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ANALYSIS OF TASKS, ACTIVITIES, AND WORK IN THE FIELD AND IN LABORATORIES [1]

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Abstract. The paper gives an overview of a conceptual framework, a taxonomy, for analysis of cognitive work in modern, dynamic work places. The framework has been developed from field studies in different work domains such as process control, advanced manufacturing, and hospitals and is intended to facilitate transfer of results between different work domains and the use of results from psychological experiments for design and evaluation of information systems. The paper illustrates the use of the framework for mapping boundary conditions of laboratory experiments onto work conditions of actual work places.

INTRODUCTION

Through the latest decades, the cognitive point of view has had a large impact on work psychology moving the focus of analysis from studies of performance in terms of overt interaction with the work domain to analysis of the mental models and strategies controlling performance. At Risø, we entered the study of mental strategies of actual work in the late 60s. At that time, use of verbal data was not quite acceptable but, to our great relief, Jacques Leplat and his group appeared on the scene at a meeting in Amsterdam in '68 with an analysis of the mental navigation strategies of taxi drivers. Since then, we have enjoyed a continued interaction with Jacques Leplat and his conceptual clarity, his never failing interest in discussing new ideas, and his wide orientation in the psychological research literature has been very influential for our work on mental strategies, human error, and work analysis in general. In the present contribution, we present some of our recent developments

ANALYSIS OF MODERN WORK ACTIVITIES

Modern work environments are characteristic by a fast pace of change, by mechanization and, frequently, automation of routine work. Consequently, tasks are discretionary and require higher level analysis and decision making for which no stable task sequence can be defined. In this situation, design of information and decision support systems cannot be based on analysis of the work procedures adopted in the present system and of the established structure and practices of work. In order to identify the actually existing degrees of freedom to change and to adopt new means in the system, an analysis is required in terms of company goals and constraints, the *potential* relationships among goals, functions, and processes, the criteria available for

[1]Contribution to Festschrift in honour of Professor Jaques Leplat. Travail Humain, Vol. 56, Nos 2-3, pp. 133-155

allocation of roles to individual agents, and the coordination needed, i.e., the work organization and management structure. In this situation, distinction between the normative task desciptions and the actual activity of people, which has been one of Leplat's recurrent themes (see e.g., Leplat, 1981, 1991a&b), becomes crucial.

Alternative ways to approach work requirements which can be important candidates when major changes are made, *can not be identified by observation of the actual work activity*. In order to identify the existing options for change and to adopt new tools in the system, an analysis is required of basic *company goals and constraints*, of the *potential relationships* among goals, functions, and processes, of the *criteria* available for allocation of roles to individual agents, and of the coordination needed, i.e., the (often informal) work organization and management structure. In stable, well established systems, the central task is the application and control of certain means for certain tasks, i.e., the usual means-ends relationships are well established and stable. In a flexible, dynamic environment, however, the first and most important requirement in a task is the selection among the available possibilities and alternatives for action, and to determine the most suited one for the goal or function considered, *under the conditions given in the particular situation.* This means that, the most important description is the *possible* means-ends relations between elements of the work domain.

In consequence, there is a need for a change of the conceptual basis for field studies, work analysis and study of organizations as emerging during work. Frequently, results of field studies are only specified by the name of the system studied, such as 'power plant control room', 'steel rolling mill', and the subjects are identified in terms of their profession such as 'process operators.' Unless, however, the characteristics of the 'process' environment and of the process 'operators' can be explicitly formulated, generalization and transfer to design is difficult. The terms 'process operators' implicitly set firm boundaries around the phenomena of interest. It implies that the work environment is bounded by the process system and that the behaviour of the actors supports the design intentions behind the system. If this, except for occasional errors and mistakes, was not the case, they would simply not be 'process operators.' However, if the characteristics behind these labels cannot be explicitly formulated, results will only be useful in the system supplying the data, i.e., for applications like training and work instruction. Generalization for prediction in a different work context, e.g., another system or in response to introduction of new tools, will not be possible. The data are only valid for an implicitly defined situational context, and consequently, they cannot be accepted as results of scientific inquiry. With reference to aviation and the operating room domain of hospitals, Cook and Woods (1990) discuss the problem of being captured by the domain itself when studying semantically rich domains, and they argue for careful generalization in order to identify 'deep structures' of activity rather than 'surface structures'. They discuss the use of analogical transfer of results between domains and warn against the involved risk of leaping to conclusions without, however, explicitly to formulate a framework for generalization.

The basic problem of the classical task taxonomy seems to be the idea of a simple one-to-one relationship between 'task' and 'behaviour;' the task being the 'cause' and the 'behaviour' the effect. Traditionally, the object of classification in work psychology has been tasks, and a taxonomy has been directed to a definition of tasks *as such*. This approach is useful, when considering stable work environments with related professions for which a work practise has evolved with stable work procedures or when considering the normative task sequence which is required for control of well structured technical systems such as technical weapon systems (and complex high risk systems such as power plants and chemical process systems) for which much of the psychological task taxonomy work has been made. For many modern flexible systems, such as manufacturing systems in a highly turbulent and competitive environment, stable work procedures are much less typical. Most of the time, tasks are discretionary, require consideration of goals and constraints and exploration of the boundaries of acceptable performance.

In most work environments, a normative task description is an instruction serving to explain to workers and other kinds of actors what they are supposed to do, to define the initial condition from which their adaptation sets out. To define the boundary condition around their activity, the behaviour shaping constraints have to be defined in terms of a framework which can capture the features of the work environment which are underlying and implicit in the normative task. Generalization cannot be done by describing the activity with reference to deviation from the "task," reliable description can only be obtained for modern, flexible work setting in terms of the behaviour shaping constraints, i.e., by going beyond the "task" representation to the characteristics of the environment and, at the same time, to the actors' goal structure and performance criteria.

To create a systematic taxonomy which makes it possible to relate properties of a work environment to the cognitive resource profile and subjective preferences of a person is no simple matter, and several different dimensions have to be considered. Furthermore, in order to be well focused and to give a rapid convergence of the number of facets to consider during analysis, a well defined *point of departure* should be found.

The theoretical basis of a taxonomy derived from our field studies in several domains (Rasmussen et al., 1991), follows from the need to be able to describe adaptive socio-technical systems operating in a flexible environment and can be summarized in some fundamental principles:

1. The systems we study are *goal directed, they have to serve purposes in an environment in order to survive.* The socio-technical system exists because the system and the environment shares certain goals, which, by recursion, is the case both for the entire system and for any sub-set in terms of teams and individuals. In stable systems, goals and constraints to a large extent are implicit, being embedded in practice and customs. In dynamic systems posing discretionary tasks, in contrast, goals and constraints are changing and must be explicitly considered. Systems for which information technology is particularly influential exist in dynamic, turbulent environments, their goals change, requirements and opportunities in the environment change, and the means and tools to pursue goals and adapt to changes vary. In this

situation, a taxonomy must reflect this exploration and adaptation by the agents to the work environment.

2. From the first principle it follows that work and work organization in a dynamic environment are depending on *self-organizing* and *adaptive* mechanisms. The system is adaptive in the sense that it will change properties to maintain match with needs when its internal conditions and/or the environment change. Adaptation is a kind of *goal following* behaviour. Performance is changed to keep some measure related to performance criteria of the system at an optimum. *Control of adaptation* is distributed across all individuals, teams and organisations. In other words, a distributed, self-organizing feature will shape the functional structure of the system, the role allocation to people, and the performance of the individuals. To be useful for analysis of work and for prediction of responses to changes of work conditions, the taxonomy must reflect the mechanisms underlying *the evolution of work practice*. Adaptation is evolutionary, it is not planned by anybody by rational analysis. The properties, i.e. the structure and performance of the system, emerges from the "survival of the fittest " of the structures and performance. This happens to a large degree as a result of trial and error experiments, planned and unplanned, conscious and unconscious.

3. Great diversity of behavioural patterns is found among the members of an organization. To identify the kind of behaviour to expect among all the possible options for action, we have to identify the *objectives and constraints* which shape behaviour by guiding the choices taken by the individual together with the subjective performance criteria which are applied by the individual agents to resolve the remaining degrees of freedom. A problem in identifying behaviour shaping constraints is that *they will not all be active at the time of the behaviour* they control. Behaviour has a prehistory. Patterns of behaviour evolve, they are shaped by prior decisions and choices. When a certain behaviour is planned by situation and goal analysis and consideration of alternative options for action, the behaviour shaping constraints are being compiled into cue-action patterns and will not be active in later situations, when the particular pattern of behaviour is re-used. It is, however, necessary to identify these 'hidden' constraints in order to predict and understand behaviour, even if they are no more needed for control of behaviour. This identification can be difficult, because often they are no more known by the actors and therefore have to be inferred from the work requirements, the resource profile of the actor, and their subjective performance criteria.

In this way, knowledge about goals, constraints, and internal functional properties of the work environment is only necessary for initial planning of an activity, for exploration of the boundaries of acceptable performance in new territory, not for control of behaviour during repeated encounters of the same situation.

In stable work environments, know-how and established work practice are normally learned by novices from the older staff members, and optimized empirically in a trial-and-error mode. In this situation, the basic understanding of goal structures and internal functionality will tend to deteriorate (see e.g., Ackermann and Barbichon, 1963). Some kind of such declarative knowledge, however, is still useful for rationalization and explanation of the reason of the activities. Therefore, a kind of 'operator logic' or myths about goals, reasons, and functionality can evolve and replace the knowledge actually underlying system rationale. Such an informal, mythical knowledge-base will not be reliable when disturbances or changes require analytical, knowledge-based planning. Therefore, to base decision support systems on 'operator logic' will be a mistake. Furthermore, mythical operator logic will not be a reliable source of information about the work domain, such a representation must be based on analysis of the actual functionality of the domain. For this, a formulation of the intentions and reasons behind work domain structure is necessary and inferences from field studies are necessary. For decision support, ways to bring this knowledge-base of the work domain to the agents' disposal should be found, if they are supposed to improvise during disturbances and changing work conditions.

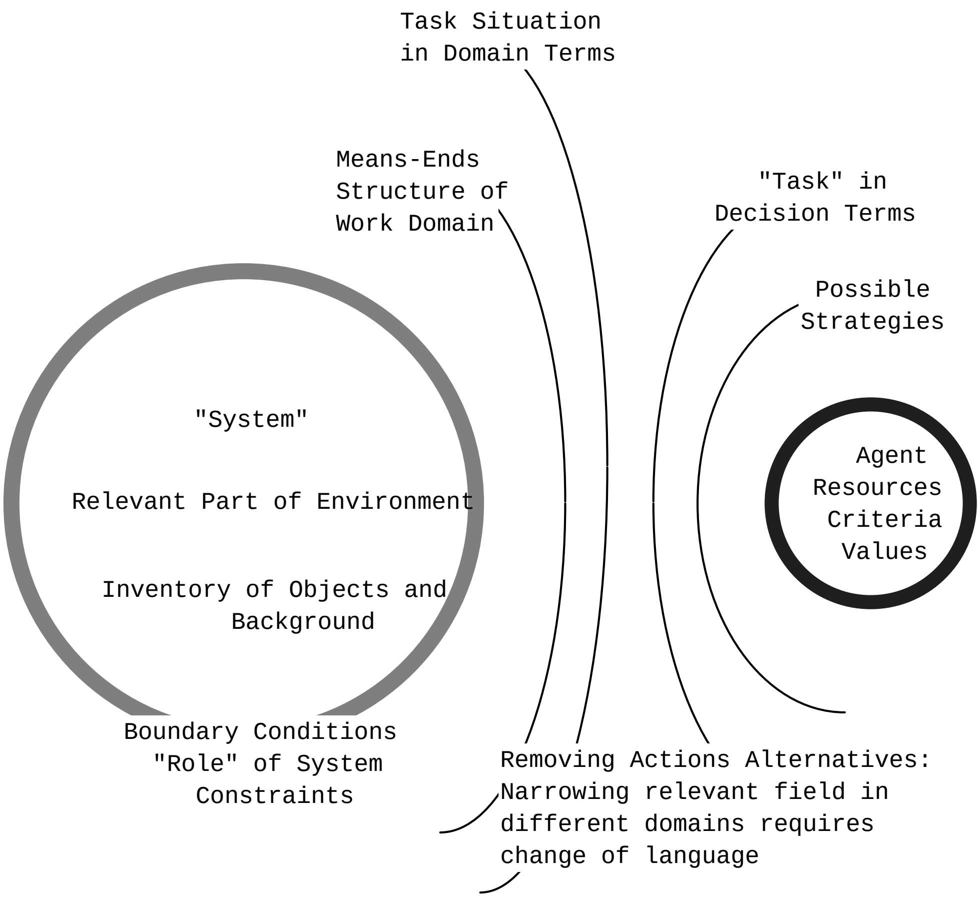

Figure 1 illustrates the problem faced when developing a taxonomy for predictive models of behaviour in a complex work context. Several layers of representation in different languages are necessary to relate a description of the characteristics of a particular staff member in terms of cognitive characteristics and subjective preferences to the characteristics of a work environment.in terms of language of the work domain.

A TAXONOMY FOR ANALYSIS OF WORK

From this discussion it follows, that a conceptual framework is needed for the strategic planning of integrated information systems including advanced human-machine interfaces in high-tech systems. This framework must serve analysis of the behaviour shaping constraints of a work place and, at the same time, reflect the subjective interpretation of the work environment by the agents involved. To comply with this requirement, the representation of the work domain should be based on interdisciplinary and ethnological studies of the actual work environment, not on normative formulations of work requirements. In this way, the approach will have to combine several sciences spanning from engineering to the basic human sciences. Concepts from several sciences are needed to formulate several levels of analysis bridging from the description of the physical properties of work domains to the subjective values of agents, as illustrates in figure 1. In order to bridge from a description of the behaviour shaping constraints in work domain terms to a description of human resource profiles in cognitive terms, several different perspectives and languages are necessary. The concepts and categories of the taxonomy is described in detail elsewhere (Rasmussen et. al, 1990) and an overview is given in table 1.

Table 1: Overview of the Elements of the Taxonomy

1. Work Domain, Task Space.

Categories related to the structure of the work domain:

Coupling to the Environment: Nature of coupling; Service offered; Goal specificity; Stability; Degree of competition; Locus of Control;

Intrinsic coupling within domain: Functional coupling and regulations; Constrains; Rules, Laws, Agreements; Level of System Integration (number of links, the strength of coupling, temporal characteristics); Predictability; Source of regularity (stable laws of nature; human intentions; or rules and regulations).

Elements of work domain: Goals and constraints, value measures for priority judgements; General functions in professional domain terms; Processes related to activities and tools; Material resources in terms of people, premises, and equipment.

2. Activity Analysis in Domain Terms.

Generic categories of activities to be labelled in domain terms: Exploration of domain; Maintenance of state of affairs in response to disturbances; Response to disturbances; Response to change of requirements; Change of state of affairs according to plans or situations;

3. Decision Analysis in Information Terms.

Generic decision functions: Data collection and observation; Situation analysis and diagnosis; Evaluation and priority judgement; Decision and choice; Planning; Execution; Monitoring.

Categories of states of knowledge punctuating decision tasks: Observed data, State of affairs; goal to pursue; Target to reach; Task to perform; Procedure to use; Action to perform.

4. Information Processing Strategies.

Classes of generic mental strategies: Analytical, model-based strategies; Empirical categorization-based strategies; Empirical recognition driven strategies.

Elementary cognitive processes of mental strategies: Induction; Deduction; Hypothetico-Deduction; Search; Comparison and Choice.

5. Allocation of Decision Roles.

Principles of Allocation: Domain Related, Function related, and Process related allocation architecture.

Allocation criteria: Organizational tradition; Functional de-coupling; Load-sharing; Agent competency; Information access, etc.

6. Management Structure and Social Organization.

Categories of management styles: E.g., Autocratic, Hierarchic, Heterarchic, Anarchistic, Democratic and Diplomatic coordination.

7. Mental Resources, Competency, and Preferences of the Individual Actor.

Type of knowledge: Declarative Knowledge; Procedural knowledge and scripts; Frames and episodic representations.

Extent of knowledge: Experts; Novices.

Ability to use knowledge: Level of training.

Meta-kognitive knowledge: Evaluation of own performance, etc.
Performance criteria: Cognitive strain, Cost of observations, Fear of failure, Joy of learning, Elegance in inference process, Etc.

Table 1 presents a brief overview of the elements of the taxonomy, for more detail see Rasmussen et al. 1990

Figure 2 illustrates two concurrent analysis of work and work performance. One serves the identification of the activities of the individual staff member, another serves to identify the role and characteristics of the individual agent. In addition, the mutual relationships between these two concurrent aspects of an analysis should be kept in mind.

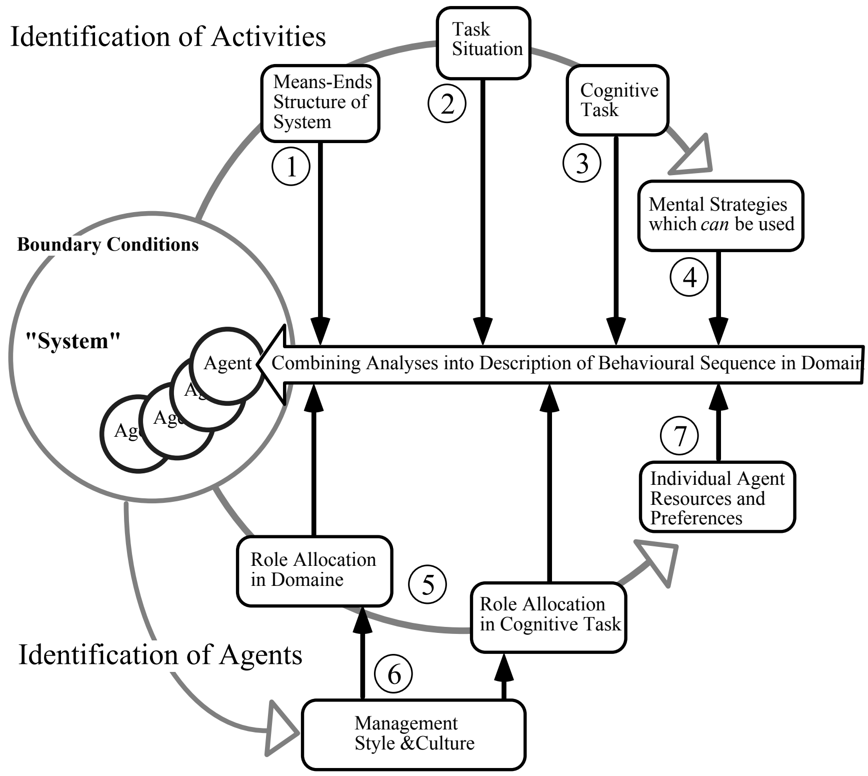

Figure 2. An overview of the taxonomic framework. The behavioural trajectory unfolds from the interaction of the task requirements, as identified by the upper analytical sequence, and the individual agents role and resource profile, as identified by the lower sequence.

1. Identification of activities. This is concerned with the 'work requirement,' which will be compared to the agent's resources and preferences in order to determine the individual choice of performance. It is important to stress that this analysis will not be a normative prescription, but should be based on an ethnologic analysis of actual performance. It includes implicitly, by the selection and formulation of task and strategies, the subjective formulation by agents of their actual goal, the way they view their task, and their possible 'cognitive styles.' This is done by including the repertoire of *'possible'* formulations of tasks and strategies which, judged from the field studies, are relevant and *can be used* by an agent dependent on the subjective interpretations.

2. Identification of the agent. The other line of analysis is aimed at a description of the role, the resource profile, and the subjective preferences of the individual agent and of the cooperative structure. This analysis involves the description of the evolution of the actual (informal) cooperative structures and work organizations. The organization here will be considered an open, self-organizing system, in accordance with the management and organization theories such as those presented by Thompson (1967). For a comprehensive review, see Scott (1987).

The interaction between the two aspects of analysis is complex and iterative. *Task allocation* interacts with the description of the structure of the work domain and the nature of the task situation. The description of the mental strategies which can be used must be compatible with the description of the individual's resources and preferences. Finally, when a match between possible strategies and preferences has identified the chosen strategy, it has to be 'folded back' onto the higher levels of analysis and the work domain in order to determine the actual behavioural sequence.

USE OF THE TAXONOMY FOR IDENTIFICATION OF BOUNDARY CONDITIONS OF PSYCHOLOGICAL EXPERIMENTS

Innovative information system design cannot be based solely on the results of work analysis in an existing work place. Due to the complexity of any work environment and the adaptation of individuals, teams, and organizations to changes of work conditions caused by a new system, predictions made from field studies can only be hypotheses. Experimental verification of design concepts as well as empirical evaluation of system prototypes will often be necessary. It will, therefore, be helpful, if the framework used for field analysis of work can also be used for design of evaluation experiments.

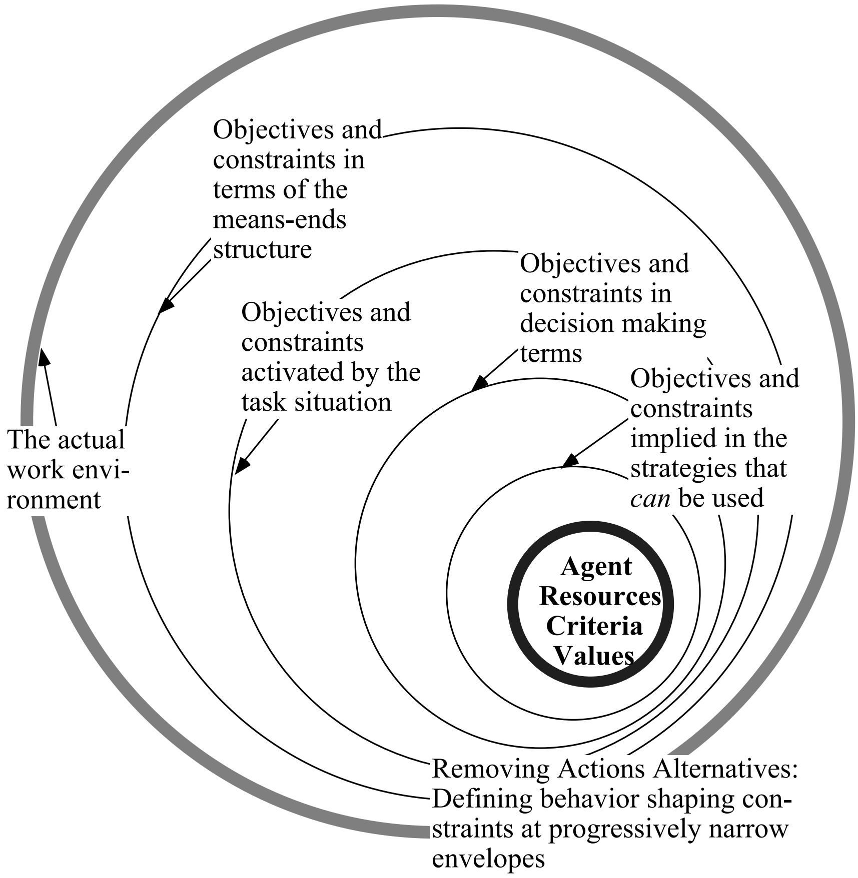

Figure 3 shows a re-interpretation of the perspectives of description of the work taxonomy as being a set of objective and constraint envelopes around an actor which can be used for generalization and transfer of knowledge during system design.

Experiments, simple and complex, have many roles in design and evaluation of information systems in particular in a period when new systems to no great extent can be based on incremental change of prior designs. During design, experiments can be necessary to test hypothesis about the effectiveness of new tools in well established tasks, of the use of certain complex mental strategies made attractive because new interfaces and tools relieve mental work load involved, etc. Following the conceptual design, experiments based on prototypes of varying complexity will be used to validate the design ahead of expensive system manufacture. Therefore, evaluation experiments are used for many different purposes, and the experimental design will be matched the scope and nature of the actual problem.

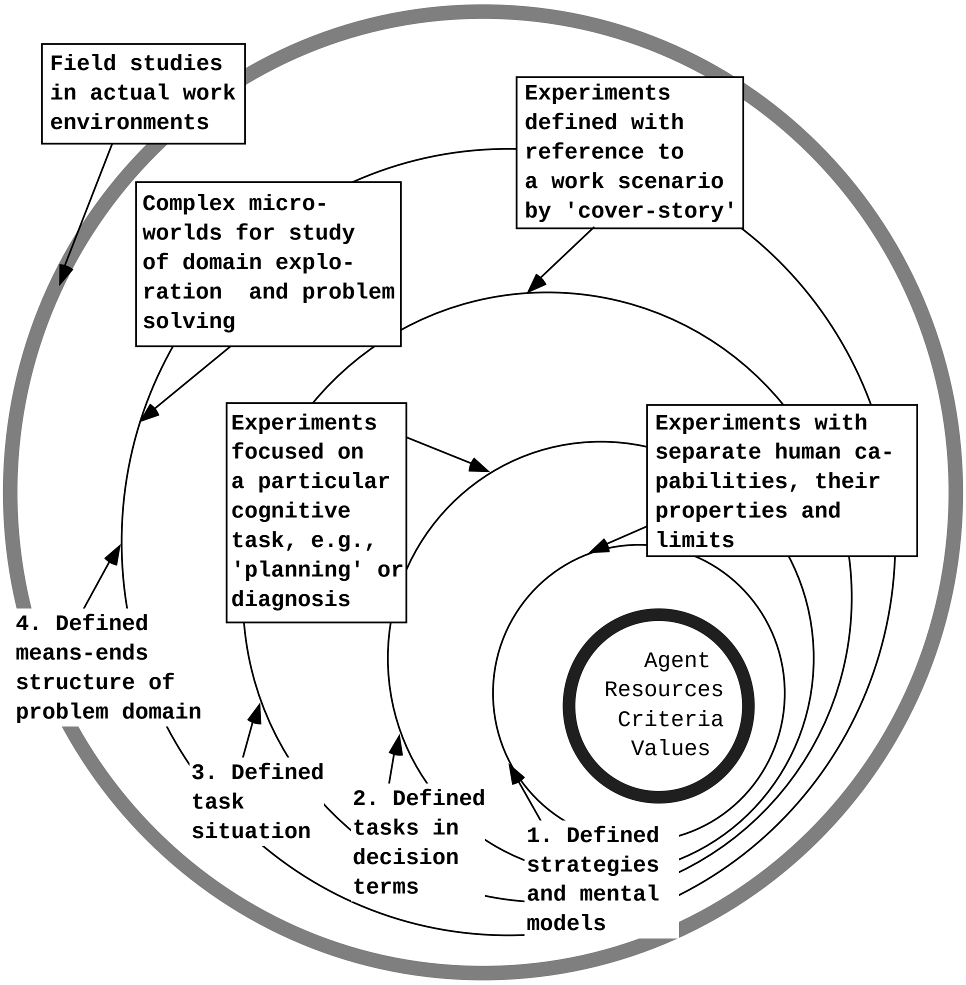

Figure 4. For psychological experiments, a sector of a natural human work environment is separated to serve as an experimental vehicle. Experimental design implies the choice of constraint envelopes around the subject, and the dimensions of taxonomy for analysis of cognitive work which is based on a representation of behaviour shaping constraints appears to be well suited to represent the conceptual design of experimental tasks. The figure illustrates the relationship between the different conceptual layers of constraints of the taxonomy and different approaches to experimental design. The constraint envelopes shown match directly the perspectives of analysis shown in figure 1.

For psychological experiments, a section of the natural human environment is separated to serve as an experimental vehicle. For the experimental design, the behavior-shaping constraints of the work place must be identified and regenerated for the experimental task. Proper experimental control implies an explicit definition of the boundary of the particular cut which, as illustrated by figure 3, can be done at each of the levels of description defined by the taxonomy. This definition of the boundary conditions "de-couples" the experiment from un-controlled influence from the rest of the (experimental) environment and identifies factors and variables which should be defined and controlled by the experimenter.

To be useful for the explication of experimental conditions chosen, a framework should represent, in an exhaustive way, the boundary conditions of the experimental work scenario and of the competence and prior knowledge of the subject with reference to the natural environment. The boundary of the experimental "world" vary considerably dependent on the aim of an experiment and, the different experiments represent different levels of representation of the behaviour shaping constraints at the boundaries.

The framework described in the previous section is based on the view that work performance evolves within a set of constraints which can be described at different conceptual envelopes around the agent. Since experimental design implies the choice of constraints envelopes around the subject, this taxonomic approach appears to be well suited to represent the conceptual design of experimental micro-worlds. Figure 4 illustrates the relationship between the different envelopes of constraints used in the taxonomy and their relationship to different experimental approaches. The point being that the present diversity in the complexity of experimental designs in fact depends on difference in the choice of controlled, conceptual boundaries around a subject. The boundaries match closely the constraint envelopes used for the framework.

EXPERIMENTAL DESIGNS

Psychological experiments have different purposes, and the experimental domain chosen will reflect these differences.

MEANS-ENDS RELATIONS	PROPERTIES OF EXPERI-MENTER'S DOMAIN	SUBJECT'S DOMAIN	SUBJECT'S NORMAL DOMAIN
GOALS & OBJECTIVES, CONSTRAINTS	*Experimental Objectives and Constraints*	*Subject's Goals*	*Goals and Constraints of Work and Leisure*
PRIORITY MEASURES, MONETARY VALUES, PERSONNEL,	*Experimental Evaluation Measures*	*Subject's Priorities*	*Subjective Priorities and Performance Criteria*
MATERIAL GENERAL FUNCTIONS AND ACTIVITIES	Experiment ***Functions involved in Experiment***		*Functions Of Work and Private Life*
PHYSICAL ACTIVITIES AND PROCESSES OF EQUIPMENT	***Physical Processes of Experimenal Equipment***		*Processes known from Work and Private Life*
APPEARANCE, LOCATION & CON-FIGURATION OF MATERIAL	***Configuration of Lab. and Equipment***		*Familiar Objects , Configurations and Topography*

Figure 5 illustrates the interaction between the means-ends structure of the experimenter, of the subject-in-experiment, and of the subject in normal context.

In addition to the identification of the boundary conditions with reference to the constraint envelopes of figure 4, an identification of the boundary conditions of the experimental work domain and the private world of the subject is necessary. It is a trivial fact that an experiment is embedded in the world of the laboratory and the researcher and, at the same time interacts with the private world of the subject. To make the interaction among these domains explicit and to characterize the dependency of the type of experiment in focus, the means-ends structure of the conceptual framework discussed above is useful. In the classical, psychological experiments, the set-up of the experiment and the instruction of the subject are intended to de-couple the experimental conditions from the private world of the subject. In complex experiments (such as the recently popular "micro-worlds"), however, "cover-stories" defining the content of the task by reference to the subjects' general world experience are used for instruction. The characteristics of such different approaches to instruction provokes a closer look at the different types of experiments as defined by the boundary conditions shown in figure 5. The figure illustrates that the equipment, its processes and semantic functions are shared by the subject's and the researcher's world, but that this is not (necessarily) the case for the related priorities and goals. In the following sections, the boundary conditions within these worlds are reviewed for different experimental designs.

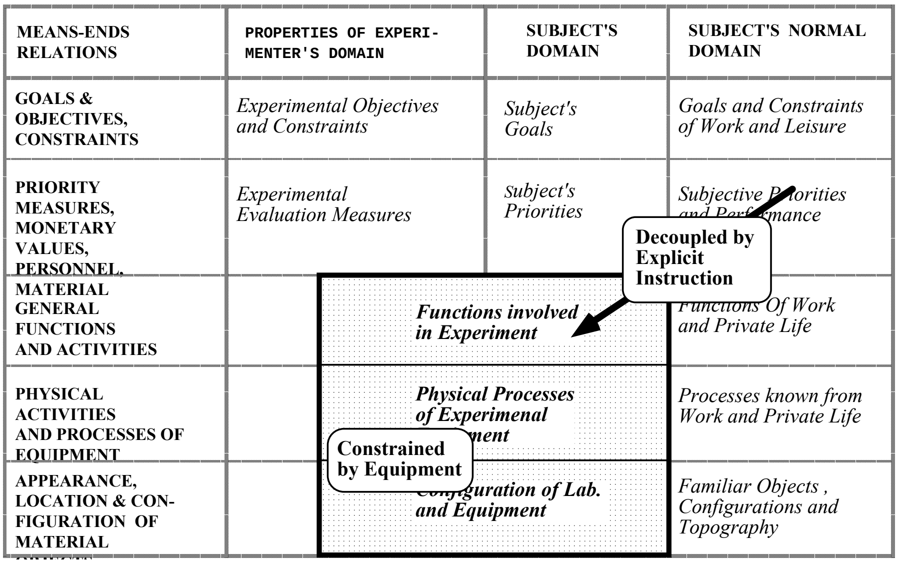

Figure 6. In classical experimental psychology, instruction of task procedures is very explicit, i.e., the particular process to be applied in the experiment is clearly specified together with a process-related criterion, e.g., related to speed or accuracy. In effect, the experimental work space is effectively de-coupled and consideration of all higher level functions, goals, and priorities is excluded by the instruction, only the lowest levels of the means-ends hierarchy are relevant for the subject. A peculiar condition is the close relationship between the processes of the experimental equipment and the experimental task, which is not found in more complex simulation scenarios.

1. Study of separate *psychological mechanisms*

Classic psychological experiments are designed to identify and describe separate psychological phenomena. Influenced by the natural sciences, experiments are based on counting and measuring observable phenomena and a well developed methodology has evolved shaping scientific accounts in a standard format of hypothesis, method, findings and discussion and with a strong emphasis on statistical significance of the quantitative findings. Good examples from the human factors domain are controlled experiments to selectively measure human performance parameters such as speed, accuracy and signal-to-noise ratio in motor control; capacity of working memory span; etc. Experiments for this purpose are based on carefully selected and well controlled experimental tasks which selectively stress the application of particular psychological mechanisms. For such purposes, experimental tasks are normally very artificial and have special research related labels such as, e.g., tracking task, dual choice task, etc.

The instruction of the task procedure is very explicit, i.e., the particular process to be applied in the experiment is clearly instructed together with a process-related criterion, e.g., related to speed or accuracy. In effect, consideration of all higher level functions, goals, and priorities is excluded by the instruction, only the lowest levels of the means-ends hierarchy are relevant for the subject, see figure 6. This explicit formulation of the instruction at the procedural level defines the constraint boundary around the situation and, thereby isolates the situation from the general, personal knowledge background and performance criteria of the subject.

2. Studies of particular *cognitive tasks*.

Another classical category of psychological experiments are focused on studies of cognitive tasks in terms of the elements of decision making, such as diagnosis, planning, manual control and monitoring.

Within the human factors areas, the methodology of experimental psychology has been extended to more complex studies in terms of manual control. Such studies have typically been made in the control theoretic paradigm, see for instance the pioneering work McRuer et al. (1957) and Crossman et al. (1962). In these studies, the boundary conditions of the experiments are rather well defined because the behaviour shaping constraints to a large degree are given by the properties of the simulated work system.

Another group of experiments is focused on studies of problem solving and decision situations. In that case, the cognitive processes are more complex and less constrained by the environment. An illustrative example of this category and the involved problems in generalization and transfer to work conditions is experiments on diagnostic reasoning.

In this category, the boundary condition of the experimental scenario is defined by the cognitive task given the subjects, in general without specifying the strategy except implicitly by the particular presentation of the problem. In the present context, a frequent problem appears to be that experiments are initiated by problems identified from actual work performance and a "cover story" is used for instruction of the subject which refers to the work context without a rigourous analysis of the difference in behaviour shaping constraints with respect to criteria for choice of mental strategy. If the difference in constraints cannot be explicitly formulated, other means of identifying the different mental strategies in work and in experiments must be used (verbal protocols, discriminant analysis, cluster analysis, etc.).

An example is diagnostic behaviour which has been studied extensively within the social judgement paradigm, based on regression analysis of the effect of available cues on the judgment of subjects in laboratory environments. Studies have been focused on diagnostic judgment in several professional activities such as stockbrokers, clinical psychologists, and physicians (see e.g., Brehmer, 1981). In experiments, cues identified as diagnostically relevant by expert judges are used to present subjects with trial cases, generally in the form of verbal descriptions on paper. From the experimental sessions, a statistical model describing diagnostic behaviour is identified. The general result has been that linear statistical models, such as multiple regression analysis, have been adequate. The conclusions from the diagnostic experiments illustrate the kind of results aimed at in this category of experiments: The judgment process tends to be very simple. Even though experts identify up to 10 cues to be relevant to diagnosis, they actually use very few, usually only two or three, and the process tends to be purely additive. Furthermore, the process tends to be inconsistent. Subjects do not use the same rule from case to case, and judgment in a second presentation of a case may differ considerably from what it was the first time. There are wide individual differences even among subjects with years of experience. They differ with respect to the cues used and the weights they apply. Finally, people are not very good at describing how they make judgments (Brehmer, 1981).

In terms of the taxonomy discussed here, the constraint envelope around the subject is defined at the decision task level, see figure 4. In the experiments professional subjects are normally used, such as e.g., medical doctors, and the task is well specified in terms of a diagnostic problem stated in professional domain terms, The experimental setting, however, is removed from the natural context and it is an important question to what extent this fact forces the professional subjects to chose a different mental strategy for diagnosis.

The problem to consider for this category of experiments is not the validity of the results, but the generalization possible. Frequently, generalization is made in terms of the behaviour of professionals in the same nominal task, e.g., "diagnosis" under actual work conditions; a generalization which is unreliable (see e.g., the discussion in Rasmussen, 1991). Reliable generalization at this level of constraint specification requires the identification of the relationship between the experimental situation, the possible mental strategies, and the performance criteria governing the actual choice. In the present case, generalization should probably be stated in terms of ability for intuitive, multiple attribute judgment, rather than expert diagnostics.

We find, that the taxonomic framework suggested here can serve to resolve much of the standing controversy about the value of laboratory experiments for understanding "real life" work which often is caused by lack of explicit description of the boundary conditions of experiments in terms which transfer to a work context. The structure of the experimental work domain, faced by the subject in this category is somewhere between the situations illustrated by figures 6 and 7. The functions required by the subjects is to a lesser degree related to the configuration and processes of the experimental set-up, and the explicit task instruction is to some degree replaced by a "cover story" referring to work context (trouble shooting, scheduling, etc.).

3. Study of performance in actual *task situations*

Recently, an increased interest has been found in more complex experimental settings serving to study hypotheses about the relationships between particular task parameters and task performance. Examples are studies of the influence of features such as task complexity, information feedback delays, interface representation, etc. Such experiments are normally made in more complex task environments than the experiments just mentioned in order to have the necessary flexibility and variability.

Therefore, laboratory tasks are frequently designed to mimic actual work situation in process control, forest fire fighting, hospital diagnosis, etc.

In this category, one line of study is based on mathematical modelling. This has, in particular, been the case for modelling human performance in aircraft and vehicle control in terms of an extension of the manual control paradigm to include complex optimal and adaptive control models (for review see Sheridan and Ferrell, 1974). Due to the rigourous representation in terms of sets of differential equations (possible due to the well known dynamics of an aircraft) and of the parameters involved in planning and decision making, the boundary conditions of the experiments are explicitly known and the basis generalization well documented.

The problem is that transfer of the methodology to less constrained environments is difficult if not impossible. Another line of experiments has therefore emerged, based on more qualitative, causally formulated task scenarios, (for a review of activities in Europe, see e.g., Funke, 1988). In this category, are the studies of decision making and diagnostic behaviour in task situations in simulators of high functional fidelity for e.g., aviation, chemical process plants, power plants, etc.

In this category, for instance, a line of experiments has emerged, based on simulated industrial process systems. Examples are the work by Moray et al. (1986, 1989), Sanderson (1990), Vicente (1991) studying diagnosis and problem solving in simulated industrial process tasks. Also Morris et al. (1985) have been doing experiments in diagnosis and problem solving in simulated industrial process tasks and other examples are GNP, a simulator of a generic nuclear power plant (Goodstein, 1985), the auxiliary feed-water system simulation (Cacciabue et al. 1990) developed by the ISPRA group. Since the simulations are designed as replicas of actual work scenarios, the expectation is of course, that the behaviour observed in these micro-worlds will mimic the behaviour of actual people in the "real situation" provided that the subjects have some experience with the real system. An important factor to consider is, however, that this kind of simulation normally is focused on a particular task, such as e.g., "diagnosis" or "scheduling" and, at the same time, is focused on a particular part of the system. This will change the constraint set at the boundaries around the experiment. For example, when the simulation is concerned with some work process, the laboratory situation will differ from the real work situation in that the subject may work alone, rather than as a member of a shift team, the motivational structure may be different, the person may work for a shorter time, and so on. Whether these differences are important must he carefully assessed. The proof of the ability to generalize, therefore, will not be in whether or not the micro-world produces the same kind of behaviour as the work situation does, but whether a theory is available which supports useful predictions about what will happen in a work situation, or for explaining what is observed in such a situation from observation during experimental situations. The only possible way to generalize from such experiments is to seek an identification of the behaviour shaping features at the boundaries of the experimental situation,in order to be able compare to other situations and systems.

In such simulated task experiments, the boundary of the experimental domain is less well defined because the a "cover-story" is used to invoke the subject's "private" context. That is, specification of the boundary conditions is made with reference to the subjects experience with or general understanding of the work scenario which is mimicked. See figure 7. It is, therefore, necessary that the functional structure of the experiment match the context alluded to by the cover story. This match can only be demonstrated by the identification of the behaviour shaping constraints by a consistent conceptual framework and intimate knowledge of the actual substance matter domain.

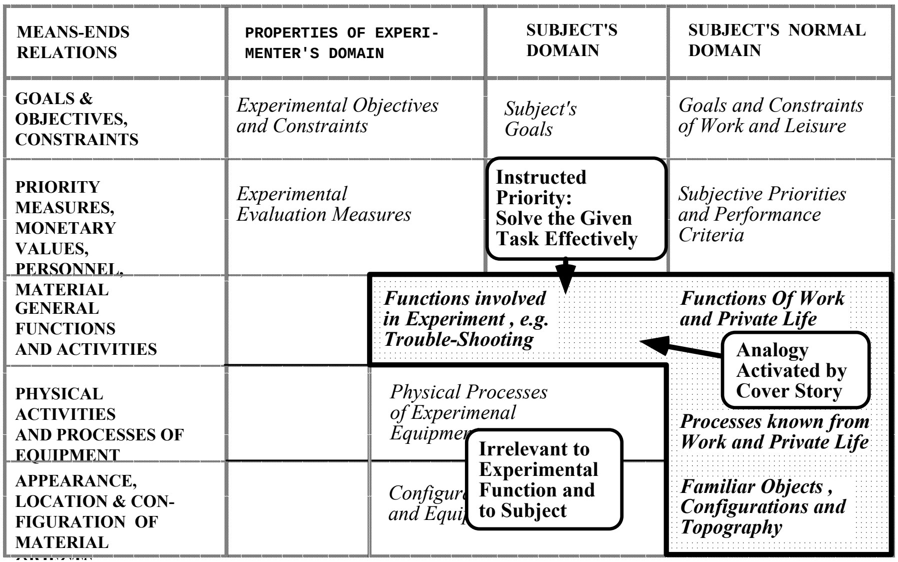

Figure 7. Complex experimental settings serving to study hypotheses about the relationships between particular task parameters and task performance are frequently designed to mimic actual work situation in process control, forest fire fighting, hospital diagnosis, etc. In such experiments, specification of the boundary conditions is made with reference to the subjects experience with or general understanding of the work scenario which is mimicked.

4. Study of performance in *complex work domains*

The experiments in this category are aimed at a study of the performance of subjects in exploration of a problem domain, their formulation of the problem they face, the goal they adopt, and the solution they generate. In this case, the instruction of the subjects cannot make explicit the goal of the experimental task, neither the experimental task procedure since the study of the formulation by the subject is the central experimental objective. Consequently, the instruction necessarily is very open and given by a description of a 'cover story,' i.e., a description of an actual work situation which has been the source of the simulated relational, functional network, see figure 7.

Such micro-world experiments have been used in the European Esprit project Mohawc to study human performance in complex work context, see the discussion by Brehmer (1990). The studies of Dörner (see Dörner, 1989) are very good examples to discuss this category of experiments from a taxonomy point of view. In a simulation of a town, "Lohhausen" subjects were asked to act as the major of the town and to look after the well-being of the inhabitants ("fur das 'Wohlergehen der Einwohner' zu sorgen." Op. cit. p. 87). The formulation of operational goals and the identification of means for action were left to the subject who, not being professional mayors, only had the choice to rely on trial and error or, more likely, to import intuition from their private life. In this case, performance is highly influenced by the particular background of the individual subject.

In this way it is very difficult to control reliably the actual goals and performance criteria adopted by the subjects, when naive subjects (e.g., psychology students) or even professional agents from the particular work domain are asked to cope with tasks in this environment.

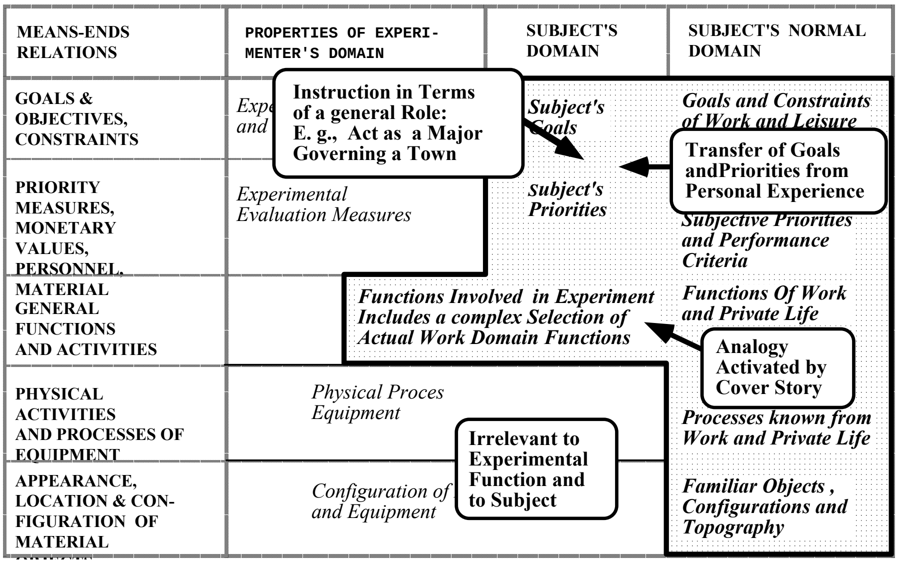

Figure 8. Recently, several experiments are aimed at the performance of subjects in complex problem domains, their formulation of the problem they face and the goal they adopt. In such experiments, instruction of subjects can make explicit neither the goal of the experimental task nor the experimental task procedure since the study of the formulation by the subject is the central experimental objective. Consequently, the instruction necessarily is very open and is given by a 'cover story,' which relates the experiment to the general experience of the subject.

When instruction in a complex experimental task is given by a cover story, the personal experience and knowledge-aboute-the-world is activated for control of the task with very idiosyncratic effects. Dörner gives some beautiful examples of this influence: In the Lohhausen experiment, a subject who is a school teacher, focus activities on particular teaching problems in the school system and leaves rest of the society at its own; a left wing subject decided to introduce extensive socialistic measures and explained difficulties by reactionist sabotage; a student subject without any experience in production planning used a simple analogy, that is her personal experience from rolling her own cigarettes, for her decision making.

It is, of course, the intention to keep the higher functional properties of the task, the working goals and subject priorities as undisturbed as possible but it should be realized that the physical process and anatomy of the real work domain are replaced by the processes and anatomy of the computer installation, see figure 8. Typically, a subject will be well aware of this fact, in particular when "in trouble". It is often found, that a subject will explain unexpected simulator performance by program inadequacies or bugs. In an actual work environment, there is a very subtle, many-to-many relationship between the goals, the functional level and the possible implementations at the physical process level and it will be very difficult for a subject to judge what is and what is not included in the simulation. The subject will, therefore, have to infer a number of goals, constraints, and functions from more or less intuitive assumptions about the task as conceived by the designer of the experiment.

In this situation, it is important to be able to analyze and describe explicitly the actual source domain of the research hypothesis as well as the research domain selected under the assumption that human agents in any work domain are basically goal directed, adaptive organisms having several mental strategies at their disposal in each situation and choosing the actual strategy from context and situation dependent performance criteria. If we accept this basic assumption, we can only draw conclusions from selective experiments and simulations, if we explicitly can describe the similarities and differences between the actual behaviour shaping constraints of the actual work conditions and of the experimental conditions.

Instructions, Metaphors and Cover-Stories.

In experiments, subjects are supposed to control an experimental set-up, a micro-world, according to an instruction. The content of the instruction changes with the experimental strategy. In classic, well controlled experiments, the instruction can be explicit and unambiguous. In complex experiments with "micro-worlds" such explicit unambiguous instructions are impractical and "metaphorical" instructions are used. A cover story is a very effective short hand instruction. An attempt to formulate an instruction without retreating to a metaphor, i.e., expressing it in terms only relating to the features of the simulation display, and actions upon it, turns out to be complicated, lengthy, and incomprehensible. A cover story should be based on a context very familiar to the subject as well as the experimenter, and the relational structure of the simulated work should be faithful to the cover story to avoid unpredictable interference from the subject's private life.

In general, the problem with complex experiments, i.e., micro-worlds, is not the ambiguity of the metaphorical or cover-story instruction, but the problem of explicating the condition for generalization. Generalization cannot be made by reference to the metaphor or the cover story. The micro-world results typically are not related to process control, trouble shooting nor to majors controlling a town. Generalization can only be made by reference to explicitly formulated behaviour shaping constraints. In short, the main problem of experiments in complex micro-worlds is one of establishing a framework for explicit representation of the features of the experimental context, it is not caused by the use of a cover story for instruction of the subjects. The cover-story works one way, the generalization back to possible contexts is another question.

CONCLUSION.

The taxonomy described here is not a classical taxonomy as found biological sciences, nor a teleological taxonomy but a conceptual framework which can serve effective generalization from scientific research, i.e., field studies and lab experiments. The problem is that research is not, generally, aimed at specific applications and the ultimate use of its results cannot be predicted. Consequently, results cannot be formulated in terms of a teleological taxonomy and an exclusive, hierarchical taxonomy is only useful for formal library classification. What is needed for generalization is a multi-facet framework for description which can be used to specify the boundary condition of an experiment or a particular analysis as it is or can be embedded in a larger context. In figure 9 an attempt is made to illustrate this problem.

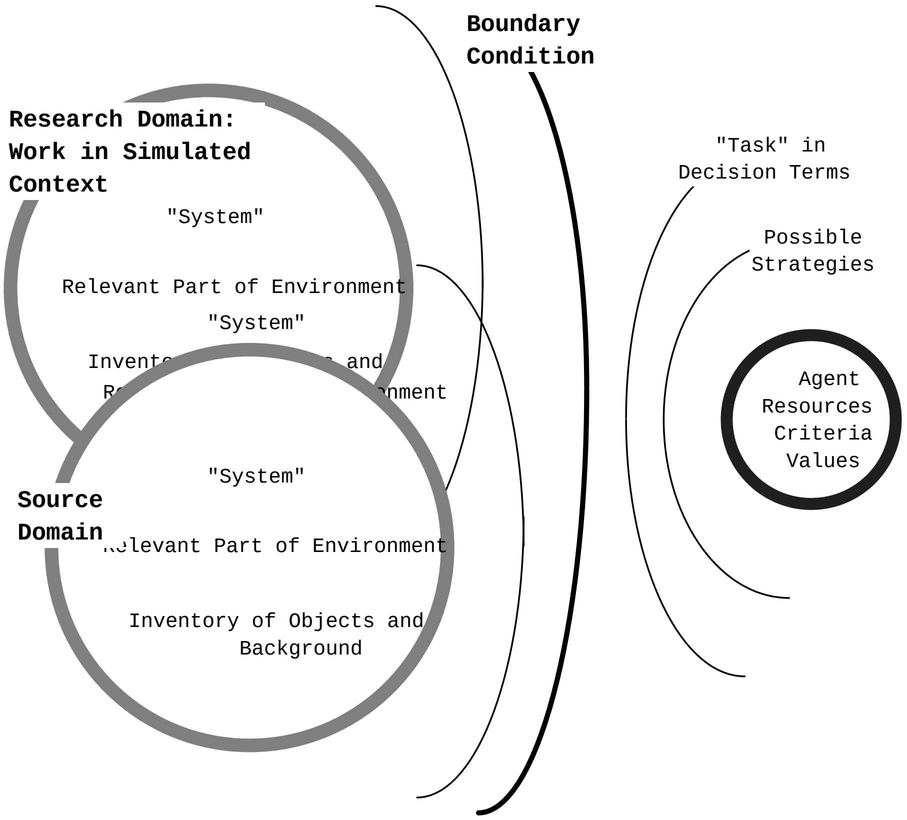

Figure 9 is intended to illustrate that for specification of the boundary conditions around an experiment, we are not seeking a classical, exclusive and hierarchical taxonomy. Instead we need to be able to specify the conditions at the "cut" around an experiment to be able to transfer to one of the many possible worlds of relevance. For this, we need a multi-facet framework for description.

Research of any kind is supposed in one way or another to separate and cut loose a phenomenon in its local context for detailed study and to formulate results in a generalized form, i.e., in a form useful for statements of the phenomenon embedded in several wider contexts or "possible worlds of interest." To enable such transfer, the boundary conditions at the edge of a cut should be specified. This is a multi-dimension specification problem, not an exclusive classification task. Precision in representation which is attained in classical, biological and library classification by a multi-level hierarchical structure, in the present problem is emerging from precision in an intersection of slices made from several orthogonal points of view.

In conclusion, the taxonomy we are concerned with in the present context is not a taxonomy in the classical, biological sense, but a multi-facet framework for specification of boundary condition for selective studies and for subsequent generalization into possible contexts for transfer of results.

REFERENCES

Ackermann, W. and Barbichon, G.(1963): Conduites Intellectuelle et Activité Technique. *Bull. CERP* 12 (1), 1-16.

Brehmer, B. (1990): *Toward a Taxonomy for Micro-Worlds.* Contribution to MOHAWC Workshop, Manchester, November 1990. [To be published.]

Brehmer, B., (1981): Models of Diagnostic Judgment. In: Rasmussen, J. and Rouse, W. B. (Eds.): *Human Detection and Diagnosis of System Failures.* New York: Plenum Press, 1981.

Cacciabue, P. C., Codazzi, A. and Decortis, F. (1990). The Analysis of the Functional Role of Man and Machine in the Control of a Notional Auxiliary Feedwater System. in J. Rasmussen, B. Brehmer, M. deMontmollin and J. Leplat (eds), *Proceedings of the First MOHAWC Workshop on Taxonomy for Analysis of Work Domains*, Liège, 15-16 May. Roskilde: Risø National Laboratory

Cook, R. I. and Woods, D. D. (1990): *Characterizing the Operating Room Domain*. CSEL Tech. Report No. 90.006. Colombus, OH: ohio State University

Crossman, E.R.F.W. and Cook, J.E. (1962): Manual Control of Slow Response Systems. International Congress on Human Factors in Electronics, Long Beach, Ca. Also in: Edwards, W. and Leeds, F.P., (Eds.): *The Human Operator in Process Control*, London: Taylor and Francis, 1974.

Dörner, D., (1988): *Der Logik des Misslingens.* Reinbek dei Hamburg: Rowohlt

Funke, J., (1988): Using Simulation to Study Complex Problem Solving. *Simulation and Games,* Vol. 19, No. 3, September 1988, 277-303

Goodstein, L. P. (1985). *Studies of operator-computer cooperation on a small-scale nuclear power plant simulator* (Risø-M-2522). Roskilde, Denmark: Risø National Laboratory, Electronics Department.

Knaeuper, A., and Rouse, W. B. (1985). A rule-based model of human problem-solving behavior in dynamic environments. *IEEE Transactions on Systems, Man, and Cybernetics, SMC-15,* 708-719.

Leplat, J. (1981): Task Analysis and Activity Analysis in Field Diagnosis. In: Rasmussen, J. and Rouse, W. B. (Eds.): *Human Detection and Diagnosis of System Failures*. New York: Plenum Press, 1981.

Leplat, J. (1991a): Organization of Activity in Collective Tasks. In: (Eds.): Rasmussen, J., Brehmer, B., and Leplat, J.: *Distributed Decision Making: Cognitive Models for Cooperative Work*. London: Wiley and Sons.

Leplat, J. (1991b): Activity Field in Dynamic Process Control or What is Controlled? Third European Conference on Cognitive Science Approaches to Process Control. Cardiff, UK, September, 1991.

McRuer, D. t. and Krendel, E. S. (1957): *Dynamic Responses of Human Operators*. W-DC-TR-56-524. US-Air Force.

Moray, N., and Rotenberg, I. (1989). Fault management in process control: eye movements and action. *Ergonomics,* 32, 1319-1342.

Moray, N., Lootsteen, P., and Pajak, J. (1986). Acquisition of process control skills. *IEEE Transactions on Systems, Man, and Cybernetics, SMC-16*, 497-504.

Morris, N. M., Rouse, W. B., and Fath, J. L. (1985). PLANT: An experimental task for the study of human problem solving in process control. *IEEE Transactions on Systems, Man, and Cybernetics, SMC*-15, 792-798.

Rasmussen, J., (1991). *Diagnostic Reasoning in Action*. Risø-M-.2952 .Roskilde: Risø National Laboratory. A revised version to appear in IEEE, Trans. SMC, May 1992

Rasmussen, J., Pejtersen, A.M. and Schmidt, K. (1990): *A taxonomy for Analysis of Cognitive, Cooperative Work.* Risø-M- 2871. oskilde: Risø National Laboratory

Rouse, W.B. (1982): A Mixed Fidelity Approach to Technical Training, J. *Educat. Technol. Syst.* 11 (2), 103-115.

Sanderson, P. M. (1990). Knowledge acquisition and fault diagnosis: Experiments with PLAULT. *IEEE Transaction on Systems, Man, and Cybernetics*, SMC-20, 225-242.

Scott, W. Richard (1987): *Organizations: Rational, Natural, and Open Systems*, Prentice-Hall, Englewood Cliffs, New Jersey.

Sheridan, T.B. and Ferrell, W.R., (1974): *Man-Machine Systems: Information, Control, and Decision Models of Human Performance,* Cambridge, MA: MIT Press

Thompson, J.D. (1967): *Organizations in Actions*. New York: McGraw-Hill.

Vicente, K. J. (1991). *Supporting knowledge-based behavior through ecological interface design* (Unpublished dissertation). Urbana, IL: University of Illinois at Urbana-Champaign.