A Data-oriented Survey of Context Models*

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ABSTRACT

Context-aware systems are pervading everyday life, therefore context modeling is becoming a relevant issue and an expanding research field. This survey has the goal to provide a comprehensive evaluation framework, allowing application designers to compare context models with respect to a given target application; in particular we stress the analysis of those features which are relevant for the problem of data tailoring. The contribution of this paper is twofold: a general analysis framework for context models and an up-to-date comparison of the most interesting, data-oriented approaches available in the literature.

1. INTRODUCTION

Many interpretations of the notion of context have emerged in various fields of research like psychology, philosophy [13], or computer science [31]. Context has often a significant impact on the way humans (or machines) act and on how they interpret things; furthermore, a change in context causes a transformation in the experience that is going to be lived. The word itself, derived from the Latin *con* (with or together) and *texere* (to weave), describes a context not just as a profile, but as *an active process dealing with the way humans weave their experience within their whole environment, to give it meaning.*

While the computer science community has initially perceived the context as a matter of user location, as Dey and Abowd discuss in [2], in the last few years this notion has been considered not simply as a state, but part of a process in which users are involved [18]; thus, sophisticated and general context models have been proposed, to support context-aware applications which use them to (a) adapt interfaces [20], (b) tailor the set of application-relevant data [8], (c) increase the precision of information retrieval [43], (d) discover services [40], (e) make the user interaction implicit [37], or (f) build smart environments [21].

Accordingly, consider the example of automated support for a natural history museums visitors, who may be endowed with a portable device which reacts to a change of context by (a) adapting the user interface to the different abilities of the visitor – from low-sighted people to very young children –; (b) providing different information contents based on the different interests/profiles of the visitor (geology, paleontology, ... scholar, journalist, ...), and on the room s/he is currently in; (c) learning, from the previous choices performed by the visitor, what information s/he is going to be interested in next; (d) providing the visitor with appropriate services – to purchase the ticket for a temporary exhibition, or to reserve a seat for the next in-door show on the life of dynosaurs –; (e) deriving location information from sensors which monitor the user environment; (f) provide active features within the various areas of the museum, which alert visitors with hints and stimuli on what is going on in each particular ambient.

Artificial Intelligence developed, since the late 80s, a notion of context [23, 25, 34, 35, 42] that differs from the one considered in this paper. The AI goal was extending the existing reasoning techniques to enable contextual reasoning. The most mature approaches are Propositional Logic of Context and MultiContext System/Local Models Semantics. While the first introduces the context as a "first class citizen" of a logic theory, the second perceives context as "a partial and approximate theory of the world from some individual's perspective". Both succeed in modeling context to enable reasoning and provide extremely expressive mechanisms to exploit context in formal theories, as proved by their recent application to the Semantic Web [11, 26]. However the need for a simple, explicit, unified model of context able to gather in a single representation several individual contexts, requires a rather different approach, whose features are presented and analyzed in Section 2.

In the general high-level architecture of a context-aware system, context design is carried out according to the application domain, by modeling the elements that affect the knowledge/services/actions that have to be made available to the user at run-time, when a context becomes active.

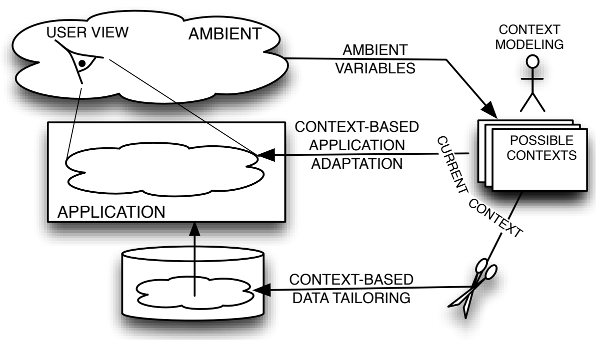

Figure 1: A context-aware system architecture

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The context information acts as the command source for input- and output- related switches, which enact alternate behaviors providing different information while all the rest remains unchanged. While in a traditional system context data are not treated as special information and the system implicitly includes all different behaviors without being aware of the multiple facets of the application ambient, in a context-aware system, context data are used to customize the way inputs are processed (Figure 1).

In Information Management, context-aware systems are mainly devoted to determining *what portion of the entire information is relevant with respect to the ambient conditions.*

Given this scenario, *context-based data tailoring* [10] can be defined as the activity of *defining data views*, based on a) the identification of the various contexts the application user is going to experience in the envisaged scenario, b) the design of a set of data views for each of the identified contexts. The aim is to provide support to the designer of data management applications, be them related to a huge (e.g., in data warehousing) or to a very small amount of data (e.g., in portable, lightweight data management systems), in determining and creating the various views to be used in the different contexts, by following a systematic approach. Indeed, nowadays the amount of available data and data sources requires not only to integrate them (still a hard problem), but also to filter (tailor) the relevant portion of data in order to: 1) provide the user with the appropriately tailored set of data, 2) match devices' physical constraints, 3) operate on a manageable amount of data (for improving query processing efficiency), and 4) provide the user with time- and location-relevant data (mobile applications).

We select the data tailoring issue as our target application because we consider it as an enabling component for the forthcoming Information Systems, such as mobile, data-intensive systems, P2P systems and in general the Semantic Web. In particular, in the last research area, huge ontologies (several millions of concepts and relations) are starting to appear, e.g., UMLS [32], while common operations such as query answering, reasoning and consistency check may be exponential in the size of the input ontology [4] [1]. Transparent context-aware sub-ontology extraction, exploiting techniques similar to the one proposed in [6], can improve the performance of ontology manipulation, while preserving the user perception of operating on the complete ontology.

Interesting surveys on context-aware systems and models have already been presented in [5, 14, 39, 45]; we contribute with a review on recent evolutions and new systems for context modeling, and challenge each model with respect to the problem of context-aware data tailoring.

We believe that no "silver-bullet" in context modeling has been proposed so far, and that a deep understanding of the context problem itself is essential to choose or design the right model; for this purpose we introduce in Section 2 a framework useful for analyzing context models and to select the most suitable one for a given application. In fact, the lack of a uniform approach for modeling context-related information makes it difficult to deeply understand the requirements that have to be considered when proposing/adopting a context model on the basis of its focus. Therefore, the central issue of this paper is to survey the current literature on the context modeling problem and to systematically highlight advantages and limitations of the different proposals and perspectives.

The rest of the paper is organized as follows, Section 2 describes the analysis framework, Section 3 applies it to some of the most relevant context models found in the literature, Section 4 draws some conclusions.

[1]Many of these tasks may have lower complexity for logics which are not very expressive, like for instance $\mathcal{FL}^-$ [4]. However, most of the interesting ontologies found on the Web are at least as expressive as OWL-Lite ($\mathcal{SHIF}$), where, for instance, just concept satifiability is EXPTime-complete [29].

2. THE ANALYSIS FRAMEWORK

Many approaches defining the notion of context have been proposed and several adaptive applications have been designed and implemented, by introducing the notions of user profile and context [1, 3, 9, 12, 13, 19, 33, 36, 47]. Although interesting comparisons of context models already exist [5, 30, 39, 45], we felt the need to establish a framework to systematically evaluate them, by defining a set of relevant, objective and rather general categories. The analysis framework we propose is intended for designers that are about to develop context-aware applications and need to decide which context model is best suited for their goals. This framework, used to analyze and compare the available context models, is built on a rich set of features which characterize the models from various perspectives. These features have been derived from the analyzed systems, by selecting the most peculiar and common ones. The first step of the analysis is the identification of the key issues for the application being developed; in this phase the designer should define which features are more relevant for his/her target application, or whether new features should be added to address specific application requirements. Here we assume *data tailoring* as our target application and, with respect to it, we show the most relevant features among the presented ones. The second step is the classification of the existing context models with respect to each feature. The result is a structured view of the state of the art, which enables the designer to consciously compare the various models, focusing the attention on the key issues isolated in step one. As a result, the best model is selected or, in case no satisfactory models are available for the target application, the designer might consciously engage in the proposal of a new, more appropriate context model. The features we isolated and classified are now briefly discussed:

Modeled aspects: The set of context dimensions managed by the model.

- *Space*: does the considered context model deal with location-related aspects?
- *Time*: does the considered context model allow the representation of temporal aspects?
- *Absolute/relative space and time*: are the space and time parameters (if any) represented absolutely (e.g., GMT time reference and GPS coordinates) or relatively (e.g., "near something", "last month", "after that")?
- *Context history*: is the history of previous contexts part of (relevant for) the context itself, i.e., the current context state depends on previous ones, or is the

context a pure snapshot of the user's current environment?

- *Subject*: who or what is the subject of the described context? This feature refers to the point of view used to describe the context itself; some models describe the context as it is perceived by the user, while others assume the application point of view, considering, as a consequence, the user itself as part of the context;

- *User profile*: is the user profile (in terms of preferences and personal features) represented in the context model? And if so, how is it represented (i.e., does the system describe the user's characteristics one by one, or does it provide a role-based model of user classes)?

Representation features: General characteristics of the model itself.

- *Type of formalism*: class of the conceptual tool used to capture the context (key-value-, mark-up scheme-, logic-, graph-, ontology-based). Different classes provide different features (e.g., high or low intuitiveness, possibility to be automatically processed, reasoning support, formal semantics) and are more or less adequate for certain applications;

- *Level of formality*: the existence of a formal definition and whether the formalization well expresses the intuition;

- *Flexibility*: the model's ability to easily adapt to different contexts: a model can be "application-domain bounded" if it is substantially focused on a single application or on a specific domain, or "fully general" if it can naturally deal with different domains or applications (i.e., is it possible to capture any kind of context with this model and how easy is it?);

- *Variable Context Granularity*: the ability of the model to represent the characteristics of the context at different levels of detail.

- *Valid Context Constraints*: the possibility to reduce the number of admissible contexts by imposing semantic constraints that the contexts must satisfy for a given target application.

Context management and usage: The way the context is built, managed and exploited.

- *Context construction*: highlights if the context description is built centrally or via a distributed effort; this indicates whether a central, typically design-time, description of the possible contexts is provided, or if a set of partners reaches an agreement about the description of the current context at run-time;

- *Context reasoning*: indicates whether the context model enables reasoning on context data to infer properties or more abstract context information (e.g., deduce user activity combining sensor readings);

- *Context information quality monitoring*: indicates whether the system explicitly considers and manages the quality of the retrieved context information, for instance, when the context data are perceived by sensors;

- *Ambiguity and incompleteness management*: in case the system perceives ambiguous, incoherent or incomplete context information, indicates if the system can "interpolate" and "mediate" somehow the context information and construct a reasonable "current context";

- *Automatic Learning Features*: highlights whether the system, by observing the user behavior, individual experiences of past interactions with others, or the environment, can derive knowledge about the context; e.g., by studying the user's browsing habits, the system learns user preferences;

- *Multi-Context Modeling*: the possibility to represent in a single instance of the model all the possible contexts of the target application, as opposite to a model where each instance represents a context.

This characterization covers the focus of the model, its representation and the way context data are used; the result is a rich set of features, emphasizing that context modeling is a varied and complex problem. Depending on the specific purpose it is designed for, each model may "include" several of the listed features; we envision five classes of use, which share general sets of features, and more important, the same target field of application. These classes can be considered as a coarse-grained categorization of the context models, or as a decomposition of the context problem itself (in boldface the key features of each class).

A. *Context as a matter of channel-device-presentation.* Systems of this class are characterized by: **variable context granularity**, the **application as subject** of the model, limited or absent management of location and time dimensions, **feature-based user profiling**, low level of formality, limited flexibility (often considering only specific applications), and a **centrally defined context**. While automatic learning features can be available, context quality monitoring, ambiguity management and context reasoning are in general not supported.

B. *Context as a matter of location and environment.* Models of this class in general provide: precise **time and space management**, high degree of flexibility and **centralized context definition**. Context reasoning may be provided, offering a powerful abstraction mechanism. **Information quality management** and **disambiguation** may be available, in particular when the context information is acquired by sensors. Automatic learning is rarely exploited.

C. *Context as a matter of user activity.* The focus of this class of models is on "what the user is doing," consequently **context history** and **reasoning** are important issues. Time and space are considered relevant as far as they provide information about the user current activity[2]. While the level of formality may vary, the **context definition** is in general **centralized** and the **user** is the **subject of the model**. When available, the **automatic learning** is used to guess user activity from sensor readings.

[2]See [37] for an example

D. *Context as a matter of agreement and sharing (among groups of peers).* Approaches of this group focus on the problem of reaching an agreement about a context shared among peers; clearly the **context definition** is **distributed**; **context reasoning**, **context quality monitoring** and **ambiguity and incompleteness management**, are key issues. Sophisticated location, time and user profiling features are uncommon in models of this class. The **level of formality** is rather **high**, due to the need of information sharing.

E. *Context as a matter of selecting relevant data, functionalities and services (data or functionality tailoring).* The models of this group focus on how the context determines which data, application functionalities and services are relevant. Context definition is typically centralized, context history and reasoning are often not provided; **time**, **space** and **user profile** are in general highly developed and well formalized. The flexibility is usually high while automatic learning features, ambiguity management and information quality are not key issues and are often not available. The key features of this group are: **the application as subject**, the possibility to express both **variable context granularity**, **valid context constraints**, and **multi-context models**.

These classes and the identified relevant features constitute the analysis framework we propose, used in the next section to review some of the most interesting approaches to the context modeling problem.

3. THE CONTEXT MODELS

Table 1 reports the results of the application of the analysis framework to a set of systems examined with the data tailoring application scenario in mind[3]. A very short description of each system follows, highlighting relevant characteristics and the context modeling subproblems they are targetting.

- *ACTIVITY*[3]: in [30] the authors provide an interesting analysis of the existing approaches to context modeling, pointing out how different solutions overlap without providing the context modeling universal solution. The authors also describe a novel approach based on Activity Theory, which allows the description of key aspects influencing human activity. In fact, in [30] the notion of context is intended as the set of elements which have some influence on users' intentions while performing an activity. The model is strongly focused on the categories of *user*, *community* and the *rules* needed to relate a user to his/her community; each category can be represented by a tree-based structure, where lower levels of the tree represent more detailed information about the context category that can be used for reasoning about upper levels. To the best of our knowledge, a formal description of the context model has not been provided and its usage is not described; the model seems to be at a very early stage of development, and too holistic to be effective in practice. The ultimate goal is the context problem as a whole, fitting into all our categories.

- *CASS*: it is a centralized server-based context management framework, meant for small portable devices, offering a high-level abstraction on context sensed by appropriate distributed sensors [22]. It manages both time and space, taking into account the context history, and provides context reasoning; it does not contain user profiling capabilities. The context is seen as a matter of location and environment, thus the system can be classified into the B category.

- *CoBrA*: The context is represented as a Context Knowledge Base [16] for the specific application of event/meeting management. On top of this knowledge base temporal, spatial and event-meeting reasoners (based on contextual rules) operate to deduce more abstract contextual information. The presence of a Context Broker makes this approach perfectly suited for context sharing and context reasoning, while its application is difficult when multiple multidimensional contexts need to be modeled. To apply CoBrA [15] to the information tailoring problem we must enrich the ontologies forming the Context Knowledge Base to extend the domain of applicability from the "meeting" domain to other application-specific domains and to define a set of contextual rules describing how various components of the context should be combined. Such rules, although specifiable as CoBrA context reasoning rules, will express how to combine context characteristics instead of supporting contextual inference, therefore forcing the original model to suit this specific goal. CoBrA belongs to the D group.

- *CoDaMoS and SOCAM*: The CoDaMoS [17, 38] and the SOCAM projects [24] propose extremely general ontology-based context models. Sets of extensible ontologies are exploited to express contextual information about user, environment and platform in both systems. CoDaMoS is the two-layered context model used in PACE [27], a middleware for context aware systems, which describes contexts both in term of fine grained facts and higher level situations which describe logical conditions; CoDaMos adds also support for service description. The richness and flexibility of such models is not complemented by a proper constraining mechanism; the two models do not offer explicit ways to limit the number of expressible contexts (i.e., Valid Context Constraints), this results in a severe limitation when the context model is applied to the data tailoring problem. Moreover a single point in the multidimensional context space is not represented in a concise way, but as a graph of concept instances, making the task of relating the set of relevant data to the specific context difficult. The possibility to express contexts at different granularity levels and to define them compositionally (e.g., as a combination of more detailed ones) is also difficult to achieve (i.e., Variable Context Granularity). Both participate to the four above-mentioned classes, being more focused in A and B.

- *COMANTO*: [41,46] the authors propose a hybrid context modeling approach to handle context objects and context knowledge. For the first purpose, a location-based context model is formalized for considering both fixed (e.g., regions, streets, etc.) and mobile location

[3]Each model appears in all the applicable categories, possibly with more values per category.

System	Space	Time	Space/Time coordinates (**R**elative or **A**bsolute)	Context history	Subject (**U**ser or **A**pplication)	User profile (**R**ole or **F**eatures based)	Variable context granularity	Valid context constraints	Type of formalism: Key-value-based	Type of formalism: Mark-up based	Type of formalism: Logic-based	Type of formalism: Graph-based	Type of formalism: Ontology-based	Formality level (**H**igh or **L**ow)	Flexibility	Context construction (**D**istributed or **C**entralized)	Context reasoning	Context quality monitoring	Ambiguity/Incompleteness mgmt.	Automatic learning features	Multi-context model
ACTIVITY	+		A	+	U	F	+					+		L	+	C	+				+
CASS	+	+		+	U						+			L		D	+				
CoBrA	+	+	A		A	F							+	H	+	D	+		+	+	
CoDaMoS	+	+	R/A		A	F							+	H	+	D	+	+			
COMANTO	+	+	R/A		A	F							+	H	+	D	+				
Context-ADDICT	+	+	R/A		A	R	+	+		+		+	+	H	+	C					
Conceptual-CM	+	+	R	+	A	R						+		L	+	C	+		+	+	+
CSCP					A	F				+				L		C					+
EXPDOC		+	R	+	U	F					+	+		H		C				+	
FAWIS				+	U	F	+		+					H		C			+	+	+
Graphical-CM	+	+	R		A	F						+		H	+	C		+	+		+
HIPS/HyperAudio	+	+	A	+	U	F			+					L		C	+		+	+	
MAIS	+	+	A		A	F	+						+	H		C					
SCOPES					A						+			H		D	+		+		+
SOCAM	+	+	R/A		A	F							+	H	+	D	+	+			
U-Learn	+	+	A		U	F		+					+	H	+	D					+

Table 1: Context model features and systems exposing them.

data (e.g., people, vehicles). For the second purpose the general COMANTO ontology is proposed as a public context semantic vocabulary supporting efficient reasoning on contextual concepts (such as users, activities, tools, etc.) and their associations. The ontology is used to collect a structured semantic representation about generic context information and is not domain-, or application-oriented. The middleware infrastructure to acquire, store, and manage context information of the COMANTO ontology is described in [46]. As for the other context models based on ontologies, COMANTO provides a general purpose and very expressive formal model, although lacking the possibility to discard useless contexts. This model fits into categories B and C.

- *ConceptualCM*[3] [18]: ConceptualCM is a conceptual framework intended to consider the context notion not simply as a state, but as part of a process. The possible contexts for a scenario are an information space modeled as a directed state graph, where each node represents a context and edges denote the conditions for changing context. Each context is defined by a set of entities, a set of roles that entities must satisfy, a set of relations between entities, and a set of situations. A runtime infrastructure is a middleware that instantiates entities, roles and relations for the current state of a context, with different levels of abstraction, by allowing the collection of all the information required to identify current context values and predict changes in the situation or in the actual context. In [18] the authors describe some principles to be considered when implementing context-aware applications; the context model informally presented can be classified into the E category.

- *Context-ADDICT*: In [7] the authors propose the Context Dimension Tree, a tree-based structure introduced in the research field of context aware applications with the specific goal of being adopted in the data tailoring task. The model globally represents the space of considered contexts; in particular, the root node of the tree specifies the entire data space of possible contexts, and the first-level nodes (called dimensions) represent the orthogonal perspectives to be considered in order to tailor data. The hierarchical structure of the Context Dimension Tree can represent contexts with different levels of detail, and the portion of data to be considered for a specific context can be determined in a compositional way, by using the data relevant for each dimension value composing the current context. The model includes constraints and relationships among dimension values to remove meaningless combinations of elements. Being focused on a specific class of applications, the Context-ADDICT approach lacks the features not relevant for the data tailoring problem such as Context History, Context Quality Monitoring, Context Reasoning and Ambiguity and Incompleteness Management. Some of these limitations may be removed in the future while other are inherent to the chosen approach. This model is classified as pertaining to the E category.

- *CSCP*: in [12] the authors present a Mobility Portal: a web portal providing an adaptive web interface, reacting to user channel, device and user profile. The focus is clearly on channel-device-presentation issues, thus the contribution is limited to a well defined set of applications, based on web interfaces. The context model represents profile sessions and is based on RDF; it does not impose any fixed hierarchical structure for the context notion, thus inherits the full flexibility and expressive power of RDF. The instantiation of the model allows one to represent a single structured session profile (i.e., a point in the space of possible contexts) with information about the device, the network, and the user of the considered session. The best classification of this system is in group A.

- *EXPDOC*[4]: it is an interesting approach based on semantic networks [44]. The goal is to support experiential systems (in particular experiential documents), in order to provide an enriched learning environment where additional, related, but not required information is made available to the users, the authors talk about "serendipitous" activities, as the set of knowledge improving activities performed by the users when accessing this kind of information. The goal of this approach is opposite to the one of data tailoring: while EXPDOC uses the context to increase the amount of information provided to the user, data tailoring exploits the context to discard useless information. As a consequence, this semantic-network-based approach suffers from the same limitations we discussed for the ontological models, in particular there are no ways to limit the contexts expressed by this model (i.e., Valid Context Constraints). Moreover, the automatic Wordnet-based mechanisms, exploited to generalize the user context in order to match the document context, focus only on the user preferences and profiles, resulting in limited flexibility (e.g., the location is not taken into account). For these reasons, the application of such model to the data tailoring problem is not advisable. This system belongs to the C class.

- *FAWIS*: the methodology of [19, 20] is focused on the adaptation of Web-based Information Systems via the transformation of the presentation and navigation, although the context model is flexible enough to be applied to different scenarios. A specific context is specified by a set of profiles, each describing an autonomous aspect of the context itself (e.g., the *user*, the *location*, the *device*, etc.). A profile is characterized by a set of simple or complex attributes, and each instantiation of a profile has a fixed set of attributes, assuming also the presence of null values. Profiles can be combined to represent a context at different levels of detail; however, the model does not allow the expression of constraints between sets of attributes or set of profiles to avoid meaningless combinations. The system mainly considers the user-profiling issues of the context modeling problem, while leaving all the other aspects not formally described, thus, in our classification it falls into group A and partially into groups E and C.

- *GraphicalCM*[3] [28]: the authors formalize a context model for pervasive computing applications, by concentrating also on some aspects not well formalized in the literature for this specific field, that are information quality and temporal aspects of contexts. The context model has a graphical notation: the possible contexts for a target application are rendered by a directed graph composed by a set of entities, describing objects, and their attributes, representing the entity properties. Different kinds of associations connect an entity to its attributes or to other entities. GraphicalCM supports quality by annotating associations with a number of quality parameters, which capture the related dimensions of quality considered relevant for each association. Each quality parameter is described by one or more quality metrics. The model is theoretically described in [28], and the authors introduce some possible extensions for their proposal, which is general, but at the moment can be classified into the C and E categories.

- *HIPS/HyperAudio*: the authors of [37] focus their attention on the spatio-temporal issues of the context, concentrating on determining the user's current activity from information about his/her spatio-temporal coordinates and a simple user profile. They consider the context as a matter of user activity, and the target of their key-value-based model is supporting an automatic context-aware museum guide. Although the approach is rather effective in this specific application, it has limited flexibility. The exploitation of this model in more general applications (e.g., data tailoring) is definitely hard, and major extensions are required to capture articulated contexts. This approach may be considered as belonging to categories B and C.

- *MAIS* [9, 33]: it is a Multi Channel Adaptive Information System meant to build a flexible environment to adapt the interaction and provide information and services according to ever-changing requirements, execution contexts, and user needs. The notion of MAIS context has the objective of configuring the software on board of the device based on: a) the user needs, in terms of presentation, and b) the device characteristics, in terms of available channel. It clearly considers the context as a matter of channel-device-presentation,

[4]This is not the original name, it has been introduced to easily refer to this system in Table 1.

thus it belongs to group A.

- *SCOPES*: the context model presented in [36] is based on the concept of *mutual beliefs*. In a P2P collaborative environment assertions are exchanged among peers to create mappings among source schemata. These sets of mapping represent the notion of evolving context proposed by the authors. The goal of the system is to enable P2P data interoperability, via the definition of the above described context. Although the system shares some of the goals typical of data tailoring systems, the presented context model cannot be applied in the data tailoring task: it is not possible with this mutual-beliefs-based approach to define a context model independent of the data sources, in fact it does not include constructs to represent elements like location or user profile. The model falls into class D.

- *U-Learn*[3] [48]: this ontology-based context-model is focused on the support of learning. The learner and the learning content are described by two ontologies (learner ontology and content metadata) and a rule-based system provides a content-to-learner matching mechanism. The content can be both a service or a set of data. The proposal is interesting with respect to the data tailoring problem; the data can be enriched by adding content metadata, the user's context described by the learner ontology and the matching can be used to select the relevant data depending on the context. Yet, the system seems at an early stage of development, and the formalization not complete: the learner and learning-content ontologies seem very general and not clearly specified, while the matching rules are not described in the available papers. The authors claim to support sensor integration without providing enough details to actually evaluate the contribution. This model can be classified into the E category.

4. CONCLUSIONS

Although a lot of work has been done, the representation and management of context can hardly be considered as an assessed issue. Due to the complexity of the "context modeling problem" as a whole and to the multitude of different applications, at the end of this comparison we advocate those models that, although being fully general, have a well defined focus, and try to support only a specific context subproblem. Indeed, we feel that the systems whose aim is to be completely general and to support the context modeling problem as a whole for any possible application, often fail to be effective. In fact, the practical applicability and usability, although not discussed because rather subjective, are important parameters, and are often inversely proportional to the generality of the model: the more expressive and powerful, the less practical and usable.

Different context subproblems and applications have almost incompatible requirements, and common solutions are still not available; as a consequence, the context model should be chosen depending on the target application. The analysis framework we have proposed can, in this sense, be used by an application designer either to choose among the available models or to define the requirements of a new context model.

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