Unifying the Sensemaking Process with Semantic Interaction

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Abstract— Visual analytics emphasizes sensemaking of large, complex datasets through interactively exploring visualizations generated by statistical models. We propose *semantic interaction* as a design space for user interaction, combining the massive-data foraging abilities of statistical models and mining algorithms with the sensemaking abilities of analysts – using a visualization as the medium for interaction to occur. While algorithms can extract and present important information to analysts, the probabilistic nature of the algorithms results in necessarily producing some irrelevant information or incorrect conclusions. The algorithms need to be guided to extract and present the information that is most relevant to the analyst's current task. Analysts need to be able to provide feedback to direct the algorithms. Thus, the goal of semantic interaction is to unintrusively capture the semantic knowledge or intent of the user in order to guide the system and support the entire analytic process.

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 analysing 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 filter and gather collections of interesting or relevant information. Then, using that foraged information, users advance through the synthesis stages of the process, where they construct and test hypotheses about how the foraged information may relate to the larger plot. In contrast to foraging, synthesis is more "cognitively intensive", as much of the insights stem from the user's intuition and domain expertise. Most existing tools focus on either foraging or synthesis, separating these two phases. Thus, the goal of semantic interaction [3] is to extract the analytic reasoning from interactions occurring during synthesis, and inject this captured user intent into the system.

Semantic interaction exploits the interactions that analysts are already naturally performing within the context of their analytic work, and extend these to direct the algorithms accordingly. While algorithm designers might think of this as indirect control, analysts perceive this as the direct route because it enables them to inject their domain expertise into the algorithms by interacting directly with the data using their own analytic methods as they cognitively synthesize information. Thus, as the analyst is organizing his hypotheses, the algorithms can increasingly co-organize additional relevant information accordingly. For example, analysts can express their expert domain knowledge about the documents by simply moving them within a spatial representation, which then guides the underlying model to improve the overall spatial layout of other information by taking the user's feedback into account [4]. This, in effect, integrates the cognitively-intense synthesis process with the computationally-intense foraging process.

Semantic interaction exploits machine learning techniques within the context of interactive visualization. Semantic interactions are interpreted and translated into *soft data*, which ultimately impact the underlying model parameters, for example by re-weighting entity importance in similarity metrics (Figure 1). The algorithms must learn incrementally, mimicking the incremental formalism in the analyst's sensemaking process. In this position statement, we provide a brief overview of the semantic interaction design space, and describe our prototype, ForceSPIRE, providing a foundation for further research in this area.

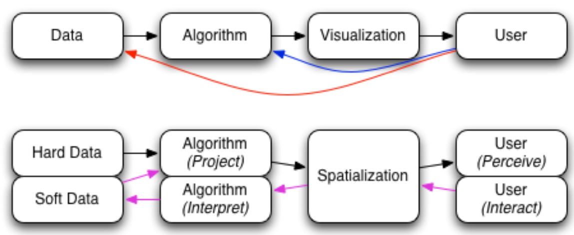

Figure 1. (top) The basic version of the "visualization pipeline". Interaction is performed directly on the algorithm (blue arrow) or the data (red arrow). (bottom) Our modified version of the pipeline for semantic interaction, where the user interacts directly within the spatial metaphor (purple arrow). Analytic reasoning is interpreted and used.

2 Semantic Interaction

Semantic interaction combines the foraging abilities of statistical models with the spatial synthesis abilities of analysts in a spatial medium [3]. For example, semantic interaction can benefit intelligence analysts tasked with gaining insight into a textual dataset, using a prototype system called ForceSPIRE (shown in Figure 2) [3]. Semantic interaction is based on the following principles. These principles outline the design space of semantic interaction, and provide one approach to the challenge of how to capture user intent to guide the analytic process (and the corresponding tool design).

1. Visual "near=similar" metaphor **supports** analysts' spatial cognition, and is **co-created** by users and statistical models (with corresponding similarity metrics).
2. **Use** semantic interactions within the visual metaphor, based on common interactions occurring in spatial analytic processes [5] 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, to capture domain knowledge.
4. **Shield** the users from the complexity of the underlying mathematical models and parameters.
5. Models **learn** incrementally by taking into account interactions throughout the entire analytic process, supporting analysts' process of incremental formalism [6] as they synthesize high-level knowledge.
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.

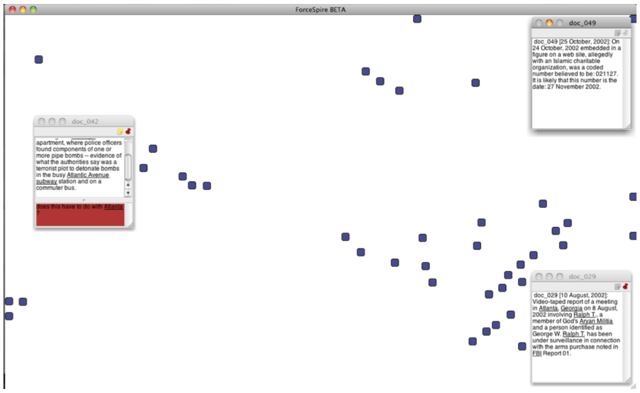

Figure 2. Our visual analytic prototype, ForceSPIRE, designed for visual text analysis using Semantic Interaction.

The key concept is that the familiar synthesis interactions are automatically re-interpreted into formal foraging interactions. Thus, as users synthesize, they simultaneously forage additional relevant information. Semantic interaction transparently supports the constant "broadening" and "narrowing" of information during sensemaking [7]. Semantic interaction leverages the cognitive connection formed between the user and the spatial layout. The following intelligence analysis scenario is representative of the process of analysts when performing an intelligence analysis task of textual documents in a spatial visualization, as previously found by Andrews et al. [5], and further motivates and explains the concept of semantic interaction:

During her analysis, an intelligence analyst finds a suspicious and interesting phrase within a document. While reading through the document, she highlights the phrase "suspicious individuals were spotted at the airport" in order to more easily recall this information later. After she finishes reading the document, she moves the document into the bottom right corner of her workspace, in the proximity of other documents related to an event at an airport. To remind herself of her hypothesis, she annotates the document with "might be related to Revolution Now terrorist group". Further examining the events at the "airport", she searches for the term, continuing her investigation.

With semantic interaction, the system learns from these interactions and provides the analyst with visual feedback. Two documents relevant to the documents in the bottom right corner begin to move closer to that cluster. She quickly reads through these, and notices that one of them seems related, and moves it into the cluster. It informs her that the "Revolution Now group is operating in airports", strengthening her insights. The other document talks about a "terrorist at an airport in Afghanistan". She moves this document away from the cluster, notifying the system that this recommendation was not relevant, as she is not currently investigating activities in Afghanistan. Through incremental learning and user feedback, the layout is co-created from the domain expertise of the user and the computed similarity of the system.

3 ForceSPIRE

To explore the possibilities of semantic interaction, we designed ForceSPIRE, a visual text analysis prototype [3]. 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 which this similarity is based on can be adjusted via the interpreted analytical reasoning (i.e., the user's intent). 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.

Table 1. Forms of semantic interaction. Each interaction corresponds to users' reasoning in the analytic process.

Semantic Interaction	***Associated Analytic Reasoning***
Document Movement	• Similarity/Dissimilarity • Create spatial construct (.e.g timeline, list, story, etc) • Test hypothesis, see how document "fits" in region
Text Highlighting	• Mark importance of phrase (collection of entities) • Augment visual appearance of document for reference
Pinning Document to Location	• Give semantic meaning to space/layout
Annotation, "Sticky Note"	• Put semantic information in workspace, within context
Document Coloring	• Create visual group/cluster • Mark group membership
Level of Visual Detail	• Change ease of visually referencing information (e.g. full detail = more important = easy to reference)
Query Terms	• Expressive search for entity

In ForceSPIRE, the spatialization serves as a medium through which users can perceive insight, as well as interact (Figure 1Figure 1). Semantic interaction is made possible through *capturing* the interaction, *interpreting* the analytical reasoning associated with the interaction, and *updating* the corresponding statistical parameters.

We refer to the captured and interpreted analytic reasoning (or intent) of the user as *soft data*. Soft data is integral to principles of semantic interaction as it it represents the human intuition (or semantics) that help guide the system through steering the underlying model. Also, it is a rich research area, as uncovering the analytic reasoning associated with specific interactions is highly dependent on factors such as the visual metaphor in which the interaction occurs, the context or dataset being analysed, etc. Table 1 shows the semantic interactions used in ForceSPIRE. Soft data presents opportunities to explore, such as reuse for future investigations or larger datasets, comparing findings between collaborators, illuminating biases to analysts, and more.

Semantic interaction illuminates a design space for integrating complex mathematical models with visual data exploration to support the entirety of the analytic process. The forms of semantic interactions in ForceSPIRE provide an initial approach, with the hope of inspiring further research on this important topic.

References

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