Sustainable Decision Support by the Use of Multi-Level and Multi-Criteria Spatial Analysis on the Nicaragua Development Gateway

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Key words: Spatial Decision Support, Web GIS, OLAP, Warehouses, Multi-dimension, Spatial Analysis.

SUMMARY

Decision support systems should help decision-makers at any organizational level in government, local communities and development organizations. The challenge of supporting sustainable development is to take into account a variety of decision makers as well as the complex natural, social and economic background over time. How can this be solved by the use of new technology for information and communication? Which are the requirements for such systems? After a review of possible solutions for spatial decision support techniques this paper proposes a technical approach which combines geospatial mapping with multidimensional analysis methods using the business intelligence capabilities of datawarehouses. The goal is a tool which can handle complex, structured data and information and which can be integrated into the decision processes of various groups of users. One task to fulfill concerns navigation through spatio-temporal data and the interactive recomputation of visualizations and analysis results when the hierarchical level or the dimensional view is changed. The other task is to the provide the information through an easy to use medium integrating existing informational and functional services. The approach in this paper will be illustrated with its application in real projects for the Nicaragua Development Gateway niDG.

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1. INTRODUCTION

Over the last decades the functional range of decision support systems has changed from structured periodical management reports to complex interrelated tools. A differentiated view of information for several tasks and persons at any organizational levels has become a major feature of the systems. A second and not less important need is access to information. Users need an adequate platform in order to perform their task, for exploring the data, for formulating or validating hypotheses, for planning, monitoring and controlling resources and events, etc.

Introducing a decision support tool for the Nicaraguan Country Gateway tries to solve various problems related with the country's highly unequal distribution of characteristics. Nicaragua is one of the least developed countries in Latin America. There is almost no region on earth haunted with natural catastrophes as often as Central America [1]. The country counts more than 600 volcanoes with high risks. Since 1973 150 earthquakes with more than 5 mb G have occurred. Nicaragua has a high probability of Tsunamis, the average outbreak is every 11-17 years. The last devastating Tsunami happened on September 1992. The distribution of the population, the infrastructure, the per capita income and the level of education, just to mention some measures, is very inhomogeneous. In Nicaragua poverty is extreme. About 85 % of its population are poor with less than 1.5 $ income per capita. Functional illiteracy reaches 50%. The average grade achieved in public schools corresponds to 4th grade of primary education. In contrast, there are about 11,000 university students in computing or related subjects and about 4,000 professionals with a university-degree. In rural areas access to a phone may be measured by walks of 8 or more hours but in Managua and other larges cities there are more than 500 telecenters with qualified personnel.

How to assist the land on natural catastrophes? Which consequences may new disasters have for the country? How to integrate economic and social factors in the planning process for prevention and recovering? How to deal with the highly heterogenic natural, economic and social distribution? Which instruments can support effective development aid?

Sustainable decision-making on environment and development in terms of the Local Agenda 21[1], demands the assessment of "knowledge systems", which can manipulate and present large amounts of complex data, taking into account local and regional aspects and the spatial and temporal distribution of all influence factors. This data should be "refined" and accessed by information processes which support data exploration, creation and validation of

[1] http://www.un.org/esa/sustdev/documents/agenda21/english/agenda21-chapter8.htm, last access Jan. 2005

hypotheses, planning of new locations, visualization of trends over the time and the simulation of scenarios. Thus predictions can be made and decisions can be rationalized or rejected. This paper introduces CommonGIS, a tool for multidimensional spatial decision support, describes how it can be applied for environmental risk assessment and for supporting technical and strategic planning exemplified by its use in Nicaragua.

2. BACKGROUND

2.1 The Nicaragua Development Gateway

The Nicaragua Development Gateway niDG-eNicaragua aims to increase effectiveness and impact of ICT as a long-term strategy to solve basic structural problems[2]. It responsibility has been assumed by CADIN -Nicaraguan Chamber of Industry - and AIN - Internet Association of Nicaragua - since June 2001 by grant of the Development Gateway Foundation DGF (Worldbank Group)[3]. AIN is a non-profit association and affiliates private ISP (Institutes of technology) and all four public universities. Together they manage 80% of Internet traffic in Nicaragua. The niDG-program is implemented by the AIN project eNicaragua[4] and offers a portfolio of ICT competence centers, ICT projects and ICT document management systems.

2.2 Related work

The most important RDBMS providers realized the importance of OLAP technology for the business world at a time when data warehousing was not yet facing the demands of such big amounts of data. Now there are tools for the construction and the query of OLAP cubes, for navigation, analysis and reporting. Unfortunately there is not yet a standardized way or language for querying the data, and the underlying technology differs. So Oracle chose the java way and developed DML as query language while MS Server uses .NET and MDX. There are several solutions that combine OLAP technology with GIS, most of them being applied to specific systems and not generic. But there are some approaches which form a good basis for a multidimensional spatio-temporal decision support tool.
Some tools like CubeView and Polaris facilitates the observation of spatial patterns and temporal trends in large volumes of data (Voss et al., 2004).
The ”Centre de recherches geomatic” of the LAVAL University in Canada defined the term Spatial OLAP (SOLAP) for visual tools which support rapid and easy spatio-temporal analysis and exploration of multidimensional data (Rivest et al., 1997). SOLAP recherches at LAVAL offers an extensible guide for development as well as applications which demonstrate the concepts. Meanwile the Centro de Informatica at the Universidade Federal de Pernambuco in Brazil is developing the concepts for a Geographical On-Line Analytical Processing Architecture (GOLAPA) and the querying language GMLA (Fidalgo et al., 2003). The concepts presented here for CommonGIS integrate both lines of research.

[2] http://www.developmentgateway.org/node/322831/interpage/index?iso=ni, last access Jan. 2005
[3] http://www.dgfoundation.org, http://www.developmentgateway.org/, last access Jan. 2005
[4] http://www.enicaragua.org.ni, last access Jan. 2005

To avoid the constraint of predefining e.g. the data and the aggregation methods on the OLAP Server, CommonGIS will offer OLAP functionality with an innovative solution to bind mulitple sources and services dynamically for a highly interactive spatial business intelligence.

3. MAKING GIS SPEAK "OLAP" FOR DECISION SUPPORT

3.1 The multidimensional space

The high number of tasks and users and the heterogeneous storage of and access to information asks for a well-defined distributed structure. The information has to be searched and generated just on demand of the decision problem. During exploration data and presentations have to be changed easily and answers have to be fast and interactive, while the corresponding transformations can not be predefined. Since in the decision-making process no "basis" data has to be changed (except some modifications for "what-if" scenarios), communication with the database can dispose of transactional mechanisms. Rather an "analytical" view of the data is required. This is the concept behind OLAP (On Line Analytical Processing) in contrasts to On-Line Transaction Processing (OLTP), traditionally supported by operational databases.

For OLAP the database should be modelled with multiple dimensions, which means, the properties of facts are classified as dimensions or measures. Time, space and every independent variable are dimensions. They describe the measures unambiguously. If some measures are not existent for specified dimension values, they have to be interpolated or computed with predefined or ad hoc input. The definition of different views of the data (e.g. for different user groups, meteorologists, public institutions, investigation centers) and the retrieval of data at different hierarchical multidimensional levels are main OLAP capabilities.

3.2 Enriching OLAP concepts with GIS

There are two restrictive properties of OLAP engines: the spatial dimension is just represented by the textual name of the places and there is no possibility to store qualitative attributes. Lack of spatial awareness in OLAP tools means that the place name is the only hint to a location. So it is not possible to discover spatial relationships on the analysis results except for users familiar with the region. Interactive OLAP tools also limit the user interaction to the tables, so the user can not pivot, slice and dice in finished charts or graphs. First the table view has to be modified and then the thematic representation is recomputed.

The other problem concerns qualitative attributes, which cannot be stored as measures in data cubes and therefore cannot be aggregated and dispersed. The visualization of elections is an example. If you just have the winner party for each election district, and want to visualize the results for entire municipalities then you have to work around and store the parties as dimensional values and set their values to one or zero to express that the party won or lost the respective district. This enables aggregation, but a visualization of the property “winner party” at district level which colors each district by its winning party will be difficult to do.

To make the best use of spatial and temporal dimensions in decision making the analysis of hierarchical multidimensional data should be combined to the visual and analytical capabilities of a GIS. The coupling of OLAP and GIS technology for cartographic navigation through the data, for analytical representation of measures in form of diagrams or shadings on maps and for the possibility of interactive data exploration is known as Spatial OLAP or SOLAP (Guimond et al., 2003). SOLAP technology achieves ease of use and fast response times (Rivest et al, 2003). Easy of use means that the user can intuitively interact with the presentations without any knowledge of the query language or the underlying database structure. Fast responses are due to pre-aggregated computation. But still there is a lack of handling non-ordinal attributes.

Qualitative attributes play an important role in powerful decision support tools: they do not only occur as raw data, but may represent hypotheses and intermediate analysis results, especially in the form of classifications. Moreover, explorative analysis does not only proceed bottom up, but also top-down or in any ping-pong way. This implies that hypotheses and intermediate results may be created at any hierarchical level and need not only be aggregated upwards but be propagated downwards. These requirements raise new conceptual challenges when building SOLAP technology into our spatial analysis and decision support tool CommonGIS.

3.3 CommonGIS: an interactive analytical web GIS

The combination of visualization and data analysis in CommonGIS empowers not just geographers and analysts to make full use of geographical information, providing a better basis for adequate decisions and later for their evaluation. CommonGIS makes geographic data, including time-series, interactively usable for authorities, enterprises, organizations or other people, as desktop or web application. The automatic generation of thematic maps unburdens the user from complex map creation tasks.

Since 2002 CommonGIS has supported parametrized attributes. It is possible to declare one or more dimensions (also time) for quantitative and qualitative attributes and visualise all or some elements of a dimensional level.
An abstract of CommonGIS functionalities are (Andrienko et al. 2003):

- effective multidimensional description of spatial objects,
- multidimensional query and search for spatial objects,
- multivariate spatial analysis (e.g. dominance analysis),
- spatial hypothesis finding,
- multi-criteria decision support and
- visual analysis of spatio-temporal data by using time-series.

3.4 Introducing SOLAP to CommonGIS

Its uncompromising interactivity is a key advantage of CommonGIS. The users may simultaneously create different thematic maps and charts. All presentations are connected: spatial selection, highlighting and filtering will simultaneously be applied to all representations. Even new created or computed attributes for a representation can be used as input for another one, and would be changed if recomputed. CommonGIS users are accustomed to this responsiveness even for representations of parameterized attributes, like time series, and should not miss it when CommonGIS is extended with new OLAP functionalities. For example, CommonGIS must automatically aggregate or distribute the values of all attributes involved in the current visualizations. If on drill-down, roll-up and drill-across movements a level is reached where the visualized attributes do not yet exist, defaults should be supplied or users should be able to enter values on the fly. Then the visualizations, for which the new attributes have been calculated, have to be "reconstructed".

A simple case to illustrate this issue are choropleth maps. Fig 1a) shows a choropleth map of the percentage of poors from the population of municipalities. By zooming to a different level (e.g. from municipalities to regions) the visualization has to be recomputed, and therefore also the color range to be applied, the map has to be updated, and the regions containing the formerly highlighted municipality have to be highlighted too, Fig b. At an inverse zoom in, all municipalities contained in a highlighted region should be highlighted. More complicated "transpositions" are required for multi-criteria analyses and the visualization of their results like cross classification or ideal point. By changing the dimensional level the data has to be retrieved and the analysis recomputed. For each dimension the user may be asked for the new formula for aggregation or dissemination if there are no data available, or defaults can be taken. The results are new attributes for the new level. These have to be retained for a possible comparison of results on different levels on different maps.

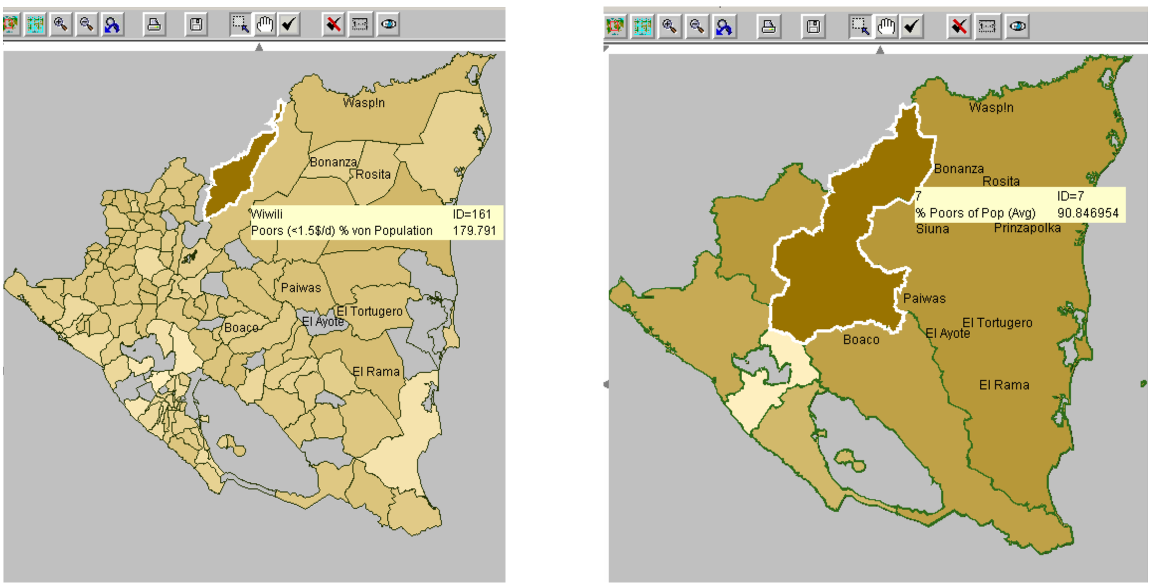


Fig. 1: Choropleth map of percent of poors per municipality a) and per region b)

Another issue concerns attributes which are not distributive or change their type at different levels of aggregation. Imagine overviews of the winner party like in Fig. 2a). At the level of regions (Fig. 2b) the visualization of the dominant winner party would be quite a loss of information. Better there should be e.g. parallel bars indicating for each party the number of municipalities won in this region. At a higher level (region) the qualitative attribute (the winner party name) then becomes a new dimension, with levels and quantitative measures inside (a quantitative attribute like sum per party).

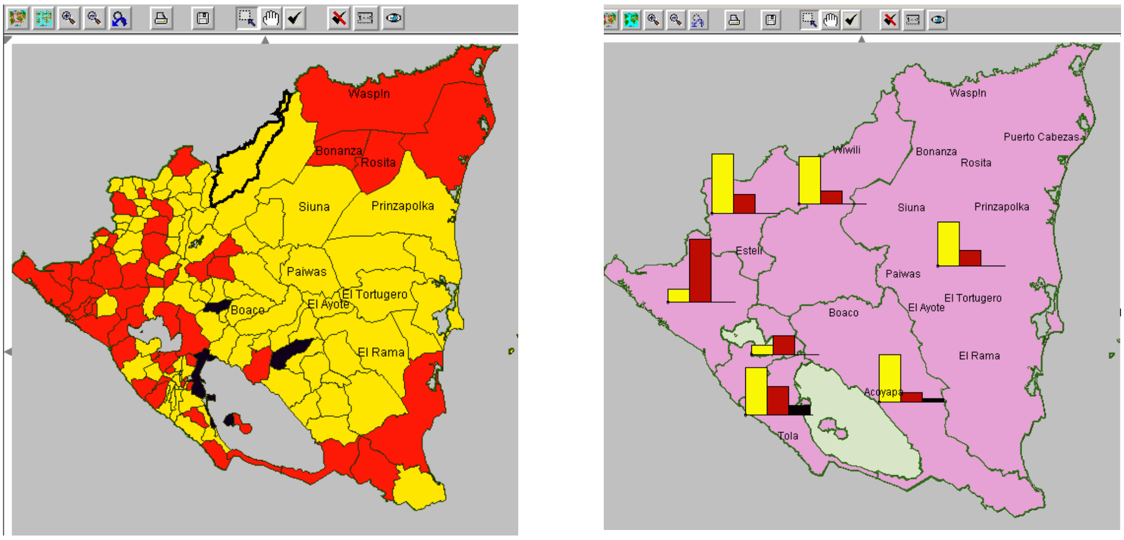


Fig. 2: Visualisation of winner party per municipality a) and per region b).

A typical example for non distributive measures in decision support is dominance. The next table shows an example of wired results for non distributive functions. The first three columns represent some comparable attributes, A1- A3. Rows L1-L3 describe locations. The shaded table cells represent the observed measures. For a region including the three locations the dominant attribute shall be computed. This is prepared by adding a fourth column which gives the attribute with the highest value in each row (dominance). However, the results differs for the vertical aggregation and the horizontal computation. The user has to be warned about such problems at the moment of aggregation or navigation and should be able to decide which computation to use.

	A1	**A2**	**A3**	**Dominance**
L1	3	2	2	A1
L2	5	10	5	A2
L3	3	2	2	A1
∑	11	14	9	A2 / A1

Further problems concern classification, filtering and selection. In classified choropleth maps, for instance, the user can introduce class borders, e.g. for low, medium and high values. Such “method control variables” must also be translated when the method is re-invoked at another level. If the aggregation function was a sum, the class borders have to be increased homologously. Filtering allows the user to supress the view and analysis of spatial objects. If an interval for the values of an attribute was defined as a filter, the new borders have to be recomputed consistently with the chosen aggregation or distribution function. Manually selected spatial objects have to be ”transposed” differently: at a higher (or lower) level, a spatial object would be selected if any of its contained objects (or its containing object) was selected.

Interaction with the user should avoid confronting him or her with any complex OLAP functions through predefined methods and data. But analysts who really want to dig into the data should be able to exploit more the capabilities the OLAP servers, still without having to go very deep into programming or query languages.

3.5 Architectural solutions

Taking into account the high number of possible information processing methods and the heterogeneous storage of the processed information a well-defined distributed structure is required. The information will be searched and generated on demand during the decision process, but this should be done fast and flexibly for high interaction and rapid data shifts.

The main requirements for the use of CommonGIS as SOLAP client are:

1. Support spatial hierarchies that automatically aggregate or distribute attributes and re-invoke analysis methods
2. Enable work with CommonGIS without an OLAP Server at the back end
3. Data and functions may come from different local or remote sources or services.

In order to fulfill these demands we define a component-based multi-tier architecture (Fig. 3), which follows the concepts of the OpenGeospatial Consortium (OGC) of using service interfaces to enable interoperability and hide the complexity of underlying components. The component view is function-oriented while the tier-view represents the technical layers of the system. Thus the creation of components, which can be integrated into the system and be accessed as services, keeps the system scalable and task oriented.

The presentation tier contains the SOLAP applications and interfaces for different user groups on the basis of CommonGIS. An application relies on different components. The creation of applications will be supported by the deployment component, which predefines “analysis tasks” to be used as a project or tool over the web. The deployment component allows defining which data to access, which analysis methods to provide and how to present the data. The deployment component will also create the metadata for the SOLAP services. The deployment can be made either through an interface or from inside an analysis process, deploying the currently used configuration. The analysis component offers an interface of data and tools to create new information through analysis. The analysis component will be linked to visualization components (maps, diagrams, legend and tables) which provide SOLAP operations (drill down, drill across, etc.). To obtain the data the analysis component will communicate with the SOLAP server, which delivers the required view of the data from the various sources (databases, OLAP server, Map or Feature Server, etc.).

The backbone of the architecture is a set of well defined metadata describing services and data. The services will be described using WSDL[9] and should register to the discovery component via an UDDI registry. The discovery component can be accessed from all components and services. Besides it offers a web interface for selecting data and services, for instance for creating composite services. Composite services include other services for complex tasks and can be seen as value-added services, but unfortunately the standards for service composition [13] still lack complex definitions [9]. Communication with the SOLAP services will use a combination of OLAP and OGC standards – GMLA[5], but not just for exchanging data. Modifications of this language will be necessary to describe "virtual SOLAP cubes" with data from heterogeneous sources. At the moment we are working on this language. The SOLAP server will preferably integrate data from data service providers, communicating via XMLA or GML or getting images from a web map server. New data services could thus be integrated by developing an interface which converts the XMLA request into the intrinsic language for querying the OLAP Server (e.g. a MDX for SQL Server, DML for Oracle or SQL for RDBM). Some other functions and operations on data can extend the SOLAP functionality and should also be defined as function services, for instance routing services, data mining services, etc.

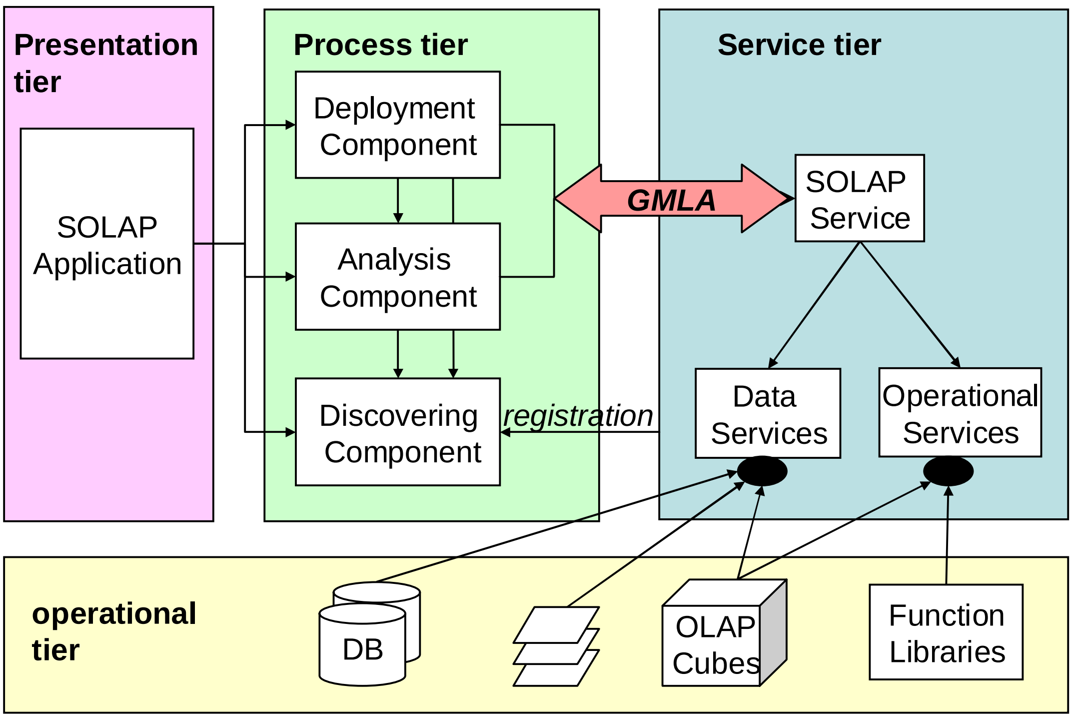


Fig. 3: component base multi tier architecture approach

In CommonGIS a compound layer will be the object that is connected to a virtual cube definition at the SOLAP server.

4. REALIZING THE PROJECT FOR eNICARAGUA

Actually lots of geo-referenced data are available in Nicaragua, but they are managed by different institutions, using different formats and maps with different scales and projections, different levels of aggregation, and different zoning of regions. Hence, in Nicaragua as in many other places, Geographical Information Systems GIS have been introduced to present the complexity geographically, but actually have not yet been exploited. Suitably bundled and targeted information is still needed for a strategic vision that suits the vast regional diversity as is demanded for sustainable policies.

The Fraunhofer Institute for Autonomous Intelligent Systems AIS has started a project in cooperation with the Asociación Internet de Nicaragua AIN and its operating entity eNicaragua. AIS provides the analytical tool CommonGIS together with a pilot demonstrator for fullfilling different tasks. The technical constrains were:

- interactive exploration and spatial analysis of attributed geographical over the web
- interactive visualization from analysis results, differentiated by region, time, context over the web
- intuitive and easy to learn interface, even for less experienced users

The tasks to be supported are:
- location planing
- risk assesment: prediction and monitoring of natural events
- environmental and migratory monitoring
- monitoring and planing of development projects.

4.1 Data integration

The project will implement a "demonstrator" which may serve as a proof-of-concept for those state agencies in Nicaragua that already have a stock of geo-referenced data, yet do not use any analytic or visual exploratory GIS-based tools.

The demonstrator will be developed in two steps. In the first step some of the available data have been bundled as "projects" in CommonGIS. Although at this stage CommonGIS was not delivered as a SOLAP-client application its multicriteria decision support methods revealed a huge gap between available raw data and information that can support decisions. The CommonGIS projects were presented by Fraunhofer AIS at a workshop on November, 26th, 2004 in Managua to reprentatives of universities, of the ministeries of environment, commerce and foreing affairs, of city administrations, of NGOs and of private enterprises. This projects were highly appreciated as a model developing further applications for a diversity of intended uses, and at the same time for training people at different institutions.

For this first stage AIS had to inspect a lot of files delivered by the partner in Nicaragua. The huge amount of files was due to a high redundancy in scattered, inconsistent and mostly undocumented data (different zoning, different ordering, varying data types and projections).

The extracted data included[11]:

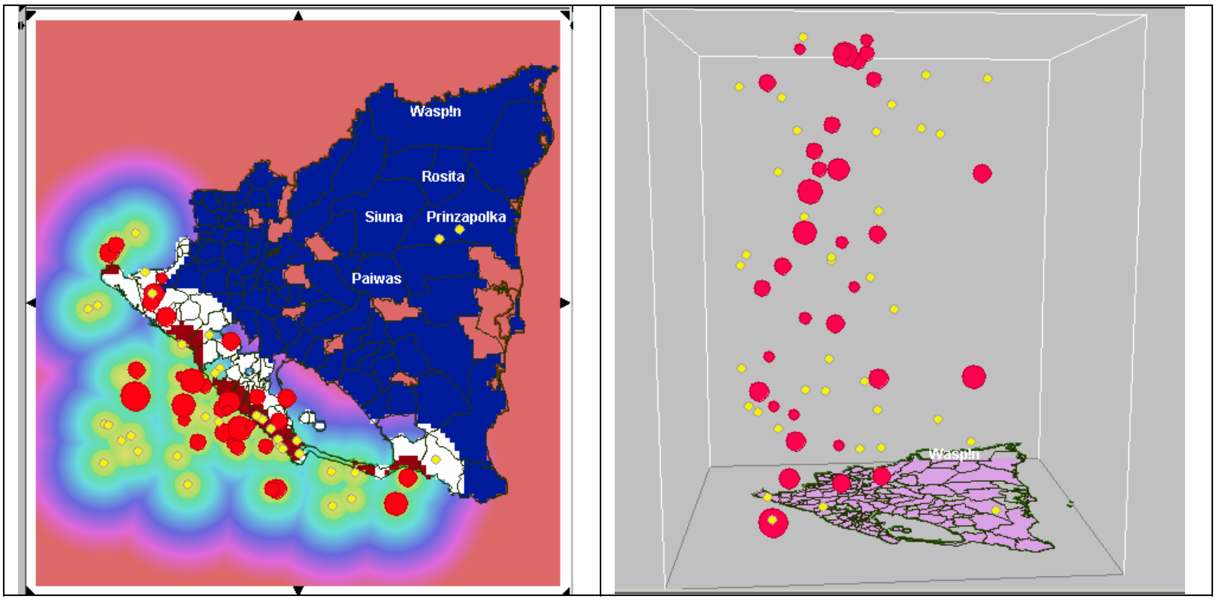
- Geo-data like maps of Nicaragua, the zoning in regions and municipalities; rivers, roads, volcanoes, earthquake epicenters; average rainfall & temperature; telecommunication lines and nodes, television lines and nodes.
- Attribute data for population, elections, risk of volcanoes, earthquake occurrence and technical data on telecommunication facilities.

The second step of the cooperation, on which we are currently working, will introduce SOLAP-client functionality to CommonGIS. An ongoing task which needs the combined functionality is a continuous monitoring of indicators for Information and Communication Technologies (ICT). This project pursues the definition of statistical parameters and a framework for their annual recompilation for a number of countries in Central America. This will define indicators of ICT use and enable the statistical validation of hypotheses on ICT penetration in relation to regional specifics. The computed indicators should automatically be updated when the statistical parameters are renewed. Analysis and monitoring should be done at different levels of detail regarding space, time and indicator parameters. Therefore OLAP cubes will be needed. Periodical mechanisms for data extraction, transformation and loading (ETL) will guarantee the timeliness of information. The project intends to be a bridge for collaboration and interchange on ICT projects and to promote synergies between the actors (stakeholders). This would improve the efficiency of the projects implicating a sustainable success of the development process in the countries.

4.2 Distribution and use

A special issue of the project is a wide distribution and use through a web portal offered by AIN, where CommonGIS can be accessed and used for different scenarios. AIN will also provide a spatial data infrastructure integrating data from different entities: tele-communication providers, and research instituts like INETER, the Nicaraguan Institute of territorial Studies [13], as well as socio-demographic data from city administrations or other intitutions that recollect statistics.

CommonGIS, as an interactive viewer for data and analysis results, can also be used for online demonstrations. Especially for functional illiterates are dynamical graphs more tangible than long texts, tables and facts, besides alternatives become transparent. The auditorium could get more insights into statistical relations and better understand their situation.



A scenario for a current task is a monitoring system for tsunamis. Figure a) gives an example of the regions with a high risk of tsunamis taking into account the last eruptions of marine volcanoes since 1973with a force higher than 5.5 and zones with a high population density. To get a more detailed classification a grid layer was introduces and an ideal point analysis was calculated on it. Fig. b) shows the distribution of earthquakes on time as Z-axis (time view), where spatio-temporal relationships of incidences are exposed. This scenario is being extended with elevation models, location of industries, schools, communication media, etc. for a realistic model for a tsunamis risk assessment project.

5. CONCLUSIONS

This paper has presented a technical approach to facilitate sustainable decision support by taking into account the following factors:

- inclusion of all influence factors in an adequate view of information at the requested level of detail
- access to “refined” data through services which get the raw data from distributed sources
- an interactive decision support system which provides not just a seamless navigation through complex data but also instant visualisation and analysis at shifting dimensional levels
- an easy to use system with a high analytic power which can be used intuitively by less experienced users as well as by experts
- high availability of information and results through web deployment
- a scalable system which can integrate data from different sources and interpolate missing information between different visualisation levels
- an open architecture which uses current standards, allowing the integration of data and interoperation of services

The importance of a service-oriented approach for a flexible solution was argued. Fraunhofer AIS is extending CommonGIS to include SOLAP functionality in ongoing and further collaboration projects. We are also developing an approach for describing integration of SOLAP services.

A presentation of the Nicaraguan CommonGIS application in Bonn on June 2004 for representatives of members of the Country Development Gateways in Bolivia, Guatemala, Kenya, Mongolia, Palestine, Romania, Rwanda, Venezuela and Vietnam arose a big interest when they saw how CommonGIS could be used to map the digital divide in such an inhomogeneous country.

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Wolf Göhrig is a retired member of the Fraunhofer Institute AIS with a strong interest in decreasing the digital divide. His research fields include learning environments, petry Networks, logic and simulation.

Cornelio Hopmann was a researcher at GMD. 1985 he moved to Nicaragua, where he is working as a university teacher and consultant. He is executive director of eNicaragua and has managed many projects on the introduction of ICTs.

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