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SPATIO-TEMPORAL DATABASES AS RESEARCH TOOL IN HISTORICAL GEOGRAPHY

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Abstract

The present article[1] discusses difficulties in the practical application of spatio-temporal databases to geographical-historical research. Apart from undeniable assets of introducing database tools to historical studies, research practice implies also quite significant difficulties related to the unreliability, incompleteness or imprecision of historical information. These features, along with the subjectivism of historical inferential methods (their susceptibility to interpretation), should be taken into consideration when creating Historical Geographical Information Systems (HGIS). Thus assembled, historical information becomes easily accessible for secondary interpretation (source scheme). The critical scheme of any database, created jointly by historians, engineering ontologists, and data modelling specialists, should account for both the 'expediency' and 'processuality' of historical phenomena, as well as the complex nature of spatio-temporal objects (the ongoing dispute between endurantists and perdurantists).

Key words

historical GIS • spatio-temporal databases • historical geography

Introduction: Terminology

Historical reality, just as modern reality, for that matter, is multi-layered and multidimensional, i.e. extremely complex. A historian might observe only its fragments or selected elements, whereas the stipulations of global history, though constantly developed, have been partially fulfilled through a shift in research interests, and not through their expansion. The impediments to applying IT solutions such as databases or spatial information systems to the humanities arise, to a degree, from the 'two cultures controversy', i.e. the discrepancy between exact

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sciences and humanities (Snow 1959). History belongs to the world of humanism, whereas databases or geographical information systems are more likely to be ascribed to the realm of positivistic science. Thus, the question which emerges pertains to how these two 'worlds' and two 'cultures' could cooperate and support one another so as to better and more fully comprehend both our contemporary reality and that of the past. There can be no doubt, however, that the division suggested by Snow (1959) refers to methods of cognition, description and presentation of reality, and not to reality *per se*, as it is always one. Hence, a great bridge to link the 'romantic' (historical) and positivistic (scientific) description of reality is constituted by ontology which attempts, even if with varying success, to work out uniform methods and criteria for the assessment and description (presentation) of entities or 'beings' occurring within reality, as well as of their mutual relations (Bodenhamer 2010; Kemp 2010).

The possibility to save and store in databases the geographical attributes of historical data turns them into vital tools of accumulating, ordering and disseminating geographical-historical information. Multi-userness of database systems decides about their significance for historical-geographical research teams. Nevertheless, the question of IT tools and their usefulness in the humanities, including history, continues to polarise academic communities. Enthusiasts clash with sceptics who question the usefulness of IT solutions for the purposes of historical research. Both the unconditional approval of these methods and their outright rejection result from lack of knowledge of the very tools themselves, as well as the potential limitations and challenges their use entails. The main aim of the present article is to provide a provisional evaluation of practical difficulties which arise when applying spatio-temporal databases to historical geography. Already the narrowing down of the scope of our interest here to spatio-temporal databases should alert researchers to the danger of an indiscriminate and uniform treatment of all available solutions, both in terms of software itself and methodology. Each and every tool should be tailor-made to suit a given research object.

Even though the article will focus on the challenges of applying spatial databases to historical research, already the initial use of such tools points to enormous advantages they hold – not only do they facilitate the accumulation of geographical-historical material, but also allow for a very effective spatial and geostatistical analysis. Thanks to databases and GIS applications, the cartographic method acquires new quality. Alongside the speed and efficiency of analyses, their precision and suggestive visualisation, spatial databases help overcome one of the major problems in historical geography research – they facilitate a permanent and orderly accumulation and storage of source material. So far, maps and geographical-statistical studies have mostly been illustrations of research results, whereas the collected source material remained in the archives of authors or research teams, frequently suffering from dispersal or even obliteration. Efficient and constructive criticism of studies or maps from the last century often calls for reaching back to the archives and, in a way, beginning work anew. Thanks to spatio-temporal databases, queries conducted by individual scholars and entire teams alike will come to constitute a unique information bank about places in past, phenomena, people and events related to them, in this way making it possible to reopen discussions on global history as it has been written on the basis of space.

Historical geography

The notion of historical geography in the context of Polish historical and geographical studies differs quite substantially from how it functions in Western Europe. Many misunderstandings are due to narrowing the scope of historical geography to only the history of cartography or historical cartography which play but an instrumental role in relation to historical geography and history. It is not possible to study history without knowing geography, or to separate geographical space from its historical context – all around is the result of complex historical processes. As Kelley has aptly noted (2010: 22): "History has always been geohistory."

The last serious methodological debate between historians and geographers took place in 1953, with the major contenders then Labuda (1953) and Dobrowolska (1953). In 2004, Geremek and Kula voiced similar reflections in their introduction to the Polish edition of Braudel's study on the Mediterranean during the reign of Philip II, in which they recalled the notion of 'geohistory' as introduced and further discussed by Braudel himself. Nevertheless, there can be little doubt that throughout the last 50 years historical geography has been studied and understood separately by historians and geographers, with probably the best expression of this distinctiveness being the 2003 publication of Baker's work under the symptomatic title of *Geography and History: Bridging the Divide*, which at the same time points also to the awareness of how necessary methodological reflection on historical geography is.

Without getting into too broad methodological disputes on the mutual relations between anthropogeography, historical geography and geohistory, historical geography should be conceived of as a sub-discipline based upon two pillars, namely – history and geography. Its primary object of study is geographical environment in the past, understood broadly both in its physical and cultural dimension. While geographers are normally much more interested in the past of the natural landscape (e.g. geomorphological changes), historians usually focus on the old cultural landscape (settling, borders, sociogeography). Thus, historical geography is also frequently categorised as belonging with humanist geography, geography of humankind, or geography of culture (Holdsworth 2003). The beginning of the 21st century has been marked by history re-claiming space – in light of the theory and practice of the 'spatial turn' (Schlögel 2009; Withers 2009). In the context of Polish historiography, the re-claiming of space by history could be seen as a re-discovery of postulates proclaimed by two Polish historians, widely recognised as authorities in the field:

- Without either a geographical chart or the knowledge of geographical conditions (especially topographic), contemporary historians are at a loss to grasp and analyse a wide range of historic phenomena (Semkowicz 1948);
- A minimal description of the past embraces, apart from time and space, also human actions (Topolski 1998).

Databases

The term 'database' commonly denotes:

- A type of computer software which enables users to accumulate data, store and analyse them (e.g. MS Access, Oracle, PostgreSQL);
- A concrete collection of data built with the aid of specific database software (e.g. employee database, 18th century sacral objects database).

Most generally, databases fall into three types: relational databases, object databases, and object-relational databases, with the first type being the most widespread, including as well spatio-temporal databases – STDBMS, which have greatly expanded over the course of the previous several decades (Abraham & Roddick 1999). In contrast to classic database systems, STDBMS are able to store temporal and spatial data through specialized column types. Extensive date fields facilitate an efficient storage of temporal data – along the classic DATE category, they also use entries such as TIMESTAMP, TIME, INTERVAL; some of the more advanced systems have even separate fields for PERIOD. At the users' disposal is also a wide range of temporal operators which can be used in queries.

Another element which singles out spatio-temporal database systems is the possibility to record within them also geographical attributes which, in their primary topology, divide into points, lines, and polygons. As in the case of temporal data, geographical attributes are accompanied by special operators which enable queries on distances, objects' areas, lengths, crossings, adjoining or overlapping objects. Option packages, in turn, enable users to model spatial data with regards to the stored geographical and descriptive input. Most popular databases which facilitate recording and saving spatial data include Oracle – in the sector of commercial applications (extension Spatial), and PostgreSQL (extension PostGIS) and MySQL (version 5 and newer), among free applications.

The necessity to adjust databases to the requirements of history and historical geography led to the emergence of a separate nomenclature for historical database systems – HDBMS (Sarda 1990), which now – due to the advancements in spatial databases – are often further defined as geographical-historical. In his textbook on historical systems of geographical information, Gregory uses the term of 'Historical GIS Databases' (Gregory & Ell 2007). Most generally, spatio-temporal databases enable users to store, analyse and share information on a variety of phenomena (descriptive attributes) in their spatial dimension (geographical attributes), accounting, too, for chronology (temporal attributes).

Challenges

Despite a marked increase in literature on spatio-temporal databases, a complex and mature methodological reflection on their application in historical geography is yet to come. Historians, geographers and IT specialists tend to focus more on presenting the practical usages of the databases and sharing the results of their investigations conducted on the basis of IT tools, in which technological reflection predominates over a historical methodological one. Significantly more is being said on using databases as tools for the presentation of research results than on their applications in the capacity of heuristic and/or hermeneutic tools. The major obstacles to a full and fruitful utilization of databases usually occur during the consecutive stages of collecting, storing, critically evaluating the source material, and finally – transcribing the findings of the assessment onto records in the form of database entries.

In the majority of expert literature on historical database systems, which most frequently refer to the 19th and 20th centuries (e.g. the Great Britain Historical GIS, Historical GIS Germany), databases are treated as loci for storing administrative and demographic data. The sources and lists are regarded as being of a systematic and mass nature, whereas maps which constitute the basis for geographical attributes are often characterised by quite a high degree of accuracy and precision. Less frequently – and with more reluctance – they are applied to research on the pre-statistical era. A historian of the early modern era, and a medievalist in particular, faces an ever greater challenge in that he/she has to account for those features of historical sources which substantially complicate their application to database systems, i.e. their implied incompleteness, imprecision, and uncertainty. All of the above might in turn affect each and every aspect of historical information – time, place, and content (Plewe 2002). While acquiring data for descriptive attributes, the historian stumbles upon difficulties and obstacles unheard of in classical information systems. The already mentioned incompleteness, imprecision, and uncertainty of source information – both with regards to the object of study and the chronology and dating procedures (Bodenhamer 2010) – forces the researchers to come up with a distinct model for the utilization of databases, starkly divergent from the classical one.

So pertinent to the humanities, interpretive subjectivism dictated by the background, formal preparation, and even psychological-mental traits of the researcher emerges already at the notional level (evaluation: river, brook, stream). Another element which needs to be considered in the context of creating historical database systems is the necessity to account also for the Event – Process relation. While historical sources usually provide information only on singular facts whose dating precision might vary considerably, narration in general makes use of processes and timelines structured on the basis of both the events as such, and the entire complex methodological apparatus (Styliadis & Vassilakopoulos 2005). One of the fundamental difficulties to overcome is transforming historical events into IT processes registered as records with the DATA_START and DATA_END attributes. Given the genetically static nature of GIS (O'Sullivan 2005), such sources are put to better use in research into singular episodes, rather than in investigations of long-term processes.

As has already been stated earlier, spatio-temporal databases not only facilitate the storage of historical data, but also enable the users to re/construct and record a geographical image of the past which most frequently is the result of cooperation between a historian and a cartographer who in its creation rely on written and cartographic historical sources. Within systems of geographical information, distinction is made between primary data capture and secondary data capture. In the case of historical data, secondary sources visibly dominate, e.g. old maps (Gregory & Ell 2007). However, using old maps as matrices for preparing historical maps is saddled with many difficulties. The older the map, the lower its accuracy. In the case of Polish areas, maps which can be used in GIS applications date back only to the 19th century and the cartography of occupant countries. Earlier maps, including the 'flagship' works by Perthees from the second half of the 18th century unfortunately cannot be utilized as cartographic basis, even if the latest advancements in geo-referential solutions are called upon for assistance (Affek 2012; Szady 2012).

Solutions

The above-enumerated problems might be at least partially solved through a skilful construction and application of spatio-temporal databases. One of the solutions might be to divide the scheme of databases into two parts – source and critical (resultant) which should be linked to one another through a network/web of adequate relations. A source scheme of any given database should store ordered data in their literal historical form, whereas in the critical scheme they should be already processed by a historian on the basis of his/her findings relating to the contents of the source level. For instance – the source scheme of a database will feature the following record: "1350, plebanus de Laczna; 1480, ecclesia parochialis in Leczna", whereas the critical part will contain the following information: "The Łęczna parish was founded before 1350, and was functioning properly in 1480" (Fig. 1).

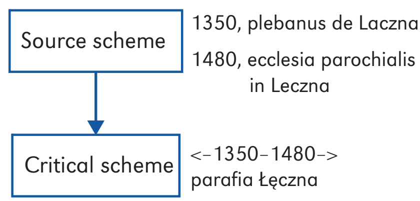

Figure 1. Division of a historical database into source and critical schemes

The legitimacy of such a procedure is determined by the necessity to conduct team work, with the evaluating historian granted access to complete source basis. The above-presented division partially solves the problem of recording uncertain or incomplete data which are contained in the source scheme and might any time become subject to reassessment following a supplementation of missing information. This would also enable the historian to comprehensively capture the collected source material. The hitherto conducted research investigations into colonization processes or the history of state or church administration practically make up exclusive projects, with one of the consequences being that each successive researcher, especially of the younger generations, faces the challenge of confronting and responding to the results of these studies. In order to offer an apt critique, the historian frequently finds him/herself forced to reach out to sources already analysed and much discussed. A case in point might be the lists included in the publications of the Historical Atlas of Poland (Rutkowski 1998, 2008) referring to the history of colonization and territorial administration, or Litak's studies of the historical geography of the Latin Church (1996, 2006). Every researcher wishing to broaden and elaborate on the issues taken up in the said sources is practically made to reread the sources in their entirety.

So far, the theoretical considerations of the representation and ontology of geographical space with regards to geographical information systems and spatio-temporal databases have not led to the creation of uniform standards or specifications (Grossner 2010). Historical geographers continue to capture and store spatial data and descriptive attributes in a rather haphazard way, without recourse to even the above-suggested division into the two schemes, source and critical. Extemporaneous critiques are only sometimes conducted, usually while dealing with particular practical problems, as in the case of recording and storing data on administrative divisions (Gregory 2002; Szady 2010).

The above-presented source scheme is quite straightforward and user-friendly, and might easily be composed of tables for bibliographical and material flashcards – all in line with practices adhered to in the classical modus operandi of historians. The model and structure of the critical scheme proves significantly more problematic due to the necessity to prepare an ontologically-founded database model for specific issues. So far, historical database models have been based on two premises – some of them will focus predominantly on objects (in the case of colonization studies this might for instance be the town), whereas others will be concerned primarily with processes (events). From an ontological point of view – and including also the concepts of time and space – a peculiar conflict ensues here between the endurantists (claiming that the temporal dimension of an object is distinct from its spatial dimension, constituting only an attribute of the object) and the perdurantists, who profess that any object exists in four dimensions and thus is actually a hyperobject (Galton 2004; O'Sullivan 2005; Goodchild et al. 2007; Liu et al. 2008). Which criteria, then, should be taken into account when conceptualising a settlement unit? One should bear in mind that both the name of a place, its geographical reach, and typology (town/village) might have been subject to various changes. The question to be solved is whether a specific place at the moment of translocation – and history knows such cases, too – did not lose its constitutive attributes (endurant). Problems of this nature cannot be solved without a complex ontological and historical reflection, a need which has been unequivocally confirmed in an experiment conducted among historians, IT specialists, and engineering ontologists at the Catholic University of Lublin with regards to building spatial database structures for historical administrative divisions within the Catholic Church, with the aid of the DOLCE ontology (Fonseca et al. 2002; Couclelis 2010; Garbacz et al. 2010).

A critical survey of models of spatio-temporal databases was conducted in 2010 by Ferreira et al. Among the ten singled out models (Time-Slice Snapshot, 1988; Space-Time Composite Model, 1988; Unified Spatio-Temporal Object Model, 1994; Event Oriented Spatio-Temporal Data Model, 1995; Three Domain Model, 1999; Moving Object Model, 1999; Geospatial Lifeline Model, 1999; Hierarchal Model, 2001; Geospatial Event Model, 2004; The Moving Feature Model, 2008) the Yuan proposition (1999) of the Three Domain Model (Fig. 2) seems most suitable, both theoretically and in terms of its practical application to capturing historical data. The scheme consists of four tables, one for each category (time, place, objects), and one domain link table. The model may well be implemented in spatial databases such as Oracle Spatial or PostGIS.

Fazal's proposition (2009) based on the ORM method (Object Role Modeling – see Fig. 3) might be treated as an elaboration on this conception, though without a direct reference. Fazal discussed not only the theoretical and methodical foundations of his model for spatio-temporal data, but also the manner of its implementation into the Open Source software (GeoDjango, PostGIS).

A. Semantic table

Sem. ID	Landcover	Management	Address
1	Old growth	USFS	12 Forest Rd.
2	Clear-cut	A. Log Co.	3 Clear Dr.
3	Bum	USFS	12 Forest Rd.
4	Clear-cut	R. Log Co	45 Pine Ave.

B. Time table

Time ID	Time	Operator ID
1	1600	2439
2	1700	2439
3	1800	7473
4	1950	1029
5	1960	1029

C. Space table

Space ID	Area	Perimeters
4	A_1	P_1
6	A_2	P_2
8	A_3	P_3
9	A_4	P_4
10	A_5	P_5
11	A_6	P_6
12	A_7	P_7
13	A_8	P_8
14	A_9	P_9
15	A_{10}	P_{10}

D. Domain link table

Sem. ID	Time ID	Space ID List
1	1	1
1	2	2
2	2	3
3	2	4
1	3	5
2	3	3, 6
1	4	7, 10
4	4	8, 9
1	5	10, 11, 13
2	5	6, 12
3	5	4, 14, 15

Figure 2. Use of the three-domain model to represent spatio-temporal information

Source: Yuan (1999: 147).

The application of the above-presented propositions by Yuan (1999) and Fazal (2009) is, however, bound to encounter quite serious obstacles in practical research. The extraction of the time table, suggested in both schemes (time table – temporal entity) and theoretically justified, is not fully legitimate when it comes to research practice, because the linkage of a semantic object (semantic table – subject entity) with a spatial one (space table – geospatial entity) always occurs in time. In a database it is much easier to use the time category in connection to each and every element in the domain link table (domain link table – base entity). Another problematic issue is the lack of object attributes in each of the schemes. Historical databases, even those with relatively simple structures, include additional data on objects – in the case of places it might be for instance type of ownership or place type (town, village); in the case of churches – their denomination or type (parochial, filial). The third problem relates to the source scheme (postulated above) which is left out of many projects.

Assuming that every object existing in the past is defined by time, geographical location, and descriptive attributes, it is possible to offer a somewhat simpler database structure which would include also the source scheme (with full awareness of a partial departure from the rules of the relationship theory). The physical diagram depicted below represents the basic scheme of a rather simple database which still exhibits all features characteristic of the manner of recording and critiquing historical data (Fig. 4). The Link Table we have introduced represents the standard mode of projecting the M:M (many to many) relationship in relational database systems. The application of the table enables us to perform a double feat – to link one object feature with several information sources, and to link one source information with several features of the object under description.

The key tables containing major data are SOURCE for source data, and OBJECTS_FEATURES for resultant data. The OBJECTS_FEATURES table enables storing both descriptive

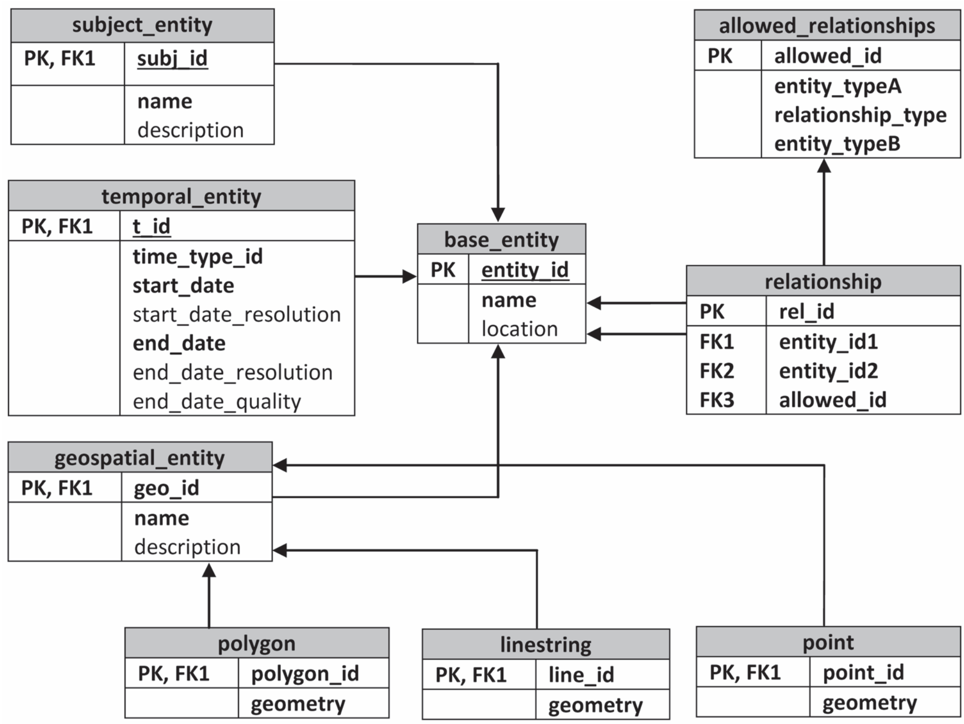

Figure 3. Entity Relationship Diagram for spatio-temporal database

Source: Fazal (2009).

data (FEATURE_INFO), as well as geographical (geom_point and geom_polygon) and temporal (DATE_START, DATE_END) attributes. So far, database solutions used by historians to place a given phenomenon in time normally featured the DATE_START and DATE_END fields. The problem with such an approach, however, is that in the Middle Ages and in the modern era the sources much more frequently provide information on the existence of a given phenomenon at a given time, than on this phenomenon's start and end point. Only sporadically do we get exact dates of when a particular town or parochial church was founded; thus, additional logical points should be introduced so as to supplement the already established temporal attributes, for instance – *terminus ante quem* or *terminus post quem* – which would determine whether through a particular date a mere mention is made of the existence of some phenomenon, or whether it denotes an actual beginning of this phenomenon. Yet another challenge rests in dating phenomena and occurrences in approximation to a specific year or month. Perhaps a good idea would be to introduce an additional field for marking the precision of a date, with the choice between *y* = year, *m* = month, and *d* = day.

The type of the attribute stored in a record (location, ownership type, place type) is denoted by the FEATURE_TYPE field. Naturally, it could well be supplemented with additional fields, e.g. OBJECT_TYPE (OBJECTS Table), or – as has been suggested by Fazal (2009) – DATE_RESOLUTION, DATE_QUALITY, SPATIAL_QUALITY (OBJECTS_FEATURES Table).

Thus formulated, a database structure might receive both source data (source scheme) and the results of historical critique (results scheme). A case in point might be the issue of the location of the Łęczna parochial

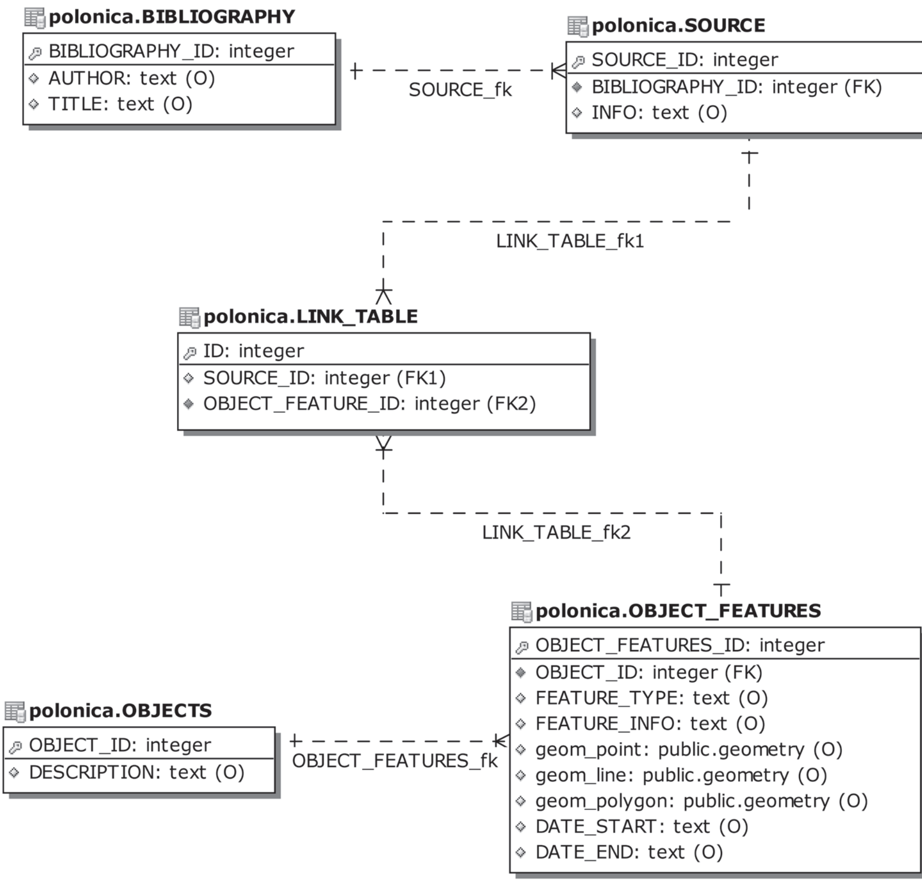

Figure 4. A simplified physical diagram of a geo-historical database

church. As revealed by expert literature, its original location is debatable – some historians believe the church's present location to be its original one, whereas others suspect its translocation (Chachaj 2010; Jop 2010). Therefore, what we are dealing with here is at one lack of certainty, information incompleteness, and plurality of opinion. It cannot be ruled out that further research queries might shed more light on the issue. All captured source information and data regarding the church's location were introduced into a database, leaving leeway for adding further information once it becomes accessible. Should such information change the state of our knowledge on the church's original location, the geographical point might be shifted, or alternatively a second point might be added to the map and related to the information base (LINK_TABLE). Such construction of a database allows for the storage of even two locations for one and the same object, each with an adequate 'certainty rating' (Gregory et al. 2001). Then, generating a results map (table) is a relatively simple operation which, however, does not stand for the end of the project but rather documents its actual level of advancement in terms of work progress.

The above-discussed considerations are of a tentative character and thus can only delineate the challenges of applying spatio-temporal databases to historical research. A proper composition of a database, in particular its division into source and inferential (critical) scheme corresponds well with historical research procedures and their categorisation into heuristics and hermeneutics. The major setback of initial investigations, which rely on mass statistical material and a prevalence of homogenous information, was the difficulty of accumulating, storing and analysing historical material retrieved from the sources, a problem particularly acute in the case of long-term team research projects in the fields of historical geography, historical demography, or economic history. The procedure described in the present study (composing dual-schemed databases) solves the issue of data and result dispersal in a historical query, allowing for a systematised accumulation of source material, both descriptive and geographical. The investigation of acquired material takes place on a continual basis, while research activities and projects are of an open character.

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Unless otherwise stated, the sources of tables and figures are the authors', on the basis of their own research.

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