A SPATIO-TEMPORAL DATA MODEL FOR ZONING

by

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ABSTRACT

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Planning departments are besieged with temporal/historical information. While for many institutions historical information can be relegated to archives, planning departments have a constant need to access and query their historical information, particularly their historical spatial information such as zoning. This can be a cumbersome process fraught with inaccuracies due to the changing organizational methods and the extended historical legacies of most municipalities. Geographic Information Systems can be a tool to provide a solution to the difficulties in querying spatio-temporal planning data. Using a data model designed specifically to facilitate the querying of historical zoning information, queries can be performed to answer basic zoning questions such as, "what is the zoning history for a specific parcel of land?" This work outlines this zoning data model, its implementation, and its testing using queries basic to the needs of planning departments.

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I. Introduction

Geography is a broad field touching on a wide variety of disciplines, but few disciplines fall more squarely under the care of geographers than does Planning. Planners attempt to manage space and its development over time, usually on the scale of local government. Unfortunately, what may on the surface appear to be a straightforward goal, the orderly and efficient development of a city or county, quickly becomes a quagmire of minutia. Some of the most important tools of planners, zoning laws and ordinances, are forced to focus on the most minute details of land use in order to control development. In addition, these zoning laws and ordinances evolve over time; quite rapidly in some cases.

Organizing and retrieving this time-dependent spatial information is an enormous challenge that planning departments face on a daily basis. There is a constant need to retrieve information related to current and past zoning as well as allowed land uses for specific properties or areas. Spatially, this problem is ideal for a tool such as Geographic Information Systems. The temporal side of this problem is another issue that has not been well defined within GIS. The purpose of this work is to address the retrieval of spatial *and* temporal zoning information through the use of GIS.

To achieve this goal a data model will be created to model both the spatial and temporal aspects of zoning. This data model will parse out the zoning information and identify relationships in a way that will allow queries which will answer the two spatio-temporal questions most commonly posed to planning departments: “What is the zoning history for a parcel?” and “What does the zoning map look like on a certain date in time?" After the data model design is complete, it will be implemented with zoning test data for a specific region. Then it will be tested to see if it can answer the basic queries just noted.

1.1 Planning and Zoning History

> ...Nothing is more to be regretted, in this view, than that the American nation, having a new world to make, and a clean map on which to place it, should be sacrificing their advantages so cheaply, in the extempore planning of towns and cities. The peoples of the old world have their cities built for times gone by, when railroads and gunpowder were unknown. We can have cities for the new age that has come, adapted to its better conditions of use and ornament. So great an advantage ought not to be thrown away. We want, therefore, a city planning profession... - Horace Bushnell, 1864

Horace Bushnell's hope for an official planning profession would not be realized for another 53 years when the American City Planning Institute was founded in 1917. In 1864 the concept of city planning was still in its infancy. Some say sewage was an initiator of the concept; or more accurately the advent of sewage systems technology in England in the 1840s. This new technology led to more sanitary living conditions, higher housing densities, and helped alleviate yellow fever epidemics. But another side effect of sewage systems was the concept of a city as a "system of inter-dependent parts." Subsequent citizen campaigns to promote city beautification and humane housing joined forces with the concept of city sanitation and eventually led to institutionalizing of the planning profession (Krueckeberg, 1983).

The period between World Wars I and II saw the implementation of zoning and master plans and the processes that came with them such as planning commissions and neighborhood design. Master plans are general guidelines outlining the preferred direction of development for a city for approximately 20-30 years into the future. A master plan would map out areas generally considered appropriate for future commercial, residential, industrial, and agricultural uses, as well as others. City policies would likely steer development in those directions. Zoning is a legal method for a city to control development. Zoning defines specific areas in a city where land use and building specifications are controlled by law according to what is deemed appropriate for that area. For example, an area zoned for residential use would have land use and building restrictions that would prohibit industrial uses within that area (Catanese & Snyder 1979; Krueckeberg, 1983).

1.2 The importance of zoning

Health, safety, sanitation, social and economic equity, city beauty, humane and available housing; these are all obvious concerns and goals of citizens and their civic leaders. Is it possible for civic leaders to achieve these goals without any direct control over land use and building in their city? The contribution of sanitation technologies to the development of planning have already been noted. But there are other issues supporting the need for zoning. Health issues are related to varying land uses. Long-term exposure to some industrial processes can be hazardous. No one wants to live next to a toxic waste dump or any other property whose emissions are harmful or detract from the quality of life. Our history is full of examples: Love Canal being one of the most notorious, but plenty of others exist. In 1915, the 42-story Equitable Building was completed at 120

Broadway in New York City. The dimensions of this building were such that it created a shadow four blocks long and effectively shut out neighboring buildings from direct sunlight. This resulted in the loss of tenants, reduced tax valuations, and an increase in sickness for the owners and tenants of the newly shaded buildings (Krueckeberg, 1983). These cases and thousands of others have shown the need for some control over land use. The Supreme Court eventually agreed that government has the authority to protect its citizens in this manner. Thus zoning became the primary tool of planners and government officials (Catanese & Snyder 1979).

One may ask whether or not planning departments are just about zoning? Without question, there is more to planning than defining zones and writing ordinance amendments; but zoning is perhaps the tie that binds the various planning department roles. Zoning is a tool of planners and is often the *result* of their efforts to guide growth and development within a city. On the other end of the planning department spectrum, zoning is the *starting point* for code enforcement officers. While zoning is derived from the work of planners, code enforcement officers derive their work from zoning. Master Plan data is also a consideration and should be a part of a planning department's geographic database; but again, these plans eventually lead back to zoning ordinances. Land use data is also a key dataset, but normally it is an attribute of parcel data rather than existing as a standalone spatial object.

1.3 The importance of historical zones

Zoning evolves over time. City officials, planning staff, and citizen boards make and approve zoning changes as goals change, development progresses, and the city's social and economic landscape evolves. A local example is a former industrial area in Provo, Utah. The area once contained heavy-manufacturing industry including a steel mill. Eventually the steel mill closed down. Residential areas now encroach around the site and the site itself has undergone demolition and environmental remediation. Government officials have decided it will soon be the location of a minor-league baseball stadium and a park. In spite of these changes, some light-manufacturing industry still exists there and will continue to exist there. Whether or not the zoning for the light-manufacturing industry in the area changes, the original, or historical zoning, continues to govern the allowed land uses of those businesses.

Decisions to develop or buy an existing property, to appeal or accept a code enforcement decision by the city, or to determine the legal occupancy for a structure are often based on historical zoning information. Planning departments are consistently asked, both internally (Deller, 1996) and by the public, to query historical zoning and land use information. Citizens often need to know the current and past zoning for a parcel of land (Miami-Dade County; Sacramento County; Amherst City). Code enforcement officers need to know if the current land use of a property is allowed due to previous zoning or if the property is in violation of city codes. It is a common scenario to find that, due to the evolution of zone definitions over time, a land use which is illegal according to current zoning laws could potentially be protected under a grandfather clause. In spite of the need for historical zoning information, most municipal planning departments would reply with a blank stare if asked to reproduce the entire city zoning map at a specific date in the city's history. Studies concerning the economic effects of zoning or any other issue related to past zoning information are difficult or impossible to carry out simply because this information is often found exclusively in hardcopy files. A transit-based housing study in Los Angeles encountered this very problem. As they attempted to study the validity of claims concerning the benefits of high-density residential developments near rail stations, they encountered a snag in researching their study areas. In spite of the value of historical zoning information to their study, they were unable to procure it because it was "prohibitively expensive" to research. They also found "different municipalities keep historical zoning records at different levels of detail, and the codes changed at different times in different cities" adding additional complexity to the search (Boarnet & Crane, 1997).

As new zoning changes supercede old zones on the city's zoning map, the historical spatial information is often discarded with the old map. Even if a department is conscientious about keeping old zoning maps as changes occur, the information is not easy to query. So while the need for historical zoning information is constant, the ability to accurately and efficiently retrieve the information is in doubt.

1.4 The Current Process

A recent code enforcement case in Provo involved a man who was cited for storing a variety of building materials and farm equipment on a large, open property in a residential zone. The neighbors complained to the city concerning the apparent disarray of this man's property and its potential as a health and safety hazard for children in the area.

The man contested the citation he received before the city's Board of Adjustment. He argued his land was originally zoned for agricultural uses long before the zoning was changed and the residential neighborhood built. He therefore claimed under the city's grandfather clause that his property was exempt from the restrictions of the residential zone. The first step in this case was to verify the man's claim that his property was once legally zoned for agricultural use. The current process generally requires a week to ten days just for the city to make that "zone verification," as it is called. The delay adds to an already lengthy appeals process.

A seemingly simple request to verify the zoning for a parcel can translate into many staff hours. A city worker will need to produce an entire genealogy of zoning for that parcel along with related historical ordinances. The zone verification process is as follows:

1. The process begins with a search through County records for the history of the parcel in question. Generally this query will return many pages of textual information from the County's assessment rolls. Sifting through this tax information will often reveal circumstantial evidence of how the property has been used since tax records indicate the usage of the land and/or buildings. In the example above, the city would be interested if the property has been continuously taxed as an agricultural property. If a code enforcement officer were trying to determine the legal occupancy of a dwelling, these records might indicate approximately when additional units were added to the structure. If the additional units were added during

a period when the zoning didn't allow it, then a notice of violation could be issued.

2. The second step is to review the old building permits for that parcel. This may yield information to corroborate or refute the findings in step 1. If the city issued a building permit enabling a property owner to add additional units to his structure, then it is likely that was an allowed use under current zoning at that time.

3. The third step is to review past zoning for the parcel. For Provo (and likely many other municipalities) this is where the information gets even more sketchy. The source for past zoning information in Provo is a stockpile of old maps. Other than looking through the thousands upon thousands of paper files one by one, this incomplete collection of maps is the only other source. Each one of these maps must be unrolled and reviewed to determine the historical zoning for the parcel in question.

4. The fourth step is similar to steps 1 and 2. It involves reviewing old directories from the R. L. Polk Company. These directories allow cross-referencing of names, phone numbers, and addresses. Again, the purpose is to find circumstantial evidence concerning the property in question. If a property has been used as a duplex for many years then the Polk directories will *likely* indicate it by showing two separate occupants at that address.

Keeping accurate records of all this information *in a consistent form* throughout the life of a city is nearly impossible as technology, personnel, and organizational methods change. The recording of building permits in Provo is an excellent example of the dilemma facing any municipality that has kept records over many years. The form used to record and issue building permits has changed many times since building permits were first issued. At one point someone decided to put the building permits on microfiche. Before that project was completed the technology changed to a type of microfiche-roll film so someone threw the old microfiche away. Eventually computers came along. Now the original software used to store the permits is archaic (DOS) and a more conventional database is needed. To make matters worse, many structures in Provo were built when they were still part of the County, before annexation into Provo. Those building permits were thrown away by the County just a few years ago. Extracting the necessary information for a zone verification from the various files and historical databases is daunting. Unfortunately, in this case the result of such a time-intensive query is a questionable answer. One of the latest technologies to find a place among planning departments is Geographic Information Systems (GIS). Coupled with relational database management systems (RDBMS), GIS can approach the problem more broadly than ever before. The prospect of managing the enormous accumulation of planning information and municipal records is more feasible than ever before.

1.5 Planning, GIS, and Temporal GIS

Planning departments have been quick to use the cartographic and analytical capabilities of Geographic Information Systems to produce zoning maps, master plan maps, and land use studies. Planning is a spatially oriented discipline. It requires visualization to be effective. That's where GIS finds its application in the planning world. GIS enables the visualization of the spatial aspect of information. Rather than trying to make sense of a stack of code violation reports, the location of those violations can be visualized on a map, perhaps revealing a pattern yet unnoticed. Before creating a master plan for the city, a review of the spatial distribution of current land uses might add direction to the effort.

It is evident time-dependent, or historical, queries are inherent in the planning discipline, but GIS development has been slow to address the need for temporal integration with the spatial capabilities of GIS. Now momentum seems to be building in the temporal aspect of GIS research. For more than a decade now, geographers have been researching the possibilities of taking GIS beyond their time-stagnant planar worlds by adding the component of time. The adage that "those who forget history are doomed to repeat it" has application even in the world of geography and databases. Historical data can remind of past decisions, serve as a benchmark for current goals, or reveal patterns leading to the current state of affairs and enabling reasonable predictions of the future. Yet quite often as new information is brought into a database, the old information is deleted. That old adage can be quite literal for a person who finds himself having to reenter or recreate historical data for a database.

Current planning information, like a city's current zoning map, is like the tip of an iceberg. There is a staggering quantity of valuable, useful, and essential information below the surface. Temporal GIS has the potential to bring the historical spatial information back to the surface in a form that can be both visualized and queried. In turn, this spatio-temporal data can be a gateway to unlocking useful queries of non-spatial planning data as well due to the inherent links between zones and their related ordinances. If temporal GIS fulfills its potential, it will be a boon to planning departments as they struggle to keep up and effectively utilize their ever-increasing amount of data.

1.6 Temporal GIS Research

The renowned Swedish geographer, Torsten Hagerstrand, broke ground on the integration of time with the spatial world of geographers back in the 1960s (Hagerstrand 1967). A basic principle of Hagerstrand's *time geography* was that the reference frame defining spatial location is implicitly interlinked with the reference frame defining the flow of time. The result is a *space-time path* that follows the life of an entity as it travels a path through a framework of both space and time. Time geography gave researchers a method with which they could work with both space and time. The space-time path gave them a model with which to work (Wachowicz, 1999). It could be considered the first spatio-temporal *data model* for researchers of temporal geography.

In the database world, data models are a means of communicating and experimenting with the design of a database before it is actually created. An effective data model would store data efficiently. It also must be capable of quickly and accurately answering a variety of queries that a variety of users need. Creating the perfect data model is difficult; sometimes these two criteria can be mutually exclusive. Spatio-temporal data models attempt to represent both the geographic and temporal aspects of phenomena.

When you mix time with geographic features, the model's complexity grows with feature complexity: points are relatively easy to represent, dealing with lines adds more difficulty, and finally polygons can be quite complex. Then throw in topological relationships or network connectivity and things start getting pretty messy. Also, different types of features naturally change differently over time. This makes some features more complex than others.

An additional difficulty is found in the two types of time that can be represented in the data model: database time and valid time. *Database time* is the time when a transaction is made in the database; e.g. when data is entered or modified. *Valid time* is the real-world time associated with features in the database. For example, the date when a zone was created by city ordinance is valid time. The date when the zone is entered into the zoning database is database time. The data model can attempt to incorporate both times, but this adds a degree of additional complexity to an already complex task. While database time is certainly a necessary data model feature, the focus of this paper will be on modeling valid time in the zoning data model. Incorporating database time will be the focus of future research.

The simplest method for maintaining the history of spatial databases is the *snapshot model*. A "snapshot," or copy, is made of the database each time a feature changes or at an arbitrary predetermined interval; then that copy is filed away. It is common for zoning maps to be archived in this manner whether in hardcopy or electronic format. The snapshot method has the advantage of being quick, easy, and intuitive. It's quick and easy because it requires require very little time or effort to simply save a copy of a zoning layer or plot a new map. It's intuitive because everyone understands how to "query" a stack of historical zoning maps. All you need to know is the map date. In spite of these advantages, the problems with the snapshot approach are significant. A search through a large stack of historical zoning maps would be very time-consuming and tedious. Every map would have to be searched just to find the handful of zoning changes that occurred for parcel over the years. A computer search of the zoning layers has difficulties also. In a short matter of time, even with the improved storage capabilities of today's computer hardware, your data would multiply to become quite cumbersome. Querying multiple snapshots would be difficult. The most problematic maintenance issue (for both hardcopy and electronic snapshots) is perhaps the issue of corrections and delays. For example, most zoning maps probably don't exist without errors. What happens when you discover an error with the zoning map that dates back weeks, months, or even years? A snapshot model, if you were really concerned about maintaining an accurate historical database, would require not only correcting the specific snapshot from the correct date but also all snapshots between the date in question and the present. There is also the problem related to what is going on between snapshots. Concerning the pursuit of spatio-temporal data managment Chrisman (1998) stated, "...we will remain far away from the goal if we continue to think that the differences detected between snapshots capture all changes." In many cases it is not feasible to create a new snapshot for every minute change that takes place among features in the layer. Therefore many changes between snapshots can go undetected, particularly when a feature changes then returns to its original state.

Versioning is a method with similarities to the snapshot method. A version is a named state of a database. It could represent the zoning map or data layer at a certain point in valid time. A version is usually a snapshot of a portion of a database rather than the entire database. Using a zoning layer as an example, one or more zones could be extracted from a database as a *version* of the database. These zones could then be altered or updated, then saved back to the original database. Versioning is meant to allow a person to make changes to the data while maintaining access to the original version of the database. So while edits were being made to a few zone features, others could access and make edits to the database, even the same features, at the same time. When the feature updates have been made, they can then be applied back to the original version of the database (Zeiler, 1999). Potentially, these updates could be wound back to a precise point in time (Halls & Miller, 1996). Halls and Miller point out that for some cartographic applications, such as some CAD applications, this is a sufficient form of temporal GIS. It has been the focus of researchers such as Worboys (1993), MacEachren (1994), Maguire (1994), and Newell (1994). While versioning may be capable of presenting snapshots of database features as they existed in the past, it still doesn’t lend itself to modeling the progression of spatial features through time (Halls & Miller, 1996).

Since topological relationships are commonly used in spatial data, including zoning data, a temporal/topological database solution would have its benefits. For instance, topologically associated polygons are convenient for editing as well as cartographic display. A potential topological solution called the Space-Time Composite was proposed in a seminal study by Langran (1992).

> The mechanics of space-time compositing begin with a base map that represents a region's geometry and spatial topology at some starting time. Each database update session generates an overlay...Once accepted for permanent inclusion (having passed error-detection procedures), the overlay is incorporated into the system...New nodes and chains are added to the historical accumulation, forming new polygons that have attribute histories distinct from those of their neighbours. Each attribute history is represented by an ordered list of records. A record contains an attribute set and the time when that attribute set is valid...To compile a single time slice from the composite, one has only to 'walk' the history list of each polygon to locate the attribute set that was current at the desired time slice. (p. 42)

The space-time composite has some advantages. First, it can be implemented easily with current GIS technology. Second, it utilizes a straightforward algorithm for answering spatial and temporal queries. However there are some drawbacks. This model will become increasingly fragmented over time. As overlays are incorporated into the system, they break the layer into smaller and smaller fragments. Eventually fragmentation could result in polygon size on the order of raster cells or smaller. While this data model may be suitable for representing data over a short period of time, it could be a mess over long periods, particularly if the features being modeled change frequently.

One criticism levied by researchers of temporal GIS is that too many proposals to date have filtered their efforts through the constraints of cartography. In other words, the focus has been on the manipulation of points, lines, and polygons, "the primitive elements of static map display," rather than the fundamental relationships between the concepts of time and space. (Peuquet, 1994; Halls & Miller, 1996). The goal of Peuquet's research is to represent the concepts of space-time and geographic theory through what she calls "non-visual 'mappings' of reality." Through these abstract and conceptual "mappings" she hopes to discover new solutions which are less encumbered by cartographic constraints and are more accurate representations of our reality. These conceptual mappings can be applied back to the practical realm of technology and cartography. Peuquet's result is the TRIAD model, which utilizes three interdependent representations that basically answer the questions what, where, and when. These representations are feature-based (what), location-based (where), and time-based (when) and rely on links between them to create a spatio-temporal entity. The feature-based representation holds information that uniquely defines the entity. The location-based representation, as the name suggests, holds locational information. This representation is implemented as a raster grid. Grids are an excellent choice in this case, since they are inherently location-based, as each cell of a grid is defined by a precise location. The time-based representation is centered on events. The basic object in the time-based framework is an event and the time at which it occurred (Peuquet and Qian, 1996). From the perspective of planning and this paper, perhaps the most interesting aspect of this conceptual model is the identification of the grid rather than vectors as the basis for defining location. Zones are inherently location-centric as are zoning-related queries. The primary focus is generally on the zoning at a specific location rather than the zone's boundaries.

It's not surprising the TRIAD model makes sense conceptually since the whole idea was to create a model based on the basic concepts of space and time. But as one often finds with attempts at pure research, the result leaves one wondering, "now what do I do with this?" There is currently no avenue for implementing the TRIAD model in its current form. Conventional GIS and databases won't work so more research is needed to accomplish the task of model implementation.

Therefore the search continues for a data model capable of integrating time and GIS. No spatio-temporal data model currently exists which meets the needs of all potential applications. A model that might work for GIS applications geared toward the transportation industry (Zhao, 1997), (Shaw, 2000) or the electrical industry (Wakim and Chedid), (Yuan, 1999) is completely unsuitable for researchers applying GIS to archaeology. It's conceivable that there is no all-inclusive, one-size-fits-all, spatio-temporal data model. Similar to the basic choice of a raster versus vector GIS, perhaps each industry or application may simply need to apply time to their data in a way amenable to the nature of the phenomena they represent and the type of queries they need to answer. The spatio-temporal morphology of phenomena can vary quite drastically. Some phenomena change suddenly, like a wildfire whose size and shape grows continuously, while others change slowly and sporadically, like land usage which can vary greatly in an small area and may remain unchanged for years. In her book on temporal GIS, Monica Wachowicz (1999) identifies the need to approach the problem at the fundamental level and reality of the spatial objects we're trying to model:

> If we could decide, once and for all, which real-world phenomena should be represented as entities, relations or attributes in a geographic layer, our modelling task would be extremely simplified.. In fact, what we need is to understand the nature of time itself with respect to the real-world phenomenon that we are trying to represent in a GIS. In order to accomplish that, the emphasis must shift from organising space over time to *representing a real-world phenomenon in space and time.* This representation gives us an entirely different perspective to how we handle spatio-temporal data in GIS. It attempts to capture the complexity of space and time at the level of an indivisible unit - the entity.(p 4)

Wachowicz defines this indivisible unit as a “space-time entity representation.” Space-time entities have an interesting characteristic. The geographic space for them was created to solve a specific task. Based on the solution to this task, certain entities can be represented spatially while others become relationships within the model. If the task is approached from a different perspective, the roles could potentially be reversed. This approach was used extensively in the research presented herein.

The goal of this research was to create an effective spatio-temporal zoning data model. This model should be able to answer basic day-to-day queries confronted by planning departments, the most common of which are: “What did the zoning map look like on a certain date in the past?” and “What is the zoning history for a specific parcel?” A database capable of answering these questions will greatly diminish the amount of time planning staff spends in zoning research: what would normally take hours and sometimes days will take only minutes.

II. Conceptual Model

2.1 The entity-relationship diagram

In Wachowicz's attempt to model Hagerstrands' space-time path she identified the need for a spatio-temporal data model to "provide constructs for representing a knowledge domain in terms of entity/event abstractions,..." In other words, the data model needs to define events (e.g. when an entity was created or changed) separately from the entities (features) to which they are related. The advantage to modeling this way is that events can exist within the database and interact with features (entities) without depending on changes with the features themselves (Wachowicz, 1999). The conceptual zoning model presented here adheres to this philosophy.

Figure 1 shows the conceptual model in the form of an entity-relationship diagram. The diagram simply shows how one real-world entity is related to another real-world entity. The central hub of this model is the Ordinance event. Ordinances are laws created by city governments. They initiate the existence of all other entities in the diagram. They are not restricted to only planning issues; they can apply to any aspect of city government and business. Planners use ordinances to create zone boundaries and their related definitions. With this tool they hope to take the competing land and development interests within a municipality and guide them to a outcome beneficial to all residents.

The Zone entity is the main focus of this thesis. It represents an area defined by

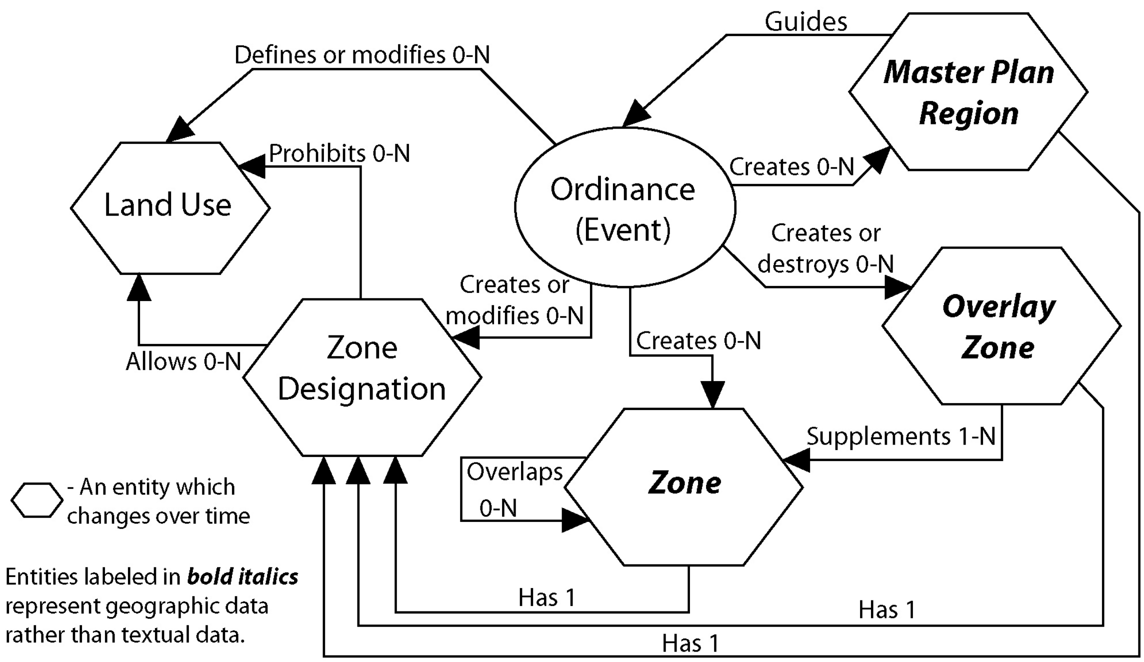


Figure 1: Conceptual Model/Entity Relationship Diagram

ordinance that designates the allowed and prohibited land uses within its boundaries. It is also a geographic feature with a distinctive set of characteristics which set it apart from other features.

2.2 The true nature of zones

A spatio-temporal *zoning* data model is going to differ fundamentally from other proposed spatio-temporal models because the spatio-temporal morphology is unique from many other phenomena. First, in the real world zones never move or change shape. They are created by city ordinances and are defined by a specific boundary, normally a legal (survey) description in the local coordinate system. They don’t mutate, expand, or contract. Rather than change, they are superceded implicitly by future zones as they are defined by subsequent ordinances, as shown in Figure 2. Movement over time along with evolving shape are often the primary concerns of those attempting to model the temporal

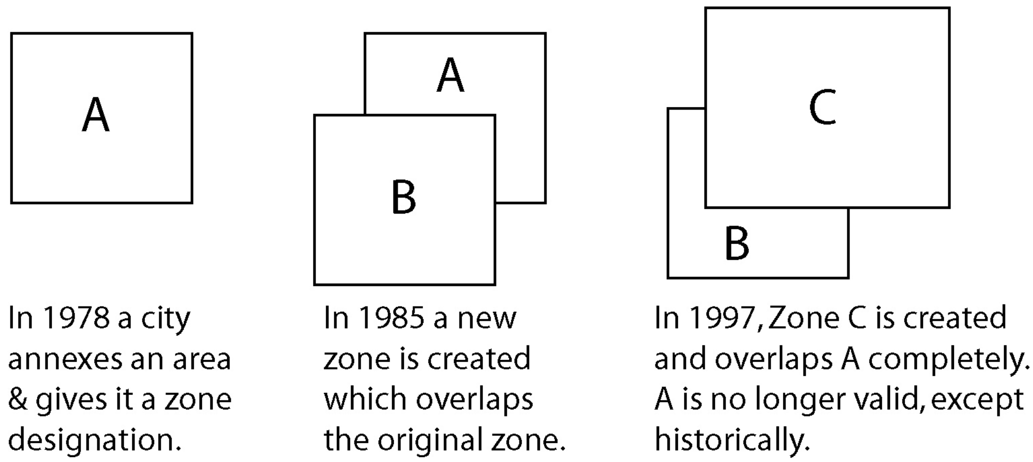


Figure 2: The overlapping nature of zones.

component of spatial objects. They are also the aspect of temporal data modeling that makes defining an effective model so difficult. These two concerns don't exist in the zoning model. Each object or zone is essentially its own immutable island defined by its own rules. This is the true nature of these spatial objects though they are not usually represented in a GIS this way. The removal of change and movement from the equation simplifies matters greatly for the database; but all the implicit relationships may make analysis more difficult. A second way zoning differs from other spatio-temporal models is reflected in the fact that zones don't die. They are never explicitly destroyed by an ordinance. As noted above, they are superceded by subsequent zones as these new zones are created by ordinance, but they don't cease to exist or cease to have continuing effect. The attributes of a zone apply to the structures and land uses within that zone for the specified time frame, even if in part or whole, the initial zone is superceded by another. Old zones never die, they live forever under the umbrella of a grandfather clause.

2.3 The other entities

The Overlay Zone entity represents a special kind of zone. Its function is sufficiently different to warrant representation as a separate entity. These special zones modify the definitions of zones they overlap. Another characteristic of overlays is that they don't follow the same overlapping pattern of regular zones. Essentially they always remain "on top" of the most current zoning. For example, an accessory apartment overlay zone might modify underlying zones to allow for accessory apartments in a zone that normally doesn't allow it (but only in the area specified by the overlay). Overlay Zones have another characteristic which differentiates them from regular zones: they can cease to exist. They would retain historical significance under the city's grandfather clause just as other zones, but they can cease to be currently applicable without being superceded by another overlay zone. The overlay zone can be repealed explicitly by another ordinance. In 2000, residents of a Provo neighborhood felt an overlay zone was harming their area. An accessory apartment overlay zone had been in effect in their neighborhood for many years resulting in many homes being turned into apartments by absentee landlords. They successfully lobbied the City Council to repeal the overlay zone returning their neighborhood back to its original residential zone designation.

Also indicated in the diagram is the Master Plan Region entity. The Master Plan Region entity represents an area of the master plan; the master plan being the 20-30 year guide to growth and development within a city. A master plan is like zoning, but it is generally simpler both spatially and categorically. Rather than designating an area as a residential zone with 10,000 square foot lot sizes, a master plan region would simply say an area is intended for low-density residential housing. The boundaries of a master plan region are normally generalized and are not intended to be strictly enforced, but occasionally they are. In Provo, the master plan has grown to be fairly specific, even down to the scale of parcel boundaries. The Master Plan Region entity can have characteristics nearly identical to that of the Zone entity depending on how the master plan changes. This can vary from city to city. In Provo, the master plan can continually be amended, just as zoning is continually amended. Other cities may simply adopt a master plan map for the entire city which remains without change for years. In this case, the various master plans for a city would be stored as snapshots.

The Zone Designation entity represents the law governing land use in each zone, overlay, and master plan region. The Zone Designation entity contains the legal definition of a particular type of zone. Each zone has just one zone designation. For example, “R1.10" is the zone designation for a certain zone entity. It defines an area where single family homes with approximately 10,000 square foot lots are allowed. General Commercial is a zone designation for a master plan region in Provo. It designates an general area where commercial land uses will be allowed. The S-overlay is an example of an overlay zone designation. In Provo, there is an S-overlay zone near Brigham Young University which allows homes in a single-family residential area to have an accessory apartment for student housing, something which isn’t allowed elsewhere in the city.

Most zone designations list multiple allowed and prohibited land uses for that particular zone. The Land Use entity defines each possible use (e.g. what is an "accessory apartment?"). As indicated by Figure 1, the Land Use entity changes over time. For example, a single-family residential unit is defined in part by its occupancy standard. It can be occupied by a single family or by three single individuals. This definition of a "family" can change over time. Perhaps a future city council will disagree with the notion of a home in a residential neighborhood being rented by three singles. They could alter the standard to allow only two singles, a number which would likely avoid excessive political contention, yet discourage the practice of renting to singles because it would not be feasible financially for the homeowner. The relationships between the Land Use entity and the Zone Designation entity define allowances and restrictions. The Zone Designation contains the text definition of the zone and allowed land uses which links directly to the definitions in the Land Use entity. Often the restrictions are implicitly defined by the allowances. In the R1.10 zone, only single-family residential structures are explicitly allowed, which implies that multi-family residential, commercial, and other uses are not allowed. Only specific types and sizes of signs are allowed within this zone, all others are prohibited. Other allowances are explicitly defined; e.g. garages, swimming pools, residences for the disabled, and non-commercial gardens are allowed in the R1.10 zone. The definitions of each of these allowances can change over time. Perhaps the standards defining a residential swimming pool versus a commercial or public pool could evolve over time.

The relationship of key interest for this research is the relationship between the

Ordinance entity and the Zone entity. This is where the important temporal relationships need to be worked out if a spatio-temporal zoning data model is to become a reality . One ordinance can create zero or many zones as indicated by the “0-N” in the diagram. This is also the case for the Overlay Zone and Master Plan Region entities. These three entities also share the same relationship with the Zone Designation entity. Each one “has 1" associated zone designation. In the majority of circumstances when an ordinance creates a zone, it ends up being a one-to-one relationship. The relationship in the diagram that both starts and ends on the zone entity is an implicit relationship between zones. It represents the overlapping that takes place when new zoning ordinances supercede older zoning. The Overlay Zone-Zone relationship line indicates one overlay can overlap any number of zones (1-N). The Zone Designation entity maintains a zero-to-many relationship with the Ordinance entity. Often this relationship will entail numerous amendments to existing zone designations. The Zone Designation can be broken down further into its constituent parts, represented by the Land Use entity. The many possible allowances and prohibitions are shown with the zero-to-many relationship lines. The allowed and prohibited land uses can also be modified directly by ordinance without the full zone designation being modified. The actual link between master plan regions and zones has already been described. The diagram demonstrates this relationship by the line from the Master Plan Region entity to the Ordinance entity. The master plan region “guides” ordinances which result in the creation of new zones.

The primary interest of this research is the *geographic* entities in the conceptual model (Zone, Overlay Zone, and Master Plan Region entities). The Land Use and Zone

Designation entities represent attribute information that is secondary to the geographic entities and has a spatio-temporal morphology that demands a completely different data model strategy. The needed queries for planning departments are based on historical zoning where the temporal placement of the zones is the key concern. All other information should be retrieved based in its relationship to the temporal placement of the zones. The focus will be further refined to the relationship between the Ordinance entity and the Zone entity. While studies related to the evolution of a city's master plan would be interesting and potentially useful, the chief concern here is to facilitate the day to day historical zoning queries needed by planning departments.

III. Data Model

3.1 Potential spatio-temporal data models

Of all the proposed spatio-temporal data models, which best accommodates the representation of zoning information? The best strategy is to choose a data model which can best mirror the real-world characteristics of zoning information. To date, representing zones as topologically associated polygons has been a common means of maintaining zoning data in a GIS. Unfortunately that model does not accurately represent the true nature of zones as previously described. It is possible to maintain a history of zoning with the topological model by taking a “snapshot” of the entire zoning layer and saving it with its database date before each new zoning update. The problems with the snapshot approach were outlined earlier in this paper. A second topological option is Langran’s Space-Time Composite. While this model is much better than the snapshot method, and perhaps still a viable option, it does have the excessive fragmentation drawback as well as not being a representation that accurately reflects the true nature of zones. It could also be a challenge to represent this model cartographically.

As pointed out previously, the issues surrounding a spatio-temporal zoning database do not include the need to know about changes in shape or movement. Perhaps if the choice were to pursue a topological model, changes in shape and movement could be considered issues due to the zones *appearing* to change shape and location. Again, that would be a departure from the true nature of the phenomena. Also, the changes could not be explicitly traced to the source documents (ordinances). Traditional topological models will normally merge together polygons sharing the same attribute (in this case, the zone designation) thereby destroying original zone boundaries and the unique identifiers needed to form a relationship back to the source documents. Zone nature is based on location. A zone is defined by its location. Queries against zoning data are based on location. Consider the example used earlier of a citizen needing to know the zoning history for a parcel. That is a query focused on a location. The question the code enforcement officer wants answered is about land use for a defined location. Arguably, a location-centric temporal data model already exists in the form of raster grids. A grid cell has a basic quality it shares with zones - a defined location as its primary characteristic. And that location can contain historical information. Seeing the benefit of grids, Peuquet said, "grid representations are more effective than vector representations for associating multiple characteristics at a specific location" (1994). That quote basically outlines a fundamental query of a zoning database. The query "what's the zoning history for parcel x" can be rewritten "what are the multiple characteristics (of zoning) at this location."

The conceptual spatio-temporal model Peuquet proposed is based in part on using the locational strength of grid representations. One advantage that grids afford is a single geometry. You don't have an ever growing database of features. The simplicity of rasters is very appealing. Providing the area covered by your municipality is not too great, even accepting the potentially cumbersome size of a raster dataset would not be too serious provided enough computing power was available. There are two significant drawbacks to using a grid as a temporal zoning database. The first is the fact that grids occasionally need to be resampled (Langran, 1992). Resampling an *image* is not a problem of course, but when each cell of a grid is related to a historical table of information, it is a problem. In resampling, grid cells are reassigned to a new grid based on sampling the cells around it. It is impossible to maintain unique cell histories if a grid were to need resampling. The second drawback is the fact that while a grid shares the fundamental characteristic of location with the nature of zones, it still lacks the ability to precisely describe shape. A grid just can't match the drawing precision of vectors when it comes to drawing a feature according to a legal description. When dealing with the legal issues surrounding land use restrictions, it is of the utmost importance that lines are drawn accurately and precisely.

3.2 The key to the solution

The key to modeling the locational and temporal nature of zoning databases appears to lie in the nature of the zones themselves. Zone characteristics can be defined implicitly or explicitly as shown in Figure 3 below.

Creation	Explicit
Initial Boundary	Explicit
Spatial Topology	Implicit
Boundary Changes	Implicit
Destruction	Implicit
Relationship to Parcels	Implicit
Relationship to Ordinances	Explicit
Relationship to Designations	Explicit

Figure 3: Zone characteristics and their relationships to the data model.

The explicitly defined characteristics are the only one that can be tied directly to documents and therefore will be stored in the data model. The implicit characteristics will not be explicitly stored in the data model, but they can be examined with spatial analysis tools in the GIS. Because spatial topology and boundary changes are difficult parts of spatio-temporal data models, their explicit exclusion from the data model simplifies the model greatly.

3.3 Events and relationships

Like the conceptual model, ordinances are the central events of the data model. The central box in Figure 4 represents a table of ordinance events. It is differentiated as a text-based table rather than a table of geographic features. It has already been noted in the conceptual model that one ordinance can create several different zones. This one-to-many relationship is indicated by the 1...* symbols in the diagram. Using an ordinance event table avoids redundancy in the database since each ordinance is stored once then linked to

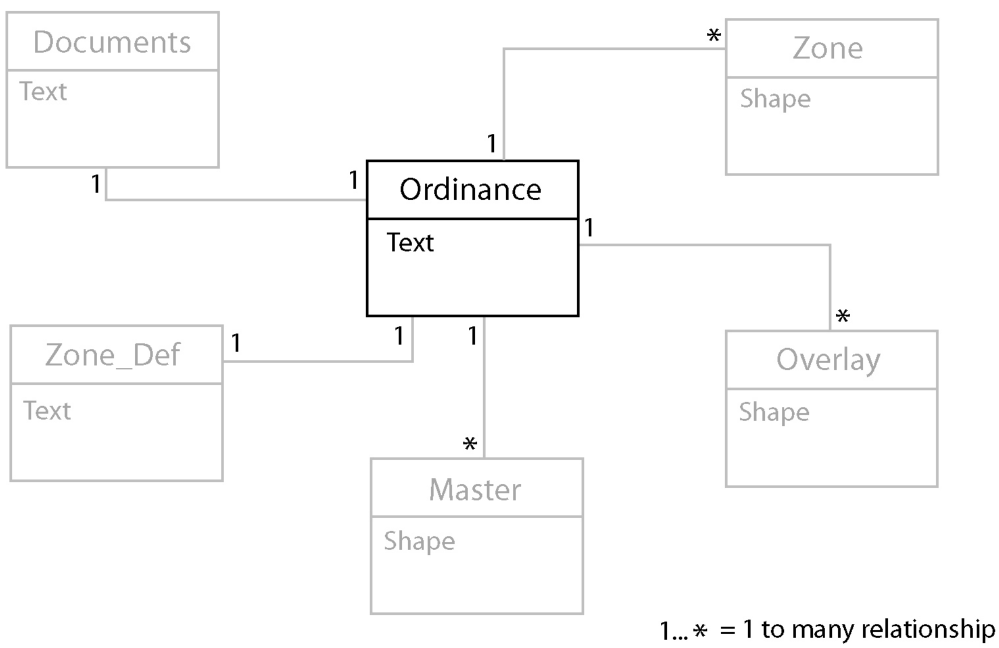


Figure 4: Data model event table.

other features by one-to-one or one-to-many relationships.

The Ordinance event table could potentially have relationships with more tables than shown here. Some of the essential tables are shown in Figure 4. While the Ordinance table contains the key identifying information for an ordinance, the Documents table holds the actual text of the ordinance (Doc_Text). The Zone_Def table represents a potential link to legal zoning designations. The Master and Overlay tables represent the master plan regions and the overlay zones described earlier. The key spatio-temporal concept being tested in this research is the Ordinance table - Zone table relationship (see Figure 5).

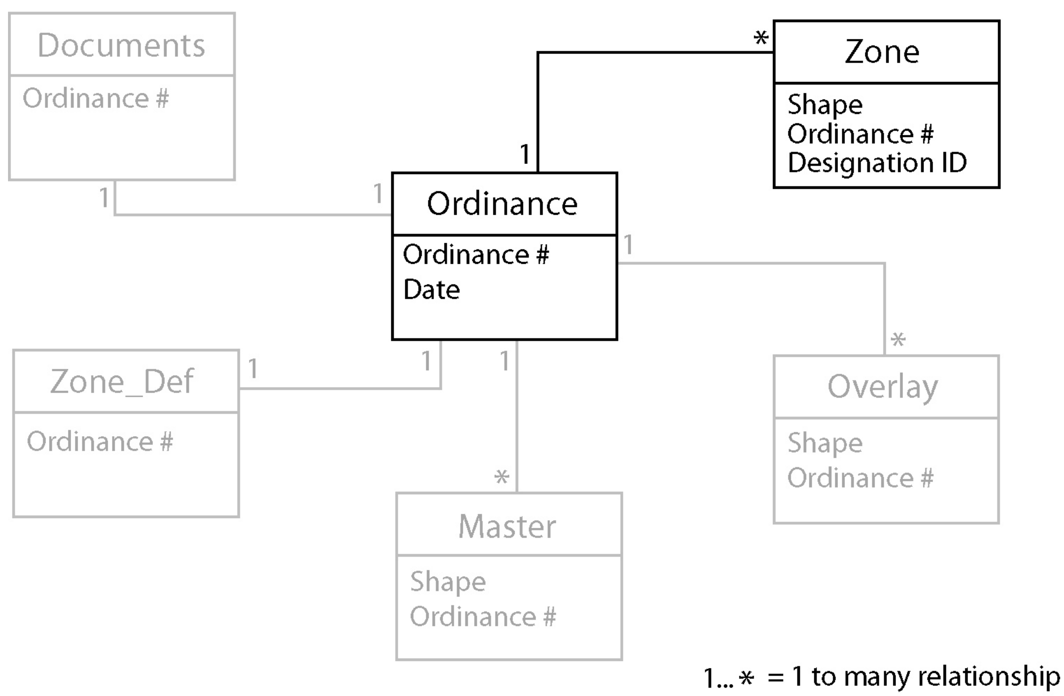


Figure 5: The relationship between ordinance events and zones.

The key fields in the Ordinance event table are an ordinance number field and a date field. Every ordinance is normally catalogued in city records by a unique identifier. That makes it an ideal primary key for the database. The date field would represent the effective date of the ordinance. The Ordinance table has a one-to-many relationship with the Zone table. It is important to note the simplicity of the Ordinance-Zone relationship. There is no complex structure of related tables to achieve the ability to perform temporal queries. The simplicity of the model can be attributed to having available and choosing a spatial feature that so closely resembles the real-world phenomena. If the natural characteristics of zones were slightly different in one way or another, the complexity of the model would increase immediately and dramatically. The Zone table contains all zone features ever created in the city. All of these features are non-topological polygons that happen to overlap each other. Their temporal nature can be modeled simply by having a link to the dated ordinances that created them. Those ordinances in turn can be linked to the zone definition as it existed at that time, a land use database, a parcel database or any other link deemed suitable for a particular planning department’s needs. Having a spatial feature in the data model that so closely resembles the features in reality creates a situation where the conceptual model can closely resemble the data model and database queries can resemble real-world questions.

IV. Implementation

4.1 The software and file structure used

The work of implementing the spatio-temporal zoning data model was done using ESRI's Arcmap software. The test data was placed in a personal geodatabase. The geodatabase model is a good choice for implementing data models because it is literally a relational database. This lends itself to a more direct implementation of data models. In the case of ESRI's personal geodatabase, a Microsoft Access 2000 database is the container for the necessary features and tables. For the purpose of evaluating the validity of the proposed zoning data model, the geodatabase was populated with just two tables: one containing ordinance information and the other containing the zones and their geometry. Each zone record was given the following attributes: an ordinance number, its full zone name, a zone label used for mapping (which would be a link to the zone designation table in the full data model), and an entry date (database time). The ordinance table was given two fields; one containing the ordinance number and the other containing the effective date of the ordinance. These two tables were linked by their ordinance number fields using a geodatabase relationship class. This relationship should aid in producing the types of queries needed from the zoning data model.

4.2 Test data

The Riverbottoms neighborhood in Provo (see Figure 6) was selected as the test area. It was chosen because it is an area that has undergone a large number and variety of zoning changes in the last 20-30 years. More than 60 zones were entered into the database from Provo rezoning ordinances and historical maps dating back to 1974. Some files were entered according to their official legal descriptions using COGO (COordinate GeOmetery - the system bearings and distances). Many were entered into the database by

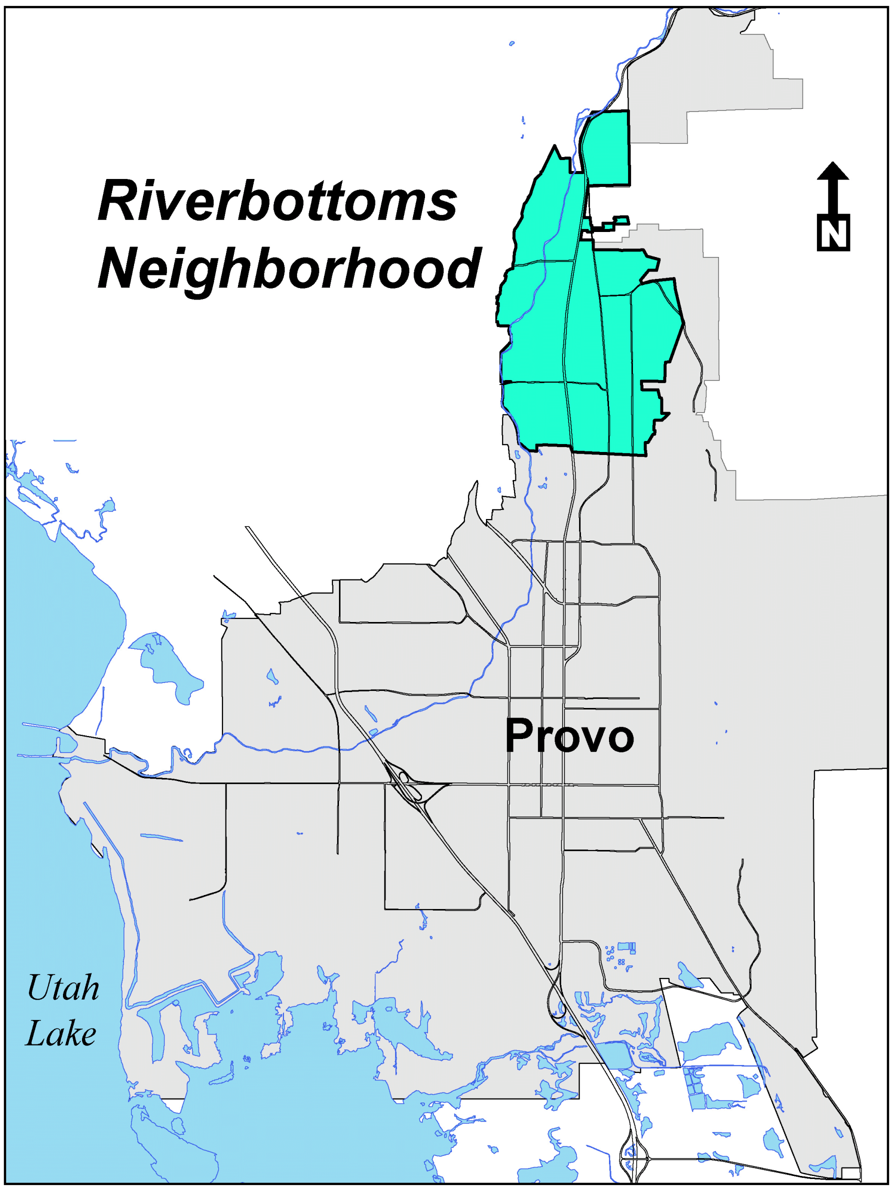


Figure 6: The test data area for the zoning data model.

snapping to features shown on maps in the files, normally parcel boundaries.

4.3 Classes of queries

Peuquet identifies three classes of basic queries and four modes of spatial analysis to run on spatio-temporal databases. The ability to perform these queries is a litmus test to gauge the effectiveness of a data model design.

1. The first class of query deals with changes in a feature (movement, changes in shape). This query doesn't apply to the zoning data model presented in this thesis since zones don't move or change shape.
2. The second class of query deals with changes in the distribution of features. This class of query would include producing the zoning map on a certain date in history.
3. The third class of query deals with the temporal relationships among multiple geographic features. This one entails the basic query sought after by the zoning data model: what is the zoning history for a specific parcel?

While the third class of query identifies the exact goal sought after in this thesis, Peuquet sees loftier goals that should be our focus. She insists the power of GIS is in spatial analysis and the identification of causal relationships. She outlines four modes of inquiry for spatial analysis. They are (Peuquet, 1994):

A. Exploration: identifying patterns of change through a sequence of images. The zoning data model can satisfy this mode of inquiry since zoning maps at any date in the history of a city can be produced and examined in sequence.

B. Explanation: identifying the factors that caused a change in distribution of features. The zoning data model could assist in this sort of query if other datasets are available. For example, if historical tax assessment data could be used in conjunction with the historical zoning, perhaps patterns of property values could be correlated with zoning changes over time.

C. Prediction: predicting the future distribution of features. If B can be done and evidence found correlating zoning to another phenomena, then reasonable predictions of the future should be possible.

D. Planning: what is the optimal distribution of features that will yield the desired goals? If you can do B and C with the zoning data model, you can do D.

It would appear that since the zoning data model apparently meets these criteria, that it can serve as a tool for spatial analysis as well as for basic retrieval of geographic information.

4.4 Running basic zoning queries

Even in light of the potential analytical uses of the spatio-temporal zoning database, perhaps the most useful query to run against this data is still the zone verification query. This is a basic query designed to fulfill the need within planning departments for parcel-based zoning histories. This query can improve both the efficiency and accuracy of planning decisions. The intent is to determine current and past zoning as well as the allowed land uses for the property in question. With this data model, the query is reduced to a common polygon overlay problem. Select the parcel in question, then use it to select all of the zoning polygons which intersect the selected parcel. The results will return a list of zones that can be ordered in a report by the effective date field in the Ordinance event table.

A parcel layer and the zoning table were brought into Arcmap and a parcel was selected (see Figure 7). This parcel has implicit relationships with zones in the zoning

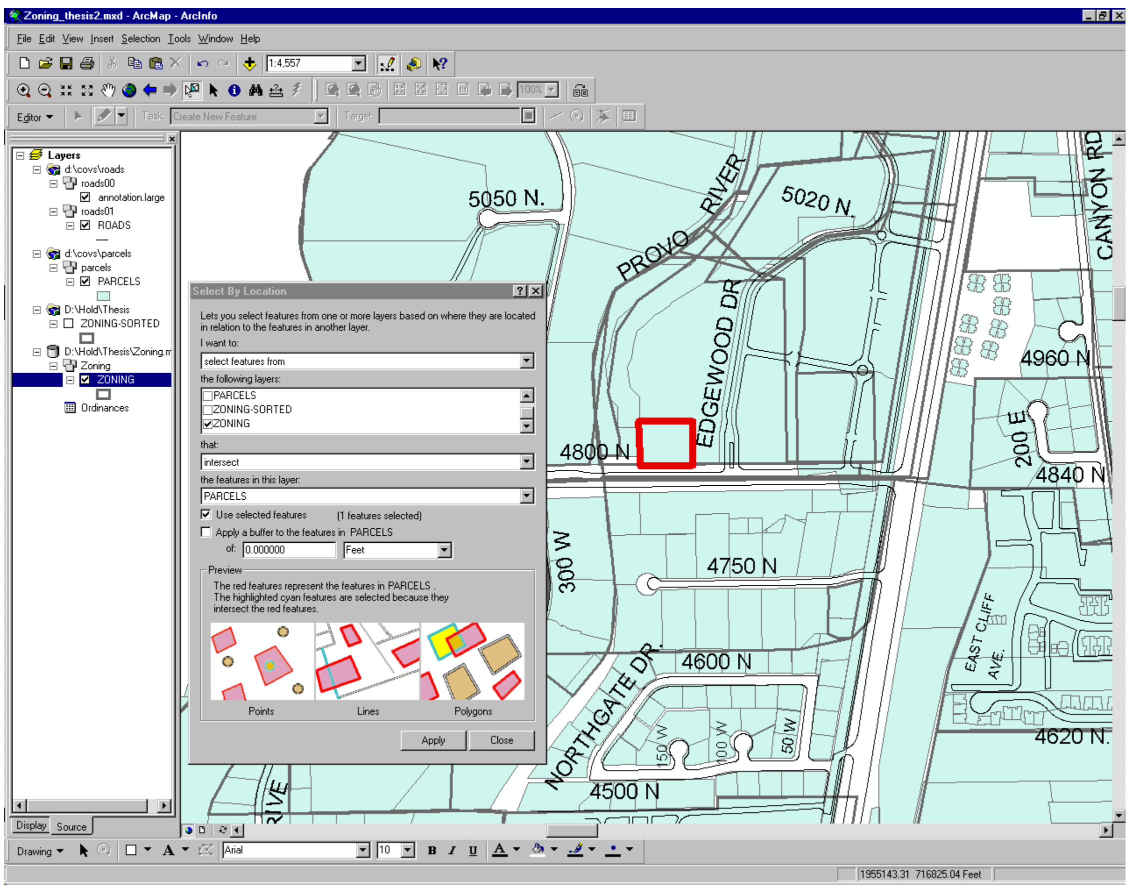


Figure 7: The intersection/overlay query in Arcmap. The selected parcel (red) is in the center of the map with the bold outline. Zone boundaries are the thick gray lines.

layer which overlap the parcel's boundaries. Using the Select By Location tool all of the polygons from the zoning layer which intersect the parcel were selected (see Figure 8).

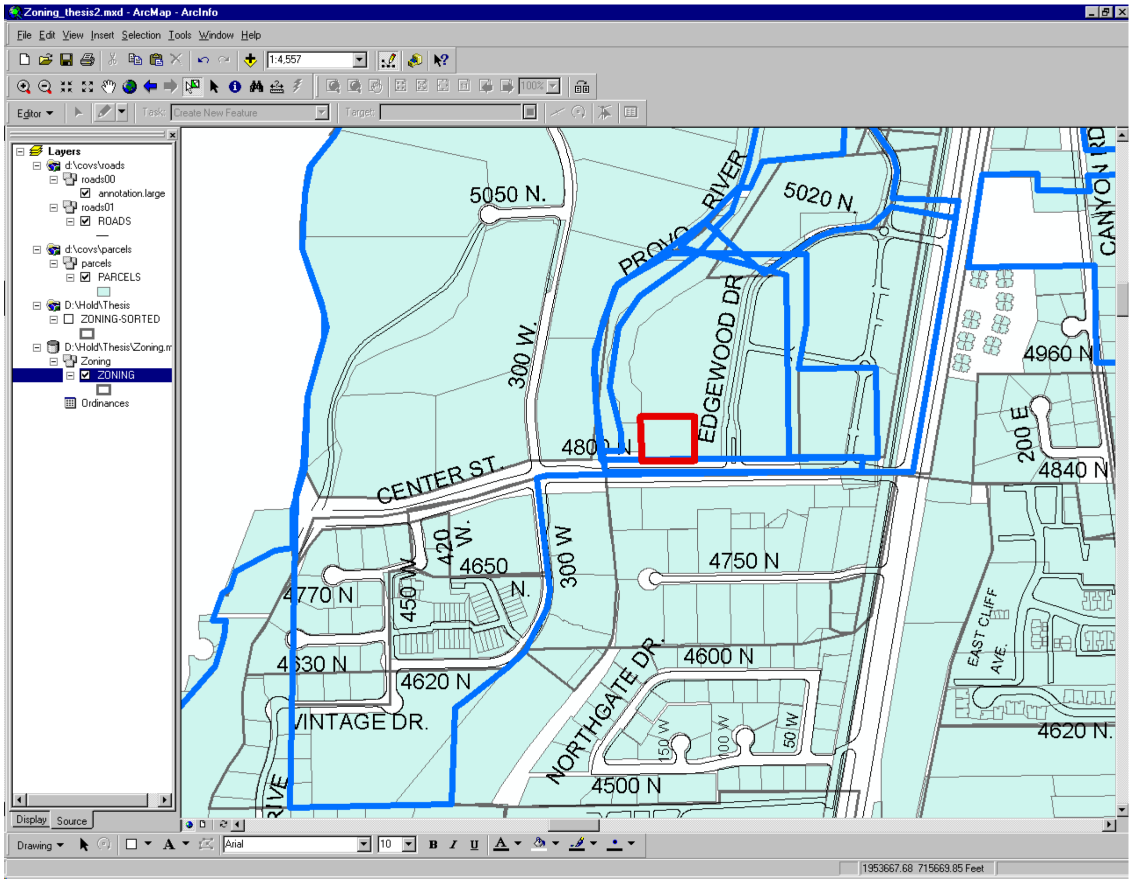
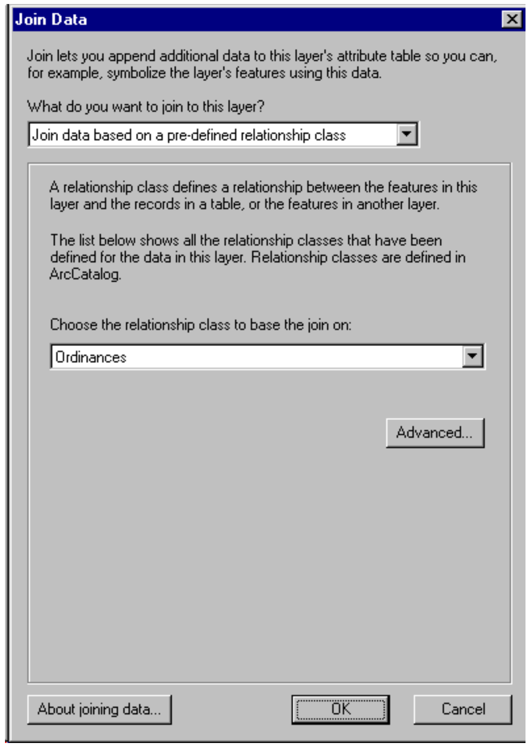


Figure 8: The selected parcel (red) with all of the intersecting zones selected using the Select By Location query (blue).

Since the ordinance date is an important piece of reporting information, the next step is to make it a part of the query. This can be done in Arcmap by combining the Ordinance and Zoning tables using a Join. Since the tables are linked via a previously created relationship class, it can be used as the basis for the join (see Figure 9). Then using a simple report tool in Arcmap, the selected zoning polygons can be placed in a report. The

Figure 9: The Join dialog box.



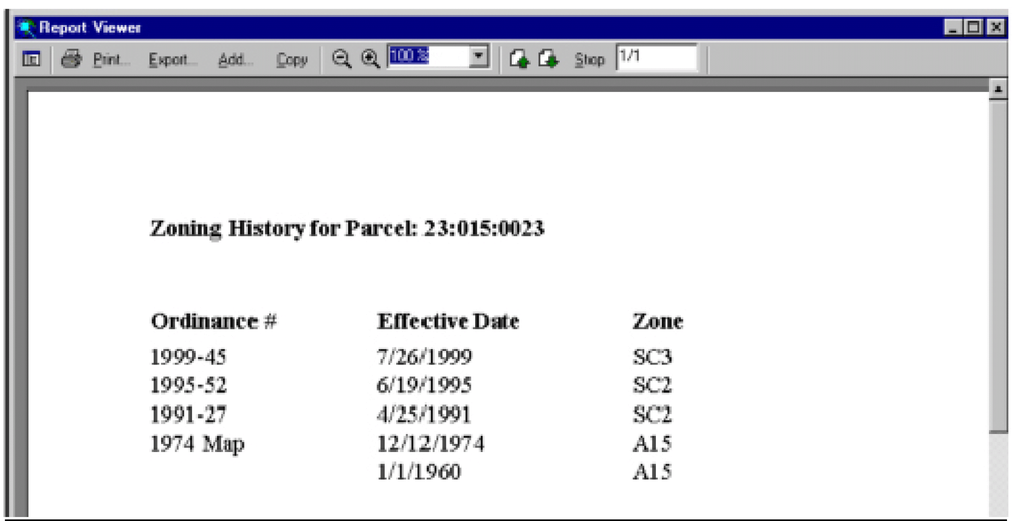


Figure 10: A basic report of the zoning history for a parcel.

query in Figure 10 can literally be done in less than a minute. If the complete data model were in place, this report could be enhanced with land use information and links to the ordinance source documents; in particular, the time-dependent information on allowed land uses as well as other information from the data model deemed relevant (see Figure 11).

Zoning history for parcel: 10:002:0011

Ordinance #	**Effective Date**	**Zone**	**Allowed Land Uses**
1999-63	1/25/1999	SC3	
		- Original definition	(A1)(C5)(E3)(M2)
		- 1998-36 amend.	(A1)(C5)(E3)(M2)(S1)(T3)
1997-03	3/31/1997	SC1	
		- Original definition	(A1)(B1)(C5)(M2)
1983-22	11/19/1983	PO	
		- Original definition	(P3)(R2)
		- 1997-11 amend.	(P3)(R2)(S4)(V2)
1972-10	9/27/72	R110	
		- Original definition	(F4)(G3)(H1)(I6)
		- 1970-14 amend.	(F4)(G3)(I6)
		- 1968-04 amend.	(F4)(G3)(H1)(L3)(N3)

Figure 11: An example of a report that could be done with a customized query and report.

4.5 Generating a zoning map

Another necessary query involves simply displaying the entire zoning map at any point in history. The most common task will be to create a current zoning map, but the map at a particular historical date will occasionally be useful. For the data model presented here, this task takes a little more work than would a traditional topological model. To produce the correct cartographic result, the strategy is to achieve the real-world overlapping of zones. By drawing more recent zones on top of earlier ones, the map falls into place visually. There are no extra steps needed to cartographically effect a zoning change; a new zone takes its temporal position and visually the map is set. Ideally, zones would be entered in the order they were passed by ordinance, that is chronologically. In the real world new zones are not necessarily entered in the order in which they are adopted. But they can be ordered easily using SQL. This can be done through the query dialog in Arcmap. First you must have joined the Ordinance table and the Zoning table as described earlier. Second, open the query dialog and enter the query shown in Figure 12. Keep in mind some syntax is not standard SQL, but is specific to queries on ESRI's personal geodatabase, like the use of [] in the expression.

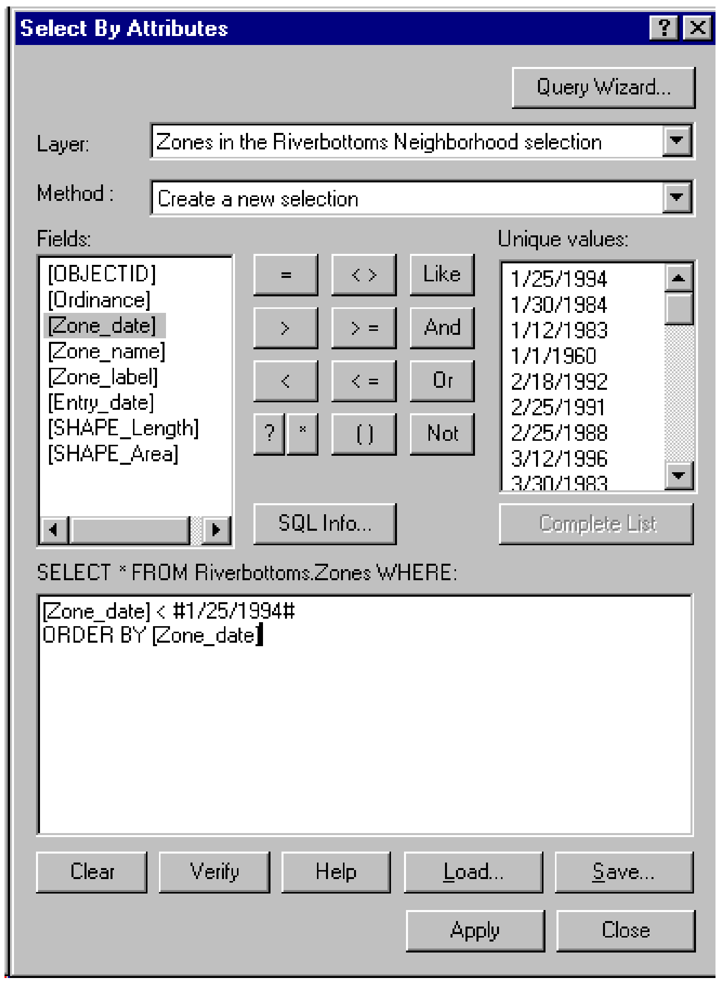


Figure 12: Query example that reorders the polygon drawing order and recreates zoning on a specific date.

The first line of the query selects every record earlier than a specified date. In the example the date is 1/25/1994. This would create a historical zoning map accurate as of January 25th, 1994. To create the zoning map for today, just put in today's date. The second line in the query orders the selection by the date using the SQL "ORDER BY" clause, where Zone_date is the name of the date field. The resulting date-ordered selection can then be exported to a shapefile or simply added to the Arcmap document as a layer. Then symbolize your new layer according to the zone designations. The implicit temporal relationships between zone polygons creates a layering effect that shows the correct zoning for the date used in the query. Figure 13 demonstrates the results of a query using the current date.

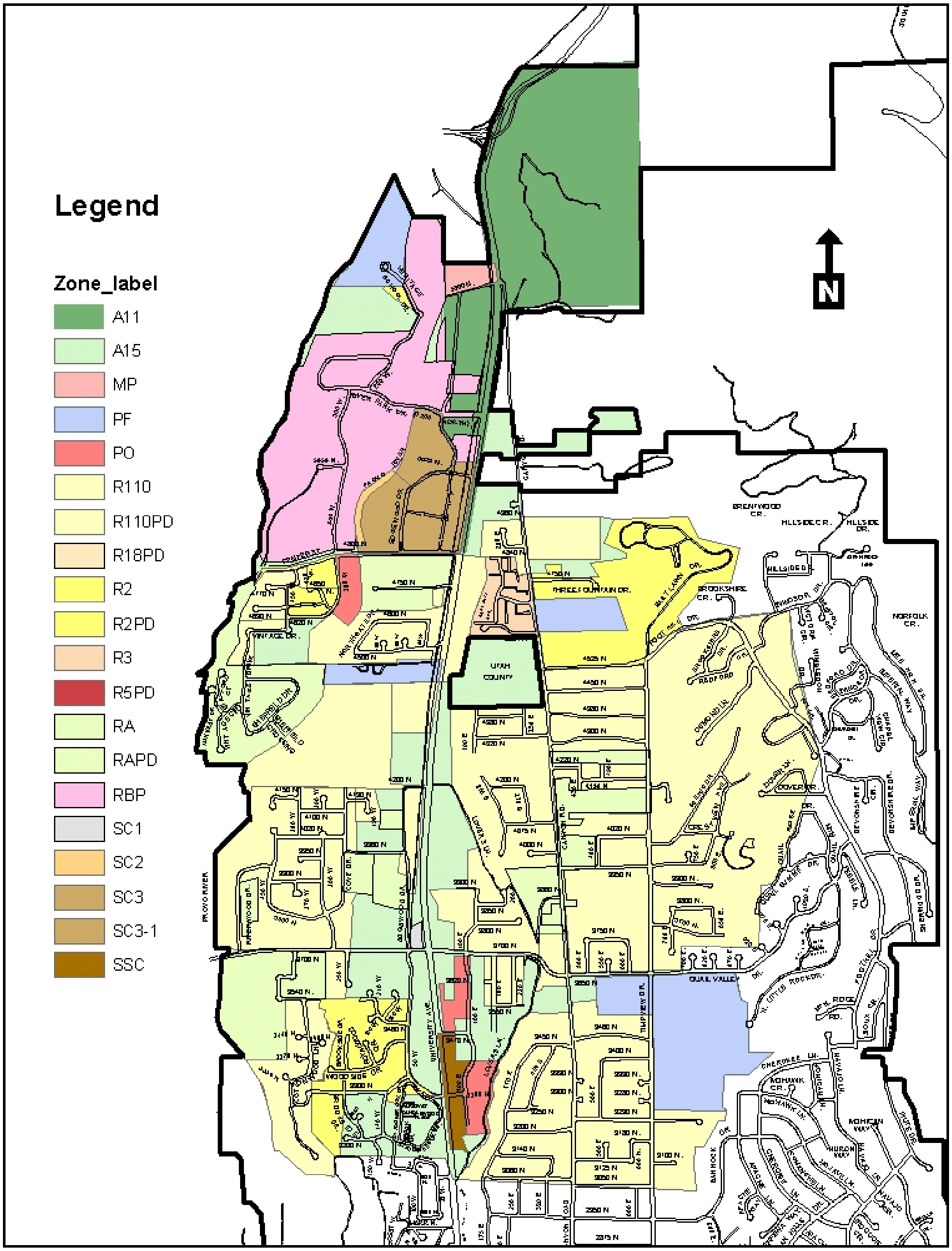


Figure 13: Producing a zoning map with a temporal query.

V. Conclusion

There is a growing recognition of the need for the integration of temporal information with spatial information. Unfortunately, implementing this integration can be extremely complex. Numerous conceptual data models have been created for the purpose of achieving this goal. Some models, like the snapshot and versioning models, are fairly simple but result in cumbersome data sets with limited usefulness. Other models, like Peuquet's Triad model, achieve spatio-temporal integration conceptually but are left with a difficult task implementing the concept within the framework of current technology. The goal of this paper was to create a presently feasible spatio-temporal data model for zoning information capable of answering a couple questions: what is the zoning history for a specific parcel? and what did the entire zoning map look like at a certain date in time?

First, the characteristics of an actual zone were identified and found to be very similar to a basic GIS feature: a non-topological polygon. The problem was greatly simplified by using a feature that can exist essentially independent of any other feature. In addition, other important characteristics of actual zones helped simplify the problem further. Zones never move, zones never change shape, and zones do not die. In the end it was shown that a relatively simple event-based data model with an event table at its center, was able to achieve the stated goals.

A tricky drawback of this spatio-temporal zoning data model is cartographic presentation. Unavoidably you will end up with adjacent polygons with identical zone designations. In a topological model, these adjacent polygons would normally be merged together in order to create a neat and unified boundary line around a “single” zone as well as a single label for that zone. Arcmap promises to visually merge features together without actually performing a data merge using its Advanced Drawing Options dialog box. Solving this issue through a visual manipulation may also be possible in other GIS software.

Since the work of planners is broad and this paper simply focused on creating a spatio-temporal data model for zoning only, there are obviously many ways this work can be further developed. Making ordinances and zone definitions fully searchable via the zoning data model is an enormous project in and of itself. Another enormous project inherent to creating any historical zoning database is recreating the necessary data. Considering the varying ways this information might be stored within a particular city and the accuracy of those records, that project would undoubtably be a tedious one and would require careful quality control; but it is feasible. In Provo, the zoning portion of this project would likely take the better part of a year to recreate. It would involve searching through city records for zoning and rezoning files; then using those files to redraw each individual zone according to their legal descriptions. The accuracy of the legal descriptions could hopefully be corroborated and problems mitigated through other sources of information such as maps or other descriptions which are normally found in zoning files. As the database grows backward in time, its usefulness would grow. Most zoning issues facing planning departments could likely be answered from information dating back just a few decades. Code enforcement issues would also need to be addressed and added to the database design.

As noted earlier, the master plan regions can also be stored in the same manner as zoning. Having this data in the database can create more queries that focus on analytical and predictive questions rather than the day-to-day queries presented in this paper. For example, one might want to determine the effectiveness of a city's General Plan. Did the General Plan designations 20 years ago result in the expected zoning and intended land use? Or how have property values or demographics changed since an area was zoned a certain way? Is past zoning responsible for creating or decreasing crime or other social problems in a specific area? These questions should be considered as the design of this database evolves.

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