Context: Yes but to whom?

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ABSTRACT
In this paper we propose an entity-centric definition of context information and in turn a definition of context. So far the definitions of context given by various authors have considered context as an absolute concept, however we challenge this view. We argue that context cannot be defined globally, rather it is a relative concept that depends on the entity that perceives it. This is the starting principle for our definition. In this paper we also present preliminary work on using mathematical formalism to describe this definition.

Categories and Subject Descriptors
I.2.4 [**Artificial Intelligence**]: Knowledge Representation Formalism and Methods – *relation systems, representations.*

General Terms
Algorithms, Management, Measurement, Design, Standardization, Theory.

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Ubiquitous computing, Pervasive Computing, Context, Context Information, Context Definition

1. INTRODUCTION
Context and context information has been an interesting research topic for the past decade with the pioneering work being that of Schilit and Theimer [1] who first coined the term ‘context-aware’ to describe the software that adapts according to its location of use, the collection of nearby people and objects and changes to those over time. Since then, the terms context, context information and context-aware have undergone through advancements with regards to their semantics, however a consensus to the precise meaning of these terms is still lacking.

We argue that there are two major problems associated with this issue. Firstly, there is a lack of formalism in the current definitions. Whenever a definition of context is presented it tends to be expressed in textual terms only. Expressing a definition using plain English or any other language for that matter possess inherent problems associated with the languages which in general carry a dose of ambiguity (just imagine the multitude of interpretations of the word ‘set’). This leads to the view that such definition, expressed using natural language will inherently become ambiguous and therefore subject to interpretation.

The second issue concerns the manner in which context information is observed. In general there are two ways to perceive context information. The first is taking the ‘bird’s eye’ point of view which states that there may be another entity; third entity (for example a context-aware system) that decides what information is context information and what is not. This is the approach taken by a number of authors, such as Dey [2], Brown [3], Chen and Kotz [4] and others when devising their definitions. For example in Dey’s definition, the ‘situation’ is one of the key terms used as criteria against which context information is judged. However it is unclear as to whom or what makes the decision as to what information is treated as context information.

The second approach to defining what constitutes context information and in turn context, is to take the subjective view, leaving it up to the entity to decide what information is regarded as context information. In this regard, Pascoe [5] argues that ‘context is a subjective concept that is defined by the entity that perceives it’, however while this is an apt approach, Pascoe’s definition comes short in specifying the key terms.

In this paper, we take the subjective line to defining context. The main motivation for taking this path is that information that may be regarded context information for one entity may not necessarily be context information for another. A typical example of this is location. Location, throughout the literature has been touted as one amongst the four main pillars of context, with the other three being time, identity and activity [6]. However, while location could be important context information from the point of view of a system that provides personalised services, for example, it may have no relevance whatsoever to a person walking in the park. In this view, it can be said that context is not an absolute concept and its relativity depends on the point of view it is observed from, that is the entity’s point of view. This is the starting point in the development of our definition.

The rest of the paper is organised as follows. We first critique the current definitions of context given by different authors followed by our views and then we present a definition of context information, which creates the necessary ground to define context. Finally we conclude by summarising the benefits of the proposed approach.

2. CURRENT CONTEXT DEFINITIONS

Context as a linguistic term has been defined in diverse ways in the areas outside ubiquitous computing, from "the interrelated conditions in which something exists" up to the "A context specifies an access pattern (or path): a set of interfaces which give you a way to interact with a model. For example, imagine a model with different colored arcs connecting data nodes. A context might be a sheet of colored acetate that is placed over the model allowing you a partial view of the total information in the model" [7]. However our aim here is to give a definition of context that is applicable in the realm of computer science and specifically ubiquitous computing.

We start by reviewing the definitions of context found throughout the literature, initially with the work of Schilit and Theimer [1] who assumed the approach of defining context by utilising context examples such as location, identities of nearby people and objects and changes to those objects over time. Ward et al. use the same approach [8] however they argue that context is current user, location and surroundings. Approaches to define context by examples are considered difficult to apply. One of the main issues concerns the ways to determine whether a piece of information is context information or not if it does not fit in any of the examples.

Brown [3] gives a very broad definition of context. He argues that context is simply the elements of the user's environment that the computer knows about. In contrast with the previous definitions, Brown goes one step further in that he does not use examples of context information to define the context, albeit the broadness of the definition creates difficulties in practical applications. Rodden et al. [9] attempt to classify context into four categories, namely application, system, location and physical context. However one of the problems encountered here is that the presented categories are not precisely defined which may lead to ambiguity when judging the context of an entity and the information associated with that context.

Pascoe [5] presents a rather different view in comparison to the definitions presented thus far. His entity-centric definition describes context as a subset of physical and conceptual states of interest to a particular entity. While we argue that entity-centric definition is the best fit to accurately describe context, the concept of states in this definition has not been precisely defined and as such, left to interpretation.

Schmidt et al. [10] amongst others ideas argue that "for each context a set of features is relevant." While this is valid, the authors miss an important point, that is who or what determines the relevance of a feature? Suffering from similar issues is the definition given by Chen and Kotz [4] that defines context as "set of environmental states and settings that either determines an application's behaviour or in which an application event occurs and is interesting to the user". Furthermore this definition relies in the idea of states; however authors come short in defining this concept.

One of the most cited definitions of context in the literature is given by Dey [2] that defines context as "any information that can be used to characterize the situation of an entity". As with above definitions the main concepts are lacking precise definitions, for example: situation.

Apart from the issues highlighted above, a commonality between these definitions is that the authors seem to be missing the full picture. In an effort of trying to define context, time and again the only question asked is 'what' is context information, though just as importantly the question 'to whom' this information is context information seems to have been overlooked. As stated in the introduction, context is not an absolute concept, but rather dependent on a particular point of view. A slight exception to this statement is the Pascoe's definition, although it suffers from other issues highlighted in the above discussion.

3. OUR DEFINITION

Considering the above elucidation, we propose an entity-centric definition that links information with activities of an entity as follows:

> *"Context information is information that is deemed relevant by an entity with respect to the entity's activity. An entity is defined as anything that can be engaged in activity. Activity is defined as the state of doing something with the purpose of achieving a goal"*

This definition represents a major shift from the current definitions critiqued in this paper. The main point is that it positions the entity at the centre of control when deciding what information is considered context information. Hence it is up to the entity to assess whether a piece of information should be regarded as context information or not. This is a very important issue, since this definition allows distinction between information and context information, an important issue that has not been addressed throughout the literature. We believe that this is one of the major obstacles in rapid development of context aware applications and we plan to develop a context aware application model based on this definition.

Since the lack of formalism is one of the issues associated with other definitions we now provide the mathematical description of the textual definition presented above. The mathematical formalism presented in this paper is still at the preliminary stage. It is anticipated that the formal part of the definition will be subject to changes in the future as a result of our current work in this area, however the primary intention here is to help illustrate the main idea.

The basic unit of information for an entity is a *fact.* The set of all known facts represents the entity's *information set*. Consequently the following applies:

$$I = \sum_{i=1}^{n} f_i$$

A fact can be already known (it is part of the information set), can be inferred from existing facts, it can be explicitly retrieved by the entity, or a fact can be presented to the entity in question by another entity.

An *activity* starts with the initial specification of a *goal* (g) until the end result. The end result could have a number of outcomes. The goal may be successful or not, another activity may be started or the entity may cease to be active. The basic unit of an activity, that the entity can be engaged in, is known as a *task.* Each activity will have one or more sub-activities, or tasks working towards achieving the goal. Of course each task may be viewed as an activity with other sub-tasks; however, for simplicity reasons we consider two levels only, the activity level and the task level. At this stage and for the purpose of this paper we do not elaborate as to how the tasks are orchestrated to achieve a goal. So an activity may be defined as:

$$a = g \bigcup \sum_{j=1}^{n} t_j$$

Therefore, the sum of all activities an entity can be engaged in represents the *activity set* and is defined as:

$$A = \sum_{k=1}^{n} a_k$$

For an activity in the activity set, the entity specifies the activity *priority* function. Priority is calculated at a certain point in time, by the entity itself and the entity may change this value over time. The priority value typically determines the importance of an activity:

$$f_{pri}(a_k) = \begin{cases} 0 & low\ priority, \\ > 0\ and < 1 & mid\ priority, \\ 1 & high\ priority \end{cases}$$

When an entity sets its activity priority level at 0 any fact presented will be relevant to that activity. Naturally, during a typical operation, an entity very rarely will set an activity priority value to 0. An exemption to this lies in the case of a *decision* activity. The decision activity realises the decision function and it is responsible for determining whether a certain fact is considered context information or not. This function is explained in the next paragraph. When a new fact is deduced, retrieved or presented to the entity, the entity will evaluate the current activity priority and set this value accordingly.

An entity has a decision function that determines whether a fact is considered context information. The decision function yields a boolean value and is defined as follows:

$$f_{dec}(f_i, a_k) = \begin{cases} 0 & if\ not\ context\ information, \\ 1 & if\ context\ information \end{cases}$$

An entity will engage in this activity whenever a need arises to evaluate a fact, for example when a new fact is retrieved by the entity or explicitly presented to the entity.

In a similar fashion, a particular fact has a *relevance* value that is calculated by the entity at a point in time with respect to an activity by utilising the relevance function. Similarly to the priority value, an entity may choose to change the relevance of a fact at any time. The relevance function for a certain fact is engaged only if the f_{dec} function is successful (yields value of 1), at which point an association has been created between a particular fact and an activity. In other words:

$$f_i \xrightarrow{assoc} a_k \Leftrightarrow f_{dec}(f_i, a_k) = 1$$

The association function can be used to determine the set of all facts that are associated to an activity. If a particular fact f_i is associated to an activity a_k then the relevance value of that fact will be equal to at least the priority value of the activity a_k .

As such, assigning a relevance value to a fact is a two step process. Firstly, the entity calculates whether a certain fact is relevant to the current activity or not, by engaging the decision function f_{dec} . If the entity decides that a fact is relevant to the current activity, i.e. it is deemed to be context information, then the relevance value of that fact with respect to the activity is calculated. Subsequently the relevance of a fact only makes sense when calculated with respect to a particular activity. The relevance function can be calculated as follows.

$$f_{rel}(f_i, a_k) = \begin{cases} f_{pri}(a_k) & low\ relevance, \\ > f_{pri}(a_k)\ and < 1 & mid\ relevance, \\ 1 & high\ relevance. \end{cases}$$

Typically, although not always, facts that have low to mid relevance are considered to enhance the current activity towards achieving the goal. Facts with high relevance typically will change the current activity, potentially starting a new activity or driving the entity into an idle state. Obviously this behaviour is not valid in every instance and will depend on the entity in question.

From the statements presented above we can conclude that a fact is considered context information with a certain relevance value if:

$$f_{dec}(f_i, a_k) = 1 \wedge f_{rel}(f_i, a_k) \geq f_{pri}(a_k)$$

Therefore a fact is deemed to be context information if and only if the relevance value of that fact with respect to an activity is greater or equal than the priority value of that activity and the decision function is successful.

Upon defining what constitutes context information paves the way to define what comprises context. In our definition, the context of an entity is the set of all activities and all the facts from the information set that are associated with those activities. In other terms:

$$C = A \bigcup I$$

$$\Downarrow$$

$$C = \sum_{k=1}^{n} a_k \bigcup \sum_{i}^{n} f_i \bullet (a_k = g_k \bigcup \sum_{j=1}^{n} t_j) \wedge (f_{assoc}(f_i, a_k) = 1)$$

Figure 1 depicts the definition in a graphical manner. The diagram shows one activity and the facts associated with it. Full line graph represents context information, while broken line represents facts at different points in time. For completeness the historical and anticipated information is included in the diagram (i.e. Past and Future). The activity is presented with the main curve and at different points in time the entity will assign a priority value to this activity as shown.

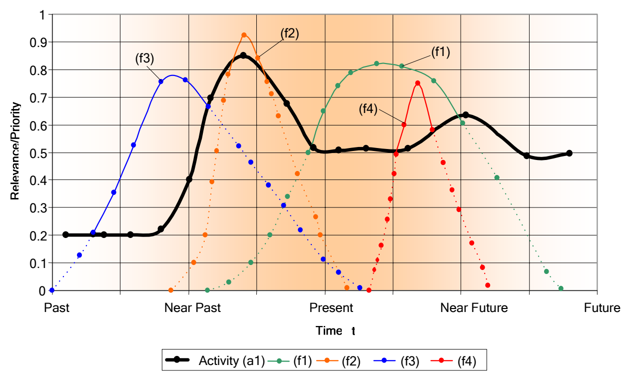

Figure 1 Context Definition Diagram

The diagram illustrates the facts becoming context information and after a certain time becoming facts again. As mentioned above, a fact is firstly subjected to the decision function f_{dec} and if this function is successful (yields the value 1), then the fact is considered context information with its relevance value set to the priority value of the activity. The next step is to subject the fact to the relevance function f_{rel} which sets the appropriate relevance value to the fact. For example at the Present point in the diagram, the fact f_1 is considered context information with respect to the activity a_1.

4. CONCLUSION

This paper has presented a new context definition based on the premise that context is a subjective concept that depends on how entity perceives it. We also have presented this definition in a formal manner, which we feel should be an indivisible component of any context definition. Such combined approach, the subjective point of view and the formalism, we feel is an improvement over the current definitions that tend to be expressed in textual terms only. This definition will be further developed to define components that have been described textually. We also plan to devise a context-aware application model based on this definition.

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