An Interactive Graphical Interface for Retrieving Multi-Attribute Data: A Case Study on Historical Relics Retrieval in 3D Digital Museum

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***Abstract*—Information retrieval (IR) has become more and more important in our daily lives. But there are few graphical interfaces or tools that can represent complex data querying and the searching process. This paper proposes a visual tool for multi-attribute data retrieval. The tool provides a Voronoi treemap combined with a selected path tree (SPT) on one window to conduct information retrieval according to different attributes of data, which are organized by a Voronoi treemap, and the other window is used to show retrieval results synchronously. Herein, SPT is used to record user's selection of attributes and is visually superimposed on Voronoi treemap. It may be composed of different levels of nodes in Voronoi treemap and it records the operations of attributes - Union, Intersection and Complement- during the attributes selecting process. Users can also adjust the SPT interactively according to displayed results on the other window. Finally, the paper gives some examples of selecting historical relics in 3D digital museum design system based on double touch-screen. The results prove the usability and effectiveness of our work.**

Keywords- Multi-attribute data; Information retrieval; Visual query language; Voronoi treemap

I. INTRODUCTION

Information retrieval(IR) has become more and more important in our daily lives. The design of visualization interfaces for IR systems is a rapidly emerging area in human-computer interaction. The popular visualization representations for IR systems include tree/hierarchical, network, scatterplot and maps [1] [2]. Herein, tree/ hierarchical visualization techniques, such as tables of contents [3], a node and link diagram [4] and a treemap [5-7], are usually effectively used to branch out complex data into levels to provide both global and local views of data. A treemap is a space-filling representation of hierarchical data.

As a classical treemap method, rectangle treemap divides a rectangle region recursively in the form of rectangular nesting, so that it uses space more effectively. A treemap is easier to understand and achieve, and is more humanized than traditional visualization methods. However, a rectangle treemap usually has elongated rectangles with a high aspect ratio between width and height, which is difficult to see, select and compare. To provide better performance in regional division and size perception of overall layout, there have been some improved methods replacing elongated rectangle with squarer rectangle, such as clustered treemap [8], squarified treemap [9], ordered treemap [10] and modifiable Treemap [11]. Compare to rectangle treemap, Voronoi Treemaps [12] replace rectangles with more general polygons defined as Voronoi cells of the centroid Voronoi diagrams. Voronoi Treemaps have better aspect ratio and enhance expression of hierarchical structure. Reference [13] presents a multi-touch tabletop application called Involv that uses Voronoi treemap algorithm to create an interactive visualization for the Encyclopedia of Life with a phylogeny tree superimposed on the Voronoi treemap. Herein, they designed a Voronoi flowmap algorithm by employing force-directed graph drawing techniques both to guide the construction of the Voronoi treemap and to overlay phylogeny tree. But most of the existing visual representations focus on visualizing the data set without combining with querying.

As an alternative to the dominant text-based method, graphical method can be used to represent querying and the search process as direct manipulation[14]. A prevalent visual scheme for Boolean search has search terms represented as circles or ovals, akin to the sets of Venn diagrams in mathematics. In this representation, the intersection of circles corresponds to the conjunction of the corresponding terms. Dynamic approaches to querying allow users to create, move and remove these circles in order to formulate and reformulate queries, ideally with rapid feedback of the result sets [15]. Some systems such as Venn diagrams [16], filter flow [17] and InfoCrystal [18] allow users to construct queries visually, and they can display results graphically. InfoCrysta1 provides a flexible, dynamic and interactive way to explore and filter information by visualizing all the possible relationships among N concepts. In InfoCrysta1, users can assign relevance weights to the concepts, use threshold to select relationships of interest and specify Boolean as well as vector-space queries graphically.

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$$((\text{Xia} \cup \text{Shang} \cup (((\text{Qi} \cup \text{Lu}) \subseteq \text{Warring Period}) \subseteq \text{Eastern Zhou})) \subseteq \text{Dynasty}) \cap ((\text{Shandong} \cup \text{JiangSu}) \subseteq \text{Region}) \cap (\text{Stone} \subseteq \text{Material}) \quad (1)$$

The query language like as (1) is a classical application in 3D digital museum design system (DMD system). It can be used to effectively and conveniently select historical relics for constructing virtual theme museums. It is hard to be performed by the existing visual query tools. In this paper, we focus on how to design a visual tool for retrieving data according to this kind of complex attributes. Herein, the attributes used to retrieve the data may have some sub-attributes, and the sub-attributes may include their sub-attributes too. The attributes used to retrieve the data can be organized by a tree. We need to graphically select different attributes in different levels with different Boolean operations to form the query language. Hence, this paper presents a novel visual tool for multi-attribute data retrieval based on Voronoi treemap combined with a selected path tree(SPT), which supplys the four information-seeking strategies for visual design of IR system: overview, zoom, filter and details-on-demand [19], especially provides a graphical method to represent query formulation by SPT. Herein, one window is used to conduct information retrieval by different attributes of data, which are organized by a Voronoi treemap. The other window is used to show retrieval results synchronously. SPT is used to record user's selection of attributes and displayed on Voronoi treemap. It may be composed of different levels of nodes in Voronoi treemap and record the operations of attributes - Union, Intersection and Complement- during the selecting attributes process. Users can also adjust the SPT interactively according to displayed results on the other window. The tool has been used in selecting historical relics in 3D digital museum design system based on double touch-screen. The results prove the usability and effectiveness of our work.

II. Overview

In this paper, we focus on how to design a visual tool for retrieving complex data by multi-level attributes tree, i.e. one attribute may have some sub-attributes, and the sub-attributes may include their sub-attributes too. In DMD system, to effectively and conveniently select historical relics for constructing topic virtual museums, the data is organized by Material, Dynasty, Function, Region, Source and other attributes. The dynasty has all kinds of dynasties, which divided into more detailed periods. The other attributes also has some sub- attributes.

The DMD system is designed based on a double-touch screen laptop. It has two windows: The horizontal window displays Voronoi Treemap and the vertical window shows the list of data (See Fig. 1). Voronoi Treemap is used to visualize the multi-attribute data. Based on this kind of Voronoi Treemap, we can select one attribute, and then select one sub attribute in the next level. We can continue the selecting operation until selecting one attribute we want. And at the same time, the other widow shows the query results synchronously. However, this is a traditional IR system, herein, only one attribute can be selected as query information. To resolve this problem, we introduce a concept selected path tree (SPT) here, which is overlapped on Voronoi treemap to visually record the selected attributes and Boolean operations. To better support the SPT, we improve the Voronoi treemap, which will be introduced in Section 3 with SPT in Section 4.

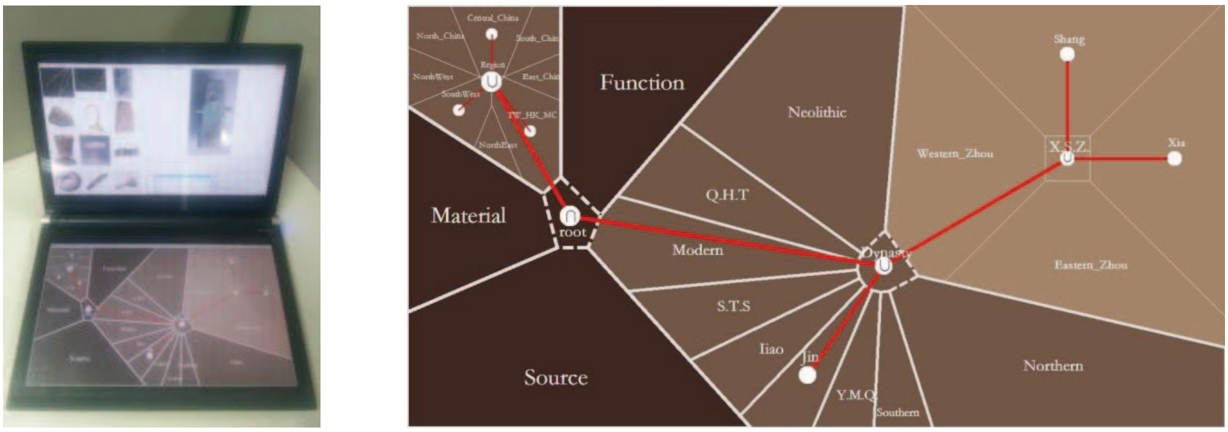


Fig. 1. Visual tool for multi-attribute data retrieval based on Voronoi treemap. An application of the visual tool based on a laptop with two touch-screens is shown in the left image, herein, the selected contents are shown on the vertical screen, and the visual tool is displayed on the horizontal screen and enlarged in the right image.

In the DMD system, a user can click the attribute, and then select sub-attribute in the Voronoi cell that represents this attribute. Repeat the operation until the selection is over. Here are two examples (See Fig. 2). The query likes "the metal and lacquer relics in Ji'nan area of Jin and Liao Dynasty ", SPT is shown as the top picture in Fig. 2, its query statement is (2).

$$((\text{Liao} \cup \text{Jin}) \subseteq \text{Dynasty}) \cap ((\text{metal} \cup \text{lacquer}) \subseteq \text{Material}) \cap (\text{Ji'nan} \subseteq \text{Region})) \quad (2)$$

If we want to extend it to Ji’nan’s neighboring regions, we can modify it like this (3) (See the bottom image in Fig. 2).

$$((\text{Liao} \cup \text{Jin}) \subseteq \text{Dynasty}) \cap ((\text{metal} \cup \text{lacquer}) \subseteq \text{Material}) \cap ((\text{Ji'nan} \cup \text{Liaocheng} \cup \text{Dezhou} \cup \text{Binzhou} \cup \text{Laiwu} \cup \text{Zibo} \cup \text{Taian}) \subseteq \text{Region})) \quad (3)$$

The operation process of selecting regions is described as follows: Find the Voronoi cell of "Shandong" attribute; Double-click the "Shandong" cell to pop up the menu and click " ∪ " button; Then click "Liaocheng", "Dezhou", "Binzhou", "Laiwu", "Zibo" and "Taian" successively.

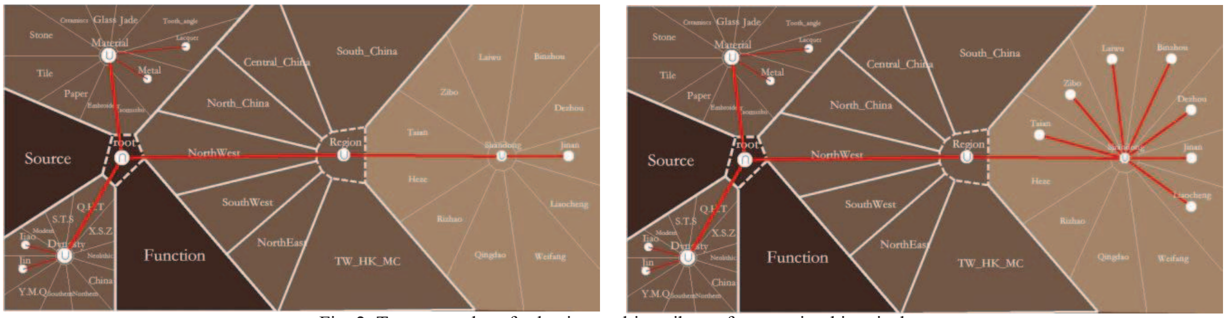


Fig. 2. Two examples of selecting multi-attributes for querying historical relics in DMD system.

III. IMPROVED VORONOI TREEMAP

As introduced in Section 2, each query formulation corresponds to a SPT. We present an improved method for Voronoi treemaps to effectively visualize the multi-attributes and SPT: For each level, besides the generators representing its sub-attributes, we add a special generator representing the attribute of this level, all of which are used to subdivide the current Voronoi cell corresponding to this level. Then we can construct the Voronoi Treemap. Here, the special generator in one level is located in the center of the Voronoi cell corresponding to the level (See Fig. 3). Then, we draw a circle in this special generator's Voronoi cell as a node of SPT and connect it to current SPT. For example, in 3D digital museum design system, when we choose "Source" cell, it is divided into many sub Voronoi cells: "Return", "Gift", "Recruit", "Unearthed", "Handed_down", "Give", "Donate", "Collect" and "Source". Herein, the "Source" in center is special Voronoi cell to represent the attribute "Source" itself, and "Return", "Gift", "Recruit", "Unearthed", "Handed_down", "Give","Donate" and "Collect" are the sub-attributes of "Source". Then, we draw a white circle in the special "Source" Voronoi cell and connect it to SPT, called a node of SPT (See Fig. 4). Especially, for the first level, the special Voronoi cell is marked as "Root" (See Fig. 3).

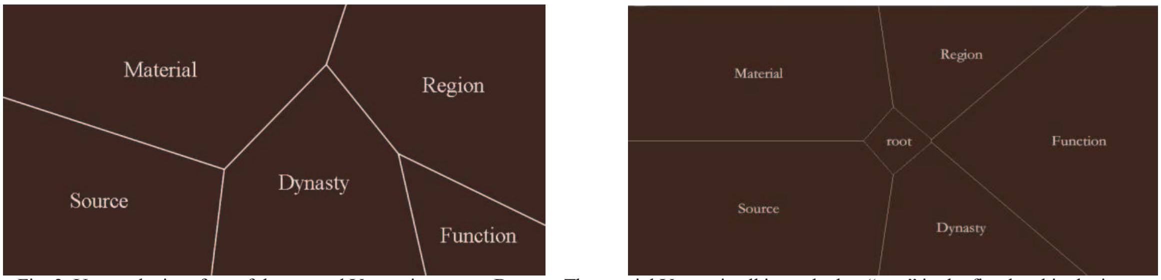


Fig. 3. Upper: the interface of the general Voronoi treemap. Bottom: The special Voronoi cell is marked as "root" in the first level in the improved Voronoi treemap.

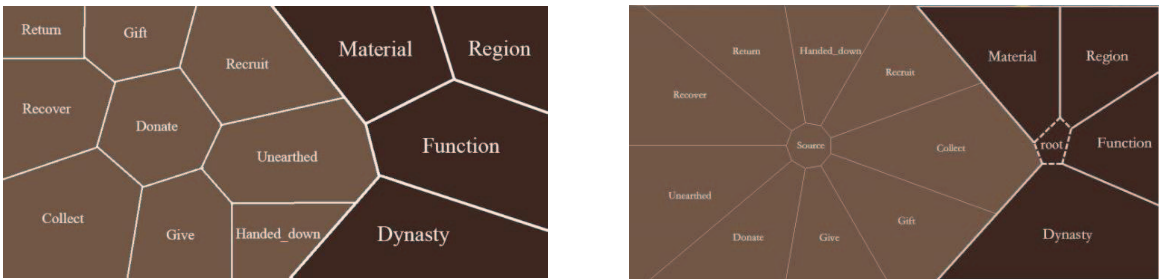


Fig. 4. Upper: The interface of the general Voronoi treemap. Bottom: The special Voronoi cell is marked as "Source" in the second level in the improved Voronoi treemap.

We also consider how to utilize the space effectively. First, the initial interface of a Voronoi cell does not show the subdivisions of the sub attributes of this level. But once one attribute is selected, the other generators are remote from the generator of this attribute dynamically, and the area of the Voronoi cell of the selected attribute is kept to a certain proportion and that of the others are reduced. Then Voronoi cell of the selected attribute is tessellated using the generators of its sub-attributes and the special generator, and the result is visualized (See Fig. 4). It can improve the efficiency of selecting on touch screen and also can conveniently reach other Voronoi cells during the selecting process.

IV. SELECTED PATH TREE

We present the concept of Selected Path Tree (SPT), which helps users to memorize and is used as a parameter to find the qualified data. The nodes of a SPT are the attributes represented by the Voronoi cells selected on the improved Voronoi treemap by users. The root node of the SPT is the Voronoi cell marked "root". The nodes represented by the selected cells in the first level are connected with the root nodes by arcs. When one Voronoi cell is selected, it is Voronoi tessellated by the generators of its sub-attributes and the special generator. Then the special Voronoi cell is represented as a node of SPT and connected by an arc. If a selected Voronoi cell includes no sub-attributes, we represent it as a leaf-node of SPT. When selecting attributes that are not leaf-nodes, users can pop up a menu by double-clicking in the special Voronoi cell to define different set operations. Herein, we provide common Boolean operation – union, intersection and complement and a delete operation (See Fig. 5). Union means that the node represents that the query condition is the union of its attributes; Intersection means that the node represents that the query condition is the Intersection of its attributes; Complement means that the node represents that the query condition is the Complement of its attributes with the current attribute. And users can use delete operation to delete the node and its sub-nodes from the SPT. At the same time, the system can update the query formulation and display the query results and Boolean expression on the vertical screen for each operation (See Fig. 6). The user can adjust, modify and delete SPT according to the displayed results.

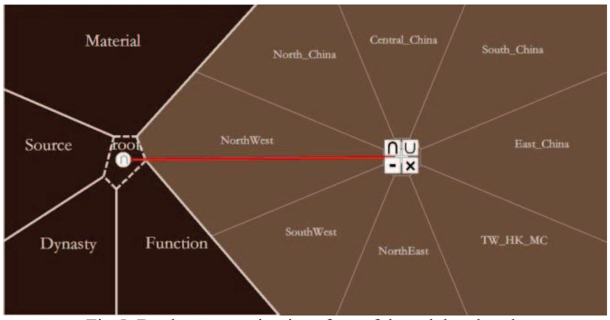
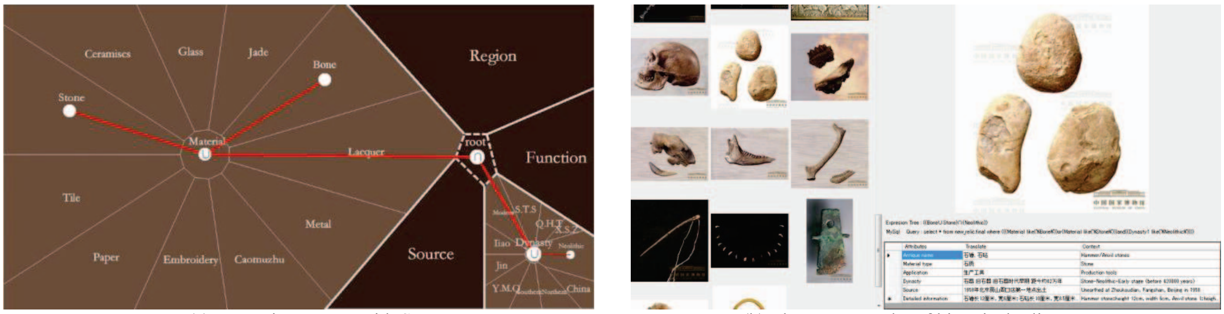


Fig 5. Boolean operation interface of the selelcted node



(a)Voronoi treemaps with SPT

(b) The query results of historical relics

Fig 6. Real-time display of SPT and the query results

V. USER STUDY

To test the usability of our system tool, we conduct a user study. A total of 22 undergraduates are recruited to participate the test by totally voluntary. All of them have never used the system before.

In this study, we use the third edition of PSSUQ (Post-study System Usability Questionnaire) [20] to examine the usability of our designed system. The questionnaire includes three dimensions: system quality, information quality and interface quality. In this study, the Cronbach's of PSSUQ and its subscales are between 0.89-0.95, showing high reliabilities.

The test procedure is as follows:

Firstly, we introduce all functions of the tool to the participants and instruct them to use it until operating it well. Secondly, we provide two missions to the participants and ask them to finish the missions with the tool. Finally, when the participants finish the missions, they are asked to complete a questionnaire.

In order to evaluate the usability of our system tool, we conducted several descriptive statistics to describe its PSSUQ scores. Then, we compare these scores with their reference scores[21]. There are three reference scores of each dimension, including lower limit, normal limit and upper limit. If the score is higher than upper limit, it means the system is good in that dimension. Results show that the scores of PSSUQ and its sub-scales are all higher than upper limit of reference score (see Table 1), which suggests our system have a high usability.

TABLE I. COMPARISON BETWEEN PSSUQ SCORE AND REFERENCE SCORES

Measures	***Mean***	***S.D***	***Lower limit***	***Normal limit***	***Upper limit***
Overall quality	5.91	0.33	2.62	2.82	3.02
System quality	5.72	0.46	2.57	2.80	3.02
Information quality	6.17	0.35	2.79	3.02	3.24
Interface quality	5.83	0.53	2.28	2.49	2.71

VI. CONCLUSION

We present a graphical query interface, which uses a selected path tree overlaid on Voronoi treemap, for retrieving multi-attribute data. Voronoi treemap is adapted to represent and search multi-attribute data, so that it can more effectively support the selected path tree, whose nodes are the selected items displayed in different levels of Voronoi treemap, to construct query formulation and reformulation graphically. SPT may be composed of different levels of nodes in Voronoi treemap and records the Boolean operations of attributes during the selecting attributes process; Users can also adjust the SPT interactively according to displayed results on the other window.

We give an application example of selecting historical relics in 3D digital museum design system based on double touch-screen. In the future, we will continue to explore how to effectively represent more Boolean operations and expand it to more different applications.

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