MORPHOLOGICAL ANALYSIS OF HCI VIDEO DATA USING ACTIVITY THEORY

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1. ABSTRACT
This paper describes methods for the morphological analysis of HCI video data based on activity theory (AT). Morphological analysis involves the description of activity during task performance as a logically organized structure of discrete actions and operations. Techniques are outlined for the isolation and classification of actions and the development of algorithmic & time-structure descriptions of activity during computer-mediated task performance.

Keywords
HCI, video, morphological analysis, activity theory.

2. INTRODUCTION
Activity-theoretical approaches to human-computer interaction (HCI) and information technology (IT) design are concerned with the multidimensional analysis and design of computer artifacts in relation to the complex, historically developing, sociocultural and technical context of their actual or proposed use. Video analysis provides a valuable resource for these efforts. Skillfully used, video can capture sequential data showing both the broad context and fine detail of IT use. Supplemented by other observational methods, video provides a basis for the development of detailed descriptions of human work activity, allowing the repeated review of complex and fleeting events, giving researchers and designers the opportunity to check and amend previous interpretations in the light of new data or analytic insights [1, 2]. Bødker's seminal work on focus-shift analysis using video data [3] presented an approach to structuring video analysis in HCI research based on general activity theory (AT) [4]. This article presents a complementary approach to video data analysis, based on the systemic-structural theory of activity (SSTA). SSTA is a distinctive activity-theoretical approach specifically oriented toward the study and design of work and learning [5-7].

The techniques described in this paper have been developed in the context of a long-term participatory action research project which studies the collaborative use of information technologies by non-professional people from low-income, low education backgrounds [8-11]. The aim of this research is to identify IT-design factors that support or hinder the development of technological fluency among users from sociocultural backgrounds identified with the "digital divide". To date, the project has included four phases of fieldwork, carried out in the setting of an Adult Basic Education (ABE) center in the South Wales Valleys region of the UK. Illustrative examples in this paper are drawn from the first and second phases of fieldwork - a longitudinal study in 2000-2001, and a shorter study in 2002 - where adult literacy and numeracy learners were observed and video-recorded as they used IT in collaborative media projects.

3. SYSTEMIC-STRUCTURAL ACTIVITY ANALYSIS
In the systemic-structural theory of activity, human activity is understood as goal-oriented; multidimensional and structured; composed of discrete, hierarchically organized elements; and involving four general stages: goal formation, orientation, execution, and evaluation [12]. The structure of activity during task performance is a logically organized system of motor and mental actions. As activity unfolds, mechanisms of self-regulation allow subjects to continually adjust their goals and behavior strategies in response to changing conditions. Systemic-structural activity analysis involves comparing the structure of an activity and the physical and logical configuration of equipment involved in that activity. In activity-theoretical HCI, such comparative analyses provide a basis for application and interface design.

SSTA utilizes three general approaches to activity analysis: the parametrical, which focuses on studying various parameters of activity using techniques such as error analyses and cognitive (process) analyses; the morphological, which focuses on the description of the structure of activity during task performance as a series of discrete actions and operations; and the functional, which analyses activity using self-regulation models. All three approaches involve some or all of four recursively related stages: (1) qualitative description, (2) algorithmic analysis, (3) time structure analysis, and (4) quantitative (complexity) analysis. This paper outlines the application of stages 1, 2, and 3 of the morphological approach to the analysis of HCI video data. These stages are carried out after initial data capture, logging, archiving, and transcription are completed.

The fundamental object of study in SSTA is activity during task performance. A task is understood a sequence of goal-directed actions involving an initial situation (the problem presented before task performance begins), a transformational situation (actions taken to solve the problem), and a final situation (initial situation changed). Tasks are organized around a supervening goal, with the vector motive_goal determining the directedness of activity during task performance [13]. The structural elements of activity - *activity, task, action, operation, function block,* along with a composite unit called *member of algorithm* – provide the basic units of task analysis. Figure 1 shows the objects of study and units of analysis in systemic-structural activity analysis.

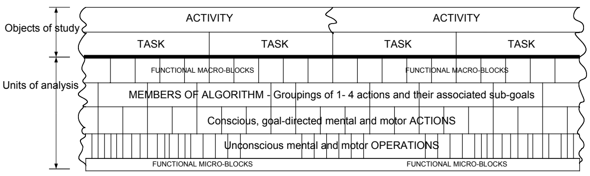

Figure 1. Objects of study and units of analysis in systemic-structural activity analysis.

4. ISOLATION & CLASSIFICATION OF ACTIONS

Video transcripts provide a basis for identifying the logical structure and temporal sequence of task and sub-task solution from the ongoing flow of activity. Tasks and sub-tasks are differentiated on the basis of their organizing goals. The formation or acceptance of a distinctive task-goal is taken as marking the inception of a task or sub-task; achievement or abandonment of a goal is taken to mark task completion. Identification of these junctures is achieved through close examination of the video footage, transcripts, and other data sources e.g. interviews, verbal protocols, etc. Once the tasks to be analyzed have been identified, morphological analysis of video data proceeds through (1) the isolation and classification of discrete actions, and (2) the generation of algorithmic descriptions of the logical structure of activity.

4.1 Action as a Unit of Analysis

An action is defined as a discrete element of activity that fulfills an intermediate, conscious goal of activity. The use of action as a basic unit of analysis supports the systematic description of the continual flow of activity during task performance, by dividing activity into individual units. Actions are temporal: the initiation of a conscious goal (goal acceptance or goal formulation) constitutes their starting point; they conclude when the actual result of action is evaluated in relation to the goal. Actions can be described in terms of a recursive loop structure, with multiple feed-forward and feedback interconnections. Figure 2 is a simplified model of action as a one-loop system.

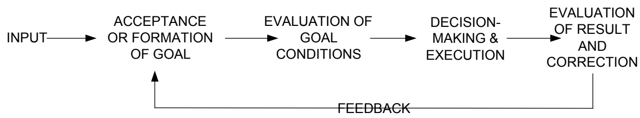

Figure 2. Action as a one-loop system.

4.2 Isolation of Actions

In order to isolate discrete actions from the flow of activity depicted by the video data, it is necessary to identify the goal, object, and tools involved in each action. The nature of an action is dependent on the interrelation of these components in any particular situation. A useful approach to isolating individual actions in a sequence of video-recorded task activity is to set out a basic sequential description of the technical steps involved. Figure 3 shows a fragment of one such description, of a Web authoring task recorded during the longitudinal study.

1. Launch or restore focus to Web browser (IE)
   a. If application already running move cursor onto window area and left click *or* move cursor onto taskbar icon and left click.
   b. If application not running, move cursor to application icon and left-click *or* move cursor to start button, left-click, navigate to appropriate menu, choose application icon or label and double left-click.
2. Load or refresh appropriate HTML document
   a. If document is already being displayed, move cursor to refresh icon (or select command from View pull-down menu) and left-click
   b. If document not displayed, load into browser by either selecting File>Open from pull-down menu, then typing file path or browsing to file location in Open dialogue box *or* use left mouse button and cursor to drag file icon from desktop or other location and drop on browser display pane by releasing mouse button
   c. In the display pane, move cursor to hyperlink being checked, left-click on link
3. View resulting display and assess

Figure 3. Extract from sequence of basic technological procedures in the task “Update Web Pages”.

Figure 4 illustrates the isolation and classification of actions involved in Step 2c of Figure 7, “in the display pane, move cursor to hyperlink being checked, left-click on link”. It can be seen that some actions involve several tools. Where tools are not defined (as in action 1) this indicates motor activity not involving external instruments – although AT always assumes that motor actions contain cognitive components – and may involve the use of "internal" psychological tools. Such tools can be assumed in action 2, which implicates not only the perception of signs visible on the interface but also the use of concepts and images to interpret them. In SSTA, the concept of tool is always tightly associated with the concept of action; outside of a specific task, it is not possible to precisely determine tools mediating a specific action.

Action	*Goal*	*Object*	*Tools*	*Type*
1	Reach & grasp mouse	mouse		Object-practical
2	Locate display pane	Interface	Graphical interface elements	Sign-practical/ Simultaneous - perceptual
3	Move cursor over hyperlink	cursor	mouse	Object-practical
4	Activate link	hyperlink	Cursor, left mouse button	Sign-practical

Figure 4. Example of action isolation & classification

4.3 Classification of Actions

A number of different approaches to the classification of actions have been developed in SSTA. Two were used in the studies reported here. The first differentiates types of cognitive, or mental actions based on two considerations: (a) the degree to which they require deliberate examination and analysis of the stimulus (direct connection with or transformation of the input); and (b) their dominating psychological process during performance: sensory, simultaneous perceptual, imaginative, mnemonic, etc. The second classification scheme is more generalized, categorizing actions according to the nature of their object, which may be either material or a sign or symbol, and according to their method of performance, either practical (motor) or mental. Table 1 provides examples of classification using both schemes. When required, standardized motor actions may also be identified and categorized, which can be helpful in determining the interrelation of mental and motor actions using time-structure analysis (see Figure 6).

4.4 Algorithmic & Time-structure Analyses

The identification and classification of actions during task performance provides a basis for developing models of the logical structure of activity, using symbolic representations known as human algorithms. These make use of a unit of analysis, *member of algorithm*, which is formed from clusters of 3-5 actions organized by a supervening goal. A completed algorithm consists of specialized notation accompanied by explanatory text. The symbols denote efferent and afferent mental and motor actions; the deterministic or probabilistic logical conditions that structure their relationships; and the various logical links between them. Explanations of the syntax and examples of algorithmic analysis can be found in [5, 7, 14, 15].

Member of algorithm	*Description of Members of Human Algorithm*
$\overset{7}{\downarrow}\overset{11(1)}{\downarrow}O^{\alpha}_{1}$	Identify appropriate Web browser window
$l_1\overset{1}{\uparrow}$	If correct Web browser window has focus go to O^{α}_{3}; if not go to O^{ε}_{2}.
O^{ε}_{2}	Bring browser window to foreground by moving cursor onto window area and left-clicking *or* moving cursor onto taskbar icon and left-clicking.
$\overset{1}{\downarrow}O^{\alpha}_{3}$	Check to see if correct Web page is displayed
$l_2\overset{2}{\uparrow}$	If appropriate Web page is displayed go to O^{ε}_{4} ; if not go to O^{ε}_{5}
O^{ε}_{4}	Refresh browser display by moving mouse cursor to refresh icon and left-clicking *or* selecting command from View pull-down menu and left-clicking
$\overset{2}{\downarrow}O^{\varepsilon}_{5}$	Open correct HTML document by either selecting File→Open from pull-down menu, and browsing to file location using Open dialogue box *or* use left mouse button and cursor to drag file icon from desktop or other location and drop on browser display pane by releasing mouse button
$\overset{4}{\downarrow}\overset{4}{\downarrow}O^{\alpha}_{6}$	Identify next hyperlink to be checked
O^{ε}_{7}	Activate link by moving mouse cursor to hyperlink being checked and left-clicking
$O^{\alpha\,th}_{8}$	Look at new page display in browser window and compare with expected result
$l_3\overset{3}{\uparrow}$	If browser display is appropriate go to O^{ε}_{9} ; if "The page cannot be displayed" HTML file is displayed *or* if link works but page inappropriate go to O^{ε}_{11}

Figure 5. Fragment of algorithmic description of activity during a Web authoring task.

Figure 5 shows a fragment from the algorithmic description of the Web authoring task depicted in Figs. 3 & 4. In this task, the subject used multiple applications (text editor, browser, file manager), each with different functionality and interface features. Construction of the algorithm helped to identify those points in the task where complexity was maximal, both highlighting sections of the video data requiring further analysis and raising other issues not readily apparent from the source data. In this case, algorithmic analysis led to the identification of conflicts between the various ways the applications in use handled windowing as major contributors to interaction breakdowns observed in this task.

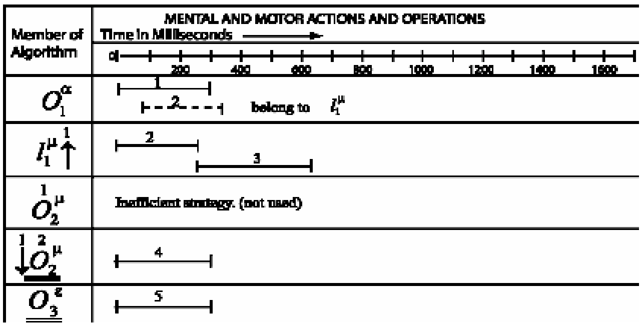

Figure 6. Fragment of time structure of computer graphics task. *From* Sengupta & Jeng [12].

Mapping the logical structure of task performance also makes it possible to describe the temporal structure of activity in terms of performed actions. Time measurements derived from the video data or independent measurements can be used to specify the duration of individual elements of activity. In time-structure analyses, attention is paid to the structure of sequential and simultaneous performance of mental and motor actions. Figure 6 shows a fragment of a time-structure developed in Sengupta & Jeng [16]. This method can be further extended through the use of standardized classifications of motor actions based on measured time and motion systems such as MTM-1 [see 6 pp. 252-262].

5. Conclusion

This paper has outlined activity theory-based design and evaluation methods involving the generation of structural descriptions of human work activity based on video data analysis. These methods provide a basis for the systematic examination of the interrelationship between the structure of work activity and the configuration of the material components of work. Their outcomes are an integrated set of descriptions, in textual, symbolic and diagrammatic forms, and at varying levels of detail, of the structure of activity during computer-mediated task performance. These descriptions support improved understanding of the relationship between the computer artifacts in use and users' actual and possible strategies of activity in the work process. The low-level descriptions produced by algorithmic and time-structure analyses are linked to broader sociocultural concerns through their recursive relationship to the qualitative stage of systemic-structural analysis which encompasses work-process, individual-psychological and cultural-historical forms of description. The embedding of these detailed, design-oriented methods in the multi-level framework of activity theory provides a basis for design interventions that take into account the wider cultural and historical contexts in which computer artifacts are used.

6. References

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