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NEXUS:
Spatial Model Servers for location aware applications on the basis of ArcView

Abstract

The research project „NEXUS“ aims at the development of a generic platform that supports location aware applications with mobile users. It is currently being carried out at the Institute for Photogrammetry in cooperation with the Institute of Parallel and Distributed High-Performance Systems of the University of Stuttgart and is financed by the federal state of Baden-Württemberg.

The main task of the platform concerns the management of dynamic spatial models of the real world which are augmented by virtual objects. The virtual objects act as brokers between the platform and external information sources and services, so that information stored e.g. within the WWW can be structured spatially. The spatial data have to be delivered in multiple representations – from highly detailed 3D representations of indoor areas to coarse 2D town plans – in order to provide the adequate level of detail for each application.

Spatially aware applications which are using the GIS models are available for the users on small handheld devices like PDAs. These computers are equipped with sensors for positioning and mobile communication. Therefore, the applications know the position of the users within the spatial models – they are „location aware“. Due to this and due to the fact that the users can receive spatial data from distributed model servers by means of mobile communication, they can not only move through the real but also through the virtual world. In order to support the users on their way, GIS functionality has to be provided: they have to be able to perform spatial queries on their environment and to navigate themselves through the virtual models and thus an interface to GIS has to be implemented.

Within a first prototype ArcView and ArcView Internet Map Server Software has been used to realize a spatial model server providing GIS functionalities. On the client side, a Java application has been developed that takes advantage of ArcViews GIS features and allows complex spatial procedures such as network analysis.

1. Introduction – the concept of NEXUS

Within our world, the amount of information we are confronted with is increasing more and more. In order to find out which information is important for us, we have to structure it. For this purpose, the spatial component of an information is a decisive factor. Location aware applications, which „know“ the positions of their users, are considering this fact and prepare information according to a user’s location. For this reason, they have to refer to spatial models that allow the assignment of information to a certain position. The central part of the NEXUS platform consists of the management of these spatial models which represent the physical world. They provide the basis for the NEXUS infrastructure and not only have to serve for particular, but for location aware applications in general.

To extend the scope of information that can be delivered by NEXUS, external information sources like digital libraries or especially the World Wide Web must be accesible via the platform as well. Therefore, the concept of virtual objects (VOs) was introduced. The virtual objects augment the NEXUS world and structure the data stored within other information systems spatially. Due to the fact that the object models include virtual representations, they are called Augmented Area Models (see Figure 1). Each Augmented Area Model describes only a part of the whole NEXUS or Augmented World respectively, e.g. an area of a City or only the detailed interior of a room. As an essential requirement, the models – which might overlap or include each other – must have a transparent structure so that their interoperability can be guaranteed.

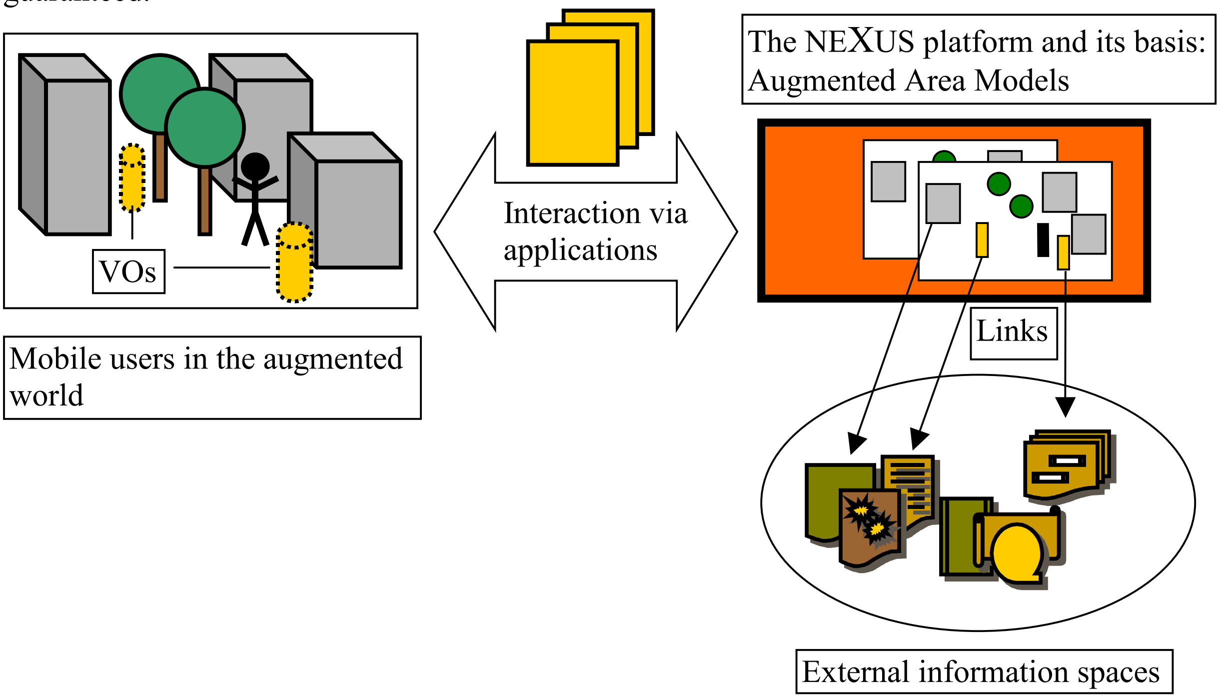

Figure 1: Augmented world and augmented world model. The virtual objects are represented as so-called virtual information towers (VITs)

Since different applications need different resolutions of data sets, the spatial models have to manage data in multiple representations – from coarse to highly detailed levels. Furthermore, huge amounts of data must be stored and handled. For these reasons it is inevitable to use large and distributed databases as spatial model servers. They have to function as a scalable Middleware layer that can be accessed by multiple users. In a first prototype, ArcView software is used to realize such a spatial model server. Its GIS functionalities like spatial selections or network analysis facilitate the support of the users on their way through the NEXUS world. With respect to Computer Aided Facility Management Systems (CAFM), not only the ability to perform geographical queries should be supported, but the interactive control of processes has to be realized, too. Therefore, an interesting objective comprises the implementation of active functionalities into the system in a way that objects of the real world can be controlled by their corresponding representations in the computer models and vice versa.
The technical environment of NEXUS is assumed to be composed of so-called NEXUS-stations – mobile, handheld computers like Notebooks, Personal Digital Assistants (PDAs) or Wearable Computers [Starner et al. 1998] which additionally dispose of other facilities, especially for positioning and mobile communication. In the future, appropriate sensor systems to acquire information about aspects concerning the state of the environment of the user like temperature, lighting, etc. will also be attached to the mobile devices. To determine a user‘s location in outdoor areas, the Global Positioning System (GPS) is used in combination with several supporting sensors. Indoor positioning requires different methods based on infrared signals, radio networks or indirect positioning techniques like map matching or image interpretation (see

chapter 3.3). The positioning information that is obtained from the sensor systems will be managed within special, also distributed databases for mobile objects, forming a so-called location service [Hohl et al 1999]. The NEXUS-station needs to be able to connect to the platform and external information sources like the Internet using wireless communication. For a wide area network (WAN) it can use the data service of a mobile telephone system like GSM [Eberspächer & Vögel 1998] or of future systems which will be more suitable for data transmission like GPRS or UMTS. Inside of a building it can use a Wireless LAN, e.g. according to the IEEE 802.11 standard.

2. An Application Scenario

To get an impression of the functionalities that the NEXUS platform has to provide, this part will illustrate the main ideas by means of an application scenario: it is planned to establish a city information system for Stuttgart that employs NEXUS.
One could imagine a user who arrives at Stuttgart‘s central station and has to attend a conference in town. To find the way in the unknown environment, he utilizes a NEXUS-station. The user visits the web sites of the tourist information. On these sites there is a service integrated which gives the possibility to search for train schedules and to cash up the fare for public transport automatically via NEXUS. Having specified his destination, NEXUS is showing the foot path to the closest subway station, the line number and the departure time of the train that leads him to the location where the conference takes place. After the meeting he is going to the city for a stroll. As he sees a famous historical building, he just points at it with the telepointing device integrated in the NEXUS-station. Directly, all historical and architectural facts about the object are transmitted to his PDA. While he is proceeding, the NEXUS-station gives an audio signal and calls the attention of the user to an incoming message. A department store informs all the people passing by about special offers. The NEXUS-station is able to filter messages because of the user profile that is generated for each user. This profile also provides information concerning the acceptance to receive external informations. The user is interested in one of the special offers, a digital camera, and enters the building. Automatically, the NEXUS-station switches to the department store information system that guides him to the product he is interested in. A virtual information tower (VIT), which is placed near the department for digital cameras allows the user to receive special information about his favourite model, e.g. technical details, WWW address of the manufacturer, etc. On the other hand, he could also attach a virtual post it to the VIT containing information about his personal experience with this particular camera.

3. The Development of the NEXUS Platform

The NEXUS platform will have to offer general services, which can be used by all kinds of location-aware applications. Its main task is the management of a dynamic model of the real world and to provide an interface through which these applications can access and to some degree modify the model. The NEXUS platform uses sensor systems to determine the state of these parts of the real world, which are described by the model. It uses the information provided by them to keep the model consistent. This section gives an outline of the architecture of the NEXUS platform, describes the spatial model that it manages and finally the sensor systems it uses for positioning.

3.1 Architecture of the Platform

Figure 2 shows the architecture of the NEXUS platform with its major components, which will be described below.

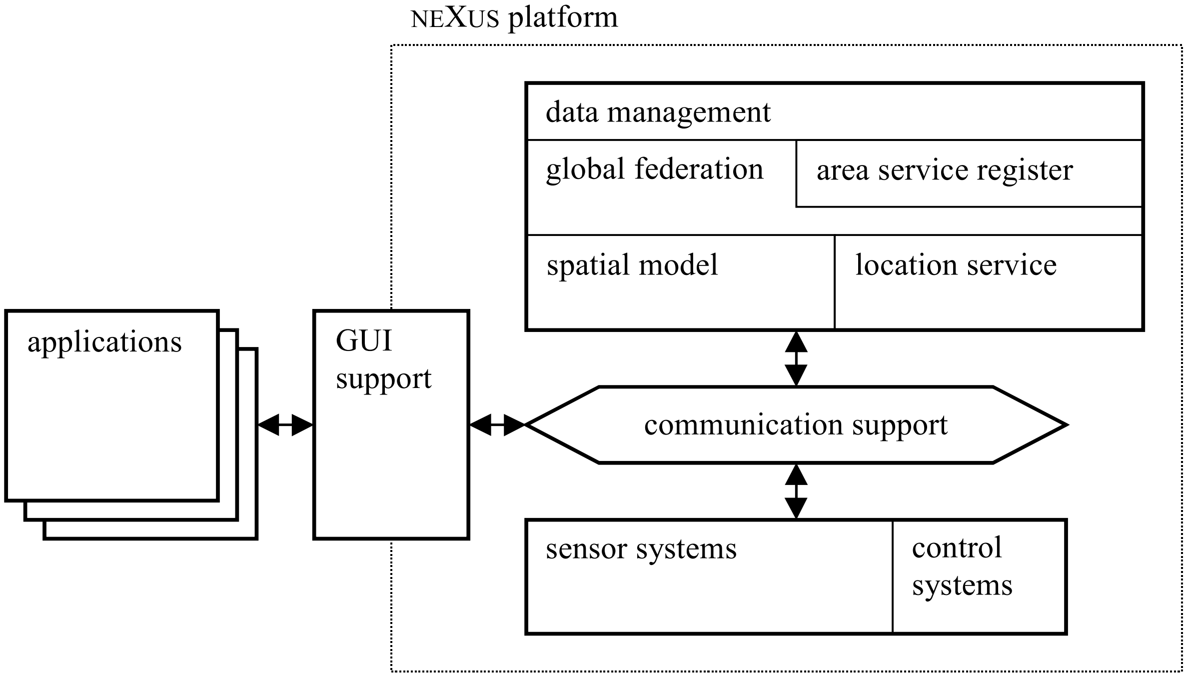

Figure 2: the architecture of the NEXUS platform

All components of the NEXUS platform communicate via the *communication support* component. This component provides a uniform interface for accessing different fixed and wireless communication media and allows a seamless hand-over between them (e.g. roaming between GSM and a Wireless LAN). It also contains mechanisms for improving the efficiency of access to the platform by caching and hoarding parts of the model.
The *Graphical User Interface support* is running on the mobile device carried by the user and contains basic functionality, which is required for interacting with the NEXUS platform and for displaying and navigating the model. It also provides support for adapting to devices with different levels of computing power, different amounts of memory or different levels of network connection. A PDA will e.g. require a completely different user interface than a Wearable Computer.
A *sensor system* determines a certain aspect of the real world and is used to update the model accordingly. Examples are a GPS receiver or a temperature sensor. *Control systems* are used to make changes to the real world according to user-actions in the model. One could think of a facility management system, which can turn on the lights, control the heating, etc.
The main component of the NEXUS platform is responsible for the *data management*. It stores the model of the real world and processes the queries and updates pertaining to it. As we also want to support models for large areas, possibly encompassing the whole world, and the platform therefore has to process a great number of queries and updates, this component needs to be distributed across many servers. Its *spatial model* sub-component stores the more static data for one Augmented Area, describing for example houses and trees, and has a functionality based on a GIS system. It is described in more detail below. The *location service* stores and manages the

location information of mobile objects, which is for now the most important dynamic aspect of an Augmented Area described by the model.

Any query or update message for the NEXUS platform is first sent to the *global federation* component, which then, using the *area service register*, determines the servers that store the appropriate parts of the real world model (servers for the spatial model as well as for the location service), forwards the messages to them and integrates their results. Each part of the spatial model stored on a single server describes the real world objects in a given area with a certain level of detail. Through the global federation, the combination of different parts of the spatial model is perceived by the applications that use them as one big single model. The area service register knows which server has a model for a certain area with a given level of detail. To this end, each server has to register his model(s) at this (distributed) service.

Two parts of the spatial model can have the relationships described in Table 1. A model of a city (2D) may have associated to it the more detailed (3D) model of the interior of one of its buildings, maybe a museum (spatial relationship: inclusion, semantic relationship: detailing). Whenever a user enters this building, the model that his application uses is switched from the city model to the more detailed one.

Spatial relationship	Semantic relationship
overlapping	detailing: objects of another model are described in more detail, e.g. concerning geometry
inclusion	complementary: adds additional attributes to some objects
identity	partial identity: models maintain some identical object classes
adjoining	identity: all object classes are identical
independent	independent

Table 1: relationships between spatial models within the NEXUS platform

3.2 The Spatial Model

The spatial model or the Augmented World Model, respectively, has to represent all the features of the physical world that could be of importance for any location aware application. Therefore, the datasets have to be as detailed as possible. On the other hand, not each application needs data of high resolution, but rather prefers coarser representations. In consideration of efficient data analysis and visualisation as well as low data transmission rates, it is very important to be able to provide the adequate level of detail for each application task. For this reason, it is a vital prerequisite for the spatial models that they can manage multiple representations. In order to achieve this goal, two different approaches have to be pursued: if data from multiple sources are used, the corresponding objects of the variously detailed datasets have to be identified by conflation procedures [Walter 1997]. Otherwise, if one disposes of a highly detailed dataset, the appropriate representations can be derived by knowledge based systems ([Anders & Sester 1997], [Mackaness et al. 97]) or machine learning techniques [Sester 1998]. For TINs, geometric simplification can be realized by means of triangulation methods ([De Floriani & Puppo 1995], [Schmalstieg 1997]).

So far, three levels of detail for building geometries of a test area of Stuttgart have been created on the basis of the municipal building information system. Figure 3 shows an extract of the virtual city model, displaying the same scene in three resolutions: the coarsest level with buildings aggregated to blocks on the left, single buildings represented in 2.5D in the middle, and the most detailed level on the right side.

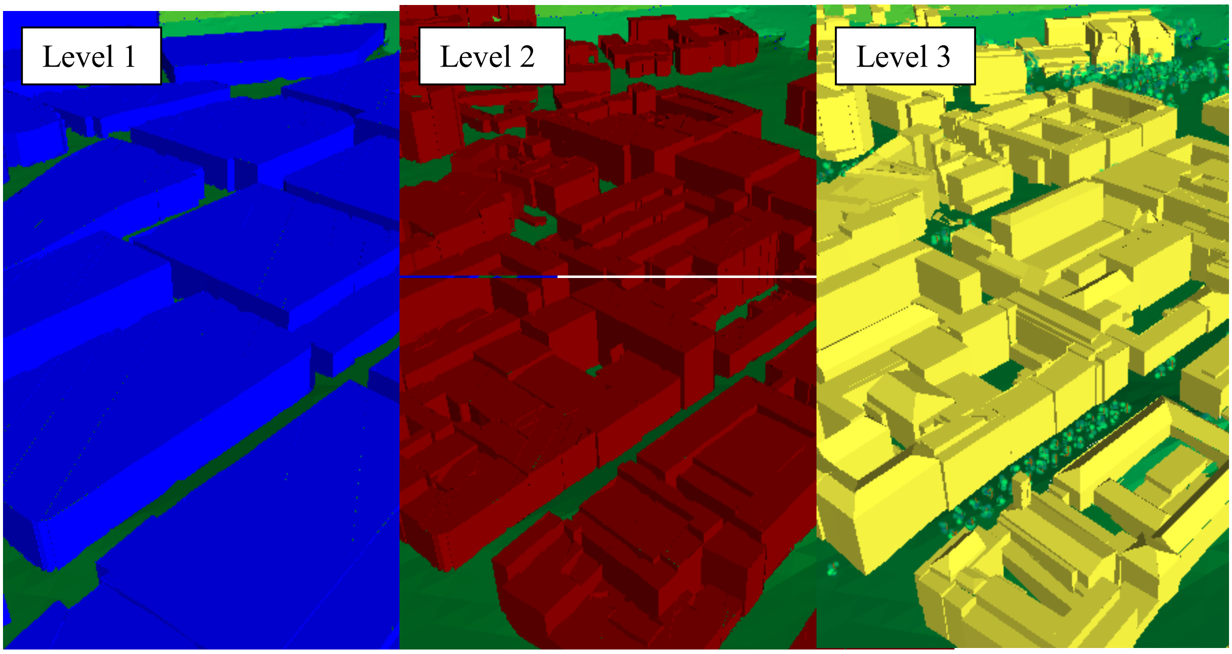

Figure 3: a scene of the virtual city model of Stuttgart in different levels of detail

The dataset with the highest resolution has been acquired by a method that combines digital ground plans with height information from laser scanner data and is able to capture detailed building geometries with different roof types automatically [Haala & Brenner 1999]. As it can be seen in Figure 4, one gets a quite realistic impression of the virtual city model if the CAD model is furnished with texture taken from terrestrial photographs. But not only the building geometries have been generated, for some buildings also the interior has been modelled additionally.

Figure 4: extract of the virtual city model of Stuttgart showing buildings of level 3 with texture from terrestrial photographs in a VRML representation.

3.3 Components for Positioning

The NEXUS-station has to provide a positioning tool to realize spatial awareness. The concepts to obtain information on the position of mobile users are different in outdoor and indoor areas. The main problem is the integration of different positioning sensors, because we have to deal with two different environments. Generally our approach is based on primary sensors for outdoor (GPS/DGPS) and indoor (Active Badges) areas. In order to enhance the accuracy and to provide positioning information in the required resolution for the detection of the user, additional sensors must be integrated. It is possible to use secondary sensors like pedometers, digital compasses, inertial systems (INS), map matching procedures [Czommer 99] and image analysis [Drane & Rizos 1998]. This strategy also has the advantage to avoid interruptions if one or more sensors break down, because one of them will provide information continously [Hailes 99]. If the two main areas are considered, it will be clear which problems have to be faced.

- **Outdoor areas**

As already mentioned, the main sensor for positioning in outdoor areas is differential GPS, because it is accurate enough and low-cost systems are available. Such systems are able to provide position information within an accuracy of 2-5 meters [Thang 1996]. In outdoor regions, this accuracy is sufficient to support spatial aware applications. But the use of GPS/DGPS causes problems, too. In urban areas with narrow streets and high buildings, sometimes no signal can be received.
Some tests on the reliability of a low-cost GARMIN DGPS receiver have been carried out. They have shown very positive results. In the test area, the density of the buildings is very high and also the streets are mostly quite narrow, but there were only few positions where no signal was available (see Figure 5).

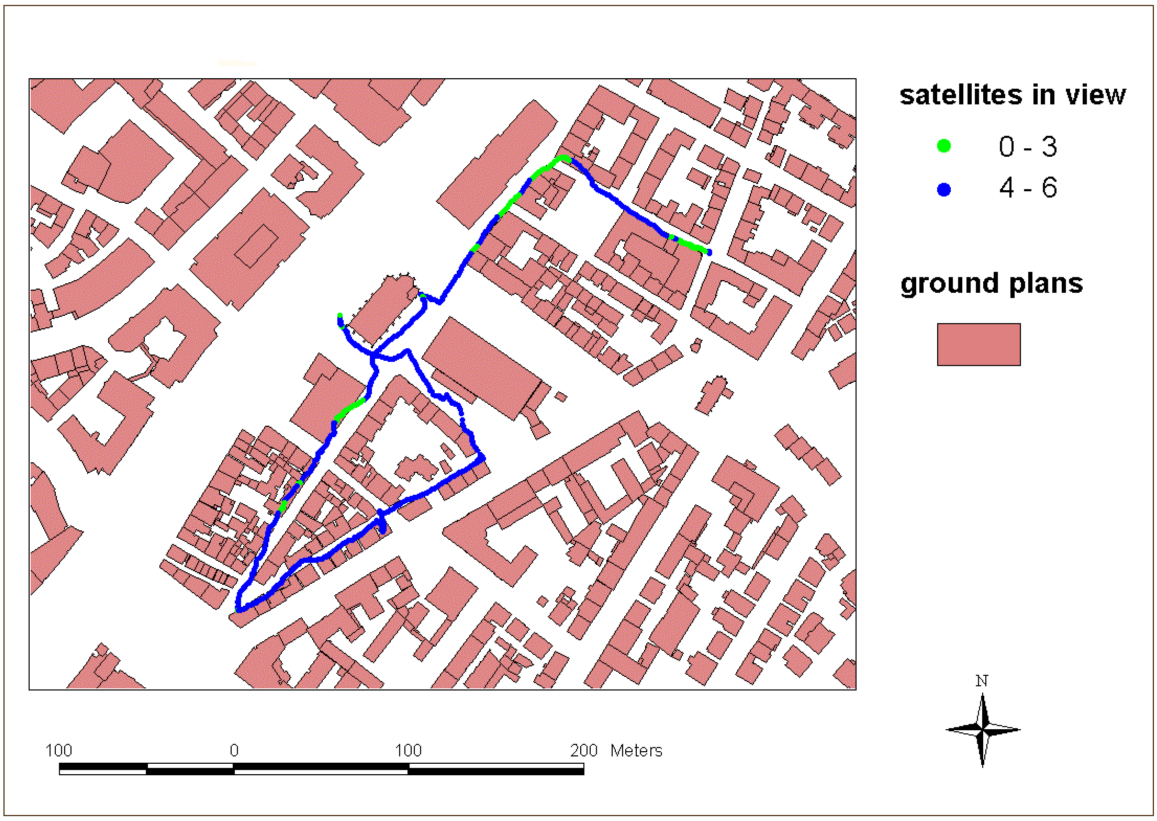

Figure 5: DGPS-Test Stuttgart-Bohnenviertel

- **Indoor areas**

When the user enters indoor areas, the main outdoor positioning sensor (GPS) will fail. For such purposes a completely new positioning technique is needed. One method is to use so called „Active Badges“ [Want et. al. 1991] where users can be located within a room. If positions in a resolution of a few decimeters are needed, other concepts must be considered. For such requirements, solidly installed cameras will be used, which locate the mobile person by using image analysis. This method is able to provide exact position information [Dulimarta & Jain 1997].

The aim is to combine the mentioned systems into one multi-sensor positioning tool (sensor fusion), which is able to handle indoor and outdoor positioning and also the indoor/outdoor handover.

4. A Server for the Spatial Model

The Augmented Area Models have to be stored in so-called Spatial Models Servers (SMS). These SMS have to manage the object models and must provide typical GIS-functionalities like spatial analysis or routing capabilities. In order to handle the huge data loads, a system of distributed SMS has to be established. An SMS has to cooperate directly with the other components of the NEXUS platform, namely the location service, the area service register and the federation component described in chapter 3.1.

4.1 Requirements

The basic requirements of the SMS can mainly be derived from the goals of the Nexus project. The functional requirements were also inspired by the consideration of GIS. In the next section, they are elaborated on in more detail.

The requirements are as follows:

- **Managing several spatial models**. The SMS manages several spatial models, enabling it to provide logically distinct models. Spatial models can be manipulated and updated by authorized clients.
- **Scalability**. In order to be able to handle areas of different sizes, areas with varying numbers of spatial objects, and bursts of client accesses, SMS instances along with the federation are supposed to offer scalable services.
- **Spatial analysis and navigation**. The SMS provides services that accomplish spatial analyses and navigation. The services to be offered are discussed in the following section.
- **Distribution of the workload**. Mobile computers as well as mobile communication perform worse and have to deal with more problems than their stationary counterparts [Forman and Zahorjan 94]. Moreover, their performance may vary tremendously. These properties have to be considered by SMS. Therefore, it should be possible to distribute the workload between SMS and client.
- **Platform-independent clients**. Since Nexus aims at supporting spatial applications of any kind, clients should not be bound to a specific platform.

4.2 Structure and Services of the SMS-Interface

This section first describes the structure of the interface of the SMS. Second, it outlines the services that an SMS offers.

The strategy, which is pursued to involve different kinds of clients, is to offer several interfaces, each of them being adequate for a certain class of clients. The combination of these interfaces results in the interface of the SMS. The SMS-interface is composed of the *fundamental interface*, the *user-API*, the *management-API*, and the *HTML-based interface*.

The fundamental interface provides complete spatial models. The models have to be processed by the client before they are of value for spatial applications. Therefore, clients are required to dispose of a component that is able to process models from SMS. Due to the high processing power, which is necessary to process a spatial model, the fundamental interface is intended to serve mighty clients like notebooks or sub-notebooks.
The user-API provides spatial services that can directly be employed by spatial applications. Hence, clients can be less powerful like PDAs.
The task of the management-API is to enable the management of the spatial models, which are served by an SMS. It can thus automate the administration of an SMS.
The purpose of the HTML-based interface is to allow weak clients to access an SMS. Users interact with the HTML pages of this interface. These pages do not encompass mobile code. The typical client of this interface is a weak PDA. WML (Wireless Markup Language) is intended to be used with such clients [WAP Forum 1999]. It can be reduced from HTML.

To structure work, the services of the SMS are classified in functional classes. The classes, which are described in the following, belong to the user-API, since they are the most crucial ones. The definition of the services of the other sub-interfaces is straightforward. It has to be considered though that the HTML-based interface has to deal with restrictions. The classes of the user-API are illustrated along with some representative sample services. They are as follows:

- **Addition/Withdrawal of spatial objects**. This class contains services, which add spatial objects to and withdraw them from spatial models. Mobile objects can be registered and subsequently signed off, for example. Virtual objects may be created and deleted. It should be noted that the classes of spatial objects form an inheritance hierarchy.
- **Spatial Analysis**. This class offers services that analyze models spatially. For example, such queries yield all spatial objects that are located in some area or that satisfy a condition on their attributes. The queries work accumulative according to integration strategies. One integration strategy is *SelectFromSet* that narrows the set of previously selected objects further down. The other services of this class come from the areas Computed Geometry and Zone Generation.
- **Navigation**. The class Navigation functionally consists of one service: the determination of an optimal path between two or more points under consideration of constraints. To present the optimal path in different ways (textual description, as image, corner coordinates), the class encompasses several variants of the service.
- **Query of spatial object attributes**. The purpose of this class is to make attributes of spatial objects available. The central service *getAttribute(objID, attrName)* provides the value of the specified attribute from the specified spatial object.
- **Manipulation of spatial objects**. This class consists of services, which manipulate and update spatial objects. By and large, the services set the geometry and the attributes of objects.
- **Spatial events**. This class allows to subscribe spatial events and to cancel subscriptions. A spatial event, which can be subscribed, occurs for instance when a specific object enters a certain area.
- **Graphical representation**. The services of this class take care of the graphical representation of spatial models. Among others, they yield three-dimensional images and VRML models. Also, they allow to set the map extent and the size of images.

4.3 Architecture based on ArcView and ArcView Internet Map Server

The architecture of the SMS is based on ArcView-IMS. The services of the SMS can be integrated in spatial applications via Java packages that shield applications from internal details of the SMS. This fact enables SMS to be accessible on virtually any platform. This section describes both the static and the dynamic aspect of the architecture. It concentrates on the realization of the server in Avenue. Also, this section demonstrates how the federation of services can be achieved.

The SMS employs a web server to accept service invocations (see figure 6). URLs denote services along with their arguments. The web server forwards a received URL to the ESRIMap WSE (web server extension), which in turn propagates the URL to one of the ArcView instances that logically are part of the SMS. ArcView eventually gets the URL via its IMS (internet map server) extension and processes it. To process a URL, a script appropriate for the specified service is invoked. The spatial data of the SMS may reside on remote relational databases, which are accessed by SDE (spatial database engine).

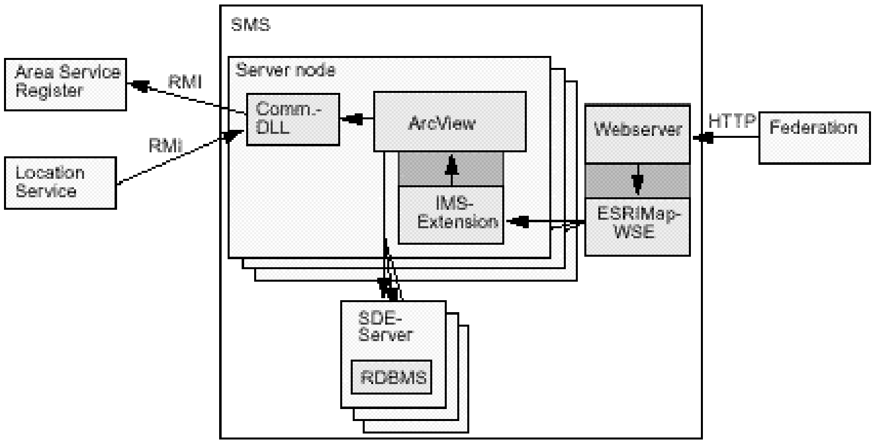

Figure 6: architecture of an SMS

The SMS makes use of the capability of ArcView-IMS to distribute service calls roughly equally among its ArcView instances. This enhances the performance of SMS. A prerequisite is that all ArcView instances of an SMS are identical.

Prior to launch, an SMS signs itself up at the area service register and identifies the area, the object classes and the levels of detail of the datasets it manages. In order to accomplish this, it disposes of the so-called communication DLL that provides the RMI mechanism. The area service register as well as the location service require RMI as communication mechanism, whereas ArcView does not support this mechanism. Therefore, the communication DLL also mediates between location service and ArcView.

The federation yields the input to SMS. It integrates ArcView-IMS, since it has to perform some spatial operations. The basic architecture is thus analogous to the architecture of SMS (see figure 7). One of the tasks of the communication DLL of the federation is to accomplish RMI calls to the area service register. These RMI calls return the SMS instances, which are adequate for specified services.

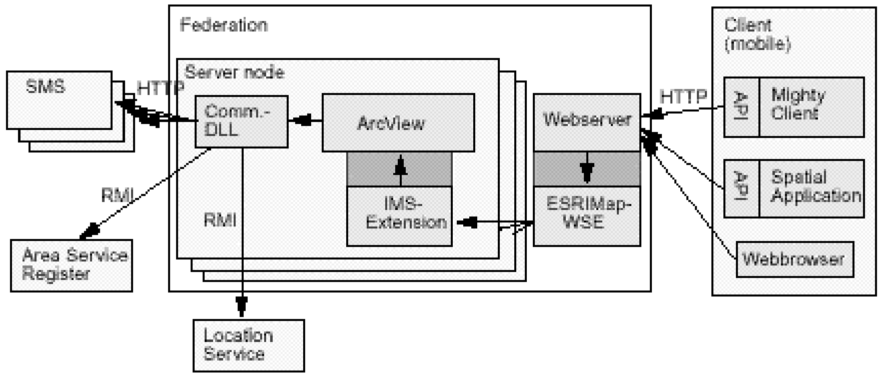

Figure 7: architecture of the federation

Clients direct their service calls to the web server of the federation. The user-API and the management-API perform the service calls over HTTP. They also deal with the conversion between high-level service calls of clients in Java and URLs that represent these calls.
After this static view on the architecture, the dynamic aspects of the SMS are considered. SMS has to preserve the states of its clients to reduce the amount of data which has to be transferred between client and server. The state of a client for instance contains map extent, image size, and a specification of the result of previous spatial analysis queries. As another advantage, less data has to be stored at the client if its state is stored on the server side, which is particularly important for weak clients. ArcView IMS only allows stateless communication and therefore the management of client states had to be integrated into the server. At first, a client has to open a session before it can invoke services from SMS. After completion of work, the session is closed.
The Avenue script, which is invoked by the IMS extension, is called *Dispatch*. It reads the arguments that are passed along and calls the script that realizes the specified service. Every service is provided by a script.
These scripts call the script *ProcessStandardArguments*, which updates the state of the appropriate client if necessary. The invocation of this script is mandatory, since each URL that specifies a service may also encompass an update command of the state. This piggybacking mechanism [Tanenbaum 1996] lessens the number of interactions between client and server. Another script is called *FindTable*. It determines the table that holds a given spatial object, which is specified by its global identifier. Objects of a class are located in different tables, if the class is extended by one or more subclasses. In order to find all objects which belong to a given class, every model of an SMS has a table that reflects the inheritance hierarchy of its object classes. Only single inheritance is supported. Since ArcView does not support object inheritance, this relational way of implementing class hierarchy had to be applied.
The federation of spatial services is demonstrated by means of two examples. The realization of the federation of the services *objectsInArea* and *nearestObjects* are presented. The service objectsInArea yields all spatial objects that are located in a given area. The service nearestObjects determines spatial objects, which are the nearest ones to a reference point out of the set of previously selected objects.
To federate objectsInArea, the federation component first forwards the specification of the area to each SMS that holds a spatial model, which intersects with the area. It subsequently integrates the sets of spatial objects that the SMS determine and return.
The federation of nearestObjects requires that the federation component accomplishes spatial operations. It should be restricted spatially, since the entire global spatial model may be searched otherwise. The mechanism works as follows. The federation component invokes nearestObjects services at the SMS containing a model in the restricted area. The SMS then compute the closest objects in their models and return these objects. The federation component eventually selects the nearest objects from the set of obtained ones.

4.4 VIT-searcher: the development of a Java-application

A sample application has been developed to demonstrate the capabilities of SMS. The application is called *VIT-Searcher* (see figure 8). Its main purpose is to determine and search for VITs (virtual information towers) that meet certain conditions. A VIT is a virtual object that provides structured information content for a specified area [Leonhardi et al.1999].

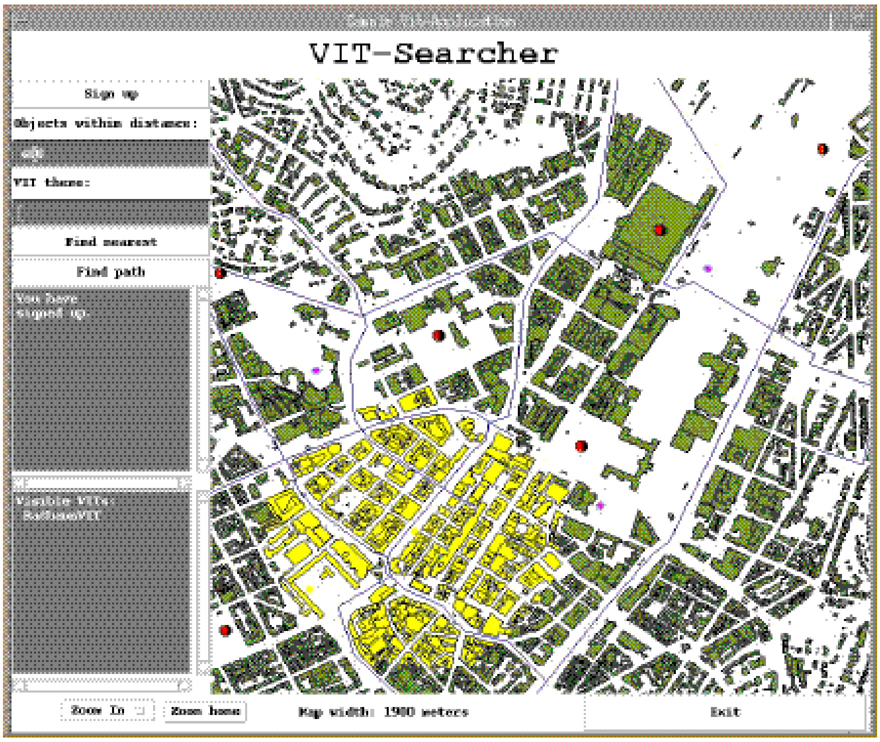

Figure 8: GUI of the sample application

The VIT-Searcher presents a portion of the spatial model of the town of Stuttgart. It allows to manipulate the view that is displayed. More specifically, it can zoom closer and farther with the point that has been clicked on as the new center. Also, it zooms to a rectangle, which users span with the mouse.

The application enables users to sign themselves up at the SMS. The SMS then integrates the user as a mobile object in the spatial model. By entering a distance in meter, the VIT-Searcher selects and highlights all spatial objects that lie within this distance to the mobile object, which represents the user. Attributively, VITs can be selected by specifying themes that in the context of this application have been assigned to them. If objects have previously been selected spatially, only these objects qualify for the selection operation on attributes. From the current set of selected objects, the nearest one to the user can also be determined. Obviously, this operation does not work if the selection set is empty.

VIT-Searcher also accomplishes navigation tasks. It yields the optimal path that visits points specified by the user.

5. Conclusion and outlook

The general concept of NEXUS aims at the production of a generic platform for location aware applications. The most important task of the platform consists of the management of Augmented

Area models within distributed spatial servers. Until now, a first prototype for such a spatial model server has been developed on the basis of ArcView in order to investigate the requirements that the platform has to accomplish. The focus has been put on the development of interfaces that allow the access of the functionalities that ArcView provides. These services have been implemented into a sample application.
In the future, the federation component has to be integrated into the system as well, so that the distribution of spatial queries can be realized. Furthermore, the data must be stored within large spatial databases to be capable of handling huge data amounts. Therefore, the functionalities of object-relational databases have to be investigated.

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