MODELLING SPATIO-TEMPORAL RELEVANCY IN CONTEXT-AWARE SYSTEMS USING MULTI-INTERVAL ALGEBRA

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ABSTRACT: In our everyday life, we communicate with each other within a certain context; our actions are also within a certain context. Events affect every aspect of human life. The importance of the context also influences how we interact with the environment and how technologies provide services for us. The Context is generally regarded as data or information which describes the situation that is relevant. The major challenge of context-aware systems is a separation of relevant and irrelevant information by finding an acceptable degree of information reduction to the relevant one, i.e. presenting as much information as needed and as little as required. In this way, spatial and temporal relationships between the users and objects are two dominant factors for selecting appropriate relevant objects or "spatio-temporal relevant objects". So introducing and applying a comprehensive model for spatio-temporal relationships would help us to find spatio-temporal relevant contexts. In this research we aim to introduce a spatio-temporal relationship model which could support context-aware services. The main contribution of this paper is applying Multi Interval Algebra to model spatio-temporal relevancy for context-aware systems. We assumed that both user and related contexts have an influence interval in time and space. We defined four intervals for user and context; two spatial and temporal intervals for the user and two spatial and temporal intervals for the contexts. Their relationships would assist to model spatio-temporal relevancy. The proposed model is implemented and tested in a context-aware tourist guide system. The achieved results proved the efficiency of the model.

1 INTRODUCTION

Since the early 1990s, the term ‘context’ has increasingly attracted the attention of researchers in mobile and ubiquitous computing (e.g. Weiser, 1993; Schilit et al., 1994). With the fast development of wireless communication and increasing the use of mobile devices, context-awareness has become an increasingly important consideration in developing systems and applications. Being aware of the context(s) in which systems and applications are run can improve their ability to adapt and react to user situations, such as surrounding locations, people and objects.

Context is generally regarded as data or information which describes the situation that is relevant to and has influence on the state of users, systems and applications. Specification of the relevant object is the major challenge of context-aware systems. In this way, spatial and temporal relevancies are two dominant factors for context-aware interactions which could influence other types of relevancies. So introducing a spatio-temporal relevancy model could help us to provide appropriate context-aware services (Brimicombe and Li, 2009).

In this research we intend to introduce a spatio-temporal relationship model which could support context-aware services. We model the "spatio-temporal relevancy" using Multi-Interval Algebra Theory. According to this theory we should define intervals for user and related contexts in space and time dimensions, and the relationships between the intervals. Since the spatial interval depends on the direction of movement and the time interval is undirected, we define two different intervals for spatial and temporal dimensions for contexts and users. Using this method, we have four intervals in the filed. Their relationships would assist modelling spatio-temporal relevancy in context-aware systems. 169 relationships are discovered for this model. These relationships are used in the system for finding spatio-temporal relevant contexts as the user moves in an urban network. With the movement of the user, the intervals are updated and the spatio-temporal relevant objects are introduced to the user.

Our approach is implemented in an area of Tehran, capital of Iran, and we focus on an tour guiding example. Also, we assumed that the tourist is equipped by a PDA or Laptop, and a GPS for positioning the user and the route is constrained by a directed network. The evaluation of the model is based on the comparison between the theoretical spatial relevant contexts and the
number of relevant contexts which is detected by the model. We used chi-square test to report the accuracy of the model. The experimental results show that the proposed approach would effectively model and accurately detect spatial relevant contexts. The remainder of this article is structured as follows: Section 2 surveys the main concepts of the research including context-awareness, spatial relevancy and then Multi-interval Algebra Theory. Section 3 introduces the proposed methodology which concentrates on the assumptions, system scenario, and architectural design of the system, finally explains the spatio-temporal relevancy model and its implementation issues. Section 4 presents the evaluation of this work and shows the results of the algorithm in the implemented case study. Section 5 discusses the model, its characteristics and effectiveness in a context-aware system. Finally, conclusions and directions of future work are given in Section 6.

2 RELATED RESEARCH
Relevancy is a parameter which depends on the contexts supported by the system. ComMotion (Marmasse and Schmandt, 2000) is a location-aware information system which is using current location and time as context, the application delivers relevant messages to users. Oppermann and Specht implemented a nomadic exhibition guide system (Oppermann and Specht, 2000) which provides an adaptive guide to exhibition of the visitors with location information. GUIDE (Cheverst et al., 2000) is a context-sensitive tourist guide system for the city of Lancaster. The application combines the contexts of location and user preference in adapting the service provided across a wireless network. Gulliver’s Genie (O’Hare and O’Grady, 2003) is a context-aware system which provides multimedia tourist guide to assist roaming tourists. The system considers context in terms of location, orientation and user profile. In all of these systems location and time are two principal criteria for detecting the relevant context.

Reichenbacher (2005) modelled relevancy parameters and proposed some general rules of thumb for the assessment of relevancy that build a kind of hierarchy of relevant geospatial objects. He claimed that the bases of finding relevant contexts are physical and spatial relationship. Kwon and Shin (2007) implemented a context-aware system “Location-aware COoperative Query system (Laco)”. They modelled the spatial relations with metric distance and applied shortest path. Also they considered time parameter as a dominant factor for selecting appropriate contexts Vieira et al. improved a context-sensitive system that use context to provide more relevant services or information to support users performing their tasks. They introduced ‘behavior metamodel’ to find relevant contexts. The model was related to the dynamic aspects of context manipulation in a domain-independent manner. They consider spatial parameter or location and time dimension in the model (Vieira et al., 2010).

Achilleos et al. proposed a model-driven approach that facilitates the creation of a context modeling framework and simplifies the design and implementation of pervasive services. They demonstrated the benefits of their model-driven approach via the creation of a pervasive museum service and its evaluation using selected software metrics. The base contexts which is used in this system is location of the user and time (Achilleos et al., 2010).

Review of the related researches proved that spatio-temporal relationship between the user and the contexts is a dominant factor for finding relevant objects in context-aware systems. However, it seems that more research to explore qualitative and quantitative spatio-temporal relevancy modelling is still needed.

3 CONCEPTS
The basic concepts of this research are introduced in this section. First context-awareness and its components are described. Then relevancy and its different types are explained. Finally, Directed Intervals Algebra and its comparison with Intervals Algebra are evaluated.

3.1 CONTEXT-AWARENESS
Context awareness was introduced by Schilit and Theimer (1994) to develop software that adapts according to its locations of use, the collection of nearby people and objects, as well as changes to those objects over time. Schilit et al. (1994) claim that the important aspects of context are: where you are, who you are with, and what resources are nearby. Pascoe (1998) defines context to be the subset of physical and conceptual states of interest to a particular entity. The definition of context has been also expanded from physical attributes to include device characteristics as well as user-specific factors such as profiles and preferences (Dey, 2001; Moran and Dourish, 2001). According to Dey's definition, context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves. This definition makes it easier for an application developer to enumerate the context for a given application scenario. Also a system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user’s task (Dey, 2001 and Saracevic, 1996)

In order to provide a user-friendly service, all of those different types of context information should be not only available in any circumstance but also integrated and handled for converting them to personalized information of a specific user without any effort. Context-awareness is the integrated process or activity to collect and deliver context specific information, and converts it to tailored data of each (ISO/TC211, Report from Ad hoc Group on UBGI, 2007).

3.2 SPATIO-TEMPORAL RELEVANCY
Saracevic (1996 p.205) offers a general definition of relevance derived from its general qualities: “Relevance involves an interactive, dynamic establishment of a relation by inference, with intentions towards a context. Relevance may be defined as a criterion reflecting the effectiveness of exchange of information between people (or between people and objects potentially conveying information) in communication relation, all within a context.”
Humans are always at a certain position in space. Usually the current position – ‘the here’ – is the centre of action, perception, and attention. Perception, e.g. what someone feels, hears, and sees, is dependent on position and the spatial distance to the source of context. Thus, the context as perceived is strongly dependent on one’s position (Schmidt, 2002).

Moving position is also a human way of selecting an appropriate context for the activity that is performed. An example is walking towards lights when observing something very closely; the lighting condition – the context – is changed by changing the position. This is a very powerful concept and adapted in many location-aware applications (Schmidt, 2002).

Humans use space and locality as an efficient tool for structuring the environment and also to support tasks and actions. Spatial arrangements of artifacts are a most natural way for humans to order things. These spatial arrangements play a vital role when interacting with objects. Especially the concept of co-location is powerful and very often used, e.g. the books that are physically chosen on the shelf are often also similar in content (Schmidt, 2002).

Situation and context can be seen as phenomena that are related and bound to a particular place or region. Two of the most widely used aspects of context are place and time. Location information can aid users in different ways. It can cause automatic system behavior at certain places, such as notification on important objects in the environment (Streefkerk et al., 2006). The place or region where context information emerges – or that is assigned to this context information – plays an important role, especially in mobile and embedded systems. The place or region must not be seen isolated, it is always an attribute assigned to an identity, a process, a device, a task, an application or data.

Collecting data from the environment and acquiring context from this data is inherently bound to a location. The readings are collected at a particular position and therefore they represent the context for this particular position or the area related to this position. The information is fully relevant at this position. Generally, the relevance of the data declines with the distance from its point of origin (Schmidt, 2002). As seen from these observations locality of context is quite important and should therefore be included in the model as one of the basic relevant parameters which is called "spatio-temporal relevancy".

The importance of "spatial relevancy" is proved in location-based and context-aware systems. However, applying this concept in such systems has not been seen in related research completely (Reichenbacher, 2005). On the other hand, "temporal relevancy" is another specification to be considered. Indeed, it can be indicated that "introducing ‘spatio-temporal relevancy’ of information will be necessary for context-aware services to provide appropriate information".

Suppose that you want to take a bus for going to your home in night time. If your location and your account satisfy spatial relevancy, it may be adverse with temporal relevancy. So specifying the bus's services will depend on the time of day, or the related services may be different (omitted, limited or expended) based on the temporal characteristic. Therefore, relevancy is a parameter which is related to user's task and it could be determined based on spatial and temporal characteristics. The element of user's tasks (including user's goals, preferences, possibilities and characteristics …) is not the domain of our work; we intend to focus on the field of spatio-temporal relevancy.

3 METHODOLOGY
In this section first we discuss about the Multi-Interval Algebra theory and development of this theory in modelling spatio-temporal relationships. Then we propose our methodology, the scenario of the research and architecture of the system.

3.1 MULTI-INTERVALS ALGEBRA FOR SPACE AND TIME DIMENSIONS
Spatio-temporal representation and reasoning can be envisaged in two different ways. First, one is the combination of a spatial logic with a temporal logic. Some spatial snapshots are combined in a temporal reasoning to derive spatio-temporal information. The second one is to view the world as spatio-temporal histories and create new reasoning based on spatio-temporal entities (Raza, 2001). Multi interval algebra which stems from Interval Algebra theory tries to combine space and time dimensions with defining spatial and temporal intervals.

3.1.1 TEMPORAL INTERVAL
The default application of the Interval Algebra is temporal. 13 base relations including before $<$, after $>$, meets $m$, met-by $mi$, overlaps $o$, overlapped-by $oi$, equals $=$, during $d$, include $i$, starts $s$, started-by $si$, finishes $f$, and finished by $fi$ describe a combination of topological relations (disconnected, externally connected, partial overlap, equal, non-tangential proper part, tangential proper part, and the converse of the latter two) and order relations $(<,>)$.

3.1.2 SPATIAL INTERVAL (DIRECTED INTERVAL)
One particular way of regarding vehicles and their regions of influence (such as safety margin, braking distance, or reaction distance) could be to represent them as intervals on a line, which represents their influence domain (Wang et al., 2008). Being similar to the well-known Interval Algebra developed for temporal intervals (Allen 1983), it seems useful to develop a spatial interval algebra for modelling spatial relevancy. There are several differences between spatial and temporal intervals which have to be considered when extending the Interval Algebra towards dealing with spatial applications (Wang et al., 2008).

- Spatial intervals can have different directions, either the same or the opposite direction as the underlying line.
- It is interesting to represent intervals on road networks instead of considering just isolated path.
- Intervals such as those corresponding to regions of influence often depend on the speed of vehicles, i.e., it should be possible to represent dynamic information.

This given direction naturally imposes a direction also on the intervals. An interval can have the same or the opposite direction as the underlying line. However, because of its original and temporal interpretation (no event can end before it starts), direction of intervals has never been considered in Interval Algebra. Actually, directed intervals have been studied in the large field of
Interval Arithmetics, but work in this field is completely different from the qualitative and constraint-based approaches studied in IA. When using the Interval Algebra for spatial applications, direction of intervals has to be taken into account (Renz, 2001). Fig. 1 illustrates the differences of having directed intervals from having only intervals of the same direction. Since all of the four combinations of the directions of the two intervals are possible, there are four structurally different instantiations of every relation instead of just one. Therefore, it is possible that inconsistent instances of the Interval Algebra become consistent when allowing directed intervals (Renz, 2001).

![Fig. 1. Four structurally different instantiations of the relation “x behind y” with directed intervals](image)

This leads us to the definition of the directed intervals algebra (DIA). It consists of the 26 base relations given in Table 1, which result from refining each relation into two sub-relations specifying either same or opposite direction of the involved intervals, and of all possible unions of the base relations. Renz (2001) proposed Directed Intervals Algebra (DIA) to represent one dimensional moving object. DIA extends the Interval Algebra, and includes both topology and direction information. Renz called his work the first step of a spatial odyssey. This approach is applied in many research areas such as road network moving object (RNMO) by Wang et al. (2008), however, it seems that no further report is published about using DIA for context-aware services.

### 3.2 PROPOSED METHOD
This section discussed the assumptions of the research, architectural design of the system and the proposed methodology implemented in this paper.

#### 3.2.1 ASSUMPTIONS
In order to illustrate the spatial relevancy model, this section introduces assumptions of the research. Consider a system that supports tourists on guiding their points of interest, the assumptions are as follows:

- The user of the system is a tourist who is equipped by a PDA or Laptop, a GPS and enables to connect with other surrounding objects via Bluetooth. Tourists are usually interested to carry around information that describes the location they are visiting, so a reasonable package would be in the form of a hand-held device. The display will present the user’s location and destination based on geographical coordinates; when the user moves, the systems adapts the display accordingly.
- The route of the user is constrained by a directed network.
- Both of the object and the user have a directed interval and the relationship between them models spatial relevancy.

The key services which should be provided by the system are as follows:

- Accessing to any related information (relevant objects).
- Guiding the user to the point of interest.
- Delivering the new situation information.
- Informing the user if there is new additional useful information in the field.
- Reporting and preparing appropriate layouts

#### 3.2.2 ARCHITECTURAL DESIGN OF THE SYSTEM
The architecture of the system is based on a three-step processing concept for the correct display of context-aware services (Fig. 2).

**Step one:** This step is related to the user and environmental inputs. Indeed complete and accurate information of this stage would guarantee the output results. Step one consists of three components, the first is the user requirement where the user is a tourist. The second is user inputs and the third is environmental inputs. The details of each component are as follows:

- User requirement: PDA or mobile system, GPS and Geo-reference generalized map.
- User inputs: The location of the user, orientation of the user, field of view, and his/her points of interest.
- Environmental input: Time of day.

**Step two:** This step is named the process unit i.e. a unit which receives the inputs and process the based on the proposed algorithm. In fact this part uses the spatial relevancy model to send the appropriate context-aware service.

**Step three:** This step is revealed the result of the process and show the context-aware services to the user.

We should denote that the result of the process is adapted to the changes of the situation which is informed by input unit. In other word the model of the process unit is fixed, but the inputs of the user/environment and the output of the system is changed. This adaptation would result from the mobility of the user or changing of the space elements.
<table>
<thead>
<tr>
<th>Directed Interval's Base Relations</th>
<th>Symbol</th>
<th>Pictorial Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>x behind y</td>
<td>b&lt;-&gt;</td>
<td>-x-&gt;</td>
</tr>
<tr>
<td>y in front of x</td>
<td>f&lt;-&gt;</td>
<td>-y-&gt;</td>
</tr>
<tr>
<td>x behind #y</td>
<td>b#</td>
<td>&lt;-x-</td>
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<tr>
<td>y in front of # x</td>
<td>f#</td>
<td>-x-&gt;</td>
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<tr>
<td>x meet from behind ~y</td>
<td>mb&lt;-&gt;</td>
<td>-y-&gt;</td>
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<td>y meet in front of ~x</td>
<td>mf&lt;-&gt;</td>
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<td>x meet from behind y</td>
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<tr>
<td>y meet in front of # x</td>
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<tr>
<td>x overlaps from behind ~y</td>
<td>ob&lt;-&gt;</td>
<td>---y---</td>
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<td>y overlaps in front of ~x</td>
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<td>x overlaps from behind #y</td>
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<td>y overlaps in front of # y</td>
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<tr>
<td>x contained-in ~ y</td>
<td>c&lt;-&gt;</td>
<td>-x-&gt;</td>
</tr>
<tr>
<td>y extends = x</td>
<td>c&lt;-&gt;</td>
<td>-y-&gt;</td>
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<tr>
<td>x contained-in # y</td>
<td>c#</td>
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<tr>
<td>y extends = # x</td>
<td>c#</td>
<td>&lt;-y-</td>
</tr>
<tr>
<td>x contained-in the back of ~ y</td>
<td>cb&lt;-&gt;</td>
<td>-x-&gt;</td>
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<tr>
<td>y extends in the front of ~ x</td>
<td>cf&lt;-&gt;</td>
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<td>x contained-in the back of # y</td>
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<td>y extends in the back of # x</td>
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<td>x contained-in-the-front-of ~ y</td>
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<td>x contained-in-the-front-of # y</td>
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<td>y extends-the-front-of # x</td>
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<td>x equals y</td>
<td>eq&lt;-&gt;</td>
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<td>y equals # x</td>
<td>eq#</td>
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3.2.3 PROPOSED APPROACH
Regarding the interval algebra for space and time, we applied Multi interval approach for modelling spatio-temporal relevancy. In this way we consider two spatial interval and temporal interval for the user and two spatial interval and temporal interval for the context. Their relationships would assist modelling spatio-temporal relevancy in context-aware systems. As we consider time and space together for decision about spatio-temporal relevancy and every dimension have 13 relations, 169 relationships are discovered for this model. Fig. 4. illustrates the scenario of the research.
4 CASE STUDY

We implemented the algorithm in Vb.net and developed a prototype in a tourist guiding system which consists of a mobile phone and GPS. We observed the position and time of the moving user by GPS and the proposed algorithm is used to model the spatial and temporal interval for the dynamic movement. The algorithm updates the intervals continuously. The study area is a part of Tehran, capital of Iran.

The model is evaluated in a directed urban network for a user with different origins and destinations in the study area. We applied the geo-referenced generalized map at the scale of 1:2000. The intervals of the user are constructed based on the position and time of the user dynamically. Then the spatio-temporal relationships are assessed between the intervals of the user and the intervals of the contexts. In order to test the algorithm, 30 different routes for the tourists are considered. In each route a number of contexts have been considered as control points and the system is run while the user moves. Then the numbers of detected contexts compared with the control contexts are counted. Fig.5 depicts the difference of the two diagrams of the detected contexts and the control contexts visually. We used the Chi-square test for evaluating the comparison outputs. The initial results proved that the proposed approach could model spatio-temporal relevancy parameters in the context-aware system with 95% confidence interval.

![Comparison Chart]

Fig. 5. Diagram of the comparison between the control objects and detected contexts

5 CONCLUSIONS

A multi interval algebra approach for modelling spatio-temporal relevancy parameters in context-aware systems has been proposed in this paper. Based on the proposed model, two spatial and temporal intervals are defined for the user and two spatial and temporal intervals for the context are determined. The prototype system and evaluation results verified the performance. The model is able to meet the requirements of context-aware systems concerning limited memory and CPU resources in pervasive computing environments. The implementation of the context-aware system in an urban area is carried out based on the proposed spatio-temporal relevancy model for a moving tourist. The initial experimental results show that the proposed approach would effectively detect spatio-temporal relevant contexts.

5 REFERENCES


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