A spatio-temporal data model for administrative division place names: a case study of Xiamen

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ABSTRACT

Place names are signs of geographic entities, and the database of which, a digital gazetteer, is an increasingly important form of geographic information. So the construction and the application of digital gazetteers are growing research areas. And significant progress has been made in the development of which, but there are still some vital issues that require further work: (1) Places and attributes related would inevitably change over time, but few gazetteer services model temporal ranges; (2) Current gazetteers do not normally hold historical information; (3) The relationships between place name entries are few considered in most existing digital gazetteers; (4) Geographic footprints currently used in gazetteers are usually confined to simple representations. In this paper, we proposed a spatio-temporal data model for administrative division place names, which are in a significant and large proportion of place names. We took Xiamen City as a case, located in coastal areas of Fujian Province, Southeast of China, to describe our model. In the model, we considered spatio-temporal changes and relationships between entries in gazetteers, and the footprints used are multi-scale patches adapting to hierarchical administrative system. Accordingly, our model could provide an important reference for digitizing gazetteers and further for implementing digital earth.

Keywords: spatio-temporal data model, digital gazetteers, administrative division, historical GIS

1. INTRODUCTION

Place names, which have specific spatial locations and spatial extent, are signs of geographic entities. They are often used to describe and to enquire about geographic information, so they play an essential role in communicating geographically-specific information [1]. Place name database, also termed digital gazetteers, is an increasingly important form of geographic information and is also an important foundation of digital city [2], so the digitization and the application of which have received increasing attention [3]. Digital gazetteers and gazetteer models developed in the 1990s [4], and significant progress in which has been made, for example, the well known Alexandria Digital Library Gazetteer (ADLG)[5], The Getty Thesaurus of Geographic Names (TGN)[6], Sydney TimeMap [7- 8], and China Historical GIS (CHGIS)[9- 10] etc., but there are still some vital issues that require further work: (1) Places and related attributes would inevitably change over time, but until now few gazetteers model temporal ranges, which are key factors indicating changes [11]. In many cases, only names are listed, with no founding dates [12]; (2) Current gazetteers do not normally hold historical information, such as name or boundary changes, and their temporal attributes [4]; (3) The relationships amongst place name entries are few considered in most existing digital gazetteers. Although some gazetteers have recorded historical place names and corresponding temporal duration, the entries in which were not related, that is, the hierarchical relations of place names entries being not considered in two spatial dimensions (e.g., the model proposed by Baogang Zhang *et al* [13]), and the evolution of relations between place names being also not tracked at different periods of temporal dimension (such as the model designed by Zhimin Man [10]). Actually, there exist relationships between entries stored in gazetteers in both spatial and temporal dimensions; (4) Gazetteers use geographic footprints to link place names to geographic locations, but the footprints currently used are usually confined to simple representations (i.e. points or minimum bounding rectangles (MBRs))[11, 14- 15]. Therefore, the current main way of visualizing established gazetteers is: assigning single pair (point) of or double pairs (MBR) of geospatial coordinates to each gazetteer entry. In fact, most of the current gazetteers generally store toponyms as point features with coordinate pairs, including Alexandria Digital Library Gazetteer [5], and MapTime [16] etc. However, simple point is not able to accurately represent the geographic extent of location [17] and MBRs would misrepresent features by oversimplifying the shape [18]. In the real

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world, under some scale, each place name obviously occupies specific spatial extent, so the visualization way of gazetteers based on polygon features is more appropriate to represent the real-world geographic entities. Therefore, considering and tracing historical names, acquiring the locations that those names occupied at different times, and understanding how these historical names relate to the current geographic entities, present many challenges to existing gazetteer services [11].

Place names are generally classified into two types [19]: one is natural geographic entities and the other refers to human geographic entities. And the administrative division place names, which belong to the later type, account for a significant and large proportion of place names [20]. So in the paper, for which, referencing previous digital gazetteers research and considering shortcomings existing in the previous research mentioned above, we propose a spatio-temporal data model (STDM). As the world around us is both spatial and temporal, we have a practical need for storing and processing dynamic geospatial phenomena that change over time [21]. In our model, we take both spatio-temporal changes and relationships between entries in gazetteers into account. Additionally, it is based on real administrative patches, instead of point. Thus, our model could provide an important reference for digitizing gazetteers and preferably representing place names in the real world. In addition, digital gazetteers are infrastructure of digital earth and are also the basic framework for organizing other geographic information. And it is well-known that the core of digital earth is a distributed, multi-scale, and multi-dimensional geographic information system (GIS), so Temporal GIS (TGIS) is one of the key technologies implementing digital earth [22- 24]. Furthermore, the core of key issues in digital earth research is the building of geo-database, and the key element of a database is data model [21- 22]. So, our model could also provide an important reference for implementing digital earth. In the following paragraphs, section 2 describes the characteristics of administrative division pace names; then section 3 elaborates on the data model we designed; and finally section 4 summarizes the advantages of the model we proposed.

2. CHARACTERISTICS OF ADMINISTRATIVE DIVISION PLACE NAMES

Administrative division place names are lingual signs, being created with the purpose of covering specific territorial and functional scopes over time by the government [20, 25]. Therefore, administrative areas have clearly identifiable locations and boundaries that are established by fiat [4, 26]. Generally, administrative division place names consist of administrative proper name and suffix word [20]. Proper name herein refers to the name for the place. For example, in the name of “Xiamen City”, “Xiamen” is proper name. Suffix word is the name of the administrative system, such as City, County, and Town etc. As the administrative divisions would be altered over time, the adjustment of administrative divisions has historical inheritance, and so administrative division place names have spatio-temporal characteristics and that of multi-scale as well.

2.1 Historical inheritance

The generation, development and change of administrative divisions were often caused by our human activities [20], and any adjustment of which was based on the previous divisions and systems [27]. While administrative division place names, formed in different historical periods, and would evolve with the historical development [20], so the change and the evolution of which have historical inheritance.

2.2 Spatio-temporal characteristics

Almost everything about an administrative unit can change, including names, hierarchical relationships, locations and boundaries [28]. In some cases, the footprint varied dynamically over time even if its name and hierarchical status remained the same [12]. And time is an essential element in tracking changes, without time there would be no perceived change [29]. The revision of administrative divisions enables administrative division place names occupying specific spatial extents at particular temporal intervals. Therefore, they have obvious spatio-temporal characteristics.

2.3 Multi-scale

Scale is one of the primary attributes in describing geographic data [30] and scale issue is increasingly recognized as a central concept representing the hierarchical organization of the world [31]. Place names in the administrative hierarchy are multi-scale in that among which there exist hierarchical relationships, affiliation of containing and that of belonging to, between place names at different scales. In this work, we took Xiamen City as a case, located in Fujian Province, southeast of China, and Fig.1 shows the hierarchical structure of administrative division place names. The historical evolution of administrative system would probably cause the scale change of place names. In some cases, the scale of place name would change with the history evolution even if the spatial extent of place name per se had not altered.

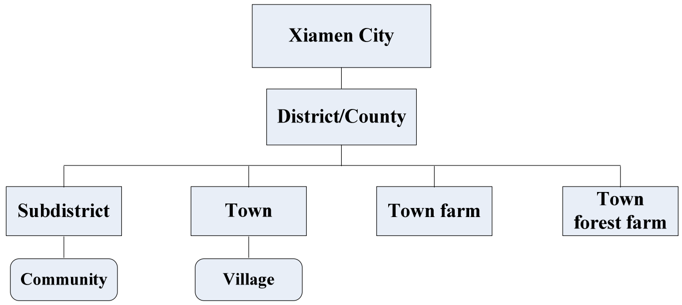

Fig. 1. Hierarchical structure of administrative division place names of Xiamen City.

3. STDM FOR ADMINISTRATIVE DIVISION PLACE NAMES

3.1 Change analysis of administrative division

Place names are the products of history evolution, and often change over time, so it is important to design an appropriate STDM for them and further the building of digital gazetteers. In the administrative hierarchy, each place name above the minimum scale (herein refers to community/ village) can be viewed as a set of basic administrative division units under its jurisdiction through a top-down approach. The adjustment of administrative division would result in the change of spatial extent occupied by corresponding place names. However, the spatial occupation of base units was rarely changed during a certain period. Based on which and on the three characteristics stated above, we proposed a STDM for administrative division place names.

3.2 Structure of the STDM

Being different from previous research, the model designed in our work stored spatial data and attribute data separately: current gazetteer entries and history changes of place names were stored in textual temporal database; while spatial patch data of current place names were that of Xiamen City (data granularity: "community/ village"), stored in spatial database.

3.2.1 Structure of textual temporal database

The STDM proposed in the paper, with limited spatial data, can retain the characteristics of spatio-temporal data of place names at different temporal and spatial scales, and then obtain an increase in the information amount of spatio-temporal database [32]. The textual temporal data of the STDM were stored in GeoDatabase, a relational database of Environmental Systems Research Institute (ESRI). The textual temporal database consists of one data table, and the structure of which is given in Table 1, where fields marked with an asterisk (*) in the upper right corner are primary keys.

Table 1. Table structure of temporal data with history changes of administrative division place names of Xiamen City.

Field Name	Field Description	Field Type	Length
OID	serial number	OBJECT ID	Default
PlaceName	administrative division place names	String	50
LevelType	administrative level (such as City, County)	String	10
UserID*	administrative division code	String	20
StartTime*	the date when the place name generated	Date	Default
EndTime*	the date when the place name being replaced or abolished	Date	Default
StartReason	reasons for the generation of the place name	String	20
BelongTo	administrative division code of superior affiliation	String	20
Contain	administrative division codes of inferior affiliation	String	600
PUserID	administrative division codes of parent place names	String	200
SUserID	administrative division codes of son place names	String	200
EndReason	reasons for the ending of the place name	String	20
LeaveNodeTag	Whether the UserID of the entry is current minimum administrative unit and whether the place name entry has corresponding spatial patch	String	2

(1) Definition of changes

In the textual temporal table, for "UserID" field value, we only assigned a unique UserID code to each current administrative division place name at all scales. But place names changed per se over time, so it is necessary to define their changes here. The change types of administrative division place names with division adjustment are shown as follows: (a) Change of administrative system; (b) Name change [10]; (c) Decomposition and combination of place names, the change of administrative spatial extent. The decomposition herein indicates narrowing of spatial extent, while the combination refers to expansion of spatial extent. With decomposition and combination of place names, new place names would generate and historical names would be replaced or abolished. (d) Combination of the above situations, such as both name change and extent change etc.

(2) Coding

UserID for administrative division place names in the textual temporal database was categorized into three types: current UserID, historical UserID and new UserID. Current UserID refers to the administrative division code of current place name. Similarly, historical UserID is the administrative division code for historical place name, and new UserID is that of new place name. The existing current administrative division code is composed of a 12-digit code, referenced the China National Bureau of Statistics [33] and the administrative divisions and history changes of Xiamen City [34]. While historical UserID and new UserID were both based on current UserID, to which the unique code was assigned according to the number of tracking back and the number of developing forward. The coding way in detail is shown graphically in Fig. 2.

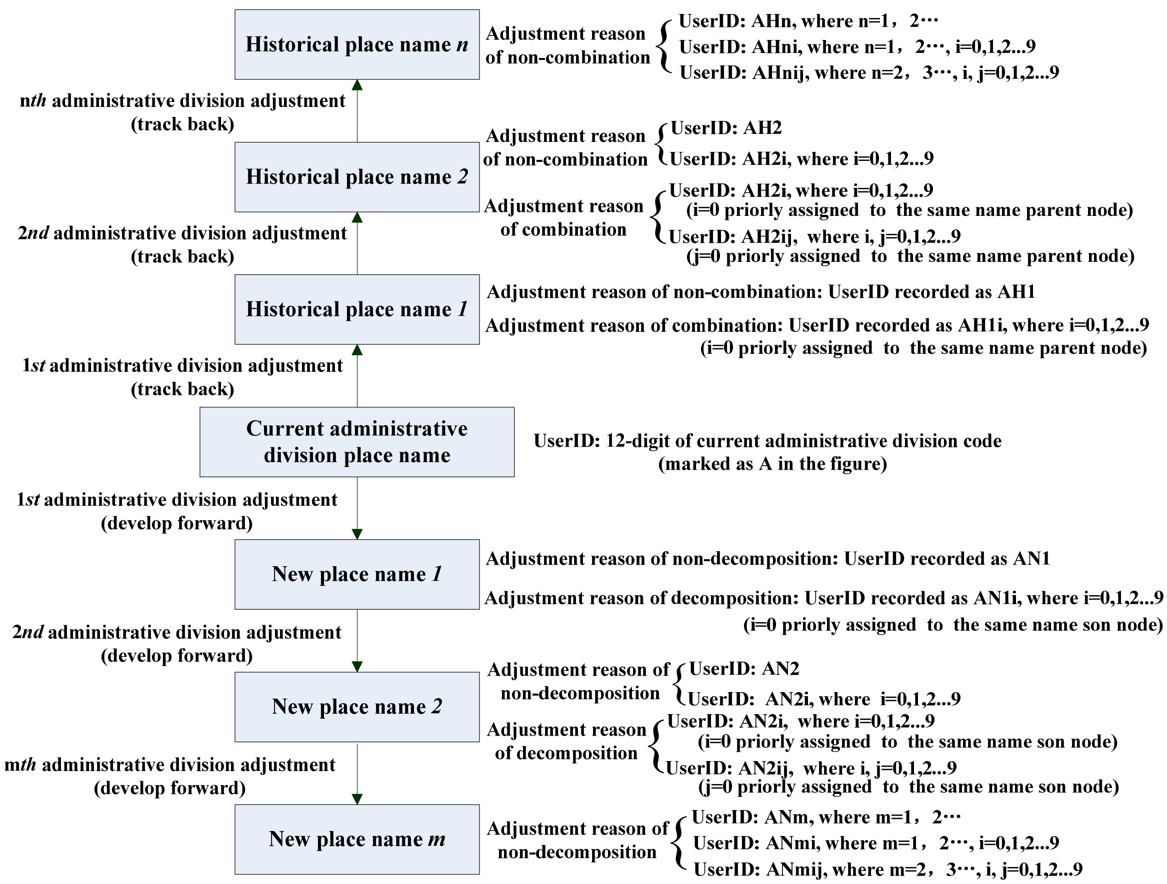

Fig. 2. UserID coding way of textual temporal database with history changes of administrative division place names.

Fig. 2 shows that the coding of historical UserID is based on the code of the current place name, adding Hn, Hni or Hnij according to the type of administrative division adjustment, where H represents historical place names, n is the adjustment number of the administrative division as tracking back from the current division, n runs over 1, 2, 3, …; the digit number after *n* is the combination number occurred when tracing back, i, j indicate the n^{th} adjustment was caused by combination, and i=0, j=0 priorly assign to the parent node with same name, while the sibling nodes of which are given a unique digit in sequence, the value of i, j is 0, 1, 2, …, 9. For example, the current administrative division code of Siming District is" 350203000000", on the temporal duration between 1^{st} adjustment and 2^{nd} one when tracking back from current division, the UserID of Siming District is "350203000000H1". Similarly, the new UserID is by adding Nm, Nmi, Nmij at the end of current administrative division code according to the type of adjustment, where N indicates new place names, m is the number of change developing forward present administrative division, the value of m is 1, 2, 3, …by parity of reasoning , he coding expanding way of developing forward is similar to that of historical tracking back.

The coding way of UserID is preferably expansible and feasible. When expanded, the previously built code is still available, needing no revision. According to the complexity of change and with the elongation of history tracing back, the digits of code can be extended flexibly. In our work, the most complex evolution situation when tracking back is two combinations continually, so the most complicated UserID code is Hnij. If more combination happens when tracing back, just expand the digits after Hn to the combination number.

In our STDM, only to the current place names at all scales and to the place name entries changed per se, the unique UserID were assigned. While for those name records which only involved in the alteration of its administrative affiliation and have no involved in the changes defined above per se, the name entry was cut into multiple records by the time point or points where their corresponding superior (inferior) affiliation place name changed. Meanwhile, the UserID of those newly cut records remains the original one. The method of dividing records is shown in Fig. 3.

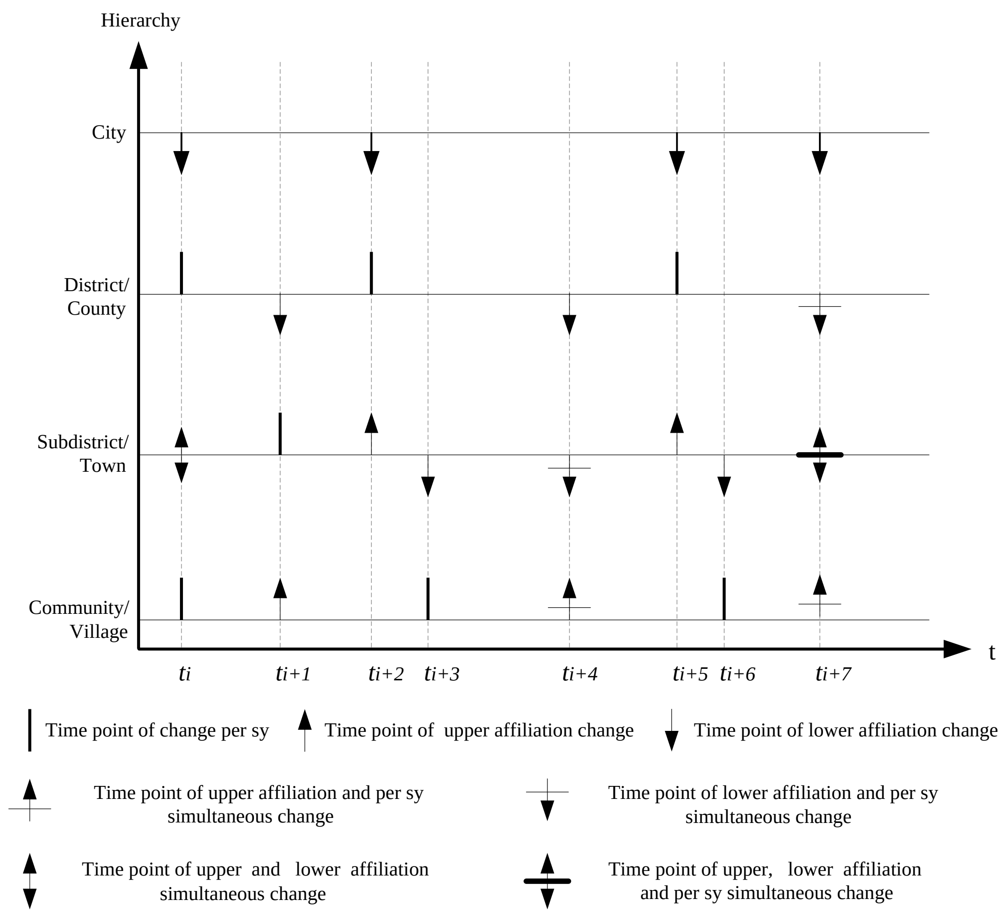

Fig. 3. Seven change types of administrative division place names with hierarchical structure.

In this way, the data redundancy is reduced and also the temporal change and the evolution relations of administrative affiliation are retained. In the textual temporal data table, the total record number for each place name is: the time point number where the entry changed per se + the time point number where its superior affiliation changed + the time point number where its inferior affiliation changed+1.

3.2.2 Structure of spatial database

The spatial data of the STDM was stored in GeoDatabase as well, and the spatial data in the study is" administrative district polygon data of Xiamen City", attribute table of which is shown in Table 2.

Table 2. Attribute table structure of administrative district polygon data of Xiamen City.

Field Name	Field Description	Field Type	Length
OBJECTID	serial number	OBJECT ID	Default
Shape	geometry type	Polygon	Default
UserID*	administrative division code	String	15
District	district name	String	50
Town	town name, subdistrict name, town farm name, town forest farm name	String	50
Village	community name, village name	String	100

The "UserID" field in the spatial database is the current administrative division code (12 digits) which corresponds to the current administrative division place names at the minimum scale. To each place name patch of the minimum scale in the spatial database a unique UserID is assigned. And the "UserID" field is key code when digitizes administrative name through relating textual temporal database to spatial gazetteer database.

3.3 Spatio-temporal database of administrative division place names

3.3.1 Textual temporal database

(1) Building of the textual temporal database

A temporal database is one that contains temporal data, being classified into 4 types: snapshot database, rollback database, history database and bi-temporal database [35]. The textual temporal database built belongs to history one. History database stores and manages the process data of event and change of status of objective entity at valid time point. The schema of history database is (A1, A2, …, An, Start Time, End Time), (Start Time, End Time) is the valid time of event. The main characteristics of history database include: (1) supporting valid time, (2) small data redundancy, and (3) relatively simple structure. Time granularity is the minimum temporal unit with which to describe temporal data [36]. As for the adjustment of administrative division name, the change generally occurs on "day" scale, so the time granularity is "day" in our study.

Lots of statistics literatures and official websites were referenced [34, 37-42] to obtain the history evolution information of place names and to validate name changes. The textual temporal database is composed of one table, and a partial of the table is given in Table 3. In which the change information from current tracing back to 1995 were recorded.

Table 3. Table of temporal data with history changes of administrative division place names of Xiamen City.

OID	UserID*	PlaceName	Level	StartTime*	…	EndTime*
1	350203000000	Siming District	District	2004-09-01	…	Now
2	350203000000H1	Siming District	District	2003-04-26	…	2004-09-01
…	…	…	…	…	…	…
16	350206003000	Heshan Subdistrict	Subdistrict	2004-09-23	…	Now
17	350206003000H1	Heshan Town	Town	2003-12-01	…	2004-09-23
18	350206004000	Jiangtou Subdistrict	Subdistrict	2004-09-23	…	Now
19	350206005000	Jinshan Subdistrict	Subdistrict	2004-09-23	…	Now
…	…	…	…	…	…	…
1231	350203003015	Shuixian Community	Community	2004-09-01	…	2006-04-01
1232	350203003015	Shuixian Community	Community	1995-01-01	…	2004-09-01
1233	350203003015N1	Wen'an Community	Community	2006-04-01	…	Now
…	…	…	…	…	…	…

“BelongTo” and “Contain” fields refer to hierarchical relations of containing and belonging to between place names in gazetteers in spatial dimension, while “PUserID” and “SUserID” fields are inheritance relations in temporal dimension. For place names on the minimum scale, the “Contain” field value is “NULL”, while for names having no upper level unit, such as “Xiamen City” is the top level place name in the work, so the “Belong to” field value is marked as “NULL”. At a specific period, each name entry has one upper level name, and it may contain lower level ones one or more, so the “Contain” field value is often a UserID set. One place name would probably be generated by combining one more historical ones, namely having multi-parents, so the “PUserID” field value would be one UserID or a UserID set. The “PlaceName” field recorded current and historical place names. For current name, the “EndTime” field value is set as “Now”, revising the field value when it changes. The possible value domain of “StartReason” is {“generate”, “name changed”, “spatial extent expansed”, “spatial extent narrowed”} etc., and that of “EndReason”[43] is{“administrative system (i.e. County, Township etc) change”, “name changed”, “spatial extent expansed”, “spatial extent narrowed”} etc. For the name entry with the minimum granularity and existing corresponding spatial patch in spatial data, its “LeaveNodeTag” field value is marked as “T”, otherwise marked as “F”.

According to the characteristics of place names mentioned in section 2, the relations between historical name, new name and the spatial administrative extent which consist of current basic units could be explored: the corresponding administrative division code or code set of current base unit to the name of current non-basic unit, historical name and new name are able to be obtained through that of their inferior affiliation and/or through tracing that of their son nodes or parents nodes. For historical place names, through tracking their SUerID in textual temporal database, a UserID or UserID set, of which the real administrative extent corresponding to their temporal period consisted, could be obtained. While as for the new names, similarly, by their PUserID, a UserID or UserID set that composed of the spatial area at specific period would be gained.

(2) Uncertainty and incompleteness of the textual temporal database

When we move backwards in time to earlier epochs, the presence of uncertainty, ambiguity, incompleteness, inaccuracy and contradiction in the geometric and attribute aspects of geographic information is well known [28, 44]. These are a particular issue for historical GIS because they are common within historical sources [28], and they are common in almost all historical research areas. Thus, for spatial history, geographical and temporal information are particular challenges [12].

In our work, the textual temporal database only track the historical changes back to 1995, in that changes of administrative base units before 1995 cannot be checked. Therefore, when the “StartTime” is before 1995, we set its value as “1995-01-01”. When building the temporal database, although we have referenced a great number of literatures, statistics data and official websites, there still remain some uncertainty issues, in which the largest uncertainty is: for some administrative division place names, change information can be acquired, yet it is difficult to obtain the accurate time point when the change occurred. To conform temporal granularity to “day”, in this paper, for accurate time granularity of month, we defaulted the day value as “01”, and for the temporal accuracy only reaching year, set the digits of month and day as “01-01”. The temporal database built can satisfy the digitization and query for the place names after 1995. For the tracking of adjustment information before 1995, further change information needs to be acquired and checked in future work, which leads to the improvement of the uncertainty and incompleteness of the temporal database.

3.3.2 Spatial database

Spatial data was current administrative division vector data of Xiamen City, and its attribute structure is given in Table 4.

Table 4. The attribute table of administrative division vector data of Xiamen City.

OID	Shape	District	Town	Village	UserID
1	Polygon	Siming district	Binhai subdistrict	Yanwu community	350203005001
2	Polygon	Siming district	Binhai subdistrict	Huangcuo community	350203005008
…	…	…	…	…	…
90	Polygon	Tong’an district	Wuxian town	Sanxiushan village	350212110215
91	Polygon	Tong’an district	Lianhua town	Xidong village	350212105218
92	Polygon	Tong’an district	Lianhua town	Neitian community	350212105204
93	Polygon	Tong’an district	Datong subdistrict	Dongshan community	350212001206
94	Polygon	Xiang’an district	Xinxu town	Jinbing community	350213103204
95	Polygon	Xaing’an district	Neicuo town	Liantang villlage	350213111206
…	…	…	…	…	…

3.3.3 Relationship of the spatio-temporal database

(1) Relationship type

In the real world, there exist relationships between objects and within ones, which were represented through relationships between entities and that of within entities in the information world [45]. Three types of relationships between two entity types are [46]: one-to-one (1: 1), one-to-many (1: *), and many-to-many (*: *).

(2) Relationship type of the spatio-temporal databases

The relationship type between place name entry in the textual temporal database and record or records of the spatial database is mixed ones, including one-to-one and one-to-many. For place names with different scales, their digitization way varies. For base unit names, the type is generally one-to-one; while as for the names on scales higher than the minimum units, the relationship is one-to-many. When related, gazetteer entries in the textual temporal database were firstly traversed according to temporal period. Then based on the corresponding superior affiliation, inferior affiliation, parent node(nodes) and son node(nodes), a UserID or a UserID set of spatial data corresponding to current place names can be obtained. The UserID or UserID set is key code. The relationship between textual temporal data table and spatial data table is shown in Fig. 4. This relation way is relatively flexible.

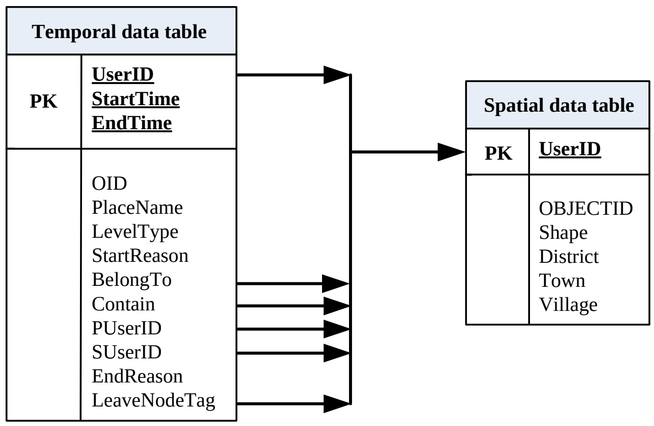

Fig. 4. Relationship between temporal data table and spatial data table.

3.3.4 Digitizing place names

Through the data model proposed in our work, a UserID or UserID set of current place names on the minimum scale could be acquired from the textual temporal database, which comprised place names on all scales and historical names at specific time periods, to which "UserID" field of spatial data was related. Using the top-down approach in the administrative hierarchy, the digitalization of place names was implemented accurately.

3.4 Functions of the STDM

The main functions of the spatio-temporal database for administrative division place names based on the model designed in the work is shown below: (1) The temporal database recorded historical changes, so actual spatial administrative extent at a particular period for place names on all scales could be obtained, then could precisely digitize place names at the particular period; (2) Through the bridge of textual temporal gazetteer, it is available to standardize the key code of relationship between one place name entry in the temporal database and a record or records in the spatial database, then enhance the digitization accuracy of place names; (3) Track historical changes of a particular place name at different temporal periods, and then view its evolution graphically and dynamically over time; (4) The model structure gives possibilities to store temporal dimensions and to analyze changes in name status and usage, and the gazetteer temporal scope makes available the reconstruction of administrative division at any hierarchical level for the requested time period, so further could generate historical map data automatically; (5) Query the adjustment reasons and further descriptive information for historical changes, and acquire administrative affiliation of place names at any scale etc.

4. CONCLUSION

Compared with previous digital gazetteers and data models, the STDM proposed in the work has these advantages: (1) Preferable expansibility. Before the change of the total boundary and of the basic administrative unit boundary, place names on all scales at different periods which consisted of the minimum scale ones could be added into the textual temporal database through the proposed model; (2) Less data redundancy. Only the spatial data of current place names on the minimum scale were stored, instead of storing those of place names at all administrative levels repeatedly; (3) Considering both spatial and temporal dimensions. The model recorded hierarchical relations of entries in the digital gazetteers on all scales in two spatial dimensions, and also considered and traced the evolution of relations between place names at different periods in temporal dimension, so it is possible to visualize the place names at different temporal period and at different administrative levels; (4) Preferable visualization way. Previous digitization way of point feature, when the number of history change or new development increases, some points of geographic names would overlay, and this would inevitably impact the visualization effect of gazetteers negatively. In our work, footprints used were polygon features, which are more appropriate to visualize place names in the real world. Avoiding the overlay phenomenon of points existed in previous data models, the place names' visual effect was improved.

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