Information Management for Location Aware Applications

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Abstract. Within the scope of the research project NEXUS that is being worked on at the University of Stuttgart in cooperation between the Institute for Photogrammetry, the Institute of Parallel and Distributed High-Performance Systems and the Institute of Communication Networks and Computer Engineering, a generic platform supporting location aware applications with mobile users will be developed.
In order to facilitate the access to location-based information, distributed data sources and services have to cooperate within the NEXUS infrastructure. Therefore, a federated data management component has to be realized that allows an integrated view on data and services for the applications by offering a standardized interface. Besides that, intelligent mechanisms within the platform have to allow for an efficient provision of the relevant information to the user.
In this paper, an overview about the information management strategies within NEXUS will be given. Furthermore, the approaches of existing client interfaces are presented briefly.

1 Introduction - general characteristics of the NEXUS platform

In times of increasing possibilities to access information of all kinds, it is sometimes difficult to find efficiently what is looked for. Thus, a growing need for methods to structure information according to ones individual needs can be observed. Location aware applications offer an approach for this purpose: they are running on a mobile computing device, know the positions of their users and provide information and services that are of special importance at their current location.
The goal of the NEXUS project is to develop a generic platform that supports location aware applications. Since the platform is designed to contain huge amounts of information and various services on which multiple users can take hold on simultaneously, the system has to be organized in a distributed environment. Not only the data storage, but also the processing has to be shared amongst different servers to optimize response time.
In terms of an open system, anyone should be able to add new information sources to the platform in a straightforward manner, just like a new web server can be adjoined to the WWW. Moreover, the different data sources have to be interoperable [Laurini 1998]. For these reasons, a common data model or class schema, respectively, has to be provided and homogenization mechanisms [Walter & Fritsch 1999] have to be realized. As a further requirement, the data model and the infrastructure's interface must be transparent to the applications. Additionally, there have to be well-defined and transparent interfaces between the components of the platform. Moreover, the spatial data must be offered in multiple representations in order to meet the individual needs of the different applications. Hence, appropriate algorithms to deduce all the necessary levels of detail have to be implemented [Anders & Sester 1997].
Another vital aspect concerning the acceptance of NEXUS deals with the privacy of data and the protection against illegal data manipulation. The NEXUS infrastructure also has to take into account that different kinds of mobile devices like cellular phones, personal digital assistants or wearable computers being equipped with different sensors to capture the current contexts of the users are accessing it and thus has to offer an adequate interface to cover the demands of all possible variations.
The users of the NEXUS system will apply different kinds of mobile communication technologies like wireless LANs (according to IEEE 802.11b) or WANs (e.g. GPRS). Therefore, a handover between these different networks has to be realized. Also, the adaptivity of the communication within NEXUS has to be guaranteed, so that, for example, bandwidth changes do not cause a breakdown of applications or the system itself.

2 A Common Data Model – the Augmented World Model

The applications must be able to perceive the combination of different spatial data sets as one big single model on which they can operate, i.e. the complexity of the distributed management of heterogeneous data has to be hidden from them. In order to allow this uniform view, an object oriented model has been developed, containing a generic set of all object classes that might be of relevance for location aware applications. It is called the standard class schema. In case that an application needs additional object classes that further specify the existing ones, they can be inherited from the classes of the standard schema, forming a so-called extended class schema. Anyone being interested in participating in NEXUS has to obey the rules of the underlying data model and has to adjust its data according to it. Since the NEXUS system should not only include real but also virtual objects, we have called it Augmented World Model.

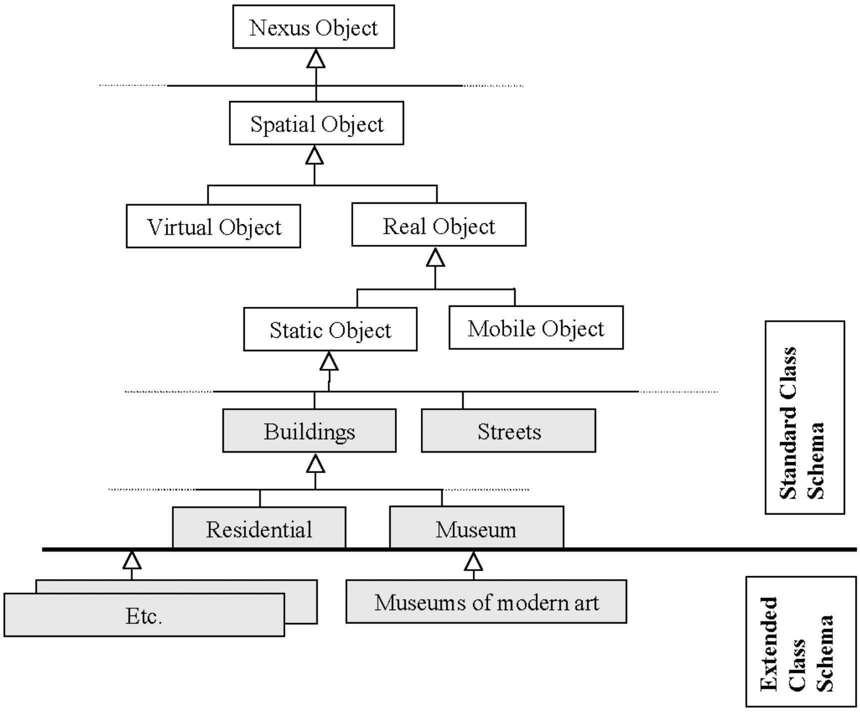

Figure 1: The object oriented world model of NEXUS. The grey-shaded boxes represent instantiable, the white boxes abstract classes.

3 Architecture of NEXUS

The NEXUS platform has to be a generic infrastructure that supports all kinds of spatially aware applications. Therefore, appropriate components have been identified that provide the required services. They have been arranged to build up a federated architecture for the NEXUS system.

3.1 Components

The NEXUS clients or location aware applications, respectively, access the platform via a standardized application interface. It has to take into account the individual demands of the various information systems and must facilitate a seamless interaction with the infrastructure for the user, i.e. the performance of queries has to function in a straightforward manner and the visualization of results must be intelligible as well. Furthermore, the interface has to adapt to the different kinds of mobile devices, especially concerning the different levels of computing power, the different amounts of memory, the different levels of network connection or the different displays. A PDA will e.g. require a completely different user interface than a Wearable Computer. Of course, the NEXUS system has to guarantee platform independent usage and so the different operating systems must also be reflected by the application interface.

Any application request is directed to a NEXUS Node (usually the one closest to the user's location). On each of the NEXUS Servers, a federation component is running. It is responsible for developing a strategy to respond to the application request in case that more than one NEXUS component has to be involved in the processing. On the other hand, it integrates data and provides services like navigation or map production on its own. Eventually, it propagates the results to the application, taking into account its interface specifications.

Apart from the federation, the NEXUS Nodes contain the other components that are vital for a distributed architecture. But not each service needs to be available at every Node. The Area Service Register can be understood as metadata repository, storing general information about a spatial data set (like its spatial extent, its level of detail, stored object classes etc.) and the address of the server it is located at. The storage and management of spatial data is taken over by the Spatial Model Servers. They also provide the necessary geoprocessing functionalities. Right not, we are using IBMs DB2 and its Spatial Extender module, but generally any database could be employed. The management of user positions is realized by the Location Service, a mainmemory database for efficiently storing and retrieving position information [Leonhardi & Rothermel 2001]. For an active user support, the Event Service was added to the infrastructure. A user could, for example, register for a spatially related event that might trigger a notification each time he is in a predefined area like in the vicinity of a sports store. Sensor systems are used to record the situation of a user as detailed as possible. For location aware applications it is most important, of course, to detect the current position of a user at an appropriate accuracy level and with a high degree of reliability. Therefore, we followed approaches for a multi-sensor integration. Besides positioning sensors, some of our mobile devices have also been equipped with digital compasses in order to derive view frustums. In the future, further sensors for the measurement of indicators like illumination or temperature will be added to capture the context a user is in. The actuator component allows to control objects of the real world by manipulating the state of their corresponding representation within the computer model. For example, an authorized user could select a certain room on the display of his computing device, change its attributes concerning the conditions of illumination and send the modifications to the platform. The data management component would carry out the commands and thereby initiate a communication process that triggers the light switch and changes the illumination in the real environment. It is an important requirement that the consistency between real world and computer model will be guaranteed. Besides the internal NEXUS services, also external services which conform to the interface of the platform could be attached.

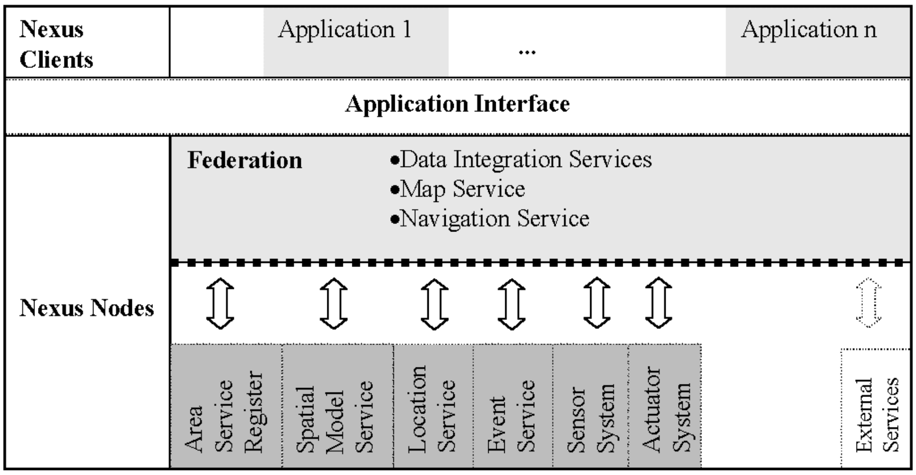

Figure 2: The architecture of NEXUS and its components.

The components of NEXUS are interconnected by a communication unit. Generally, the communication infrastructure consists of fixed and mobile hosts. Fixed hosts are running one or more NEXUS services and are attached to the network by wire based interfaces. Mobile hosts, however, are usually carried around by the participants of the system and therefore rely on wireless interfaces. On mobile hosts, there will be more than one network interface since various network technologies might coexist at one place (e.g. a wireless LAN according to 802.11b and a wireless WAN like UMTS). The communication within NEXUS is based on the Internet Protocol (IP), enhanced by several mobility add-ons. The mobility support will be handled in the network layer and for this reason it is transparent for the applications. Furthermore, the communication API of NEXUS has to provide additional functions to the applications, e.g. in order to choose which network interface should be applied for data transmission (possibly depending on billing tariffs or other circumstances).

3.2 Information Exchange

In order to guarantee a structured and transparent exchange of information between the NEXUS components on the one hand and the platform and its applications on the other hand, we have defined XML-based languages. For all of them, detailed DTDs have been specified as a preliminary solution. Since DTDs do not support data types and inheritance, the XML schema concept will have to be applied in future versions.

The Augmented World Modeling Language (AWML) describes all objects that NEXUS can deal with. Generally, it is intended to stick to standards as close as possible. For example, the AWML contains all definitions of the Geography Markup Language (GML), defined by the OpenGIS consortium [OpenGIS 2000], as a complete subset. For the purpose of queries and updates, the Augmented World Query Language (AWQL) has been defined. It is composed of restrictions like boolean (and, or, not), comparative (equals, etc.) and geometrical (overlaps, includes, etc.) predicates and allows to select objects. The AWQL can be seen as a limited subset of SQL, specified to meet the requirements of NEXUS.

Besides these fundamental structures, further languages have been developed, mainly defining the parameters of services. For instance, the Augmented Area Description Language (AADL) specifies which meta information (like spatial extent, available object classes, etc.) is available for spatial data sets. As a second example, the Map Predicate Language provides the features to describe, how a map should look like (format, resolution, etc.).

3.3 Interfaces

Since we have defined XML-based exchange and query structures, functional interfaces of the NEXUS components could be reduced to a minimum. Thus, an easy extensibility of the interfaces can be achieved. For each component, four functions are basically sufficient: insert, update, delete and query. For data manipulation procedures (insert, update and delete), change reports are returned so that it is possible to control the success/failure of operations.

4 Efficient Provision of Information

In order to improve the efficiency of the access to information and the communication between client and platform, the NEXUS system needs to provide adequate services. These services should facilitate a straightforward user interaction.

Besides an intelligent Caching mechanism, a Hoarding (or Prefetching) component is part of the infrastructure. It estimates which data will be of interest for the user in the near future and downloads this information in advance [Kubach & Rothermel 2001]. Thus, it is already stored at the user's mobile device and can directly be accessed when it is actually required. The estimation is mainly based on statistical analyses: information units are assigned to cells covering the geographical region a user is located in. Depending on the global request for information units, each cell receives an average value, reflecting the probability that a user wants to access the information available within this cell. The attractiveness of information can be very dynamical, i.e. the value of cells might change frequently. Therefore a high rate of updates is necessary.

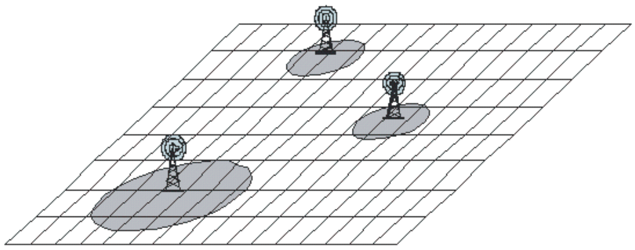

Figure 3: Info-Fueling: The grey-shaded circles represent hot spots, the white rectangles cells of a wireless WAN

Directly related to the Hoarding Service is the idea of Info-Fueling. It implies that within a geographical region there are so-called hot spots or info stations (typically wireless LANs, see figure 3) which offer a much higher bandwidth. Thus, if users want to transfer information, the system takes into account that information should preferably be up- or downloaded within a hot spot region.

The Event Service (see 3.1) is also contributing to the goal of an efficient access to information. Users will be able to register for events via the GUIs of spatially aware applications. If the conditions for triggering an event are satisfied, they are actively notified by the system. For example, a user might want to receive a message if a certain person enters a building or if she/he is in a predefined area, like in the vicinity of a museum. Events can also be triggered if a certain situation occurs, e.g. if more than a given number of persons are located within a certain room, if the temperature within a room exceeds 20 degrees Celsius, etc. Thus, introducing spatial events extends the capability of the users to perceive their surrounding.

There are different predicate templates for events like [onEnterObject], [OnMeeting], [OnEnterArea], etc. Clients will register for a certain event by instantiating the variables of the specified event (e.g. OnEnterArea(polygon, person_ID)) and by defining the actions that have to be triggered in case that the event comes true. Regarding the architecture of this service, there have to be components which produce an event (like the Location Service), components that observe if an event occurs and components which carry out the specified actions, namely the notification of users. For this purpose, another service of the NEXUS infrastructure called Geocast can be applied. It deals with techniques to send messages into geographical regions. With this functionality, useful Use Cases of the NEXUS system can be realized, like e.g. the 'virtual warning sign' scenario. It assumes that in case of a car accident, all other cars approaching the place of accident would receive a warning information.

As another means of realizing an optimal support for user interaction, the users of NEXUS will be able to define their individual user profiles. By specifying priorities, a selection of information and services a user is most probably interested in within a geographical region can easily be done. In the context of personalized information, security an privacy issues play an important role for the acceptance of the NEXUS system. A special interest group was established to care for the confidentiality of the information handled by the infrastructure. Several approaches like encrypting user identities by pseudonyms or anonymization techniques are being examined currently.

5 Existing User Interfaces

Based on a centralized prototype of the platform, some applications have been developed that are using NEXUS services. The CityNav User Interface which is illustrated in Figure 5 provides some facilities in order to offer an easier handling for the user. Since the mobile device on which the application is running disposes of a digital compass, the map can always be oriented so that it coincides with the direction a user is looking in. The line of sight can also be drawn into the map. Since there might be inaccuracies due to the GPS receiver and the compass, a triangle has to be constructed that represents the tolerance, in which the line of sight can actually be. This functionality can be used for a service we called Telepointing, which allows to identify objects by adjusting the mobile device in the direction of the object's location.

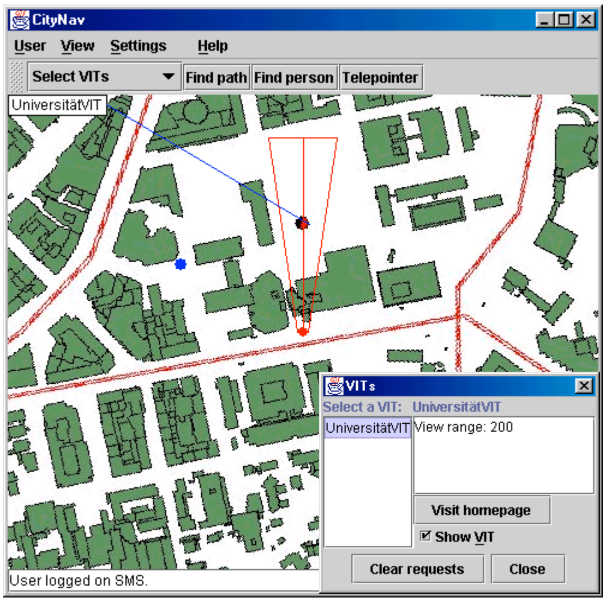

Figure 4: User Interface of the CityNav application, illustrating the Telepointing functionality

Another application uses virtual objects, so-called Virtual Information Towers (VITs), as metaphors to structure the availability of location-based information [Leonhardi & Bauer 2000]. Each of the VITs has a certain area of visibility attached to it, reflecting where the information available at a VIT is most important. Moving through an area, the application only displays those Virtual Information Towers whose areas of visibility contain the location of the user. Thus, irrelevant VITs are faded out automatically. Via the VITs, not only information stored within the NEXUS databases can be accessed, but also external resources like web pages or digital libraries are available so that, for instance, information stored in the WWW can be assigned to a geographical position or area, respectively.

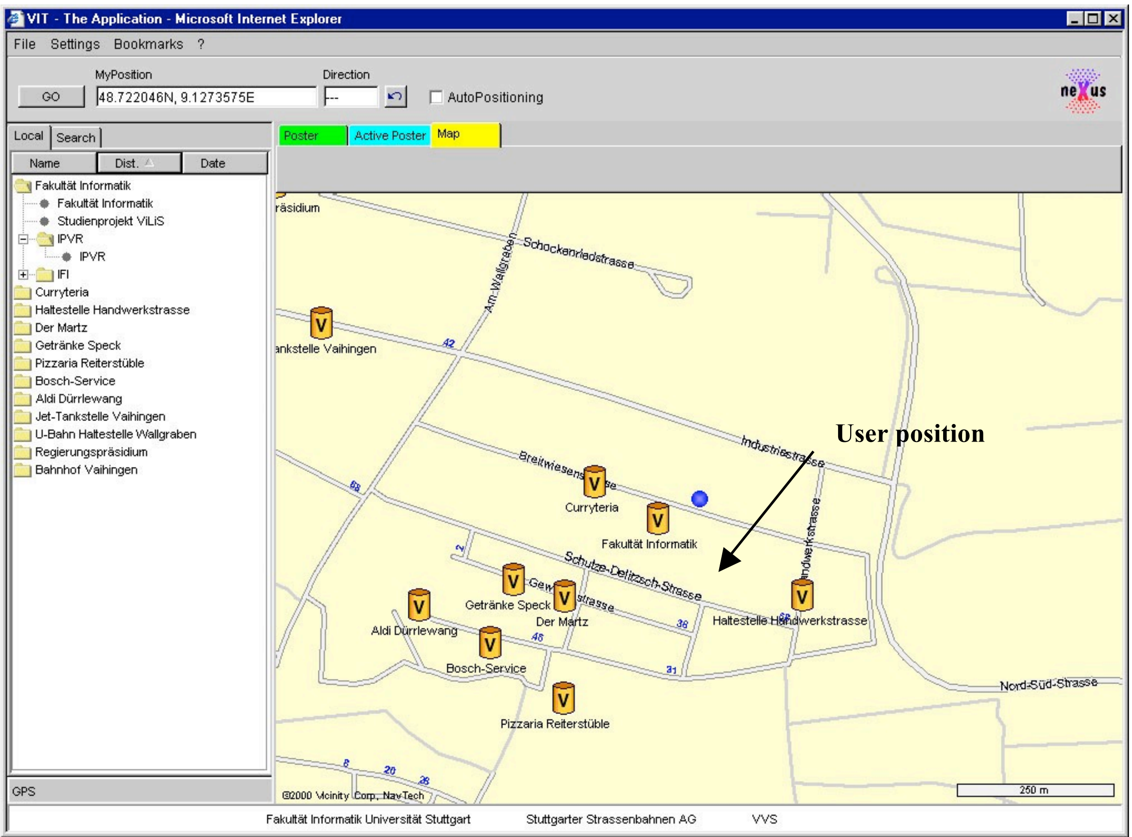

Figure 5: The interface of the VIT application. Different VITs are visible for the user via which he can query for information about his immediate environment.

5 Conclusion

The NEXUS infrastructure focuses on a system-level support for spatially aware applications. It is intended to facilitate the access to required services and location-based information and to support user interaction as extensively as possible by appropriate mechanisms within the platform

Up to now, the emphasis has been put on the development of the information management. A first prototype of the NEXUS infrastructure providing basic functionalities will be available next year.

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