An Operational Definition of Context

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Abstract. The definition of context experienced an evolution in the research area of context-aware computing, but still suffers from either generality or incompleteness. Furthermore, many definitions are driven by the ease of implementation. This paper introduces two extensions to available context definitions that provide a natural understanding of this concept to users of context-aware applications and facilitates the engineering of this concept for software developers of such applications.

1 Introduction

Since the term *context-aware computing* was first introduced by Schilit et al. in 1994 [20], a large number of definitions of the terms *context* and *context-awareness* has been proposed in the area of computer science. In [7], Dey presents alternative views on context and its definition. Basically the majority of existing definitions of the term context can be categorized into definition by synonyms and definition by example. Context experienced various characterizations using synonyms such as an application's environment [13] or situation [2]. Many authors define context by example [3, 10, 19] and enumerate context elements like location, identity, time, temperature, noise, as well as the beliefs, desires, commitments, and intentions of the human [5].

For the operational use of context, such indirect definitions by synonym or example suffer from generality in the first and incompleteness in the latter case. Specifically if the term context, situation and environment are used with similar meaning, any definition including one of the terms is self-referencing in loops. The practical usefulness of such a definition is limited. The definitions fail to establish any fundamental basis for their construction, since they are basically driven by the ease of implementation. However, the active involvement of users in a user-centered design process for the creation of usable context-aware applications requires a formal and operational definition of context that can be communicated to the users. This paper introduces a context definition comprising three canonical parts: a definition per se in general terms, a formal definition describing the appearance of context and an operational definition characterizing the use of context and its dynamic behavior. In contrast to other context definitions, this structured approach to a definition aims at bridging the user-developer gap, since it provides both, a natural understanding of the concept for users and the ease of the engineering of the concept for software developers.

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2 Extending Available Context Definitions

Addressing the quite limited notions and early definitions of context, Dey provided the following general definition, which is probably the most widely accepted: *"Context is any information that can be used to characterise the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between the user and the application, including the user and the applications themselves."* [7]

This application-centric definition clearly states that context is always bound to an entity and that information that describes the situation of an entity is context. However, in using indefinite expressions such as "any information" and "characterize the situation" the definition becomes general. Practically, the provided notion of context includes any kind of information that is relevant to the interaction between a user and an application, and thus, any application defined as adaptive in traditional terms, is actually a context-aware application.

Dey also introduces the user's task as an important concept in context-aware computing through his definition of context-aware systems. The task itself is also part of the context as it "characterizes" the situation of the user. This central role of the task is shared by [6] and [15] who assume that user's actions are generally goal driven. They introduce the term activity to accurately capture the observation that the user is concerned with several tasks simultaneously. In a more recent work, Chen documents his understanding of context that "*extends to modelling the activities and tasks that are taking place in a location*" [5]. Henricksen even puts the task in the centre in her specific definition of context: *"The context of a task is the set of circumstances surrounding it that are potentially of relevance to its completion."* [12]

Each of the provided definitions introduces a considerable amount of expert knowledge that needs to be incorporated in further research. However, many approaches fail provide a justification of their context definition. Dey's definition is intended to be adequately general to cover the work conducted by research in context-based interaction. In order to further constrain its universality, this general definitions need to be enclosed by a formal and an operational part:

Definition: Context
Context is any information that can be used to characterize the situation of an entity [7]. Elements for the description of this context information fall into five categories: *individuality*, *activity*, *location*, *time*, and *relations*. The activity predominantly determines the relevancy of context elements in specific situations, and the location and time primarily drive the creation of relations between entities and enable the exchange of context information among entities.

The following sections explicitly address the two extensions to Dey's definition comprising the formal and the operational part of the definition.

3 Formal Extension: Categories of Context Information

A context model rapidly becomes large and complex and can only marginally comply with demands on the comprehensibility and manageability [1]. This section introduces a formal structure of context information, which constricts and clusters this information into five fundamental categories. This structuring of context is vital for any pragmatic approach and facilitates the engineering of a context model for context-aware applications, since these fundamental context categories determine the design space of context models.

3.1 Available Structuring Approaches

As constituents of the context Schilit et al. (1994) enumerate *"the location of use, the collection of nearby people, hosts, and accessible devices, as well as to changes to such things over time"* [20]. On a conceptual level it is also argued that further issues, such as lighting, noise level, communication cost, and social situation are of interest and can be regarded as context. Dey et al. (2001) extend their definition of context with the statement *"Context is typically the location, identity and state of people, groups, and computational and physical objects"* [8]. A high amount of enumerations separates context into personal and environmental context [10, 18]. Most of the issues that are classified as personal context are often also referred to as user profiles and usually stay the same during the operation of the application. Environmental contexts are of a more general nature and include attributes like *"the time of day, the opening times of attractions and the current weather forecast"* [18].

In the field of modeling and reasoning within real world knowledge, Lenat suggests to concretely define context as a point in a twelve dimensional space in which context information is characterized [16]. These contextual dimensions organize the background knowledge for reasoning processes. Four of these dimensions refer to spatio-temporal issues and most of the remaining eight dimensions allocate human intent. In [21] Schmidt provides some structure for the characterization of context, as well, and qualifies context as a three-dimensional space with the dimensions *self*, *activity* and *environment*. The *self* dimension introduces a relation of the context to one specific entity (user, device, application, etc.). However, his description lacks an approach of how his model would capture a setting comprised of many interacting entities, each bound to a context by the self dimension. The dimensions time and location are consciously missing due to the fact that time is implicitly captured in the history and due to the observation that context is not necessarily related to location.

3.2 Fundamental Categories of Context

Any information describing an entity's context falls into one of five categories for context information as shown in Fig. 1: Individuality, activity, location, time, and relations. The individuality category contains properties and attributes describing the entity itself. The category activity covers all tasks this entity may be involved in. The context categories location and time provide the spatio-temporal coordinates of the respective entity. Finally, the relations category represents information about any possible relation the entity may establish with another entity. The following paragraphs describe these five categories of context information in more detail.

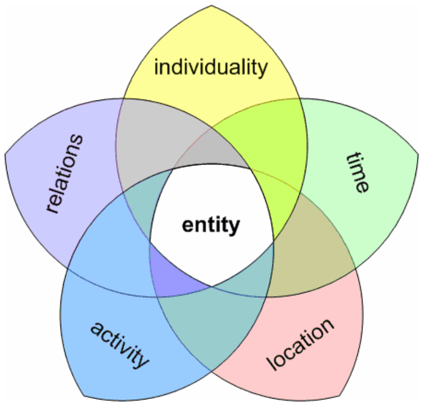

Fig. 1. Five Fundamental Categories for Context Information

3.2.1 Individuality Context

This category gives access to contextual information about the entity the context is bound to. This information comprises anything that can be observed about an entity, typically its state. An entity can either be an individual entity or groups of entities that share common aspects of the context. Entities can act differently within a context-aware system or obtain different roles. Basically they can be active, i.e. able to manipulate other entities, or passive. In addition, entities can be real, i.e. existing in the real world, or virtual, i.e. only existing in information space. Furthermore, there exist mobile, movable and fixed entities. The following sections cluster individuality context information into four entity types: natural, human, artificial and group entities.

Natural Entity Context

This category comprises the characteristics of all living and non-living things that occur naturally and are not the result of any human activity or intervention. The natural environment is usually different form to "the built environment" and includes for example plants, stones, and other things relating to nature without any artificial add-on. Furthermore, any product of the interaction between nature and humans is part of this category as well.

Human Entity Context

This category of context information covers the characteristics of human beings. In order to automatically perform adaptations that meet the user's necessities, adaptive system need to base their decisions on the evaluation of the user behavior and consider basic user properties such as preferences in language, color schemes, modality of interaction, menu options or security properties, and numberless other personal favorites. The General User Model Ontology (GUMO) by Heckmann provides a comprehensive view on the characteristics that potentially are taken into account [11].

Artificial Entity Context

The artificial entity denotes products or phenomena that result from human actions or technical processes. In a broad sense, this category covers descriptions for any human-built thing like buildings, computers, vehicles, books, and many more. It includes computing hardware descriptions for devices such as laptops, Personal Digital Assistants (PDAs) or Smartphones, characterizing properties like screen or display size, the bandwidth or reliability of the accessible network connection. All sensors that measure physical or chemical properties (like temperature, humidity, pressure, sound, lightness, magnetism, acceleration, force, and many more) are also artificial entities. Beside hardware, software related artifacts resulting from a software engineering process such as the design, the product documentation, an application, or service are part of the category as well.

Group Entity Context
A group is a collection of entities, which share certain characteristics, interact with one another or have established certain relations between each other. The primary purpose of using groups is to structure sets of entities and to capture characteristics that only emerge, if entities are grouped together. Characteristics that members of the group may share include interests, skills, cultural background, or kinship ties in a social sense, and computing power, network connections, or display size in a technological sense. As members of the group, these entities share a common identity. Groups may be large (e.g. "the Germans") or small (e.g. "the Smith family"), and in principle, entities may belong to none, one, or many groups. The membership to groups may emerge dynamically during system operation, e.g. based on observations, or in advance, e.g. to express a fixed relation (cf. Section 3.2.5).

3.2.2 Time Context

Time is a vital aspect for the human understanding and classification of context because most statements are related over the temporal dimension [10]. This category subsumes time information like the time zone of the client, the current time or any virtual time. A straightforward representation of time is the Central European Time (CET) format, which facilitates mathematical calculations and comparisons. Overlay models for the time dimension are often applied in context-aware computing and provide categorical scales like working hours or weekends. Other domains require a more process-oriented view of the time concept (e.g. work flows). The ability to represent intervals of time also constitutes a fundamental requirement on the context model. In combination with the ability to capture and express recurring events (e.g. always on Sundays), intervals are a significant feature for modeling user characteristics.

Persistently storing context or situations creates a data pool containing a history of obtained contextual information. This history forms the basis for accessing past context information, analyzing the interaction history, inferring usage habits of users and predicting future contexts. The evaluation of the interaction of users with the system includes the history of the usage process in order to establish a continuous context model for a short-term or a long-term perspective. Moreover, context management issues also benefit from the access to historical context information, since incomplete or imprecise context values can be extrapolated.

3.2.3 Location Context

With the development of portable computing devices the location became a parameter in context-aware systems. Physical objects and devices are spatially arranged and humans move in mobile and ubiquitous computing environments. Since tasks often include mobility, this category describes location models that classify the physical or virtual (e.g. the IP address as a position within a computer network) residence of an entity, as well as other related spatial information like speed and orientation [26]. Furthermore, a location may be described as an absolute location, meaning the exact location of something, or as a relative location, meaning the location of something relative to something else. Models for physical locations can be split into quantitative (geometric) location models, and qualitative (symbolic) location models [22].

Quantitative location models refer to coordinates with two, two and a half, or three dimensions. For example the two-dimensional geographic coordinate system expresses every location on Earth in the format degrees, minutes and seconds for the longitude and latitude. Tracking or positioning systems such as the satellite-based Global Positioning System (GPS) supply location information through measuring distances or angle to known reference points and translating these relative positions into absolute coordinates. Furthermore, such systems can be classified according their indoor or outdoor operating mode, their granularity of position determination and their underlying technology, e.g. radio or light signals [17].

Instances of qualitative spatial information are buildings, rooms, streets, countries, etc. that depict a mutually nested relationship. Such qualitative information increases the transparency for humans regarding their spatial cognition, since they introduce several spatial granularity levels. Overlay models allow for an interpretation of quantitative spatial information and transformation into appropriate qualitative information. Stahl and Heckmann (2004) undertook an investigation on spatial concepts and models, and propose a hybrid location modeling approach [22]. In general, an entity always possesses one physical qualitative location, which can be represented by different quantitative locations, but also several virtual locations at the same time.

3.2.4 Activity Context

An entity's activity determines to a great extend its current needs. The activity context covers the activities the entity is currently and in future involved in and answers the question "What does the entity want to achieve and how?" It can be described by means of explicit goals, tasks, and actions. In most situations when interacting with a context-aware system, an entity is engaged in a (potentially demanding) task that determines the goals of the performed activities [4].

A task is a goal-oriented activity expectation and represents a small, executable unit [14]. Tasks include operation sequences with a determined goal, to which a context-aware system can adapt the necessary functions and sequences of functions. In particular human entities change their goals very frequently depending on quickly appearing conditions or decisions, even without leaving the session with a computing system. Therefore a differentiation between low-level goals, which can change quite often, and high-level goals, which are more consistent, is reasonable. Accordingly, the activity context can be represented by (domain-specific) task models that structure tasks into subtask hierarchies, which is the most advanced representation of possible user goals [24]. The determination of the current goal is either specified by the entity or a choice from the set of goals, which depicts the highest probability.

3.2.5 Relations Context

This category of context information captures the relations an entity has established to other entities. Such surrounding entities can be persons, things, devices, services, or information (e.g. text, images, movies, sounds). The set of all relations of the entity builds a structure that is part of this entity's context. A relation expresses a semantic dependency between two entities that emerges from certain circumstances these two entities are involved in. The characteristics of the entity's environment (i.e. presence and the arrangement of other entities) are primarily determined by the spatial and temporal context of this entity. Secondarily, the individuality of the respective entity description impacts the relations (e.g. people of the same age). In general, each entity plays a specific role in a relation. Potentially, an entity can establish any number of different relations to the same entity. Additionally, relations are not necessarily static and may emerge and disappear dynamically. Section 4.2 describes the exploitation of relations between entities. Since the set of possible relation types between two entities is large, a clustering of relations regarding the types of the entities involved is helpful. Therefore, the relation category is subdivided into social, functional and compositional relations:

Social Relations

This sub-category describes the social aspects of the current entity context. Usually, interpersonal relations are social associations, connections, or affiliations between two or more people. For instance, social relations can contain information about friends, neutrals, enemies, neighbors, co-workers, and relatives. One important aspect in a social relations context is the role that the person plays in this relationship. Social relations differ in their levels of intimacy and sharing, which implies the discovery or establishment of common ground. Information about shared characteristics with other people, or in turn about individual differences, also contributes to the characteristics of a person. From this, patterns in behavior may be derived or groups of people with identical interests, goals, or levels of knowledge.

Functional Relations

A functional relation between two entities indicates that one entity makes use of the other entity for a certain purpose and with a certain effect, e.g. transferring a specific input into a specific output. For example, such relations exhibit physical properties like using a hammer, sitting on a chair or operating a desktop computer. Furthermore, functional relations show communicational and interactional properties like typing in a word or speaking into a microphone. Moreover, this relations subcategory indicates mental and cognitive properties like reading an article, giving a presentation or reasoning a concept.

Compositional Relations

A very important relation between entities is the relation between a whole and its parts. In the aggregation, the parts will not exist anymore if the containing object is destroyed. For example, the human body *owns* arms, legs, etc. The association is a weaker form of the composition, because it does not imply ownership and parts can have more then one whole they belong to. For example, a fax machine may belong to different secretariats or different departments.

4 Operational Extension: The Use of Context

Context obtains a specific role in communication, since it is an operational term: something is context because of the way it is used in interpretation, not due to its inherent properties [25]. When interacting and communicating in everyday life, the perception of situations, as well as the interpretation of the context is a major part [10]. Humans already have an informal sense of interpreting and using context information. The following paragraphs present the operational additive to the general definition that addresses dynamic properties of context and fosters a systematic foundation of the use of context in context-aware applications: the transitions between contexts of one entity and the sharing contexts among several entities.

4.1 Context Transitions

Entities, particularly human entities, change contexts and actually two consecutive contexts are never exactly the same. The knowledge necessary for context changing is basically contained in the context itself and thus, closely enlaced with the categories of context information and their characteristics. The following paragraphs describe the coherences of how context attributes change from one context entering another.

4.1.1 Variation of Approximation

While migrating from one context to another, the contextual knowledge represented by the current context experiences a specialization or an abstraction. The level of specialization or abstraction of the context is closely connected to the different levels of granularity exhibited by context information [23]. A representation of the real context of an entity is always an approximation. Fig. 2 shows the variation of approximation within the boundaries of the context model. The notion of approximation is relative: one representation is more approximate than the other, because details that the other takes into account are lost by abstraction. Through varying the degree of approximation a partial ordering over contexts emerges: if two contexts are compared with each other, one contains all the information of the other and probably more. An additional mechanism for varying the degree of approximation is the memorization of past situations in context histories. This accumulated knowledge leads to making experiences explicit in the context representation and to transferring knowledge from one category to another.

4.1.2 Change of Focus

The focus of a context refers to the reachability or accessibility of specific elements of the context description in a specific situation. Context information has a time and a point or region of origin, at which the focusing or relevancy of this context information is maximal [21]. For an entity, the spatial and temporal distance to the source of this context attribute determines, whether this attribute is in focus or not. As Fig. 3 shows, this relevancy, as well as the certainty on the correctness of the provided value, decreases with an increasing temporal or special distance from the origin of the context information. This fact can contribute to the disambiguation of multiple values for the same type of context information.

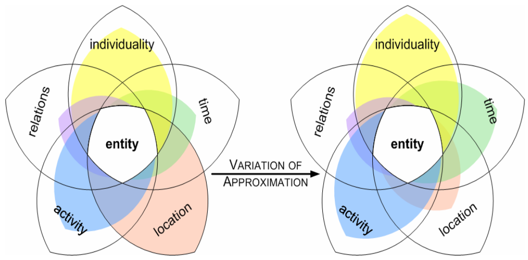

Fig. 2. Variation of Approximation

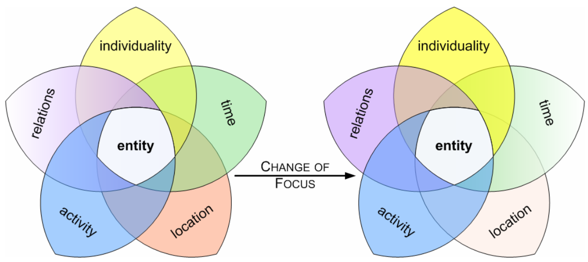

Fig. 3. Change of Focus

4.1.3 Shift of Attention

The current activity and the task of an entity have influence on the type and amount of knowledge required for their processing, including contextual knowledge. More precisely, the activity determines the focus of attention on specific aspects of the contextual knowledge. Features of the world become context through their use [25]. The focus of attention is switched when the activity of an entity changes, indicating that a new task is to be performed. A switch in the attention focus changes the need for contextual knowledge and therefore leads to different perspectives on the context information. Fig. 4 illustrates a shift of attention towards a more location-oriented perspective. Each aspect of the context plays a specific role during the performance of a task and this role might show considerable variance across the course of an activity. For example, the context attribute heart beat of a person is most likely irrelevant during the task of driving to the hospital, but it might become highly relevant during a task like being operated.

4.2 Shared Contexts

A shared context emerges, when the contexts of two entities overlap and parts of the context information become similar and shared. Besides the occupancy of its own context, an entity can belong to one or more different (parts of) contexts owned by other entities. Thus, through sharing contexts an entity can be viewed under different perspectives. Additionally, a group of entities sharing certain context parts share knowledge of how things are done and understood in this group. In the following, the emergence and exploitation of shared context is described: First, the correlation

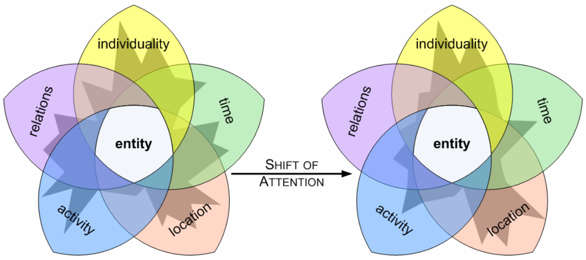

Fig. 4. Shift of Attention

concerning time and space enables the detection of a relation between two or more contexts. Second, the regression of time and space enables estimating which type of relation is detected. Third, the newly established relation is consolidated.

4.2.1 Establishing Relations

The human's attention, action and perception of context are strongly dependent on the current point in time and position of the user. This observation can be transferred to entities that converge in one or the other way: spatial and temporal proximity enable them to start responding to each other. Before two entities can establish shared contextual knowledge, time and space are the cardinal bridging mechanisms for detecting similarities between two contexts. Fig. 5 depicts the process of establishing a relation between two entities A and B: The two entities approach each other, time and location overlap and a new relation between A and B is established. Additionally, temporal and spatial proximity leads to reciprocity of two entities' contexts and thus, forms the basis for the creation of groups or communities. It is worth mentioning, that similar locations in particular appear in various forms: visitor in front of a painting, people on the same bus, or two persons accessing the same web page.

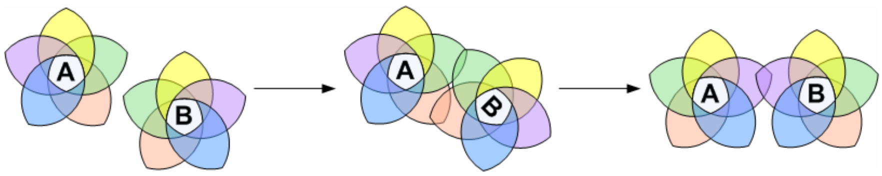

Fig. 5. Establishing a Relation

4.2.2 Adjusting Shared Contexts

Humans possess a different perception of contextual information, which mostly is due to the availability of context information on different levels of granularity or abstraction. The participants in an interaction need to share the same understanding or interpretation of the meaning "behind" a context description. For example, the granularity of the discussion between two doctors will be different compared to a doctor-patient conversation about the same disease, since more detailed and precise context information will be required. Fig. 6 exemplifies such an adjustment of the abstraction level regarding one topic: entity A and B need to adjust their respective knowledge regarding this specific topic, since entity A has deeper and different knowledge compared to entity B. Once a relation between two humans is established, they use specific mechanisms or rules to obtain a common understanding of their shared context. By observation or questioning, human beings are able to assess and clarify specific aspects. Such an adjustment expands a shared context and provides a common understanding in the communication between two parties. The same object can have different names in different contexts and by taking into account the "translation" of a representation into another a change of the perspective is possible. For example, a disambiguated reference to an article both parties read may result in an additional shared experience and thus, immediately lead to a better understanding of each other through uncovering a lot of background knowledge.

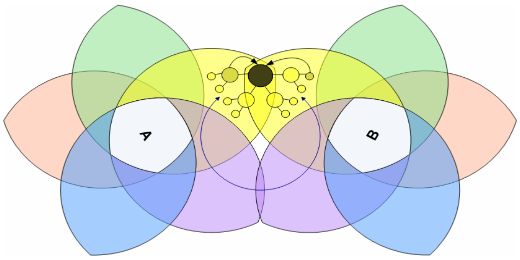

Fig. 6. Adjusting Shared Contexts

4.2.3 Exploiting Relations

The larger the shared context between two interacting parties, the more it facilitates communication, since they better understand what is expected without being explained in detail. After a relation is established and the shared context is adjusted, an entity gains special insight into the context of the other entity. Such an intense relation enables for context fusion or synthesis through three different mechanisms (cf. Fig. 7): Building of an internal model of the other entity, extending the own model and transcending relations.

Persistent relations among entities lead to the creation of internal models of their counterparts based on inquiry or observation (cf. Fig. 7 (a)). The internal model of the counterpart consists of two parts: facts, known from public and accessible parts of the partner's context, and assumptions, which are uncertain derivations and inferences about private and inaccessible parts. Since this internal model relies on interpretation and derivation, a mismatch may exist between this model and the real entity. An example is the system's model of the user's context, which will always be an approximation because of the limited capabilities of the computer system regarding inference mechanisms and representation. The "intellect" of a computer system comprises the rules and algorithms that it works with and that a developer implemented.

Furthermore, established relations can be exploited in a way that the own context is extended by attributes that lie in the intersection of the two shared contexts (cf. Fig. 7 (b)). For example, if a user establishes a "carries"-relation with a mobile device that

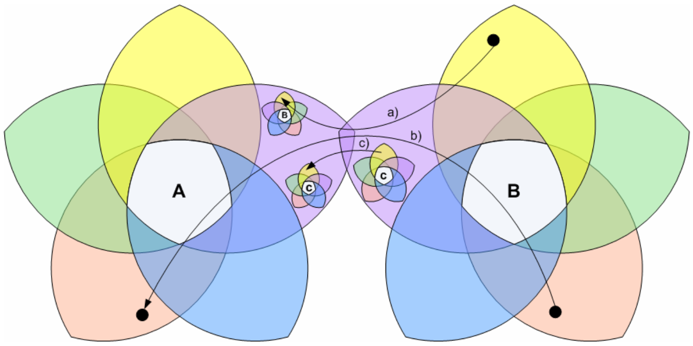

Fig. 7. Three Ways of Exploiting a Relation

obtains its position through GPS, this position implicitly can be transferred to the position of the user, since it is likely that both entities share the same location. Moreover, the exploitation of relations between entities includes the recognition and discovery of transitive relations that allow for reaching further unknown entities. From within a shared context, entities can "reach" any entity that belongs to the relations of an entity within that context and build an internal model of this entity (cf. Fig. 7 (c)). Potentially, this procedure can be repeated recursively with any entity that lies on the path. For example, if user A established a "trusts"-relation with user B, who in turn "trusts" user C, it is likely that user A can trust user C to a certain degree.

5 Conclusion

The core contribution of this paper lies in the introduction of a context definition that comprises three canonical parts: a definition per se in general terms, a formal definition describing the appearance of context and an operational definition characterizing the use of context and its dynamic behaviour. The resulting perception of context puts each entity in the centre of a surrounding individual context. This definition fosters a systematic foundation for the use of context in context-aware applications and emphasizes the dynamic properties of context emerging from context transitions and sharing contexts among entities. Furthermore, the paper contributed a formal structure of context information and presented five fundamental context categories that determine the design space of context models. This definition bridges the user-developer gap because it provides a natural understanding of the concept for users and eases the engineering of the concept for software developers. This understanding of the notion of context has been successfully applied in various context-aware applications [27].

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