motive of that Activity, just as Activities of one Subject must fulfil that Subjects Role.
Examining Activity S2.01 'get assessment questions' we identified Goal driven component Actions. These are identified in Table 7.

Table 7: Actions for Activity S2.01. "Get assessment questions"

Subject 2 (S2) = Student (s)	
S2.01.01	get notification of assessment questions availability
S2.01.02	get assessment questions
S2.01.03	get supporting materials

Observe that Action S2.01.02 'get assessment questions' has the same name as the parent Activity S2.01. Despite appearances, this is not an inconsistency, as AT tracks the protagonists cognitive involvement. Actions are of a lower order than their parent Activity. The analyst must however, be careful in situations of this kind and keep the nomenclature convention in mind. Wherever possible, it is better to describe Activities by their Motives, and Actions by their Goals.

6.4 Phase 4 – Operations

As Phase 4 marks the turnaround from decomposition to recomposition it attempts to specify a Switch of the proposed System for each Operation that involves the System.

Utterances from Students of Academics A and B, indicated different Conditional Operations, shown in Table 8. One set follows a manual process, the other an online process.

Some confusion arose in negotiating common Operations. The utterances "I go to the right lecture class" and "I go to a networked computer" initially seemed to equate. Asking 'why' questions, revealed otherwise. Going to the correct lecture class in fact functionally equates with going to the correct course sub directory after logging on to the network.

Table 8: Candidate Operations for Action S2.01.02. "get assessment questions"

Subject 2A (S2A) = Student of Academic A	
S2A.01.02.01	go to networked computer
S2A.01.02.02	logon to FTP network
S2A.01.02.03	go to appropriate sub directory for the correct course
S2A.01.02.04	go to the appropriate sub directory for the correct assessment task
S2A.01.02.05	download, copy or print out the assessment questions
S2A.01.02.06	check assessment question document for completeness and correctness
S2A.01.02.07	logoff
Subject 2B (S2B) = Student of Academic B	
S2B.01.02.01	go to correct lecture theatre
S2B.01.02.02	collect assessment questions
S2B.01.02.03	check assessment question document for completeness and correctness
S2B.01.02.04	ask clarifying questions regarding the assessment questions and/or the constraints they impose
S2B.01.02.05	leave the lecture class

While some Operations are subsumed, dropped or added, others were outside the scope of the System. Operation S2.01.01 had no initial equivalent for S2B however, Academic B decided that it was a useful feature, and agreed to impose this Condition. Operation S2B.01.02.04 was removed and migrated to Activity S2.04, now expanded and associated with all Student-to-Academic/Tutor communications. Common Operations are shown in Table 9.

Even after the System is deployed, not all Doings will invoke its use. Numerous technical, psychological and mechanical Tools are available. By our definition however, at least some Doings of each member Activity will invoke the System. Our aim is to capture and describe these as System Requirements.

Table 9: Operations for Action S2.01.02. "get assessment questions"

Subject 2 (S2) = Student (s)	
S2.01.02.01	establish identity
S2.01.02.02	select correct course
S2.01.02.03	select correct assessment
S2.01.02.04	download/Copy/Print assessment
S2.01.02.05	verify assessment
S2.01.02.06	leave

Table 10 shows Phase 4 identified Conditions and maps them to UI widget Switches. Operation S2.01.02.01 can be achieved by a System Logon Doing. For our purposes, complex multi-part GUI widgets such as a FileSave dialogue, are deemed atomic by their near universal adoption.

Operation S2.01.02.03 'select correct assessment' implies exclusive choice from a finite number of pre-set options. Accordingly a Radio Button panel or a Pull-Down Menu may be suitable.

Several standard Switches may be suitable and the choice would reflect the personal leanings of the analyst (and/or stakeholders). The analyst should be confident that the design would be functional, appropriate and feasible at least, if not necessarily elegant.

Table 10: Operations and Switches.

	Operation	**Switch**
S2.01.02.01	establish identity to the system	LOGON widget
S2.01.02.02	select correct course	Radio button **or** Drop down menu
S2.01.02.03	select correct assessment	Radio button **or** Drop down menu
S2.01.02.04	download, copy or print assessment questions	FileSave **and/or** Copy-Paste function **and/or** Print widgets
S2.01.02.05	verify correct assessment questions	Task switch to local system
S2.01.02.06	leave	LOGOFF widget

6.5 Later Phases - Recomposition

The Switches identified in Phase 4 will be composed into Screens in Phase 5. Screens and Actions are closely related but there might not be a 1:1 mapping. We do however expect that ScreenSets will have a 1:1 mapping to Activities.

Leont'ev (Leont'ev, 1978) predicts that familiarity and expertise leads to Doings dropping down the hierarchy. After some experience, we could able to

short-cut some of the more perfunctory mechanisms, as our own Actions became Operations. This interesting confirmation of AT also indicates that the method will ultimately serve both as a prescriptive toolset for the novice and an informing framework for experienced practitioners.

The analyst however, should collect data in decomposition that serve for the recomposition phases (see Figure 1). Roles help inform Phase 7; the Motives of Activities help compose ScreenSets in Phase 6. Temporal and Deontic constraints, recorded in the RULE and DivLAB nodes, indicate of how UI elements should best be collected, shared and sequenced to facilitate the Group Agenda.

7 CONCLUSIONS AND FUTURE WORK

Our method shows potential to be a systematic and prescribed process with a solid theoretical base. We believe it will elicit meaningful Requirements from stakeholder utterances without requiring the analyst to have a deep knowledge of Activity Theory.

Whilst mechanisms, heuristics and tools are still being refined, preliminary findings indicate that an AT based method can be an excellent match for complex multi user Doings. We are satisfied that AT can indeed underpin a design methodology for systems within our scope. There is indication that an end-to-end AT based method may have some advantages over some current tools and methods.

Method components for the recomposition phases and for final evaluation are beyond the scope of this paper, and will be demonstrated in future papers.

A normative evaluation study of the 5-S method for a real-world system design scenario will be conducted as soon as the method components have been fully described. The evaluation will appear in future publications.

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