# Chapter 5: Time in Historical GIS

## *5.1 Introduction*

For many years researchers in both geography and history have been arguing that to truly understand a phenomenon there must be a proper handling of both location and time. This effectively means that data should be handled using all three of their components: *attribute*, *space*, and time. As we have seen, GIS is good at handling attribute and space. Unfortunately most commercial GIS software packages do not include temporal functionality. This is because there are some serious conceptual issues that present barriers to handling time fully within the GIS data model. Users are thus left largely on their own in how they approach handling spatio-temporal data. This makes implementation difficult but provides the researcher with the opportunity to develop solutions that are sympathetic to both data and research, rather than being saddled with off-the-shelf solutions provided by vendors. This chapter reviews the issues and problems associated with using time in GIS, and looks at some examples of how researchers have approached handling all three dimensions of data simultaneously.

## *5.2 The need for understanding through space and time*

Researchers have long argued that to truly understand the world, one must understand change through both time and space. This was the argument underlying Langton's article where he claims that rather than simply comparing isolated snapshots that are assumed to be in equilibrium (termed *synchronic analysis*), researchers should be able to study how processes operate through time 'cutting across a successive series of synchronic pictures of the system' (Langton 1972, 137). He terms this *diachronic analysis*. More recently, Massey presents a strong argument for the need among geographers for a full understanding of space-time (Massey 1999). She argues that we need to be able to understand time to tell the story of how an individual place developed, and to understand space to understand the complexity of the way different places develop. Only by having multiple routes through space and time can the full complexity of the world be understood. Unfortunately, the complexity of handling data's three components simultaneously has usually led to researchers either simplifying space to preserve temporal detail, or simplifying time to preserve spatial detail. Cliff and Haggett (1996) summarise this by saying 'If we are to preserve a consistent time series, we need to sacrifice (through amalgamation) a great deal of temporal detail. Conversely, if we wish to retain the maximum amount of spatial detail then we can only have short and broken time series’ (Cliff and Haggett 1996, 332).

Researchers using GIS in a historical context have also argued for the need to understand the temporal as well as the spatial. Healey and Stamp argue that to understand regional economic development fully, the researcher must be able to disaggregate through both space and time as much as possible (Healey and Stamp 2000). In their study this involves looking at thousands of individual firms, preferably on a monthly basis over an extended period of time. Doing this requires being able to incorporate the rapidly changing locations of the firms and also developments in the transport network and changes in land ownership. MacDonald and Black researching the history of the book and print culture, come to broadly similar conclusions (MacDonald and Black 2000). They argue that a spatial and temporal framework is needed because to understand the development of print culture over time one must understand the complex relationships between such diverse activities as migration and other socio-economic variables (especially literacy rates), information about people employed in the book trade (location, occupation, and gender), the growth of libraries (location, type, and size), newspaper circulations, and so on, as they develop over time.

## *5.3 Time in GIS*

Peuquet (1994) argues that a fully temporal GIS would be able to answer three types of queries:

1. Changes to an object such as ‘has the object moved in the last two years?’, ‘where was the object two years ago?’ or ‘how has the object changed over the past five years?’

2. Changes in the object’s spatial distribution such as ‘what areas of agricultural land-use in 1/1/1980 had changed to urban by 31/12/1989?’, ‘did any land-use changes occur in this drainage basin between 1/1/1980 and 31/12/1989?’, and ‘what was the distribution of commercial land-use 15 years ago?’

3. Changes in the temporal relationships among multiple geographical phenomena such as ‘which areas experienced a landslide within one week of a major storm event?’, ‘which areas lying within half a mile of the new bypass have changed from agricultural land-use since the bypass was completed?’

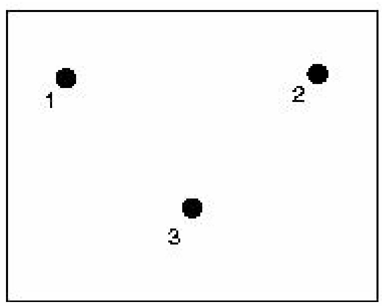
Unfortunately, the layer-based data model used by GIS does not allow easy handling of queries of this type and relatively little progress has been made in this direction. The basic problem relates to topology. GIS handles space efficiently by incorporating spatial topology (see Chapter 2) but to also handle time efficiently it would need to have spatio-temporal topology. Although some suggestions have been put forward for doing this, mainly based on object-orientated technology (see, for example, Egenhofer and Golledge 1998; Wachowicz 1999) these have not yet been well incorporated into GIS software.

## *5.4 Methods of handling time in historical GIS*

Although the temporal functionality included in most GIS software packages is usually very limited, there are many ways that time can be handled with a GIS. The best method to choose will depend on the nature of the individual researcher's data.

One simple way of handling time is to treat it as an attribute. Healey and Stamp (2000) do this in their study of regional economic growth in Pennsylvania. For both firms (represented as points) and railroads (represented as lines) the dates of their founding and closure are attached to the spatial features as part of the attribute data. In this way the development of the transport network and industrial development can be examined over time and the links between the two can be studied.

**Spatial data**




| ID | Start Date | End date | Name | Output |
|---|---|---|---|---|
| 1 | 1/1/1870 | 31/12/1870 | Smiths | 870 |
| 1 | 1/1/1871 | 31/12/1871 | Smiths | 930 |
| 1 | 1/1/1872 | 31/12/1872 | Smiths | 990 |
| 2 | 1/1/1870 | 31/12/1870 | Jones | 405 |
| 2 | 1/1/1871 | 16/5/1871 | Jones | 115 |
| 3 | 1/1/1870 | 31/12/1870 | Frasers | 610 |
| 3 | 1/1/1871 | 31/12/1871 | Frasers | 540 |
| 3 | 1/1/1872 | 30/6/1872 | Frasers | 205 |
| 3 | 1/7/1872 | 31/12/1872 | Bloggs | 365 |

[Time as an attribute]

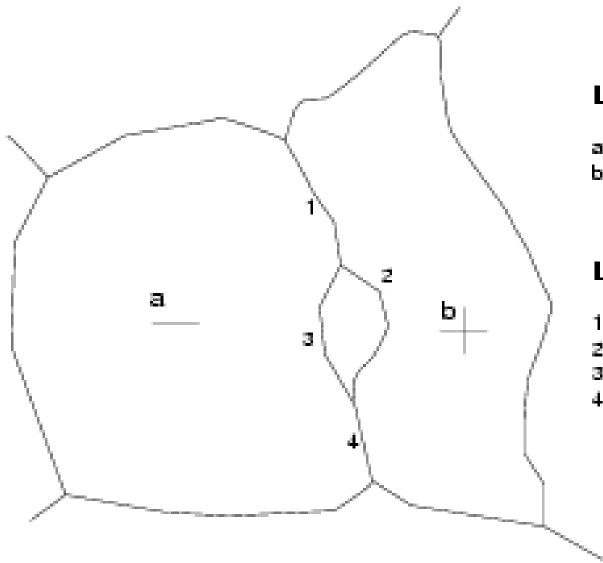
The simplest way to implement this is with a single row of attribute data attached to each spatial feature. Multiple rows can also be attached to each spatial feature with each row having a start and end date. This allows us to handle complex situations, for example, where the aim is to monitor a firm's economic statistics, such as output, profit, and employment, but where the name and ownership of the firm also changes over time. A simplified example of this is shown in Figure 5.1. Handling time in this way allows spatial features to be created and abolished and their attributes to change over time. The limitation of this approach is that the location of features cannot change.

Where the temporal nature of the data is more explicitly spatial, different layers can be used to represent the situation at different dates. This is termed the *key dates* approach and is particularly suitable where spatial data are taken from source maps from different dates. A good example of this approach is taken by Kennedy *et al*. 1999 in their atlas of the Great Irish famine. The atlas uses census data to show demographic changes resulting from the famine. At its core are layers representing the different administrative geographies used to publish the censuses of 1841, 1851, 1861 and 1871. These layers are linked to a wide variety of census data from these dates. This allows sequences of maps to be produced showing, for example, how the spatial distribution of housing conditions and use of the Irish language change over time.

While this approach is simple and effective, it is only suitable for a limited number of dates or where change occurs at clearly defined times between periods of relative stability. More complex situations are more problematic. If, for example, a researcher wanted to create a database of changing administrative boundaries for an entire country, the key dates solution would be to digitise the boundaries for every date at which maps are available. There are two problems with this: first of all, where boundaries do not change the same line has to be digitised multiple times. This results in redundant effort and will inevitably lead to problems with sliver polygons (see Chapter 4). Secondly, it is unlikely to be possible to digitise the boundaries for every possible date, and while linking attribute data to spatial data for a nearby date may provide a good approximation of the actual boundaries, there will be some error introduced as a result. This can range from an incorrect representation of the administrative unit concerned, to either polygons with no attribute data or attribute data with no polygons.

These limitations have led researchers in various countries to attempt to build systems that are continuous records of boundary change. This allows the researcher to extract the boundaries for the appropriate date and link them to any suitable attribute data. Two distinct approaches can be identified to doing this: the *date-stamping* approach used by the Great Britain Historical GIS (Gregory *et al.* 2002; Gregory and Southall 2000), and the *space-time composite* approach which was proposed as a theoretical structure by

Langran (1992). A variant of this approach has been implemented by the Historical GIS of Belgian Territorial Structure (De Moor and Wiedemann 2001) while a thorough description of its architecture has been developed by Ott and Swiaczny (2001).




**Label point attributes:**

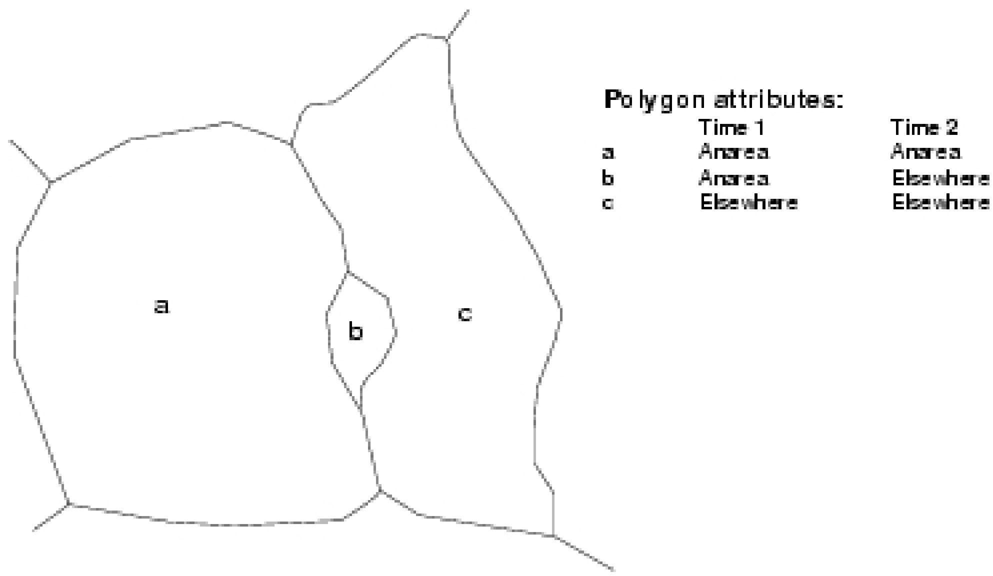
| | Name | Start Date | End Date |
|---|---|---|---|
| a | Anarea | 0/0/0000 | 0/0/5000 |
| b | Elsewhere | 0/0/0000 | 0/0/5000 |

**Line attributes:**

| | Start Date | End Date |
|---|---|---|
| 1 | 0/0/0000 | 0/0/5000 |
| 2 | 0/0/0000 | 1/9/1894 |
| 3 | 1/9/1894 | 0/0/5000 |
| 4 | 0/0/0000 | 0/0/5000 |

[Storing changing administrative boundaries: the Great Britain Historical GIS]

The date-stamping approach handles time as an attribute in a manner similar to that described above; however, it is complicated by the need for polygon topology. Gregory and Southall (2000) cope with this by storing all their spatial data in what they term “master coverages” (i.e. master layers). These are layers that have both label points, representing administrative units, and lines, representing their boundaries. There is, however, no topology to link the two at this stage. In this structure, boundary changes can be handled in the manner shown in Figure 5.2, showing a transfer of territory from one unit to another. More complex changes, such as where an entire unit is created or abolished, can be handled using the label point attributes. Within this structure, a user can specify a date and custom-written software extracts the appropriate label points and lines and creates topology to form a polygon layer for that date.




[Storing changing administrative boundaries: a space-time composite]

The space-time composite approach creates administrative units through aggregating smaller polygons, by storing the unit that each polygon lies in at each date as attribute data. These smaller polygons are referred to as the Least Common Geometry (LCG). This can consist of low-level administrative units that are known to be stable over time such as Irish townlands. Where no such units are available, it can consist of polygons created as a result of boundary changes, as is in the Belgian system. In either case the basic structure is the same, as is shown in Figure 5.3. A dissolve operation is used to re-aggregate the polygons in the LCG to form the units in existence at the required time.

## 5.5 Conclusions

Historical research has frequently been hampered by its inability to manage data effectively through attribute, space and time simultaneously. This has meant that, traditionally, researchers have had to simplify at least one and often two of these three components in order to perform their analyses. GIS opens up a wide new potential for managing data through all three components without having to resort to simplifications. Although time is currently poorly integrated into GIS software, there is still real potential for using GIS to manage complex spatio-temporal datasets, as is illustrated by the case studies provided. As will be discussed in later chapters, this opens up the potential for exploring, analysing and visualising complex spatio-temporal change in a more sophisticated manner than has previously been possible. This should ultimately provide a more detailed and less simplistic understanding of the processes that drive these changes.

## *Further reading from chapter 5:*

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