The Systemic-Structural Theory of Activity: Applications to the Study of Human Work

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Abstract. This paper offers an introduction to the central concepts and principles of the Systemic-Structural Theory of Activity (SSTA), an activity-theoretical approach specifically tailored to the analysis and design of human work. In activity theory, cognition is understood both as a process *and* as a structured system of actions. Building on the general theory of activity, SSTA's use of structurally organized analytical units makes it possible to develop taxonomies and theoretical models of human activity which provide a scientific basis for ergonomic design, education, and industrial-organizational psychology. The primary focus of this paper is on design problems in ergonomics. Whereas cognitive psychology has shown a tendency to reduce design problem-solving to experimental procedures, systemic-structural activity analyses focus on the interrelationship between the structure of work activity and the configuration of the material components of work. SSTA presents methods for the classification and description of human work activity, identifying activity during task performance as the primary object of study, using *action* as one of the major unit of analysis. We outline some applications of SSTA to the study of human work processes, and define and discuss some basic concepts and principles of activity theory.

1. Introduction

Contemporary psychology offers a multitude of empirical studies of psychological functions, processes, and phenomena. Yet, in the absence of any holistic theory through which they may be synthesized, experimental data may remain as disparate elements that resist consistent interpretation or generalization. In this paper we discuss and apply some of the basic concepts and principles of the systemic-structural and general theories of activity, arguing that the integrated and consistent theoretical framework they offer can support the effective use of psychological data to inform the analysis and design of work processes and provide a scientific basis for ergonomic design.

Any theory which sets out to provide a unified basis for the psychological aspects of design must fulfill two basic requirements. Firstly, it cannot simply be a micro-theory, but should be highly generalized, with a broad range of applications. Secondly, for such a theory to be used to understand human work and learning, it must have a clearly worked out analysis of behavior that can support both experimental and analytical methods of study. The need for this dual approach becomes apparent when we consider the problems of design in human performance, man-machine systems, human computer interaction and computer-based learning. Despite making progress in these fields, cognitive psychology largely remains tied to experimental investigation. The cognitive approach lacks a behavioral unit of analysis; this not only has a negative impact on the interpretation and description of experimental data, but also makes it difficult to apply psychological methods to practical design.

1.1 Psychology and Design

The essence of design lies in the application of analytical and descriptive methods to some not-yet-existing object, for the purpose of materializing that object for practical use. Design always involves the modeling of artificial objects in accordance with some requirements and characteristics. These models, and the descriptive languages employed for modeling, are critical factors in design. The primary models used in the design process are symbolical models, and the process of design can be conceptualized as one of translation from one descriptive language into another.

In cognitive psychology, a central notion is the psychological process. However, this focus on process has tended to underemphasize the concept of structure, without which it is extremely difficult to develop a standardized language of description for human activity, hindering the application of analytical methods to the study of human performance. As a consequence, cognitive psychology has shown a tendency to reduce design problems to experimental procedures. In contrast, systemic-structural activity theory approaches cognition both as a process and as a structured system of actions or other functional information-processing units, making it possible to develop a taxonomy of human activity through the use of structurally organized analytical units.

Activity theory is a psychological approach which originates in the works of S. L. Rubinshtein (1889-1960) and A. N. Leont'ev (1904-1979), and which has been developed through the work of P. K. Anokhin, N. A. Bernshtein, and others[1]. One of the principal foundations of activity theory is the cultural-historical theory of the development of the human mind proposed by L.S. Vygotsky (1896-1934). However, AT should not be limited to the cultural-historical paradigm as has been the tendency in many recent Western interpretations (e. g. Engeström, 2000). Whereas in Vygotsky's theory meaning is the major unit of analysis, and close attention is paid to social interaction as a condition for mental development, the major units of analysis in general activity theory are cognitive and behavioral actions; the central focus is on interactions with the "actual reality" of material objects. Human activity is portrayed as a hierarchically organized structure, consisting of conscious, goal-directed actions. Actions can be both mental and practical; while mental actions manipulate images and symbols, practical actions explore and transform real material objects. Actions are themselves constituted through smaller units, operations, which are automatic and unconscious.

The general theory of activity developed from Rubinshtein and Leont'ev's work offers the possibility of overcoming mentalist orientations, by connecting the abstract notion of activity with concrete practice through the concept of action. However, in this general form AT does not provide any exact methodologies specifically developed for the study of human performance; rather, it only suggests general ways of thinking about activity, offering a non-traditional viewpoint on the understanding of human work. For example, the general theory does not develop methods for extracting separate actions from the flow of activities which unfold over time, does not suggest principles for the classification of mental and motor actions, and does not include the concept of self–regulation. In practice, this makes it difficult to apply to the field of human performance.

The systemic-structural theory of activity (SSTA) sets out to address these issues, building on the general theory of activity to provide an effective basis for both experimental and analytic methods of studying human performance, using carefully developed units of analysis (Bedny & Meister, 1997; Bedny, Seglin, & Meister, 2000; Bedny, Karwowski, & Kwan, 2001; Bedny, Karwowski, & Seglin, 2001; Bedny & Karwowski, 2003b, 2004). In this paper we set out some of the basic concepts and principles of SSTA, describe its units of analysis and discuss some practical applications to the understanding of work processes.

2. Activity as a Structured System

Definition of activity. According to a basic textbook of Soviet general psychology (Petrovsky, Yarochevski, & Korenko, 1995), activity is defined as consisting of internal (cognitive) and external (behavioral) processes, which are regulated by conscious goals. Here, we will further refine this definition to state that, from the systemic-structural perspective:

> Activity is a goal directed system, where cognition, behavior and motivation are integrated and organized by a mechanism of self-regulation toward achieving a conscious goal.

Primary aspects of activity. When analyzing activity, it is important to consider who is engaged in that activity, what their intentions, goals and motives are, and what type of activity they are involved in. There a two primary types or aspects of activity – "object oriented" and "subject-oriented" activity. "Object-oriented" activity is performed by a subject using tools on a material object, where the subject of activity is the individual or group of individuals engaged in that activity. Subject-oriented activity, also known as social interaction (in Russian, obshenie), involves two or more subjects and is constituted through information exchange, personal interactions and mutual understanding. During task performance, the object-oriented and subject-oriented aspects of activity continuously transform into one another. In any analysis of object oriented activity, inter-subjective relationships must always be considered (Bedny & Karwowski, 2004).

Social interactions develop in a surrounding world of physical objects, and interactions with those objects arise on the basis of social norms and standards. Therefore, inter-subjective relationships exist not only in the obvious forms of subject-subject relationship, but also within subject-object relationships, as an inner dialogue. In this understanding of mental development, semiotic mediation and external practical activity are totally interdependent and never exist separately.

Object, goal, subject and result. The object of activity is that which is modified and explored by a subject according to the goal of activity. Modification or exploration include not only physical transformation, but also the classification of objects according to required goals, the discovery of features of the object that correspond to goal of explorative activity, and so on. Objects may be either concrete or abstract. Abstract objects are e.g. signs, symbols or images, and their constitution as entities transformed by the subject in accordance with goals. Initial, intermediate, and final states of objects may be distinguished.

Currently, one of the most widely known representations of activity theory is the triadic schema elaborated by Y. Engeström (Engeström, 1987, 1999). The central axis of Engeström's schema presents the relationship:

Subject ← → Object → Outcome.

In recent years this formulation has led a number of researchers to interpret the term "object" as being synonymous with "objectives" (see e.g. Bellamy, 1996). This confuses two different concepts: the notion of 'objectives', which is related to the *goal* of activity; and the concept of 'object', which, in our understanding of activity theory, always refers to that which is modified and explored by a subject *according* to the goal of activity. Analysts should be clear that it is only the *desired future final state* of an object that corresponds to the notion of the goal of action or activity.

The *goal* is a conscious cognitive representation of the desired future result of activity. Goals may be accepted in advance, or formulated and specified during activity. Sometimes the goal is very ambiguous during the preliminary stages of task performance; goals may be modified or even entirely transformed during the course of activity. It is important to note that *in the absence of a definition of the goal and the task, the object itself cannot be defined.*

Figure 1 presents a triadic schema of activity that aims to clarify the central relationship between subject, object and goal in activity.

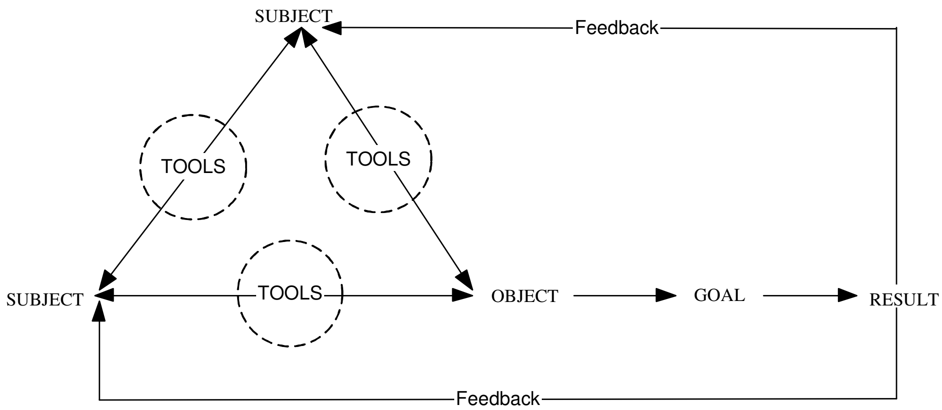

Figure 1. Triadic schema of activity.

In our schema, the object and goal are treated as distinct components and not only the subject-object relationship, but also intersubjective relations are illustrated. This emphasizes that any notion of 'objectives' must relate to the goal, rather than the object of activity. The broken circles in the figure indicate that subject-object interaction may be either direct, or through the use of external mediating instruments. By the same token, intersubjective interaction may be direct (speech, gesture), or instrumentally mediated (e.g. telephone, email). In both object-and subject-oriented actions, direct interaction should not be taken as implying an absence of mediating instruments; rather, in such cases the subject employs "internal" tools. In activity theory, the *subject* is always understood as a socially constituted individual, in possession of internal, psychological tools acquired during ontogeny. Such internal tools are assumed as a precondition of subjectivity.

Unlike Engeström's triadic schema, Figure 1 also distinguishes between the concepts of goal and *result*. Whereas the goal is a primarily cognitive mental representation of the desired future state of the object, the result is the *actual* outcome of activity. The result of an activity may coincide with the goal, or it may not. It follows that subjects' attempts to reach a desired result align with their established goal; if the actual result of an activity does not coincide with the subject's goal, then she or he must reformulate their strategy for goal achievement, or reformulate the goal itself. This process of continual adjustment requires the presence of feedback influences, and implies that activity is organized according to principles of self-regulation. These feedback influences are also presented on the schema, represented by arrows connecting the result with the subject.

3. Some Basic Concepts and Units in Activity Theory

Action. An action is a discrete element of activity that fulfills an intermediate, conscious goal of activity. The performance of all the actions required by a task leads to achievement of the task-goal. The structure of activity during task performance is formed by a logically organized system of motor and mental actions; action emerges as the primary unit for the morphological analysis of activity. Actions can be further divided into unconscious operations, the actual nature of which is determined by the concrete conditions under which activity takes place. In activity theory, cognition is considered not only as the storage of images, concepts or propositions, but also as the system of mental actions and operations carried out with and upon them.

All actions have a temporal dimension. The initiation of a conscious goal (goal acceptance or goal formulation) constitutes the starting point of an action, which concludes when the actual result of action is evaluated in relation to the goal. This understanding allows for the depiction of continual flow of activity, divided into individual units. Actions can be described in terms of a recursive loop structure, with multiple forward and backward interconnections. Figure 2 presents a simplified model of action as a one-loop system:

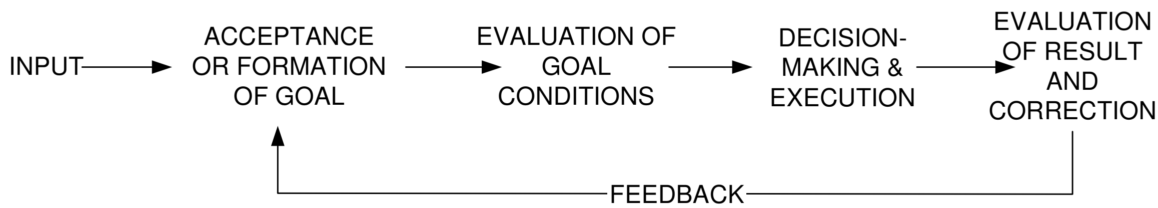

Figure 2. Action as a one-loop system.

Function blocks. Even very short mental actions can be further sub–divided chronometrically into a series of distinct stages of information processing, each occupying a very brief duration. In activity theory these stages are referred to as functional micro-blocks. For example, empirical investigations have established that perceptual actions consist of such functional micro-blocks as sensory register, iconic memory, scenic mechanisms, program formation mechanisms, etc. (Zinchenko & Gordon, 1981). This approach to the decomposition of actions is called micro-structural analysis. While Sternberg (Sternberg, 1969) was the first to describe micro-stages in the processing of information, V. P. Zinchenko introduced the concept of micro-blocks to the study of cognitive and motor actions. At present, exact descriptions of the content of cognitive actions are not available. However, studies to date demonstrate that cognitive action should be considered not simply as a process but also as a complicated, self-regulating structure.

In order to extend the functional approach to include the analysis of activity during task performance, activity theorists have developed the concept of the functional macro-block. These macro-blocks represent clusters of distinct functional elements within self-regulating systems of activity, such as the goal, motive, subjective assessment of relevant task conditions etc. Collectively, functional micro- and macro-blocks are often simply referred to as *function blocks*. The function block is the major unit of analysis applied during the functional analysis of activity, which is based upon models of the self-regulation of human activity. While space does not permit further discussion of functional analysis here, the interested reader is referred to (Bedny & Meister, 1997, 1999; Bedny & Karwowski, 2003a).

The goal. As noted above, the goal is a cognitive, informational component of activity involving the conscious representation of the future desired result of actions or activity. As a cognitive mechanism, the goal can be more or less clear and precise, and either totally or partly conscious. For example, in explorative activity the goal may be initially vague, gradually becoming more precisely formulated as the object becomes clearer. In explorative activity, goal-formation is closely associated with the subject's level of aspiration. From a self-regulation (functional) point of view, when a subject attempts to solve a task-problem, she creates a level of aspiration that may be changed by her evaluation of the results of activity. As the subject performs exploratory actions, she produces and analyzes a sequence of trials-and-errors. This leads to the creation of a hypothesis about the situation, and the formulation of a preliminary goal for activity. This preliminary goal can be considered as corresponding to a particular level of aspiration; it results from an evaluation of task difficulty that includes not only an assessment of the objective characteristics of a task, but also elements of self-evaluation. Goals are always associated with a motive – while it is, of course, possible for a subject to imagine a future result that does not depend on his or her own actions, this is not a goal.

Motive. In activity theory, the motive is considered as the energetic component of activity. Motives arise when a connection is made between needs and objects; motivation includes both long-term and situational elements, and may be more or less intensive. Whereas goals guide and direct, motives "push" activity. The more intensive the motive, the more effort a person will expend to reach their goal. Following Leont'ev (Leont'ev, 1981), the relationship between motive and goal can be considered as a vector that gives activity its goal-directed character:

Motive → Goal

A more detailed schema of activity may be presented in the following form:

Motive → Method → Goal → Result

3.1 Objects of study and units of analysis.

In some current interpretations of activity theory there appears to be confusion regarding the relationship between objects of study and units of analysis. In developing his broad philosophical outline of the general theory of activity, A. N. Leont'ev (Leont'ev, 1978, 1981) was at pains to distinguish his approach from reductive psychologies (such as behaviorism) by strongly emphasizing the holistic, irreducible nature of activity. This is undoubtedly a centrally important orienting principle, which must be fully reflected in any activity-theoretical methods. However, in seeking to apply the general theory of activity, some researchers have attempted to use activity, or activity system, as their basic unit of analysis. It is our view that with regard to applied research, and especially research concerned with design, this approach will often prove inappropriate. It is frequently more practical to approach activity as the object of study, an object that must be described with the help of a variety of carefully developed analytical units, appropriate to the purpose of the study in hand.

In order to clarify this issue, we present below a general scheme of the structural components of activity. Note that this includes the task as an important element, a point we return to later:

Activity → Task → Action → Operation → Function Block

The first two components of this schema (activity, task) are considered primarily as the objects studied by activity theory, the remainder as the units of analysis employed for the study of these objects. Because activity is understood as a holistic, structured, systemic entity, when an activity becomes the object of study it must be approached from a variety of perspectives, using a variety of interrelated units of analysis. In this way, the primary object of study, some specific activity, can become the subject of a number of methodologically different, but closely interrelated descriptions.

Recognition of the shortcomings of task analysis methods based on cognitive psychology has led some Western AT researchers to reject the notion of task altogether (Holland & Reeves 1996, Nardi 1996). It should be noted that, despite these misinterpretations, the task is actually a critically important concept in activity theory, where activity during task performance is considered a basic object of study (Bedny, Karwowski & Jeng, 2001).

3.2 Units of analysis in the systemic-structural description of the work process.

When carrying out a systemic-structural analysis of human performance during a production process, it is initially activity itself that is the object of study. In this preliminary stage, analysis does not focus on separate production operations, but rather pays attention to general characteristics of work activity such as the context of work, social norms, standard, rules etc. In the following stage of activity analysis it is the task, understood as some fragment of activity that is organized around a task goal, which becomes the object of study. At this stage, the focus shifts to activity during the performance of a production operation, or during the solution of some practical problem.

Leont'ev defined a task as some situation requiring achievement of a goal under specific conditions (Leont'ev, 1981). In order to clarify this definition, we will consider an example involving an aircraft pilot. A pilot controls her aircraft in a particular situation according to the goal that is relevant to that situation. While this goal may have been externally supplied, perhaps by the aircraft dispatcher, it will, to some extent, be idiosyncratically interpreted by the pilot. In some cases, the pilot herself may formulate the goal, in a form dependent on the specifics of the situation. However the task is set, the pilot will develop different strategies of task performance based on an evaluation of task difficulty and the significance of the task goal. Pilots do not simply receive information; they evaluate it from the point of view of a desired goal and the significance of the task. Similarly, pilots may evaluate the result of actions involved in task performance according to significance of the task for them, and their own motivational intentions.

Units of analysis. Figure 3 presents a schematic representation of the objects of study and units of analysis used by activity theory. Units of analysis are unified components into which we divide the whole, for the purposes of studying those components and their integration into the dynamic whole. The main object of study is human work activity, which is principally analyzed as activity during the performance of some specific task. The principal unit of analysis for the morphological analysis of activity is the action, which may be further decomposed into operations. When undertaking functional descriptions of activity, function blocks may be used for either macro- or micro-analysis, according to the focus of the study. It should be noted that in activity theory, meanings and signs are treated as the psychological tools of mental actions, but not as units of analysis. Meanings are themselves products of action that, in turn, become tools for action.

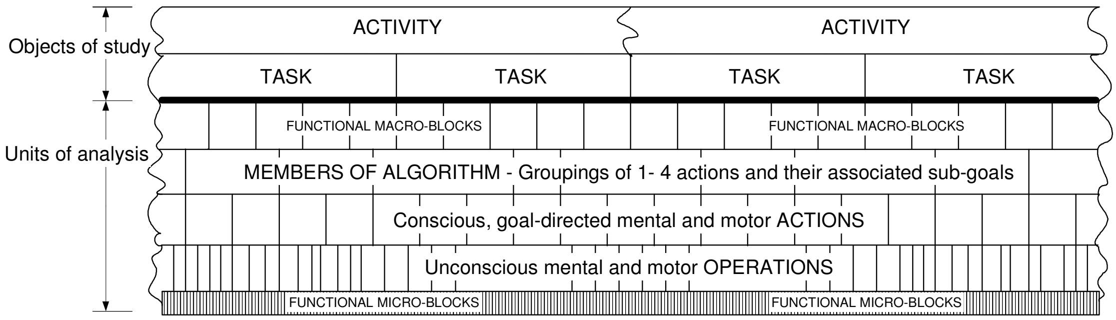

Figure 3. Objects of study and units of analysis in activity theory.

Figure 3 shows that in addition to actions and operations, the systemic-structural approach employs additional units for morphological analysis. These units are called "member of algorithm", and they are used to describe task structure in terms of "human algorithms". Members of an algorithm comprise a cluster of approximately one to four interdependent actions, integrated by a higher order (subtask) goal than those that guide the individual actions themselves. A human algorithm is used to represent the logically organized system of actions through which an individual subject transforms some initial material in accordance with the required goal of the task. These algorithms are distinguished from similar devices such as flow charts by their use of actions as the basic units of analysis.

Having established a number of basic terms, concepts and principles, we now proceed to consider additional aspects of the systemic-structural approach to activity analysis and design in relation to work processes, beginning with a discussion of the production process.

4. Structure of the Production Process

A production process can be defined as a sequence of transformations of raw material into finished product. The process usually begins with the entry of raw material, and proceeds through various steps until the material becomes a finished product, or result, in accordance with the purpose of the production process. Any production process can be seen to contain three basic elements: the human work activity, or work process; the means of work; and the product. The means of work are those tools, equipment and instruments used by subjects in the production process. While, in general, the purpose of any production process is the transformation of raw material into finished product, it is possible to distinguish various types of production process. For example, in manufacturing there are mechanical production processes, physical-chemical processes, transportation, and control production processes (Gal'sev, 1973).

The structure of production process is presented in Figure 4. The left side of the figure represents the work activity, or *work process*. Here, the term process is used to emphasize that activity is performed according to some prescription or order. The work process contains a substructure of basic components: (a) *Motive-goal* as a vector which demonstrates the directional and energetic aspects of work activity, (b) *knowledge and skills* which demonstrate the relevance of past experience to the work process, (c) *abilities* in relation to the tasks to be performed, and (d) *work actions* which are organized into a structure, and together present the *method of activity*. In this scheme, "action" refers to both cognitive and motor actions. The presence of the concepts of knowledge and action in the structure of the work process implies the existence of mental tools.

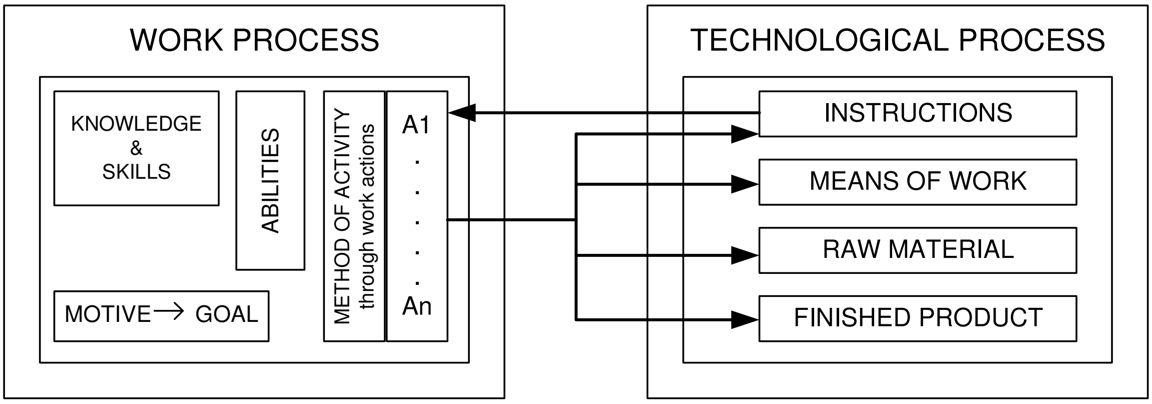

Figure 4. Structure of the production process.

The right side of Figure 4 represents the technological aspects of the production process, which are also performed in accordance with some prescriptive order. The technological process includes (a) the *instructions* according to which the worker performs the job, (b) the *means of work*, (c) the *raw material* or initial material object; and (d) the *finished product* or result.

Production operations. A production process can be described as comprising a sequence of separate steps or production operations. A production operation is some isolated part of the production process that is performed upon the work object, in one work place, and by one or several workers. A production operation is characterized by the presence of the same equipment and tools, the same object of work, and by its technological completeness. Production operations can be further subdivided into smaller, standardized, technological units. As can be seen from Figure 4, any production operation includes human activity, technological components or means of work, and the object under transformation. The nature of the changes undergone by the object depends both on human activity and the specifics of the technological components of the process.

Both production operations and the holistic production process may be studied from either the technological viewpoint or from a human activity perspective. It is when production operations are studied from the activity perspective that the term *task* becomes applicable. Tasks are understood as being organized in accordance with technological requirements and the relationship between the work process and technological process becomes of critical interest. When analyzing a task or production operation from the activity point of view, it can be divided into a logically organized system of cognitive and motor actions, which in turn can be subdivided into the smaller units of operations or function blocks. At the same time, and as required, it is also possible to integrate actions into those analytic units referred to as members of algorithm.

Types of tasks in the work process. The scheme presented in Figure 4 considers the work process as a specific type of activity. One of the most important characteristics of the work process is that the subject knows something about the materials, tools, equipment, and final result of his or her activity in advance. The worker is required to possess the appropriate abilities and the necessary professional background, and must perform in accordance to given instructions. However, individual tasks can be associated with varying degrees of freedom of performance. Some tasks may be deterministic, or skill based, requiring a standardized sequence of actions each time they are performed. Some tasks may be deterministic-algorithmic, that is, they are performed step-by-step according to a deterministic prescription. At times, the task may be probabilistic-algorithmic.

Algorithmic tasks are performed according to rule-based principles. The subject must conform to a sequence of actions and technological steps that cannot be violated without disrupting the production process. From an activity-theoretical viewpoint, this kind of work is amenable to design, whereas it is more difficult to design work processes that involve a high levels of freedom of performance, creativity, and unpredictability.

4.1 Operational-monitoring Processes

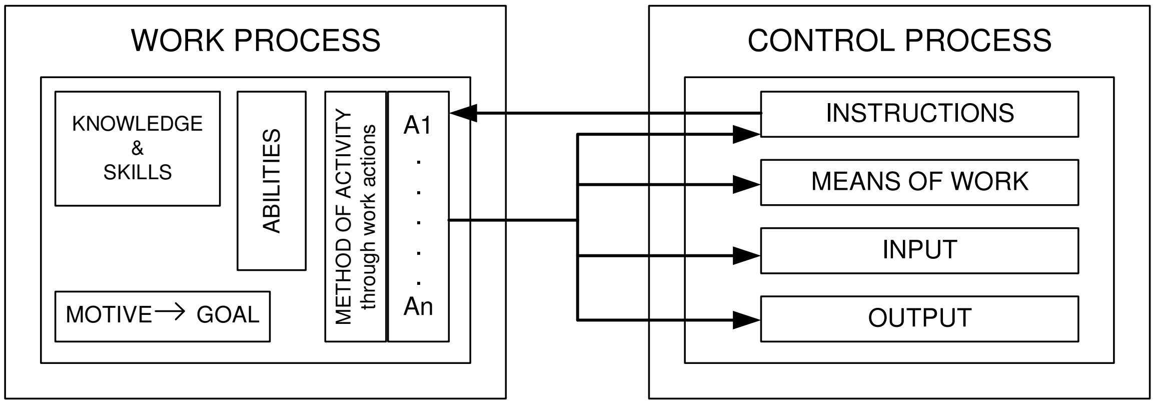

Figure 5. Structure of the operational-monitoring process.

An operational-monitoring process is defined as a combination of duties essential to accomplish some automated or semi-automated system function. One of the specific characteristics of work with automated and semi-automated systems is that the operator is not simply involved with changes to physical material, but also with the transformation of information. In many cases, it is the operator themselves who must determine what has to be done. Although the work is based on certain procedures and rules, it also involves creativity and problem solving. In these cases, the work process can be seen as organized through probabilistic algorithms and quasi- algorithms, with the operator forming the performance rules based on his or her experience.

Another common characteristic of an operator's performance with automated systems is that he or she is required to perceive information from a variety of displays and instrumentation. Rather than controlling the power sources directly, the operator uses intermediary control devices. Inspection, controlling and monitoring functions predominate, and the motor components of activity are significantly reduced. Work activity in its external appearance (as motor actions) loses continuity and acquires an episodic character, while at the same time, the role played by the sensory-perceptual and thinking components of activity increases.

Structure of the operational-monitoring process. Recognition of the specific characteristics of this kind of process requires some reconsideration of the general description of the work process shown in Figure 4. The notion of production operation used earlier is no longer appropriate; rather, it is tasks that form the basic components in operational-monitoring processes. A schema of the structure of an operational-monitoring process is illustrated in Figure 5.

In contrast to Figure 4, "technological process" is replaced by the notion of *control process*. It is now the transformation of information, rather than the material transformation of the object that plays the major role, as changes in the physical state of a controlled object become possible mainly on the basis of the transformation of information. In the control process, the components "raw material" and "finished product" are replaced by *input* and *output*. In most cases, the input is information received by the operator about the initial state of the control object. The output is information about the control object following completion of task. In this type of process, it is very often the case that a sufficiently detailed description of how to accomplish the task goal is lacking; the task then takes on a problem-solving character. Thus, the operational-monitoring process can also be described as a system of logically organized problem-solving tasks.

4.2 Task acceptance and formulation.

In a production process, the tasks or production operations are prescribed in advance. By contrast, in an operational-monitoring process the tasks are often self-initiating. To return to our earlier example, while a pilot may have as her overarching task-goal the completion of a flight from one city to another, she will be required to formulate a variety of ongoing sub-task goals herself, according to the situation presented by flight conditions. Thus, when analyzing operating-monitoring processes, the concepts of objectively given task and subjectively accepted or formulated task become important.

Acceptance or formulation of a task-goal is closely associated with the subject's representation of the task. The subjective or mental representation of a task is characterized by the following features (Kozeleski, 1979):

1. It is dependent on the objectively presented structure of the task.
2. It is a dynamic phenomenon that can change during task performance.
3. The mental representation determines task performance.
4. Success in solving a task is dependent on the performer's personal representation.

Investigating the influence on task performance of the relationship between the objective presentation of task and its subjective representation is a major concern of the functional analysis of activity.

Computerization significantly alters the specifics of an operational-monitoring process, often leading to greater demands on the task performer. When a subject directly interacts with a computer during task performance, this becomes a specifically human-computer interaction (HCI) process, which includes logically organized computer-based tasks. From the point of view of AT, the schema of an HCI process is basically the same as for operational-monitoring processes, the only major difference being that the computer is now the dominant means of work.

4.3 Task structure and characteristics in the work process.

The materials presented above illustrate how, from the perspective of systemic-structural analysis, a work process is understood as a combination of tasks performed by subjects to accomplish the objectives of the system. Each task in the work process is regarded as a situation-bounded activity which is directed to achieve a goal under given conditions. Any task includes both the subject's activity and the material components of task, with all the elements of activity during task performance being organized by the task goal. It is only when the objectively given or subjectively formulated requirements of the task are accepted by the subject as a desired future result that they become the goal of task.

Whatever is presented to the subject for the performance of the required actions constitutes the *conditions* of the task. These task conditions include both the subject's own past experience and components such as instructions, means of work in given conditions, raw material and input information. Task conditions also determine the possible constraints on activity performance. The raw material, or input information, is considered to be the object of activity. What is actually achieved (finished product, output) is the result of activity. The vector motive→goal determines the directedness of activity during task performance. Any task includes an initial situation, intermittent situations and a final situation. By associating the notion of *situation* with stages of task performance, it becomes possible to study how the structure of a task changes during different stages of performance, and how many basic transformational stages are required.

In the schema presented in Figures 4 & 5, *knowledge* includes images, concepts, propositions and non-verbal sign systems. According to Landa (Landa, 1983), knowledge includes not only data about objects, their attributes and relations, but also knowledge about (motor or cognitive) actions on objects. When a subject is able to perform mental actions on images, concepts, propositions, and other sign systems, those sign systems become internal, psychological tools for action. The ability to use signs as tools is essential for the practical application of knowledge.

5. The Classification of Tasks and Work Processes

5.1 Deterministic and algorithmic types of task.

As we have noted, any work process includes a number of different tasks. The simplest type of work task is rigid and deterministic, as when workers produce identical products in large quantities. Such tasks are often highly repetitive and carried out at great speed. In Rasmussen's terminology (Rasmussen & Pejtersen, 1995), these are skill-based tasks. More complex tasks are algorithmic, that is they are performed according to some logic and rules. As outlined above, algorithmic tasks can be divided into deterministic and probabilistic types. In deterministic-algorithmic tasks workers perform simple "if-then" decisions based on familiar perceptual signals. Each decision usually has only two outputs. For example, "if the red bulb is lit then perform action A; if the green bulb is lit then perform action B". Deterministic-algorithmic tasks are comparable to rule-based tasks in Rasmussen's terminology. Probabilistic-algorithmic tasks are more complicated, involving logical conditions with the possibility of three and more outputs, each output possessing a different probability of occurrence. Probabilistic task elements significantly increase an operator's memory workload.

Non-algorithmic task components. Probabilistic-algorithmic tasks can also include non-algorithmic problem-solving components. Landa (Landa, 1983) suggests that these can be divided into three groups: semi-algorithmic, semi-heuristic, and heuristic. This categorization is based on the relationship between task instructions and the mental operations required to solve the task-problem. Distinctions between types of task are relative rather than absolute, being defined by: (a) The extent to which the instructions specify the actions to be performed by the subject, (b) whether or not the actions are relatively elementary for subject (if an action can be performed virtually without error it is considered as relatively elementary), (c) how well the instructions specify the "field" from which the goal object must be selected, and (d) how well the instructions delineate or specify the criteria for identification of the goal object.

When instructions completely define the physical and mental actions to be performed by subjects, do not require any independent actions to be performed, and guarantee successful solving of the problem, such instructions are categorized as algorithmic. When instructions contain some uncertainty (perhaps resulting from vagueness in the criteria that determine a logical sequence of actions) and therefore require the subject to create his or her own methodology, they are considered semi-algorithmic. However, it should be noted that even when instructions relate to an objectively given, deterministic-algorithmic task, the terms in which the instructions are expressed may give rise to a subjective perception of the task as non-algorithmic.

A probabilistic-algorithmic task requiring multiple decisions often becomes a problem-solving task for the performer. In cases where the uncertainty is even greater, the task is termed semi-heuristic, the major criterion for categorization as a heuristic task-problem being that it presents an undefined field of solution. Semi-heuristic problems may also include algorithmic and semi-algorithmic sub-problems. One important goal for the ergonomic design of such tasks is to reduce the degree of objective and subjective uncertainty in problem-solving. It should be noted that all non-algorithmic tasks, and a significant proportion of probabilistic-algorithmic tasks, are considered as knowledge-based tasks in Rasmussen's terminology (Rasmussen & Pejtersen, 1995). In this regard, activity theory suggests a more detailed system of task classification than cognitive psychology.

5.2 Classifying work processes.

On the basis of the materials presented above we can now sketch out an activity-theoretical classification of different types of work processes. The criteria for classification include: (a) The features of the object of activity (that is, the material components of activity), (b) the extent to which the subject is involved in the transformation of the work object (which may be raw material or input data), and (c) a broad categorization the constraints and possibilities on functions performed by workers derived from economic studies and studies of human labor (Cemach, 1969; Gal'sev, 1973; Barnes, 1980). A classification of work processes according to these criteria is presented in Table 1.

Other types of work activity. Of course, other types of work activity exist in addition to the work processes described above. There are numerous professions where the task performance methods are not precisely determined. For example, the work activity of engineers, medical doctors, teachers, etc., can be widely varied in order to respond to the conditions for achieving a particular goal. Strumilin (Strumilin, 1983) designates this kind of work as "independent work within the given set of the requirements". It is also necessary to distinguish the kinds of creative work performed by scientists, artists, inventors, etc. In this type of work, at times it is not only the method of achieving the goal that is unknown, but also the goal itself. It can be seen that the activity-theoretical classification of work activity based on criteria of predetermination must have a relative character. Work processes, independent work within the set of requirements, and creative work may be combined in different proportions in different professions.

Table 1. Classification of Work Processes

Classification Criteria	*Type of Work Process*
Character of object	Substance-energetic Informational Mixed
Extent of subject's involvement in transformation of object	Manual Mechanical-manual Automated
Functions performed by the subject	Work processes performed by blue-collar workers (e. g. factory labor, manufacturing, construction.) Work processes performed by white-collar workers (e.g. work study in the office) Operational work processes (e.g. operator-technologists, operator-controllers, operator-dispatchers, etc.) Work processes involving the performance of computer-based tasks.

Work process analysis and ergonomics. Analysis of the work process demonstrates that work activity contains both anticipated and unanticipated elements (Vicente, 1999), and the proportion of predictable to unpredictable factors will vary across work processes. We can conclude that the more predictable the work process, the easier it will be to precisely design the work activity. It is important to recognize that, as with any models, models created during the process of systemic-structural activity analysis represent idealized versions of activity, and can only approximate to the real activity of the work subject. However, useful comparisons of various factors affecting the work process, such as different versions of equipment design and configuration, can be accomplished based on an analysis of these idealized models of activity.

The physical characteristics of equipment impose different strategies of activity, in a probabilistic manner. The space of possible strategies for activity in any work process is defined by the totality of these strategies, taking into account constraints on performance. Given the same performance constraints, changes in equipment configuration will result in a new space of possible strategies for activity. In order to understand the basic characteristics of the space of possible activity strategies, the ergonomist need not consider all possible strategies of performance. Rather, analyses should focus on those strategies of activity that are most representative and critical, and which correspond to basic trajectories of activity within the space of all possible strategies. This approach facilitates understanding of the space of activity strategies under the given performance constraints. Based on this understanding, we can distinguish three major aspects of ergonomic design: (a) The design of equipment, (b) the design of human performance, and (c) the design of human computer interaction. In the next section, we consider a practical example connected with the latter category.

6. Example of Morphological Analysis

6.1 The computer as a means of work.

In our discussion of the work process we utilized the notion of *means of work*. This concept includes a variety of tools and equipment; it cannot simply be used as a synonym for tools. In systemic-structural theory, the concept of tool is tightly associated with the concept of action; outside of a specific task, we cannot precisely determine what is a tool. In this sense, a personal computer cannot be classified simply as a tool. Rather, the computer is a means of presenting or creating a variety of artificial tools that mediate the subject's actions during the performance of a computer-based task. Moreover, a computer also creates artificial objects toward which tool-mediated actions may be directed. In this sense, the computer is a special kind of means, mediating human interaction with the external world through the creation of artificial objects and tools required for the performance of computer-based tasks.

6.2 Classification of actions.

Prior to discussing an example of activity analysis, it is necessary to briefly consider some principles for the classification of actions. Systemic-structural activity theory offers two major approaches. The first is based on noting the dominating psychological process during action performance. The second categorizes actions according to the nature of the object (material or sign/symbol) and the method of performance (practical or mental) (Bedny, Seglin, & Meister, 2000). For example, according to the first principle one can categorize actions as sensory, simultaneous perceptual, imaginative, mnemonic, etc. An example that applies this principle to the classification of actions required by a computer-based task can be found in (Sengupta and Jeng, 2003). Applying the second principle distinguishes (a) object-practical actions performed with material objects, (b) object-mental actions performed on mental images, (c) sign-practical actions performed with external signs, and (d) sign-mental actions performed through the mental manipulation of sign or symbols.

6.3 Example HCI analysis.

We now consider a generalized example drawn from the domain of human-computer interaction which involves applying the second approach, action classification based on object and method of performance. The task involves a subject using basic word-processing software running on a personal computer to produce some document. As text is entered, misspellings are underlined in red. At this particular stage of the task, subjects are required to correct all misspellings. This is a deterministic task, requiring a well-defined sequence of actions. In order to correctly extract those required actions and develop their classification, we need to identify the object, tool, and goal of each action; the nature of an action being dependent on the interrelation of these components in any particular situation. As a first step, we describe the actions required during the performance of this task:

1. Reach and grasp the mouse with the right hand.

2. Move the cursor to the initial position preceding the misspelled word and depress the left mouse button with the index finger.

3. With the mouse button depressed, highlight the required word by dragging the cursor to the end of the word; release the mouse button.

4. Move the pointer to the spelling icon on the toolbar; depress the left mouse button with the index finger, then release.

5. Examine the list of options presented by the dialogue box.

6. Decide which is the most suitable spelling option.

7. Move the pointer to the chosen spelling option; depress the left mouse button with the index finger, then release.

8. Move the pointer to the OK button; depress the left mouse button with the index finger, then release.

When a subject performs the first action, the mouse is the object to be engaged by the subject. The conscious goal of this action, that is, what the subject understands that he or she wishes to achieve as result of taking action, is to grasp the mouse. As the mouse is a real, material object, this is classified as an object-practical action. In action 2, the mouse becomes a tool through which the subject implements the movement of an object, the cursor, to the start position. The transformation of the object (cursor) is performed according the current goal of action, to the move the cursor to the required position. Although the pointer is a symbol on the screen, the meaning of the sign is not especially important at this point, so this is also considered as an object-practical action.

At the third step, the word to highlight becomes the object of action. The subject transforms the quality of the object according the goal of action; the background of the text becomes black while the characters become white. (It should be noted that at times subjects may not be aware of all changes in the object. For example, sometimes the subject may not be aware that the characters have changed color, illustrating that the subjectively formulated goal of action may not always coincide with the objectively required goal and result of action.) This third step also includes several tools: the cursor, mouse and left mouse button. In the fourth action, the spelling icon is the object of action and the mouse and pointer the tools. Actions 3 and 4 are both classified as object-practical.

In fifth action, the list of options in the dialogue box becomes the object. In executing this action, the subject does not employ any external tools. This action is classified as sign-practical; a sign becomes the tool of internal, mental action. In terms of the dominant psychological process, this is a simultaneous perceptual action. In action six, a particular item in the list of options is the object, so this is also a sign-practical action; the dominant psychological process is decision-making.

In action seven, the pointer, mouse and button are the tools, and the spelling option chosen in the previous action is the object. In the last action, the OK button is the object, the mouse, mouse button and pointer the tools. Actions 7 and 8 are both object-practical actions. At times, it may be difficult to decide whether an action should be classified as object-practical or sign-practical, because the subject simultaneously manipulates different tools. When actions with the mouse are performed almost automatically, we can classify them as object-practical actions.

When a conscious manipulative effort involving meaning is required, the actions can be classified as sign-practical.

When attempting to solve HCI usability problems, a series of question may be raised on the basis of this kind of analysis. For instance, during the performance of the first action in our example, the usability of the mouse, its 'graspability' and 'clickability' are the issues of concern. In the second action, the ease and precision of directing the pointer are highlighted. Similarly, perceptual actions, such as action number five, and simple decision-making actions (number six), present issues connected with the ease of performance of such mental actions. This approach also supports quantitative evaluations of the complexity of performance. For example, it is possible to estimate the time involved in decision-making processes during a task, and define its a ratio to the overall time taken for task performance, giving a basis for considering ways to reduce task time and/or complexity.

The hypothetical example given above illustrates one stage in the morphological analysis of activity. It is intended to provide a simple demonstration of one way in which the activity-theoretical concepts of object, action, goals, etc. can be applied for detailed studies in HCI and other design-oriented research. When undertaking a morphological activity analysis, the activity under study is initially formulated in terms of tasks. Next, the structure of task performance is described. As in our example, this involves determining the content of tasks through the delineation of the actions implicated in task performance. Alongside this kind of analysis, we may also need to precisely describe the actions in terms of typical elements of a task (technological units), or in terms of typical elements of an activity (psychological units). Additionally, the type or level of attention required for each action may be studied. However, further discussions of these aspects of action classification are outside the scope this article.

The morphological analysis of activity constitutes only one aspect of a four-stage, multi-level, methodology for the systemic-structural analysis and design of work activity[2] The systemic-structural approach offers an integrated framework for the iterative description and analysis in both qualitative and quantitative terms, supporting the stepwise development and testing of models of human activity, which are used as a basis for the design of equipment and work processes. Both the morphological and functional aspects of activity are studied and described from multiple perspectives and at varying levels of decomposition.

7. Conclusion

In this paper we set out to offer an introduction to the central concepts and principles of the Systemic-Structural Theory of Activity (SSTA), an activity-theoretical approach specifically tailored to the analysis and design of human work. We began by discussing the relationship of psychology to design, arguing the need for a standardized approach to describing and analyzing human work activity. At present cognitive psychology remains mainly concerned with experimental studies, failing to suggest suitable analytical principles or methods. Our aim has been to demonstrate that the systemic-structural theory of activity, with its carefully developed units of analysis and systemic principles of description, can provide a platform for the more effective application of psychology in design practice.

We have described some of the background and basic concepts of the systemic-structural and general theories of activity, and presented principles and methods for the classification, and description of human work activity. In our view, design-oriented studies of human performance should take as their primary focus the interrelationship between the structure of work activity and the configuration of the material components of work. The systemic-structural approach to activity design and analysis involves identifying (a) the available means of work, tools and objects, (b) their relationship with possible strategies of work activity, (c) existing constraints on activity performance, (d) social norms and rules, (e) possible stages of object transformation, and (f) changes in the structure of activity during skills acquisition. Increasingly, the material components of work include artificial objects and tools created by a computer. In this paper we also argued against a simplistic notion of the computer as a tool, suggesting that it is more appropriate to think of the computer as a means for the creation of artificial tools and objects for task performance.

Notes

[1]See Bedny & Karwowski, 2004 for a fuller account of the emergence of AT from the SSTA perspective.

[2]For further information see Bedny & Meister, 1997; Bedny, Seglin, & Meister, 2000

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