DIGITAL DOCUMENTATION OF MONUMENTS & SITES: A CAD-BASED SPATIO-TEMPORAL ANALYSIS

by
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ABSTRACT: Representations used within today digital documentation applications usually assume a world that only exists in the present. Information contained within an historical spatial database may be added-to or modified over time, but a sense of change or dynamics through time is not maintained. This limitation of current Information Technology / GIS capabilities has recently received substantial attention, given the increasingly urgent need to better understand geographical processes and the cause-and-effect inter-relationships between human activities and the environment. Models proposed so far for the representation of spatio-temporal data are extensions of traditional raster and vector representations that can be seen as location- or feature-based, respectively, and are therefore best organized for performing either location-based or feature-based queries. Neither form is as well-suited for analysing overall temporal historical relationships of objects (eg. monuments) and events, as well as patterns of events throughout a geographical area as a temporally-based representation.

In the current paper, a new spatio-temporal data model suitable for digital documentation of monuments and sites is proposed that is based on 3-D modelling and time as its organizational basis, and is thereby intended to facilitate analysis of temporal relationships and patterns of 3-D modelling changes through time. This model is named the Object-based Spatio-Temporal Digital Documentation (OST-DigiDoc). It is shown that temporally-based queries relating to 3-D models of objects can be implemented in an efficient and conceptually straightforward manner using OST-DigiDoc by describing algorithms for three fundamental temporally-based retrieval procedures, used in architecture and archaeology and based on the proposed model. In these procedures the monuments and sites, in a 3-D modeling form, are regarded as objects.

Finally, analytical time efficiency estimations of the above OST-DigiDoc procedures are given, showing that OST is also an efficient and compact representation of spatio-temporal information in general.

Keywords: Geographical Information Systems, Spatial analysis, Temporal analysis, Digital documentation, Monuments Management

1. INTRODUCTION

The need to better understand the effects of man's interesting creations (monuments, sites, etc.) on the natural environment at all geographic scales is now viewed with increasing urgency. In cultural resource management within the developed world, the emphasis is shifting from inventory and manual documentation toward implementing and maintaining a decision support system with spatial (geographical, usually 2-D) & modeling (3-D) capabilities and digital documentation functionality (Styliadis *et al.*, 2003).

This task requires integrated and broad-scale process analysis in order to better understand historical, natural and human processes and how they are interrelated to historial buildings.

The advent of remotely-sensed satellite and high altitude photogrammetry data of archaeological sites in addition to other spatio-temporal observational data, like close-range photogrammetry images of historical monuments, has made the empirical study of large-scale, complex spatio-temporal processes possible, further increasing the demand for integrated computer-based tools for this task. As a result of such data storage and processing needs, enhancement of the spatio-temporal capabilities of GIS towards the Temporal Spatial Information Systems (4-D SIS) is now an issue that is receiving attention. A key element in this work is how to represent detailed and accurate 3-D models of monuments and sites in time, as well as in space, so that spatio-temporal data can be effectively stored and analysed. In this way a decision support system for digital documentation of monuments and sites can be designed and implemented.

In the current paper, a new type of spatio-temporal data model is proposed which is based on 3-D modeling and time as its organizational basis and thereby it is intended to facilitate analysis of temporal historical relationships and patterns of 3-D modelling change through time. The specific spatio-temporal data model described is called OST-DigiDoc (the Object-based Spatio-Temporal Digital Documentation System). This data model also represents an extension (add-in component/‘socket’) of the NAOS object-oriented modelling scheme for byzantine churches (Styliadis, 1996).

In the remainder of this paper, current and potential approaches for representing spatio-temporal data will be discussed within the context of varying tasks and types of queries. The OST-DigiDoc will subsequently be defined and its advantages for temporal analysis of cultural objects and data will be presented. Algorithms for performing some basic tasks will then be described together with relative analytical time efficiency estimations. Finally, potential variations of this data model and areas for future research will be discussed.

2. CURRENT REPRESENTATIONS

Any representational scheme is inextricably linked with a set of specific uses. This fact was demonstrated within the spatial realm during the lengthy raster versus vector debate that began in the 1970s. Functional trade-offs that have become recognized between these two representational approaches and with other non-spatially oriented approaches, Relational Database Management Systems (RDBMS) in particular, have resulted in modern GISs being implemented increasingly on the basis of a multirepresentational database design. If monuments digital documentation in the future is to provide sophisticated temporal analysis capabilities as well as the ability to efficiently answer specific types of time-based queries, it is necessary to utilize a type of representation which is specifically suited to that type of application.

The only data model available within existing CAD/GIS/Modeling software that can be viewed as a spatio-temporal data model in a digital documentation system for monuments and sites, is a series of *Layer-based 3-D Models*. This type of representation, known as the *Snapshot Model*, simply employs the grid data model, using a sequence of spatially registered 3-D models of monuments and sites. Instead of a single gridded file representing a complete thematic map layer as in a static, i.e. non-temporal spatial database, each gridded 3-D model Si, represents a 'monument historical state' relative to a given thematic domain, storing an accurate and complete layer-based 3-D model, at a known point in time, ti. Actually, each cell within a separate snapshot contains a pointer to the corresponding 3-D model at that time.

This approach is conceptually straightforward, and the 'monument historical state' for any given monument and site in time within the recorded temporal interval can be easily retrieved or interpolated. Nevertheless, the actual changes that occurred at monument's component elements between given points in time are not explicitly stored, and can only be derived by comparing either the pixel value differences in photography or the element information (co-ordinates, qualitative data) between successive layers of graphical information.

Another potential approach should be based on the so-called *Grid Model*, which was proposed within a GIS/SIS context by Langran (1997). The basic idea of this approach is to represent each pixel in a gridded array of discretized objects (monuments) as a list. With this representation, any change at a given component element of the current monument is added to the beginning of the list for that monument. The result is a set of variable-length lists referenced to grid cells. The 'present' (i.e. most recently recorded) monument historical state for the entire monument is easily retrieved as the first value stored in all of the locationally-referenced lists. This representation has the advantage of storing only the changes related to specific monuments and has the related additional advantage of avoiding the storage of redundant information (i.e. qualitative data) which remain unchanged, in contrast with the layer-based representation.

Several spatio-temporal models have been proposed that explicitly record spatial changes through time as they relate to specific geographic/cartographic entities (Hazelton, 1991), (Langran, 1997). These approaches are not suitable for real-world 3-D objects. At a broad conceptual level, all of these proposed spatio-temporal models represent extensions of the classical vector representational approach. These spatio-temporal models rely on the concept of amendments, where any changes subsequent to some initial point in time in the configuration of polygonal or liner entities are incrementally recorded as additions to the original entities.

The first of these models was proposed by Langran (1997) and relies on what she described as *Ammendment Vectors*. The time that any change occurred is recorded as an attribute of each amendment. This organization allows the integrity of individual features (e.g. 3-D models of churches, baths, sites, etc.), components of those features (e.g. arches, domes), elements (e.g. stones, bricks), and their spatial interrelationships to be explicitly maintained over time.

Hazelton utilized this basic idea within a 4-Dimensional space-time Cartesian space, and proposed an extended hierarchy comprised of nodes, lines, polygons, polyhedra, polytopes and polytope families as the conceptual organizational basis (Hazelton, 1991). Each of these, in succession, adds a single dimension so that polyhedra are 3-Dimensional enclosed areas, polytopes are 4-Dimensional enclosed areas, etc.

All of the extended vector and grid models described above incorporate the temporal dimension in some indirect way while still retaining their fundamental organizational basis. They thereby also retain their relative functional advantages and disadvantages. All *vector* models are feature-based in the sense that all locational and temporal information, as well as other types of attribute information (metric or qualitative), is stored relative to specific geographic/spatial features, and/or the topologically-defined elements (lines and nodes) which make up those features in a 3-D modeling scheme. In other words, geographic / spatial entities in general and 3-D models of monuments and sites in particular, serve as the basic conceptual element and organizational basis of the vector representation.

Conversely, the *grid* model, or more generally any tessellation model, can be said to be location-based, since all other information is stored relative to specific locations.

Because of these two fundamentally different orderings of stored information, a *vector* model, based on the 3-D representation of its components, can be used more effectively to store information and perform tasks relative to spatial features, including topological relationships between them over space. This model is suitable for a 3-D model-based spatial digital documentation of monuments and sites. On the other hand, the vector model is not really so good to store information and perform tasks relating to a specific location or set of locations and even more it can not directly be used for temporal support.

Conversely, a grid model can much more effectively perform tasks relative to specific locations and locational overlay, i.e. locational set relationships. This model, as well, can not directly be used for temporal support.

In vector and grid models associating additional temporal information with individual features can be performed only with software extensions of the supported environment. These extensions allow and support changes through time to individual monument features or their components, and then easily traced and compared, including changes in their spatial topological relationships.

Similarly, associating temporal information with locations allows the history of individual locations and sets of locations to be traced and compared. Locational overlay operations can also be used in a location-based spatio-temporal representation to characterize locations on the basis of the co-location of multiple changes or types of change.

In using a spatio-temporal GIS to analyse processes, it is also essential to be able to examine changes on the basis of time, retrieving locations, objects and features on the basis of the temporal relationships of a specified monument and, moreover, to be able to examine overall patterns of temporal relationships.

Change through time can also be converging or diverging. Individual monuments, objects and events can be characterized as clustered, forming '*time episodes'* that perhaps can be further grouped into '*time cycles'*. Perfectly cyclical distributions is an important form of steady-state behaviour over longer temporal intervals. Thus, a series of church constructions between 1300 and 1400 can be grouped as a drought *episode*. This drought episode may in turn be part of the global Byzantine *cycle*.

Specific examples of gueries which relate spatial and non-spatial changes occurring with respect to specific spatio-temporal relationships would include:

- When did the last monument renovation occur anywhere in a particular city?
- What monuments are known to have suffered from a particular major fire event?
- What monuments are known to have suffered from major fire events in sixties?
- Which Monuments changed in appearance within ten years after a specific event?

Thus, in addition to extending traditional raster-based and vector-based approaches in order to incorporate temporal changes, change also needed to be explicitly modelled as a function of time.

The need for a time-based representation for examining temporal relationships and patterns was also described by Langran in 1997, but no example of such a representation was given.

3. THE TIME-BASED APPROACH

In the time-based approach, location in time becomes the primary organizational basis for recording changes. The sequence of events through time, representing the spatio-temporal manifestation of some process, is noted via a *time-line* (see Fig.1). Such a time-line represents an ordered progression through time of known changes from some known starting date to some other known, later, point in time.

Each location in time along the time-line (with its temporal locations noted as t_o, t_l, ..., t_n) can have associated with it a particular set of 3-D models of monuments and component elements in space-time that changed (or were observed as having changed) at that particular time and the new value to which they changed.

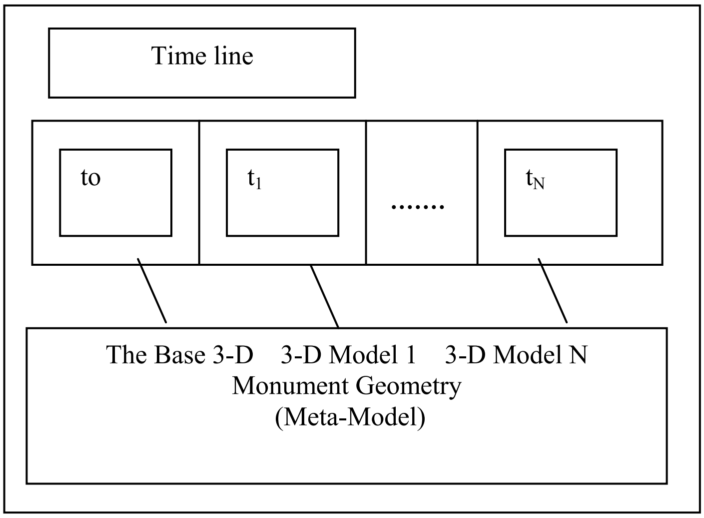

Figure 1. Representation of monument's changes organized as a function of time.

Recording only times when changes occur as opposed to a complete time-line that contains an entry for every '*tick of the clock*' at a given temporal resolution can also be viewed as *temporal run-length encoding*. This is analogous to well-known *raster run-length encoding* for recording spatial variations. In *raster run-length* encoding, a value is recorded only when it is different than the last one encountered along the scan-line.

The length of the *run* of contiguously locations along the same scan-line is also recorded either as starting and ending y-locations or occasionally as an increment value Δy. Thus, it can be said for *run-length encoding* generally, only 'meaningful' locations in time or space are recorded. In the spatial domain, this is usually coincident with some change over space. This can be an edge, such as a dome's boundary or the change in construction materials from stones to bricks.

The top-level of information is called the '*object list*' since an object, through its 3-D model, usually represents a change in state (i.e. change in geometry, change in some property, change in an attribute value, etc.) that can be denoted as such for some feature, location or set of features or locations. In other words, the *changes* relating to *time* are explicitly stored.

Besides sudden changes as might be caused by some catastrophic event such as a fire or war, change can also be gradual such as the amount of bricks used or the type (form) of dome's architecture associated with a particular x, y location. For such instances of gradual change, a change 'object' (3-D model) would be recorded at the time when the amount of accumulated change since the last recorded change is considered to be significant or by some other domain-specific rule.

In the objects-based approach, the time associated with each change (i.e. each 3-D model) is stored in increasing order from the initial 'monument historical state' at time t0 (e.g. 10 January 1902) to the latest recorded change at time tn (e.g. 31 October 1998). These may be recorded at any desired temporal resolution (e.g. year, month, week, day). For most phenomena, the length of any temporal interval (i.e. temporal distance between ti-1 and ti), and any other such interval will be unequal. Associated with each ti are the changes which occurred between ti-1 and ti. The only exception to this is that the meta-model or the starting monument's 3-D model state must be stored with the first recorded time t_0.

The changes associated with any ti may also be extensive, affecting a large historical/archaeological area and many monuments within t_i, or perhaps may be only a single location, monument or component element.

4. THE PROPOSED SPATIAL & TEMPORAL DATA MODEL

Based on the discussion above, a specific data model is now defined. The proposed data model, which is called the *Object-based Spatio-Temporal Digital Documentation System* (OST-DigiDoc), represents a specific example of the time-based approach that temporally orders changes to 3-D modeling within a pre-specified monument. A generalized form of OST will first be described before presenting the details as actually implemented.

OST-DigiDoc in its simplest form stores specific changes associated with each time ti, in the *time-line* (see Fig. 2). The specific stored temporal location ti is called a *time-stamp*, using the convention from Temporal Database Management Systems (TDBMS) terminology (Jensen *et al.*, 2001). It is assumed that each time-line and associated 3-D modeling changes are related to a single thematic domain (e.g., Byzantine monuments category). The set of 3-D monument models, recorded for any t_i, consists of the x, y starting co-ordinates of the monument component element which changed since t_{i-1}, attribute values and a pointer to corresponding 3-D component model.

One obvious potential disadvantage of this method for storing modeling changes is that the number of x, y, *attribute values*, *pointer* records is related directly to the total number of discrete component elements which changed between t_i and t_{i-1}. In the next paragraphs an optimization OST procedure for this disadvantage is presented. The representation of changes for a specific *time-stamp* consists of grouping together individual cell locations (i.e. x, y pairs) which share a common new attribute value. Then, the tabular/graphical display is acquired by using the pointer *ptr*. Such a pointer-to-model specific mapping is stored within a single structure, which is called *DisplayFile*.

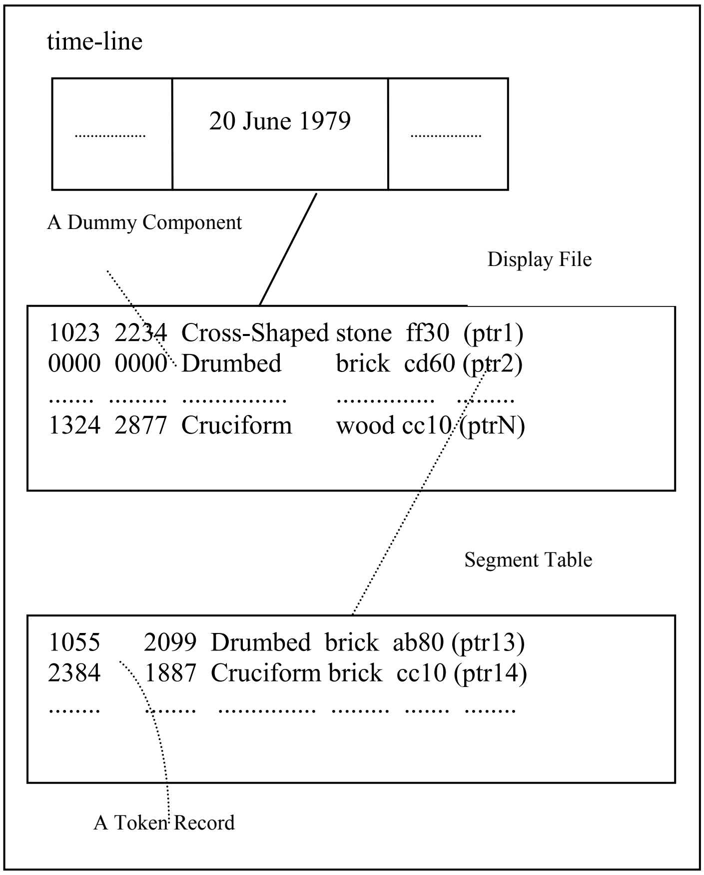

Figure 2. The display file structure of the proposed OST-DigiDoc.

In OST, all monument's component elements that have changed to the same values within a single thematic layer, regardless of their location or previous value, are stored together as members of the same dummy component. This means that any given value is stored only once per monument instead of once for every x, y component's location (space optimization). A separate component structure, called *Segment Table*, is stored for each value to which at least one locational cell has changed. By storing locations in this manner, it is also possible to apply *raster run-length encoding* within each component in order to reduce the volume of storage space required for recording locations of monument's component elements. Grouping locations which changed to a common value also greatly facilitates certain search tasks, as will be discussed later in this paper.

As seen in Figure 2, the *Display File* and *Segment Table* structures are defined as having two primary elements: the new value, called a *component descriptor*, and an array of locational space-defined elements called *tokens* (records). A single token represents a set of consecutive cells along a row in a gridded map *utilizing run-length encoding*. It consists of five entries: the row number x_i, the column number y_i, the name of the component element, the 'same' value and a pointer to the corresponding 3-D model.

Utilizing the neutral terms of components and tokens, the object-based model can be defined in general as being composed of a series of temporal locations, each location corresponding to a single point in a 1-D time-line, and one or more components associated with each of these points containing the new values and the elements to which they apply.

The OST-DigiDoc Data Structure

The detailed OST-DigiDoc for representing temporal changes can now be described. The OST structure as implemented, consists of a header, a base-map that defines the initial world (space) state for the entire monument at t_0, and a time-line with set of monument's component elements attached to individual *time-stamp* entries in the time-line (see Fig. 3). A single OST-formatted file that represents the spatio-temporal dynamics of a single thematic domain for a specific archaeological area, equivalent to a single thematic map layer, is called an *OST series*.

The *header* contains the name of the thematic domain, a pointer to the base map, the name of the base map, the time-stamp of the initial time value associated with the base map, and pointers to the first and last elements of the time-line. The *base*-map consists of a complete *raster run-length encoded* 'snapshot' image of the entire monument represented.

Each object entry in the time-line contains a time-stamp, a list of pointers pointing to each component element (3-D model), and a pair of pointers, prev and next, that point to the previous and the next elements in the modeling list respectively. The pointer prev of the first element points back to the header and the pointer next of the last element in the modeling list is assigned the value NULL. The modeling list is thus constructed as a *double-linked list*.

The use of pointers to connect adjacent entries in the modeling list allows new 3-D models that happen as time progresses forward to be easily added. This conceptually entails new models to be simply added to the end of the modeling list because of its temporal ordering. At the implementation level, the use of pointers allows OST-formatted files (i.e. OST series) to expand in order to accommodate the additional data while avoiding the need to physically recopy the file. Adding a new 3-D model (which has occurred at some time more recent than the last model already in the modeling list) onto the end of the modeling list, requires only the following straightforward pointer adjustments:

- Change pointer next of the last entry in the modeling list from NULL to the storage location of the new model (i.e. the time-stamp with its associated components).
- Assign the location of the last entry in the modeling list as the value of pointer prev of the new model.
- Assign the pointer next of the new model the value NULL.

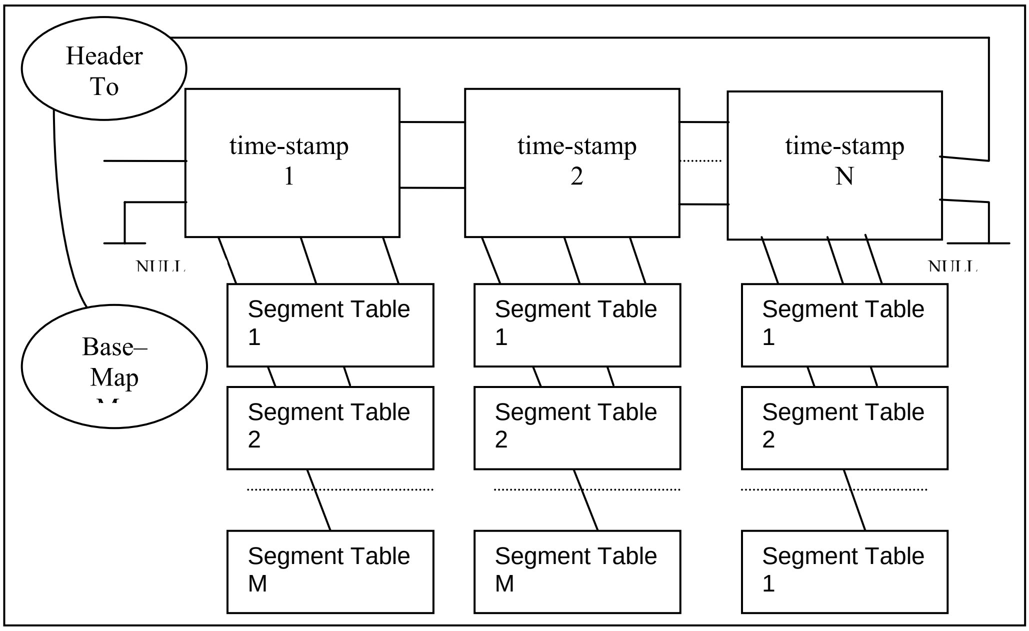

Figure 3. The OST-DigiDoc showing all primary elements and the pointer structure.

The new model thereby becomes the last model in the updated modeling list. The use of backward pointers allows the modeling list to be searched in reverse order as well as forward order. The separation of the base-map in an OST series as a separate element and not as event component is done for both representational and efficiency reasons. Obviously, t_0 must be considered as 'the *beginning of time'* as far as the data are concerned. This means that the nature of the values for all locations at that time are unique in that it would not be valid to view these initial locational values as 'changes' from some previous time since there is no previous time. It is also because of this that the pointer prev of the first event is NULL to allow algorithmic clarity.

5. FUNCTIONAL EVALUATION OF OST-DIGIDOC

The most significant and unique capabilities of OST-DigiDoc in a GIS/SIS context arise from its ability to perform temporal manipulations on monuments 3-D modeling, e.g. temporal scale changes, and temporally-based comparisons in a sequential manner. The primary ordering of information, on the basis of time, facilitates search and retrieval of not only specific temporal intervals looking in either a forward or backward temporal direction, but also of change to specific monument attribute values within those temporal intervals.

Such an ordering also makes comparison of different temporal sequences for differing thematic domains, or of the same thematic domain in different monuments, a straightforward task of comparing two or more *OST series* by comparing the *time-stamps* in their respective *time-line*, in sequence. Temporal sequences within the same OST series may also easily be compared in a similar manner.

The hierarchical organization of data within the OST-DigiDoc offers additional functional advantages. For comparing only the times at which events occur (looking for overall temporal pattern), the times alone are retrieved directly from the time-line without need of retrieving the associated attribute values or 3-D monument models. Also, since changes associated with each event are organized on the basis of each unique value occurring in association with that event, the frequency and variability of occurrences of specific values, regardless of their spatial location, can easily be examined as change progresses through time. Using the third level in the storage organization, questions relating to locational changes (e.g. determination of which 3-D models of monuments or archaeological sites are changed to a specific attribute value or set of values at a given time) can be easily answered as a more complete retrieval operation.

Temporally based Queries

Specific algorithms for performing several elementary temporal-based queries are given below. Each of these algorithms deals only with a single OST series. Algorithms for performing similar gueries relating two or more series can be derived as extensions of the proposed algorithms. These algorithms are given simply to serve as examples of how implementing time-based queries can be straightforward and efficient using OST-DigiDoc. These would also serve as some of the elementary building-blocks for implementing more complex and application-specific tasks:

1. Retrieve and Display in tabular/graphics form all component element objects, in Monuments and Sites, which a) were changed to, or b) had had, a given attribute value <u>at</u> a given time.

The retrieval of all 3-D component element models which changed to a particular given attribute value *gav* at time *ti*, is the most fundamental retrieval task for which OST is designed. The basic procedure for accomplishing this task is a two-stage search. The first stage is to find the event with the desired *time-stamp* within the *time-line*. The second stage is to find the component c, associated with this event whose descriptor matches the given attribute value gav, the component co-ordinates are then returned.

Since the *time-line* is arranged in increasing temporal order, the first stage of the search relies on a comparison of whether the given time gt, is greater than the time-stamp of the current event in the event list. If $t_{first} > gt$, then the entire list occurred after the desired time and the search returns FAIL. Otherwise, the search continues until $t_e > g_t$, where te is the time associated with event ***e***. Here, it is assumed that the value of g_t does not necessarily match any *time-stamp* stored in the *time-line*. If $t_e <> g_t$, the simple rule of closest temporal distance is applied, i.e. whether te or te-1 is selected, although this can change depending on the application. Remembering that OST is defined as a complex structure, then the general logic of the algorithm can be described more formally as follows (in Pascal-like coding):

```
Proc.Get&Display_3-DModels_Value_Time(OST,gt,gav)
Begin
    if (t_first > gt) return FAIL;
    for each Monument (3-D Object) in OST
            if (t_e >= gt)
                begin
                    if (gt <= (( t_e + t_e-1) / 2 ))
                        3-D Model=previous(3-D Model);
                for each component c of the 3-D Model
```

```
                if ( c(value) = gav) return c(xy-coords);
            end;
      return NULL;
End; {Procedure Get&Display_3-Dmodels_Value_Time}
```

Since both the search of the *time-line* and the search of *component descriptors* within the desired event once found are exhaustive, linear searches in the algorithm as described above have as worst case efficiency: $O(n_e + n_c)$, where:
n_e = *the total number of events in the time-line* and
n_c = *the maximum number of components for any given event*.
This can be improved to: $O((\log n_e) + n_c)$, by using any $O(\log n)$ search, where n denotes the total number of elements to be searched. Performing the same task by using the snapshot model the following three steps will be required:

- Find the 3-D model with the right time-stamp in the monument 3-D models sequence.
- Create a difference monument 3-D model between that model and the preceding model. This difference 3-D would then contain the new values in all 3-D cells whose values had changed from the preceding model and zero or NULL in all cells whose values had not changed.
- Find those cells whose contents match the given attribute changes.
- The first and third steps are generally equivalent to the two phase search as in the

OST-based algorithm described above. The primary difference, however, is the addition of the second step to create the difference 3-D. This process is necessarily exhaustive, always requiring (n_x*n_y) cell-by-cell comparisons between two adjacent snapshots, where n = the total number of cells. This means that the entire task is performed in O(n) time for a complete snapshot image.

2. Retrieve and Display in tabular/graphics form all component element objects, in Monuments and Sites, which a) were changed to, or b) had had, a given attribute value <u>over</u> a given time interval.

This procedure, a simple variation on the previous one, utilizes a range of temporal values at the first level of search, retrieving element components for all monuments frorn a starting time *gts* to an ending/finishing time *gtf*. For the sake of simplicity, it is assumed that the temporal distance between *gts* and *gtf* is wide enough that at least one 3-D monument model will be found.

```
Proc.Get&Display_3-DModels_Value_Interval (OST,gts,gtf, gav)
Begin
     if (t_first > gt) return FAIL;
```

```
    for each Monument (3-D Object) in OST
        if (gts <= t_e <= gtf)
            for each component c of 3-D Model
                if ( c(value) == gav) return c(xy-coords);
    return NULL;
End;
```

From the above, it can be seen that this task has the same logical structure that involves the same two-level search as the previous algorithm. Given retrieval of 3-D models with a temporal range of gtf...gts instead af a single model from a temporally-ordered list, the time efficiency would be:

$O((\log n_e) + (n_f * n_c))$, where:
$\log n_e$ = the amount of time needed to search the time-line for the starting event.

Since all object models after the starting one to the finishing n_f, are then retrieved sequentially, this is nf additional steps. Also, for each 3-D model, nc additional steps are required to examine each component for each model. This means that after the starting model is found, additional ($n_f * n_c$) steps are required. The worst-case in terms of efficiency would be the case where the starting time coincides with the first event in the time-line and the finishing time coincides with the last event in the time-line. This would require all components for all monument 3-D models in the time-line to be examined. In this case the resulting efficiency would be: $O(n_e * n_c)$.

3. Calculate and Display in tabular/graphics form total changes in an Archaeological Site Area to a given value over a given temporal interval.

Finding the amount of areal change is another basic spatio-temporal query, both for finding how much changes have taken place over a specific temporal duration, and for calculating the rate of changes over that temporal interval. Within the OST-DigiDoc, the amount of areal change over a previously defined temporal interval is represented by the total number of areal units represented within a component or within the c(xy-coords) returned by either of the algorithms above. Since *run-length coding* is used for both of these, counting the total number of areal units requires a very simple procedure that accounts for the cells not explicitly noted in the structure. If it is assumed that the input xy-coords represents a *run-length encoded* list of x, y cell locations that is returned from either of the algorithms above, an OST areal change algorithm reduces to a simple counting procedure as follows:

```
Procedure Area (xylist)
Begin
    area = 0;
```

```
    for each Cell Component with xy-coords
        area = area + f(xy-coords);
    return area;
End;
```

Obviously, the time efficiency of this procedure is a direct linear function of the number of compacted records in the xy list coordinates.

6. CONCLUSIONS

In this paper, a new type of spatio-temporal data model for geographical information systems, called the *Object-based Spatio Temporal Digital Documentation System* (OST-DigiDoc) has been described. Unlike existing approaches used in GIS/SIS, the OST is designed to explicitly represent 3-D modeling change relative to time.

From a user perspective, a temporally-based representation is needed in order to effectively allow empirical analysis of space/time dynamics, and ultimately allow temporal 3-D modeling and simulation of geographical processes as an integrated GIS capability. Because OST explicitly stores change relative to time, procedures for answering queries relating to temporal relationships, as well as analytical tasks for comparing different sequences of change are facilitating in OST-DigiDoc.

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