Human Activity Modeling for Systems Design: A Trans-Disciplinary and Empirical Approach

Saadi Lahlou

EDF R&D/SINETICS/ Laboratory of Design for Cognition
1 ave du Gl. De Gaulle,
92141 Clamart, France
CNRS-EHESS/IIAC/ Centre d'Etudes Transdisciplinaire,
UMR 8177, Paris, France
saadi.lahlou@edf.fr

Abstract. Complex system design is about technical specifications, but also how humans act in the loop in Dissemination, Operation, Maintenance and Evolution (DOME) of the system. In system specification, we focus on distribution of work between humans and systems. In design of system's DOME, on building an ecology of individual motives, organizational rules and mediating structures to keep the system sustainable. In our participative design process itself, on how to enroll and maintain test users in realistic experiments. We adopt a complementarist approach: we use different models of human cognition and behavior for each aspect. Human behavior is determined by many factors including subject's motives and goals, constraints and affordances of the context. We list here which models we use and how.

Keywords: design**,** activity theory, cognitive attractors, cognition, social representation, affordances, goals, distributed cognition, situated action, ecological psychology, involvement.

1 Introduction

A main issue in complex systems design is that they include humans in their loops. Most devices and sub-systems are man-made artifacts; they are therefore somewhat predictable, even in their failure. But the "human factor" remains a source of uncertainty in design and operation. Of course, humans are also partly cultural artifacts, and behavior can be made predictable by training and rules. But there are limits. As Lomov [1963, p. 23] states: "(…) a man remains a man even when he enters the role of a link in the control system". We need humans in the loop of complex systems since Man is more plastic than machines with regard to information input, processing, execution, and is able to "grasp" improbable events [Lomov, 1963, p. 21]. So at least in the near future of complex systems design the human factors issue is here to stay.

After a brief overview of literature (section 2), we describe our design approach, "experimental reality" (section 3). *Experimental reality* is based on collaborative design and incremental change; it has lighter requirements in terms of cognitive

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models of the user. Section 4 describes which models of human behavior we use, for system functions specifications, for "process of system design" itself, for design of the system's life cycle: Dissemination, Operation, Maintenance and Evolution (DOME).

2 Models of Human Cognition

Many are the models of human cognition and behavior. Let us briefly mention some, in a short and incomplete overview, to show the variety of existing models, and how they address different levels: mind, subject, organization, culture.

In Herb Simon's seminal work [Simon, 1945, Simon & Newell, 1972], the human is seen as an entity who solves problems. Subjects strive to find an efficient pathway in an incompletely known "problem space". Using bounded rationality, they apply heuristics to reach solutions until they find one which is good enough ("satisficing"), e.g. by trying existing routines and previously known solutions.

In this now classic perspective, an important issue is what mental structures and which cognitive processes are used to represent the situation, and deal with it. *Mental models* [Johnson-Laird, 1993], *social representations* [Moscovici, 1961; Abric 1994], *simuli* [Minsky, 1985] *scripts* [Shank & Abelson, 1977, Rumelhart & Norman, 1983] are some the many theories dealing with these entities.

Other authors focus on how the situation provides actors with constraints and possibilities. *Ecological Psychology* describes how elements in the context are directly interpreted in terms of what action is possible: "connotations of activity" [Uexküll, 1965] or "affordances" [Gibson, 1967]. *Situated action* [Suchman, 1987; Lave, 1988] describes how action emerges as subjects try to realize their plans while been taken in the flow of situations. Subjects can make sense of their *course of action* [Theureau, 1992] but they are far from being in full control. Still, there are general principles which account for the activity of operators in complex systems.

Rasmussen (1983, 1985) with the *Skills, Rules, Knowledge* model introduces a hierarchical perspective on the levels of operator behavior, as problems require more or less cognitive resources to be solved (from the simple routines at "Skill" level to complex reasoning at "Knowledge" level for completely new situations).

Subjects are not solely driven by the problem: they have intentions, goals and values. *Activity theory* [Rubinshtein, 1940, Leontiev, 1959, 1974; Nosulenko & Samoylenko, 2006] provides powerful conceptual tools with the notions of goals (conscious representation of the desired state) and motives, and of the Man's relations with instruments [Rabardel, 1995]. In the course of goal-driven activity, "actions" are steps to the goal in the conditions given. Actions or parts of actions can become automatic "operations" which are executed beyond consciousness. "Subjects" in activity theory can be individual or collective.

The collaborative aspect of work is dealt with by many models grounded in anthropology, sociology and social psychology. These models tend to include institutions and artifacts as major factors for coordination. In these theories, the focus is on the system as a whole. Humans are considered from his perspective as agents in the system, while in the previous approaches the system was rather considered as a context for human action. *Cognitive sociology* (Cicourel, 1973) and *distributed* *cognition* (Hutchins, 1995a; Cicourel, 1994) are powerful conceptual frameworks; they describe how processes are distributed over the cultural and socio-technical system, and how artifacts and institutions play the role of *mediating structures* (Hutchins, 1995) which guide action.

This short trip in theory shows how varied current models are; we believe they all do have some explicative value. This is why we opt for a complementarist approach [Devereux, 1970]. Instead of choosing a single model of cognition for everything[1], we use different models for different situations or design issues, (see section 4).

Although global theories may be quite different, a recurrent, mainstream, trend in cognitive ergonomics when it comes to application and actual systems design is to consider the human as an information processor and decision maker, with specific focus on *cognitive bottle-necks*, especially attention and memory. In this perspective, great care is taken to design interfaces for low workload, to avoid multitasking, to distribute information over several sensory modalities to avoid overload. The empirical literature reflects this pragmatic approach which goes with the need to give quantitative specifications to the engineers who build the devices and interfaces in the system. Operational models and methods exist which link theories of cognition to this technical issue of resource allocation and Man-System interface design, e.g. Cognitive Function Allocation [Boy, 2001].

In the design phase, a risk is that a great deal of the cognitive aspects of the aforementioned theories is lost, and that in the final system humans find themselves playing the role of the general-purpose plastic link between rigid mechanical systems described by Lomov. In other words, humans in complex systems do have a specific functional role, but they often also implicitly have the vicariant role of fixing a technical system that was built imperfect. This reality of this “human as a repair” contrasts with the claims that systems are user-centered. Our design approach tries to avoid this problem by constantly keeping users empowered in the design process, hereby forcing designers, engineers and other stakeholders to *continuously* take the human user’s perspective into account.

3 Design in Experimental Reality

Constructing models of human cognition in general is a daunting task. Fortunately, designing systems is a specific activity and therefore we do not need to solve the general issue of human cognition.

Also, some design approaches need less cognitive modeling than others. This is the case of our design approach, e*xperimental reality*, based on procedural, incremental changes rather than on a full analysis and specification of the problem space. This section describes our approach.

“Experimental reality” [Lahlou, Nosulenko & Samoylenko, 2002] is an attempt to practice *participative design* in comfortable conditions. The general idea is to obtain the enrollment of a population of subjects in a long term realistic test of successive versions of the system being developed, under intensive observation. To do this, *a whole real system is instrumented for observation*. For example, when designing systems to fight against cognitive overload, we transformed individual offices into

[1] “For who has only a hammer, everything looks like a nail”.

observation rooms with continuous monitoring, where we could change various elements of furniture and measure changes [Lahlou, 1999]; to design augmented work environment, we constructed a whole building which was equipped for observation, and then inside this living laboratory we installed a population of real users with their workstations to do their everyday job [Lahlou et al., 2002]. The experimental but real system becomes a “work in progress” where designers and users work *together* on a continuous basis to imagine and test new arrangements. For example, to develop augmented meeting rooms, we provided a comfortable meeting space which could be reserved for free, in an industrial facility housing more than 2000 office workers (engineers, scientists, administrative personnel). Maintenance and operation of the space was provided by the designer team, so the space was fully functional and used as such; hundreds of actual meetings took place in the space. This space was continuously filmed and interactions analyzed [Lahlou, 2005]. The design team could then modify gradually the system (here, the room, devices, interfaces etc.) to fix emerging issues. In doing so, the design team focuses attention on the failures of the system, on the parts of the process which the users complain about, or which seem “strange” or costly from an engineering or human factors perspective. This is a first place where we need cognitive models of activity. This approach is different from testing a new solution on a case, since our process also interweaves both test and continuous (re)design phases.

This design strategy needs strong and long term support from the management ; and trust from users ; it requires straight ethics so that observation is accepted by observees, it costs important investments in observation (sensors, procedures and analysis) ; but in the end it proves more efficient and cost-effective than classic approaches. This strategy is especially adapted to the design of complex systems which must be scaled out and endure continuous evolution because of technological drift. For example, in the case of augmented collaborative rooms, even though meeting rooms have been scaled out in the company since 2002 based on the specifications of the test room, we currently (2007) keep research on this “mother room” active in order to test new devices and possible improvements. When these improvements prove positive, theses changes are scaled out to the existing rooms, therefore ensuring that the whole fleet of rooms is up to date.

An interesting aspect of this approach is that it solves naturally the problem of transition from present state of the art to the new system; since what it does is precisely experimenting this transition with real users.

This design strategy can be applied only when one can construct a system that is operational enough to be used by actual users in a real process; and if this population of users can be enrolled in “playing the game” of continuous design. This is another place where we need cognitive models of humans. Although this seems quite a tough requirement, in fact these conditions are not as drastic as it may seem. Indeed, many complex systems are actually not designed from scratch, but often stem from a present version which can then be used as the test system. And recruiting users in the design process is also often possible as long as the design process accepts to take into account users’ goals and personal interests beyond the mere functional optimization of the system.

4 Models of Cognition for Experimental Reality

In order to proceed with experimental reality, we need models of human behavior at three levels: for system functions specifications, for design of DOME, for the process of system design itself.

In system specification phase we try to understand which functions can be supported by the devices, and which by humans; we also investigate the sources of malfunction, mistakes, and users' displeasure. We focus especially on how the environment can prompt and support the users into best collective practice.

In the design of DOME, we focus on the growth and sustainability of ecology of individual motives, organizational rules and more generally of mediating structures which will ensure the viability of the system on a daily basis at reasonable cost.

In the process of system design, we are interested in users as participants in the design process, we focus attention on how to enroll and maintain the relevant actors in the design process.

These three aspects are not independent. Some of the cognitive models we use serve more than one aspect, but they will be presented separately for more simplicity.

4.1 Design of Functional Specification of the System

The main model we use is Russian *activity theory*, because it helps specifying the goals of the system (common goals). We try to avoid situations where goals of users as individuals are against the common goals. So, at every step of design, we try to make *explicit* the goals of the humans in the loop. We do so by observing and asking the subjects. In the frequent cases where there is discrepancy between goals, we try to modify the situation so that individual goals can be pursued without conflicting with global system operation. It is our philosophy not to try to fight against individual goals because we consider that individuals will find their way through whatever counter-measures we could design as long as they are motivated; the final cost of their frustration or hidden activity to reach satisfaction may be more costly to the system than organizing legal or tolerated paths for individual satisfaction.

For example, many reasons why individuals participate in meetings have nothing to do with the meeting agenda. E.g. they want to discuss informally other issues with some participants [Lahlou, 2005]. Unless this goal can be satisfied in the margins of the meetings (e.g. onset, breaks) participants may be restless and tend to introduce theses topics in the discussion. This was a problem in the design of systems for distant collaboration (visio-conference, etc.) since the structure of distant-meetings breaks was not adequate for such informal discussions. We therefore installed a "boarding" procedure which enables informal contacts.

Understanding the goals and motives of operators is also important because these goals can be used to remind the operator what is important e.g. in emergency.

Another model we use is *cognitive attractors*. It states that humans are always potentially following several paths of activity, since they carry many goals to reach; and that subjects arbitrate their resources between these different paths. In other words, subjects continuously choose between various potential problem spaces to deal with ("problem choosing"). Empirical evidence suggests they tend to choose the problem with the best value/cost ratio. Cognitive attractors theory states "problem choosing" is often a low level "capture" of the subject by a specific type of activity rather than the result of a conscious decision-making process.

Capture by a specific activity occurs when a critical mass of elements of this activity both in the context and in the mind "attracts" the subject. The force of the attractor is a combination of the value of the goal of the activity, the cognitive cost to be spent, and the pregnance of the elements [Lahlou, 2000].

When designing new systems, we manipulate these factors in order to keep the humans in the track of what they are supposed to do individually, to ensure a correct global operation of the system. For example, we use displays to keep operators focused on their present goal and task; we try to filter out potential distractors, we carve the affordances of devices so as to keep present course of action at a lower cognitive cost than potential distractors. Also we try to keep the activity *fluid* since break-downs or pauses in the process are often moments when subjects switch to another activity. For example a pause when the subject waits for system-response is often used to start another (short) task in parallel.

Ecological psychology is the cognitive model which guides us in the design of affordances of devices. We try to make "what is to be done" explicit in the form factor of objects. Moreover we do not merely consider that objects have affordances or connotations of activity; we consider them as full actors in the system, as does Latour [1993]. This means that not only devices should provide system feed-back to users, but also that they should behave as agents capable of initiative, e.g. by modifying their display to engage humans into specific actions. In this perspective we consider the system as an arena for set up for distributed activity (and this is how we understand Hutchins's distributed cognition), where an ecology of agents try to make the state of the system progress towards the goal [cf. Hutchins's cockpit, 1995b]. In this perspective, human or artificial agents reciprocally serve each other as mediating structures to guide, control, and remind what is to be done. Any part of the system which recognizes a specific situation or critical state through its sensors and interpretive equipment may signal it to other parts of the system.

Social representation theory [Moscovici 1961; Abric, 1994] helps us to understand how the common knowledge necessary for coordination between actors is structured, created, and disseminated. Social representations serve as an internalized user's manual for operating objects and behaving in the system [Lahlou, 2001]. Creating or modifying representations, and pushing the subjects into mobilizing the proper ones, is a crucial aspect of fluid system operation. For example, single participants in multiplex visio-conference meetings behave differently whether they participate from their office or from a meeting room. When they are in a meeting room, the social representation of "meeting" is activated by the context and they tend to be more attentive and to sidetrack less in individual tasks (like processing their email). A new practice goes with a modified social representation, and therefore constructing this modified representation (with training, manuals, rules, communication etc.) is part of interaction design.

Still, in this ecological vision of a collaborative work between humans and other artifacts, our bias is towards the anthropocentric perspective adopted by Russian psychology (Leontiev, 1974). Although artifacts and humans are involved in a collaborative activity, humans have preeminence in decision and the right to bypass or override mechanical systems.

4.2 Design of Dissemination, Operation, Maintenance and Evolution

A system must survive, and evolve in time to do so since its environment changes. Dissemination, Operation, Maintenance and Evolution take place in every system. If they are not designed *ab initio*, the system will not adapt properly to its environment, and the organization will have to input pressure and investments to keep it alive. For example, dissemination can cost a lot if the system is difficult to learn, and even more if it conflicts with other existing systems or practices. Such costs often stay hidden because they incur on other budgets, but from the global organization and the user's perspective, operation is much more fluid and comfortable is these issues have been considered and solved at initial design stage.

First, we check every stake-holder will get a benefit in having the system work. This is true for the innovation phase, as Latour shows, but also for the rest of the life of the system. For every problem encountered, we set up a solution which brings some benefits to the stake-holder involved. Some of these solutions may very pragmatic and involve managerial decisions and trade-offs (e.g. recognizing a new qualification to employees with a specific pay bonus); for the dissemination phase we may set up informal deals with specific individuals (e.g. contributing to the test brings them in contact with new partners or other Divisions, which may help their career).

In Dissemination design, when we use trickle down theory [Veblen, 1899]. We make participation in the new system desirable and fashionable by involving the top management. Another technique we set up with success it to build in some empowerment for viral dissemination. E.g. for our collaborative platforms, any registered user of the system can enroll another user upon his own responsibility and therefore get the social benefit of this offering this "enablement" Lahlou, 2005].

But finally, the most important is to keep users in track, by manipulating costs and creating social rules so as to make the "good practice" (understand: the one coherent with the common goal) have a lower cognitive cost for the user than other practices. This is done, as said in section 4.1 by distributing mediating structures over the environment to remind the users the goals, provide them with adapted affordances all along the activity path, filtering out potential "distracters", and organizing "drainage" so that individual goals can be satisfied in way that does not get in the way of general goals. So what we try to design is not a system-as-it-should-be, but a system-in-actual-use, including the "informal" aspects inherent to the fact that Man-in-the-loop is a human, with other interests and goals than simply be a part of *this* system. To start with, each human is part of *many* systems inside and outside the organization.

As no present cognitive theory in powerful enough to directly provide specifications for all these aspects, we proceed by trial and error during design phase and all along the system's life cycle, by observing and solving problems and discrepancies as they emerge, in a pragmatic way. Keeping a trustful and constructive relationship with the users provides us with rapid feedback and often with excellent design ideas. When users believe that reporting problems and suggesting solutions will indeed produce re-designs of the system, they get motivated in doing so and their contribution prove extremely useful. Not all users have good ideas all the time, but some users have very good ideas sometimes.

4.3 Models for the Process of System Design Itself

Our approach depends upon the involvement of the users in the design process. For this, we rely again on activity theory: we try to find ways of aligning the test user's goals with ours. For example, we ensure that users have some real interest (and no risk) in providing us with accurate behavioral data, and to use our experimental systems. This may lead us to choose subjects who either have a strong interest in the new functionalities offered by the new system; or have a specific interest in showing cooperation, or are interested in using the behavioral data for their own purpose. This is especially true in the first stages of design when the advantages of the new system are counterbalanced by poor usability, and when we need "friendly users".

Another theory we use is the social psychology of involvement [Lewin, 1952; Joule & Beauvois, 1998]. E.g. subjects get more involved when they have top "pay" in some way. We make the participation of a user a volunteer and formal process, where users sign off "informed consent". Subject's involvement is public, and ritualized. They are warned that having access to the experimental system is a privilege, in exchange of which they may have to undergo cumbersome interviews. Everything is done to transform the participation into a formal social contract between the subjects and the design team, especially in the initial phase.

5 Conclusion: Better Many Conceptual Tools Than One

Our pragmatic design approach led us to abandon the procrustean dilemma of choosing a one-fits-all model of cognition. Although our position is sometimes difficult to stand on academic grounds, we use different theories for different aspects of our design process, mainly: *activity theory, cognitive attractors, distributed cognition, ecological psychology, social representations, social psychology of involvement*.

Most important remains to set up a work-in-progress structure where actual users are empowered along the whole design and DOME process. This way, once again, the human factor brings innovation and compensates for the limitations of models. The fact that our design teams mix engineers, designers, stake-holders and end-users helps us to stay focused as a group on the problem, and to keep models of cognition in the modest role of *tools*. When we try to create solutions our belief in the power of these models remains limited. Experience showed that, in practice, it is sometimes possible to solve, *in specific cases,* problems for which we do not have, yet, general solution in theory.

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