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Integrating visual analysis with ontological knowledge structure

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Abstract

Most existing visual analytical tools that incorporate knowledge are tailored for specific analytical tasks. Although these tools are useful and powerful, it is often difficult to generalize the approaches utilized in these tools for knowledge incorporation to new problems or domains. In this paper, we propose a method for integrating a visual analytical tool with an ontological knowledge structure such that concepts can be dynamically created or modified through the ontology while the overall system retains the exploratory capabilities of the visual tools. In order to understand how such integration is possible, we first examine the roles of the visualization and the ontology. The relationship between the two then depict a generalizable model that describes the types of communication that are useful and practical between the visualization, the ontology, and the user.

1 Introduction and Related Work

The incorporation of knowledge into the process of solving analytical tasks is a fast emerging area in visual analytics There have been many notable publications in this new area that demonstrate the value of integrating domain knowledge into visualization. Ling et al presented a traffic analysis system to analyze network traffic using knowledge representation [2]. However, with few exceptions, the process of knowledge integration utilized in these publications is often specific to the task or the domain, making it difficult to generalize into new problem areas.

In this paper, we propose our method to integrate a visual analytical tool with an ontological knowledge structure such that concepts can be dynamically inserted or modified through the ontology while the overall system retains the exploratory capabilities of visual tools. A concept refers to user's understanding of data, whether inspired from internal knowledge or external knowledge sources. For example, when the user is trying to determine the volume of a cube based on its three dimensions (width, height, length), the concept is in the relationship between the volume and the product of the three dimensions. This simple concept could then be represented as an equation and stored in an ontological structure. By utilizing such concepts in a visualization, an analysis could be performed at a higher level instead of faithfully representing the original data.

In order to understand how a visualization could be connected to a knowledge structure to utilize the concepts stored within, we first examine the functional relationship between a visualization and an ontological structure. Visualization is commonly accepted to be useful in exploring data, through which the user could gather information and make conclusions based on visual patterns. On the other hand, an ontology provides an explicit conceptualization (i.e.,meta-information) that describes the semantics of the data. [1] Similarly, our ontological structure focuses more on allowing a user to create concepts and then later on reusing these concepts to assist the discovery of inferential information. Although visualization and ontology are seemingly disjoint, we believe that they could complement each other in solving analytical tasks (Figure 1A).

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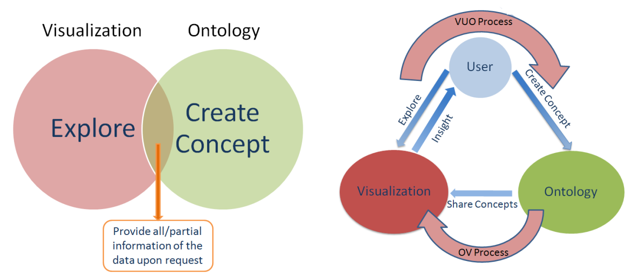

Figure 1: (A) The relationship between visualization and an ontological structure (B) A communication model derived from the relationship in Figure 1A

This complementary relationship, as elaborated in section 2, is the basis of our model, which describes the types of communication that are useful and practical between the visualization, the ontology, and the user (Figure 1B).

In the important work by Gilson et al [3], they proposed a well-defined generalizable approach for automatic generation of visualizations via ontology mapping and applied the approach to web data. Although both approaches utilize visualization and ontological knowledge structure, our approach focuses more on dynamically creating, sharing and storing concepts to support visual analytical tasks.

In the remainder of this paper, we present our understanding of the complementary functional relationship between visualization and ontology in section 2. In section 3, we demonstrate several possible scenarios and applications of our approach. Finally, we provide our conclusion and future work in Section 4.

2 Functional Relationships between Visualization and Ontology

In order to integrate the visualization with the ontological knowledge structure, we need to understand what their relationship is and why the integration is meaningful. By examining visualization and ontological structure separately, we discover a complementary functional relationship between the two, as shown in the Venn diagram Figure 1A, in which orange and blue circles represent functions of visualization and ontological structure, respectively.

As shown in the overlapping region of Figure 1A, both visualization and ontological structure share similar functions that could provide specific information, in the forms of visual selections and data queries respectively. For example, when searching for risk level higher than 0.4, the user could either filter the corresponding data dimension with Parallel Coordinates to location those information, or equally, they could write a data query directly to the ontology. ("select * from riskDB where riskLevel > 0.4").

However, the functions of the visualization and the ontological structure are not always similar, due to the different ways of interpreting and representing information. As mentioned previously, vi-

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sualization is good at supporting the exploratory reasoning process, while ontological knowledge structure focus more on assisting the user in creating and storing concepts.

For example, when a user wants to explore the interrelationship of two tuples X and Y, both the visualization and the ontological structure could provide different yet valid information. Through interaction with the Parallel Coordinates view, a user could notice certain trends that indicate Y increases non-linearly with respect to X, without knowing the exact relationship. Whereas, the ontological structure could provide empirical concepts, such as: $y = x^2 - 5$ or $y = -3x^3 + 10$. Then it is up to user to decide which interrelationship fits better to the visual pattern.

3 Implementation and Validation

Based on the understanding of the complementary relationship between the visualization and the ontological structure, we derived a communication model that would integrate these two components. Based on this model, we develop a corresponding visual analytics system, shown in Figure 2 A.

3.1 Model Overview

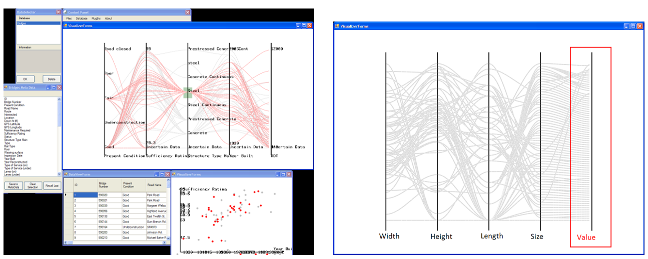

Figure 2: (A) A prototype system built on the communication model. (B) Sharing Concepts from Visualization through User to Ontology (VUO) Process.

In figure 1B, we provide a model for our system, which shows the communication between the visualization, the ontological structure, and the user by means of a concept sharing mechanism.The model is composed of two primary processes. The first is the VUO process (from Visualization through User to Ontology). In this process, the user could gather insights from the visualization, transform the insights into concepts and store them into the ontology for future reference. The second is the OV process (Ontology to Visualization), in which the ontology shares certain concepts with the visualization. Although in OV process, the ontological structure directly communicates with the visualization by sharing concepts, in the VUO process, the visualization could only indirectly communicate with the ontological structure via the user's interpretation.

To show the feasibility of our model, we identified two scenarios that demonstrate possible ways in which the model could be validated.

3.2 Scenarios and Validation

In the first scenario, we examine the plausibility of the OV process, through a task like "Show me all bridges over water". This kind of semantic tasks could not be directly solved by the visualization since there is no data labeled as "bridges over water". However, using the OV process in our system, this task is first processed by the ontological structure, which searches for relevant predefined concepts. Then the ontological structure infers that bridges with type "Waterway" and "Structure Type" should be considered as potential answers, and finally it shares these dimensions and their relationships as concepts with visualization.

In the second scenario, we validate the feasibility of our VUO process, which assists the user in creating, verifying and storing knowledge to ontological knowledge structure, without losing the exploratory capabilities of the visual analytic tools. For example, shown in Figure 2B, when using Parallel Coordinates to explore the four attributes of cubes, like height, length, width, and size, the relationship between combinations of dimension may not be easily discovered. However, through VUO process, the user could visually create a new data dimension, "Value", which is the multiplication of height, width and length. By doing this, a one-to-one visual mapping between "Value" and "Size" has been revealed. Then the new finding is stored in form of a concept into the ontological knowledge structure.

4 Discussion

In this section, we discuss the potential benefits gained by integrating the visualization and the ontology.

First of all, integrating a visual analytical tool and an ontological structure is one step towards shortening the semantic gap between the user's intentions and the visualization, like described in the example of "Show me all bridges over water"(Section 3.1). Due to the potential semantic gap caused by the visualization's limitation on interpreting a user's questions, the visualization could provide meaningless information to the user. An ontological structure, on the contrary, could interpret the user's questions and search for relevant information, by utilizing its collected concepts. Therefore, by integrating ontological knowledge structure as an "interpreter", the semantic gap between the user and visualization could be shortened in system.

In addition, integrating visual analytics tools with the ontological structure reduces a certain amount of opportunistic exploration, through a repeatable and retrievable visual exploratory process. By inserting new concepts to the ontological structure, findings and insights during the visual exploration process could be stored and later reused. Hence, the user's exploration processes could now be retrievable and later be repeated if requested. Our system takes advantages from both the visualization and the ontological structure and is capable of guiding inspectors through the entire reasoning task.

5 Conclusion and Future Work

In this paper, we present our approach to integrating the visualization and the ontology, by utilizing their complementary functions. We start by understanding the functional relationship between visualization and ontological structure. Based on which we derive a model that describes the types of communication that is useful between the visualization, the ontology, and the user.

In future work, we want to formally evaluate the effectiveness of the integration of the visualization and the ontology. We would like to know to what extent this integration could augment the functionalities of visual analytics tools. In addition, we would like to investigate the possibility of applying it to multiple ontological structures and other knowledge sources.

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