A descriptive model of contextual activities for the design of domestic situations

Pascal Salembier
ICD-Tech::CICO (FRE 2848 CNRS)
University of Technology of Troyes
Troyes, France
Pascal.Salembier@utt.fr

Julie Dugdale
MAGMA-LIG
University of Grenoble
Grenoble, France
Julie.Dugdale@imag.fr

Myriam Frejus
Yvon Haradji
EDF R&D
Clamart, France
myriam.frejus,yvon.haradji@edf.fr

ABSTRACT
A challenging topic for cognitive ergonomics and cognitive engineering is the development of smart applications and devices which apply some “intelligence” of the situations, i.e. commonsense knowledge about the occupants of the household, their individual and collective routines, and their expected patterns of behavior. Most people spend more time at home than in any other place, including work places, but few studies have been conducted on how new context-aware technologies could support people in their everyday life. Spaces that subtly reconfigure themselves according to their occupants and use can cause rejection or acceptance, depending on how intelligently they are designed. In this paper we describe a descriptive framework for contextual activities that aims to support collective thinking about the design of services for the domestic users.

Keywords
Scenarios, Situation Modeling, Design, Contextual technologies

ACM Classification Keywords
H.1.2 [Models and principles (e.g., HCI)] User/Machine Systems – Human Factors

1. INTRODUCTION
Contextual technologies are said to help us manage different critical aspects of individual and collective situated activities in various social contexts. However, it is also a new source of complexity and a challenge that designers have to face when introducing new services. The range of traditional issues have extended to new ones: for example what can we expect when moving information technology from the centre of actors’ focal attention into the periphery and what are the likely consequences on the organization of cooperation between users and devices and between the occupants of households themselves. In the recent years many studies have been conducted in order to better understand the articulation between ambient technologies and the social organization of domestic activities. These studies show the variety of approaches currently used, from a mere description of domestic life through ethnographic studies which attempt to assess the impact and role of technologies on domestic life, to more technology oriented views which tend to focus on computational, rather than social aspects of domestic life [1,2].

The approach we have adopted in the In-Situ project is to build heuristic descriptive models of contextual activities in order to provide a basis to support thinking about the design of services for the domestic users. The idea is not to provide a computational cognitive model of the contextual mechanisms held by the members of the household when coordinating their individual and collective activities, but rather to define:

- An acceptable, semi-formal description of these activities with a special emphasis on particular dimensions.
- A descriptive model that is a descriptive abstraction of actors’ activities in their environment, which refers to the analyst’s understanding of this behaviour.
- A transition towards the use of models for design, that is proactive models that can orientate and assess some design issues concerning the possible interest and impact of introducing contextual technologies in home settings.

The section 2 describes the background of the framework and the notion of model-based evaluation and design at the centre of the approach. Section 3 provides details of the model and focuses on describing the notions of viewpoints and cognitive equipment which are critical for the interpretation of context relevant information. Section 4 describes how the model may be applied to the analysis of a domestic scenario and the type of results obtained. Section 5 concludes the paper with a broader discussion of the implications of the model and gives our directions for future work.

2. BACKGROUND
The increasing use of mobile interactive systems and pervasive and ubiquitous services available anywhere, anytime leads researchers and designers to question what is interaction and cooperation. Ubiquitous and pervasive applications have contributed to put the notion of incidental interaction [3] at the forefront of research on interaction and cooperation in “intelligent” environments. For example: a young child walks around in a kitchen (a potentially hazardous area) and incidentally this information is made visible to her/his parents in another part of the house; the music being played in a room adapts automatically when people within starts chatting; the heating system adjusts the thermostat to the occupants’ current activities.
One critical design issue now concerns what contextual factors need to be incorporated into these systems and services. The general idea is that in order to enable meaningful interactions between the context-aware environment and its occupants, the system should be aware of the occupants’ context of activities. But what value do context sensitive services create and what is the induced cost (in terms of expense, loss of control, privacy and so on)?

Amongst the different approaches that may help to open the design space, we propose a framework based on the definition and simulation of different models of context processing. This approach to model-based evaluation uses a model of how an actor or a group of actor would behave in a particular environment in order to generate feedbacks by simulation of the model (be it a pen and pencil simulation or a computerized one).

Like traditional model-based evaluation in HCI the approach presented here can be seen as a valuable supplement to more traditional evaluation (usability testing, user-based evaluation, etc.). But the main practical objective of this type of models is to inform the design process. It is intended to be used as a tool for helping us to conduct analysis of individual and collective situated activities in domestic settings. Additionally, the tool could help the design team to assess different artifacts or different implementations of context-aware systems for assisting the collective organization of activities in the household (including energy, comfort and safety management).

The framework is grounded in the analysis of data drawn from the empirical study of several scenarios concerning various aspects of domestic life. One of these scenarios, concerning the management of lighting, is used in this paper to illustrate the approach.

3. GENERAL APPROACH

3.1 Identifying relevant key factors

By analysing both the literature on empirical studies in domestic situations and different real-life scenarios, a set of relevant dimensions for defining a framework for analysing and modelling contextual activities has been defined [4]. The following identified dimensions have been included so far in the descriptive model:

- **Routines** as a resource for efficiently organising individual and collective activities at a low cognitive cost.
- The role of **artefacts** in the domestic situation. The interpretation of an artefact’s state at a given moment determines the local context of use.
- The role of the **organisation of domestic space** is a contextualised way of organising activities.
- Implicit communication between actors in the physical environment. These communications may or may not be related to the actions of the actors.
- The **awareness** that an actor has of others activities defines the context of activity for that actor.
- The **dynamics of actor engagement**. The actors may need to manage different concerns in parallel.
- The **evaluation of an actor’s availability** is an important aspect in defining the context for the actor and for other actors.

This analysis has yielded important insights about the dimensions of domestic activities that are directly related to contextual thinking issues.

3.2 Defining different levels of “contextual ability”

3.2.1 Environment, context, situation

Contextual abilities are partly determined by the capabilities, or the cognitive equipment, that an actor has to interpret the situation. An actor uses perceptive and cognitive resources in order to recognize different events, to give them a meaning and then perform an action or not. These capabilities vary depending on the actor, for example an elderly person or a young child does not have the same perceptive and cognitive capabilities as a young adult. This means that the viewpoints of the actors will be different and hence the ability to perform an action will be directly affected.

In order to take into account these differences of equipments and to apply this idea of “levels of contextual capability” in the context of designing context sensitive systems, we drew inspiration from a generic classification made by Quére [5], who, based on Dewey’s seminal work, identified three complementary categories of “contexts”: environment, context and situation.

- **Environment**
  - An environment can be defined as a relatively stable structure composed of a location, and in which different objects are present. For example, we can speak of the kitchen as an environment defined by more or less precise physical boundaries and by the artifacts disseminated over this physical space.
  - **Context**
    - The context is the wholeness that enables meaning to be given to an event (a behaviour, a signal in the environment, etc.) and that enables the justification of meaningful actions. Broadly speaking, context can be seen as an “interpreted environment”.
  - **Situation**
    - A situation can be seen as an environment “ordered” by the experience through time and space of this environment. This “ordering” is made possible by configurations, that is walkthroughs in the environment, paced by actions involving available resources.

Let us consider the following example:

“X intends to purchase an object O. She goes out of her place, but realizes that it is raining; she then goes back home in order to get an umbrella. In the stairs she meets one of her neighbors; she chats with him for some minutes. She then goes upstairs to her flat but has forgotten the reason why she came back. She goes out and notices a traffic jam in the street; she also realizes that she is late and therefore decides to take the subway.”

We can see that X evolves dynamically in different environments (her place, the stairs, the street, etc.) that are populated by objects, e.g. other people, and in which different events may happen (rain, meeting someone, traffic jam, etc.). These different environments are interpreted in terms of background knowledge and practices and in relation with the actor’s current course of action (previous and future). This contextual set enables X to give meaning to the events that happen in the environment, and to generate relevant actions and, if needed, to justify them. For example, if there is traffic in the street, it is likely that it will be crowded in the whole area, so it
is not a good idea to take the car as X is already late due to what has just happened; that is why X finds it more appropriate to take the subway.

This ordered experience in time and space, constituted by different episodes (expected and unexpected) that take place in a succession of environments, can be viewed as a "situation" (figure 1), that is, a sequence of different contexts whose meaning or motive is given by the successive engagements and commitments of the actor, by the dynamics of her/his activity. Without this engagement, the sequence of contexts is just a set of unarticulated “contextual snapshots”.

Figure 1. Environment, context and situation

It is noticeable that a larger family of notions that stress the importance of the mutual constitutiveness of activity and context has emerged in the past years. For example the concept of “place” initially developed in the mid-nineties has recently gained interest in the HCI community. A place can be seen as a space invested with shared social meanings and expected behaviors; the space has to do with location even though the place has to do with activity. In a similar way, using the concept of situation is a mean (especially compared to the perspective stressed in the ethno-oriented studies) to re-introduce the actor’s point of view, that is the different manifestation of his/her cognition including his/her own private thinking. Concerning the underlying assumptions carried on when performing empirical analysis of activities in real settings, this kind of approach permits a switch in focus from approaches centered on the individual or on the collective toward approaches centered on the concept of situation [6].

From an analytical point of view, this three layers framework makes it possible to make an explicit conceptual distinction between the three, often confused, terms. Furthermore, it provides a basis for the integration of the aforementioned critical points identified in the literature and gives an analytical foundation for the examination of real world scenarios.

3.2.2 Technological translation

In order to better fit to a transition from human to technological contextual capabilities we have interpreted the distinction between environment, context and situation as sensor, epistemic and historical equipment needed to design a context sensitive system.

- “Sensor” or “environmental” equipment

A human actor or a system can have access to events in the world by means of different modalities (visual, auditory, olfactory, etc.). Unless he or she suffers a particular handicap, a human actor having the standard perceptive abilities would be able to capture a set of data in the environment in a predictable way. Similarly, some contextual data would be unavailable to an actor even with standard perceptive abilities: for example a human actor cannot detect a modification in the infrared spectra or a surge of power in the mains electricity supply.

- “Epistemic” equipment

Different kinds of knowledge may be required to correctly give meaning to a particular event. It may be general-purpose knowledge of the world in which the system or the agent moves. For example, by grouping sequences of actions into schemas we could plausibly infer an agent’s motives. It may be also specific knowledge about the local practices and routines i.e. the social context which gives meaning to and justifies the behaviours of the members of the group. For example, the usual organization of the household members’ activities during the preparation of the meal prescribes a mode of cooperative activity. This knowledge allows other human actors and smart systems to generate expectations about the actors’ possible actions.

- “Historical” equipment

The historical account of individual and collective experiences through time and space gives meaning to events in a particular environment. A specific previous episode of an agent can provide relevant clues to interpret the behaviour of this agent and to infer some aspects of his or her internal states. However, keeping a trace of all previous events is not enough; they must be organized in meaningful episodes.

3.3 Defining different points of view

 Actors sharing the same physical environment may have different perceptions of the context. Similarly a context-aware device may have different levels of representation of the context of the occupants’ activities depending on the nature of its sensors, and the knowledge it can apply to interpret raw data acquired by sensors. To account for these different perceptions we introduced the notion of point of view, which describes the relevant context for an actor at any given moment. The idea is to compare the views of different actors at a given time and see to identify the consequences in terms of accuracy in the process of interpreting the situation. This may be used to inform the design process and, more precisely, to check to what extent a system equipped with specific contextual abilities (sensors and intelligent inferences) would be able to interpret a situation in a meaningful or at least useful way in order to act appropriately.

Three points of view were identified: Actor, Analyst and System.

The Actor point of view can be seen as a situated model of context when a person who is equipped with identified perceptive and cognitive abilities is engaged in a specific course of action. Different actors may interpret an action in different ways. Since the same context, as seen by an external observer, may vary for each singular actor it can be interesting to differentiate as many context viewpoints as actors present in the house. Most of the time the “context for the agent” remains an individual, situated experience of the world, which is only accessible by the agent himself/herself. But the actor’s motive for performing an action may be publicly known if it has been made explicit, for example by a communicative act. However, very often there is no evidence for a motive or the internal states of an actor. The external observer therefore does not know the motive or has to infer it from perceptible manifest facts and background knowledge.

The Analyst point of view may take different faces. It can be the sum of all actors’ points of view (providing that the analyst has an access to them). When data on one or several actors are missing, the analyst must refer to available issues (manifest
behaviour, location in the house,…). The Analyst point of view may also be seen as a hypothetical, idealistic viewpoint. We can ideally imagine an omniscient, ubiquitous observer who could have a non-restricted access to all the events and facts in the environment, including the motives of the different agents. This kind of viewpoint is in some way close to, and may be seen as an enriched version of the “God’s view” used in simulation. The pragmatic interest of using such a viewpoint is that it provides a basis of reference to systematically compare the results of the application of different viewpoints to a theoretical optimum.

The System point(s) of view refers to the different levels of contextual equipment designers may consider at a given time of the design process. At a basic level (environmental equipment level) the system viewpoint describes the set of events that happen in the physical environment as raw sensor data. It may include physical events (e.g. door bell, microwave signal, phone ring), behavioural events (e.g. opening the refrigerator, entering the lounge). The environmental point of view concerns tracing the state of technological artifacts and the presence of identified people in the different part of the domestic space. The scope of environmental events that a system has access to depends on its perceptive equipment (sensors) and whether it can have access to the event at a time t or not.

A more sophisticated version of the system can add background knowledge (commonsense, local knowledge on the routines of the household,…) to the system equipment in order to interpret the behavior of the occupants or, broadly speaking, to build a picture of what is going on in the home at a particular moment. Meaningful contextual information can therefore be derived from the raw sensor data.

A step further, the designers may consider giving the ability to the context-sensitive system to keep a trace of the occupants’ commitments in order to build an historical representation of their activities. The underlying hypothesis being that this historical equipment may help the system to better interpret the motives of the human actors, and to better fit the occupants’ needs by automatically adapt its behaviour on context changes.

4. SCENARIO ANALYSIS EXAMPLES

4.1 Micro/qualitative analysis

The aim of this section is to describe how a simplified version of the framework may be used to analyse context and to show what additional information is provided by taking into account different levels of context.

The following excerpt of a real scenario comes from a large empirical study led in domestic situations. The chosen scenario concerns the implicit and explicit management of lighting by household occupants. For brevity we have extracted only a few minutes of the scenario:

The father (F) is engaged in an activity that requires a comfortable level of light.
- F is engaged in an activity that requires a comfortable level of light.
- F is engaged in an activity that requires a comfortable level of light.
- The level of light in the bedroom is too low.
- Usual routine: turning on the light in the bathroom gives the extra light needed.

In order to understand correctly why F turned on the light in the bathroom while resting in the bedroom, one needs to know these different points or must be able to infer the third one rather than knowing (and recognizing) the routine. Understanding in real time the rational behind the decision to let the light on in the bathroom, or identifying a local routine may prevent a third part (member of the household or energy regulation device) to turn off the light. From a processing point of view the inferential process needs more resources than the routine identification process: some facts may require very specific situated knowledge about the household and its members.

If we consider now the mother’s point of view, the potential problem here is that the coexistence of contradictory contextual viewpoints might lead to a misunderstanding (the mother might consider for example that letting the light on in the bathroom is useless and energy-consuming) and then lead to an inadequate (from the father’s point of view) action (i.e. turning off the light). But the background knowledge associated to this context of activity (the mother knows that the father applies this routine when he works in the bedroom and understands the rational behind it) prevents her from doing so. This example put into evidence that it is not enough to share the same environmental context (being aware of the location of the actors and of the status of the artificial light in the rooms) with an actor in order to act in a sensible way. Indeed it is necessary to infer the actor’s underlying motives (which may require a complex chain of inferences based on the available facts in the environment and on general knowledge or common sense of the situation) or to identify the presence of a routine associated to a particular action or non-action. Here, sharing a common ground with the actor may prove very helpful: it enables to quickly recognize a situation in which a local routine is applied and gives relevant meaning to a collection of events in the physical environment.

- The Analyst’s point of view

In this example the analyst has an access to the points of view of F and M and can therefore give an informed account of the context and of the rational underlying the behaviour of the actors. Would the mother have switched off the light, he could have similarly given an explanation of the context by referring to the difference in the actors’ points of view and subsequently to the expectation breakdown between M and F.

- The System points of view

Let us consider different descriptions from the point of view of a sensor-based system (Table 1). The first one considers only the states of a pre-defined set of relevant artifacts (here the light in the different rooms).

| 18:43:00 | The father is in the bedroom |
| 18:43:00 | The light in the bedroom is on |
| 18:43:00 | The light in the bathroom is off |
| 18:44:00 | The father is in the bathroom |
| 18:44:00 | The father turns on the light |
| 18:44:00 | The light in the bathroom is on |
| 18:44:10 | The father is in the bedroom |
The sensor description listed above cannot enable a “simple” system to understand that the father intentionally switched on the light in the bathroom in order to work in the bedroom. A different level of description is needed to get a correct, meaningful picture of the situation. A “smart” device equipped with enough knowledge about daily events and individual and collective routines may correctly interpret the behavior of F and act in an appropriate way (in this example doing nothing…).

In the context of the application of this type of viewpoint for design purpose (assessment of different services associated to specific tools and interfaces, for example), it is possible to define a set of “context for the agent” viewpoints that cope with the cognitive equipment different versions of a system have been provided with (the actors’ internal states may be not considered, or the tacit rules that govern one aspect of the collective organization of the household may remain hidden).

### 4.2 Macro/quantitative analysis

The simple example discussed above put emphasis on the qualitative analysis of episodes of activities.

In order to better inform the process design, it may equally be useful to take into account some relevant criteria (energy savings, comfort, safety,...) in a more systematic way. To be useful to take into account some relevant criteria (energy savings, comfort, safety,...) in a more systematic way. To illustrate how the framework may be used this way, it was applied to a real-life scenario of domestic interaction concerning the collective management of lighting. The goal was to show how different contextual competences categories produce different results. The outputs in terms of energy consumption were compared to the reference scenario (real situation). These purely quantitative data are balanced by more qualitative considerations concerning the perceived comfort and the quality of the coordination between the actors.

The first criteria used to assess the effect of the two first levels of contextual ability (environmental and epistemic) concerns the energy-saving management in the household during a particular period of time (from 6:30 pm to 8:30 am). More precisely we have identified the time during when the lights are left on in each room. The results from the reference scenario and the output of the « manual » simulation generated by the viewpoints 1 and 2 are shown in the figure 2.

Results put into evidence that the first level of contextual capability and the associated actions induce a reduction of the time during which the light is switched on, and consequently some potential energy savings in most situations but the extreme case of managing the light in the bedrooms (Ctxt_syst-ENV-1). This later situation is in some way a bit artificial and must be imputed to the rather weak capabilities of the system (which in this version is only able to detect presence of actors in a place and the current binary status of the lights – on/off). It makes more sense here to consider that the light will be turned off in the bedroom by the occupants themselves before going to sleep (Ctxt_syst-ENV-2)). The gains are obvious in two types of cases: when a light has been left unintentionally on by a person (generally during a long duration when a light has been forgotten in a non visible area, and therefore remains on) or when a light has been left on intentionally during a short time; the rationale behind the decision being for example that the actor is expecting to come back quickly into the room, or that the light on may have a meaningful function even though there is nobody in the place.

![Figure 2. Results from the simulation of the light management scenario for two levels of context processing (environmental 1/2 and epistemic).](image)

The second level of context processing adds to the “environmental” equipment, mainly based on simple sensors, a set of pre-defined general and local knowledge on the habits of the members of the household.

The results show that, with the energy savings criteria, in most of the cases the performance of the epistemic equipment is weaker than the performance of the environmental equipment. Additionally the results show that, in some cases, the performance of the system is weaker than what can be seen in the real scenario. In some cases it can be due to the fact that the system observes some local rules in a stricter manner. For example the light may be left on in a hazardous situation according to a usual tacit rule (for instance when young children are in the stairs with the light off). In some other cases this output of the manual simulation can be explained by the fact that the system applies a local routine or rule (a place is used in a continuous way during a period of time, and may therefore be left on). This kind of general principle may be directly associated with a « comfort » concern: during some particular moments associated with specific activities, the light will remain on in some a room in order to avoid repetitive manipulations of light commands that may induce additional moves (when the commands are implanted in a non optimal manner for example) or unpleasant changes in ambient light.

### 5. DISCUSSION AND FUTURE WORK

Currently we have used the model in a manual mode to analyze the implications of different levels of context. Ultimately we envisage performing computer simulations of the scenarios. However, one problem is that the analysis of contextual issues goes well beyond what can be implemented in a simulation tool. It is unlikely that a computer based analysis tool would ever be able to replace totally a human analysis. Nevertheless, it may be interesting to think about how far a computer based simulation tool could go towards helping a human designer analyze the situation. One promising approach is to use a multi-agent based system and to draw upon the work in the domain of agent-based social simulation (ABSS). The objective is to simulate collective behavior in a multi-agent simulation with an explicit « physical » model of places, facilities, tools, and a socio-cognitive model including human abilities and general or local

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1 Historical capability was applied in a more complex scenario
knowledge (for example, patterns of activities, routines and social rules that governs the organization of the household). One of the main advantages of ABSS is that it gives the opportunity to explore emergent sociocognitive phenomena, see different viewpoints and experiment with situations, which we might not be able to do in real life. ABSS is similar to an experimental methodology: simulation model can be set-up and executed many times, varying the conditions in which it runs and exploring the effects of different parameters [7]. ABSS may produce a set of data that may provide a heuristic basis and a design guidance for different actors involved in a design project. This approach has recently been demonstrated in different works focused on the notion of « participative simulation » which aims at exploring different organizational and technological issues with multi-agents platforms [8,9].

For a framework to become a practical agenda in the design of context sensitive technologies it must articulate different criteria. In the example presented above we took into account two complementary dimensions: energy savings and comfort. But other criteria may be of critical importance when designing and assessing systems devoted to safety purpose such as the supervision of elderly occupants or young children. Here the problem of shared context [1,10] between the occupants of the house and between the occupants and the smart systems become of crucial importance in order to avoid misunderstandings and breakdowns in coordination.

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7. REFERENCES


2 See for example the Simweb project (http://www.simdigital.com)