Engineering Trust in Ubiquitous Computing

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1 Introduction

In Weiser's vision of ubiquitous computing (ubicomp), computers, as they are common today, vanish more and more [5]. Instead we will be surrounded by a multitude of smart items. The smart items are developed for different purposes, and therefore have different computational resources and communication capabilities. This increases the need for interaction with nearby devices. E.g., if it is not possible for an item to connect directly to the internet to get some information, it may receive this information form a nearby item, or connect to the internet via another item.

Furthermore, ubicomp applications need to adapt their configuration depending on the context information, like time, location, or infrastructure. E.g., the available communication partners can change with the location, and therefore some services are no longer available, but could be replaced by others.

We expect the ubicomp world to offer redundant services for all kinds of purposes. But those services may differ in quality, availability, privacy statements, and billing. The application developers will no longer be able to come up with a standard configuration which is perfect for everybody and we cannot expect the user to adapt the configuration of dozens of smart items perhaps several times a day. We need a dynamic concept which provides the user with a reasonable feeling of safety, which adapts the applications to the users preferences, and which takes advantage of the computational power available by interaction with other resources in the infrastructure.

In the following part of the paper we will show that trust is the appropriate foundation for interaction in ubicomp and how it should be implemented in applications. We believe that trust will become an important concept for applications in ubicomp environments and therefore has to be considered early in software engineering.

2 Concept of Trust

> That we get up at all in the morning is a sign of the trust we have in society and our environment. (Niklas Luhmann, 1979)

2.1 Social Trust

Trust is a well-known concept of everyday life, which simplifies complex processes. Many processes are enabled by trust and would not be operable without. Trust allows us to delegate tasks and decisions to an appropriate person, and trust facilitates efficient rating of information based on the experience with communication partners and, if applicable, on their reputation. Essential aspects of trust, besides personal experience and reputation, are the expected risk and benefit associated with the engagement of concern [4].

Trust has several features on which most researchers on this topic agree, and which are relevant if the concept is applied to ubicomp. Trust is subjective and therefore asymmetric. That is if Alice trusts Bob, we cannot make any conclusion about Bob's trust in Alice. Trust is context-dependent: It is obvious that Alice may fully trust Bob in driving her car, but not in signing contracts in her name. Trust is also dynamic. It can increase with good experiences and decrease with bad experiences, but it can also decrease if too much time has passed without any experience.

Furthermore, trust has different levels [3]. We think that it is not necessary to model trust continuous since people are better in assigning discrete categories [2], but trust cannot be modeled in a binary way.

Finally, there is the sensitive point of transitivity of trust. If Alice does not know Charly, but Alice trusts Bob in a certain context, and Bob trusts Charly in the same context, Bob can report the recommendation of Charly to Alice. She will decide what to do with this recommendation based on her trust in Bob's ability to recommend other opinions in this context and on the trust level assigned to Charly by Bob for this context. Since it seems unnatural to build arbitrary long chains, we point out that trust is not transitive in a mathematical sense.

2.2 Trust in ubicomp

In computer science there is much research ongoing on trust [1, 2]. Trust has been successfully applied to many areas, e.g. security, eCommerce, virtual communities, and the semantic web. Trust is a concept, which helps people to deal with aspects like uncertainty, limited resources and interaction with others, and this way increases the efficiency of many everyday process. Since these aspects are main issues of ubiquitous computing, it is a very promising approach to transfer the concept of trust to this area, in order to exploit the potentials of the ubicomp environment. It will not be sufficient to add some trust mechanism to ready-made ubicomp applications. The concept needs to be integrated early in software engineering.

2.3 Definition

There is much work about the concept of trust in different areas of computer science, but there is no coherent understanding of trust [2]. Although trust is a well-known concept, it is hard to define. In our definition of trust we point out the basic social foundations of trust:

> Trust is the well-founded willingness for a potential risky engagement in the presence of uncertainty. Trust is based on experience, reputation as well as on the context of this engagement, including especially the expected risk and benefit.

The engagement will in general be the delegation of a task or of some information (more technically speaking, the delegation of a function or some data) from the delegator to the delegatee. For ubicomp, this means that trust is the appropriate basis for interaction between known and unknown devices described in the introduction.

3 Trust-aided computing

Our vision of trust-aided computing is about applications which explicitly model trust and use trust as basis to make decisions for risky engagements. Hence, it has direct impact on many kinds of interaction between ubicomp applications. Trust-aided applications are more than simple applications which get trusted by their users with growing experience. They model trust themselves. Therefore, they keep track of the devices they are surrounded by, they collect their experiences with those devices and information about the reputation of them. This way they can adapt to changes in the infrastructure and keep preferences for interaction with devices which are already trusted, or are reported to be trustworthy by other trusted devices. Trust-aided applications have to implement the following aspects.

3.1 Trust management

In trust management, we include the evaluation of the relevant context (e.g., time constraints, location, minimum level of expected quality of service), the evaluation of expected risk and benefit of the engagement, and the collection of opinions about the potential delegatees.

We do not want trust management to make a decision due to the credentials or certificates which a potential delegatee could present. The verification of a authentication of a certificate does neither imply that the delegator trusts the owner of the certificate, nor does it make a statement how much the delegator trusts in the binding between the identity of the one presenting the certificate and identity stated by the certificate. These parameters are not part of the trust management but of the trust model.

3.2 Trust model

The trust model aggregates the collected opinions and defines their representation. There are many different approaches to represent and aggregate opinions [2]. We identify two main requirements for opinion representation. At first, the representation has to be readable for man and machine in an easy way. This enforces a mathematical or logical model, which should be designed in a way that allows an intuitive representation for humans. Secondly, man and machine have to be able to update their own opinion according to latest experiences and preferences. From our point of view, trust depends on the overall number of experiences on single subject, as well as on the number or ratio of positive and negative experiences. Therefore, we think that trust cannot be expressed by a single value. An opinion should at least express our rating of the subject (positive, negative, or degrees inbetween) and the certainty of our rating, which should increase with the number of experiences.

Since experience is an essential issue of trust, the collection of experience and feedback from the user becomes an important aspect to be addressed by software engineering.

3.3 Decision making

The result of the decision making should obviously be the decision whether to trust or not, that is, whether to carry out the risky engagement or not. Since the user is not used to this kind of autonomous decision making (he does not yet have any trust in it, since he has no experience with it), the computed decision can be presented to the user with the possibility of manual overwrite. This seems to be reasonable, but will reduce the benefit of the automatization dramatically. Therefore, we need a way to reduce the risk of the user, without taking the benefit. The user should be able to define a set of expected results, and if the decision is part of this set, it will be carried out without any further user interaction.

4 Conclusion

Trust provides an excellent basis for delegation, which helps to cope with sparse resources and enables efficient evaluation of data presented by trustees. Trust is a concept which is able to adapt decisions to infrastructure changes, due to its dynamic nature. Furthermore, the building of trust chains seems to be the appropriate way to make interaction more reliable. In our future work, we will develop a robust trust model which can be applied to ubicomp applications and includes the social aspects of trust, especially the aspects of experience and risk. In the end, a framework should be developed which allows the explicit integration of trust in different kinds of software applications, as a first step towards trust-aided computing.

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