Data Warehouse of Spatial Information

Qi Li[1] Chaowei Yang[2]

[1]*CyberGIS Studio, The Institute of RS&GIS, Peking University, beijing, 100871,China*
Tel: 86-10-62751964 or 86-10-62752671, Fax: 86-10-62751964
e-mail: Liqi@pku.edu.cn
[2]*CyberGIS Studio, The Institute of RS&GIS, Peking University, beijing, 100871,China*
Tel: 86-10-62751962 or 86-10-62762386, Fax: 86-10-62751964
e-mail: ycw@263.net

ABSTRACT Digital earth calls for the sharing of spatial information, spatial data warehouse (SDW) is a convenient way for managing and distributing information among public. In this paper, the society and institutional context of building spatial data warehouse is given, that is followed by the discussing of strategies used when constructing SDW and architecture of SDW. Then related key techniques of SDW are discussed in detail. Based on these theories discussed, a prototype of SDW is designed and implemented to display how to build a SDW.
KEY WORDS spatial data warehouse, strategy, architecture, key technique, prototype, digital earth

1. Introduction

1.1.Digital Earth

Digital earth has become more and more popular among the information industry, the academic, the politic and the public. Since its emergence on Jan.31, 1998(Al Gore, 1998), many countries have paid much attention to it. In American, an organization of Digital Earth has been organized by government, includes NASA, NOAA, NSF, DOD, many other organizations and agencies. In china, the scholars in many universities (Li Qi, 1998) and CAS (Yang Chongjun, 1998) have carried on many conferences to stimulate the initiative of it. The information industry has showed their interest to build the digital earth. The government has also decided to carry on the digital china project (Jian Zeming, 1998). Many other countries have also made up their mind to build digital country. But how could the digital earth be used in the future?

Al Gore(1998) give us an example to illustrating what the digital earth will be in the speech of digital earth on Jan.31, 1998. Ralph Kahn (1999) gives us 13 examples to show how the digital earth will help in our daily life. Xu Guanhua (1999) also tell us that the digital earth can be used in supporting sustainable development and national economical development. As you can see, in all of these examples or promising use of digital earth, the user has to have access to lots of information and services of lots of analysis and presentation at the same time. How to build the information system to realize these scenarios is a complex system project. One of the most important steps is to build a robust and fast SDW, which can manage and process the large sum of spatial information, i.e., we need to build SDW (Yang Chaowei, Li Qi, 1999).

1.2.Data Warehouse

Scholars have given out data warehouse for 10 years or so (Delvin Barry, 1997). Many information corporations, such as Microsoft, oracle and Informix have proposed implementation policies. The father of data warehouse defines it as “subject oriented, integrated, nonvolatile, and time variant collection of data in support of management decisions.” (Inmon W H., 1996) Data warehouse is a new way to think of information management from a new philosophical point of view (Gary Dodge, Tim Gorman, 1998).

There are 2 kinds of data warehouse: one is data mart, another is data warehouse. They are different from each other although many people especially the system integration administrators take them as the same. They are different at the data model, the historical information quantity, the subject relationship, the query type, the user type and the main structure.

Many successful data warehouse cases have existed these years (Delvin Barry, 1997). But the SDW is still a dream for most of us, because of the complex of spatial relation, computation and analysis (Yang Chaowei, Li Qi, 1999).

1.3.Spatial Database and Spatial Data Warehouse

Database has gained rapid progress and success for the past 30 years since the relational algebra proposed by Dr. E.F. Codd. Relational database and its query language SQL have become standard.

The spatial information is managed with file system at first. Then the DBMS is used to manage the spatial information and construct spatial database. The spatial database is constructed with a database and a spatial data engine (such as SDE and SpatialWare), the database is used to mange data in a structural way, the spatial data engine is

used to provide spatial information access ability (such as spatial analysis, spatial computation and spatial query)(Li Qi , Yang Chaowei, Chen Aijun, 1999).

Since the revolution of quantitative in geography, many methods, knowledge have been accumulated, they are very useful in the SDSS (Spatial Decision Support System)(Yee Leung, 1997). The development of information science and management science calls for the integration of these method, knowledge together with the spatial data engine and DBMS to provide support for the SDSS, i.e., SDW (Yang Chaowei, Li Qi, 1999).

From this background information, we can see that the SDW is the integration of data warehouse and the spatial processing and analysis. From the pointview of an information scientist, the most difference is that the SDW need to process the non-structural information. Since the difference is apparent and data warehouse has been mature, we'll focus on SDW in this paper.

1.4. Content of This Paper

The general things of SDW will be addressed in this paper. In the first section, the background of SDW is given. Section 2 will focus on the strategies to be taken when constructing SDW according to the status and characters of SDW. The structure of a SDW will be given at section 3. Then it follows the key technique of SDW in section 4. At last, a prototype of SDW is given to illustrate how to build a SDW.

2. Strategies Needed to Build a Spatial Data Warehouse

The data in a SDW or used by a SDW is distributed at different places, so we need to solve the problem of spatial data distributed. The SDW will serve for a large sum of people or users in a company, they are formed with different levels of importance, requirement and place, and different storage method should be provided for these different users. The access to the different data sources at different place and the security control require a center to manage and exchange spatial information, i.e., a data exchanging center (Harjinder S.GILL，1997).

2.1. Spatial Data Distributed

The spatial data is made up with data and metadata, metadata is the data about spatial data. There are 3 ways to implement spatial data storage. The first one is to store all the data in a data center. Another one is to store different data at different place respectively. The 3rd one is to store the whole data wherever it is used.

2.1.1. Data Center Strategy

In this strategy, the data is stored in the data center all together, every time any user want to have access to the data must access the data center. In this strategy, the data can be access directly, but the data center server's burden is heavy. The processing procedure is listed as below (Fig.1),

a) The user sends the request to client computer.

b) The client computer interprets the request and sends a data request to data center.

c) The data center receives the data request and processes it at the data center

d) The processed result is sent back to client computer

e) The result is displayed to the user

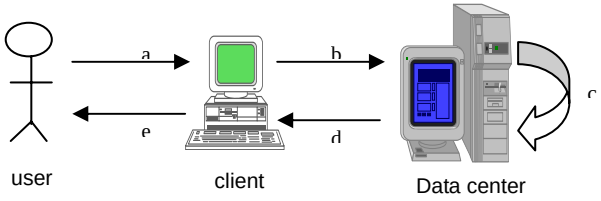

Fig.1 data center strategy

This strategy is used at the small company where many people want to have access to simple functions of SDW with less spatial data. The data mart is a typical use of this strategy.

2.1.2. Distributed Strategy

In this strategy, the data are distributed at different places, different data and respective metadata are stored at different places. This strategy is used at the middle or big company ,

But the speed request is not so strict.

The processing procedure is as follows (Fig.2),

a) The user sends the request to client computer.

b) The client computer interprets the request and sends a data request to data center.

c) The local server receives the data request and sends request for data at other server

d) Other servers process the request and send result back to local server

e) The local server receives and processes the data and sends result back to client computer

f) The result is displayed to the user

This strategy is widely used for data warehouse because it is suitable for the status that many DBSs

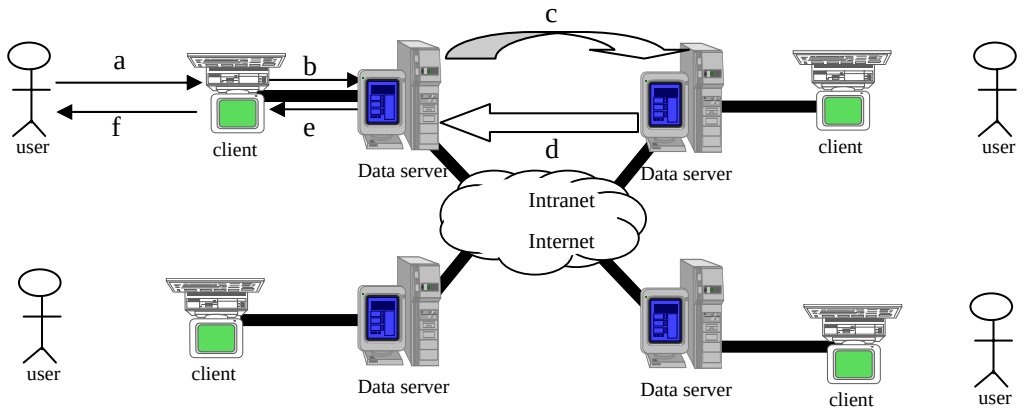

Fig.2 distributed strategy

have been constructed before the data warehouse is constructed.

2.1.3. Distributed Duplicate Data Strategy

In this strategy, the whole data of the company is stored at every server, and the data will be updated at a certain period of time. The network structure is the same as distributed strategy, but the process procedure is just like the data center strategy. This strategy is used for the big company and every user who want to have a rapid access to the data warehouse. They system maintenance is the most complex one for frequently duplicate data among the data centers.

2.2. Storage Method of Spatial Information

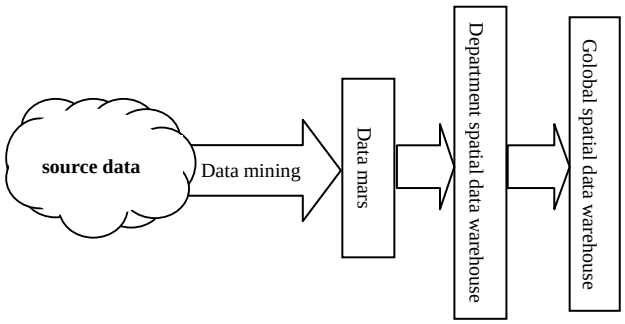

Fig.3 storage method of spatial information

In general, SDW is constructed by a company. In a company, almost every one needs to have access to it. These users are come from different background, have different request to the SDW. The application logical difference and the level difference are very clear. To meet the different level request and to respond as fast as possible, multi-level storage method of spatial information is used (Yang Chaowei, Li Qi, 1999).

There is 3 levels storage (Fig.3): data marts, department SDW and global SDW, the data marts is the low-level query result data set. It can be used for many general users, the department data warehouse is used for the leader of a certain department, and it is constructed according to the subject of the department. The global SDW is constructed for the executives of the whole company and used for SDSS.

2.3. Data Exchanging Center

The data request and transfer is carried out directly between the local server and remote server in Fig.2. There are many problem, e.g., it will be difficult to manage the exchange of data, especially the metadata will be stored on every server. In order to manage the data in a SDW

In a universal way, a center for the exchange is needed.The data exchange center will be constructed to manage the exchange of data, all the metadata of the data will be stored

Here, a catalog will be maintained at the data exchange center. The user access the data in SDW in the following procedure (Fig.4),

a) The user sends the request to client computer.

b) The client computer interprets the request and sends a request to local data server.

c) The local data server sends a request to data exchange center.

d) Data exchange center find the place of the data and send it back to local data server.

e) The local server receives the place and sends a request for data at other server indicate by the place information.

f) Other servers query the data and send it back to local server

g) The local server receives and processes the data and sends result back to client computer

h) The result is displayed to the user

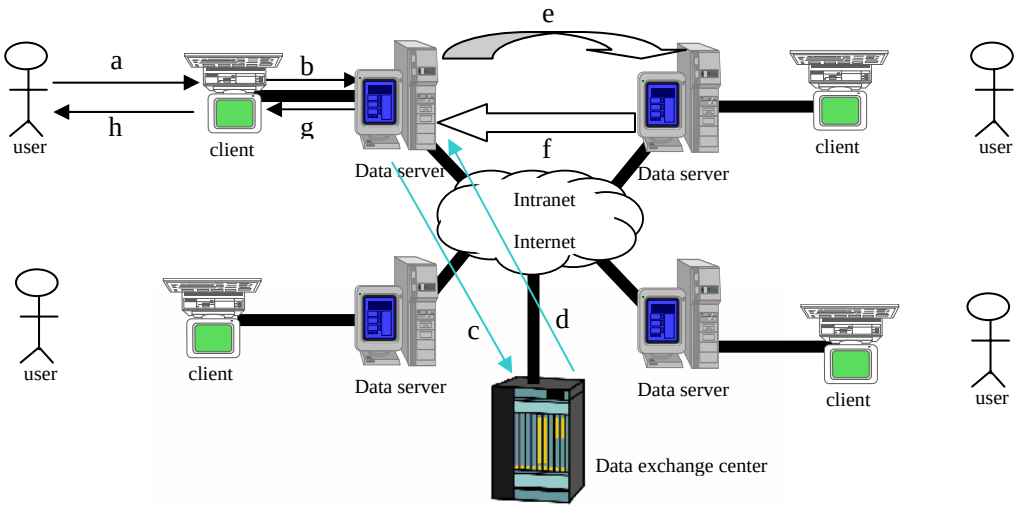

Fig.4 The role of data exchange center

These strategies covers some of the decision must be made before constructing a SDW. But what will be the overall view of the SDW? Architecture of the SDW will be stated at the next section.

3. Architecture and Information Flow

SDW will manage the whole information and data in a company or Corp. to provide support for SDSS. How could it do this? Let's take a look at its inner structure to see how it did this (Yang Chaowei, Li Qi,
1999, Li Haochuan, 1998).

The structure of a data warehouse is composed of

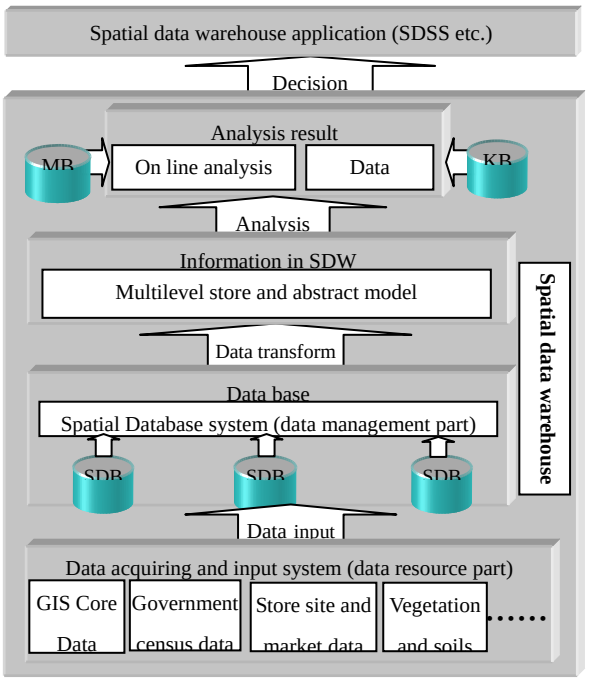

Fig.5 architecture of SDW

data/information and respective human resources, Hardware/software. Just as illustrated in Fig.5, its data/information flow is data resource, database, information in SDW, analysis result used for SDSS. The hardware/software needed are data acquiring and input system, database system, data transform and cleansing tools, data analysis tools (OLAP or DM). The output of the SDW is used to support SDSS.

3.1. Data Source

Data source is the information source for SDW, it contains 2 parts: the GIS core data (named Framework data set in NSII or NSDI) and the added application-specific data. The GIS core data contains Geodetic Control, Orthoimagery, Elevation, Transportation, Hydrography, Governmental Units and Cadastral Information. The added application-specific data is the data used for a specific application, such as population distribution information in city sustainable development SDSS.

The framework data set can be obtained by surveying or extracting directly from the image taken by satellites or plane, and processed by GIS software, such as ARC/INFO, ERDAS etc. The application-specific data is obtained through the application department or data center of respectively department.

The data acquiring tools are become more and more intelligence, the framework data set acquiring method will be automatic in the near far future.

Before been input into databases, Data must be projected to a certain reference system, geo-encoded and formatted. In this process, many

different kinds of heterogeneity will come out.

- Data Format Heterogeneity: not only the data come from different resource, but also the same resource have different data format, such as image files, raster files and database data for different abstract method and different model used, e.g., for vector files format, there are coverage, e00, shp, mif, tab, etc.
- Thematic Heterogeneity: different kinds of data resource may give different name to the same spatial object, vice versa.
- Symantec Heterogeneity: different people come from different community, with different background will give different attention to the same spatial object, so different kind of spatial objects were abstracted for their use
- Coding Heterogeneity: different system, sometimes, different application adopted different coding rule to code the spatial object and the respective attribute.
- Projection and Reference System Heterogeneity: different projection and reference system were used for different spatial objects.
- Precision and Data Processing Heterogeneity: different processing and precision of data were used.
- Data duplicated: different system acquires their own data, sometimes, they survey and keep their own data for the same spatial object.

In order to resolve these problems the following tasks should be finished in the process of data acquiring or mining period.

- Construct metadata
- Unify the name of spatial element to the same rule.
- Select the data will be used in SDW.
- Keep the value time of the data.

3.2. Databases

All the data in SDW will be managed by databases. At first, the spatial data is stored in files, then it is stored in relational database as a BOLB field, a SDE is added to provided spatial access ability to it, it is SDB, the next generation of the databases used to manage spatial information will be OODB (Object-Oriented DataBase) or ORDB (Object-oriented and Relational DataBase).

SQL3, a new version of the standard query language for RDB, has been expanding to have the ability of accessing spatial information. In the future, we can have access to the spatial data in the same way we access the structuring data in RDB today.

There are many mature database products can be used for SDB, such as SQL Server of Microsoft, Oracle, Informix etc. Nowadays, many SDB are constructed with this database and a SDE added to it, e.g., SDE of ESRI, SpatialWare of MapInfo.

3.3. Storage Structure

The vast amount of information and the distributed characteristics of SDW require it to provide efficient information storage strategy to achieve better performance. We can't find all of the data in the whole world after we receive the request, this can be resolved by constructing multi-layer storage mapping.

The SDW may reside on the Internet across the whole world; we can carry on data analysis and data mining to get the information needed by the global SDW in a certain period of time. In this way, we can collect the general information before they are needed, and we can build the application specific SDW. As illustrated in Fig.3.

3.4. Spatial Data Warehouse or Data Marts

In SDW or data marts, the information are organized according to a certain subject, the subject will contain a lot of factors, one factor is taken as a dimension, just as the 3D of spatial and 4D for time and spatial. In this way, the information in a SDW or data mart will be vast amount.

SDW use multidimensional technique to organize vast amount of data. Construct cube or super cube data model. The dimension decision is decided by spatial query requirement. General geographical query and analysis can be classified as when, where, how, what happened. We can use 3-space dimension and time dimension and thematic dimension to organize data, for the customer's requirement to observe the world in this way; thematic dimension can be classified according to different subjects.

Dimension is organized in a multi-layer way with different size. Time can be classified to date and time (second) or year; spatial dimension can be classified to nation, province, city, county, etc. Thematic dimension can be classified according to the respectively standard or specification used by certain field. Size is direct related to the abstract and aggregate operation of data resource. The smaller the size, the more information we have, the larger the size, the less information we'll have.

In the process of spatial information integration, we can carry out them in this way; it is just the 4.5 dimension or 5-dimension model proposed when made research on digital earth. In fact, it is multidimensional (more than 4.5 or 5), i.e., 3 dimension for space, and 1 dimension for time, and multidimensional for attribute.

The construction of SDW or data marts of spatial

dimension is the fusion of spatial information, the technique of map combination, edge processing, DEM or 3-dimesion integration are all used in integration. The combination of time is to give time period to data, and carry on the time integration based on it, the integration of attribute is according to the certain attribute, and this kind of multidimensional integration is easy to be analyzed by the analysis tool in SDW.

3.5. Analysis Result or Knowledge

The goal of SDW is to provide support for SDSS, whatever we do at first, we must got the knowledge for SDSS at last, in the process of analysis, the knowledge base and method base are used for reference and the signal system is used to present knowledge.

In this part, we've had a look at the information flow and structure of SDW, but how these flows were realized? we'll explain it in the following part.

4. Key Techniques

The construction of SDW is a big, complex and progressing system project, the realization of it relies on the realization of some key techniques(Joyce Bischoff, Ted Alexander，1998), we'll give a concise illustration of them in the following parts.

4.1. Fast Computation, Broadband Transportation, Mass Storage

Vast amount of information in SDW require mass storage techniques, to support SDSS, vast amount of information must be accessed, lots of data mining and vast amount of data must be transport thorough the network. All of them require fast computation, broadband transportation and mass storage,

Fast Computation: before the emergence of computer, the work done by theory and experimental scientist are limited in computing ability. But what they research on is either too short or too long, either too fast or too slow, it becomes very difficult for them to make experiment. But the computer's computing ability has brought the resolution to these kinds of things.

Broadband Network: the information of SDW is distributed across the whole intranet/internet at different places, they are not stored in a same big database, and this means these different place must be connected through fast network, i.e., broadband network.

Mass Storage: the information collected has amounted to Pbytes, everyday the amount is growing with several hundreds Tera-bytes, to collect these information, we need mass storage.

These are the hardware requirement of constructing SDW, the technique today has been able to provide enough ability for SDW use, e.g., The current computation ability has grown up to 10^{13} MIPS. The bandwidth of Internet will be grown up to 10^{12} bps in a year later. The storage ability has grown up to 20-30 giga-bytes.

4.2. Data Integration

There are different types of Heterogeneity in SDW (section 3.1). Such as, different format and different modals, textual, records in database, image and graphics are all common format. The multi-definition encoding method, spatial referencing, data processing, data quality and data duplicate make it very difficult to integrated them (Lijun, 1998).

Appropriate strategies must be used to manage and store these data for easy use. This can be reach by data integration. The integration can be taken out through multi dimension (section 3.4), multi-tiers (section 2.2).

4.3. Metadata

Metadata is the data used to describe data, the variation of data format and data storage make it important to give good metadata to them for information change and interoperability (Yongping, Zhao, 1998).

The process of the general distributed data is guaranteed by respective standard and protocols. Nowadays, lots of standards have been given to hardware and software. But the standardization of metadata is still on the way, it needs research and correct. Lots of organization has taken part in this field, such as ISO TC/211，FGDC, OGC(1998). They proposed the following contents of metadata.

- Identification information
- Data quality information
- Linear information
- Spatial data presentation information
- Spatial referencing information
- Application characteristics classified information
- Publishing information
- Metadata referencing information
- Application information
- Contact information
- Address information

Apart from the endvour of try to cover all the aspects, attention should be paid to the simplification of metadata information, and the level differentiates of metadata.

4.4. Data Mining

With the development of database and the application of it, the information in database

becomes more and more. Lots of important information, which can be used to support the decision, is hide in the vast amount of data, it is difficult to find them out due to the tools we used before. With the fast development of database and Artificial Intelligence, the data management and the machine study comes together, data mining is generated to extract the information from data.

Data mining is to extract useful, reliable, efficient and new information from vast amount of data; this kind of process is a high level processing procedure. Data mining can be used to support decision-making.

Data mining must be based on the KB and MD as illustrated in Fig.3, all the general spatial knowledge and method together with those from subject-specific should be used for data mining in SDW. The result of data mining will be used as knowledge for SDSS.

4.5. On Line Analysis and Processing

To compensate the drawback of operational process of data in database, people begin to research and develop tools for data analysis processing; E.F.Codd called this kind of processing OLAP (On Line Analysis and Processing). It can help analyst, manager and executives to access the information in a fast, interactive, consist way. The goal of OLAP is to feed the need of decision made, the core of its' technique is dimension, in this way, OLAP can be called a collection of multidimensional analysis tools (Shan,Wang, 1998,).

The industrial field takes the 12 rules supposed by Codd or Garter and IRI software corp. It is carried on 3-tier c/s structure, it distinguished application logic and GUI from DBMS, complex application reside on the application server rather than reside on different PCs, some server provide high efficient process, arrange backend and excel process. It can be based on multidimensional or relational database, named MOLAP and ROLAP respectively.

OLAP in SDW is based on data mining and many other query/analysis tools to provide fast online processing for high level users of SDW.

4.6. Service and Interoperability

The service SDW provided to SDSS is the efficient way to make decision, these services can be classified into 3 classes, general query service, general management, analysis service and decision supported service.

General query service is the common function almost all kinds of database provided, the different is that it take all of the information in SDW to serve people or application. It is used to generate report and simple statistical table.

General management and analysis service refers to the function used by manager to carry on information analysis to get some managing information. The result of the question is somewhat fuzzy enabled, e.g. what can help our customer to assess different kinds of goods.

Decision supported service is help system simulate the result by given some apart rules, thus help the executives to make decisions. In this way, the power of information system to help decision made can be achieved, and executives can make the decision based on scientific basis.

Interoperability has become an issue with the vast amount of distributed information. The distributed characteristics and heterogiety make it a dream for user but a nightmare for system developer to realize interoperablity. Lots of international organization are striving for this work, such as, OpenGIS(1998)，interoperability can be classified in 6 tiers as illustrated in Fig.6. (Andrej Vckovski, 1998)

All these techniques are vital to the construct of a SDW, before constructing a SDW, it should be made clear, these techniques of a certain subject related to the SDW have been solved. But how to build a SDW? the next section will give a general idea about this.

5. Building a Spatial Data Warehouse

Just as Gary Dodge and Tim Gorman(1998) told us,data warehouse is not a project but an ongoing process. A data warehouse is not a product or set of products but a new way of thinking about the data of an organization. A data warehouse is also not the same as an operational data store. If an organization has unmet reporting needs about the current operational data these needs should be addressed separately and before building a data warehouse. Finally, a data warehouse is not a

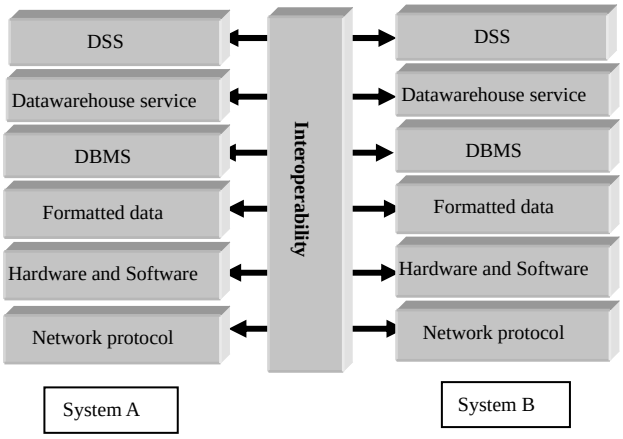

Fig.6 the interoperability tiers in SDW

specific place. It does not replace current application system but is a supplement outgrowth of traditional data processing.

The SDW is just the same way should be looked on as. To build a SDW, an ongoing process is needed. Although it is more than a project, it should be carried on in a project way, in an information system project way. There will be a procedure and some specific problems to address in building a SDW.

5.1. Steps for Building Spatial Data Warehouse

The construct logic of a SDW can be illustrated in Fig.7 (Microsoft, 1998), the data flow of the SDW is showed with a pointer, all these data are maintained with their metadata, the metadata is used by different function component to carry on data flow. These components are managed by the manage system of SDW.

The first thing should be addressed is to interpret the subject of the SDW is to be built. Then the system requirement could be analyzed and extract from the environment. The system design can be give out due to the system requirement, then the system implementation can be carried out. After constructing of a SDW, the work is not over, there are still the people education to provide human resource for SDW and the sustainable development of SDW. To build on and on based on what has been done. So the steps should be understand subject, system requirement, system design, system implementation, people education, and system sustainable.

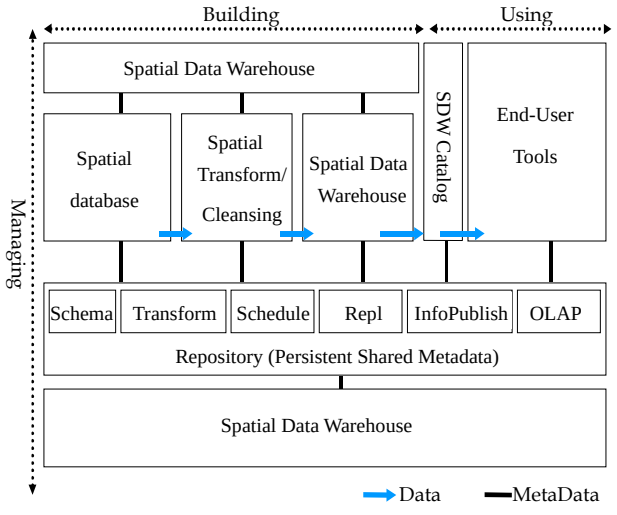

Fig.7 the structure and environment of SDW

5.2. Understand Subject

The first thing to do when constructing a SDW is to understand what subject the SDW is focused on. This process is to contact with the higher level of a company to see what problem they want to solve by the SDW. The everyday work flow of a company, especially the work flow of the executives will be help to construct SDW, it will provide the main topic and related things needed for understanding the subject of the SDW. In this step, the following things should be made clear.

- The main topic of the SDW, e.g., product sales or transportation management
- The related fields, e.g., will the topic relate to production, person, etc.
- The types of users, e.g., the executives, the managers, the accounts, etc.
- The leader of every type of users, e.g., CEO, department manager, etc.

5.3. System Requirement

The second step is to understand the system requirement of SDW, it is vital important to the success of an information system. In this stage, the contact with the user community is widely required. These works are based on the work of the first step. In this step, the following problems should be solved.

- What is the requirement of every type of users of the SDW?
- What is the workflow of every type of users of the SDW?
- What the users want their future end-users tools to be like?
- What have been done about the SDW, especially the operational DB?

5.4. System Design

The 3rd step is to design the hardware and software system for the implementation of SDW. At this stage, it is important to involve the different type of developing people from different fields, hardware engineer, software engineer, system analyst, the future maintenance people of the system. In a word, it is the stage for the technique specialist to play an important role. In this stage, the following things should be make clear.

- The logical structure of the SDW.
- The physical structure of the SDW.
- The model needed in the SDW.
- The existing information system will be integrated into SDW, e.g., the database.
- The hardware environment of the system.
- The hardware will be added according to the requirement of the SDW.
- The software will be added according to the requirement of the SDW.
- The detail hardware information of the system.
- The detail software information of the system.
- The detail information flow and respective

software structure.

- System function models and realization method.

5.5. System Implementation

After design of the system, the step will comes to the implementation of it. A full-time project team will be organized, it will be classified into several sub-teams. With a clear define of the work of every one in this project team. Who will be the supervisor to maintain the overall progress? Who will lead the sub-teams and who will program? A timetable for the progress of the project will be calculated. In this stage, the following things will comes out.

- The overall operating SDW system and its documents.
- The function model of the SDW and their documents.
- The system test result report and document.

5.6. People Education

The people education should be carry out before the system is transferred to the user. There are different types of users to be educated. The executive will be told how to use the highest but the simplest operational user-tool to help their everyday decision-making. The everyday users of the SDW should be educated to use the user-tool for them and respective maintenance of the system. The system administrator should be educated to understand almost all of the system.

5.7. System Sustainable

The companies are developed very fast, the decision support will become more and more difficult and complex with the development of the companies. So the SDW will be upgraded from time to time to meet the requirement of the development of the company.

All these steps are important to the constructing of a SDW, but always keep the following things in mind will help the success of the SDW.

- An identified, involved user community
- Executive sponsorship
- An efficient project team
- Quick, small, incremental success
- An architecture environment

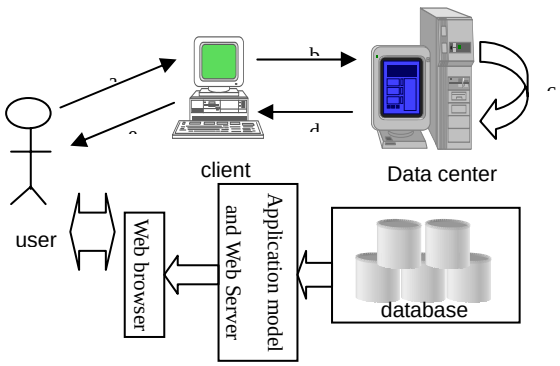

Fig.8 system structure of ecological evaluation system of yunnan province.

5.8. Ecological Evaluation System of Yunnan

In order to protect the ecological system of YunNan province in china. The government needs to construct an ecological evaluation system. Based on this background, the evaluation system is constructed.

The system is composed with the county map with the scale of 1:1,000,000 and five thematic databases: hydrology, soil, population, and desolation area and forest area database. In this system, the data center strategy is used. The DBMS is SQL Server 7.0, the SDE is WebGIS, as illustrated in Fig. 8.

The system can be accessed anywhere only if user can have access to Internet by http://www.cybergis.net.cn/yn/yn_main.htm. GUI is constructed with 3 parts(Fig.9), map browser, thematic map layer and the result area, the user can select any county on the map and click the "查询" button, the evaluation result and related factors will display on the result area.

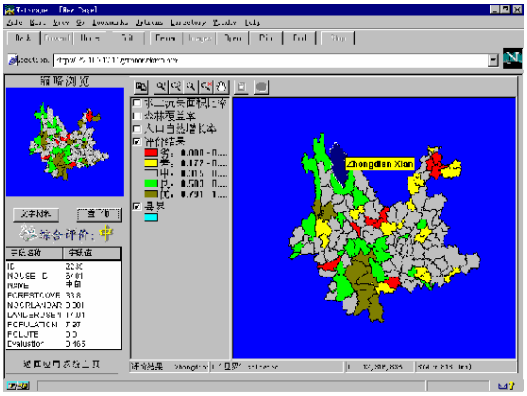

Fig.9 the running GUI of ecological evaluation system of yunnan province

6. Conclusion

In this paper, the environment of SDW is discussed, then the structure and respected information flow, key techniques and how to building a SDW is discussed. The SDW is far from mature, many effort should be put on the techniques discussed in section 4.

References

Al，Gore，1998, Digital Earth: Understanding Our Planet in the 21st Century, Given at the California Science

Center, Los Angeles, Califoria, on Juanuary 31, 1998, http://www.digtialearth.gov/speech.html

Andrej Vckovski, 1998, Special Issue: Interoperability in GIS, International Journal of Geographical Information Science. 12(4)

Delvin Barry, 1997, Data warehousing: from architecture to Implementation, Addison Wesley Longman, Inc. 1997

Gary Dodge, Tim Gorman, 1998, Oracle8™ data warehousing, wiley computer publishing, 1998

Harjinder S.GILL，1997, Datawarehouse-C/S Computing Reference, Tsinghua University Press，1997

Inmon W H 1996, Buiding the Data Warehouse, 2nd edition, John Wiley, 1996

Jiang Zeming, 1998, People Daily 6, 31, 1998

Joyce Bischoff, Ted Alexander，1998, Datawarehouse Techniques，Electronic Industry Press

Li, Haochuan, 1998, Thesis, Peking University

Li, Jun, 1998, Thesis, Chinese Academy of Science

Li Qi 1998, http://www.cybergis.net.cn/

Li Qi, Yang Chaowei etc. 1999, Research on WebGIS, Chinese Journal of Image and Graphics, Vol.4(Supplementary Issue of Digital Earth):106-108

Li Qi ，Yang Chaowei and Chen Aijun, 1999, Research on Geographical Relational Database Model in WebGIS, Chinese Journal of Image and Graphics, accepted

Microsoft, 1998, Microsoft SQL Server 7.0 Data Warehousing Framework, Microsoft White Paper, 1998

OGC, 1998, OpenGIS Abstract Specification. Version 3

Ralph Kahn et. al. 1999, http://digitalearth.gsfc.nasa.gov/Scenarios199902.htm

Shan,Wang, 1998, Techniques and On-Line Analysis Process, Scientific Press

Xu Guanhua, 1999, Pay Much Attention to the 'Digital Earth', weekly science news, 1(1999)

Yang Chaowei, Li Qi, 1999, Spatial Data Warehouse in Digital Earth, Chinese Journal of Image and Graphics, Vol.4(Supplementary Issue of Digital Earth):58-62

Yang Chongjun 1998, http://www.digitalearth.net.cn/

Yee Leung, 1997, Intelligent Spatial Decision Support Systems, Springer, 1997

Yongping, Zhao, 1998, Thesis, Peking University