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Geospatial Topographic Attribute Maps

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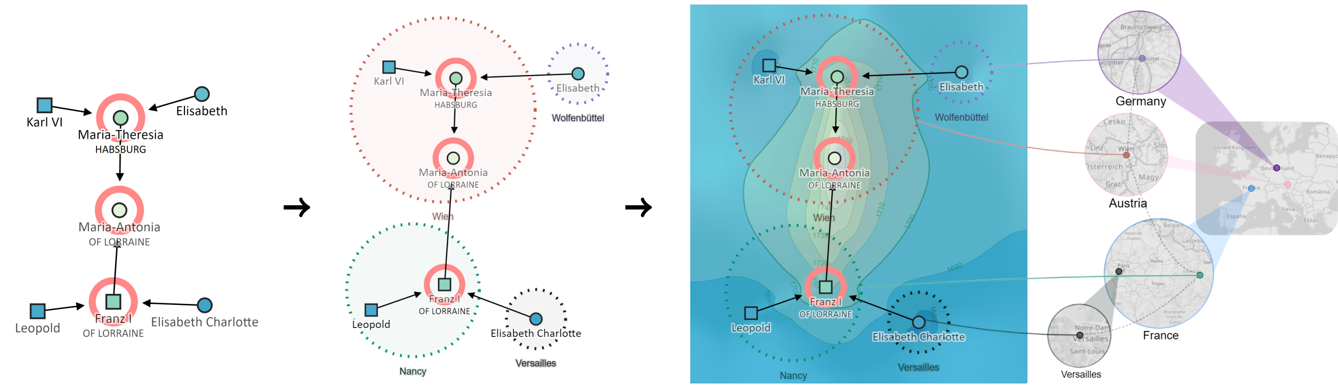

(a) *Input Genealogical Graph* **(b)** *Clustring Nodes by Area* **(c)** *Augmenting Topographic Time and Linked Hierarchical Map*

Figure 1: *Overview of the generation of our Geospatial Topographic Attribute Map visualization. Nodes of an input graph (a) are visually grouped by their geospatial attributes, visualized by containing circles that represent a geospatial location (b). The resulting layout is augmented by a topographic map of time [PSK*20] visualizing temporal node attributes, and linked with an hierarchical cartographic map that can be interactively expanded for geospatial exploration (c).*

Abstract

Genealogists study familial and ancestral relations in the temporal and historical context of their life events, including a geospatial context that studies the spread of families' origins, familial historical migration events, and varying relations between families and certain places over time. Genealogical data often constitute large, multimodal graphs encoding familial ties, which genealogist usually want to analyse using graphical representations. Geospatial information can supplement these relations, reflecting dates and locations of significant life events. To account for this additional information, we present Geospatial Topographic Attribute Maps (GeoTAMs). GeoTAMs extend Topographic Attribute Maps (TAMs), integrating a structural and temporal view on an ancestral graph with means to depict geospatial information about families and individuals. We employ a multi-view approach to represent temporal and spatial information in a genealogy graph. Evaluation results from a user study show that GeoTAMs support complex queries over graphical connections, time, and space.

CCS Concepts

• ***Human-centered computing*** → ***Visualization;*** • ***Applied computing*** → ***Arts and humanities;***

1. Introduction

Genealogy is the study of individuals' familial and ancestral relations and the temporal and historical context of their life events. Genealogists usually deal with large multi-modal data containing relational components that constitute a graph, where nodes represent persons or families, links encode their familial connections, and additional spatiotemporal attributes reflect dates and places associated with individuals and particular life events. Genealogists aim to analyze the geospatial context of families' origins and spread, their historic migration events, and varying relations between families and certain places over time. The intricate connections between the relational structure of a family graph and its temporal and geospatial context pose a particular challenge for finding answers to often very individual questions in the genealogical research process.

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Suitable visualization techniques that integrate the relational, temporal, and geospatial aspects in a holistic, structured, and intuitive way can facilitate the exploration of the data and spot intricate genealogical facts that incorporate all three data dimensions.

Traditional, still most widely used pedigree charts [Cum97] focus on a strict time- or generation-oriented layout. However, these temporal constraints typically conflict with a structure-optimized layout, creating increasingly cumbersome plots that impede a clear view of the familial structure as the size and complexity of the graph increase. In contrast, structure-oriented layouts, such as force-directed graphs [vLKS*11], represent a suitable alternative applicable to a wide range of domains where large graphs comprising different levels of complexity need to be visualized

To appropriately reintroduce the temporal context, *Topographic Attribute Maps* (TAMs) [PSK*20] augment structurally optimized node-link diagrams with topographic maps of landscapes whose 'altitude' encodes time. The landscape-like visualization metaphor regains the chronological order of events, such as a person's birth and death dates. It facilitates depicting an entire lifetime as a curve through the temporal landscape. The major limitation of TAMs is their lack of support for visualizing geospatial information associated with the graph, which is an essential aspect of genealogical research in practice.

This paper addresses TAMs' limitation by integrating geospatial attributes associated with graph nodes into the visualization. Integrating geospatial data is not trivial, as directly mapping graph nodes onto a cartographic map would similarly counter the aim of a structure-oriented layout. Moreover, TAMs already utilize the 2D spatial domain to illustrate the temporal dimension, impeding a direct integration of such maps. We approach this problem in two coherent ways: (1) We extend the force-directed layout of the graph by grouping nodes by their associated location. This provides a holistic, integrated view of the relational, temporal, and spatial data dimensions. (2) In addition, we introduce a second view that pinpoints specific locations in an interactive linked hierarchical map.

We have conducted a user study that shows that Geospatial Topographic Attribute Maps (GeoTAMs) can effectively address different relevant research questions involving the spatial aspect of genealogical graphs.

2. Previous Work

Graph and network visualization are core fields in visualization research and have been extensively studied in recent years.

Graph and network visualization. A general approach to visualizing graphs is the usage of node-link diagrams. In this representation nodes are generally represented as circles and edges as lines. When positioning the nodes, different graph layouting algorithms can be employed, reaching from force-directed, constrained, multi-scale, to layered [vLKS*11] approaches. Multivariate networks comprise attribute data in nodes and edges. An encompassing survey of approaches for visual analysis of multivariate networks is given in [NSML19]. Graphs with additional, often scalar node values are generally referred to as attributed graphs [FP13]. Layouts for attribute graphs commonly include linear layouts, such as pedigree charts [Cum97] or *TimeNets* [KCH10]. Burch et al. [BtBC*21] combined node-link diagrams with matrix visualizations for a better attribute representation, similar to the *NodeTrix* approach [HFM07]. Interaction techniques for graph visualization can comprise, for instance, reducing or filtering nodes, detecting structural patterns such as circles [VBW17], incorporating details-on-demand approaches, or embedding network structures with detailed node glyphs [vLKS*11]. The Caleydo framework [SLK*09] employs a multiple-window approach for exploring graph structures in more detail. *In our approach we outline how to suitably define a node-link data structure that supports heterogeneous node types in a force-directed layout.*

Geospatial graphs and networks. Graphs whose nodes and links can be associated with geographic locations are called geospatial networks [BKA*16]. In their study, Schöttler et al. [SYPB21] divide existing approaches according to how explicitly they encode geographic and network information and how they are composed and integrated visually. Franke and Koch [FK23] show how data from digital humanities can be displayed on a map. Geospatial networks are often explored in traffic data analysis [AAFW17]. Mobility data can be interpreted as a geospatial graph, and by using graph visualization techniques, it is possible to find trends and compare different situations [vLBR*16]. Graphs representing traffic or social media data are usually dynamic [LBW17], where the visualization has to switch between a temporal and a structural representation of the data [HSS11]. In our approach, we work with static geospatial networks where the nodes carry additional geospatial information. *We integrate the geospatial information into the already existing TAM representation, similar to Brodkorb et al.* [BKA*16] *by using maps, but by employing linked views instead of an integrated view.*

Topographic Attribute Maps. *Our approach GeoTAMs is built upon Topographic Attribute Maps (TAMs) as presented by Preiner et al.* [PSK*20]. TAMs constitute a visualization approach for presenting attributed graphs [FP13]. Preiner et al. employ a metaphor of a continuously varying landscape to visually represent node attributes and embed a force-directed graph layout within. The representation of node attributes as landscape results in a map-like representation with mountains and valleys, rendered as a height field. The authors employ techniques from topographic mapping to create a visual context of the spatial distribution of the attributes over the graph. TAMs have already been successfully applied to different use cases, such as genealogy, network simulation, and large graph analysis. Preiner et al. mention several possible future work directions, including integrating additional metadata.

3. Approach

Topographic Attribute Maps (TAMs) [PSK*20] constitute a visualization approach for attributed graphs. Figure 1a shows an example of a genealogical graph, where *persons* are shown as circles or boxes, and *families* are depicted as red circles enclosing groups of siblings. Figure 1c augments such a graph with a landscape-like map representation that depicts the temporal distribution of values among the graph nodes. The original approach [PSK*20] does not

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support the visualization of information about the geographic locations of nodes (e.g., birth places of people). Integrating this information is not straightforward, as geospatial information is most natively displayed using a 2D projection of a map. However, in the TAM approach, the 2D visualization domain is already utilized for graph layout (topology) and time (landscape) visualization. For GeoTams, we, therefore, use a side-by-side visualization of TAMs with additional linked interactive hierarchical maps to also depict geospatial information in the same view.

3.1. Visualization Design

The design triangle by Aigner and Miksch [MA14] describes the fundamental aspects influencing the design of Visual Analytics solutions. It contains the three major key aspects of data, users, and tasks. Based on this definition, we define the following three key elements of our proposed new approach.

Data: The genealogy information is stored as GEDCOM data files [JCF*19]. GEDCOM supports referencing events (e.g., birth, marriage) with geographic information. For this paper, we curated existing GEDCOM data containing non-sensitive genealogical information with geospatial attributes on historic persons and persons in the public eye. In the examples studied in this paper, we opted for localizing persons at the location of their childhood home, as for genealogists it is more relevant in which areas families developed, rather than the exact location of the hospital at which individuals were given birth to.

Users: The target users for GeoTAMs are analysts in need to analyze attributed graphs with geospatial information. This comprises, for example, genealogists.

Tasks: We identify the following tasks:

- **T1**: Depict geospatial patterns in a TAM graph (e.g., number of geospatial locations that can be found in a family graph).
- **T2**: Get an overview of geospatial patterns of a TAM graph.
- **T3**: Combine temporal and spatial information to depict geospatial changes over time (e.g., families moving to another country).

3.2. GeoTAM Approach

Visualizing geographic attributes alongside relational and temporal data within a single visualization domain is not trivial. However, it conveys crucial information to researchers across various fields. To achieve an optimal visualization of all three dimensions, several components of the TAM approach are adapted and extended.

Graph Layout. TAMs provide a well-structured force-directed graph that encompasses both the temporal and relational attributes of nodes and minimizes the overlapping of nodes and links. Introducing a third dimension to the force layout, specifically geographic attributes, presents a significant challenge. The force simulation can become unstable if additional properties are not correctly coordinated and potentially can cause issues such as exploding forces. To address this problem, we introduce area circles into the graph layout. Each area circle represents a geographic location and is differentiated by distinct colors. Area circles are categorized into three levels of abstraction: country, city, and street,

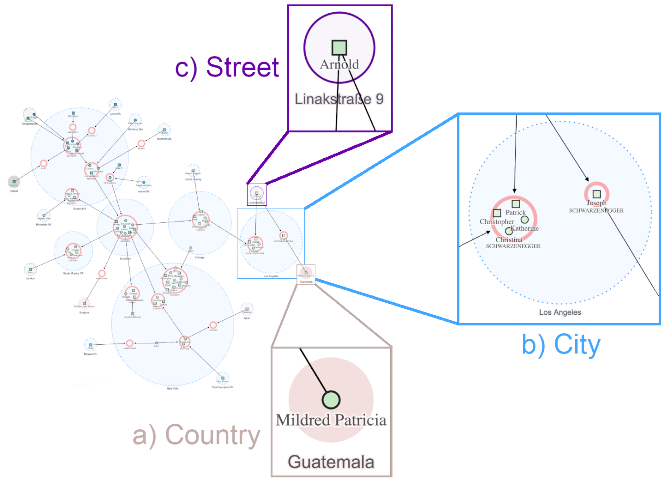
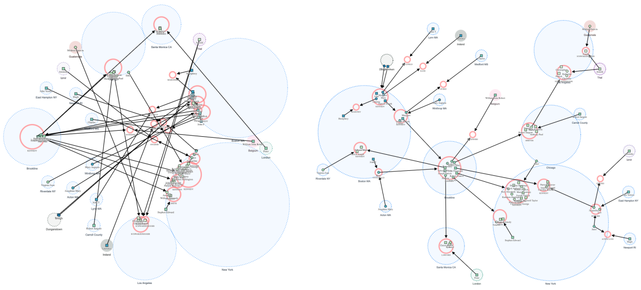


Figure 2: *Detailed view of area circles types. (a) Country circles (Guatemala) are visualized by circles without a border. (b) City circles (Los Angeles) are displayed with dotted lines. (c) Street circles (Linakstraße 9) have a solid line.*

distinguishable by different border styles (see Figure 2). These levels represent the granularity of the geographic attributes in which the nodes should be summarized in. Area circles act as containers, enclosing all nodes associated with the respective geographic attribute. The radius of an area circle gets calculated based on the number of nodes it encloses. The radius of an area circle is chosen to encompass the areas of all containing circles with a given scale to provide sufficient space for the layout. We determine it by $r_{area} = 4 * \sqrt{\sum_i r_i^2}$, where r_i denotes the radius of the i-th child node of the area (person or family node). To integrate these area circles effectively, the setup of the TAM force layout algorithm needs to be adapted accordingly (see Figure 3). Maintaining a cohesive global layout requires balancing the behavior of area circles and nodes without geographic attributes. Additionally, nodes within area circles must be arranged according to their attributes and link connections while respecting the boundaries of the area circle. This is achieved by introducing links between nodes and the center of their respective area circles. These links are subject to spring forces with a rest length of half the area circle radius. This rest length represents an empirically determined sweet spot keeping nodes widely within the boundaries of area circles while still allowing them to produce a desirable force-directed layout. Furthermore, a collision force is applied to the nodes with their radius as a collision parameter. After each force-layout iteration, nodes are constrained to the inside of their area circles, and single nodes inside area circles are positioned at their center to provide a more structured layout.

Hierarchical Map Layout. Map visualizations significantly enhance the insights and interpretation of geographic data [HHS20]. However, representing geographic data with map-like visualizations can also lead to problems such as cluttering or oversimplification of the maps [HHS20]. Our approach minimizes these issues by employing hierarchical maps, which adaptively provide the appropriate map resolution for different areas based on their local



(a) *Area circle grouping only* **(b)** *Final force graph*

Figure 3: *(a) TAM force layout after introducing area circles and constraining family and person nodes to their boundaries. (b) Layout after introducing links between nodes and area circle centers, and manual collision handling between area circles.*

density of localization markers. We use these maps in a side-by-side view with a TAM force graph layout (Figure 1c). This approach preserves the benefits of a graph layout while adding the advantages of a map visualization, such as the interpretation of the geographical information that is given by the graph nodes. A three-level hierarchy mirrors the area circle abstraction types (country, city, street), starting with a world map view that denotes countries using markers (see Figure 4). To easily identify the association of nodes to their country, all area circles sharing the same country are colored equally according to the marker's colour in the world map. This can be seen in Figure 2, where all area circles belonging to the United States are equally colored according to the blue marker color of the US shown in Figure 4. Upon clicking a country marker, the second layer of the hierarchy, the country map, becomes visible. Its initial placement is chosen outside the world map at closest distance to the associated marker and can subsequently be replaced by the user. At this level, new markers appear on the country map, visualizing cities within that country. This step introduces a color change among the area circles in the force graph, where each city is colored differently to represent a finer granularity of geographical data. The final hierarchical layer consists of highly detailed city maps that visualize specific street addresses associated with individual nodes. This hierarchical view allows users to easily select their desired level of abstraction within the visualization, providing only the necessary amount of information and avoiding data overload.

Connection lines. A side-by-side view of different visualization techniques can make it difficult for users to bridge the data visualized in two separate ways. To address this, optional connection lines are added to link the graph and the hierarchical map layout. Solid lines connect area circles in the graph with the respective markers in the map hierarchy, making it easy to locate the corresponding markers on the maps without any back and forth search between the two visualizations. The number of lines emerging from a marker also indicates the number of nodes connected to that geographic attribute. Dotted lines connect markers on the maps and visualize relationships between areas, corresponding to direct links between nodes in the graph layout (see Figure 5). The lines are drawn over the remaining graph using semi-transparent strokes,

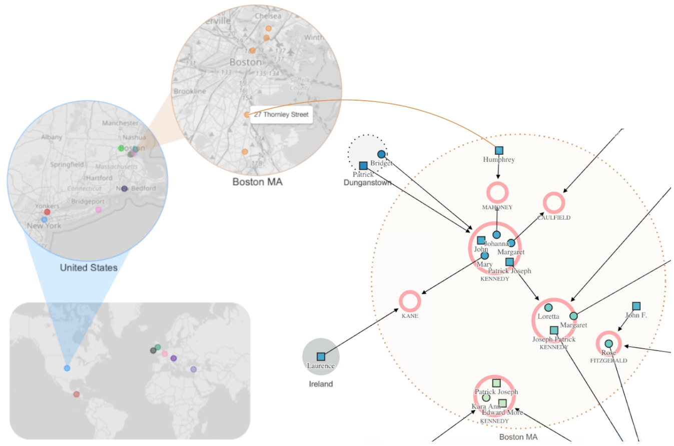


Figure 4: *Visualization of the map hierarchy for the Boston MA area circle. Upon opening the country map of the United States, area circles of cities within this country change from the country color (blue for the US as seen in Fig. 2) to individual marker colors, e.g., Boston MA colored orange. The Boston MA city map shows the street level geographical information of the nodes associated with its area circle. The marker inside the city map locates the person node of Humphrey at street address 27 Thornley Street.*

and can optionally also be hidden entirely to reduce overplot. This allows the users to analyse and explore the relationships between areas more intuitively.

Augmenting a Temporal Landscape. Besides the relational and spatial domain, an important aspect of the visualization is the temporal dimension, which is already provided by the original TAM approach [PSK*20]. By rendering a topographic map underlying the graph, temporal aspects and context of a geographical area can be assessed and explored, as shown in Figures 1c and 7. This conveys essential information, such as the period of time an area circle spans or the earliest recorded time attribute within an area.

Interaction. Our visualization offers several intuitive interactions that enhance the analysis of the data. The interactive map hierarchy can be expanded or collapsed to adjust the level of detail. When hovering over a marker on the map, only nodes associated with this geographical attribute, along with their direct connection links, are highlighted to quickly access the relevant information within the graph layout (see Figure 5). Contrarily, when hovering over an area circle, connection lines to the markers are highlighted, helping to locate the geographic position of an area within the map hierarchy. This streamlined process ensures efficient retrieval of necessary information within the side-by-side view.

3.3. Implementation

Our web-based visualizations are implemented using JavaScript. The TAM source code [PSK*20] was extended using the library D3 [BO24] (v5.16.0) to incorporate area circles in the force graph simulation. The built-in D3 force simulation are customized

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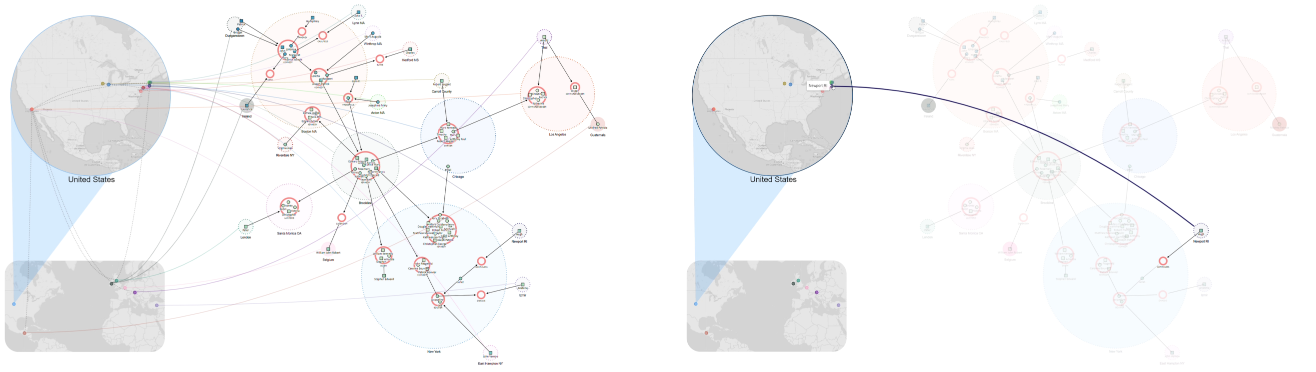

(a) *Solid area connection lines and dashed relationship connection lines* **(b)** *Highlighted area Newport*

Figure 5: *(a) Solid connection lines connect area circles with markers that visualize this area on the maps. Dashed lines between map markers additionally visualize a relationship, equally to the links in the graph. By the connection lines can be observed, that most nodes are connected to the United States area. (b) Highlighted area Newport RI with its link to the area circle and the marker with connected nodes that can be observed by the directed links in the graph and the dotted lines between the maps.*

to ensure that family and person nodes remain within their respective area circles while maintaining an optimal global graph layout with minimal intersections. Geographical data from the OpenStreetMap [Ope24] project, accessed via the Leaflet 1.9.4 API [Aga24], forms the backbone of the map visualizations. Leaflet UI markers inside map containers are defined by coordinates that are automatically computed from address strings using Leaflet GeoSearch [Mei22] with OpenStreetMap API as the provider. Dotted connection lines between markers and lines connecting maps and the force graph are drawn onto an overlaying HTML canvas and are updated simultaneously with the force simulation.

4. Use Cases

Our visualization reveals different spatiotemporal features in a dataset displaying ancestral relationships. Next, we discuss two use cases at the example of the Kennedy family graph.

4.1. Geospatial - Relational

Area circles depict information about how families are spread over geographic regions. In Figure 6, the areas New York and Los Angeles, highlighted in yellow, do not exhibit any outgoing links, symbolizing that no outgoing migration activities happened from these areas. Nonetheless, the area circle of New York exhibits notably many in-going arrow links, which indicates that New York was an important destination for many migrating families in this dataset.

4.2. Geospatial - Relational - Temporal

When adding the temporal dimension represented by TAMs, users can make several more observations in the resulting GeoTAM visualization. Figure 7 highlights a family branch containing Christina Schwarzenegger, daughter of Arnold Schwarzenegger and Maria Shriver. The temporal landscape immediately reveals their earliest recorded ancestors, Patrick and his wife Bridget from Dunganstown, Ireland, located in the dark blue region. Patrick and Bridget moved to Boston in the US where their children grew up. This can be seen by following the arrow links in the graph layout. Further following their descendant's path up the temporal landscape (highlighted in violet) we observe in total 5 generations between them and Christina, which lived in 5 different areas. The majority of area changes took place in the same country, which is denoted by the color of the area circles. Moreover, it is visible that 17 decades lie between Christina and her earliest ancestors. Besides the highlighted path, we can also observe that Christina's parents originate from different areas. At the same time, on the relational level, the graph reveals that Christina has a half-sibling, Joseph, born in the same decade, who also grew up in Los Angeles.

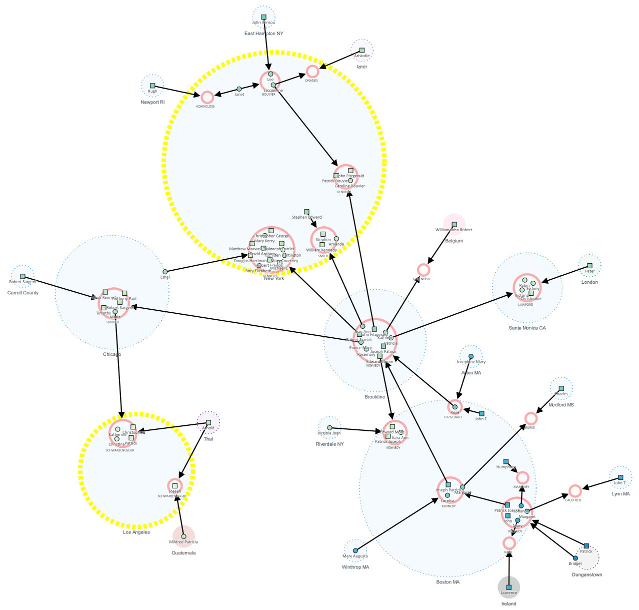

Figure 6: *Migration Endpoints: Highlighted area circles (yellow) show no outgoing migration over any family.*

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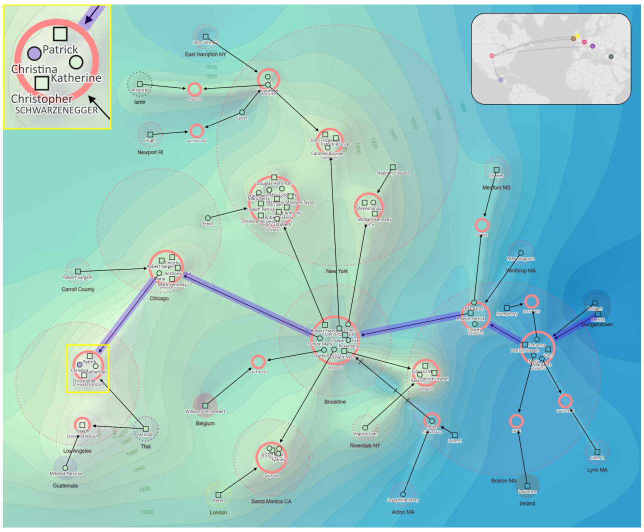


Figure 7: *Following the highlighted path (violet) through geographical locations (area circles) and time from node 'Christina' to her earliest recorded ancestor.*

5. Evaluation

Following the nested evaluation model of Munzner [Mun09], the evaluation of a visualization's encoding and interaction design is required to assess the usefulness of the proposed approach.

5.1. User Study Design

To test GeoTAMs regarding their abilities, strengths, weaknesses, and value, we decided to combine three established evaluation methods to get broad feedback: a. Observational task performance analysis [WCBR16], b. Thinking aloud [Lew82], and c. Qualitative feedback [DMN23].

These methods are inexpensive in their implementation expense and do not require additional equipment (e.g., eye-trackers). The applied evaluation process consists of three consecutive parts:

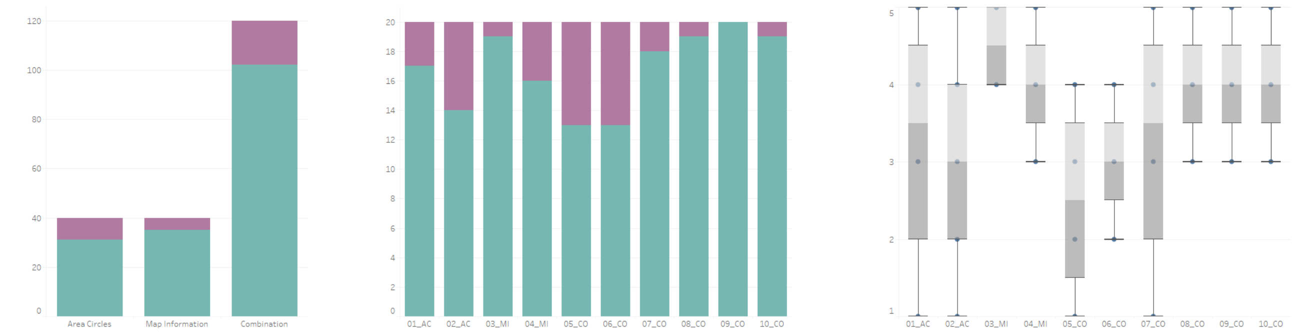
1. **Introduction**: Collecting necessary meta-data of the test persons and introducing the user to GeoTAMs and the evaluation procedure. This first part contained an explanation of the general approach and a presentation of the main components of GeoTAMs. Participants had to agree to the evaluation's terms of data recording, privacy, and anonymity.
2. **Task performance analysis**: The test person had to solve a set of 10 pre-defined tasks. Each task started with an introduction to the task, the targeted context, and its goals. Participants could use interactive features of GeoTAMs like hovering and node expansion. The tasks were completed when the test person entered an answer in a designated field, selected an option or a node in the graph representation, and moved on by clicking a button. We also measured the participant's confidence when doing the task on a 5-point Likert scale. We classified tasks according to the following topics:
   - **Area Circles (AC)**: Identifying families and persons within the same area, depicted by an area circle. We designed 2 tasks in the study for this topic.
   - **Map Information (MI)**: Combining the information in the family graph with the depicted map information (e.g., finding families where parents were from different countries). We designed 2 tasks in the study for this topic.
   - **Combination (CO)**: Answering complex GeoTAM queries over all three concepts (i.e., family graph, area circles with map information, and temporal information given by TAM topology). We designed 6 tasks in the study for this topic.
3. **Qualitative feedback**: The test persons were asked to rate different aspects of the GeoTAM visualizations on 5-point Likert scales and answer open-ended questions about the tool.

We used the tool *ScoSciSurvey* [SoS24] for task definition and collecting answers from the participants. The evaluation was conducted by recruiting participants, asking them to open the ScoSciSurvey study, and observing them while doing the tasks in the same room or via video communication tools. Every test person received an evaluation token that allowed them to enter the evaluation. The token guaranteed that all results could be assigned to the test person while ensuring the person's anonymity.

5.2. Results

We recruited 20 participants with different backgrounds (genealogy, data science, and computer science). Study participants were observed while doing the tasks, and we asked them to express their opinions about the presented visualizations. We also required participants to use a computer screen instead of a mobile device. We recorded correct and incorrect answers and task completion time. Every user study pass took approximately 15-25 minutes.

In general, we observed mixed error rates for tasks in the *Area Circle (AC)* and the *Map Information (MI)* topics (see Figure 8a). The results indicate that participants generally understood the concept of area circles, but that some would have needed more time to get familiar with the new concept. Detailed error rates for all task can be seen in Figure 8b. The highest error rates for the AC and the MI topic where found for task *02_AC*. Here participants had to answer the question 'Find an area containing an area containing at least two persons, where no outgoing migration, i.e., no person starting a family outside their area, is happening', which required to check all nodes in the graph in combination with descending nodes. This is a complex search task in a dense graph, which led to higher error rates. Participants also had difficulties completing the first two *Combination (CO)* tasks. Here, for the first time in the study, participants had to process area and temporal information in parallel (*05_CO*: 'Are any descendants in this graph still living in the same area as the earliest ancestor?', *06_CO*: 'What is the highest number of generations in a direct blood line that stayed within one area?') and count family nodes in the graph. The results indicate that such complex tasks require additional training on the TAM representation first and could be supported by additional interactions. The confidence values (see Figure 8c) also reflect the higher error rate for tasks *05_CO* and *06_CO*. The error rates and confidence values indicate that with solving more and more CO tasks, participants scored better and also became more confident in solving the tasks. The difference between error rates for the topics



(a) *Correct/incorrect per topic* **(b)** *Correct/incorrect per task* **(c)** *Confidence per task*

Figure 8: *The share of correct (green) and incorrect (violet) answers varied for all tasks. Participants had trouble solving the second Area Circle (AC) task, which is also reflected by the confidence values. Error rate decreased and confidence values increased for all participants when working on the Combination (CO) tasks.*

ID	Question	1	2	3	4	5	Avg
Q1	It is easy to find information about the family relationships of people in the graph.		1	4	12	3	3.85
Q2	Area circles made it easy for me to find which persons belong to which area.				7	13	4.65
Q3	Area circles made the information on family relations hard do read.	2	11	3	2	2	2.55
Q4	I found that maps helped me to solve tasks efficiently.	1	2	4	6	7	3.80
Q5	It was easy for me to understand the graphs with area circles.			5	10	5	4.00
Q6	It was easy for me to understand the graphs with maps.		1	5	8	6	3.95
Q7	It was easy for me to understand the graphs with topographic maps of time.		5	4	10	1	3.35

Table 1: *Feedback by 20 participants on a sentiment questionnaire, measured on a 5-stage Likert scale ranging from 1 (strongly disagree) over 3 (neutral) to 5 (strongly agree). The table shows the frequency of each answer as well as the average score.*

AC and MI and for the topic CO are also statistically significant (ttest, $p < 0.0001$). The full list of tasks with images can be found in the supplemental material.

We eventually decided to not consider task completion times in our final evaluation of the results. Participants asked different numbers of questions and sometimes paused before giving an answer in ScoSciSurvey to clarify a certain issue. Therefore, we concluded that task completion times will not be meaningful for interpretation.

In addition to task performance, we also collected qualitative feedback from the participants. They generally liked the idea of combining family genealogy information with geographic locations ("*I totally see the benefit of tool*"). Table 1 shows the answers to questions about the shown visualizations on a 5-point Likert scale. The answers reflect that participants understood the representation of area circles to depict geographic information. Participants also said that they understood the representation of the graph and the map information. However, we got mixed replies for *Q*4, where we asked whether the visualization helped participants to be more efficient. The mixed replies also mirror the answers we recorded during task completion, where participants highlighted the need for more time to get familiar with the full functionality of the GeoTAMs approach ("*[...] after some while with explanations, one finds out how to approach problems with visualization techniques, but you have to use the tool more often*", "*Takes some time to fully understand*"). When discussing additional visual cues, the participants' feedback indicated the need for more guidance ("*There should be lines connecting the markers [...]*").

5.3. Summary

The user study showed that the concept of area circles and connected map information was understood by the participants, and that GeoTAMs support complex queries over graphical connections, time, and space. Decreasing error rates and increasing confidence values indicate that users needed some training to become familiar with the proposed graphical representations. Difficulties for some of the tasks indicate that additional interactions (e.g., node highlighting) could have helped participants when solving this task. Guidance and additional interactions can thus be identified as promising directions for future work.

6. Discussion and Conclusion

We presented GeoTAMs, an approach that extends Topographic Attribute Maps to visualize geospatial information. So far, our method supports depicting single geospatial locations associated with nodes, thus covering many graph visualization applications where nodes represent events occurring at a specific place. In other application domains, graph nodes that might be attributed with multiple geospatial locations cannot as easily be grouped into areas as in our examples. Potential ways to address this in future work are the investigation of suitable means for visualizing multiple geospatial relations per node or the systematic decomposition of graph nodes into multiple nodes of single locations.

We have shown that our method addresses a broad set of use cases involving both spatial and temporal aspect of graphs. While our work focuses on examples in genealogy, our method can be helpful in any domain where experts need to investigate graphs of nodes attributed to spatiotemporal data.

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