Modeling Personalized and Context Sensitive Behavior for Location Aware Services by Employing Fuzzy Logic

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Abstract: - Location-aware technologies will have a great impact on potential applications in the civilian security domain. For applications involving lone worker protection or security officer's guide, there is a need for selecting and ranking the context information from a vast amount of vague and incomplete data. Moreover, the bulk of information available is dynamic and incomplete and our preferences about certain actions are vague, ambiguous and otherwise fuzzy. A fuzzy approach for making-decisions in such an environment is facilitated by the natural accommodation of linguistic grades for all possible alternatives. The objective is to find the best alternative, which satisfies the interest and will of the user. This paper discuses the potential of fuzzy decision-making on ubiquitous data and demonstrates how such an approach may be employed for improving the level of services for mobile users in a context aware application where precise positioning is provided by an augmented satellite positioning system. It also presents an overview of the location-based information system and it formulates a process for making fuzzy decisions under uncertainty in a context aware environment.

Key-Words: - location-based services, mobile computing, navigation, guidance, context sensitive, fuzzy decision-making, security, GPS, EGNOS.

1 Introduction

Smaller and more powerful mobile communication devices improve connectivity in a wireless environment [8]. It is reasonable to expect that such devices will play a major role in shaping what is known as "*ubiquitous computing*". Although some progress has been made, there is still a lot to be done before this vision is materialized. Much of the research is focused on improving the mobile devices (reduce size, cost, power consumption etc.), enhancing the communication technologies (bandwidth, coverage, connectivity etc.) as well as facilitating data management (efficient caching, querying, delivering of data).

Although, all of the aforementioned research endeavors are central to the successful development of ubiquitous computing application, an equally important issue is the modeling of context sensitive behavior for location aware services. Context awareness is the driving force of ubiquitous computing, as it requires the devices to be aware of the environment as well as the tasks the user will perform in the near future. Context aware applications range from an intelligent notification system to a "*smart space*", which is a self-adaptive environment that adjusts itself according to who is present and what they are doing.

This concept is especially important for non-military security applications (police or anti-fraud officers, social workers, guards) that often have to work in dangerous but constrained areas of which they have limited knowledge. Context-aware interaction with the local environment together with guaranteed and precise position knowledge (3-5 meters) can greatly improve the working conditions, safety and efficiency of their work.

Context awareness imposes significant demands on the knowledge maintained by the system and the inferencing mechanism is used. It requires an internal representation of the user's preferences and role as well as a sophisticated mechanism for monitoring the environment and tracking the user's actions while assisting the user in performing the required task in real time. Whether the information comes from sensors, user input or specialized information management sources, a context sensitive system must be able to assess the state of the environment and the intention of the user and provide suggestions. The increased demands on inferencing combined with the incompleteness of the data impose requirements on developing structures that can model uncertainty. Such structures must reflect the user's preferences and styles as well as the characteristics of the environment.

In this work, we look at the potential of fuzzy modeling technology as a tool for classifying and customizing location based services. Fuzzy logic is employed for modeling user's preferences and responsibilities as well as for expressing representative characteristics of the environment. The European Geostationary Overlay Navigation System (EGNOS) is used to provide guaranteed and high precision positioning information [4], [8]. In the following, we investigate the construction of a fuzzy logic location aware computing system. Our goal is to develop intelligent assessment functions, which more realistically capture the user's style by including the user's attitude, profile and preferences into the decision function.

In our approach, location-based data is described as a set of *Location Data Points* (LDP). Each LDP attributes an alternative in the decision process. Our approach utilizes fuzzy clustering to generate a number of fuzzy classes containing LDPs and then it prompts the user to show his interest. User's preferences take the form of goals and constraints, which are assigned a grading value for each LDP. This forms a decision matrix, which can be used for making decision either by employing a Max/Min evaluation or a weighted vector in case the goals and the constraints are of varying degrees of importance.

The rest of the paper is organized as follows: Section 2 discusses related work. Section 3 presents an overview of the location-based service system. Section 4 discusses how location data points are modeled to handle uncertainty. Section 5 formulates fuzzy goals and constraints and section 6 discusses the fuzzy decision-making process. Section 7 summarizes the contributions and concludes the paper by providing some directions for future work.

2 Related Work

The exponential growth of wireless networks combined with the new advances of positioning systems has given a compelling impetus towards location based services and ubiquitous computing in general. Perhaps the original vision about pervasive computing could be traced back to Mark Weiser's seminal article [10] where he advocated the notion of invisible networked computing system empowered by actuators, sensors, displays and computational elements. An overview of ubiquitous computing is discussed in [9] along with the hardware and software components as well as promising applications and computational methods. An overview of the research efforts in the area of context-aware applications is discussed in [1] where the accomplishments and future challenges are presented.

In [6], the author attempts to organize ubiquitous computing application from the data management perspective and outline the challenges for data management research. The GUIDE project [3] is an example of developing a network-centric electronic tourist guide. This context sensitive tour guide facilitates the generation of custom tours by taking into account contextual triggers and user preferences.

Fuzzy decision-making has seen a great adoption since the work of Bellman [2] and Zadeh [12]. Fuzzy decision-making has been used for the selection of design alternatives in test and design space [5]. Recently, Yager, in [11], suggests an approach for the construction of decision functions including probabilistic information about the user's attitude.

The challenge presented by our approach differs in several aspects to previous works on managing decision support on location-based services. Our focus is on capturing the uncertainty and incompleteness of data by introducing fuzzy sets. Our approach forms the basis of a unique tool for selecting location data points from a number of alternatives in a context aware environment.

3 System Architecture

In this section, we discuss the architecture and the communication environment of the location aware system in which fuzzy modeling is employed to improve the provided services. The system is based on a client/server paradigm with the clients being the mobile devices (like pocket PCs, personal digital assistants etc.) and the server being on a desktop computer on a Local Area Network (LAN). The communication link that physically connects the client with the server is based on either a wireless LAN or a General Packet Radio Service (GPRS). The interaction between the client and the server is realized via a web interface through CGI and java technologies. Beside the HTTP server resides the Location Service Adviser (LSA), which is responsible for answering all user's requests. Each LSA covers a given domain and it has the jurisdiction over this domain to serve the clients assigned to its domain. Fig. 1 shows how large-scale location based services can be divided into several domains.

Each mobile client is connected to a single LSA. However, if the mobile client changes domain, it is assigned to a new LSA. The connection between the client and the LSA server is illustrated in Fig. 2. The primary work of the LSA is to manage the initialization and the termination of the connections with the mobile clients. It keeps track on several dynamic aspects of the client connections such as the number of the mobile clients currently served, type of users, user preferences etc. The LSA server basically consists of several intelligent agents each one of which serves a mobile user. Among the agents, there is also one that coordinates the initialization and the termination of the connection with the mobile client. Among other responsibilities, the coordinating agent is in charge for starting-up the serving agent, which serves up the requesting client. From that point on the serving agent is the entity that directly supplies information to the client and provides intelligent advice to the user according to the user's preferences and the available information associated with the current location of the user.

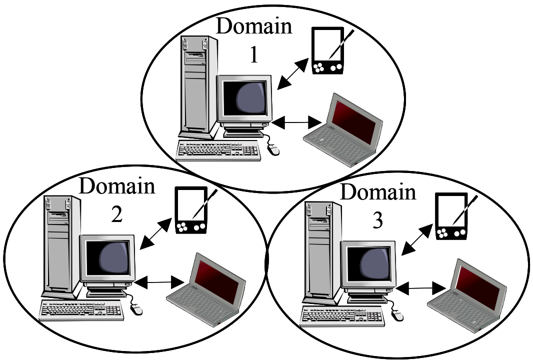

Fig. 1 Location based services in several domains

The user location is determined through EGNOS, which consists of three geostationary satellites and a network of ground stations. EGNOS transmits a signal containing information on the reliability and accuracy of the positioning signals sent out by GPS. It allows users in Europe and beyond to determine their position to within 5 m compared with about 20 m based on stand-alone GPS. Similar systems exist in the US (WAAS) and in Japan (SMAS). The EGNOS receiver is connected to the mobile device and allows computing the own geographic location according to its relative position to the set of GPS satellites and the corrections received by EGNOS. As long as the mobile terminal is connected to the LSA, its global position is reported and registered into the database of the LSA server. The serving agent is a light-way process, which is realized as a distinct execution thread. When the connection with a given client is lost (because the mobile device changes domain) the coordinating agent on the LSA server terminates the serving agent that has served the client so far and it performs any necessary book keeping procedure.

Incomplete data comes to the data store from external sources that incrementally enrich the database. The external data elements that come from the external sources may be numeric or non-numeric. The evaluation of such ill-defined or incomplete data elements is often vague and ambiguous. Each serving agent is able to retrieve data from the database that might be useful for both answering a user query and updating the knowledge base. The knowledge base is the place where any rule (fuzzy or crispy) is stored.

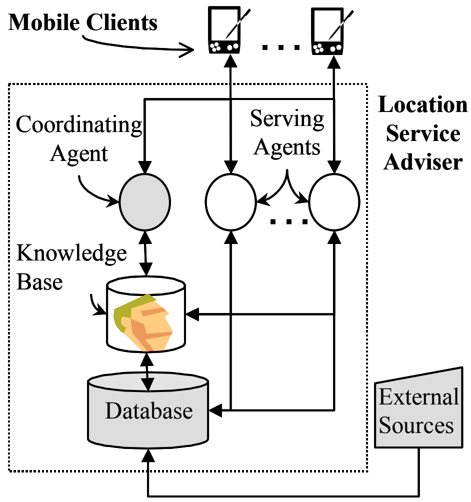

Fig. 2 Connecting the client with the LSA

A serving agent is an intelligent and intuitive entity acting in a proactive and responsive manner to user's preferences and requirements. To achieve such a behavior, the serving agent must have a semantic and contextual understanding of the information being exchanged. This requires a framework for representing uncertain knowledge about the environment surrounding the mobile client. This framework should be able to assess whether there is a matching of the user's profile against the location-based information that is available in the current context.

Fuzzy modeling is used in this context to facilitate the decision of a serving agent and allow it to assess both the state of the environment and the preferences of the user. Therefore the objective is to create the mechanism that it makes possible for the serving agent to give expert advices to the users by assessing what is available in the area close to the user and what the user is interested in. This problem is close to a decision-making problem involving uncertain and incomplete data.

4 Fuzzy modeling of LDP

To facilitate better the decision making process and make the system adaptable to incoming data, we propose the data processing steps for fuzzifying location based information as depicted in Fig. 3. Row data initially come from independent external sources and stored in the database as *Location Data Points* (LDP). This step is called data attribution. A location data point is an object accompanied with its global positioning coordinates and it provides information about a particular site or place within a given domain. An LDP is usually described via a vector of attributes (dimensions) each one of which designates a different aspect of the location point. Availability, activities to be performed and services provided are only some of the attributes a location point may have. Then, a fuzzy classification mechanism is applied that categorizes the LDP objects into classes by assigning a membership grade to each LDP for each class. For example, an LDP about a *museum* may have a membership value equal to 0.9 associated with a given fuzzy class referring to *high risk*, whereas it may have a membership value equal to 0.2 associated with a fuzzy class referring to *parking space*. In that sense, each fuzzy class is defined as a fuzzy set containing LDPs, the membership grade of which reflects the acceptability of the particular LDP in the given class.

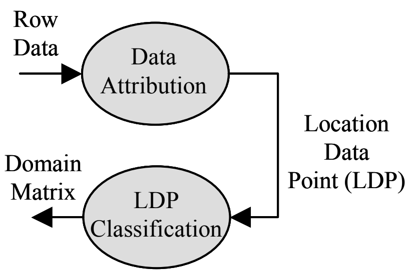

Fig. 3 Generation of a domain matrix

Fuzzy clustering is employed for identifying the number of fuzzy classes. In our approach, we employ a fuzzy clustering technique for incomplete data [7] for identifying the c-partitions.

Let us assume that we have *m* fuzzy partitions (classes) and *n* LDP ($L_1,\ldots,L_n$) in a particular domain D. Then the domain D may be represented by a 2-dimensional matrix of the following form

$$\begin{array}{c} \quad\; L \quad \cdots \quad L_j \quad \cdots \quad L_n \\ D = \begin{bmatrix} \mu_{11} & \cdots & \mu_{1j} & \cdots & \mu_{1n} \\ \vdots & & \vdots & & \vdots \\ \mu_{i1} & \cdots & \mu_{ij} & \cdots & \mu_{in} \\ \vdots & & \vdots & & \vdots \\ \mu_{m1} & \cdots & \mu_{mj} & \cdots & \mu_{mn} \end{bmatrix} \begin{matrix} C_1 \\ \vdots \\ C_i \\ \vdots \\ C_m \end{matrix} \end{array}$$

Where μ_{ij} is the membership value of the *j-th* LDP (L_j) in the *i-th* fuzzy partition (C_i).

5 Fuzzy goals and constraints

When the mobile client is active and registered with an LSA domain server, the user is assigned a serving agent and he may request several location-based services. To illustrate how decision making is performed we give an example of a location based service known as "*what is around?*" In such a service, the user requires from the serving agent a set of interesting sites or places that are close to the user's preference. Initially, neither the user knows what information is available in the surrounding area nor the system knows the interest of the user. This is a difficult situation that one encounter in practice where the user cannot pose his profile since it knows nothing about the surrounding environment. An attempt of the user to send his profile to the serving agent may not have the expected results for several reasons.

- The user profile is incomplete. Although, the user might be interested in the information provided, his ignorance about the environment hinders him from updating or completing his profile.
- Even if the profile is complete, it may be useless because the serving agent cannot understand its semantics. The user may be interested in "heritage" but such a concept is unknown to the agent because the nearby museum is under the concept "archeology".
- Even if a conceptual framework is used to handle relationships among concepts, it is still very difficult for the user to maintain a single profile for all the domains. Different domains may use different conceptual frameworks and different semantics.

On the other hand, it is easy for the serving agent to send the user, upon request; an overview of the types of information provided in the domain and then let the user select what type of information is close to his interest.

So, right after establishing the connection with the mobile client, the agent sends to the user a brief about the information, which available in the present domain. This consists of the names of all of the fuzzy classes in the domain accompanied with a brief description. Upon receipt, the user selects those, which are close to his needs. Let $C=\{C_1, C_2, \ldots, C_m\}$ be the fuzzy classes in the domain and let the user select $G=\{G_1, G_2, \ldots, G_w\}$, where $w \le m$ and $G_i \in C$ $(i=1,2,..,w)$. Each of the fuzzy set G_i is seen as a user's goal. The user may also pose constraints in addition to goals. While goals specify what information the user wants, the constraints usually define a threshold value and require no further improvements beyond this value. In the case of the "*what is around*" service, a constraint could be the minimum or maximum distance from the current user position where an interesting site should be.

Let $S=\{S_1, S_2, \ldots, S_t\}$ be the set of constraints and R be the final set of requirements (goals and constraints). Then R may be denoted as $R=\{R_1, R_2, \ldots, R_w, R_{w+1}, \ldots, R_{w+t}\}$, where $R_i=G_i$ for $i=1,\ldots,w$ and $R_{w+j}=S_j$ for $j=1,\ldots,t$. The requirements R together with the location data points $L=\{L_1,\ldots,L_n\}$ define the following decision matrix P.

$$
\begin{array}{ccccc}
L_1 & \cdots & L_j & \cdots & L_n
\end{array}
$$

$$
P=\begin{bmatrix}
\mu_{11} & \cdots & \mu_{1j} & \cdots & \mu_{1n} \\
\vdots & & \vdots & & \vdots \\
\mu_{w1} & \cdots & \mu_{wj} & \cdots & \mu_{wn} \\
\mu_{(w+1)1} & \cdots & \mu_{(w+1)j} & \cdots & \mu_{(w+1)n} \\
\vdots & & \vdots & & \vdots \\
\mu_{(w+t)1} & \cdots & \mu_{(w+t)j} & \cdots & \mu_{(w+t)n}
\end{bmatrix}
\begin{array}{c}
R_1 \\ \vdots \\ R_w \\ R_{w+1} \\ \vdots \\ R_{w+t}
\end{array}
$$

Where μ_{ij} is the membership value of the *j-th* location data point (LDP) in the fuzzy class representing the *i-th* requirement (goal or constraint). The objective is to find out the LDP that satisfies all the user requirements. This suggests that the user can select one of a number of alternative LDPs. In the above decision table, each alternative is described by a set of attributes, which reflect the gain of the attribute within a given goal or constraint of the user. This also reflects the fuzziness and uncertainty associated with a user's objective.

$$f(x)=e^{-\left(2\frac{x-a}{\theta a}\right)^2} \quad \text{for } x\geq 0$$

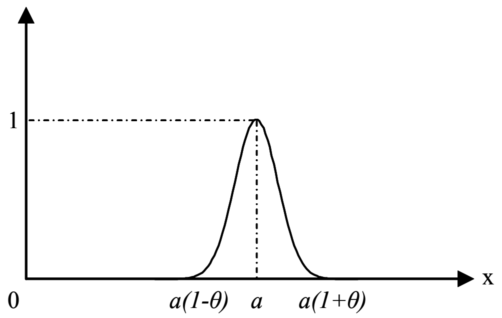

Fig. 4 The fuzzy set *"around a"*

We associate with each requirement a fuzzy set that formalizes the fuzzy meaning of the requirement. The fuzzy set of a goal is specified during clustering, since the task of clustering is to place the LDP in the relevant fuzzy partitions. However, the fuzzy constraints such as: *"around"*, "*at most"*, "*at least"* etc. need to be defined. Fig. 4, Fig. 5 and Fig. 6 show the fuzzy set for the constraints "*around a*", "*at most a*" and "*at least a*" respectively as exponential functions. The horizontal axis x represents the distance from the current position of the user. The parameter a represent the current position of the user and $0 \leq \theta \leq 1$ is a tolerance factor that specifies the range of varying degrees of acceptability. If $\theta=0$, we have the case of crisp acceptability where "*around a*" means "*exactly a*".

$$f(x)=\begin{cases} 1 & \text{for } 0\leq x<a \\ e^{-\left(2\frac{x-a}{\theta a}\right)^2} & \text{for } x\geq a \end{cases}$$

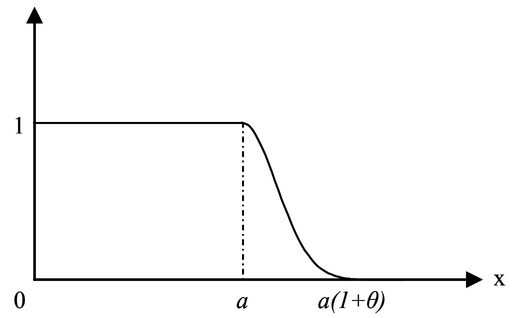

Fig. 5 The fuzzy set "*at most a*"

$$f(x)=\begin{cases} e^{-\left(2\frac{x-a}{\theta a}\right)^2} & \text{for } 0\leq x\leq a \\ 1 & \text{for } x>a \end{cases}$$

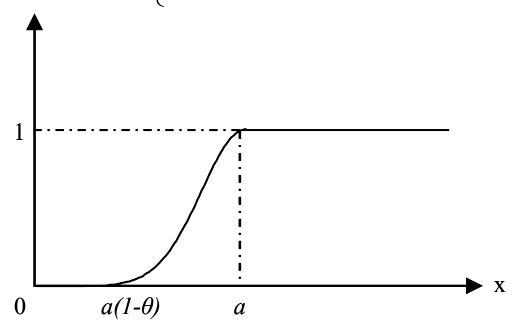

Fig. 6 The fuzzy set "*at least a*"

6 Fuzzy decision making

The fuzzy requirements of the user are linked up through the *AND* connective, which corresponds to the intersection of the fuzzy requirements. This implies that the combined effect of the fuzzy goals and constraints is represented as $R_1 \cap R_2 \cap \ldots$ Therefore, the membership function of the intersection, which results in the *evaluation vector*, is given by

$$\lfloor m_j \rfloor = Min\{\mu_{ij} \mid \forall i \text{ and } \mu_{ij} \in P\} \qquad (1)$$

Where m_j indicates how well the *j-th* alternative satisfies the imprecise goals and constraints. The optimal decision m_o, which is the best alternative, is given by the larger m_j value, that is

$$m_o = Max\{m_j \mid \forall j\} \qquad (2)$$

The above Max/Min estimation is one approach. Others, such as algebraic or weighted sum, may be equally employed.

In case the requirements of the user are not equally important, the above decision-making method is extended to handle varying degrees of importance. Let $\boldsymbol{u}=(u_1,\dots,u_i,\dots)$ be a fuzzy vector whose dimension is equal to the number of requirements. The vector $\boldsymbol{u}$ assigns a set of scores (u_i) to each of the requirements and it is defined such that

$$\sum_i u_i = 1 \qquad (3)$$

Then the evaluation vector may be given by

$$\mathbf{u} \circ \mathbf{P} = \lfloor m_j \rfloor = \underset{j}{Max}\left(\underset{i}{Min}\left(u_i, \mu_{ij}\right)\right) \qquad (4)$$

The optimum decision is given again by evaluating the maximum component of the evaluation vector as shown in the equation (2). In this formulation the decision-making depends not only on the goals and the constraints themselves but also on their relative importance. This is very useful when we want to degrade the less important goals or constraints.

7 Conclusions

In this paper, we have presented a method for modeling location-based information by employing fuzzy sets. Fuzzy logic has been employed to construct fuzzy decision-making functions. The key aspect outlined in this paper is the construction of fuzzy decision matrix expressing the user preferences in terms of goals and constraints. Location data points are the alternatives in the decision matrix, whereas the user's goals and constraints are the evaluation factors. The optimum selection of location data points is achieved by estimating the satisfaction degree of the relevant goals and constraints. The location data point that fulfills all objectives is the one, which is closer to the user's requirements.

The purpose of our work is to provide a tool that is able to facilitate the decision-making in a context aware environment. This leverages the user's actions while assisting the user in performing the required tasks. We believe that fuzzy decision-making will play a central role in the selection of ubiquitous information. In the future we plan to extend our tool to capture hierarchical relationships among location data points.

References:

[1] Abowd, G.D. and E.D. Mynatt: Charting past, present, and future research in ubiquitous computing. *ACM Transactions on Computer-Human Interaction*, **7**(1): 29-58 (2000).

[2] Bellman, R. E. and L.A. Zadeh: Decision-making in a fuzzy environment, *Management Science*, **17**(4): 141-164 (Dec. 1970).

[3] Davies, N., K. Cheverst, K. Mitchell and A. Efrat: Using and Determining Location in a Context-Sensitive Tour Guide. *IEEE Computer*, **34**(8): 35-41 (2001).

[4] EGNOS System Test Bed, *EU Space Agency site*, http://www.esa.int/export/esaEG/estb.html

[5] Fares M. and B. Kaminska: Exploring Test Space with Fuzzy Decision Making. *IEEE Design & Test of Computers*, **11**(3): 17-27 (1994).

[6] Franklin, M. J.: Challenges in Ubiquitous Data Management, In *R. Wilhelm (ed.), Informatics: 10 Years Back, 10 Years Ahead*, LNCS 2000, pp. 24-33, Springer-Verlag (2001).

[7] Hathaway, R.J. and J.C Bezdek: Fuzzy c-means clustering of incomplete data. *IEEE Transactions on Systems, Man and Cybernetics PART B*, **31**(5): 735 -744 (Oct. 2001).

[8] Kotsakis, E., A. Caignault, W. Woehler and M. Ketselidis. Integrating Differential GPS data into an Embedded GIS and its Application to Infomobility and Navigation. In *Proceedings of the 7th EC-GI & GIS WORKSHOP EGII (GI&GIS'01),* Potsdam, Germany, June 2001.

[9] Weiser, Mark: Some Computer Science Issues in Ubiquitous Computing. *Communications of the ACM*, **36**(7): 74-84 (July 1993)

[10] Weiser, Mark: The Computer for the Twenty-First Century, *Scientific American*, **265**(3): 94-104 (Sept. 1991).

[11] Yager, R.R.: Fuzzy Modeling for Intelligent Decision Making Under Uncertainty. *IEEE Transactions on Systems, Man, Cybernetics-PART B,* **30**(1): 60-70 (Feb. 2000).

[12] Zadeh, L.A.: Outline of a New Approach to the Analysis of Complex Systems and Decision Processes. *IEEE Transactions on Systems, Man, Cybernetics,***SMC-3**(1):28-44(Jan. 1973).