SYDNEY TIMEMAP: INTEGRATING HISTORICAL RESOURCES USING GIS

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INTRODUCTION

The development of a city will have a clear pattern in time and space.1 To unravel the history of a city it is important to be able to place artefacts into their correct place in time and space and interpret them in the context of other artefacts. Doing this however is very complex as traditionally databases have been poor at handling space, while maps are usually only concerned with a single point in time. This paper examines a project concerned with the development of the city of Sydney. To study the development of the city through time and space it uses a GIS approach that allows a wide variety of archaeological and historical sources to be integrated, queried and displayed through a spatio-temporal interface. GIS software typically provides an effective way of handling space but has little temporal functionality. As a result this project uses a custom-written software, TimeMap to handle space and time together.

The TimeMap project is based at the Archaeological Computing Laboratory (ACL) at the University of Sydney.2 Since 1996 it has been developing a practical methodology for the recording, manipulation and display of spatio-temporal data with potential applications in research, teaching and presentation. The project has worked in three areas: the definition of a methodology for time-stamping historical and archaeological spatial data; the development of software to manipulate and display such data; and the testing of these with real-world data as part of the development process.3

The development of software which allows the presentation of mappable data—through time-enabled map viewers—in both spatial and temporal context has been fundamental not only to the project itself but also as part of its involvement with the Electronic Cultural Atlas Initiative (ECAI).4 The
requirements of ECAI have led to three further developments: thematic filtering whereby only data with certain user-specified attributes are selected, incremental loading of data to allow an increasingly complex representation of the study area to be developed, and spatial contextualisation of searches made across the Internet via a metadata clearinghouse to allow integration of data accessed through different servers. The software has also been developed across two platforms, TMView for Windows and TMJava for web browsers. The details of these developments, and the future directions of this research, which include the use of animation to enhance the delivery of spatio-temporal material, are beyond the scope of this paper.5

The dense and diverse historical information available for late eighteenth and early nineteenth century Sydney made it an ideal source of data for testing and demonstrating the application of the developing TimeMap methodology. Since 1998, historical maps, images, verbal descriptions and other sources have been digitised and used in parallel with the development process as case studies in the application of real historical data (Figure 1).

As this research is continuing, the purpose of this paper is not to present final results but to give an overview of the project to date and in doing so discuss in detail some aspects of the approach we are taking to building historical GIS for Sydney. In particular, it will look at the use of existing digital mapping and cadastral data as the basis for our work, the use and analysis of historical maps geo-registered within the GIS and the use of data derived from such maps.

SYDNEY TIMEMAP

In 2000, building on its earlier work, the ACL began a three-year project funded by the Australian Research Council under a grant scheme based on research partnerships with industry. Our partners in this project are the Historic Houses Trust of New South Wales (NSW) and ESRI Australia. The primary aim of the research, apart from supporting the further development of TimeMap, is the adaptation of the methodology and technology for presentation, in a museum context, of a complex and extensive set of historical information via a time-enabled map-based interface. The museum in question, the Museum of Sydney on the site of First Government House, is relatively new, having been opened in 1995. Its lack of a traditional object-based collection and its general curatorial philosophy makes it an ideal venue for this type of display. The museum describes itself as ‘a multi-media, multi-disciplinary installation about the nature and narration of this place now called Sydney’ and includes within its brief not just the archaeological site, which it displays, but the whole history of Sydney from before the European invasion to the present.
Figure 1: Drape of historical maps over reconstructed topography of central Sydney created as part of an animated sequence for the Powerhouse Museum, Sydney in 1999.

Note: The maps are (left to right); William Dawes and John Hunter, 1788, *Sketch of Sydney Cove, Port Jackson*; James Meehan, 1807, *Plan of the Town of Sydney*; Hoddle, Larmer & Mitchell, 1831, *Map of the Town of Sydney*. Source: *Sydney Takes Shape*. 
The initial product of the partnership project was a public-access kiosk, called ‘Sydney TimeMap’, installed as a central feature of the museum’s new computer and video interactive Information Centre in November 2000. The installation has proved the robustness of the TimeMap software and demonstrated the value of the methodology. It also provided an opportunity for assessing user reaction to a relatively complex map-based interactive exhibit. User reaction has been overwhelmingly positive. Museum visitors seem to have an intuitive understanding of the map-based interface and soon come to terms with the basic navigation tools. Those with some experience of GIS have commented favourably on the depth and complexity of the material presented.

The installation takes advantage of the integrative power of GIS to bring together, in digital form, a wide variety of historical information drawn from several public collections. It uses TMView to provide a time-enabled interactive map interface to historical images and other digital resources, presented in the context of historical maps and overlays of modern map data. The museum limited the coverage of the kiosk content to the central area of Sydney, focusing on the site of the initial settlement and staying within the historical boundary of municipal government. This area takes in the current Central Business District (CBD) and most major administrative and cultural institutions. Museum requirements also specified that user interaction was to be via a mouse, so that the functionality of the TMView and browser interfaces had to be developed accordingly.

In order to maximise the screen area available for map display and avoid confusion that might arise if users lose sight of the map, a dual screen display was used. The left screen displays the main menu and map views, while resources called up via the map interface are displayed on the right screen.

The opening screens of the interactive were written in Macromedia Director® in order to provide a full range of graphic functionality. The main menu appears on the left screen and allows users to choose a map by theme or from a timeline. There are eight thematic choices such as Cadigal (the Aboriginal inhabitants of the city area prior to the European invasion), Archaeology (excavated sites and the NSW State Heritage Inventory) or Plague (documenting the 1900 outbreak of Bubonic Plague). The timeline divides the history of Sydney into twenty year periods, from Pre-1788 to the end of the twentieth century. As the user moves the mouse over the theme or period icons, an image and short explanatory statement appears on the right screen. When a selection is made, a more detailed explanation and description replaces the rollover response and a map is displayed in TMView on the left screen. Figure 2 shows the response to a user’s initial selection. The archaeology theme having been chosen the left screen shows an 1807 map with vector overlays including the name and location of sites and the right screen displays an explanation and description of the data.
Figure 2: Sydney TimeMap Screens: map and explanatory text.
In each case the selection includes an appropriate historic map which acts as a backdrop to the overlaid vector data. This involves geo-registering the historic maps to provide them with an underlying co-ordinate system in the form of latitude and longitude. They may also have to be warped to systematically distort them such that they fit the modern map base. Each theme is stored as a separate layer that the user can turn off or on. The user’s ability to orient themselves through time is aided to by presenting the modern coastline in every view, and by providing the modern street grid as a further optional layer.

In order to develop this map sequence, 23 maps were geo-registered of which 14 were chosen for the final display. The selection was based on chronological spread, with aesthetics a secondary factor. These maps range from a 1788 plan of the encampment and fleet by John Hunter to an aerial photograph from 1998.

In constructing the map backgrounds we had to solve a number of problems. In some cases there were difficulties in finding adequate ground control points due to limited coverage, physical damage to the maps or attrition of recognizable features as the city developed. In others, sections of maps appeared to bear no relation to reality either through spatial distortions based on mapping and survey methods or through the representation of buildings or works that were never carried out.

A particular difficulty lay in creating sets of rotated and warped maps with different spatial coverages which would have acceptable aesthetics for our museum partners. This issue was resolved by adopting graphic devices shown in Figure 3, which we refer to as a ‘map table’ display. In this example, an 1831 map of Sydney is presented within the GIS and overlaid with the modern coastline and streets. The inset shows the lower left-hand corner of the map as displayed. Damage and archival identity tags have been retained to emphasise the historic map is a physical object, while the use of the drop-shadow serves to define the map as an historical document within the GIS.

Overlaid on each historic map is an appropriate selection of viewpoints of historical images drawn on-the-fly from a database of images. Digital versions of more than 500 sketches, paintings, engravings, etchings and photographs were dated, classified according to theme and entered in an SQL server database along with their location coordinates and their direction of view. The images are represented by arrows which indicate the location of the viewer and the direction of the view. The selection overlaid on each map is drawn from the database using queries against the date and theme fields.

Links to other types of digital file are possible. For example, Aboriginal place names known from the earliest colonial records were included as labels for the geographical features they referred to. These names are important because there is very little surviving evidence of pre-European central Sydney. To present these unfamiliar words more forcefully, and to emphasise their ephemeral nature, the names on the map were linked to sound files which play a recording of Aboriginal people speaking the word.
Figure 3: 1831 map of Sydney displayed within the GIS.
The version of the TMView interface used in the kiosk has normal but limited GIS functionality. The user can zoom to the extent of the whole map, or to a single layer. It is possible to zoom in or out, or drag the map view with a pan tool, and layers can be turned on or off. In addition to these normal functions the interface includes a time bar that allows the user to change the time range of the view by dragging the ends of the bar. Where appropriate, layers are ‘time-enabled’ by assigning them, or objects in them, a suitable date range. Time-enabled layers that fall outside the time range are greyed out and display a clock icon. The interface also limits the range of scales over which a layer can be displayed. Outside this range, layers are greyed out and display a plus or minus zoom icon. Clicking on a disabled layer in the legend flashes its spatial extent on the map and its temporal range in the time slider-bar.

With a few mouse actions, the interface allows users to choose from a range of predefined maps and then explore them. They are able to focus on particular areas, overlay and compare mapped features across time and navigate backwards and forwards through time. Users can also make selections from the overlaid vector data. The kiosk delivers three different types of response to such selections.

In all layers, when the cursor is passed over points the name of the object is displayed. The simplest response, as in the case of the archaeological sites, is to open a predefined HTML page on the right screen. This allows for the delivery of pages with complex layouts combining images, site maps, captions and text.

In the second type of response, that used with image view-points, a selection opens the image and its details on the right screen via a database query and web-browser template. Users can select individual points or marquee select a group. If the selection includes points from more than one layer, a pop-up menu appears at the cursor listing a result summary for each layer. Group selections are displayed in a list template which shows thumbnails and titles.

The list template includes a count of the selection results; it is scrollable if needed and has a back and forward button. Figure 4 shows the response to a user’s selection of a group of image viewpoints. The left screen shows an 1831 map with vector overlays including the viewpoints and the right screen displays a list of the selected images with thumbnails. Selecting the thumbnail or title brings up a full size image and further details, including creator, date and collection details, delivered via another template. Selection of a single image brings up this template directly. Figure 5 shows the response to a user’s selection of a single image. The left screen shows a 1998 aerial photograph with vector overlays and the right screen displays the image. The image could be chosen directly from the map or via a generated list.
Figure 4: Sydney TimeMap Screens: selection of a group of image viewpoints.
The third response can take the user to an external web site accessed live across the Internet. For the kiosk the New South Wales Heritage Inventory, maintained by the NSW Heritage Office as a database driven web site, was treated in this way.\(^9\) When users select one or more items TMView queries the on-line database and delivers the inventory page for that item.

The real strength of the system is that TMView uses SQL queries against the master database of digital resources and their spatial and temporal locations to create different map layers and to respond to users’ selections on the fly. This means that a museum visitor can make a selection from within one of the predefined themes or time periods, or a researcher can expand the time-slider to its full range and use the interface to select all resources related to a particular site, building or area. In either case, their selection can include predefined web pages, data drawn from a database and delivered via one of several web page templates and data delivered live across the Internet from an external web site.

As our work with the museum is collaborative, the database was implemented as a web accessible server database using Zope\(^\circ\), so that data could be entered and updated from both the ACL and the museum.\(^{10}\) As well as storing the basic information, such as creator, title and source, the database was also used for administrative purposes, such as tracking copyright clearances.

The project is now focussed on extending the application of TimeMap from a stand-alone interactive to a network of touch-screen kiosks distributed throughout the museum. Each kiosk will present a different initial view, with appropriate themes and content, depending on its location within the museum, all of which will be drawn from the central server database. The touch screens will orient the visitor within the broad chronological layout of the museum and provide both generalised and specific contextual information for exhibitions on display. They can also give the visitor access to documentation and digital records of exhibitions that have closed and to resources in the collection that have never been displayed. The database can also act as a central searchable repository for digital resources collected by the museum regardless of whether they are used in displays or publications.

Exploration within the central database will be facilitated through a self-configuring interface based on ThinkMap\(^\circ\), which will assemble resources on the fly according to thematic, temporal and spatial associations, and launch TimeMap as a client to view time-sensitive maps with hotlinks to images, text, plans and multimedia resources.\(^{11}\) In this way we aim to present rich and varied historical data within an intuitive framework which communicates the museum’s message, tailored to location within the museum display, while still allowing the visitor the flexibility to break out, explore the database, drill down to reveal further detail and pursue new associations.
Figure 5: Sydney TimeMap Screens: selection of a single image.
In the research phase, we will assemble structure and content for a small number of themes, with particular emphasis on the various roles of the kiosks, the variety of digital resources and the development of the interface design and navigation scheme. Once tested, these themes will form a model for the development of additional themes and content as the project moves to the installation phase.

The stand-alone installation allowed us to develop and refine our approach to integrating historical information within a GIS and displaying it in a time-enabled interface using the TimeMap methodology. While the initial work concentrated on central Sydney, our research interests and the requirements of the distributed kiosks have dictated a shift in scale to that of the whole of the metropolitan area. Greater Sydney is normally defined as the County of Cumberland, the area between the coast and the Nepean-Hawkesbury River to the north and west and its tributaries to the south. Some of the earliest European settlements were established on both sides of the river so the study area of the project includes the county and most of the adjacent parishes across the river, covering an area of 5,317 square kilometres See Figure 6, which shows, on the left, the turnpikes and carriage roads in 1820 and on the right, the expressways, highways and main roads, in 2000.12

Given the current state of the research, this paper provides an opportunity to discuss several aspects of the implementation of an historical GIS at a city scale. The most fundamental of these is the use of current digital data as the basis for historical mapping and especially the use of cadastral data as the basis for consistent and systematic geo-registration of historical maps. Also important are the analysis of geo-registered historical maps and the use of data derived from them. When properly analysed, historical maps are the chief source of the data required to supplement existing mapping resources and build an historical GIS. Although the examples used in the following discussion are specific to Sydney, the issues are generally applicable.

EXISTING DIGITAL DATA

Any historical GIS must be based on reliable modern maps. If these are available in digital form this is a considerable bonus. In New South Wales, state level mapping is managed by a government agency called Land and Property Information New South Wales (LPINSW). During the 1990s they oversaw the digitisation of maps of various scales to create the Digital Topographic Database (DTDB) for the state. The DTDB includes all the information found on traditional topographic maps, such as contours, watercourses, roads, railways, public buildings and parks. The data covering the study area was made available to the project, and forms the basis for all the project’s mapping.

Given that the DTDB represents the current situation it is not difficult to see that a process of subtraction will provide maps of earlier times. It follows that the major research effort is not in locating map features but in dating changes. There are, of course, important exceptions to this generalisation.
These include any element not represented on the current maps, such as Sydney’s once extensive tram network, the re-alignment of roads and replacement of bridges and also extensive redevelopments that have obliterated earlier features. In these cases historical maps or other records have to be used as the basis for digital versions of the missing elements.

We have used the topographical data that forms part of the DTDB as the basis for visualisations of the landscape that act as backgrounds for much of the data when displayed. However, even the background landscape changes through time. Apart from urban landfill there are large-scale modifications, such as the building of airport runways into Botany Bay or the flooding of reservoirs, which either alter the landscape or leave gaps in the digital record. In either case digital data has to be developed from historical maps in order to model the landscape before these events took place.

Our experience with historical maps showed that cadastral mapping data, because it recorded and represented land ownership, was the most accurate and reliable through-time mapping data. Comparison of many maps, from the earliest colonial period to the present day, showed that physical features, such as coastline and rivers, can not be relied on to provide stable location information. The reasons for this include that fact that some features change

Figure 6: Sydney’s network of major roads in 1820 and 2000
location over time, there are a variety of ways to define and render such features, and in many cases topographical detail is derived from sources other than the primary survey base of the map.

The massive process of digital capture of the New South Wales cadastral data was begun in 1987 and completed in 1993. The Digital Cadastral Database (DCDB) is now updated daily and is also maintained by LPINSW who provided this data to the project as well. This amounts to approximately 1.5 million cadastral polygons, as well as administrative boundaries of many types. Access to these data allows us to harness the resources and expertise that have been devoted to developing and maintaining land ownership records since the 1790s. More important, the geo-registered maps and historical GIS data that the project produces will all be based on this accurate, consistent and well-documented data set.

The DCDB documents the complex current cadastre and does not include records of past transactions. However, the current situation has been arrived at largely by a process of subdivision, where large original grants and purchases have been steadily divided since their original acquisition. This means that earlier cadastral boundaries are still recorded in the current GIS and are available to geo-register historical maps and to reconstruct earlier versions of the cadastre by merging current polygons into larger earlier units.

As with the topographical data, this generalisation has exceptions. One of these is the trend towards the aggregation of land parcels that has become more common since World War II. In urban areas there has been a tendency to aggregate land for larger multi-storey redevelopment projects. This means that many of the earlier subdivision boundaries are now gone. Similarly, large-scale suburban redevelopments have in some places obliterated the tradition rectilinear pattern imposed by the nineteenth century land parcels.

Another group of exceptions are phenomena that may not have been definitively mapped or which precede the current cadastral framework. An example of this is the early colonial period land districts. The instructions drawn up for the founding of the colony in 1788 included the requirement to survey the settlement and document land alienated from the crown. Within a year a surveyor-general and deputy had been appointed, but it was not until 1825 that instructions specified that the colony be divided into counties, hundreds and parishes. It would take another decade before this system was instituted. Before this an ad hoc system had developed which grouped the original grants into districts that were only given definite boundaries as disparate groups of grants began to converge. These districts disappeared from the mapping record when the new parishes were formally proclaimed on 27 May 1835. Figure 7 shows this abrupt change in administrative geography. The left hand map is based on a map by Surveyor-General Charles Grimes about 1810 and the right hand map displays the parishes that replaced them.

The importance of the old land districts is that almost all administrative and statistical data for the first 45 years of the colony are tied to them. Therefore the spatial definition of these administrative units is essential if these data are to be integrated into the GIS and made comparable with later information.
ANALYSING HISTORICAL MAPS

Historical maps are a major potential source of information about features not represented in current map data. Even when the principal source for such features may be in another form, such as verbal definitions of land parcels, maps can still be useful as a spatial key to such features, providing an overview that is useful to check and identify features and target more detailed research efforts. To be used effectively within a GIS an historical map has to be geo-referenced, but successful geo-referencing is only the first step in an analytical process that should be carried out before a map, or any data derived from it, can be used.

A 1903 map of Sydney by the NSW Surveyor-Generals Office provides an example. This map was geo-registered using a group of widely spaced ground control points; that is, points that can be identified on the map image and in the digital cadastral data. These points are from a set that has been used to register many other maps of central Sydney. The map is at a scale of eight chains to an inch (1:6336), enough to show all streets and major buildings in the city. Close examination reveals that it is based on the cadastral data, which records property boundaries not street alignments and curbs. The property
boundaries were preferred by the map’s makers for the simple reason that when only they are represented they allow enough space for the labelling of streets.

The map proves to be extremely accurate, a testament to the exacting standards met by nineteenth century surveyors using optical instruments and manual calculations. This accuracy and the ability provided by the GIS to compare the map directly with the modern cadastral data offer considerable potential for analysis. Two types of information are revealed by detailed comparison, those related to historical changes and those related to errors in the original map.

Figure 8 shows the area south of Hyde Park (where the scale is printed) in central Sydney. Parts of this area were quarantined and demolished during the outbreak of bubonic plague in 1900, and over the next 30 years the whole area was progressively resumed and remodelled by the city council.15 The overlay of the modern street grid shows clearly where streets on the 1903 plan no longer exist. These include Upton, Stephen and Little Campbell Streets. New streets have also been created. These include the southern extension of Brisbane Street and the wide unnamed street that runs from north centre to the south-western corner, obliterating Wexford Street. This new arterial road is called Wentworth Avenue. Other streets have been widened. These include Elizabeth (on the west), Goulburn (running east-west) and Oxford Street.

Information on such changes in street layout and alignment is often available from archival sources, but the research required to find and identify each change would be prohibitive. The comparison made possible within the GIS acts as a shortcut to these changes and can be used to check undocumented examples and focus research effort on significant cases.

Figure 9 shows the area immediately south of Circular Quay (where the scale is printed), part of commercial and administrative core of the city in the nineteenth century. It provides a clear example of a major error in the 1903 map. The blocks between Alfred Street in the north and Bridge Street in the south are displaced 5 metres to the north. The error is confined to these four blocks, which slope down steeply to the north. There are many minor errors throughout the map, such as streets or lanes incorrectly located. These appear to be one-off errors resulting from mistakes in measurement or drafting. This major displacement error seems be caused by a flaw in the survey data or calculations applied to it. Such an error could have a significant impact on the use of the map or data derived from it if it remained undetected.

The correct identification and analysis of differences between historical maps and the modern data is an essential prerequisite for their use. In this example the scale of the discrepancies are minor but in many cases they can be considerable. The focus of the analysis is obviously on the differences that indicate historical changes, but information on these changes cannot be utilised until other types of discrepancies are identified and understood.

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It is, of course, axiomatic that historical maps be treated the same way as any other historical document. They should be analysed for their purpose, their intended audience and any likely bias that might arise from these factors. In addition to the intention of the creator, their skill and accuracy have also been suggested as additional factors to be considered when dealing with maps.\textsuperscript{16}

While it has always been possible to compare maps of an area that have different dates, scales and styles, when historical maps are integrated into a GIS a new level of analysis is possible; one that takes into account the nature of the map document itself.\textsuperscript{17} Successful integration is dependant on issues that are technical and that are often specific to the GIS or image processing software being used, so they will no be discussed here. However, the correct application of the two major variables at work in the geo-registration process is easy to describe. The ground control points that form the basis of the registration and the transformation and re-sampling processes that warp the map images to fit the within the GIS must be the same.\textsuperscript{18} If maps are geo-registered using matching control points and identical transformation algorithms then the differences that are displayed are differences between the maps themselves.
When geo-registered maps are analysed within the GIS it often becomes clear, as in the example above, that they are not evenly accurate, something that can be extremely difficult to establish using simple visual comparison alone. The analysis of a map, or sequence of maps, is based on detecting, interpreting and documenting the discrepancies revealed after geo-registration, whether these exist across the whole map, in sections of the map, for depicted items or parts of items.

These discrepancies fall into two general types. The first are those related to physical damage or distortion or displacement of map elements. These may be as simple as folds or breaks in a map sheet, they might be distortions of the map caused by copying or during the creation of the digital image or they might be as complex as those that relate to the construction of the map or the original survey. Such discrepancies can be recognised by the displacement of some areas of the map and not others, or a general displacement of the whole map image. Examples include maps where manual slope corrections have been applied, or accurate cadastral maps with generalised topographic detail derived from different sources. In these cases multiple registrations of the same map may be both a tool of analysis, helping to define the areas of consistency, and the means of making the map useful as a source of data. Of course, discrepancies of this type do have the potential to render the map, or some part of the map or class of data depicted on it, useless within the GIS.
After discrepancies of the first type have been defined, analysis can then proceed to the second type. These include errors in the map and the depiction of buildings or works that might have been proposed or planned or are simply fanciful. Errors can occur anywhere on a map and be at any scale, they are normally the misorientation or misplacement of map elements. Remembering that many historical maps were manually produced and copied helps in understanding these errors. They are analogous to errors in any manuscript. It follows that they can be completely random and can include the absence of data, although this is extremely difficult to identify. The recognition of anticipated or imaginary phenomena can present similar difficulties. Even in otherwise accurate and reliable maps some elements can be false. This can be because of actual attempts to mislead or, in the case of a commercially produced directory map for example, an endeavour to extend the life of the document and make it a more desirable purchase. Unlike discrepancies of the first type, interpretation of errors and misrepresentations will often depend very largely on detailed historical knowledge of the mapped phenomena and the interpretation of the map as an historical document.

It follows that when all examples of both these types of discrepancy have been identified, either through pattern recognition or detailed historical interpretation, the remaining inconsistencies in the map are the historical changes that the analysis has set out to identify.

The accuracy of the analysis and the level to which it can be taken will depend on the accuracy of the current map data against which the historical data is measured and the purpose of the research. However, successful geo-registration should been seen as only the start of an analytical process that can not only identify historical changes but has an enormous potential to reveal information about the nature of a map document, its construction, its errors and its purpose. This information can form the basis of an interpretation of the map document that is unlikely to be possible through any other means.

DERIVING DATA FROM HISTORICAL MAPS

Once the error has been analysed data can be derived from the historical maps and incorporated into the GIS. Without the analysis process, the validity of the data remains untested. Integrating historical data derived from maps, or other sources, is one of the great strengths of a GIS.

A good example of this process is provided by nineteenth and twentieth century fire risk maps. Such maps are an important source of historical information about the fabric of modern cities. They are commercially produced maps designed to facilitate the assessment of fire risk by insurers and such maps are common from the late nineteenth century. The earliest example produced for Sydney was published by H. Percy Dove in 1880 as A new and complete wharf, street and building plan directory of the city of Sydney.
Dove’s maps were issued in the form of a book, with each page recording a block or group of small blocks. The scale and orientation varies from page to page, so that they do not provide an overall map view of the city. The map base is also not very accurate; shapes are simplified and regularized, presumably to make drafting easier. Even with these limitations the maps contain a considerable amount of information in the form of labels and codes. These include the function and name of commercial and public buildings, the materials the buildings are made from and their height recorded as the number of stories. More expensive versions of the book were hand coloured.

The maps are an excellent illustration of the gains that can accrue from integrating historical data into a GIS. The maps were geo-registered, digitised and the descriptive data was entered into a database and linked to the map objects via a database join. The results of this process can be seen in Figure 10. The individual block from the Dove volume has been digitised and all the descriptive data has been entered into a database and linked to the map objects. The original map is shown on the left with its codes and annotations and the same block digitised, with buildings shaded by the number of stories (darkest to lightest: four stories to one storey) and building material (black-brick or stone; hatching-shingle roof; grey-wood). Any of the data recorded on the densely annotated and coded maps can now be displayed and analysed.

Equally important, the data is now available to build up a true map. In its original form the book could not be used as an overall map, especially given the changes in scale and orientation from page to page. Transferred to the GIS, the data can become a map of the city in 1880, based on a building-by-building record with the size, materials and function of each building recorded. Another advantage of a GIS is its ability to display data in different modes. In the case of the Dove data it is was possible to quickly generate simple three-dimensional models of the buildings as illustrated in Figure 11. This shows the same block depicted in Figure 10 viewed from the southeast. Using the 3D Analyst extension in ESRI ArcView, the digitised building footprints have been extruded by their number of stories to create a simple three-dimensional model of this area of Sydney in 1880.
Data displayed in the GIS is not limited to that derived from the map itself. In the example above similar data about the buildings represented could have been derived from other archival sources, although the research effort would have been increased, not least because the link between textural sources and map objects can be problematic. Data from many sources can be integrated and displayed using the standard thematic mapping capabilities of any GIS.

**CONCLUSION**

GIS provides the facility to build up rich and complex sets of integrated historical data from a wide variety of sources. The basis for any historical GIS should be modern map data. Historical evidence of many kinds can be used as the source of information about change and location that are required to construct the historical GIS. Obviously this process is not to be approached naively—each type of historical evidence has to be understood, assessed and analysed in its own terms before it can be properly integrated and become available for comparison and evaluation in context with other resources and other types of evidence. Further, the ability of many GIS to geo-register images of historical maps against modern map data can be used as a powerful analytical tool in the understanding and interpretation of these maps. When
such maps are data can be derived from them and integrated with other historical data.

GIS can also be used to deliver historical resources in digital form. As the example of the Sydney TimeMap museum installation shows, a GIS can provide access to a wide variety of digital resources by integrating them spatially and temporally and delivering them via a map interface. This access can be provided to researchers and the public and is independent of the location or form of the original resource. It can include static files or dynamic information delivered via the Internet. When based on a database structure it can be an accumulating resource set—so that as new resources are identified they can be added and integrated.

This potential for the integration, analysis and presentation of historical data is increased considerably if the GIS is time-enabled. In order to realise this potential, the TimeMap project will continue to research methods for the structuring and presentation of diachronic spatial data of all kinds.

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ENDNOTES

1. The author can be contacted at the Archaeological Computing Laboratory, University of Sydney NSW 2006, Australia.

2. TimeMap is a registered trademark of the University of Sydney. The TimeMap project website is at http://www.timemap.net.


4. The Electronic Cultural Atlas Initiative, based at the University of California, Berkeley has been a major supporter of the research and software development through grants from the Lilly Foundation and the California Digital Library. Their ECAI website is at http://www.ecai.org.

5. For a discussion of these issues see I. Johnson, 'Contextualising historical information through time-enabled maps', Internet Archaeology 12 (2002).

6. Some maps and images are from the Museum of Sydney's own collection. The majority were drawn from NSW State Records, the City of Sydney Archives, the Mitchell Library, State Library of NSW, the National Library of Australia and the Natural History Museum, London.

7. The kiosk is implemented using the TimeMap Windows viewer program (TMView) and Internet Explorer, embedded in a controlling program written in Macromedia Director®. TMView was programmed by Artem Osmakov, Astrid Noake and Reba Kearnes, under the direction of Ian Johnson, using Borland Delphi® and ESRI MapObjects®.

8. Geo-registering and warping (or 'rubber-sheeting' as it is sometimes called) are fundamental GIS operations that are described in most introductory GIS texts, for example: I. Heywood, S. Cornelius and S. Carver, An introduction to Geographical Information Systems (Harlow, Essex, 2nd edition, 2002).

9. The NSW Heritage Office kindly made the Heritage Inventory data available for mapping. The online version of the inventory is accessible from their website at: http://www.heritage.nsw.gov.au

10. Jesse Sweeney (ACL) was responsible for most of the development of this database.

11. ThinkMap® is a product of Plumb Design: http://www.thinkmap.com

12. The 1820 map of main roads is based on Governor Lachlan Macquarie’s list of public works: F. Watson, ed., Historical Records of Australia: January 1819-December 1822, Series 1: Governors Dispatches to and from England (Sydney, 1917), 696-7.

13. Surveyor General's Office New South Wales, Map of the City of Sydney, New South Wales, 1903 (Sydney, 1903).

14. Two New South Wales statutes, Act 4 William IV No. 7 (1833) and Act 5 William IV No. 20 (1834), effectively established a system that made the location of curbs the primary basis for survey and street alignment within the town.


18. Unlike aerial photographs, map images should not normally be subject to complex transformations in order to make them conform to a modern map base. Generally speaking, simple transformations, often called first order or affine transformations, which shift, rotate and rescale maps but do not grossly distort them are what is required. The specific characteristics of a transformation should be understood and documentation of the transformation process should form part of the metadata that is associated with the transformed map.


21. The database design and capture of digital information for 12 city blocks was carried out in 2001 by Elizabeth Black, Nicole Bordes, Damian Evans, David Hobson, Margaret O’Connor and Sam Player as a class project in a senior course on computing applications in archaeology at the University of Sydney. As the Dove maps are simplified, the NSW Surveyor General’s City of Sydney Section Maps, produced during the 1880s, and made available by the University of Sydney Department of Geography Map Library, were used as the base map.