Cadastre 2014 – From Vision to GIS

Carsten BJORNSSON, USA

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SUMMARY

This paper presents suggestions on how to proceed from a Vision expressed in a scheme to building a physical GIS database. It focuses on three main areas namely expression of a physical design for a GIS database, supporting multi user environments and finally provides suggestions on what to consider when making data public available using Web Services. In designing GIS databases discussions are promoted on defining spatial relationships between object classes. Multi user support in enterprise environments discusses options for versioning and disconnected editing. Web services introduce openness and interoperability. Throughout the paper suggestions are made on what to consider when designing GIS databases.

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1. INTRODUCTION

With the Cadastre 2014 initiative the traditional Cadastre transforms from a description and registration of parcels to include description of the complete legal situation on the land including public rights. It proposes (Kaul and Kaufmann, 2003; Kaufmann and Steudler, 1998):

- That an inventory of data concerning all legal land within a certain country or district is methodically arranged in land objects defined by either private or public law (This presumes including all elements of civil, common and statutory law where those exist);
- That the definition/outline of a land object is either based on survey of object boundaries or through other means of boundary definition like legal descriptions of boundaries;
- That land objects are systematically identified and arranged in groups of legal land objects each sharing the same characteristics namely the legal aspect that defines them;
- That the outlines of the property, the identifier together with descriptive data, may show for each separate land object the nature, size, value and legal rights or restrictions associated with the land object;
- That land can be modeled using multiple representation of land objects each identified by unique group definition;
- That in identifying land through land objects, relationships can be established between land objects or groups of land objects;
- That any Cadastral system no longer should be seen as individual and isolated but rather being a part of a larger group of systems receiving and contributing with Cadastral information.

The sharing of Cadastral data and models across multiple systems allows for integration between maps and registers. The perception of maps is changing from maps being legal documents storing information to temporal, user defined representations of the cadastral object model. From the cadastral object model maps can be created at different scales and registry data in different forms/reports.

1.1 GIS evolution

During the last decade Geographic Information Systems (GIS) has evolved from PC based applications, with georelational file structures, into enabling spatial data to be stored in relational databases and accessed through Enterprise wide application services with the ability to:

- Define, manage and maintain spatial and spatial related data sets and their relationships;
- Visualize information and generate cartographic products;

- Analyze geographic data sets to create derived information;
- Support query-based information services;
- Share data with other systems through industry specified interchange and communication standards.

With its ability to design and implement database schemas with spatial objects, their spatial and associated relationships, main and strong use of web services for data publication GIS technologies has matured to fit the vision of Cadastre 2014. Developing methods and technologies to accommodate the recommendations of the Cadastre 2014 represents the real challenge for the Cadastral communities.

1.2 Designing the GIS database

From a GIS perspective the design of any GIS database initially involves three steps (Arctur and Zeiler, 2004):

- The first step is to verify the conceptual design, which involves the identification of the products that will have to be produced by the application. What are the information requirements and what would be the key spatial and spatial related objects to represent these requirements?
- The second step is the logical design, which involves the definition of the tabular database structure and behavior of descriptive attributes, spatial properties of the datasets and preliminary GIS-database design.
- The third step involves the physical design, which implements, reviews and refines the preliminary GIS-database design and further defines workflows to conform to the organizations business practices.

The Cadastre 2014 is expressed as a cadastral object oriented model and represents a generic formulation of best practices within the Cadastral community. As such it expresses parts of the conceptual and logical design in the GIS database modeling process. Being a generic model however it represents an excellent starting point for defining a modern cadastre but likely needs to be adapted and modified to the individual needs of any Cadastral organizations. This presentation suggests three areas to consider when moving from vision to physical design of the Cadastre 2014:

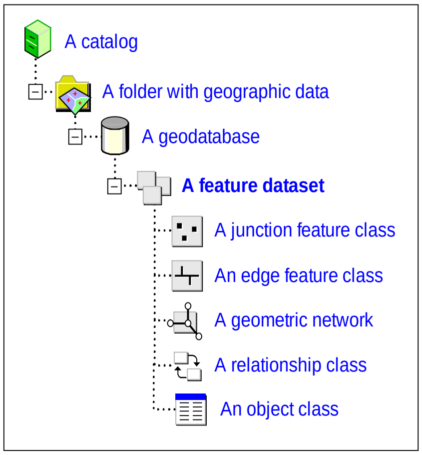
- Develop a physical design;
- Support for multi user environment;
- Openness and Interoperability.

2. DEVELOP A PHYSICAL DESIGN

A GIS database is different from an ordinary database structures in its ability to work with spatial objects and spatial and associated relationships. Designing a GIS database scheme from the Cadastre 2014 vision should include options to define:

- Spatial associated objects like parcel owner name, zoning restrictions, rights obtained through common law, conveyance;

- Spatial objects like point, lines, polygons, annotation or dimensions outlining monuments, survey boundary lines, parcel identification, measurements;
- Subtypes for optional grouping of objects within an object class or table with common domains or topology rules;
- Relationship classes to manage thematic relationships between spatial associated objects (tables), spatial objects or a combination like parcel to owner identification, survey point to coordinate;
- Topology for describing special relationships between spatial objects like Survey Boundary shares boundary with parcel;
- Rules to define legal attribute values, thematic relationships between objects/classes, topological relationships between spatial objects or subtypes like range values for measurements.



Cadastre 2014 was developed through an object oriented modeling approach using the Unified Modeling Language (UML) syntax. The UML syntax can be used to define object classes with spatial representation (point, line and polygons), subtypes and associated tables. UML however does not include syntax to describe spatial relationships like topology rules and spatial relationship classes.

2.1 Defining spatial relationships

A spatial relationship defines relations between spatial objects like the boundary of a zoning district is determined by the boundary of parcels, which again is defined from the survey boundary line. Modeling of spatial relationships can happen through general association between object classes, topology rules that determine the topological integrity of the object data and network structure like cadastral networks. Associated relationships are typical defined as joins or relate associations being either defined in the GIS database design process or generated ad hoc during user interaction with the GIS database. After building the initial GIS database with classes and associated relationships (using UML schema) GIS software allows for the definition of topology rules to validate the spatial integrity of data. Topology rules can be either permanently defined in the GIS database or created on fly during a user editing session. A third type of spatial relationships is reference established between objects in a point class and objects in associated point, line or poly object classes. In a Cadastral GIS database the location of monuments can be determined from either field measurements like terrestrial survey or Global Positioning System. In either case monuments are defined by a physical reference to a coordinate system. Monuments define survey boundary lines, which again defines parcel boundaries. Any change in the location of the monument will be reflected in its dependencies, which will update their own location. More popular this type of relationship has been termed survey linking. In the GIS database this can either be modeled through permanent relationships, which are rather resource intensive, or through on-the-fly computation of displacement vectors.

2.2 Defining topology

Within GIS topology has moved from a traditional stored topology being a spatial data structure ensuring format consistency to a rule based topology represented by a collection of tools and techniques for modeling consistency between different spatial objects and supporting different types of relationships between these. Stored topology has been used to ascertain that spatial data structures were consistent and had a 'clean' topological fabric like polygon closes and lines were snapped together. All topology rules for point, lines and polygons were stored in table structures. Any updates to the geometry of the spatial objects would require either geometric modifications of individual objects based on user defined settings and/or an update of the point-node topology. These updates included an update of all content in each tables defining the stored topology. Another shortcoming was the inability of the model to support intersecting lines without creating a split. An example is survey measurement lines which can intersect without splitting lines into segments.

Alternatively a topological relationship between spatial objects could be expressed by topological rule like: "A legal description polygon object **must share boundary** with a surveyed boundary line". Rule based topology validates spatial relationships on the fly and provides tools to manage shared geometry between spatial objects and flag any inconsistencies hereby maintaining the referential integrity between objects. Once established it only verifies rules on altered objects in participating object classes and hereby minimizes the load on the database when checking the rules and updating the object geometry.

When defining a topology, spatial object classes that will participate in that topology will have to be associated to the topology. Topologies can contain one or more spatial object classes whereas a spatial object class only can participate in only one topology. Using topology to maintain shared geometries cluster tolerance, ranking and topology rules can be defined.

- Cluster tolerance, is the distance range in which all vertices and boundaries are considered identical or coincident between two spatial object classes. Vertices and endpoints falling within the cluster tolerance are snapped together.

- Ranking is defined at an object class level, and controls how much the objects in that class can potentially move in relation to objects in other classes when a topology rule is validated. The higher the rank, the less the objects may move in relation to objects from other classes. For example, a topology is defined with two spatial object classes: parcels and survey boundary lines. These two object classes need to be coincident, but in some cases they are not. In the cases in which the object classes are not coincident, the parcels should move and snap to the survey boundary lines. To accomplish this, the parcel lines are given a lower rank than the survey boundaries.

- Topology rules define a condition in the topology, which is a problem or possible problem in the topology objects. Topology rules can be defined for the objects within an object class or alternatively for objects between two object classes.

Dirty areas are associated to a topology and represent regions where the spatial objects participating in the topology have been modified (added, deleted, or updated) spatial integrity of the topology has not been validated (Hoel et.al, 2003). When a topology is initially created the full extent of the spatial object class is regarded as dirty area and needs to be validated according to the topology defining them. Validation is a process that manages object geometries and identifies violations in the defined rules. Based on the cluster tolerance and ranking, objects are snapped together and aligned based on an underlying integer grid ensuring that coincident points stays coincident. After geometry updates topology rules are verified and any violations are marked as errors. Once an error has been identified it is up to the user to correct the error or mark it as an exception. Errors can have three states:

- Leave the error unresolved in the database;
- Fix the error with available tools;
- Mark the error as an exception.

When marked as a legal exception subsequent validations of the objects will not regenerate an error. Allowing errors to exist and persist in the GIS database creates an environment in which many diverse workflows can be applied. Because errors are stored in the database users have the option of saving edits (as well reconcile and post – see versioning) without fixing the errors. This topology structure supports a variety of workflows and allows objects to be displayed without having to validate them.

One advantage of the shared geometry approach is that when polygon objects are stored as closed rings, meaning that the boundary between polygons is stored with each polygon object coincident boundaries can easily be generated on the fly. Edits to one shared boundary will then affect other shared boundaries. Compared to query performance from traditional stored topology structures this on the fly discovery of shared geometries has proven to increase performance significantly. Further storage through shared geometries makes editing more flexible.

2.3 Queries and Indexes

One important thing to note when designing a GIS database is to ensure its ability to maintain performance during different loads. Careful analysis has to identify what queries, being spatial and non-spatial, are necessary to execute against the database and estimate the effectiveness of those queries from a load perspective. A simple example, to stress the point, could be to manage error estimates for a given survey measurement. One design approach is to store all error estimates for a given survey with each individual measurement record in measurement table. Every time an error estimate for a given survey has to be updated a SQL SELECT statement will have to identify all the measurements belonging to that survey and UPDATE the relevant fields in each record with the new value. Through normalization a Survey Meta Information table can be defined storing error estimates for each survey in one record. Updating error estimates now only requires selecting and updating one record. During the physical design process of the GIS database prototyping and testing of performance and scalability running scenarios with expected data load and simultaneous user access is an utmost necessity. The point is that improper database design can have huge performance and scalability implications potentially failing projects.

Once a solid database design has been developed and tested using the main queries (as well as a sampling of the organizations project data), indexes can be introduced into the physical design process to further optimize the performance of the queries against the GIS database. Indexes allow speeding query performance of commonly used columns and thus improving the overall speed of the database. Indexes are pointers to the individual fields in records which supports fast retrieval of data from queries. Two types of indexes are: Clustered indexes and non-clustered indexes. The clustered index represents a physical sorting of the rows in a table allowing for only one clustered index per table. The non-clustered indexes are created outside the database table and contain a sorted list of references to the table itself. It is worth noticing that non-clustered indexes will affect the performance process of the database when doing inserts and updates. For this reason it is important during the design phase to test queries to be implemented to verify and tune indexes in the data model. Some GIS software allows for the creation of indexes to object classes and associated tables during the physical design process of the GIS database. To further enhance performance indexes and spatial indexes are often generated default by the GIS software when generating GIS databases from the database schema.

3. SUPPORT FOR MULTIUSER ENVIRONMENT

Cadastral systems have a potential to develop themselves towards large enterprise systems managing and associating itself with a variety data. Many types of users will be associated working with information from the Cadastre from collecting field data, to manage, use and publicizing cadastral data through either map services, intra net or web applications and portals providing information to public and professional communities. Each of these users will have different needs and requirements to the interaction with the cadastral system. Thus the system will have to support maintainability, scalability, usability and interoperability.

3.1 Scalability of the GIS database

Two technologies are currently competing in introducing GIS enterprise systems being either database vendor driven and GIS software vendor driven. The database vendor driven developments are based on traditional database design where a number of tables are established and different vendor applications maintain the relationships. In this configuration most of the processing load is placed on the data server with little load on the application server. In a small scale (large) multi-user environment this approach could lead to an overload of the database server. In the GIS vendor driven approach the load is balanced between the client server(s) and the database server(s) thus optimizing processing time when doing querying. If performance is an issue and the number of records in a table is less than 10^8 a binary structure in the database schema will provide some advantages. The binary structure compresses data into a single row structure thus providing lesser data volume. Having data in a single row further optimizes performance since data will not have to be processed out of a VARRAY structure or from multiple rows as would be the case with complex linear or polygon data as could easily be the case with Cadastre 2014. If data corruption is a concern GIS vendor drive server technology performs integrity checks of the data through business rules in the application. This environment maintains the integrity of the object geometry, which cannot be destroyed through SQL statements that may be executed directly against the database.

3.2 Scalability of user environment

An enterprise cadastral solution must provide support for many users creating and updating large amounts of geographic information. In providing this functionality, the editing environment must have the capability to support edit sessions that typically span longer periods, undo or redo changes made to the database, and a facility to monitor how data and the database have evolved over time. The established workflow processes for many cadastral applications are based on a cycle of job definition, -execution, -approval, and -maintenance - processes that requires many people to simultaneously edit data in an environment that allows them to make those changes visible only to those who have an interest in seeing them. Any GIS solution for a Cadastral system should approach long transaction and history management and be capable of supporting this type of project workflow in a simultaneous fashion.

Due to the inherent connectivity and spatial relationships in the Cadastral 2014 vision a more flexible approach is required to multi-user editing, which does not depend on row locking tables. This is so, because the types of edits typically done on spatial data may introduce lock escalation and deadlock situations, which would ultimately degrade performance. The following provides an example. Although related to surveying it serves well as a general example. Suppose there are two editors both working on a cadastral network. One editor makes changes to one of the object classes involved in the cadastral network; the observations of a survey boundary line, while another editor updates spatial elements of a related object class; applying GPS observation to a monument (Survey points). Changes made to objects in either object class could have an adverse effect on objects in the other. For example, GPS observation on a point could move the survey boundary line. In a row locking environment this situation could introduce lock escalation (when row locks become page locks, page locks become whole table locks), and deadlock situations (where two transactions are waiting for each other to unlock data, preventing any further updates to the data until the deadlock is resolved). This can have a huge negative impact on database performance and scalability. Once committed to the database, such transactions are also difficult to undo, because the database has only one state—namely the most recently committed transaction.

An alternative approach is to implement an optimistic concurrency data-locking model called versioning, which means that no locks are applied to the affected features and rows during long transactions. Versioning involves recording and managing changes to a multi-user GIS database by creating a ‘version’ of the database— which is an alternative, independent, persistent view of the database that does not involve creating a copy of the data and further supports multiple concurrent editors. A version is a type of virtual workspace, and typically could represent a job or a historical snapshot of the database. As the changes made to each version are recorded independently, versions are unaffected by changes occurring in other versions of the database—editors can simultaneously update the features or rows in one version without explicitly applying locks that would prohibit other users from modifying the same data in another version. Once the edits in a specific version are complete, the editor will submit them for posting to the master version, which constitutes the production database. During the posting process edits from the version (or virtual workspace) will be reconciled with the production dataset and potential edits posted from other version.

Although the absence of row locks introduces the inevitability of editing conflicts, versioning makes it easy to detect and resolve those conflicts. In real-world editing situations, conflicts are the exception rather than the norm. Given the small number of edits in comparison to the volume of data stored in a GIS database, the overhead of resolving these conflicts is relatively minor compared to the restrictions of prohibitive data locks or having to check features out of a central database to some local repository for the duration of a long transaction.

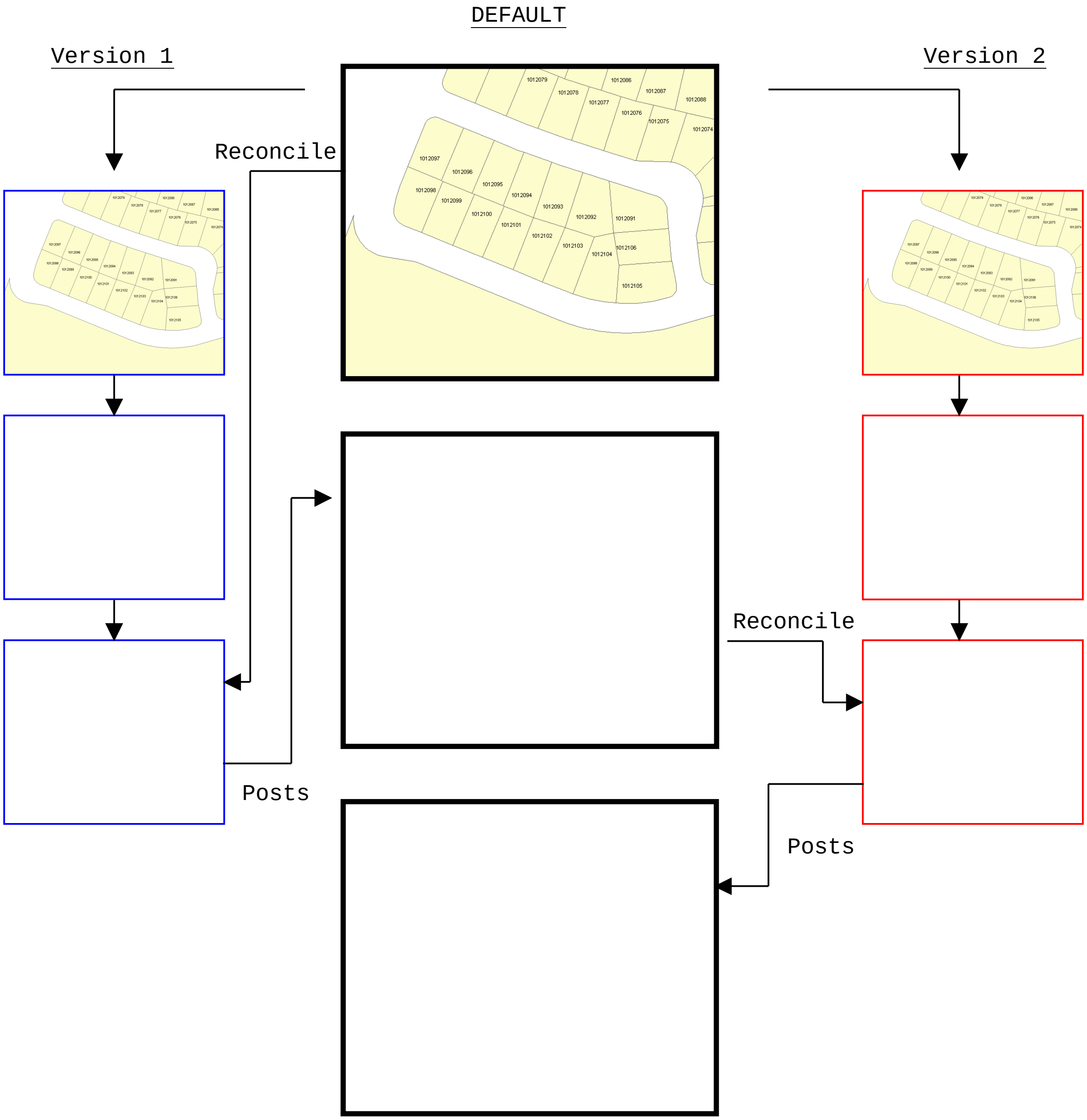


Fig. 1 *Two versions, Version 1 and 2, are created from DEFAULT. In Version1 two parcels are merged into 1 parcel. Version 1 is reconciled for changes in DEFAULT and posts it changes which then become DEFAULT. Two new parcels are added in Version 2 and Version 2 is reconciled with DEFAULT. Since a change has occurred to DEFAULT this change is reconciled into Version 2. No conflicts are detected and Version 2 is posted and becomes DEFAULT.*

3.3 Disconnected editing

In supporting users another important design aspect is to determine how work processes will take place. Will users access the cadastral system online or is there a need for some users to work disconnected from the system. Disconnected editing is a concept that supports a system architecture where users inside an enterprise database are connected from the field or regional offices through a WAN or LAN. Maintaining an open connection for these remote users is either impossible due to physical constraints or will carry to heavy a load on the network increasing the interaction time with the system. Disconnected editing allows these users to edit an enterprise GIS database while physically being disconnected from the database server. Users generate a version in the enterprise database. The version is checked out and extracted to a local machine. The user performs edit operations and once connected to the enterprise system all changes are reconciled and posted back to the enterprise database.

4. OPENESS AND INTEROPERABILITY

The Cadastre originally had the focus, with rare exceptions, on individual, organizations. With the recommendation of the Cadastre 2014 the focus is on the integration of spatial data and analysis in the mission-critical business processes and work flows of the enterprise and on increasing the return on investment (ROI) in GIS technology and databases by improving interoperability, decision making, and service delivery. The cadastral model thus needs to support interoperability to be able to exchange information to share and transfer this information between organizations with different standards and software.

4.1 What is openness?

An open Cadastral system should allow for the sharing of geographic data, integration among different GIS technologies, and integration with other non-GIS applications. As discussed it should be capable of operating on different platforms and databases and scale to support a wide range of implementation scenarios from the individual contractor or mobile worker using GIS on a workstation or laptop to enterprise implementations that support hundreds of users working across multiple regions and departments. An open GIS should expose objects that allows for the customization and extension of functional capabilities using industry standard development tools.

A Cadastral chief surveyor, for example, would expect a Cadastral enterprise GIS solution to provide a spatial data warehouse supporting shared spatial data and services across multiple agencies such as tribal land, environmental protection, water rights, mining claims, and information technology (IT). Each agency might also have a local GIS database to update and maintain the framework data for which the agency is responsible and provide an e-government portal for public access. Today's "always on" availability requirements and the growing security considerations also dictate that any GIS solution operate in clustered, high-availability environments and be easily replicated to remote backup server locations.

4.2 What is interoperability?

Many organizations need a cadastral solution capable of integrating services and data from multiple sources and in different formats. Any GIS technology and products must support this level of interoperability. Spatial data within a Cadastral system should be easily accessible by other technologies and applications through data converters and direct read access like Spatial Data Transfer Standard (SDTS), Vector Product Format (VPF), imagery, computer-aided design (CAD) files, digital line graph (DLG), and TIGER®. Of equal importance, a cadastral GIS application should enable organizations to share services and communicate across different vendor implementations. An open, distributed, and networked GIS architecture provides the framework for sharing data and services.

4.3 Metadata

To build a strong spatial data infrastructure, metadata is crucial. Metadata and metadata servers should enable users of a cadastral system to integrate data from multiple sources, organizations, and formats. Metadata for geographical data may include the data source, its creation date, format, projection, scale, resolution, and accuracy. Some GIS vendors allow users to create, manage, and edit metadata stored in an XML representation of Federal Geographic Data Committee (FGDC) Content Standards for Digital Geospatial Metadata or of the ISO 19115 Metadata Standard. Metadata Services should be established to enable users to create a central, online metadata repository which facilitates publishing and browsing metadata over the Internet.

4.4 Web services

A cadastral publication solution based on Web services avoids the issues and complications of a Cadastral applications being tied to the spatial schema of a specific RDBMS vendor and allows GIS vendors to manage their own data using the best methods and formats for their tools in whatever database environment they choose. In addition, Web services allow server-to-server sharing of data and services, as opposed to integration only happening at the client level as it does with standards that are focused on the DBMS. Some GIS vendors choose to use an RDBMS with schema and methods that perform optimally for their tools. Others use file systems. Web services provided by GIS vendors means that each organization can build and manage its own GIS data and readily provide GIS services (data, maps, and geoprocessing) to a larger audience in a common environment. Web services provide a framework for fusing computing devices via open networks (the Internet, wireless, and local networks). In Web services, computing nodes have three roles: client, service, and broker. A client is any computer that accesses functions from one or more other computing nodes on the network. Typical clients include desktop computers, Web browsers, Java applets, and mobile devices. A client process sends a request to a computing service and receives results for each request. A service is a computing process that awaits requests, responds to each request, and returns a set of results. A broker is essentially a service metadata portal for registering and discovering services. Any network client can search the portal for an appropriate service. Server and broker technologies are typically used on UNIX, Linux, and Windows platforms. Web services can support the integration of information and services that are maintained on a distributed network. This is appealing in organizations, such as local governments, that have entities or departments that independently collect and manage spatial data (e.g., surveys, land records, administrative boundaries). At the same time, many of the functions of a local government require these data sets to be integrated. The use of Web services (a connecting technology) coupled with GIS (an integrating technology) can efficiently support this need. The result is that the various layers of information can be dynamically queried and integrated, while at the same time the custodians of the data can maintain this information in a distributed computing environment.

4.5 Communication

With the introduction of Web services, standards providing interoperability needs to be supported. Distributed multi vendor GIS services can be dynamically integrated into applications using the interoperable standards of XML and SOAP. Adapting OGC's Web Map Service (WMS) and Web Feature Service (WFS) connectors enables GIS to provide Web map services that adhere to the OpenGIS® Web Map Service Implementation Specification. The OGC WMS connector produces maps of georeferenced data in image formats (PNG, GIF, JPEG) and creates a standard means for users to request maps on the Web and for servers to describe data holdings. The OGC WFS connector enables GIS vendors to provide Web feature services that adhere to the OpenGIS Web Feature Service Implementation Specification. The connector provides users with access to geographic (vector) data, supports query results, and implements interfaces for data manipulation operations on Geographic Markup Language(GML) features served from data stores that are accessible via the Internet. GML is an OpenGIS Implementation Specification designed to transport and store geographic information. It is a profile (encoding) of Extensible Markup Language.

5.0 CONCLUSION

Implementing Cadastre 2014 represents just the beginning. Current GIS technology provides a variety of options for implementing a robust land records management system; as it should. A core cadastre data model should be the foundation of a system built upon industry standards and interoperable information technology. While the model needs to be flexible, adaptable, and extensible (Lemmen, et.al.), as represented in the Cadastre 2014 Data Model, there are other technical issues to be addressed as land administrators approach the design and implementation of such a model. Regardless of the GIS or database product chosen, whether open source or commercial, the design and implementation must follow a data modeling process, and support such land records functions as rule-based topology, multi-user access with version management, and interoperability of data and other systems. Finally with the mandate and growth of e-government, the Web has become the technology, which modern systems must reside, or support for open access to public domain data

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BIOGRAPHICAL NOTES

Carsten Bjornsson is working as a Project Manager at ESRI Professional Services responsible for the Survey and Measurement Management system design and architecture of the National Integrated Land System (NILS) in the United States. Before that he occupied a position as Associated Professor in GIS and Surveying at the Royal Veterinary and Agricultural University of Denmark. Mr. Bjornsson holds a Masters Degree in Surveying and LIS from Aalborg University.

CONTACTS

Carsten Bjornsson
ESRI – Professional Services
380 New York St
Redlands 92373, CA
United States
Tel. + 1 909 793 2853
Fax + 1 909 793 3014
Email: cbjornsson@esri.com
Web site: www.esri.com