Geochronological Tracking: Specialized GIS-Analysis Tool for Historic Research

Yan Ivakin and Sergei Potapychev

Abstract Geo-information systems are widely applied in modern humanities. Such research studies are based on the use of geo-information technologies' universal functionality; however, there is an objective shortage of the specialized GIS-analysis tools intended for historic, ethnographic, and other research. Geo-chronological tracking gives us an example of the methodological and technological analysis tool specifically developed for solving a given class of historical problems. This chapter is dedicated to the analysis of the principle capabilities and specifics of such a GIS tool.

Keywords Geographic information systems · GIS technologies for historic research · Geo-chronological track · Modeling of geospatial historic process · GIS-based interdisciplinary research

1 Introduction

Today, geographic information systems (GIS) play the role of an effective analysis tool in humanities and, first and foremost, in historical research. However, the class of specialized methods and GIS tools intended for the intelligent support of researchers who are solving historical problems, and running computer simulations of various historical processes in geo-space, is somewhat insufficient. As a rule, such research studies are based on the use of GIS universal functionality, namely, on the use of geodesic, topographic, and universal geographic applications. Geo-chronological tracking gives us an example of specialized GIS-analysis tools

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aimed at solving the corresponding class of historical problems. The main form-factor of the proposed GIS-analysis tools is a mechanism of integration of chronological and geospatial data, in the form a geo-chronological track, that implements data methods presented in works [1, 2].

On the basis of an encyclopedic understanding of the "track" notion, that is, a number of points along the motion trajectory or chain of events, the Geo-Chronological Track could be interpreted as an aggregate of parameters (data) that describes series sequential events in the life of an individual (of a group, some historic community of people) bound to the time and location of these events' emergence. On the geographic map, such a track will be represented as a curve connecting the geographic points of the historical figure's (group's and other) whereabouts with color-gradient binding to the events' chronology [3]. Correspondingly, geo-chronological tracking is a procedure (method, process) meant for construction, generalization, and interpretation of the geo-chronological tracks' aggregate in accordance with a statistically significant social group, which allows to reveal new facts and regularities in the development of historic processes.

The development of algorithmic and software mechanisms for the construction and correct representation of geo-chronological tracks of some historical figures and members of small social groups on an electronic map, along with the integration of generalized historic and geographic information, form the core of this paper.

2 An Individual's Geo-Chronological Track as a Result of the Integration of Biographic and Geographic Information

Building of the geo-chronological track of an historic figure or a historic object based on the geospatial interpretation of their biographic information essentially is an integration of chronologic and geographic data in form of a graph that connects geographic points of the historical figure's (group's/other) whereabouts with color-gradient binding to given parameters of this individual's or historic events. At such, the nodes of such a graph have strong historical and geographic binding, and its arcs have a conditionally logical character. The essence of the above-described geo-chronological track concept is given in Fig. 1.

Development of the geo-chronological track of the historic figure (or object) can have a number of peculiar features in response to fragmented initial data. In this case, an adequate implementation of the proposed software and methodical analytical tools is provided by the combination of geo-information technologies and capabilities of modern geo-space/time–process development simulation modeling. For the mathematico-algorithmic and program realization of geo-chronological track-building in the form of a corresponding graph, under the objective conditions of fragmented historical and archival initial data, simulation-modeling methods allow to solve the following problems:

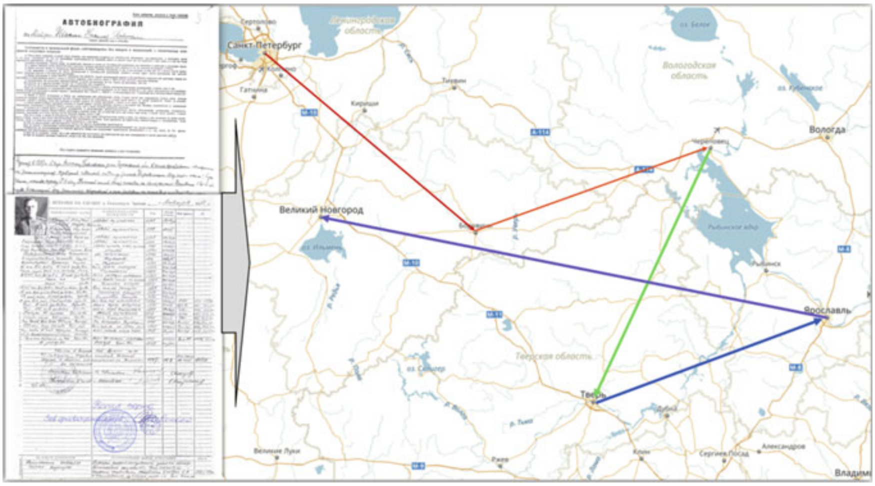

Fig. 1 An individual's geo-chronological track on a map

- probabilistic assessment and consideration of irregular movements of historic figures in time and space for track representation (mathematically, the absence of continuity and uniformity in increments of the historic figure or group);
- consideration of uncertainty and inaccuracy of the available historical data about the historic figures' movements in geographic space, of the location of given historical events represented as corresponding confidence intervals and confidence probabilities;
- consideration of the impact of changes in geographic space itself (landscape of historic processes' development) in time; and
- assessment of the impact of search specificity and preparation of initial historic and geospatial data necessary for track-building and a number of other similar problems.

Application of algorithmic and software mechanisms for building as well as correct representation of geo-chronological tracks in GIS for certain historical figures, members of small social groups, etc. allows to reduce the uncertainty and inaccuracy in historic knowledge while solving the following types of historical problems:

- determination of the encounter possibility, historic events relations, and others;
- detection and disavowal of historical falsifications; and
- rectification of computer reconstruction in the context of historic and geographic aspects, etc.

The process of accumulation and summation of geo-chronological tracks over a statistically significant sample of an individual's autobiographic data is of particular interest for researchers. Precisely, such a process is called "geo-chronological tracking."

3 Conceptual Model of Geo-Chronological Tracking

Geo-chronological tracking is understood as a process of accumulation and integration of data on a historical figure's (or object's) geographic movements over a given time period with as representation of the results in form of a generalized graph in GIS. As such, the nodes of such a generalized graph have strong geographic binding, and various characteristics of the arcs (color, thickness, shape, direction, etc.) represent the matching parameters of the historical figure's mass movements. Figure 2 schematically depicts, under the notation proposed in [4], a representation model of the arcs of a generalized graph.

Geo-chronological tracking allows to reveal, study, and visualize the hidden historic factors that concern the activities of the state, military, and other administrative agencies in the area of human-resources management as well as unobvious aspects of migratory, ethno-confessional, and other orientations. For instance, it can be used to trace the peculiarities and significant factors in the military-administration policy during recruitment arrangements for border military units in a pre-war period based on a statistically significant sample of service records. Also, an opportunity might be provided to analyze undocumented, although objectively existing, tendencies in repressive policy in the USSR during the 1930s to 1950s, etc.

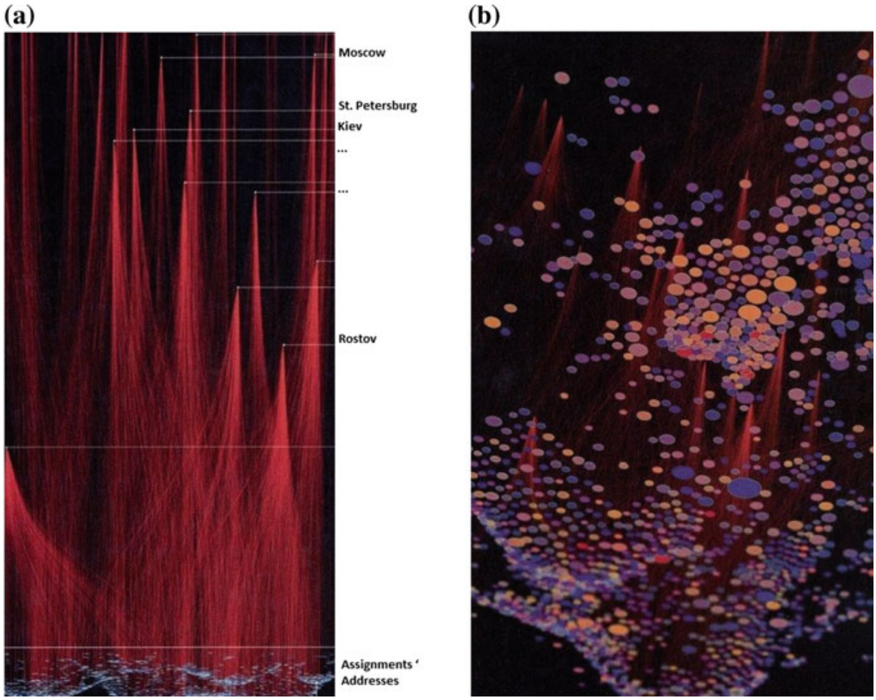

Fig. 2 Model of generalized graph's arcs (**a**) and the matching representation of geo-movement parameters (**b**)

Apparently, geo-chronological tracking, as a methodical research apparatus, is not of universal character; however, it provides a possibility of parameterization and development of nomenclature for undertaken research problems of historic and geographic spatial-processes analysis, i.e., a possibility of changing the process of acquisition and generalization of initial data with its further visual representation on map in a corresponding notation.

The subject of further research lies in identifying the limits of the proposed approach applicability as well as its boundary conditions, which is a challenge for both developers and potential users, namely, humanitarian researchers.

4 Generalized GIS Architecture for Geo-Chronological Tracking

Specialized GIS is the main analytical tool for the construction and analysis of geo-chronological tracks and for their generalization within the framework of tracking technology. The service-oriented architecture [1] allows to perform the most complete implementation of the geo-chronological tracking conceptual model. Figure 3 depicts the generalized service-oriented architecture of the proposed GIS in UML notation.

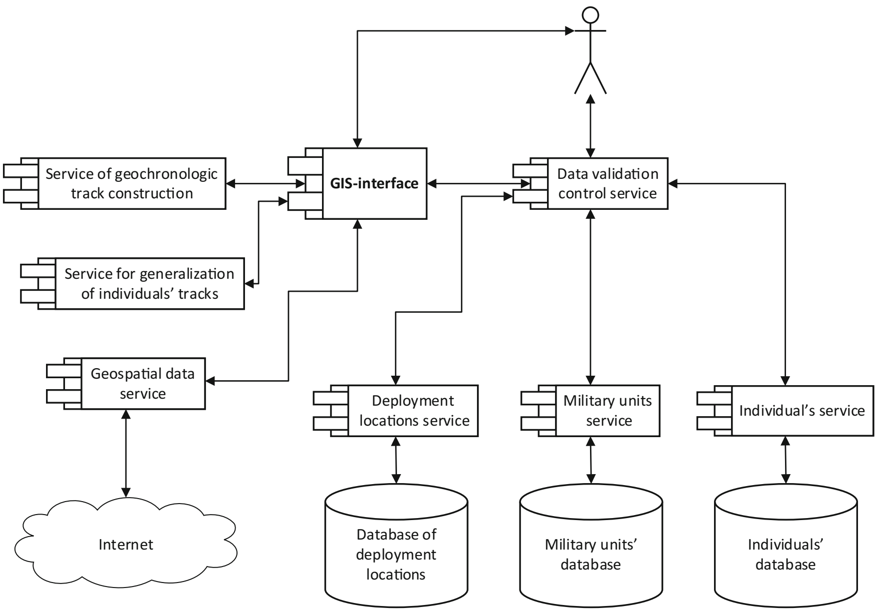

Fig. 3 GIS architecture of geo-chronological tracking

A geo-information system's interface (GIS interface) [1] is the main tool for the user's interaction with the software system. The GIS interface is a set of graphic-interface components that allow to perform system management through various information input devices. Such interface supports visualization and editing of data acquired from other GIS components in a user-friendly form.

GIS interface receives geospatial data through a corresponding service. The said service provides data as sets of raster files and sets of attributes for specific geospatial objects. All data are received by the server through the Internet, and OpenStreetMap (http://www.openstreetmap.org) is the main geospatial data set for the given service.

The data for geo-chronological track building are stored in the corresponding data bases; access to the data bases is realized through the set of services. Listing of the databases and services includes the following:

- database and service of military units deployment locations;
- database and service of military units; and
- database and service of individuals.

The data validation control service is intended for validation of the input data. In case the input data is incorrect, a special icon is displayed for the user suggesting these data correction.

The service of geo-chronological track building is the most important component of the given GIS. This service provides the following:

- building of geo-chronological tracks for different time intervals (months, years, centuries);
- adjustment of geo-chronological track visualisation (color, lines' thickness, etc.); and
- editing of geo-chronological tracks for better visual representation.

The service of generalizing individuals' tracks is necessary for the logical, mathematical, and visual representation of the generalized graph over the statistically significant sample of individual tracks within the studied historic (time) period.

5 Technology of Realizing Geo-Chronological Tracking

While considering the area of application of the proposed technology, the authors arrived at the conclusion that most representative information about migration of groups of population over long enough periods of time used to be stored in the military archives, so the decision was made to use these reliable sources for acquisition of the most accurate data. It became clear that geo-chronological tracking entails the following sequence of generalized steps of realization of its applied software functionality (drawn on the example of human resource management research in the military sector):

1. Initially, the user creates a listing of the human settlements with the military units' distribution in form of a separate database. Under the human settlement with the military units' distribution is understood the human settlement where the military unit headquarters were located, and in case of the headquarters absence, the place of the official distribution the unit's commander along with the group of assistant chiefs and assistants. At that, it is assumed that such human settlements are specified only once. The geographic location of the human settlement is specified by this settlement main post-office latitude and longitude (Table 1).

User detection of the data concerning a change in the status or in the name of the human settlement with static geographic coordinates requires corrections (additions) in the field "Human settlement name/Human settlement names used in the historic retrospective." The change of geographic coordinates with static name or status of the human settlement requires an introduction of a new entry in the field "Human settlement name/Human settlement names used in the historic retrospective" with a definition of the time period when these changes actually took place [e.g., City of Orenburg (1712–1728), currently City of Orsk]. The given table is not allowed to contain entries about human settlements with similar geographic coordinates. Fulfillment of this requirement is provided by an appropriate software function to control the accuracy of the entries in the table titled Military-Unit Deployment Locations.

The names of the human settlements that are not region centers should be entered under their full names (e.g., City of Dzhankoy, Crimea Region, Ukrainian SSR). The entered dates' accuracy equals 1 month.

To simplify the determination of geographic coordinates for the human settlement, an auxiliary function of these coordinated "chippings" from the user's work map is introduced.

2. In a separate modular window, a listing of those military units analyzed at the geo-chronologic tracks' construction is formed. The given sub-process also bears a character of introduction of the matching entries in a special tabular form as represented in Table 2.

Table 1 Structure and examples of entries in the table titled Military-Unit Deployment Locations

No.	Technical identificator	Human settlement name/human settlement names used in the historic retrospective	Location latitude	Location longitude
1.	12345HE	City of Orenburg/City of Chkalov	53 6′1 S	24 12′2 W
2.	54321A	City of Lepel, Vitebsk region, BSSR	33 6′1 S	28 12′2 W
…	…	…	…	…

Table 2 Structure and entries examples in the table titled Military-Unit Listing

No.	Military-unit name	Deployment	Deployment start date	Deployment end date
1.	44 cavalry regiment, 11 cavalry division, Turkestan military region	City of Orenbrg	June, 1919	May, 1925
		City of Lepel, Vitebsk region, BSSR	June, 1925	June, 1941
		City of Teheran, Iran	July, 1941	May, 1947
2.				
	…	…	…	…

Table 3 Structure and some examples of the entries in the table titled Individual's Geo-Chronological Track

<table>
<tr><td colspan="2">Name: Ivakin, Nikolaj Petrovich</td><td colspan="2">Date of birth: May, 1895</td></tr>
<tr><td colspan="4">Additional data …</td></tr>
<tr><td>No.</td><td>Military unit name</td><td colspan="2">Enrollment date</td></tr>
<tr><td>1.</td><td>Krasnodar courses of the Workers' and Peasants' Red Army (WPRA) commanders</td><td>Month</td><td>Year</td></tr>
<tr><td>2.</td><td></td><td colspan="2"></td></tr>
<tr><td></td><td>…</td><td colspan="2"></td></tr>
</table>

When identifying the listing of military units for their gradation, a military unit, such as Regiment, is taken. In the absence of the regiment membership (affiliation), the user should decide on the regiment equal or matching categories: military school, separate artillery battalion within a division, sub-division, air regiment, district hospital (at healing), and other.

The redeployment dates (change of deployment locations) are considered to have an accuracy of one month. Time gaps are not meant to exist in a chronology of the military unit redeployments. A time identifier, such as Up To Now, is permitted.

Military unit renaming, i.e., its reorganization, involves entering other units into the composition, and this is considered as the first unit's extinction followed by the emergence of a new unit bearing a new name.

Filling out the field Deployment in the military units listing is made through the picking units up from the list proposed by the available menu as determined by the table titled Deployment Locations of Military Units. Thus, if the military unit, over some significant time period, was deployed in a human settlement not listed in the table titled Deployment Locations of Military Units, the above-mentioned human settlement would be preliminary specified by the appropriate entry in the table.

3. The existence of structured data in the above-mentioned tables allows for the tabular formation of personal service records called the Individual's Geo-Chronological Track. The record format is given in Table 3.

The individual's (service person's) date of birth is filled out with an accuracy of one month. The field "Military-unit name" is filled out through the picking up from the list proposed by the available menu as determined by the table titled Military Unit Listing. In the field, the date of enrollment in the military unit has an accuracy that equals one month. At that, it is considered that a service record has a continuous character, and the new enrollment date is also a date matching the end date of the previous enrollment.

Based on the common data in the tables titled Military Unit Deployment Locations and Military Unit Listing, the user forms a statistically significant database out of individual service records titled Individual's Geo-Chronological Track.

Visual interpretation of such a database on the platform of GIS underlay exactly represents the essence of the software-tool operation as follows:

4. Initiation of construction and generalization of the individuals' tracks on the geographic map is performed by the separate request (i.e., clicking the appropriate virtual button). Result of the functionality realization for the software analysis tool of geo-chronological tracking is a geographic map with a mapped graph that generalizes the individuals' geo-chronological tracks, the service records of which are filed in the database. The nodes of such a graph are the military units' deployment locations, and the arcs are directed lines characterized by:

   - Thickness: Thickness indicates the number of enrollments-redeployments over a considered time period having the main gradation in accordance with the principle: 1 to ≥ 100 enrollments.
   - Color: Color indicates the middle age of people enrolled in the given directions during the analyzed time period with a smooth gradation in accordance with the principle of smooth change of the color gamut from warm colors to the cool ones where the light ellipse = 18 years and younger and the dark ellipse ≥ 55 years.
   - Arc-cut color: Arc-cut color indicates the generalizations of additional data preset by the user in the field of "Additional data" entries in the table titled Individual's Geo-Chronological Track, which is depicted by an example shown in Fig. 2.

Accounting for the fact that settings, as a rule, bear a bilateral character, visually the adjacent arcs between two nodes of a graph generalizing geo-chronological tracks are convex in regard to the shortest line connecting such nodes. The user has the possibility to receive numeric parameters, each of which determine a characteristic for each arc of the graph that generalizes the individuals' geo-chronological tracks in the emerging modal window by initializing the arc with a cursor.

6 Conclusion

Implementation of the methodical apparatus of geo-chronological tracking—in combination with modern intellectualization technologies [5], mathematical–statistical modeling aids applicable to the humanities [6–8], and information integration and fusion in GIS [9]—allows to assure a new quality of certain research related to humanitarian knowledge that incorporates history, ethnography, anthropology, and other disciplines.

Summing up the new capabilities demonstrated by the geo-chronological tracking as a result of combining the information-fusion methods and geo-information technologies, we can formulate quite a few directions of further development of this research-methodical apparatus and its applicability to historic research as well as of its software-data ware improvement as follows:

- determination of additional attributes (properties) that specify spatial displacements of historic individuals that can be reliably revealed, generalized, and visualized as parameters of the generalizing graph;
- study of the specifics in representation, by geo-chronologic tracking means, of sparse sampling of individual tracks for large time-intervals (>100 years) at the maximum possible geographic theater;
- analysis of the electronic-map scale's impact and the positioning accuracy for the individuals locations on geo-chronological trackings' effectiveness and representable appearance;
- development of ways and technological procedures aimed at implementation of software tools that realize geo-chronological tracking in integrated GIS-environments oriented to solving specific historic, ethnographic, anthropological, and other research problems;
- application of the mathematical apparatus of statistical estimation and simulation in order to reveal and increase the confidence level of the information received due to the use of geo-chronological tracking; and
- development of auxiliary- and service-information infrastructure of geo-chronological tracking such as test and service databases, specialized digital sets of electronic maps with a binding to a definite time interval, etc.

The approach that proposes the implementation of geo-chronological tracking research-methodical apparatus as a special purpose GIS-analysis tool for historic research, as proposed in this paper, will obviously benefit from the further development. However, the clarity of its realization and its high effectiveness allow to arrive at a tentative conclusion on its broad research and development applicability.

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