Mapping Landscape Change: Space Time Dynamics and Historical Periods.

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Abstract Human induced changes in the environment are reflected through time in landscape change. A spatial temporal model can be used to analyse and visualise the rate of change. This paper presents a spatial-temporal application: quantifying and animating a landscape history of the Sydney Region. The space-time cube model is used to create a period based data structure. Fundamental to the structure of the space-time cube model is temporal continuity. In the data structure presented, each cell in the space-time cube is defined by a succession of periods indicating different landscape states. For example the state 'agriculture' maybe be recorded from 1820 to 1951, followed by 'conservation' from 1951 to 1980. The cell record for each period is determined by the integration of historical documentation. In addition to the data structure other GeoComputing principles used in the design of the temporal – spatial database are discussed. Aspects of the design considered include historical data collection and integration, query and display functions, populating the database and updating procedures.

1. INTRODUCTION

The study of landscape change is used to understand man's impact on the environment. Knowledge of previous landscapes informs our understanding of the landscape we have today. The rate of landscape change provides information to analyze issues such as the loss of agricultural land to urban development. Comprehension of landscape change during different periods in history is enhanced by the use of visualisation.

This paper reviews methods of representing landscape change and proposes a practical methodology for developing a quantitative analysis of rates of change and the visualization of this information in a public display and enquiry environment (a museum exhibition).

The impetus for this application lies in the availability of a tremendous amount of historical documentation. These documents are not often valued for the contribution that it can make to the study of landscape change. Data sources are not generally stored or catalogued in a manner that encourages their use, for example maps are often scanned, but not geo-registered, a small step that adds significantly to their usefulness.

The Landscape History model proposed is being developed within the *T*imeMap project (Archaeological Computing Laboratory, University of Sydney). This project has developed tools and methods to present historical information in a space-time context. These tools are used in conjunction with a meta-data clearinghouse maintained by the Electronic Cultural Atlas Initiative (ECAI – www.ecai.org)

A grid-cell version of the Space-Time Cube model (Langren, 1992) is used to describe a period based data structure (see figure 1)

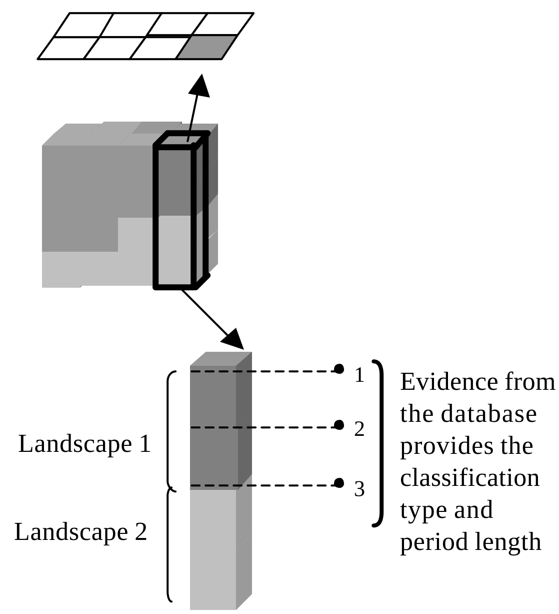


Figure 1: Landscape History Model

Each cell in the model is defined by a succession of periods indicating landscape states. The cell's landscape status is determined using historical documentation stored in an evidence database.

The discussion that follows starts with an investigation of landscape history by presenting the Landscape History model components and requirements. Next is a description of the study area, then alternative approaches to temporal landscape mapping are reviewed. The historical landscape data structure is described, including functions such as populating the database, types of queries and analysis. The paper concludes by considering probable errors.

2. THE INVESTIGATION OF LANDSCAPE HISTORY

The selection of a spatio-temporal model is based on the requirements of the study. Data sources, the classification method, the temporal interval, analysis that needs to be undertaken and visualizations have all been considered.

2.1 Data Sources

Historical documents and related studies provide a wealth of information about landscape change. The integration of various information sources creates a rich database with which to cross-reference and determine the reliability of the sources.

There are three main sources of data: digital spatial data, images and text. Each type calls for a different methods of preparation for inclusion into the model.

2.2 Classification

The cultural-landscape units used for classification in this study are based primarily on land use. The modification to the land use approach includes a focus on cultural elements in the landscape and landscape conversion, rather than modification. This method allows for mapping across different cultures and time periods. Classification types used are:

Aboriginal dominant, Industry, Grazing, Conservation, Agriculture/Horticulture, Abandoned, Infrastructure, Urban, Commercial/Infrastructure mix.

2.3 Temporal Interval

Each piece of historical documentation is time stamped by the year that it represents. (E.g. A land granted dated February 1793 is time stamped as 1793.) The time increment used for analysis is one year. The model could accommodate other intervals with minimal changes.

2.4 Analysis and Queries

Analysing the rate of landscape change is achieved through a series of site based historical queries. In addition to this, the history of a selected site and the historical sources that support this history must be accessible. The Landscape History model focuses on the recording of historical events, allowing assumptions about change to be tested and irregularities identified. The following list is a sample of site and area queries.

- What area does this data source cover?
- What data sources fall within this site?
- What landscape classification changes has this site undergone?
- What was the landscape composition at a given time?

In addition to the simple queries above more complex queries are also expected. Examples are:

- Select all cells with the classification value ‘infrastructure’ in 1855.
- Select all cells that changed from classification ‘agriculture/horticultural’ to ‘urban’.
- Select all cells that where classified ‘industry’ in 1945 that have since become ‘urban’.
- Show the change in landscape between two given times.

2.5 Visualisation

An additional aim of the work is to support the visualisation of landscape change through animation and queries based on user-selected sites. The ability to display change and to query user selected sites is required as part of an interactive public exhibition.

3. THE STUDY AREA

The study area is the Sydney Region of New South Wales, Australia. This region has undergone significant landscape change subsequent to the arrival of Europeans in 1788. The time period selected is from 1780 to 1980; the period after 1980 is well covered by other studies using modern data sources such as satellite imagery. The need to integrate historical data sources past 1980 is not as pressing due to access to modern data sources and modeling techniques.

The cell size used in this study is 50m, equaling 1.3 million cells over the Sydney region. It is estimated that each cell undergoes three to four landscape conversions during the period 1780-1980, generating a table with four to five million records.

4. SPATIO - TEMPORAL REPRESENTATION

A great deal of research has been undertaken on temporal mapping. A review of alternative models is presented before discussing the application of the Space-Time Cube model.

4.1 Snapshots

The Snapshot approach (Langren, 1992) uses a series of selected times to create a model of landscape change, it does not store the change events between snapshots (Hornsby and Egenhofer, 2000). Research in this area is looking at ways to interpolate changes between snapshots (Halls and Miller, 1996), but the ability to access historical event data sources is lacking. The selection of snapshots at critical times is flawed as it leads to pre-conceived ideas of what is critical (Hoinkes and Mitchell, 1994).

4.2 Cellular Automata

The cellular automata method (Clarke 1997) has been used in landscape change studies to generate urban growth models. The cellular automata method does not support drilling down to historical sources, which is a requirement of the study. Historical sources are, in general, used for model calibration purposes and the method generally focuses on one classification type, i.e. the cell is either urban or not. In the study presented the cell can be one of nine landscape types. There are, however, developments to move cellular automata beyond the single classification stage (Candau et al, 2000).

Cellular automata's reliance on rules to model changes in the landscape reduces the importance of actual events. For example, slope limitations are often used to indicate building restrictions. Historically people have been known to build in inappropriate places. Technology has also allowed for building to occur today in places that could not have been considered 50 years ago. Rules therefore need to include a temporal component to deal with these changes. In addition, the underlying geology and the general stability of an area can govern the role that slope plays in land development. For example, the Sydney region is considered a low earthquake risk area and building areas differ from those areas of high earthquake risk. Rules therefore become site specific, with new rules required for each site analyzed. Finally, development does not always follow logical rules; other factors such as politics play a role. Cellular automata's focus is developing rules for modeling and then predicting change.

4.3 Display and Query of multiple themes and datasets

This approach is generally used to retrieve and display a variety of data types. An example of this method is the STEM (Spatio-Time Environmental Mapper) (Morris et al, 1999). The mapper provides a visual and temporal method of querying land – ocean interactions.

4.4 Space-Time Composite

This method decomposes objects and records temporal changes by the grouping of these objects. An example of this approach is the SIIASA/CHINA Historical Project (Yates and Crissman, 2001). Event based applications often use the space-time composite model (Hornsby and Egenhofer, 2000). The Space-Time Composite is not used because for this study the cell is an object that does not require decomposition.

4.5 The application of the Space – Time Cube for landscape history

The Space-Time Cube model is the model selected for the Landscape History model. The Landscape History model uses cells as the core of it's data structure. The focus on cells as the object of analysis is different from other studies that concentrate on the extent of the landscape type. Events that occur in these cells reflect the changes in the landscape classification. Evidence that these events have taken place is provided by historical documents. Yuan (1996) identifies the application where this approach can be used.

'For a given site where occurrences and duration of events or attributes may change from time to time, analysis is done by: fixing location, controlling attribute and measuring time.'

The cell is used to fix location. The attribute is controlled by the classification. The time is measured using the intervals created for each cell. (see figure 1). This allows for the answering of questions such as: What changes have occurred at this site? When did these changes occur?

Several authors have expressed reservations about the use of the space-time cube model due size of the database generated and the processing implications (Halls and Miller, 1996). Computing power and software data structures have recently progressed, indicating that these reservations are greatly reduced (Openshaw, 2000). The speed of processing the Historical Landscape model depends on the type of query. Cell based queries are considerably quicker than entire grid queries. The selection of the optimum combination of database and GIS interaction will consider processing and storage efficiencies.

5. LANDSCAPE HISTORY DATA STRUCTURE

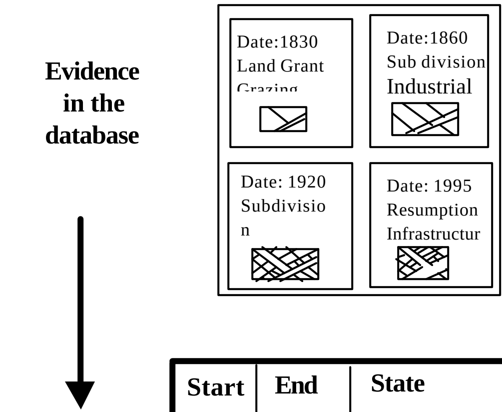
Yuan (1996) suggests that the application she identified can be accommodated using "historical transactions" in a relational database management system.

Evidence of landscape change, which is required to record a historical transaction, is stored in a database. Each piece of evidence is assigned a cultural-landscape unit classification and timestamp. Histories for each cell are then created from these transactions (see figure 2).

Simple queries and analysis are based on four combinations

- Classification value of a site at a particular time.
- Site history for a particular time interval.
- Area history for a particular time.
- Area history for a particular time interval.

The more complex queries and analysis use the data structure to query landscape classification change combinations for selected time intervals and areas.



Start	End	State
1830	1860	Grazing
1860	1920	Industrial
1920	1950	Urban
1950	1980	Infrastructure

Figure 2: Landscape History Cell Data Structure

6. POPULATING THE DATABASE

Each piece of evidence has three variables; timestamp, landscape classification and extent of coverage. It may be that not all of these variables are able to be determined for each piece of evidence. A combination of evidence can be used to determine the landscape period for a given area. For example, a parish plan maybe used to record the extent of a subdivision, indicating conversion from ‘agriculture/horticulture’ to ‘urban’ landscape. A street directory may then be used to confirm the date that urban structures appeared on the site. In this situation the two pieces of evidence are cross-referenced in the metadata to show that some variables are sourced from other evidence.

Some sources of information may provide evidence for more then one landscape type. In this case the two records are added to the evidence database, indicating two different landscape classifications. Again, metadata is used to indicate the source of this evidence.

There is a distinction between evidence that is used to support the classification of a site and that which provides evidence of the landscape classification conversion. Supporting evidence is used to increase the accuracy of the model by showing additional evidence that confirms the classification, but is not related to the landscape change event.

7. UPDATING THE DATABASE

One of the advantages of the Landscape History data structure is the ability to add new evidence to the database. As queries are database-driven, the addition of new information does not require the model to be rebuilt. As each new piece of evidence is added the cell history table is modified accordingly (see figure 3).

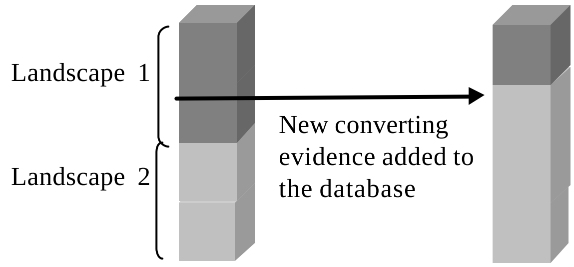


Figure 3: The effect of adding new evidence on the cell history table

As new evidence comes to light through research effort additional evidence is added. If more accurate information is found and the conversion evidence is proved inaccurate then it may be relegated to supporting evidence.

8. ERRORS

Three types of potential errors have been identified: temporal, spatial and classification assignment. Metadata plays a large role in acknowledging these errors and allowing users to understand the context in which the evidence has been used.

Temporal errors occur when the timing of landscape change is difficult to assess. This happens on two occasions. The first is when there is not enough information to indicate the exact year when the landscape change occurred. The other instance is when there is no evidence of the landscape change being undertaken however it is likely that it did occur. This error is a function of data availability and collection effort.

Spatial errors occur due to the nature of raster representation. These errors affect accuracy in two ways. The first is an inconstancy between the boundaries of historical documents. The scale and accuracy of the historical documents will differ. The second error occurs during the conversion from the polygon-based dataset into a cell-based dataset. In this case original polygon layer boundaries do not match cell boundaries, creating a mixed pixel error.

Classification error arises when a piece of evidence is incorrectly allocated a classification value.

9. CONCLUSION

The Landscape History model has advantages over other models when historical accuracy and user-based site queries and display are required. The ability to add to the database is a benefit in the discipline of History as access to historical sources is increasing, particularly by way of archive digitization projects.

The challenges of the project are in dealing with the large amount of data available and the size of the datasets used. The method of referencing the cells and linking of the relational database to the GIS in a way that minimizes processing time and storage requirements is still to be decided.

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