MEDINFO 2007
HISA Ltd Australia
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Conceptual Model as a Tool for Assessing Knowledge in Decision-Support Development

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Abstract

In the development of a decision-support system the domain knowledge as well as the target work environment need to be assessed in order to capture the knowledge to be integrated in and provided by the system. This work describes the model used for the assessment, which is based on Activity theory and case studies of patients investigated concerning suspected dementia. The purpose is to investigate to what extent the theory is useful for the assessment and for transforming the informal knowledge into formal descriptions for knowledge representation and design of interaction. The resulting structure provides the data and their sorts and qualities, the tools that are used in assessing the data, the actions of transforming the data and contextual factors such as who is responsible for a certain action. The semi-formal structure can be transformed into a formal structure for representation by using the structure to identify requirements for formalisation languages.

Keywords:

decision making, computer-assisted;
artificial intelligence; models, theoretical, logic

Introduction

The decision-support system COGITAMUS is being developed for assisting medical personnel in the investigation of suspected cases of dementia [1]. When focus is put on the clinical activity, issues such as the distinction between facts, judgements, qualities of evidence, what is normal vs. abnormal, levels of dysfunctions, distinction between acts of decision and acts of data collection, sources of evidence, etc, become essential to clarify in order to formalise the knowledge correctly. An analysis of the qualities of the medical domain knowledge expressed in clinical guidelines is needed [1] as well as a thorough activity analysis of how the actual clinical work is performed. This work presents the investigation of the informal structures in the use context such as decision making processes, clinical guidelines, patient's health, domain knowledge, actors involved, vocabulary and language, etc, and the process of transforming the informal knowledge into a formal structure useful in decision-support development. The main purpose is to investigate the use context of the system through a work analysis with the prototype system integrated, which can serve as a coarse system specification for further development and be used for future evaluations of the system in daily practice.

Tools are needed in the process to accomplish this transformation, which have the ability to capture both low level details about qualities of evidence and high level purposes and other ingredients of clinical activity. Important aspects are the dynamics of a changing and evolving work situation and individual patients' need when facing a degenerative disease such as dementia. While there are methods that can be used for assessing structures of tasks and data-flow, Activity theory provides in addition the dynamic perspective, means to define levels of skill and knowledge of actors and motives for activity [2]. These are important aspects when evaluating decision-support systems. We use the cultural-historical Activity theory as described by Engeström [3] as theoretical framework in the analysis of the clinical work situation, since the theory embraces the multi-purposes of a decision-support system. The theory evolved within Russian psychology in the 1930's [2] and has been extended since then, mainly within social sciences, CSCW and developmental work research [4, 3]. The theory however, is often considered too broad and general to be of use in concrete design or formalisation tasks when developing systems [3, 5]. Therefore, a second purpose of this work is to evaluate the theoretical framework in this perspective, and form a model based on the theory useful for assessing formal knowledge and for informing the design of the interaction with the system.

Materials and methods

The activity analysis is conducted as qualitative case studies of five patients in the setting of an out-patient ward at a geriatric clinic which investigates patient's cases with suspected cognitive diseases including dementia. The patient's encounters with a physician were observed during a period of investigation. The physician's use of the decision-support system was video-taped and interviews were conducted with the patient, relatives and medical personnel.

The data was analysed by categorising events by their purposes and what object was in focus, in terms of Activity theory. Themes were identified, and further categorisation evolved in the process. When a semi-formal structure was obtained, the patient's cases were re-analysed using this

structure in order to test the validity and usability of the structure. The structure was adjusted accordingly.

Results

We take as starting point, the view that the clinical activity of investigation essentially consists of two parts; the *clinical activity* with its actions and sub-processes, and an *activity system* in terms of Activity theory, which includes the object for activity, resources involved and their relations, and which imposes constraints on the execution of the investigation activity. A necessary property of the anticipated model is an ability to capture dynamic and changing situations and objects. We use the notion of *object* for data and phenomenon such as symptoms or diseases, when referring to what is in focus for each action.

The presented results include definitions of views on the investigation process, sorting of purposes of activity, definition of activity, and the relation between clinical actions, evidence and mediating tools.

Levels of activity

In the initial analysis of actions with different purposes as part of the main activity, three types of processes were identified. Two of these constitute *reasoning procedures* including medical decisions; the investigation of specific domains and the main reasoning process. Further, a distinction is made of the *logistic* or *administrative* process, which is imposed by the rules governing the whole process. The three types represent different views of the clinical investigation activity. The processes are executed in parallel, they are cross-fertilizing and dependent on each other, and are partly overlapping depending on circumstances in the environment. This dynamic view of the activity of investigating cognitive diseases will be used as a basis for the analyses in subsequent sections and they correspond roughly to the levels of activity defined by Activity theory.

Some of the sub-processes involved in the activity are viewed in Fig 1. The levels distinguished by lines in the figure indicate the different levels of complexity in the actions. As can be seen in the figure, the activities of analytic and decisive character are organised in the upper levels. The actions defined at this level are typically defined as necessary for the main activity to be executed, according to the clinical guidelines and the domain knowledge. However, the level of necessity can differ depending on which guideline is used as tool for reasoning.

The object-creating actions, which are typically automated processes (i.e. operations in terms of Activity theory) for the experienced actor, are organised at the bottom of the structure in Fig 1. They are automated in the sense that the actor does not have to put mental load or conscious thought on the execution, instead the actor can focus on the larger perspective and motive for the activity, of which the action constitutes a part. These actions are typically administration of tools, such as executing tests and examinations involving the patient. The actions defined at the lower levels in our analysis can be exchanged by other actions which produce equivalent information necessary for accomplishing the decisive actions. Typically, this is the case when the routines and priorities at different workplaces direct the usage of different tools in the process, for instance, which x-ray methods to use. Differences in which tools that are used can also be consequences of different habits and values hold by individual actors.

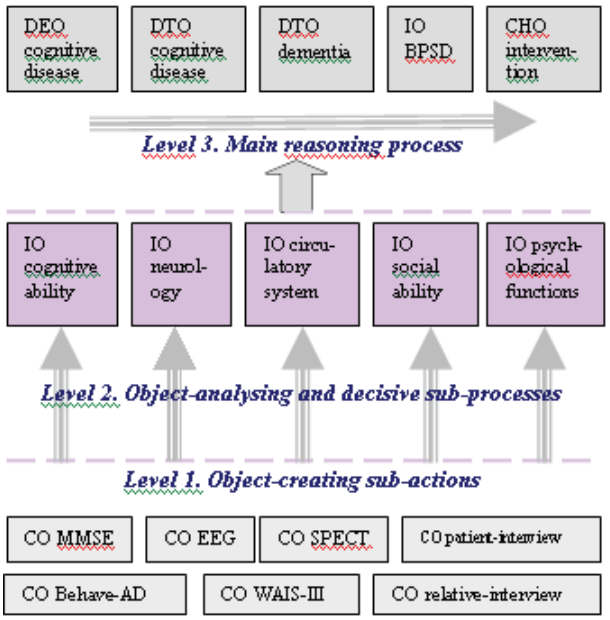

Figure 1 - Different levels of complexity in activities in the process of investigating cognitive diseases

The participation of patient and/or patient's family is necessary in the object-creating actions at the lowest level, however, not at the other levels. This gives suggestions on how a decision-support system should be designed and for what kind of clinical situations, depending on which kind of actions are to be supported. There may be less need of a support system in the clinical patient encounter situation for the experienced actor when the examinations for obtaining evidence are executed. However, at this level there are different clinically validated methods as well as ad-hoc methods that can be used. The less experienced actor can be supported in the choice of methods and in the execution of these sub-actions, as well as in the higher level actions of diagnostic reasoning.

A decision-support system should reflect the two-dimensionality of the reasoning process where one dimension can be seen as the gathering of data and interpreting the data into information, which is a process done with the general perspective of (healthy) function vs. dysfunction

(Level 2 in Fig 1). This process is orthogonal to the process of diagnostic reasoning and intervention, to which the information is fed as evidence in the reasoning towards diagnosis and appropriate choice of intervention. These two different purposes of actions are important to distinguish in the formalisation of the domain knowledge that is used in the transformation of information at the different levels. Basically, the first purpose is to value functionality per se and the second purpose is to value the function or dysfunction in the perspective of dementia diagnosis and intervention.

Sorts and typing of activity

When the investigation process as performed in the case studies was analysed, different sorts of actions were distinguished by the purpose, or the *goal* of a particular action (Table 2). Typically, the actions were aimed at either collecting raw data (CO); refining or interpreting raw data or knowledge (RO); using the interpreted data for higher level of reasoning for the purpose of determining the existence of a phenomenon (DEO); determining the type of a phenomenon, i.e., increasing the level of granularity in the knowledge (DTO); imposing changes to the phenomenon in focus, and valuing the effects thereof (CHO; ECHO). The actions of higher complexity which aim at a holistic assessment and change of a phenomenon we denote *investigation* actions (IO), which typically integrate all the other purposes. In addition, actions were identified which aim at controlling and directing the process (DA). Examples of such actions are referrals for examinations, involving colleagues for consultations, assignment of tasks to team-members and team-meetings. In Table 2 the sorts of actions are defined.

Table 1 – Sorts of action

Sort	Purpose	Examples of clinical procedures
CO	Create object	Laboratory tasks, executing clinical tests, interviews, etc
RO	Re-representation / refinement of object	Interpret test results, documentation
DEO	Determine the (amount of) existence of object	Value evidence, diagnosis
DTO	Determine the classification of object, increase granularity	Differential-diagnosis
CHO	Change of object	Interventions
ECHO	Evaluating results of change action	Follow-up
IO	Investigation of object	Include diagnosis, intervention, follow-up
DA	Direction of activity	Referral, delegation, consultation, team-work

IO corresponds to the level of *activity* in terms of Activity theory. The definition implies both assessment of information about the object and change of the object, thus, including the other types of actions. In the larger perspective of investigation of dementia, activities of sort IO can also constitute actions. The basic difference between the different levels of activity in terms of Activity theory is the definition of the purpose of the task, where activity has a *motive* and is driven by a need, while actions have a *goal*, which constitutes a sub-goal for the activity they are sub-actions to. Operations have no consciously defined goal on their own. We make no firm distinction between the levels other than distinguishing the main activity as an activity. Whether the operations are interesting to distinguish from actions depends on the perspective of analysis. An evaluation of an individuals' use of the system needs to integrate the distinction in order to capture a learning process. However, for the purpose of the general analysis in this work we take the notion of *action* as the basic entity for all tasks independent of level of activity.

Definition of activity

All types of actions are executed by the same kind of structure, the *activity system*, here represented by *Actor, Tool* and the context-related sort *Community* which includes roles, rules and division of work. Further, since the foci of all actions are related to issues concerning the patient, a patient ontology contributes with the *Object* and *Motive* to the definition of activity. Lastly, the components which describe the execution of an action are added, such as the sort, state, outcome and information about the hierarchical structure of actions. We use the same constructor for all sorts of actions, where *Goal* defines the sort of an action and the sets of actions (*Act, A*) can be used to identify the position of an action in the main activity. Further, the actor, set of communities and set of tools (*Actor, T, C*) define the physical and social context of the activity. The following constitutes a general definition of *Action*:

action: [Motive, Goal, Object, Act, A, T, Actor, C, State, Outcome] −> Action

where *action* is the constructor, *Motive* is the anticipated, needed change of the *Object* in focus, *Actor* is one or several subjects representing the social organisation responsible for the execution of the activity, and C is the set of related social organisations or persons (communities) involved, including the rules and division of labour governing the behaviour of its members. *State* can be one

of the following at a certain time point: {*Not initiated, Initiated, Paused, Aborted, Completed*}. *Outcome* is simply the changed object when the state of the action is completed. *Act* is the set of "parent-actions" the action is a part of, which in the case of a main activity is the empty set. Consequently, the only distinction between activity and action in terms of Activity theory becomes a structural issue of in what context a certain action is executed.

Capturing the object of activity

The object in focus for activity can be an abstract mental construct such as medical knowledge or a physical entity such as the human body and its parts. The purpose of focussing the object in an activity is to monitor, or change it, therefore each object has measurable or describable qualities which are used in the clinical activity. These qualities are preferably captured and valued by using validated tools, such as cognitive screening tests. Therefore, the information about which tool or tools that were used in the execution is essential, together with the outcome of the valuation. The constructor for the Object becomes:

Object: [Entity, V] –> Object

where Entity is the object in focus, and V is the set of different valuations based on the usage of different tools: V_i={$Tool_i$, Qualifier}. At this level of analysis tool can be seen as the sort for the measure. In our work analysis we use the sort *Subjective* in the case when no validated tool is available and used.

The object and its qualities is the current state of the object at a certain time point, for instance, when the action is initiated. The outcome of an action, i.e. the Object and its qualities when the action is completed, is defined as the *Evidence*, which is used in subsequent clinical reasoning.

Clinical actions, evidence and tools

The different sorts of activity distinguished in Table 2 put different demands on the formal representation of the evidence and generate different types of outcome.

The first type concerns the actions which create data, or objects, where the outcome consequently constitutes the created object. The status of the object can be seen as the Boolean value *present* to distinguish it from before the action was initiated, when it was *absent*. One example is the executed cognitive screening-test, which exists, in the form of a test protocol in the electronic health record (EHR).

The second case is when an analysing or refining action (RO) is executed which aims at interpreting an object at a primitive state into a more useful state. Examples can be when thresholds are applied to numerical values in order to identify pathologic features or when the numbers in the cognitive screening-test protocol is summarised and documented in the EHR. There is a range of situations in which data and knowledge needs to be re-represented and/or refined in order to be communicated and documented in the process.

The third relates to the DEO type which determine whether a particular critical phenomenon is present or not (Boolean valuation), and if present, provide if possible a valuation of the degree of presence (qualitative or quantitative), preferably based on a clinically validated screening tool. Consequently, the outcome may be a set of valuations of different specificity of the same entity, using different tools. Ideally, these values can be mapped to each other in a valid and reliable way when a certain level of specificity is required.

In the case when the goal of the action is to differentiate between types of an entity (DTO), the level of specificity of the entity increases in the execution of the action. Consequently, the values will correspond to each type at the higher level of specificity, i.e. as a set of sub-entities, however closely related to (constituting sub-sorts of) the original entity.

The fifth case constitutes the completion of an investigation activity (IO), which provides an assessment of the situation in focus. If interventions have been executed, also the outcome of the interventions is included in the assessment. Typically, this information is documented in the EHR using natural language. If the information concerns the outcome of the main investigation activity, an answer to the initial referral is formulated and sent to the referring organisation in addition to the documentation in the EHR. A corresponding assessment is provided by the prototype system COGITAMUS, however, at a more specific level of interpretation.

Mediating tools

Tools are identified by its mediating function in the framework of Activity theory [2, 3, 4]. Three main categories of tools were identified for our purposes: 1) tools used for mediating physical actions, 2) tools mediating reasoning processes and 3) tools mediating the logistic process.

We chose to distinguish complex cognitive processes such as reasoning, decision making and learning from basic cognitive functions such as memory, recognition and language production. These basic functions are supported in the logistic work process, where tools are typically used for the storage and mediation of knowledge. These tools may also serve the reasoning process when a system integrates intelligent inferences, i.e., has mechanisms of transforming / refining data or presents information as if it does. One example is the list of data from laboratory examinations, which highlights measures which are abnormal.

In addition to these tools external to the actor who uses them, there are tools integrated (internalised) in the actor

such as knowledge, rules of thumb, conceptual models of interpretation, models of procedures, etc. A majority of those used for professional work were external tools when a person first used them, which have been internalised by practice and learning. Examples are terminologies and classifications of diseases. However, internal tools are also created as conceptual models of how things work and should be organised, models which are continuously modified in the interaction with the environment. Internal tools can be externalised when focussed as an object of re-interpretation, which is the case when internalised knowledge needs to be communicated to others.

The aim for the development of the decision-support system COGITAMUS is to provide knowledge and support to novice users, which may become internalised in the process of using the system. For both novice and skilled users, the system should support the externalisation of knowledge if needed in difficult cases in order to consult colleagues or the integrated guidelines. Furthermore, the knowledge integrated in the system constitutes a synthesis of external evidence-based domain knowledge and internal expert knowledge, which has been externalised by the participating domain experts in the development process.

The category of tools which are particularly interesting in the formalisation of evidence are those which are used for valuing features, qualitatively or quantitatively. External, validated tools are preferred to the internal subjective assessments, in order to assure equal care and reliable decisions based on objective common grounds. However, since there are several tools that can be used for the same purpose, and which may produce ambiguous evidence, the actor sometimes needs to value which tool to use and on which to base further reasoning. Further, in some situations there are no validated tools available, thus leaving the valuation to the actor. In the actions where the user's experience and internal knowledge is needed for valuation of evidence, these tools need to be assessed as well, in our analysis by referring to them as *Subjective*.

A knowledge tool such as a clinical guideline integrates both knowledge in the form of implicit rules and a set of values which can be used in the valuation of evidence. By identifying these qualities of a clinical tool, the basic elements (sentences and types) necessary for the integration of the knowledge into a formalism can be identified. As an example from the domain of dementia, a tool such as the clinical guideline DSM-IV-TR [6] may come equipped with a formalisation of the content in the form of a set of sentences as part of a logic language where $^{\text{DSM-IV-TR}}$ consists of a set of rules formulated in propositional logic [7]. A sub-set of these rules, $^{\text{DEO-dementia}}$, corresponds to sets of core features necessarily present or absent in a patient in order to establish the presence of a state of dementia, as formulated in the guideline. The result of a valuation using the guideline may become:

Evidence: [State of dementia, $\{^{\text{DEO-dementia}}, \textit{present}\}$].

The user can be provided the evidence interpreted within different contexts of valuation, contexts consisting of the tools used for the valuations, thereby giving the user access to clinical guidelines and an overview of evidence in a patient's case.

Discussion and conclusions

The presented work provides a conceptual model for a clinical investigation activity based on analyses of the domain knowledge and case studies of investigations of actual patients. The model is used to frame the investigation process, as an alternative method to the formal ontology and workflow approaches. The purpose is to identify relevant actions to formalise for decision support in the system and actions to support by the design of interactive reasoning. The model can be viewed as a bridge between the informal view on clinical actions obtained in field studies and the formal implementation of the reasoning using suitable formalisms for representation.

The framework integrates the domain knowledge, procedural knowledge, resources and constraints imposed on the investigation activity by the environment, and in particular, the framework is dynamic and patient-oriented in that it is the need of the individual patient that defines the investigation activity and corresponding activity system.

The conceptual structure is based on Cultural-historical Activity theory and forms a foundation for the formalisation of the knowledge. The adapted theory is well suitable for the purpose in the semi-formal version presented in this work. The structure provides the data and their sorts and qualities, the tools that are used in assessing the data, the actions of transforming the data and contextual factors such as who is responsible for a certain action. A key issue is how the semi-formal structure can be transformed into a formal structure for representation. A critical feature is the formalisation of the content of guidelines, treatment protocols, scales and values provided through the use of different tools in the process. In order to extend the model to include a framework for the formalisation, we use category theory as a meta language for the identification of the fundamental building blocks, independent of the logic language used in the implementation of the knowledge. To what extent the activity structure is useful for the integration of knowledge in the formal framework of category theory and institutions [8] is currently being investigated.

Since the work presented in this paper is based on a limited amount of patients and focussing a specific domain, the structure will be further evaluated and developed using

additional patient's cases and used for developing knowledge systems in different domains.

Acknowledgments

I am grateful to the clinical personnel, patients and their relatives who participated in the study.

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