Unifying the Sensemaking Loop with Semantic Interaction

Alex Endert Patrick Fiaux Chris North

Abstract— Visual analytics emphasizes sensemaking of large, complex datasets through interactively exploring visualizations generated by statistical models. For example, dimensionality reduction methods use various similarity metrics to visualize textual document collections in a spatial metaphor, where similarities between documents are approximately represented through their relative spatial distances to each other in a 2D layout. This metaphor is designed to mimic analysts' mental models of the document collection and support their analytic processes, such as clustering similar documents together. However, in current methods, users must interact with such visualizations using controls external to the visual metaphor, such as sliders, menus, or text fields, to directly control underlying model parameters that they do not understand and that do not relate to their analytic process occurring within the visual metaphor. In this paper, we present the opportunity for a new design space for visual analytic interaction, called *semantic interaction,* which seeks to enable analysts to spatially interact with such models directly within the visual metaphor using interactions that derive from their analytic process, such as searching, highlighting, annotating, and repositioning documents. Further, we demonstrate how semantic interactions can be implemented using machine learning techniques in a visual analytic tool, called *ForceSPIRE*, for interactive analysis of textual data within a spatial visualization. Analysts can express their expert domain knowledge about the documents by simply moving them, which guides the underlying model to improve the overall layout, taking the user's feedback into account.

Index Terms— interaction, spatialization, sensemaking, analytics, textual datasets.

1 Introduction

Visual analytics bases its success on combining the abilities of statistical models, visualization, and human intuition for users to gain insight into large, complex datasets [1]. This success often hinges on the ability for users to interact with the information, manipulating the visualization based on their domain expertise, interactively exploring possible connections, and investigating hypotheses. It is through this interactive exploration that users are able to make sense of complex datasets, a process referred to as sensemaking [2]. The sensemaking loop models the series of cognitive stages users traverse when analyzing and progressively making sense of a dataset. The two primary parts of this model are foraging and synthesis. Foraging refers to the stages of the process where users are filtering and gathering collections of interesting or relevant information. Then, using that information, users advance through the synthesis stages of the process, where they construct and test hypotheses about how the foraged information may relate to a larger plot. Tools exist that support users for either foraging or synthesis – but not both.

In this paper, we present *semantic interaction*, combing the foraging abilities of statistical models with the spatial sensemaking abilities of analysts. Semantic interaction is based on the following principles:

1. Visual "near=similar" metaphor **supports** analysts' spatial cognition, and is generated by statistical models and similarity metrics. [3]
2. **Use** semantic interactions within the visual metaphor, based on common interactions occurring in spatial analytic processes [4] such as searching, highlighting, annotating, and repositioning documents.
3. **Interpret** and map the semantic interactions to the underlying parameters of the model, by updating weights and adding information.
4. **Shield** the users from the complexity of the underlying mathematical models and parameters.
5. Models **learn** incrementally by taking into account interaction during the entire analytic process, supporting analysts' process of incremental formalism [shipman].
6. **Provide** visual feedback of the updated model and learned parameters within the visual metaphor.
7. **Reuse** learned model parameters in future or streaming data within the visual metaphor.

To demonstrate semantic interaction, we present ForceSPIRE, a prototype for spatial analysis of text documents. ForceSPIRE is a flexible workspace merging the ability to forage and synthesize.

1.1 Foraging Tools

We categorize foraging tools by their ability to pass data through complex statistical models and visualize the computed structure of the dataset for the user to gain insight. Thus, users interact with these tools primarily through directly manipulating the parameters of the model used for computing the structure. As such, users are required to translate their domain expertise and semantics about the information to determine which (and by how much) to adjust these parameters. The following examples further describe this category of tools.

Visualizations such as IN-SPIRE's "Galaxy View" (shown in Fig. 1) present users with a spatial layout of textual information where similar documents are proximally close to one another [5]. An algorithm creates the layout by mapping the high-dimensional collection of text documents down to a two-dimensional view. In these spatializations, the spatial metaphor is one in which users can infer meaning of the documents based on their location. The notion of distance between documents represents how similar the two documents are (i.e., more similar documents are placed closer together). For instance, a cluster of documents represents a group of similar documents, and documents placed between two clusters implies those documents are connected to both clusters. These views are beneficial as they allow users to visually gain an overview of the information, such as what key themes or groups exist within the dataset. The complex statistical models that compute similarity between documents are based on the structure within the data, such as term or entity frequency. In order to interactively change the view, users are required to directly adjust keyword weights, add or remove

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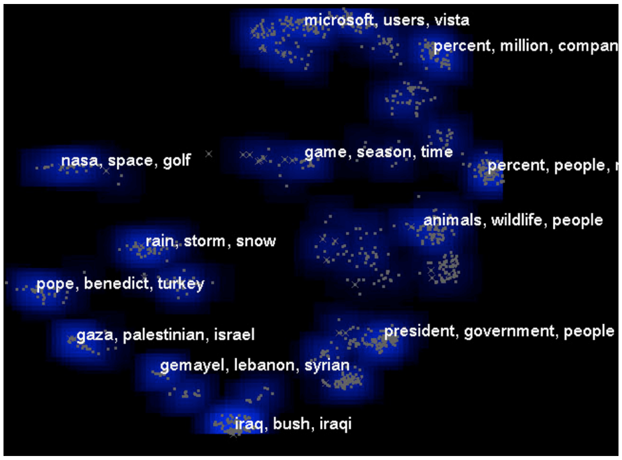

Fig. 1. The IN-SPIRE Galaxy View showing a spatializtiation of documents represented as dots. Each cluster of dots represents a group of similar documents.

documents/keywords, or provide more information on how to parse the documents for keywords/entities upon import.

Similarly, an interactive visualization tool called iPCA uses Principal Component Analysis (PCA) to reduce high-dimensional data down to a two-dimensional plot, providing users with sliders and other visual controls for directly adjusting numerous parameters of the algorithm, such as individual eigenvalues, eigenvectors, and other components of PCA [6]. Through adjusting the parameters, the user can observe how the visualization changes. This allows users to gain insight into a dataset, given they have a thorough understanding of PCA, necessary to understand the implications behind the changes they are making to the model parameters.

Alsakran et al. presented a visualization system, STREAMIT, capable of spatially arranging text streams based on keyword similarity [7]. Again, users can interactively explore and adjust the spatial layout through directly changing the weight of keywords that they find important. In addition, STREAMIT allows for users to conduct a temporal investigation of how clusters change over time.

1.2 Synthesis Tools

Synthesis tools focus on allowing users to organize and maintain their hypotheses and insight regarding the data in a visual medium. In large part, this is done through presenting users with a flexible spatial workspace in which they can organize information through creating spatial structures. In doing so, users externalize their thought processes (as well as their insights) into a spatial layout of the information.

For example, Analyst's Notebook [8] provides users with a spatial workspace where information can be organized, and connections between specific pieces of information (e.g., entities, documents, events, etc.) can be created. Similarly, The Sandbox [9] enables users to create a series of cases (collections of information) which can be organized spatially within the workspace.

From previous studies, we found cognitive advantages associated with the manual creation of a spatial layout of the information [4]. By providing users a workspace in which to manually create spatial representations of the information, users were able to externalize their semantics of the information into the workspace. That is, they created spatial structures (e.g., clusters, timelines, etc.), and both the structures as well as the locations relative to remaining layout carried meaning to the users with regards to their sensemaking process.

1.3 Semantic Interaction

With semantic interaction, the challenge is to combine the strengths of the foraging tools with those of the synthesis tools. That is, the goal is to leverage the flexibility and ease in which the synthesis tools allow users to inject their semantics about a dataset

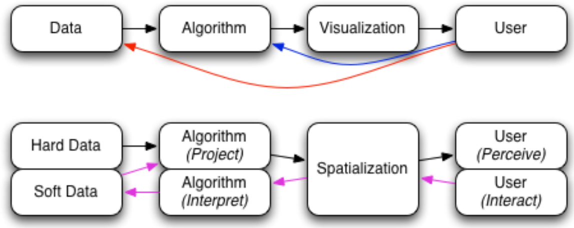

Fig. 2 (top) The basic version of the "visualization pipeline". Interaction can be performed on directly the Algorithm (blue arrow) or the data (red arrow). (bottom) Our modified version of the pipeline for semantic interaction, where the user interacts within the spatial metaphor (pink arrow).

into the layout, with the computational power of the statistical algorithms used in foraging tools. As such, semantic interaction occurs within a spatial workspace, with the added benefit that it is tightly coupled to the statistical model. Through this coupling, the system interprets the analytical reasoning associated with the interaction within the spatial layout, and updates the corresponding statistical parameters of the model.

In ForceSPIRE, the statistical model generating the spatialization is tightly coupled with the interaction. That is, the algorithm generates a layout of documents based on similarity, and the parameters and characteristics upon which this similarity is calculated can be adjusted through user interaction with the documents in the spatial metaphor. ForceSPIRE utilizes a modified force-directed system (modified from the original algorithm presented in [10]), to create a visualization where a spatial layout is algorithmically generated. The modifications of the layout (and in turn the algorithm) are performed through forms of semantic interaction such as document movement, text highlighting, text querying, and annotations. In previous work, we have shown how movement in itself can be used to guide other statistical models (e.g., Multidimensional Scaling, Probabilistic Principal Component Analysis, and Generative Topographic Map) [11]. The statistical parameters modified in ForceSPIRE are relative importance of keywords (entities), addition or removal of entities, and anchoring specific documents to locations in the layout. Thus, interaction takes on a deeper, more integrated role in the exploratory spatial analytic process. Essentially, users are able to input their domain knowledge by modifying the spatial layout, which in turn informs the layout models to respond and produce a better overall layout.

Semantic interaction is grounded in the principles of how users are familiar with analysing and exploring information spatially [4, 12]. We leverage these interactions and tightly integrate them into the modified force-directed model of the system, creating methods for users to input or change algorithm parameters, while being abstracted from the complexities of doing so directly. Thus, semantic interaction is different from interactions designed to directly change statistical parameters (e.g. those incorporated in many foraging tools, modelled by the traditional visualization pipeline), and are more computationally powerful than manual layout interactions used by many synthesis tools. In contrast, semantic interaction transforms the role of the spatialization into a medium through which users can perceive insight, as well as interact (Fig. 2). Semantic interaction is made possible through *capturing* the interaction, *interpreting* the analytical reasoning associated with the interaction, and *updating* the corresponding statistical parameters.

2 Text Analytics using ForceSPIRE

ForceSPIRE is a visual analytic system designed for semantic interaction. It features select instances of semantic interaction (document movement, text highlighting, search, and annotation) for interactively exploring textual data. The system has a single view, where a collection of documents is represented spatially based on

Fig. 3. Moving the document shown by the arrow, ForceSPIRE adapts the layout accordingly. Documents sharing entities with the document being moved follow.

similarity (i.e., documents closer together are more similar). Documents are represented as nodes, and when clicked on, show edges to other documents with shared entities. The shared entities are displayed on the edge.

ForceSPIRE is designed for large, high-resolution displays. As such, users have the ability to display documents at two different levels of detail: either small nodes or full detail text. As semantic interaction emphasizes the importance of context in which the interaction takes place (e.g., highlighting text in the context of the document), having the full detail text available in the context of the spatial layout is beneficial over having a single document viewer.

2.1 Constructing the Spatialization

The spatial layout of the text documents is determined by a modified version a force-directed graph layout model [10]. This model functions on the principle of nodes with a mass connected by springs with varying strengths. Thus, each node has attributes of attraction and repulsion: nodes repel other nodes, and two nodes attract each other only when connected by a spring (edge). The optimal layout is then computed by iteratively calculating these forces until the lowest energy state of all the nodes is reached.

We apply this model to textual information by treating ***documents*** as ***nodes***. The entire textual content of each document is parsed into a collection of entities (i.e., keywords). The number of entities corresponds to the ***mass*** of each document. A ***spring*** (or edge) represents one or more matching ***entities*** between two nodes. For example, two documents containing the term "airport" will be connected by a spring. The strength of a spring (i.e. how close together it tries to place two nodes) is based on two factors: the number of entities two documents have in common, and the ***importance value*** associated with each shared entity. The importance value of an entity, and thus the strength of a spring, can be adjusted through the various instances of semantic interaction, explained in the following sections. The higher the sum of the importance values of all entities within a spring, the tighter the spring will pull the two documents that it connects. While we only create edges between two documents that share at least one entity, the model can also be thought of as all pair of documents have edges, and if there are not shared entities between the two documents, the strength of that edge is set to zero.

The resulting spatial layout is therefore one where similarity between documents is represented by distance relative to other documents. ***Similarity*** in this system is defined by the strength of the spring between two documents.

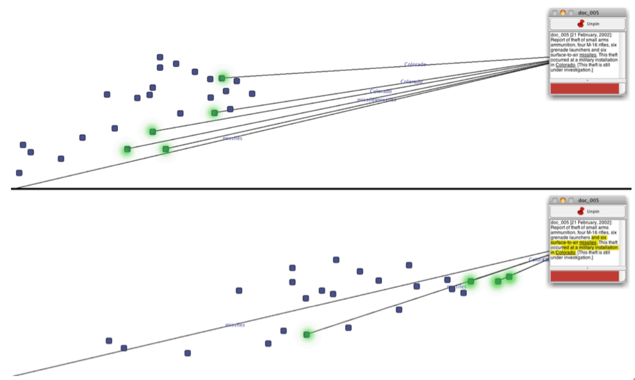

Fig. 4. The effect of highlighting a phrase containing the entites "Colorado" and "missiles". Documents containing these entities move closer by increasing their importance values.

fancy name of naming interactions use this

2.2 Semantic Interaction in ForceSPIRE

ForceSPIRE allows users to analyse a textual dataset by positioning documents at specific locations, highlighting phrases within the documents, performing searches, and adding annotations to documents. ForceSPIRE couples these interactions to updates of the corresponding parameters of the force-directed model. The primary parameters of the force-directed model that are being updated by these interactions are the strengths of the edges through updating the importance values of entities.

2.2.1 Document Movement

Users are able to interactively explore the information by ***dragging*** a document within the workspace, ***pinning*** a document to a particular location (see Fig. 3), as well as ***linking*** two documents. In previous work, we have shown how document movement in spatializations can be described as either *exploratory* or *expressive* [11]. An exploratory document movement enables users to *explore* the relationships between the information given the current model parameters. In contrast, through performing an expressive form of document movement, users can add semantic information into the system. For example, when dragging a document, the force-directed system responds by finding the lowest energy state of the remaining documents given the current location of the dragged document. As a result, documents rearrange based on similarity. Documents similar to the one being dragged will follow, while documents not similar will remain stationary. This allows users to explore the relationship of that document in comparison to the remaining documents.

In addition to the exploratory dragging of a document, users have the ability to ***pin*** a document (an expressive interaction). By pinning a document, users are able to incrementally *add* semantic meaning to locations in their workspace (i.e., to *express* their domain knowledge into the system). By specifying key documents to user-defined locations, the layout of the remaining documents will adapt to the locations of the pinned documents. Thus, users can explore how documents are positioned based on their similarity (or dissimilarity) to the pinned documents. For instance, if the layout places a document between two pinned documents, it may imply that the particular document holds a link between the two pinned documents, sharing entities that occur in both.

Finally, users can ***link*** two documents by dragging one document with another. In performing this expressive interaction, ForceSPIRE calculates the similarity between the documents in terms of shared entities, and increases their importance values. As a result, the layout will place more emphasis on the characteristics that make those two documents similar.

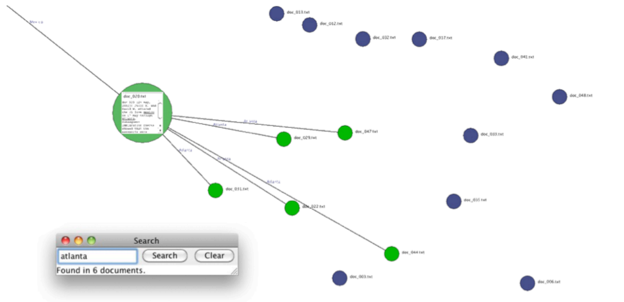

Fig. 5. Searching for the term "Atlanta", documents containing the term highlight green within the context of the spatial layout. Additionally, the importance value of entity "Atlanta" is increased.

2.2.2 Highlighting

While reading a document, users commonly utilize highlighting a term or phrase as a way to emphasize parts of the text. In a previous study, we found analysts highlighting text within a document in order to mark important terms or phrases and personalize the visual representation of the document based on the highlights [4].

In ForceSPIRE, we present users with the similar ability to highlight text within documents, with the added benefit that the system makes use of this information. When ***highlighting a term***, the term is turned into an entity (if not already one), and the importance value of that term is increased. This term importance value increase is global, meaning all edges between documents that include this entity will increase in strength. Similarly, ***highlighting a phrase*** results in the phrase being first parsed for entities that it contains, then increasing the importance value of each of those entities. Thus, users are able to focus on reading and understanding a particular document while ForceSPIRE performs the corresponding parameter updates (see Fig. 4).

2.2.3 Searching

When coming across a term of particular interest, analysts usually search on that term in order to find other instances of where the term is found. In a spatial workspace, this is of particular importance, because the answer to "where the term is also found" is not only given in terms of what documents, but also where in the layout those documents occur. The positions of documents containing the term are shown in context of the entire dataset, from which users can infer the importance of that term.

ForceSPIRE takes advantage of users searching by adjusting the importance value of the terms that are searched. ForceSPIRE ensures that the search term is an entity, and increases the importance value of the term accordingly. Fig. 5 gives an example of how a search result appears in ForceSPIRE. Searching for the term "Atlanta", documents that contain the term are highlighted green, and links are drawn to show where the resulting documents are in relation to the current document.

2.2.4 Annotation

Annotations (i.e. "sticky notes") are also viewed as a form of semantic interaction occurring within the analytic process, from which analytic reasoning can be inferred. When a user creates a note regarding a document, that semantic information should be added to the document. For example, if Document A refers to "Revolution Now" (a suspicious terrorist group), and Document B refers to "a group of suspicious individuals", and the user has reason to believe these individuals are related to Revolution Now, adding a note to Document B stating "these individuals may be related to Revolution Now" is one way for the user to add semantic meaning to the document.

ForceSPIRE handles the addition of the note as follows (shown in Fig. 6). First, the note is parsed for any currently existing entities in the dataset (in this case "Revolution Now"). If entities are found, they are added to the document, and any new corresponding edges to other documents are added. In the example in Fig. 6, edges are created between Document B and Document A (as well as any other documents that mention "Revolution Now"). Second, if the note contains any new entities, they are created, with the intent that any future entities that may match to that note can be linked at that time. Finally, any of the entities in a note receive an increase in their importance values. ForceSPIRE also handles cases where notes are edited, with text added or removed from the note, by updating the entities associated with the document, and adjusting the importance values of these entities accordingly.

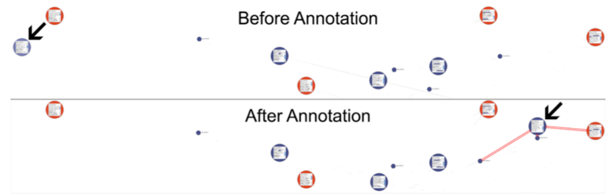

Fig. 6. The effect of adding an annotation ("these individuals may be related to Revolution Now") to the document shown with an arrow. As a result, the document becomes associated with other documents mentioning the terrorist organization "Revolution Now".

3 Conclusion

In this paper we briefly discussed how semantic interaction in ForceSPIRE can help combine the strengths foraging and synthesis tools for text analytics. We present how each of the four primary interactions in ForceSPIRE (document movement, search, highlighting, and annotation) are tightly coupled with the underlying statistical model. Thus, users are able to focus on their task of analysis, without the added complexity of directly modifying statistical parameters.

References

[1] Thomas, J. J., Cook, K. A., National, V. and Analytics, C. *Illuminating the path*. IEEE Computer Society, City, 2005.

[2] Pirolli, P. and Card, S. Sensemaking Processes of Intelligence Analysts and Possible Leverage Points as Identified Though Cognitive Task Analysis *Proceedings of the 2005 International Conference on Intelligence Analysis, McLean, Virginia*, 2005, 6.

[3] Skupin, A. A Cartographic Approach to Visualizing Conference Abstracts. City, 2002.

[4] Andrews, C., Endert, A. and North, C. Space to Think: Large, High-Resolution Displays for Sensemaking. In *Proceedings of the CHI* (2010).

[5] Wise, J. A., Thomas, J. J., Pennock, K., Lantrip, D., Pottier, M., Schur, A. and Crow, V. *Visualizing the non-visual: spatial analysis and interaction with information for text documents*. Morgan Kaufmann Publishers Inc, 1999.

[6] Jeong, D. H., Ziemkiewicz, C., Fisher, B., Ribarsky, W. and Chang, R. iPCA: An Interactive System for PCA-based Visual Analytics. *Computer Graphics Forum*, 28, 2009, 767-774.

[7] Alsakran, J., Chen, Y., Zhao, Y., Yang, J. and Luo, D. STREAMIT: Dynamic visualization and interactive exploration of text streams. In *Proceedings of the IEEE Pacific Visualization Symposium* (2011).

[8] i2 Analyst's Notebook.

[9] Wright, W., Schroh, D., Proulx, P., Skaburskis, A. and Cort, B. The Sandbox for analysis: concepts and methods. In *Proceedings of the CHI '06* (New York, NY, 2006). ACM.

[10] Fruchterman, T. M. J. and Reingold, E. M. Graph drawing by force-directed placement. *Software: Practice and Experience*, 21, 11, 1991.

[11] Endert, A., Han, C., Maiti, D., House, L., Leman, S. C. and North, C. Observation-level Interaction with Statistical Models for Visual Analytics, In *Proceedings of the VAST*, 2011.

[12] Robinson, A. C. *Design for Synthesis in Geovisualization*. PhD thesis, Pennsylvania State University, University Park, PA, 2008.