Managing Cadastral Data in a GIS

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SUMMARY

The development of the cadastral layer in geographic information systems has until recently been driven by cartography and tax assessment purposes rather than by a demand for survey accurate data. As a result the information in these databases has generated maps that are 'pictorial' rather than spatially accurate. Similarly, the limitations in traditional surveying and GIS technologies have imposed restrictions on the transference of spatial accuracy from survey records into the digital data of GIS. New hardware and software technologies, together with the enormous influence of GPS tools and expertise, have highlighted the need for improving the coordinate accuracy of existing data, and for keeping newly entered data true to its original survey record. These modern advances invite a new era of maintaining and communicating spatial accuracy through GIS.

The technology presented in this paper defines cutting-edge GIS methodologies, a core data model that supports cadastral survey record maintenance, and the ability to maintain spatial accuracy across all layers of the GIS. The traditional parcel base-map is evolving into a cadastral fabric layer for supporting spatial coordinate quality.

Different government authorities have adopted a variety of processes to ensure the survey integrity of their cadastral database and to support the future growth of their GIS. The approach described in this paper offers a path forward, with many operational and business benefits accruing along the way.

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1. INTRODUCTION

When comparing the software technology used in the surveying industry with that of GIS, there are many commonalities; for example, both systems are dependent on coordinate information, both rely on mapping information about the earth, and both display their data in a pictorial form.

Surveyors are well recognized as the earliest contributors to society's spatial information. The ancient cartographers were surveyors, often cadastral surveyors (Brock, 2005)
With the advent of GIS technology in the 1960's, many new kinds of specialized jobs evolved, including the GIS cartographer.

Through time the roles of the surveyor versus the GIS cartographer have diverged; this divergence can be attributed to the technology of digital maps. Though different technology paths have been traversed, it is ironic that new technology is now bringing the paths of cartographer and surveyor back together.

Surveyors have a number of domains within the industry, and may specialize in different areas. The focus of this paper is on the technology geared towards the cadastral surveyor in a GIS environment, or Land Information System (LIS), in this context.

2. SURVEY INFORMATION AND GEOGRAPHIC INFORMATION

2.1 The Surveyor's Mental Model

In the development of a software application, a key design task is the formulation of a *mental model* for the proposed user of the system. A mental model is a description of a person's expectations in a particular environment. It is a description that provides just enough information to make good cause-and-effect predictions. This section provides a description of a surveyor's expectations when working with survey information and geographic information in a digital environment. The mental model is formulated by comparing aspects of survey and GIS software.

2.1.1 Points and Coordinates

In most surveying software, emphasis is placed on points and their coordinates. Each point has a set of attributes: an identifier (ID) such as a point number, or name, X Y coordinates, height values (ground level, finished surface etc.) a type, and so on. To a cadastral surveyor, parcels are defined by the point numbers at each corner. A change of coordinates does not alter the parcel's definition. Two corners are coincident if they have the same ID on the corner point, matching is by point ID, and there is only one point defining the same corner for two or more parcels. The point ID does not change but the coordinate may change based on calculations from sequential measurements that improve the coordinate's accuracy.

By contrast GIS uses coordinates as internalized, unnamed building blocks for representing the shapes of polygon, line and point features represented in the table of a database. This is where the mental model of the surveyor begins to diverge from that of the GIS cartographer. In a GIS, point matching is by position, rather than by ID, and corners of features are defined as coincident if they share coordinates.

2.1.2 Managing Data

Data that is entered into any recording system from survey sources should remain unchanged, this stems from a legal obligation, and general good survey practice. Hand-written field books are archived, electronic files are stored and are not edited. This needs to be emulated in any new systems that record survey information.

There should be a thorough notation of source documents with cross-referencing and distinctions made between derived, calculated, and measured values. For example, coordinates found in survey calculations may be calculated from record and these are explicitly differentiated from coordinates computed by other means. Physical markers defining features in the field have textual descriptions that have legal evidentiary standing, especially in the case of cadastral surveys.

The system should not automatically introduce new data or change existing data through geo-processing in order to accommodate system requirements. Changes in coordinates should be based on sound survey practice.

2.1.3 Coordinate Accuracy

Coordinate accuracy is a metric of how well a published coordinate matches the ground truth position of the thing that the coordinate represents.
To the surveyor's way of thinking, a published coordinate is secondary to *knowledge* about the accuracy of the coordinate. This understanding of coordinate accuracy makes spatial data considerably more useful to all concerned, not only the surveyor. Given the coordinate of a physical feature, one is unable to make an informed decision about its potential use without information about the coordinate's source and accuracy.

Surveyors apply this knowledge also when collecting data; a topographic survey has a different accuracy requirement compared with a cadastral survey, compared with a construction project, compared with a geodetic control network, and so on. The level of accuracy needed for any particular task is foremost in a surveyor's mind, and is a key part of the service provided to his or her client.

Before digital maps, coordinate accuracy could often be implied from the scale of the physical paper map document. When spatial data became digital, this knowledge of accuracy was lost because digital maps allow flexible scale representations. Similarly, the accuracy in a coordinate quoted by a surveyor can be implied by the number of decimal places used, but again, this knowledge is lost when coordinates are extracted from a vast sea of 'computer-quoted' numbers represented to many decimal places. This has created the problem where machine precision is mistaken for spatial accuracy, invoking the age-old surveyor's lecture about accuracy versus precision. (Buckner, 1983) Without some knowledge of their lineage, coordinates for a physical feature cannot be used as absolutes, and are only useful in a relative sense with respect to depiction on a map and the feature's neighbouring coordinates.

Early GIS was first used for the geometry functions that became possible with the new computing power; spatial intersections, buffers, overlays and many other geo-processing calculations introduced the power of visualization to spatial analysis. The focus was aligned towards *analysis* of data at *small* scales rather than *representing* data at *large* scales. (Elfick, Hodson, Wilkinson, 2005) Emphasis was placed in topological relationships rather than in absolute coordinate positions, and so early GIS technology was not designed for the typical surveyor's realm of large scale mapping. As a result surveyors resorted to using modified computer aided design (CAD) systems for this purpose.

3. IMPACTS OF TECHNOLOGY ON LAND INFORMATION SYSTEMS (LIS)

The preceding section outlines what surveyors expect from digital forms of spatial information, in the context of performing their daily business processes. This section outlines a few areas of technology that are beneficial to land information systems and the survey industry, and reinforces GIS technology as a fundamental framework to accomodate the surveyor's mental model.

3.1 Global Positioning Systems (GPS) – versus Local Coordinate Systems

As described in the preceding section the typical surveyor's large scale mapping projects have driven surveyors towards CAD-based solutions.
CAD has been sufficient for surveyors until the advent of GPS technology; accurately surveyed coordinates can now be acquired very quickly in a projected coordinate system, versus being derived through directly observed distances and bearings in a local coordinate system. In addition, the lengths of GPS baselines far exceed the observed distances of traditional techniques. GPS baselines in excess of 20 kilometers are typical, making derivation of accurate coordinates possible over much longer distances, equating to smaller mapping scales than have been typical previously.
Though relative accuracy is still important and will continue to be depicted as lines with distance and bearing between points on survey record maps, coordinates can now be much more easily collected and added in a projected coordinate system. GIS is vastly superior to CAD in handling projected coordinate system data, and modern surveyors can appreciate the advantages to be had from technology that projects coordinate data on-the-fly.

3.2 On-the-fly Projection

Perhaps a more important advantage of projection on-the-fly is that data can be stored in a geographic coordinate system. This is particularly relevant for cadastral agencies that manage and maintain a continuum of spatial information covering large areas defined by a number of different projections.
Rather than storing a set of different datasets for each projection, and then having to duplicate maintenance efforts in areas of overlap, the data can be stored in a single dataset in a geographic coordinate system.
A digital map allows the information to be extracted, visualized and processed in the projected coordinate system of interest, and then converted back to geographic coordinates when stored in the dataset. The data can be maintained in the projection of choice, and areas of overlap need only be handled once.

3.3 Numerical Precision

Because of the smaller scales used in GIS and some data storage restrictions, GIS has used large integer numbers to store the geometric shape information used for mapping the features stored in a table. The available precision for the data is limited by the spatial extent of the dataset. The largest dimension in either X or Y is divided by the maximum possible integer number to determine the dataset's working units. All coordinates are then converted to working units as they are read into the GIS. If the extents are small, the working units may only be small fractions of a millimetre, however the larger extents required for a country-wide system, may define units for the mapped shape at the centimetre range, making their numerical precision impractical for survey-based calculations.

The next generation of the 64-bit integer technology available on new personal computers will start to be used in GIS software in 2006. This will provide numerical precision in coordinate data to nanometre precision, even where the extents of the GIS dataset are the entire earth. Therefore 64-bit systems now provide a numerical precision that allows survey calculations to be carried out directly on the mapped shape coordinates.

3.4 Cartography

Similar to the trend seen in global positioning systems (GPS), cartography is now becoming available to everyone, not just the surveyors and GIS cartographers. (Bahree, 2006)
This makes the role of the surveyor ever more important, as it remains critical to communicate and formalize the information about accuracy for a particular purpose, a fundamental role of the surveyor. Attribute information provided through database tables is a powerful motivator in this regard. CAD was not designed as an information system, (ESRI, 2002), and therefore cannot adequately fulfil this role. Surveyors need much better tools to effectively communicate and manage the information that is currently represented in paper or digital scans of cadastral maps generated through CAD. GIS now provides the technology for such an electronic system.

3.5 Geographic Web Services

The technology for geographic web services have made the availablility of quality coordinate information from respected government survey sources vastly more accesible, providing a reliable path to improving cadastral data represented in GIS, with reduced field survey work, and reduction of cumbersome data retrieval processes. The potential positive impact of this web-trend within the domain of LIS is vast. (Hodson, 1997) The development of standard formats for electronic representation of survey information will further spur electronic submission and processing via web services.

3.6 A Technology Alliance

In 2000 ESRI released Survey Analyst to manage survey datasets within a GIS environment in the form of the Survey Editor. As was true in 2000, the goal remains to have survey information act as trasactions on the GIS data, continually improving its spatial accuracy through time. (Dangermond, 2000) This year the Survey Analyst functionality is being expanded to include a Cadastral Editor, for assembling and managing cadastral networks using data from survey plans that represent cadastral records. This is part of a new generation of software to integrate GIS with survey and land information systems, and has been developed as an alliance between ESRI and Geodata, Australia.

Geodata developed the fundamental computation engine – proven in the industry over the past fifteen years – into a core engine component that ESRI has incorporated into the Survey Analyst – Cadastral Editor software. Geodata provided a solution and concepts for a workflow that ESRI developers have emulated in the new solution for the ESRI *geodatabase* format.

ESRI and Geodata have jointly defined a new XML data format, that allows a seamless communication of parcel data between the geodatabase and the computation engine. The development process has resulted in a new data model for parcels built within a geodatabase, that defines the primitives of a land information system, and that many clients can expand on to incorporate their own specific needs, whether they be in Australia, Canada, the USA, the Phillipines or elsewhere.

ESRI developed the concepts and technology for leveraging the improvements in spatial accuracy of the parcel fabric into the other GIS layers that use the cadastral fabric as a base map. ESRI used a practical approach to using the multi-user geodatabase versioning environment for managing the GIS layer adjustment as well as the least squares adjustment of the cadastral fabric.

The accurate coordinate data available from these new technologies and techniques can be combined with recorded land descriptions to improve spatial accuracy in *geodatabases*. The Cadastral Editor for Survey Analyst provides a simple framework and data model for efficiently performing these workflows. The data model for the cadastral fabric has been designed to support a natural parcel editing workflow experience that fits the surveyor's mental model, and supporting the goal of improved spatial accuracy.

The key elements of the technology are as follows:

- Provides a base-map for parcels as recorded by cadastral surveyors through deeds and subdivisions.
- Improves spatial accuracy of the fabric by processing the legal record information from parcels using a least squares algorithm designed by surveyors.
- On demand, spatially update GIS feature layers that coincide with the fabric.

The new processes provide:

- methods for the direct data entry and analysis of cadastral survey data,
- a data model for representing and managing this dimensional data,
- methods to import, export and update coordinates values in dimensioned cadastral networks and
- methods to apply the effect of movement in coordinates in the cadastral network to feature classes in the GIS.

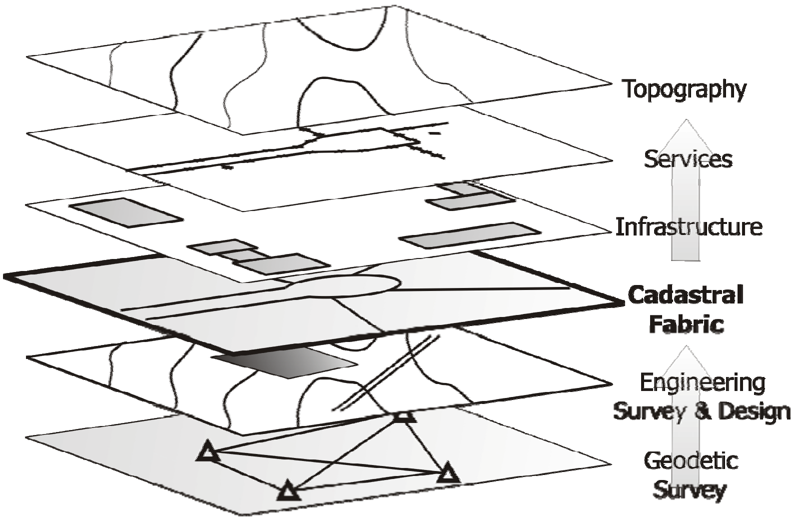

Figure 1: Building a Basemap Layer

The database structure and the methodology for managing cadastral boundary networks are based on systems developed over the last fifteen years by cadastral surveyors in Australia. By integrating these processes within a GIS, the source data (cadastral survey dimensions) can be kept in database tables in a secure environment and at the same time generate and manage a cadastral fabric layer displaying the cadastral boundaries. This builds on the concepts behind Survey Analyst which holds general survey data as the building blocks for GIS.

Other GIS layers are edited using the cadastral fabric as the background reference of spatial control. Since the cadastral fabric may be frequently adjusted with shifts of a large number of coordinates, discrepancies will appear between the cadastral fabric and these layers. The technology provides the mechanisms to allow these layers to be adjusted similarly, thereby maintaining relative positioning.

With this new generation of GIS software it will be much easier for individual organizations to build their own systems directly from accurate survey data and it is likely that systems dependant on digitized maps will become redundant.

4. SUMMARY

4.1 Implications for GIS

Existing GIS systems have been created from digitized maps and plans. Some utility service authorities (power, water etc) maintain a high quality charting system and their coordinate data may be accurate to about half a metre. Elsewhere, boundaries are mainly shown on maps in their approximate location for charting administrative information; the positional accuracy of this data is poor. In all cases, the accuracy of the data is not represented at the level of granularity required to make informed decisions. This information can be calculated and stored in the database for effectively communicating this knowledge.

Because most of the GIS systems in the world have been digitized from small scale maps, the problems flowing from inaccurate cadastral data are widespread.

Over time additional data gets added and processes used to incrementally upgrade the accuracy of the cadastral fabric. The accuracy of a data set is limited by the accuracy of the source data. Adding additional data and adjusting by various means will really only influence the points near to the control and degrade the quality of the new data as it tries to fit in with the old data from digitized maps. However, the data model of the cadastral fabric, and functions available in the cadastral editor, for the first time provide a means to improve the coordinate quality in the GIS.

The knowledge stored in LIS about coordinate data quality, make it easy to identify where coordinates need to be collected by survey methods. This is bringing the powerful analysis capabilities of GIS into the hands of the survey industry.

4.2 Challenges for Managers of Land Information Systems

Accurate position based data poses some challenges. First, there is the difficulty of merging it into existing data sets. While it may be convenient to simply fit the new to the old to minimise the changes needed to existing layers, this is simply putting off the need to adjust layers to match the ground truth position.

If new data has to be fitted to the old until sufficient data is available for a major revision, then the accurate coordinate data should be maintained in the system so that it can be used later to apply in an adjustment.

There needs to be a focus on data quality and the need to hold information regarding its positional accuracy.

It will be a challenge for managers of Land Information Systems to encourage surveyors to use GIS in a dynamic way as part of their day-to-day activities.

4.3 Implications for Surveyors

Traditionally surveyors have provided the base data for maps and plans as well as carrying out a variety of other work for projects of various sizes. Each project, once completed, is filed away as a separate data set. At a later date, if another project is commenced nearby, parts of the old data may or may not be used in the new project and so the cycle continues. Over time, a considerable amount of data is accumulated but its use is limited because of the way that it is held and the isolated nature of each data set.

In the past, it was always easier to measure a line than fix the absolute position of a point. With GPS and other positioning systems such as Glonoss and Galileo the opposite is now true.
The developing GNSS technology which encompasses both satellite and ground based systems can provide centimetre accuracy levels in real time and will completely dominate location based data capture technology in the future.

Surveyors need to take full advantage of this technology and work with geodetic coordinates rather than local coordinates. This will require a different approach as issues like projection scale factors will have to be accommodated; however the long term benefit from having all survey datasets on a single datum greatly outweighs the difficulties.

GIS is now providing the tools and systems to allow its use by surveyors as an integral part of their business processes. It provides a comprehensive data management system that will have long term benefits both in job efficiency and quality assurance.
Modern surveyors and forward thinking GIS cartpographers by embracing this new technology will no longer need to travel separate paths.

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