A Comprehensive View of Ubiquitous Learning Context Usage in Context-Aware Learning System

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Abstract. Research related to context-aware u-learning system has proliferated during last decades. Systems identified in literature are developed in ad-hoc manner to resolve a specific problem in a given context; however, u-learning systems developers need to have a clear and a general view of how their intended systems make use of the ubiquitous context. The paper details a general descriptive view of context usage within learning systems through three different view-points inspired from Dowson's work [1]. Each view is capturing a particular aspect of context handling. Then a set of facets is associated to each given aspect in order to study, understand and appropriately describe it. This work would be useful for context-aware u-learning system developers in order to have a clear understanding of the context usage in such systems and to underline the requirements of the u-learning environment to respond. This research is also aimed to establish a structured baseline to help in comparing and evaluating context-aware u-learning systems according to the descriptive system views.

Keywords: Context-awareness · Ubiquitous learning · Context modeling · Context analyzing and management · Context execution

1 Introduction

The quality of distance learning is strongly linked to its degree of adaptation to the learning context [2]. This has led to the evolution of distance learning environments into context-aware environments, particularly into ubiquitous ones [3], with particular focus on learning context. These environments aim to provide the necessary means to take into account the context and assist learners in following a learning situation personalized to their contexts. However, current context-aware u-learning applications are often developed in ad-hoc manner to resolve a specific problem in a given context. Such ad-hoc approaches did not dictate general requirements of ubiquitous context usage; subsequently developed applications rarely fulfill environmental requirements.

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Hence, u-learning system developers need to have a clear view and understanding of the different aspects of u-learning context usage.

The context usage world in u-learning environments deals with the locations where the context is established and handled. Three interactive domains are inspired in this research from Dowson's work [1] - to describe processes in process centered software engineering environment - dealing with the three aspects of the context usage: *context modeling*, *context analyzing and managing*, and *context execution domain*.

The ***context modeling domain*** contains the model of the ubiquitous learning context and describes how the context is represented. A context model defines and describes the context information and associated relationships.

The ***context analyzing and managing domain*** enables following functionality:

- *Building the ubiquitous learning context*: In order to build the current context instance, the *context analyzing and managing domain* has to (1) capture the context information; and, (2) instantiate the context model as shown in Fig. 1.
- *Analyzing the context information*: The *context analyzing and managing domain* has to interpret low-level sensor information, detect the imperfection of the detected information, and detect the evolution of the learner context.
- *Managing the context*: The management of the context consists of the aggregation of new context information, the summarization of the history information, the resolution of the detected imperfection, the adaptation of the learning system and the context model, and, the evolving of the context model.

The ***context execution domain*** concerns the learning environment, the actors and their activities conducted during the learning process.

The interactions between described domains (numerated in Fig. 1) are as follows:

- **Context information traces and feedback**: The *context analyzing and managing domain* uses traces and feedback captured from the *context execution domain*. When feedback is negative, the system has to adapt the learning situation to meet the learner needs and preferences (arrow 3 in Fig. 1). Concerning the context information traces, an update or an evolution could be detected. In case of update detection, the context instance is updated and adaptation techniques are applied to

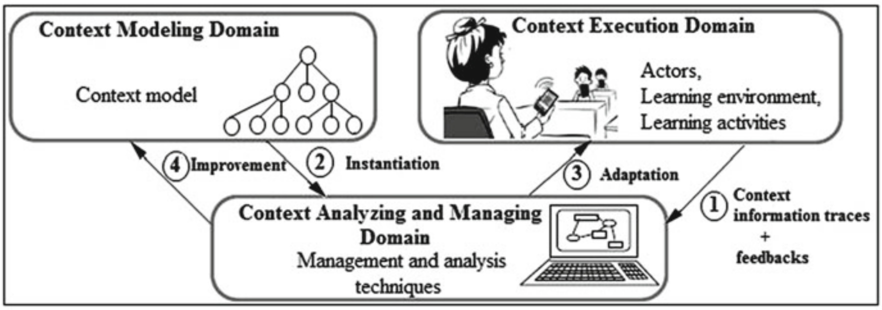

Fig. 1. Ubiquitous learning context usage world

guide the learning situation (arrow 3 in Fig. 1). In case of context evolution detection, the model has to be improved (arrow 4 in Fig. 1).

- **Context model instantiation**: Having detected context information, the *context analyzing and managing domain* has to create the context instance via the instantiation of the context model.
- **Adaptation**: The *context analyzing and managing domain* applies adaptation techniques in order to adapt the learning situation to the learning context information traces and feedback.
- **Context model evolution**: When capturing unanticipated context information from traces, the *context analyzing and managing domain* has to improve the context model so that it could model the newly detected information.

In this paper, a description of the three aspects of context usage is given via three viewpoints associated to the previously mentioned domains. Each view is described with a set of facets; each facet is illustrated with a set of sub-facets or valued attributes suitable to characterize a given aspect of context handling. Attribute values are defined within a domain. The later could be a predefined type such as ***Integer***, ***Boolean*** and so forth, an enumerated type noted as ***Enum{a, b, c}*** (the attribute takes its values in the list *{a, b, c}*), or a structured type designated by ***Set***.

Sections 2, 3 and 4 present faceted descriptions of each domain according to their associated views. Section 5 illustrates a comparative analysis documenting the instantiation of views' facets to evaluate a list of systems and to identify new research issues. Finally, Sect. 6 concludes the paper.

2 The context Modeling View

The representation of learning context is studied in terms of the following points:

- Q_a: What should be represented?
- Q_b: What are the properties of what is represented?
- Q_c: To what extent the context model is faithful to the real world?

The *coverage* facet deals with the object to be represented (Q_a). The *description* facet treats the properties of what is represented (Q_b). The *faithfulness of the context model* facet concerns with the capacity of the context model to be able to model the real learning context (Q_c).

2.1 Coverage Facet

This facet answers the question "*What should be represented?*" It concerns with the contents of the ubiquitous learning context to be modeled. The real context of learning is composed of a set of information and semantic relationships among those information pieces. Thus, this facet is characterized by the attribute *coverage* as follows:

Coverage: Set (Enum {information, relationship})

2.2 Description Facet

The *description* facet treats the properties of what is represented. It is described via its two sub-facets: the *context information properties* facet and the *relationships properties* facet. Table 1 summarizes the content of the current facet.

2.3 Faithfulness of the Context Model Facet

This facet describes the extent to which the established model describes faithfully the real world. The attribute *faithfulness degree* indicates whether the model is faithful, moderately faithful or unfaithful to the learner's real context. So this attribute takes on values from the enumerated domain {*faithful*, *moderately faithful*, *unfaithful*}.

Faithfulness degree: Enum{faithful, moderately faithful, unfaithful}

3 Context Analyzing and Managing View

The current view is studied in terms of the following three questions:

- Q_a: How to construct the u-learning context?
- Q_b: How to analyze it?
- Q_c: How to manage the analyzed context?

The *construction* facet indicates the construction technique used for building the current context instance (Q_a). The *analyzing* facet describes how the *analyzing and managing domain* analyzes detected learning context information (Q_b) in order to generate more abstract context information and to detect the imperfection of the captured information. Finally, the *managing* facet illustrates used techniques to manage information (Q_c). It consists of the reuse of the history information, the resolution of the detected imperfection, the adaptation of the learning system and the context model, the recommendation of useful materials and the evolution of the context model based on the detection of the evolution of the learner context.

3.1 Construction Facet

Using the context information traces detected by the *execution domain* and the instantiation of the context model built by the *modeling domain*, the *analyzing and managing domain* has to construct the current learning context. The *construction* facet indicates whether the context instance is built centrally or in a distributed way [8].

Construction technique: Enum{central, distributed}

Table 1. Summary of the description facet

Context information properties facet		
Sub-facet	Description	Sub-facet details
Heterogeneity	Context information sources are classified in three groups: physical sensors, virtual sensors and logical sensors [4]. Context information can be categorized into three classes: sensed, profiled and derived.	-Information source: Set (Enum {physical, virtual, logical }) -Information type: Set (Enum {sensed, profiled, derived})
Mobility	Changing context information is retrieved from local and remote providers. In [5] three types of update are identified in order to guarantee correct and updated information: periodical update, update on change and update on request.	- Provider: Set (Enum {local, remote}) - Update type: Set(Enum{periodical update, update on change, update on request})
Quality	Due to its dynamic and heterogeneous nature, the information may be of varied quality. To model the quality of data, following QoC (Quality of Context) parameters will be used as proposed by [7]: up-to-datedness, trustworthiness, completeness and significance.	- QoC parameter: Set(Enum {up-to-datedness, trustworthiness, completeness, significance})
Subjectivity	Subjectivity is a main characteristic of context [6]. Learning context entity can be perceived from different viewpoints (teachers, learners and/or systems) and consequently have different quantitative or qualitative subjective ratings.	- Multi viewpoint: Boolean - Subjectivity_viewpoint: Set(Enum {system, learner, teacher}) - Subjective_rate_type: Set(Enum{quantitative, qualitative})
History	Recorded information pieces may be useful for predicting learner behavior, detecting learning style, and inferring other information. The provision of a complete history of the dynamic learning context is a difficult issue and may in fact not be feasible. Therefore, summarization function may need to be applied.	- History_recording: Boolean - Recorded_information: Set (Object) - History_record_format: Enum {Set (Object), function}
Abstraction	U-learning systems are able to treat low-level sensor information pieces, to use interpreted ones or to combine them for more significant data (e.g. learning situation).	- Abstraction_level: Set(Enum {low-level, interpreted, aggregated })
Granularity	Context information elements are of different levels of detail qualitatively measured as low, medium or high. Information with high granularity may lead to a more appropriate adaptation decision.	- Granularity_level: Enum {low, medium, high}
Relationships properties facet		
Description		Facet details
It is necessary to represent not only the context information values but also the context information relationships. The main types of semantic relations that are considered in this work are: association, dependency, hierarchy, composition, aggregation and instantiation. Besides to that, constraints may be indicated on modeled relationships.		- Relation type: Set (Enum {association, dependency, hierarchy, composition, aggregation, instantiation}) - Constraints on relation: Boolean

3.2 Analyzing Facet

The *analyzing* facet illustrates the used techniques by the *analyzing and managing domain* to analyze context information. Associated sub-facets are given in Table 2.

3.3 Managing Facet

The *managing* facet illustrates the used techniques by the *analyzing and managing domain* to manage context information. Associated sub-facets are given in Table 3.

4 Context Execution View

The exploitation of the current context information and users' feedback is used to guide the system's operation and to adapt and evolve the context model. The current view has to be described with reference to the *context change* facet and *feedback* facet responding respectively to the following two questions.

Table 2. Summary of the analyzing facet

Sub-facet	Description	Sub-facet details
Information processing	Low-level sensor information is processed in order to generate more abstract information using processing techniques such as interpretation and aggregation.	- Processing technique: Set (Enum {interpretation, aggregation})
Imperfection detection	The dynamic and heterogeneous collected information may be imperfect. The imperfection detection techniques are based on QoC evaluation policies. In [7], five types of QoC evaluation policies are detailed: up-to-datedness, trustworthiness, completeness, significance and combinations based policy. The imperfection detection could occur at different levels [7]. It may occur when making the selection of low level context information among different sensors, processing, and applying the context information.. The detected imperfection may be of different types: incorrect, inconsistent, incomplete or redundant. The imperfection detection strategy could be of two types: static (anticipated at the design time) or dynamic (occurs at the runtime).	- Detection technique: Set(Enum{up-to-datedness based, trustworthiness based, completeness based, significance based, QoC combinations}) - Detection level: Set (Enum{context acquisition, context processing, context appliance} - Imperfection type: Set (Enum {incorrect, inconsistent, incomplete, redundant}) - Detection strategy: Set (Enum {Static, Dynamic})

Table 3. Summary of the managing facet

Sub-facet	Description	Sub-facet details
History reuse	U-learning systems need to deal with history reuse in order to predict future context values. The reused objects need to be considered to evaluate the extent to which the system takes into account the reuse of saved history in the adaptation process.	-History reuse: Boolean -Reused objects: Set(Object)
Imperfection resolution	U-learning systems need to use resolution techniques to avoid the use of imperfect data. Resolution policies have been defined, based on user preferences [9], QoC parameters [7], discarding the entire conflicting context, the last received or the bad context information [10]. Resolution could occur at the design time [9] or at the execution time [11]. Given that the system has to cope with the dynamic context, runtime resolution has to be applied.U-learning systems may allow user intervention to resolve conflict situations.	-Resolution technique: Enum{user preferences based, QoC parameters based, drop-latest, drop-all, drop-bad} -Resolution time: Enum{design time, execution time} -User intervention: Boolean
System adaptation	Context-aware learning applications use context data to evaluate whether there is a change in the learner's situation and whether any adaptation to that change is necessary. This amounts to adapting certain context information piece(s) (adapted object(s)) based on other one(s) (adaptation factor(s)). Adaptation may occur at three levels: presentation, content and behavior level. Systems can be classified into adaptable (static adaptation) and adaptive (dynamic adaptation) systems. They may allow mixing automatic and static adaptation.	-Adaptation factor: Set(context object) -Adaptation level: Set (Enum{presentation, content, behavior}) -Adapted objects: Set (context object) -Adaptation type: Enum{adaptativity, adaptability, mixed}
Recommendation	U-learning systems could recommend different objects that may possibly meet the learner's needs. Recommended objects may be internally designed by the system tutor, or externally collected and integrated into the system. In literature, four recommendation techniques have been identified [12]: collaborative, content-based, and knowledge-based techniques. Recent research works have proposed hybrid ones.	-Recommended material: Set(object) -Material type: Enum {internal, external} -Recommendation technique: Enum {collaborative, content-based, knowledge-based, hybrid}
Context model adaptation	U-learning systems need to dynamically adapt the context model in order to represent only the useful runtime context data and relation to reduce the monitoring overhead [13].	-Runtime model adaptation: Boolean
Context model evolving	The system has to evolve the context model in order to cope with unanticipated changes [13]. The model could be evolved after interrupting the system execution. However, the more efficient the learning systems are, the better they have to perform in a highly dynamic environment, and therefore have to improve dynamically the context model.	-Model evolving: Boolean -Evolving type: Enum{Dynamic, Static}

- Q_a: What kind of change occurs while execution?
- Q_b: What are the learners' feedbacks?

4.1 Context Change Detection Facet

When detecting a change in context information, the *context execution domain* returns the detected information to the *context analyzing and management domain* for exploitation. The detection of new information is due to the dynamic nature of the environments. In such case, the system has to cope with the unanticipated context changes that were not considered at the design time by evolving the context model. However, when detecting updates, only the context instance is modified.

Context change type: Set (Enum {new information, updated information})

4.2 Feedback Detection Facet

Feedback is considered to be of great importance knowing that it helps in adapting the learning system to the learner performance. Learning systems could allow qualitative and/or quantitative feedback for assessing the relevance of learning and may allow the learner to express him/herself through comments and suggestions [14].

Feedback detection: Boolean

Feedback type: Set (Enum {quantitative, qualitative, comment, suggestion})

5 Review of 6 U-Learning Systems

In this section, the use of the context usage world is illustrated for u-learning systems via the evaluation of six systems: PERKAM [14], TSUL environment [15], JAMIOLAS 3.0 [16], JAPELAS [17], LOCH system [18] and TANGO system [19]. The instantiation of the description of the context usage world within listed systems (Table 4) allows their evaluation by bringing out their main features and limits.

Majority of developed systems does not cover modeling the relationships between context information pieces. PERKAM and TSUL environment take into consideration the modeling of only associations and/or aggregations. Dependency relationships are ignored by all systems. Subsequently the used context model by each system is moderately faithful to the real world. JAPELAS, LOCH and TANGO do not detect any type of context change from the *execution domain* and subsequently do not take into consideration neither update types when modeling the context nor imperfection detection and resolution when treating the learning context. Studied systems, expect TSUL environment, use only interpreted information pieces and/or low-level sensor ones. JAMIOLAS and LOCH didn't deal with system adaptation. The remaining four systems use very few context information pieces as adaptation factors and tend to adapt only one or two contextual elements. The adaptation of the presentation and

Table 4. Systems' evaluation according to the context usage world

Modeling view

				PERKAM	TSUL	JAMIOLAS	JAPELAS	LOCH	TANGO
Coverage	**Coverage**			Information Relationship	Information Relationship	Information	Information	Information	Information
Description	**Context information properties**	**Heterogeneity**	**Information source**	Physical Virtual	Physical Virtual	Virtual	Physical Virtual	Physical Virtual	Physical Virtual
			Information type	Sensed Profiled Derived	Sensed Profiled Derived	Sensed Profiled	Sensed Profiled Derived	Sensed Profiled	Sensed Profiled Derived
		Mobility	**Provider**	Local	Local	Local Remote	Local	Local Remote	Local
			Update type	Periodical update Update on change	Periodical update	Periodical update	-	-	-
		Quality	**QoC parameter**	Up-to-datedness	Up-to-datedness	-	-	-	-
		Subjectivity	**Multi viewpoint**	true	False	true	true	False	False
			Subjectivity viewpoint	System Learner	Learner	Teacher System	System Learner	Learner System Teacher	System Learner
			Subjective rate type	Quantitative Qualitative	Qualitative	Qualitative	Qualitative	Qualitative	Qualitative
		History	**History recording**	true	True	False	true	true	true
			Record format	Set (Object)	Set (Object)	-	Set (Object)	Set (Object)	Set (Object)
			Recorded information	Learner's experience	Learner's capability	-	Learner conversation	Learner's location Task activities	Learner's experience
		Abstraction	**Abstraction level**	Low-level Interpreted	Low-level Interpreted Aggregated	Low-level	Low-level	Low-level	Low-level Interpreted
		Granularity	**Granularity level**	Low	High	Low	Low	Low	Low
	Relationship properties	**Relation type**		Association	Association Aggregation	-	-	-	-
		Constraints on relation		False	False	False	False	False	False
Faithfulness of the CM	**Faithfulness degree**			Moderately faithful	Moderately faithful	Moderately faithful	Moderately faithful	Moderately faithful	Moderately faithful

Analyzing and managing view

			PERKAM	TSUL	JAMIOLAS	JAPELAS	LOCH	TANGO
Construction	**Construction technique**		Central	Central	Central	Central	Central	Central
Analyzing	**Information processing**	**Processing technique**	Interpretation	Interpretation Aggregation	-	Interpretation	-	-
	Imperfection detection	**Detection technique**	Up-to-datedness based	Up-to-datedness based	-	-	-	-
		Detection level	Acquisition	Acquisition	-	-	-	-
		Imperfection type	Incorrect	Incorrect	-	-	-	-
		Detection strategy	Dynamic	Dynamic	-	-	-	-
Managing	**History reuse**	**History reuse**	true	true	False	true	true	true
		Reused objects	Learner's experience	Learner's capability	-	Learner conversation	Learner's location Task activities	Learner's experience
	Imperfection resolution	**Resolution technique**	QoC parameters based	QoC parameters based	-	-	-	-
		Resolution time	Execution time	Execution time	-	-	-	-
		User intervention	False	False	-	-	-	-
	System adaptation	**Adaptation factor**	Learner's profile Learner's location Learner's social network	Learner's capability	-	Hyponymy Social distance Situation's formality	-	Learner's comprehensive level Learner's location
		Adaptation level	Content	Content	-	Content	-	Content
		Adapted objects	Peer helper Educational material	Learning task Peer assistant	-	Japeneese polite expression	-	Expression
		Adaptation type	Adaptability	Adaptability	-	Adaptability	-	Adaptability
	Recommendation	**Recommended material**	Peer helper Educational material	Learning task Peer assistant	-	Japeneese polite expression	-	-
		Material type	External	External	-	Internal	-	-
		Recommendation technique	Knowledge-based	Knowledge-based	-	Knowledge-based	-	-
	Model adaptation	**Runtime adaptation**	False	False	False	False	False	False
	Context model evolving	**Model evolving**	False	False	False	False	False	False
		Evolving type	-	-	-	-	-	-

Execution view

		PERKAM	TSUL	JAMIOLAS	JAPELAS	LOCH	TANGO
Context change detection	**Context change type**	Updated information	Updated information	Updated information	-	-	-
Feedback detection	**Feedback detection**	true	False	False	False	False	False
	Feedback type	Quantitative-Qualitative Comment -Suggestion	-	-	-	-	-

system behavior are not taken into consideration. None of evaluated systems evokes runtime model adaptation to reduce monitoring overhead. None of the systems evokes the detection of new context information from the *execution domain* and thus none of the systems evokes the evolution of the context model.

Subsequently, main research issues could be summarized as follows:

- U-learning systems need to model a very complex and dynamic learning situation including context information pieces and relationships.
- In order to serve learners with personalized learning, systems need to enable learning in a very complex situation combining online and offline information pieces and relationships. Hence, adaptation factors should cover the combination of situation entities, and adaptation should take into consideration adaptation of the content, the presentation and the system behavior.
- Context model covers very large context information pieces and relationships which are not all needed based on the runtime detected situation. Hence, runtime model adaptation could be applied to reduce monitoring overhead.
- A main issue for u-learning systems is to cope with the runtime learning context, especially with unforeseen changes that could occur during system execution.

6 Conclusion

In this paper, a descriptive view of the context usage in context-aware u-learning systems is detailed. A comparative analysis within this description is established for a non exhaustive list of u-learning systems in order to highlight their strengths and limitations and to demonstrate the implications of this research.

The suggested description was build to respond to the following purposes: to establish a structured baseline from which the three aspects of context usage can be easily identified within every studied u-learning system, to identify its drawbacks and to analyze the possibility to propose new research issues. In this paper, the focus was maintained on how the u-learning context should be used; however, there is still no consensus on *what is learning context*, *how it should be represented*, and *how its representation should be developed*. Hence, next work will focus on the establishment of a common evaluating framework for u-learning systems along four complementary worlds (including the usage world) capturing the four mentioned aspects of context.

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