Towards Visual Analytics of Multilayer Graphs for Digital Cultural Heritage

Fintan McGee, Marten Düring, and Mohammad Ghoniem

Abstract— In this extended abstract we examine the visual analytics requirements of researchers in the field of Digital Cultural Heritage (DCH) and we look at the current approaches used by researchers in this field. We suggest that data structures produced during the analysis of a DCH corpus, might better be modeled as a set of inter-related graphs and subgraphs, that together form a "multilayer graph", a concept recently defined within the field of complex systems.
We consider some existing visualization approaches that may be suitable for visualizing and analyzing DCH data within a multilayer graph visual analytics system. We examine how to build a multilayer graph data set from DCH data. We also describe an initial set of tasks, based on interviews and discuss how we will use the expertise of professional researchers in the field of DCH to evaluate and validate our design decisions made as part of our research.

Index Terms—Visual Analytics, Digital Cultural Heritage, Multilayer Graphs.

1 Introduction

In this extended abstract we describe the potential of *multilayer graphs* to support the visual analytics of Digital Cultural Heritage (DCH) data. DCH concerns the collection, preservation, analysis and provision of open access to digitized cultural heritage objects, which may be any man-made objects throughout history. In recent years, large amounts of digitized materials have for the first time become freely available to the public and to scholars. The range of digital material covers any digital representation of artifacts and the metadata which describes them. In our case, these are texts, images and video footage which cover political figures and institutions, which in turn can be linked by many different relationship types that change over time. Domain experts often need to inspect various types of information from multiple perspectives to better analyze and grasp complex mechanisms. A growing number of practitioners in DCH and researchers in the humanities choose to work with graph visualizations and social network analysis methods to achieve this goal. To-date, there are only few attempts to exploit more advanced visualization techniques and to evaluate them systematically. Instead, the vast majority of applications rely on unipartite or bipartite node-link diagrams for visualization and basic centrality measures for the quantitative analysis of data. These approaches can often not adequately represent the highly complex interactions and inter-dependencies which practitioners observe in their data but lead to a drastic over-simplification of observed real-world complexities [23].

Multilayer graph analytics have emerged recently as a way of understanding complex systems (or networks) and can address some of these shortcomings [29]. Complex systems can be modeled as a set of interconnected networks. It may therefore be effective to model DCH data as multilayer graphs. For example, documents from different sources may be considered as separate layers, or interactions between institutions could be considered as a separate graph layer to interactions between individuals.

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Manuscript received xx xxx. 201x; accepted xx xxx. 201x. Date of Publication xx xxx. 201x; date of current version xx xxx. 201x. For information on obtaining reprints of this article, please send e-mail to: reprints@ieee.org. Digital Object Identifier: xx.xxxx/TVCG.201x.xxxxxxx

2 Background

2.1 Graph visualization in the Digital Humanities

We observe three types of applications of graph visualizations in the Digital Humanities:

Firstly, there are those that support analysis of carefully, often manually created datasets which represent a network theory- and question-driven model of complex social relationships. Typically inspired by social network analysis theories and methods developed in the social sciences, this approach seeks to understand and reconstruct social interaction by means of data analysis, see [12, 14, 17, 31, 42].

Secondly, there are applications for the *distant reading* of graph visualizations of larger datasets which were created automatically, e.g. by means of entity co-occurrences [36, 46]. The term "distant reading", coined by Moretti [32], refers to gaining an understanding of a text or a collection of texts through the construction of artifacts such as graphs, maps and trees generated from the text. The Fingerprint Matrices of Oelke et al. [34] can be seen as a recent example of this. These matrices provide a visualization of the interaction between characters throughout a novel. Such a visualization allows a reader to understand aspects of the relationships between the characters of a text at a glance. Other visualization techniques can provide quick insight into other aspects of a text or corpus, such as topics, patterns, as well as statistical analysis of the text, as can be seen in the journalistic tool "Overview" [9]. Jänicke et al. describe and classify many different types of visual text analysis techniques in their 2016 survey [27].

Finally, there are public facing interactive graph visualizations which target the exploration of corpora by non-expert users. Systems like ePistolarium [26] provide access to dedicated corpora of digital cultural heritage contents. In addition, HuNI - Humanities Networked Infrastructure [2] and histograph [20] encourage users to enrich and/or validate datasets.

There are also dedicated software packages which seek to serve the specific graph visualization needs of practitioners in the cultural heritage/humanities sector [1, 4, 5]. For a bibliography of works on network analysis in the historical domain see [13].

2.2 Multilayer Graphs

Many systems are modeled by graphs, and many complex systems contain many sub-graphs (or sub-networks) which interact [29]. These layers of graphs may be modeled independently, but also interact with each other. Multilayer graphs may have multiple types (or modes) of node (as in Ghani et al. [16]) with many different attributes (Kerren et al. [28]), and many different types of relationships (Singh et al. [41]). Consider for example a person's social networks. People frequently use more than one one social network platform, e.g. Facebook for their personal social network or LinkedIn for their professional. Both of these networks can be considered independent graphs, however they can also be considered as layers in a multilayer graph. The graphs interact as some people may be present in both layers. A significant change in one network may also correlate with or cause changes in another. For example, a change of employer may cause immediate change in the professional network graph and a slower more gradual change in the personal social network. While multilayer graphs are only a recent formal concept [29], many aspects of multilayer graphs have existed for some time. Graphs with many or all of the characteristics of multilayer graphs have been called heterogeneous, multi-edge , multi-modal etc. Kivelä et al. [29] describe multilayer graphs in detail and also provide a comprehensive list of synonyms and related terms. The name "multilayer graph" is itself an attempt to unify nomenclature. Within graph visual analytics, graph metrics, such as clustering coefficient or degree, betweenness, or eigenvector centralities, are often used to help better understand graph structure and as an input to improve visualization. Multilayer graph analytics offers similar analytics capabilities [7, 29], while also taking into account the multilayer nature of the data.

2.2.1 Multilayer Graph Visualization

Many existing graph techniques have been developed that have potential for visualizing DCH data as part of a multilayer graph visualization system, which goes beyond the status quo in DCH. Ghani et al. [16] in their visualization of multi-modal data (where graph nodes can be of different types, of "modes") adopt a list-based approach. Nodes are listed in vertical columns with edges only being drawn between adjacent columns, an approach that is visually similar to parallel coordinates. However, this interesting approach is effective only where there are limited types of relationships between node types, as edges do not connect nodes in columns that are not adjacent in the visualization.

Many existing attempts at visualizing multilayer networks adopt an approach that utilizes 3D [11, 15], such as placing layers on different planes in 3D space. However three dimensional visualizations of graph data have only ever been empirically shown to be effective when using stereoscopic displays [18,47], and it is questionable whether the benefits offered outweigh the negative aspects of stereoscopic 3D (such as the dependency on extra hardware and user acceptance).

It may also be possible to adapt some existing hierarchical visualizations for use with multilayer graphs. For example, Stasko and Zhang [43] use radial layouts for the hierarchical visualizations, and such a visualization may easily be adapted replacing hierarchical levels with different layers of the multilayer graph. Hybrid graph visualizations [21] are those which combine both node-link and matrix visualization to visualize graph data. These types of visualization have previously been used for hierarchical data [37], and may provide an interesting avenue for visualizing multilayer data.

Multilayer graphs may also contain multiple types of edges (i.e. they are multi-relational). Edges are frequently a source of clutter and edge bundling techniques, such as [24, 25], reduce clutter by routing the edges in bundles of curves. Routing of edges, particularly if there are multiple types of edge, in a multilayer graphs may prove challenging. Initial attempts have been made to bundle edges in multi-relational graphs [8]. However, there is still much scope for research in edge routing for multilayer graph data.

There are many established techniques for interacting with graph data [22], and interacting with multilayer data raises some questions not seen with single layer graphs. For example, if a user selects data in one layer, how should the relationships between the data in the selection and data in other layers be conveyed. Previous work by Shneiderman and Aris [40] examines citations between law judgments at the circuit and supreme court levels in the United States. Edges within the levels and between them are shown on demand using an interactive filter. Other approaches such as edge filtering lenses and fisheye distortions [45] may also be suitable for multilayer graph visualization, but may need adaptation to be useful when visualizing multiple layers. A key question around interaction is in the area of graph layout, specifically: if the layout of one layer is altered how does this affect the layout of related layers? This question is best investigated by focusing on the tasks of end users, as the goal of a good layout is to facilitate the users at a specific task.

2.3 Digital Cultural Heritage Use Case

We work with data derived from documents on the European integration since 1945 collected by CVCE, Centre Virtuel de la Connaissance sur l'Europe), a former research and documentation center which in 2016 was integrated into the University of Luxembourg [10]. CVCE was dedicated to a deeper understanding of the European integration process from a historical, legal, political and economic perspective. To achieve this mission, CVCE created a collection of 30,000 digitized objects, 20,000 of which were organized in 29 thematic corpora such as "Historical events in the European integration process (1945-2009)", and "The end of the European colonies". The documents differ significantly in nature: Among them are newspaper articles, diplomatic notes, personal memoirs, audio interview transcripts, cartoons and photos with descriptive captions. They were collected with the goal of complementing each other and highlighting different aspects, not as a homogeneous dataset. Topics were organized hierarchically in distinct levels. Each level contains a list of documents, which are associated to it. In total there are 13,000 text documents, 4,000 photos, 1,800 videos, an authority list with 800 personalities and institutions, 300 audio recordings, 300 tables, 150 biographies, 150 interview transcripts and 100 maps.

In order to create and update their corpora, researchers need to keep a good overview of the materials they have catalogued and how they relate to each other. Those who have worked with the documents for a long time can rely on their memory from previous projects and have an advantage over newer colleagues. At this stage however, researchers can only use a keyword search in their backend system or browse existing corpora to find specific documents.

3 Processing DCH Data

Given an input corpus of documents, one key issue is generating a data structure for analysis. Often there is expert guided manual curation of data, however there are also many different automated approaches. Here we discuss two of the most prominent ones, named-entity recognition and topic modeling.

3.1 Named Entity Recognition (NER)

Entity co-occurrence in a text has long been the basis for the creation of graphs based on a text, e.g. Knuth's frequently used graph of character interactions from *"Les Miserables"* [30]. In this approach named entities are extracted using Named-Entity Recognition software such as [3, 44]. If entities occur within a specified distance from each other in the text (e.g. same sentence, paragraph, or chapter) an edge is created between them.

Graph structures based on these techniques not only convey character relationships, but also allow the graph metrics to be calculated to try and gain more insight, as done by [36].

An example of the the creation and use of a co-occurrence graph which was created for the representation of CVCE data is histograph [48], a tool for the graph-based exploration and crowd-based annotation of multimedia document collections. For text documents and document metadata, this tool compares the output of two systems for the annotation of named entities, TextRazor [44] and YAGO [3].

In a second step it considers annotations for multilingual versions of documents and compares them, e.g. annotations in a French version with those in the English version. This serves two purposes: Entities which have been detected in both versions indicate a higher validity of automatic annotations. Entities which have only been detected in one version may indicate false negatives: If for example the entity "Robert Schuman" was detected only in the French version it can still be added to the English. In addition, it relies on human annotations. These compensate for entities which have been missed by NER tools but also provide additional annotations which are hard to obtain automatically, namely the identification of persons in historical photographs. All annotations are then subject to validation and error correction by a crowd of users who vote on the best matching annotation. The graph is created using entity co-occurrences within a document.

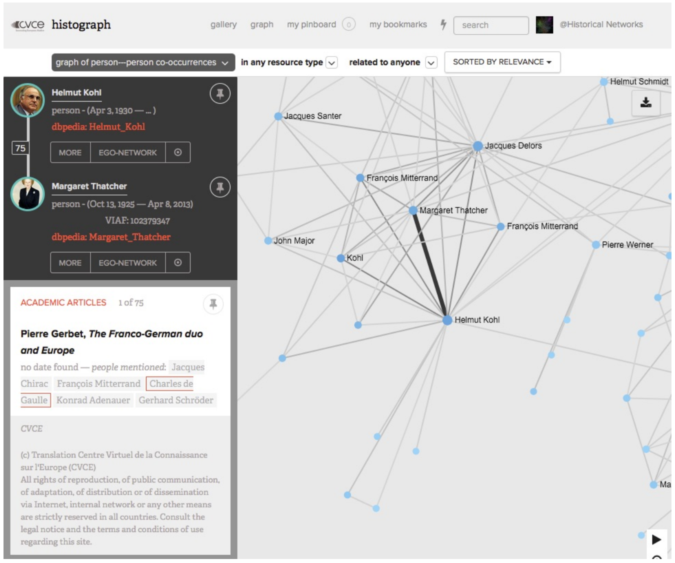

Fig. 1. Screenshot taken of histograph's graph exploration component [20].

3.2 Topic Modeling Techniques

Topic Modeling is one of the predominant text analysis tools. Techniques such as Term Frequency - Inverse Document Frequency (TF-IDF) [38] and Latent Dirichlet Allocation (LDA) [6] are used to analyze a corpus and extract the dominant topics to classify documents. Topic information can be utilized in visualizations used to explore a corpus as a means of visually organizing data, as done by [19], for example.

4 Research Directions

We will be researching the topic of visual analytics of multilayer graphs to support research in the field of Digital Cultural Heritage, as a part of the BLIZAAR project. The goal of the project is to develop visual analytics techniques for multilayer graphs, and one of the use cases is in the domain of DCH. As part of this project, researchers in visual analytics and digital humanities work together to help researchers maintain an overview of their corpora and to facilitate their exploration.

4.1 Addressing user requirements

As a part of initial investigation into the needs of researchers in the field of DCH, we conducted interviews with some of the target researchers. The interviews were unstructured and informal, as the goal was to determine an initial set of tasks. More detailed interviews will be conducted at a later stage in the project. In these initial interviews we have identified three related, yet distinct tasks which are part of their workflow.

4.1.1 Diversity and continuous coverage

Researchers need to be able to determine to which extent corpora adhere to internal quality standards. For example, for each entity (person, institution) researchers strive to strike a balance between different types of archives, different types of media (photo, text, video, etc.). Important entities need to be covered for the full time period of the respective subsection of the corpus. In order to evaluate corpora, researchers need to be able to 1) quickly assess whether these conditions have been met and 2) be made aware of the sections within the corpora where they have not. For example, there might be a gap in the continuous coverage of the activities of an entity, such as the European Central Bank for 2011. Such gaps are usually found by chance or following a specific search for them. Continuous coverage over time is entity-dependent: The European Central Bank was established in 1998, therefore a lack of references to it before this year does not constitute a gap.

4.1.2 Search by tag

Researchers would like to have several tags associated with each document and to be able to use combinations of them to search the corpus. Tags depend on the interests of a researcher, there can therefore not be a definitive or objective catalogue. In contrast to a faceted search, a tag-based approach should allow 1) the discovery of related entities and documents which would be missed by a known-item search and 2) provide a higher-level perspective on a corpus (and the history it represents) as opposed to a document/entity-focus. For example, a search for "Glasnost" should also consider relevant documents about "Mikhail Gorbachev" in the 1980s.

4.1.3 Exploration

To get a bird's eye perspective on the CVCE corpus, an interactive dynamic map of all entities, documents and their relations is needed. There is no one way to grasp and represent the complexity of these relations but several use cases are conceivable:

- identify (un)wanted gaps between them;
- understand where a new document, that is about to be added to the system, fits in this map and which gaps it closes;
- receive recommendations for other documents.

4.2 Characterization of Layers

A key question in building a multilayer graph for DCH data is how to define the layers. The effectiveness of multilayer graph visualizations is in many ways related to the definition of layers. It also depends on how well the visualization supports the user at their specific task.

Entities extracted from DCH data contain many different types, e.g. people, institutions, national governments, and the parent documents themselves may have come from a range of sources (e.g., various national archives and libraries or private collections). Each of these entity types, in a suitable analytical context, may exist as a separate layer in a multilayer graph. Layers could also be custom defined, based on user tags, supporting the exploration requirement described in section 4.1.2.

Networks can be created based on personal correspondence between individuals as well as official correspondence, and each of these may be represented as a separate layer in a multilayer system. Co-occurrence networks of influential people in a text may also be created as one layer, while co-occurrence of influential people in photographs may be used as another. The classification of documents as describing different topics using topic modeling may also allow for the formation of layers based on topics. This sort of layer definitions, along with defining layers based on document source, may be useful for the diversity and coverage user requirement, described in section 4.1.1.

Time can also be used to define layers. The historical events that are described are usually associated with a specific time or time span. This can result in extracted data structures that change over time. These dynamic (or temporal) graphs can considered as a type of multilayer network [29], with different time-slices representing different layers. Layers defined on a temporal basis, possibly along with layers defined by topic could support the exploration requirement described in section 4.1.3.

4.3 Evaluation

The recent increase in popularity in visualization for digital humanities has led to many visualization systems and novel techniques for DH. Evaluation is a key part of the process in developing systems and techniques, that is unfortunately currently often overlooked [27]. Many modern visualization techniques papers provide an informal evaluation, in which domain experts are asked about their opinion of a technique. However to fully understand the effectiveness of a technique an empirical evaluation (including rigorous statistical analysis), is required, such as those described by Purchase [35], and these are often lacking. In the case of systems with real-world users an empirical evaluation may not be practical due the high level nature of the users use of the tool, but if a design model, such as [33] and/or a design methodology such as [39] is followed, it should be possible to get validation of the effectiveness of the designed system. The evaluation of the journalistic data mining tool “Overview” provides a good example [9].

A key aspect of our research is access to real-world researchers to provide an input to our design as well as validation and evaluation of newly developed techniques. This will allow us to not only run empirical evaluation similar to those in [35], it will allow us to get repeated design feedback and validation, as well as allowing a more long-term qualitative evaluation with end users.

5 Conclusions and Future Work

In this extended abstract we have presented the early stages of our work on the visual analytics of multilayer graphs to support research in the field of Digital Cultural Heritage. We have described the requirements of DCH researchers and how multilayer graph visual analytics may be used to support their research. In the next stage of our research we will begin an iterative process of design implementation and validation, following the nested design model for visualization design, suggested by Munzner [33].

Acknowledgments

BLIZAAR is funded by INTER, the international cooperation program of the Luxembourgish National Research Fund (FNR) and the French National Research Agency (ANR), under grant number INTER/ANR/14/9909176.

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