Opinion nets for reasoning with uncertain context information

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Abstract. Context-aware systems must be able to deal with uncertain context information. We propose a generic context architecture and representation that incorporates the uncertainty of context elements in terms of upper and lower bounds of probabilities. It is shown how opinion nets can be used to reason with these upper and lower bound probabilities. In this way it is possible to combine ambiguous or conflicting context information that comes from different sources. Moreover, information coming from different sources can be combined with experience learned from the past in a clean way.

1 Introduction

Pervasive systems that can adapt to changing environments and availability of resources must be aware of their context. These systems sense and react to context. Most systems make the assumption that the context they use is completely accurate. However, the information about context may not come from a reliable source, may be out dated, not available or may be erroneous. Firstly, a context-aware system senses its context via a network of sensors working together. The resolutions, accuracies and formats of these sensors can differ from each other. The resulting sensed values can have conflicts and ambiguities. The second cause of uncertainty are the current limitations of the underlying reasoning systems that deduce high-level context information from low-level sensor data. Lastly, due to the asynchronicity of context acquisition and use of context we must deal with the imperfection and aging of the context information. A challenge for the development of real-life and commercial context-aware systems is therefore the ability to handle uncertain and ambiguous context information.

We propose a generic context architecture consisting of context synthesizers, providers and consumers. Context elements are represented as predicates, with which are associated upper and lower bound probabilities. Then opinion nets are used to reason with these probabilities. If the context comes from different sources contradictions and ambiguities can arise. It is shown how opinion nets can resolve conflicts and ambiguities by combining several probabilistic inputs to a single output.

This paper is organized as follows. In section 2 the context architecture and representation are described. In section 3 we introduce opinion nets and show

how they can be of great value to deal with uncertainty in context-aware systems. Section 4 gives an overview of related work and compares it with the presented approach. Finally, section 5 gives an outline of future work and draws conclusions.

2 Context architecture and representation

The context architecture is a generic infrastructure inspired by Gaia [2]. It supports gathering contextual information from sensors, inferring higher level context and delivering context information to the correct entities. A context provider provides context information in a synchronous way. A context consumer or context synthesizer can invoke the provider in order to acquire information about context. A context synthesizer is an aggregator of context information from different sources. A context consumer is an entity that needs context data. A context consumer can retrieve context information by sending a request to the context provider. Every component can play more than one role. A component can be a context provider if it provides context data about a specific domain and at the same time a consumer if the component also needs data from other domains.

The general uncertainty model is based on predicates representing context elements or facts with associated confidence values. The predicate name describes the context element. The arguments are mostly of the form subject-object or subject-verb-object, e.g. *location(John, in, room3, lower, upper)* or *activity(room7, conference, lower, upper)*. The confidence values of the predicates are expressed as upper and lower bounds of probabilities. Alternatively we could express confidence values as a probabilistic value together with an accuracy measurement of the probability. We will call the confidence value an opinion.

3 Opinion nets

In a simple approach we could work with a singular probabilistic value to indicate the frequency that a predicate is true. However, in opinion nets [1] , each opinion is translated into a range of probability numbers. That range is specified as an upper and a lower bound on the probability of the predicate to be true.

Opinions coming from different sources can be tied together in several ways. The different sources could for example be one or more context providers and context synthesizers. The combining of the inputs to one output can be done in a context provider, synthesizer or consumer, depending on the requirements and structure of the application. The inputs of a context provider or synthesizer can also be put together with historical information that is learned from the past. In that way history can be taken into account and easily incorporated in the opinion net approach.

The advantage of working with upper and lower bounds is that we can work with imprecise probabilities. When there is not enough information to give an exact probability, but if the system knows enough to say that the probability is definitely between 0.4 and 0.7, we can capture this with opinions. Also, ambiguous information can be presented in a straightforward way. Lastly, conflicting information that comes from different sources can be combined in a clean way by using opinion nets.

Figure 1 shows the different opinions and how they are put together, for clarity only for the lower bounds. The opinions can be propagated through opinion nets. The boxes are called constraint boxes, and they can be *and* or *or* boxes. The following constraint equations govern the action of the or boxes. A and B represent inputs and A *or* B represents an output. Then, *l(A)*, *l(B)* and *l(A or B)* are the lower bounds of the probabilities. Similarly *u(A)*, *u(B)* and *u(A or B)* represent the upper bounds of the probabilities.

$$\begin{aligned} u(A) &\leq u(AorB) \\ l(A) &\geq l(AorB) - u(B) \\ u(B) &\leq u(AorB) \\ l(B) &\geq l(AorB) - u(A) \\ u(AorB) &\leq u(A) + u(B) \\ l(AorB) &\geq max[l(A), l(B)] \end{aligned} \tag{1}$$

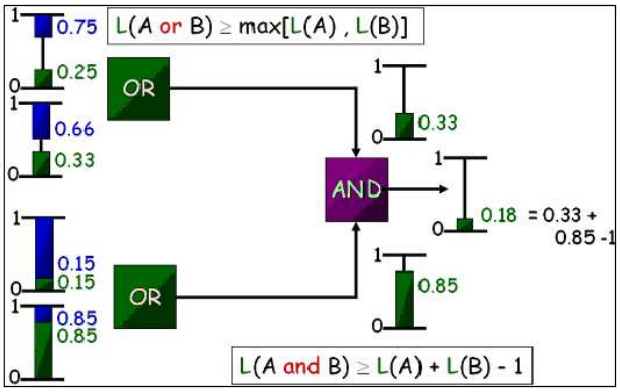

Fig. 1. Forward propagation of lower bounds in an opinion net

The equations for the *and* operator are similar. The combination of these assertions and boxes is an opinion net. An opinion net is thus a numeric constraint net in which it is possible to keep track of a conclusion's probability.

4 Related work

There exist several approaches for dealing with uncertain, ambiguous and inconsistent context information. The Integrated Context Model proposed by Truong

[3] allows to construct a Bayesian Network for reasoning with context information. Although this technique deals with uncertain context information, there is no straightforward way to combine conflicting and ambiguous information that comes from different sources, which is possible with opinion nets.

Gaia [2] is a prototype pervasive computing middleware system that allows to reason about uncertainty. Several mechanisms like probabilistic logic, fuzzy logic and Bayesian Networks can be plugged in. Context information is represented as predicates. Each predicate is described as a class in an ontology defined in DAML+OIL. A confidence value between 0 and 1 is attached to a predicate. Since our context architecture and representation is based on Gaia, opinion nets could be plugged in as a reasoning mechanism in Gaia.

Several techniques can be used to deal with imperfect context. However, Dey and Mankoff [4] argue that in realistic scenarios not all ambiguity in the data can be removed. Moreover, certain human aspects of context cannot be sensed or inferred by technological means. Their proposal is to involve end users in removing the remaining ambiguities through a process called mediation. The uncertainty inherent to the context information is explicitly presented to the user. Mediation can be fitted well in our approach. The opinion of the user can be treated as an opinion next to that of the system or next to an opinion inferred from experience learned from the past. Then these opinions can be combined using opinion nets.

5 Future work and Conclusions

To validate our approach a simulation environment will be developed. Experiments with context information coming from different sources have to be carried out. A test scenario can be the introduction of a vague concept like proximity as a context element. Context-aware systems such as a portable touristic city guide are location-aware and can suggest a tourist to visit a touristic attraction that is nearby. Proximity however is a subjective measure of distance depending on the context of the tourist. How close an attraction is depends amongst others on whether the tourist is on foot or by car, what his mood is, whether he is really interested to see the attraction and so on. Opinions concerning the proximity of a location that come from different sources can be combined by an opinion net to a single output of a probability range.

Based on a context architecture and representation, we proposed the use of opinion nets to deal with uncertain, ambiguous and conflicting context information. This approach allows to resolve ambiguities and conflicts arising from information that comes from different sources in a natural way. Moreover, the reasoning mechanism with opinion nets is general in the sense that it can be plugged in into every context system that represents information with probabilities and accuracies. We believe that further research will show the usefullness of opinion nets for reasoning with uncertain context information.

References

1. Patrick Henry Winston. Artificial Intelligence. Addison-Wesley, third edition, 1993 234–241
2. M. Roman et al.: A Middleware Infrastructure for Active Spaces. IEEE Pervasive Computing **1-4** (2002) 74–83
3. B. A. Truong, Y.-K. Lee, S.-Y. Lee: Modeling Uncertainty in Context-aware Computing. 4th Annual ACIS International Conference on Computer and Information Science (ICIS'05)
4. A. Dey, J. Mankoff: Designing Mediation for Context-Aware Applications. ACM Transactions on Computer-Human Interaction, Vol. 12, No. 1, March 2006, 53–80