A New Interactive Information Visualization Framework based on the Object-oriented Views of Querying and Visualizing Databases

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Abstract: In this paper, we propose a new visualization framework which can help users to create highly-customized and interactive visualizations. This framework includes an Object-Oriented View Manipulation Model for querying and manipulating data, as well as an Object-Oriented Visualization Implementation Model for creating visualizations. The visualizations created using our framework allow users to directly manipulate them, which indirectly modifies the tree structures of the two models. Such interactions enable users to visually define an Object-Oriented view for querying the database, to visually create visualizations, and to modify existing visualizations. Users can also interact with the visualization results to filter out their visual objects which do not satisfy the user-specified conditions.

1 INTRODUCTION

Information Visualization is a widely-used technique for representing data, using easily comprehensible visual properties(Spence, 2001)(Ware, 2004). A well-designed visualization can reveal information relationships that are not immediately obvious from the original data. To the same data set, we can create different visualizations to convey different information aspects to viewers, because different visual properties will lead to different images in visualization readers' minds(Mackinlay, 1986). The design of how to represent data using graphical objects and their visual properties is called the visualization scheme. Many people are working on providing new visualization schemes which may improve the user's comprehension, reveal more information relationships, or emphasize the visualization creator's intentions. Some of these proposed visualization schemes may not be implemented immediately. The visualization creators can not directly use these schemes in an existing visualization system except newly implementing them by themselves.

Since the data set becomes more and more complex, visualization creators frequently need to create highly-customized visualizations by implementing their own schemes. Only few visualization systems allow such custom design only through detailed procedural schema definition. Even using these systems, the task of implementing the visual schemes designed by others or even by themselves is not easy for non-programmers. We believe that users need a unified visualization system for easily deploying a variety of visualization schemes, and for easily creating the highly-customized visualizations. Now many users are not satisfied with the static visualization because more information only can be obtained during the process of manipulating the visualization(Spence, 2007). The interaction between users and visualizations is becoming more and more important. To solve these problems, we will propose a new visualization framework which supports users to create highly-customized visualization by structure manipulations.

2 RELATED RESEARCH

By using the preceding research results on information visualization, many powerful visualization systems are developed to demonstrate the researchers' theories and to improve users' visualization experiences. We list up six widely-used visualization systems, and compare them from six different view points (Table 1). In this table, ”Without-Programming” denotes whether programming is necessary for creating visualizations. “Chart Reuse” denotes whether a system supports to reuse an existing chart as the component of another chart. This kind of reuse is used to create embedded charts like the one

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Table 1: The evaluation and comparison of six representative systems and our system.

	(1)	(2)	(3)	(4)	(5)	(6)
Many Eyes(Viegas et al., 2007)	○	☓	☓	☓	○	○
Polaris(Stolte et al., 2002)	○	☓	△	☓	○	○
InfoVis(Fekete, 2004)	○	☓	☓	☓	○	○
Protovis(Bostock and Heer, 2009)	△	☓	○	○	○	○
Mathemetica(Shaw and Tigg, 1993)	☓	△	○	☓	☓	☓
ggplot2(Wickham, 2009)	☓	△	○	☓	☓	○

☓:Not supported; ○:Well supported; △:Partly supported
(1)Without-Programming (2)Chart Reuse (3)Scheme Customization
(4)Appearance Customization (5)Interactive Chart (6)Large-Scale Database

in Section 5.2 or combining two charts together as the one in Section 5.1. "Scheme Customization" denotes whether it is possible to customize the visualization scheme of a visualization. "Appearance Customization" denotes whether it is possible to freely modify the appearances of the coordinate system, the background and the legend of a chart. "Interactive Chart" denotes whether a system supports the user interaction. "Large-Scale Database" denotes whether a system can visualize a large scale data set. Although this feature is important, our research does not focus on this. Too many visual objects in a chart will make our system overloaded. Our framework can be extended to support this by simplifying the graphical objects used as visual objects to reduce the system load. But we will not focus on this capability in this paper.

Most of these preceding researches realize the visualization process by using the pre-defined data model and/or pre-programmed code. Some researches define new programming language or packages of visualization functions for creating visualizations. The scheme and appearance of a chart are predefined in these researchers, the visualization results can only be generated in a common style. Users are not allowed or are restricted to apply their preference on creating the visualizations. In some visualization systems, they provide programming environments to users for customizing the charts, but the programming ability is requested. Most visualization systems treat the visual objects and the charts as two different kinds of objects. They always do not allow users to manipulate charts freely. This means it is difficult to create embedded chart or combine charts easily. Because of these limitations, the final charts created by these system always can not totally satisfy users needs.

In contrast to previous systems, our framework allow users to create charts only through structure manipulations. In our framework, we treat visual objects, chart components (such as the coordinate-system axis), or charts as general graphical objects with several parameters. Users can customize visualization schemes and the appearance of chart components by modifying the parameters of corresponding graphical objects. By manipulating the parameters of charts and defining the relations between charts, our framework can arrange charts freely to create composite charts or embedded charts (Section 3.1).

User interactions are available in our framework and most other visualization systems. The preceding researches always try to implement some user interactions to make their systems more powerful or easier to use. They focus on proposing new user interactions or improving the users interactions. But they did not define the generic relationship among the user interactions and both the change of database views and the visualization results, and did not formalize how to realize the user interactions (Yi et al., 2007). Different from most of the previous visualization systems, our framework provides users direct manipulations of the visualization results. These manipulations are internally mapped to the operations on the logical structures defined in our framework. Such mapping between direct manipulations of visualization results and the operations on our logical structures allows users to use these direct manipulations not only to visually explore visualization results, but also to modify the processes of the data retrieval and the visualization definition.

3 A NEW VISUALIZATION FRAMEWORK BASED ON THE TREE STRUCTURES

In this section, we will introduce how to use our framework to reate visualizations based on the object-oriented design(Wilkinson and Wills, 2005). In our framework, the visualization scheme of a chart is determined by a kind of graphical object which is called the visualization template. Our framework will copy the visualization template and modify the parameters of each copy using the data set from a database. We refer to each template copy with it's particular instan-

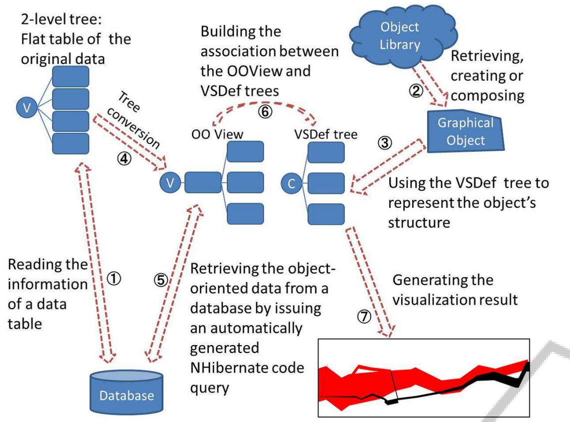


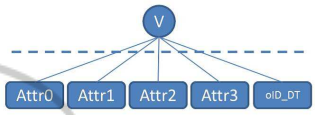
Figure 1: The visualization process of our framework.

Attr0	Attr1	Attr2	Attr3	oID_DT
$V_{0,0}$	$V_{1,0}$	$V_{2,0}$	$V_{3,0}$	*DT_0*
$V_{0,1}$	$V_{1,0}$	$V_{2,1}$	$V_{3,1}$	*DT_1*
$V_{0,1}$	$V_{1,0}$	$V_{2,2}$	$V_{3,2}$	*DT_2*
$V_{0,0}$	$V_{1,0}$	$V_{2,3}$	$V_{3,3}$	*DT_3*
$V_{0,1}$	$V_{1,1}$	$V_{2,4}$	$V_{3,4}$	*DT_4*
$V_{0,1}$	$V_{1,1}$	$V_{2,5}$	$V_{3,5}$	*DT_5*
$V_{0,1}$	$V_{1,1}$	$V_{2,6}$	$V_{3,6}$	*DT_6*
$V_{0,0}$	$V_{1,1}$	$V_{2,7}$	$V_{3,7}$	*DT_7*
$V_{0,0}$	$V_{1,1}$	$V_{2,8}$	$V_{3,8}$	*DT_8*

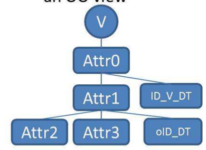
(a) A flat table representing a relational view

Attr0	Attr1	ID_V_DT	Attr2	Attr3	oID_DT
$V_{0,0}$	$V_{1,0}$	V_DT_0	$V_{2,0}$	$V_{3,0}$	*DT_0*
			$V_{2,3}$	$V_{3,3}$	*DT_1*
	$V_{1,1}$	V_DT_1	$V_{2,7}$	$V_{3,7}$	*DT_2*
			$V_{2,8}$	$V_{3,8}$	*DT_3*
$V_{0,1}$	$V_{1,0}$	V_DT_2	$V_{2,1}$	$V_{3,1}$	*DT_4*
			$V_{2,2}$	$V_{3,2}$	*DT_5*
	$V_{1,1}$	V_DT_3	$V_{2,4}$	$V_{3,4}$	*DT_6*
			$V_{2,5}$	$V_{3,5}$	*DT_7*
			$V_{2,6}$	$V_{3,6}$	*DT_8*

(b) An aggregate table representing an OO view



(c) The tree representation of the relational view represented in (a)



(d) The tree representation of the OO view represented in (b)

Figure 2: The relational view(a), the OOview(b), and their tree definitions(c)(d).

tiation of parameter values as a visual object. The copy of the template is called the visual object.

In our framework, we divide the visualization process into two stages: (1) how to query and to organize the original data set, and (2) how to visually represent data. Corresponding to these two stages, we propose two models. Figure 1 shows the visualization process. Our framework uses a two-level tree to represent the tabular structure of the data set which will be visualized (Fig.1 ①). Next, users need to access the library for retrieving the graphical objects that will be used as the visualization template, the chart background, and the chart legend (Fig.1 ②). Our framework provides a tree structure called Visualization Definition (**VSDef**) tree to define the chart structure and the parameters of the each chart components (Fig.1 ③)(Section3.1.2). According to the template subtree, users can convert the 2-level tree in the first step to a hierarchical tree to define an Object-Oriented View (**OOView**) (Fig.1 ④). This tree is named the OOView tree (Section 3.1.1). Our framework will use the defined OOView tree to retrieve a data set from a database in the user-defined data structure (Fig.1 ⑤). After users define the bindings between the nodes of the OOView tree and the nodes of the VSDef tree (Fig.1 ⑥) to specify the mapping relationships between the data set attributes and the parameters of the template, the copies of the template can be used to visually render the data retrieved using the corresponding OOView to automatically generate the visualization result, without any further conversion of the data structure (Fig.1 ⑦). Our framework focuses on creating 2D visualizations. In these visualizations, each visual object is an instance of the visualization template, and it is limited to use the data directly retrieved from the database or computed from the retrieved data to instantiate its parameters. Our framework aims to help users to create the charts as they want. To enrich the library of the visualization template, we reuse a template composition method proposed in another paper (Shi and Tanaka, 2010), which supports users to define a new template by combining existing templates together.

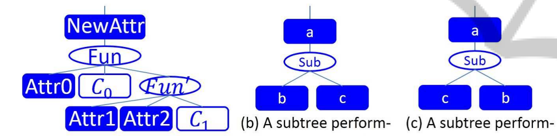
3.1 Defining Visualizations by Manipulating Two Tree Models

3.1.1 OOVM Model

Normally, the data set retrieved from a relational database is represented as a table. Visualizing this data set, we often need first to perform the structure conversion. In some cases, we need to divide the set of records into groups according to the value of one or more arbitrarily selected attributes. Our system uses the OOView tree to represent the data structure, and users can manipulate the data set through this tree representation, such as dividing the data set into groups, or defining the derived attribute. Figure 2(a) shows a flat-table defined as a relational view of a data set. Figure 2(b) shows a hierarchical table defined as an OOView of the same data set. We call a basic data unit of a view a data object. A record is a data object of a relational view, and a set of records having the same value of one or more attributes is a data object of a OOView. We use a two-level tree to represent a relational view (Figure 2(c)), and a tree with two or more levels to represent an OOView (Figure 2(d)). Users can define an OOView by directly manipulating the original two-level tree-representation of a relational view. The evaluation of an OOView provides a structured data set that is retrieved from a database and organized in the user-defined structure. This structure

Table 2: Nodes of the OOView tree.

Name	Appearance	Function
View or Database node	A colored circle with a title (View)	It denotes a table, a view or a database, and its title indicates what kind of node it represents.
Attribute node	A colored rectangle with a title (Attribute)	It denotes an attribute in a view, and its title indicates the name of the attribute it represents.
Function node	A transparent ellipse with a title (Function)	It is used in defining a new derived attribute by applying a computation to some attribute values. Its title indicates which function it represents.
Constant node	A transparent rectangle with a title (Constant)	It denotes a constant or a parameter that is used in defining a derived attribute. Its title indicates a constant value or a parameter name.
Quantifi-cation node	A transparent triangle with a title (QC)	It can be added as a child of some attribute node or of the view node. It has a property to save the quantification condition. Its title is generated as QC_*AttributeName_i*.



(a) An example of using function nodes to create a derived attribute (b) A subtree performing the computation "a:=b-c" (c) A subtree performing the computation "a:=c-b"

Figure 3: The examples for how to use the function node.

should match the data structure requested by a visualization template.

Our OOVM model provides five kinds of tree nodes for manipulating and defining trees. The five kinds of nodes are explained in Table 2. Figure 3(a) shows how to create a derived attribute using function nodes. Each function node has a single output directed to its parent, and one or more inputs coming from its children. The input of a function node may be an attribute node or the output of another function node. In the subtree for creating derived attributes, the order of the child nodes of a function node determines the parameter order of the corresponding function. For example, the subtrees in Figure 3(b) and (c) respectively denote "a:=b-c" and "a:=c-b". Users can manipulate the tree by the common tree operations, such as adding a node or copying a sub-tree. We also provide two special operations for users to define the hierarchical relation between attributes. We use the "group-by" operation to define the hierarchical structure of the OOView tree and to divide records into several sets. It is different from the "group-by" statement of SQL, which is always used together with an aggregate function to obtain a single value. To convert the tree in Figure 2(c) to the tree in Figure 2(d), we can apply the "group-by" to the "Attr0" and the "Attr1". Its inverse operation is called "Ungroup-by".

We introduce an ID attribute which is used to generate an identification to each data object instance . The ID node in the OOView tree represents the ID attribute. The ID node is a protected attribute node. Users can only ask the system to add an ID node to the OOView tree to specify IDs to objects in the OOView, but can not manipulate it further. The IDs of the objects in different OOViews are used to find the relation among these objects (Section 4). When users initially define a two-level tree to represent a data table, the system first automatically adds an ID node as the brother of all the attribute nodes (Figure 2 (c)). Then the IDs will be specified to all the records (Figure 2 (a)). This automatically defined ID is called a system-defined ID. After converting a two-level tree to a hierarchical tree, users can ask the system to add a new ID node as the brother of a selected attribute node to specify the IDs to data object instances. Such a kind of ID is called a user-defined ID. In Figure 2(d), the ID node is added as the brother of Attr1. The ID of each object instance is specified as shown in Figure 2(b).

3.1.2 OOVI Model

Every chart has four components: 1) a set of visual objects, 2) its coordinate system, 3) its legend, and 4) its background. We can combine more than one charts together by specifying their relative positions to create a composite chart. We can also use a chart as the visualization template of another one to create a nested chart. This model allows users to use the VSDef tree to flexibly define and customize these different kinds of charts. Figure 4 is a part of a VSDef tree for defining a complex chart. Nodes used to define VSDef trees are listed in Table 3. In the VSDef tree, we name each subtree with its root node name, e.g., a subtree with "*Chart_1*" node as its root node is named as "*Chart_1*" subtree.

To define a chart, we need to separately define each component by manipulating the corresponding subtree which starts from one of the chart component nodes (Column 3, Row 2 in Table3). In the template subtree and/or the background subtree, the parameters of the graphical objects used as the visualization template and/or the chart background are extracted by the system and provided to users (Figure 4(B)). In the coordinate-system subtree, users can customize the coordinate-system by its property nodes (Figure 4(A)). We define two property sets for each coordinate axis. They are separately used to define the ap-

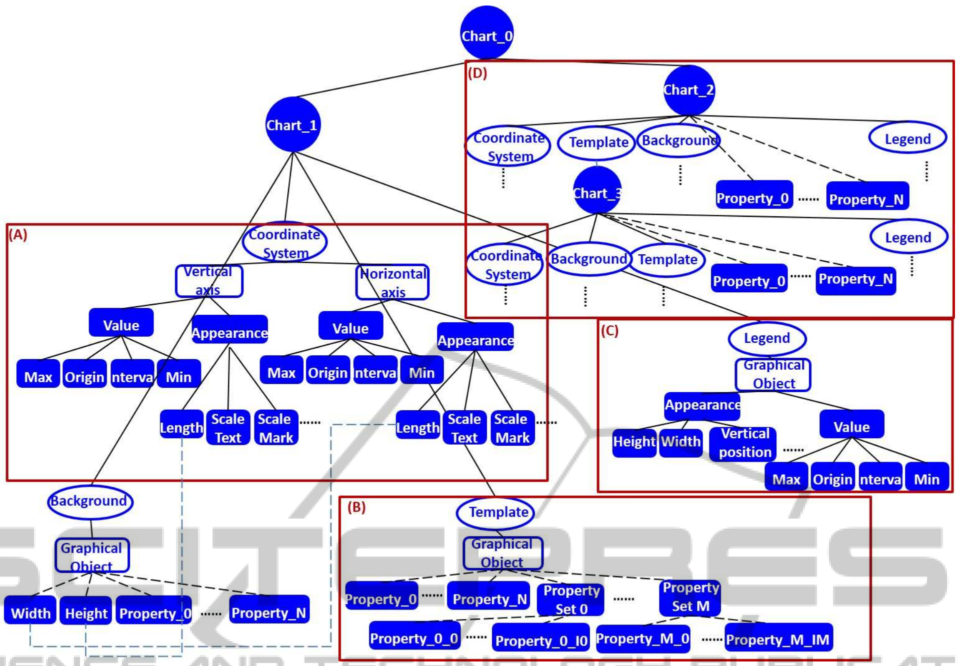


Figure 4: An example of a VSDef tree for defining a nested chart and a composite chart.

Table 3: Nodes of the OO VSDef trees.

Name	Appearance	Function
Chart node	A colored circle with a title Chart	It represents a chart or a sub-chart. Its title indicates the chart name. Normally it is automatically named as Chart_i.
Chart Component node	A Transparent ellipse with a title ChartComp	It denotes a chart component. Its title indicates which component it denotes. We define four chart-component nodes: Template node, Coordinate-System node, Legend node, and Background node.
Visual Component node	A transparent rectangle with a title VisualComp	It is a child node of a chart component node. It denotes which graphical object is used as the parent chart-component node.
Property node	A colored rectangle with a title Property	It indicates a property or a set of properties of the parent graphical object node. Every property node should have a data type, nominal or numeric.

pearance of the axis (the Appearance subtree), and to define what information is indicated by the axis (the Value subtree). In the legend subtree, users can choose a graphical object to create a chart legend and customize it. The generality of our framework implies that we can also treat every chart legend as a small visualization. As in the case of defining the coordinate-system, we need to define both an appearance property set and a value property set.

Users can easily define nested charts and/or composite charts by manipulating the chart subtrees. Figure 4(D) shows the chart subtree of a nested chart. We add the Chart_3 subtree as a child of the template node whose parent is the Chart_2 node. The modified copies of the Chart_3 will be the visual objects of the Chart_2. Section 5.2 shows an example of defining such a nested chart in details. For creating a composite chart, users need to add one or more chart subtrees to another Chart node. In Figure 4, we use Chart_1 and Chart_2 to create a composite chart Chart_0. To arrange these sub-charts, users need to specify the relative position and the size of each sub-chart by specifying the values of the corresponding property nodes.

3.1.3 Defining the Binding between Tree Nodes

Users can define the binding (1) between some node of the OOView tree and the corresponding property node of the VSDef tree, or (2) between some two nodes of the coordinate subtree, the legend subtree or the background subtree of the VSDef tree. The former case of the binding definition is used to establish the mapping from some attributes of the data set to some properties of the visual objects. To build such kind of bindings, users need to wire the nodes in the OOView tree to the nodes in the VSDef tree using dashed lines. After the user defines the bindings between the OOView tree and the template subtree in the VSDef tree, the bindings from the nodes of the OOView tree to the nodes of the corresponding legend subtree, and to the nodes of the coordinate-system subtree are automatically established. These bindings between some attributes and either the legends or the axes of the coordinate-system of the visualization result can be manually added, edited or deleted. The latter case of the binding definition is used to specify the value-equality between two chart component properties. This value-equality means that, when the property value of one chart component is changed, the value of the corresponding property of the other chart component will automatically change to take the same value. Users need to wire two nodes of two different subtrees in the same VSDef tree to build such a binding. In Figure 4, we define equality relationships between the lengths of the two coordinate axes and the size of the background image of the Chart_1. The width and the height of the background image always be equal to the lengths of the two axes of the coordinate-system.

3.2 Relating Visual Objects in Different Visualizations of the Same Data Set

Users can create two different visualizations using different OOViews of the same data set. The object IDs in these OOViews can help users to find out the correspondence between the visual objects in the two different visualizations. In the view node of each OOView tree, the system will generate a table named the selection state table which uses the ID of each data object instance to record its selection state and the hierarchical structure between this data object instance and its sub data object instances. For the OOView in Figure 2 (d), its selection state table directly extracts two columns, ID_V_DT and oID_DT, from the table in Figure 2 (b). The default selection state of each data object instance (or sub data object instance) is 'false'. In the chart, if a visual object is selected (or released), the selection state of the corresponding data object instance in the table will become 'true' (or 'false'). On the other hand, if the selection state of a data object instance becomes 'true' (or 'false'), the corresponding visual object in the chart will be selected (or released). Suppose that the ID of a data object instance is "oID" and that this data object instance has n sub data object instances with "soID_i" ($0 \leq i < n$) as their IDs. We define the selection propagation rule as follow:

- Downward selection propagation:
  if *oID*=True, then, for all *i*, *soID_i* = True.
- Upward selection propagation:
  - Any-to-One:
    if there exists *i* such that *soID_i* =True, then *oID*=True;
  - All-to-One:
    if, for any *i*, soID_i =True, then oID=True.

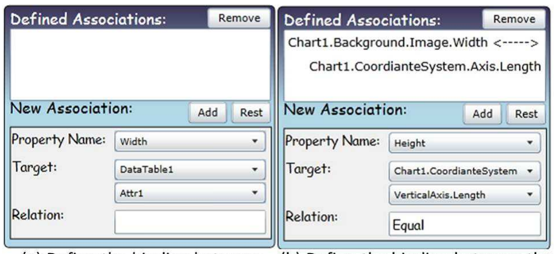
In the downward selection propagation, when an object is selected. all of its subobjects will be selected. In the upward selection propagation, there are two modes. In the All-to-One mode, when all the subobjects of an object are selected, the object will be selected. In the Any-to-One mode, if a subobject of an object is selected, the object will be selected. If the selection state of any system-defined ID is changed in an OOView tree, the system will propagate this change to all the OOView trees created from the same two-level tree. All the selection states of the same system-defined ID in different tables should be the same. By updating the selection states of corresponding visual objects in different visualizations, the system will realize the brush-and-linking between these visual objects in different visualizations.

4 DIRECT MANIPULATION OF VISUALIZATIONS

Instead of directly manipulating the OOView tree and the VSDef tree to define the OO query and the visualization, our framework also allows users to indirectly manipulate these two trees by directly manipulating the visualization results. Users can (1) define the binding between some attribute of the data set and some visual property of the visualization template by directly filling in an input form on a window called the binding editor which can be opened by right-clicking one of the visual objects in the visualization result, (2) define a binding between two properties of two chart components to define the value-equality between them by filling in an input form in the same binding editor in (1), (3) merge or divide visual objects (4) use the legend or a visualization as a filter , or (5) embed a graphical object or a visualization to another existing visualization as its new visualization template.

For performing the operations (1) and (2), we use the object called the binding editor. For the operation (1), the user can select a property of the visual object, a data table, and an attribute of the selected data table in the editor (Figure 5 (a)). Similarly, for the operation (2) the user can select a property of the selected chart component, another chart component and a property of the second chart component in the binding editor (Figure 5 (b)). According to the user operations on the binding editor, the system will automatically bind a node of the OOView tree and a node of the VSDef tree, or bind two nodes of the VSDef tree.

For the operation (3), users can select a visual object or a set of visual objects and use the menu to per-



(a) Define the binding between the property Width of the visualization template and the attribute Attr1 of the DataTable1

(b) Define the binding between the property Height of the background and the property Length of the vertical coordinate axis

Figure 5: The binding editors for defining two kinds of bindings.

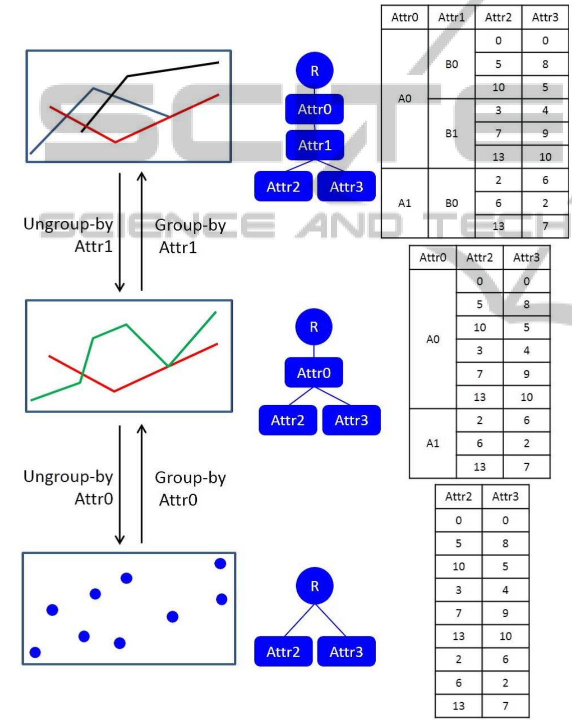
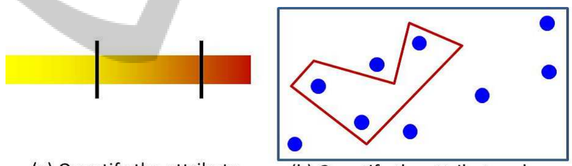


Figure 6: Two situations for performing group-by or ungroup-by operation on the chart.

form the merging or dividing operations. The system will ask which attribute(s) should be used to perform this operation. Figure 6 is an example for explaining these two operations. In this example, the visualization result, the OOView tree and the tabular representation of the retrieved data are shown.

Our framework allows users to quantify the values of the attributes by specifying a region on the legend or on the visualization (Figure 7). According to the specified region on the legend, the system will calculate the corresponding value range of the attribute associated with this legend. Then a quantification node will be added to the OOView tree as the child of the node representing the bounded attribute, and set the obtained value range as the quantification condition. Users can also specify a polygonal region on the visualization to select all the visual objects in this region. The system can filter out the visual objects that are not selected in the visualization. The system will add the quantification nodes to the OOView tree as the child of its view node, and set the object IDs of the selected visual objects as the quantification condition. If users set the visualization VS1 as the filter of the visualization VS2, and select the visual objects in VS1, the system will find out the corresponding visual objects in VS2 using the mechanism introduced in Section 3.2, and filter out the other visual objects. For realizing the operation (5), users first need to load a graphical object "gObject" from the library or load an existing chart "newChart". Then users can drag it on an exiting visualization "existChart" and drop it there. Then the embedded object will become a new visualization template of the "existChart". Our framework will insert a copy of the corresponding sub-tree whose root node represents "gObject" or "newChart" into the VSDef tree of the "existChart" as the child of the template node. Section 5.2 shows an example of creating a nested chart by adding a pie chart as the new template to a line chart.



(a) Quantify the attribute values by specifying a region on a legend

(b) Quantify the attribute values by specifying a polygonal region on a visualization

Figure 7: Quantify the attribute value or visual objects by specifying a region on a legend or on a chart.

5 EXAMPLES

5.1 The Chart of Napoleon's Russian Campaign

In this section, we will show how to recreate Minard's famous 1869 chart of Napoleon's Russia campaign by using two data tables. One has five attributes, i.e., longitude, latitude, group, direction and survivors. It shows the number of the survivors in each army group at each different key location in one of the two directions during the campaign. We will create a path chart to represent the data in this table. The other table has two attributes, i.e., longitude and temperature. It shows the temperature change during the retreat, and

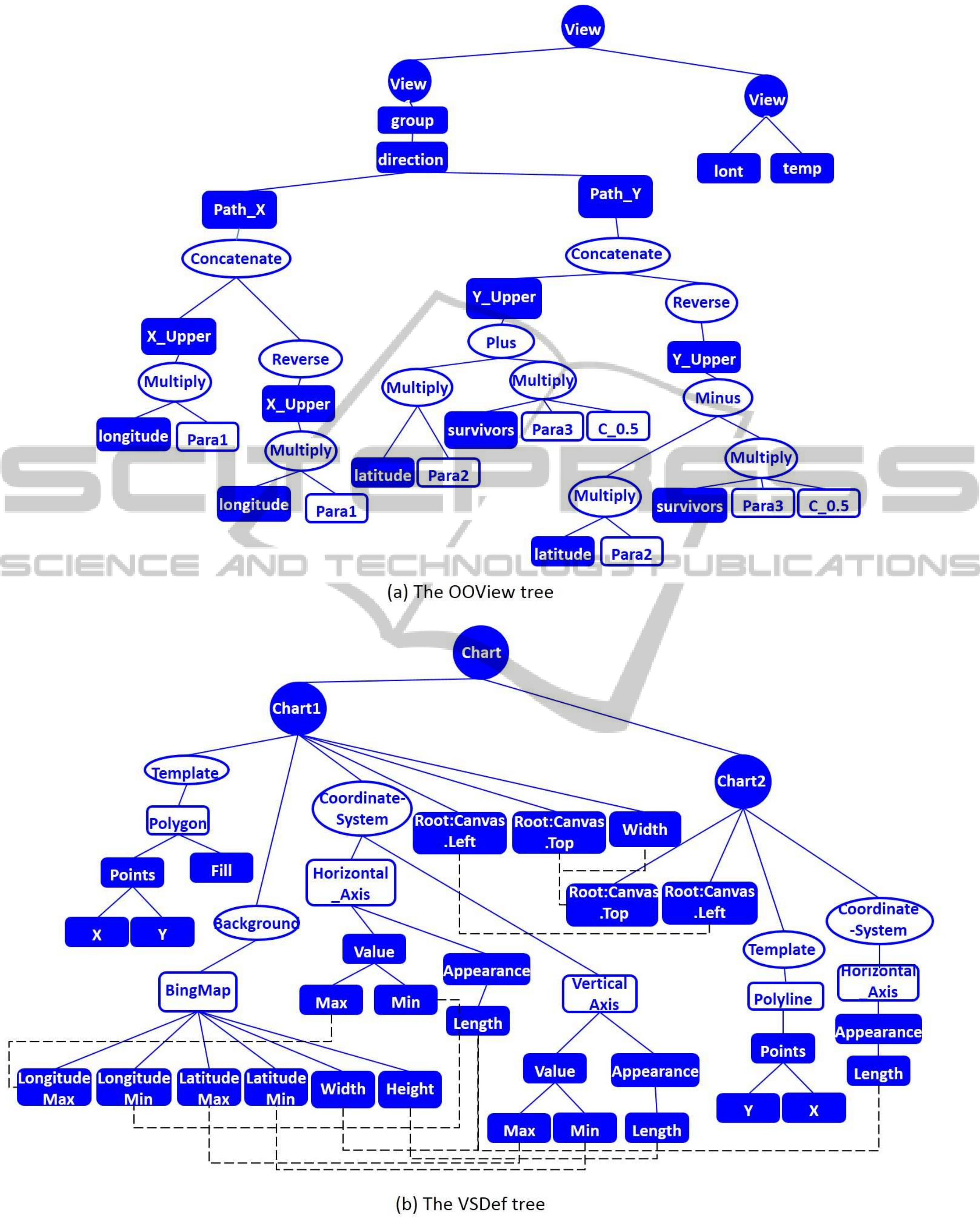


Figure 9: The OOView tree and the visualization tree for creating the chart in Fig.8.

will be represented by a line chart. Finally, we will combine the two charts together to create a composite chart as our desired chart (Fig.8).

For creating the path chart, we use a simple polygon Webble as the template and use a Microsoft Bing map showing the geographical region as the background. The visual objects in the path chart are used to represent the campaign paths of Napoleon's armies. The vertical width of each path represents the number of survivors of each army at each key location. For

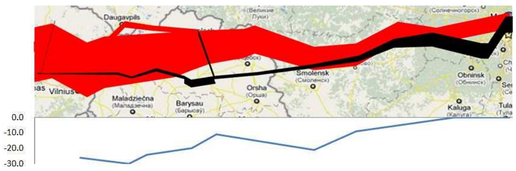


Figure 8: The chart of Napoleon's Russia campaign.

creating this chart, we first apply the "group-by" operations to the attributes "group" and "direction". The records in the first data table are then divided into six sets, because the attribute "group" has three different values and the attribute "direction" has two different values. Each set corresponds to one path. We use the three attributes, "longitude", "latitude" and "survivors", to generate four new attributes "X_Upper", "Y_Upper", "X_Lower" and "Y_Lower". The values of these four attributes, respectively, represent the X and Y coordinates of the vertices in the upper and lower edges of each polygon from left to right. We need to arrange all the vertices of each polygon in a clock-wise order, so we reverse the order of the vertices in the lower edge by using the "reverse" function node as the parent node of the "X_Lower" node and "Y_Lower" node. We then separately concatenate "X_Upper" and "X_Lower", and "Y_Upper" and "Y_Lower" to define two new attributes "Path_X" and "Path_Y". The computation among attributes will be performed in each set. Each set in these two attributes includes the X or Y coordinates of the vertices of each polygon in the proper order.

Fig.9(a) shows the OOView tree for creating this chart. Note that we define the visualization tree (Fig.9(b)) with two subtrees for defining our desired chart. In this tree, we specify the relative position between the path chart and the line chart of the temperature. After we build the linkages among the OOView tree and the visualization tree (the linkages among the nodes in the tree of Fig.9(a) and the tree of Fig.9(b) are omitted), and the coordinate among nodes in the visualization tree (the dashed lines in the Fig.9(b)), the system will generate the composite chart.

In Mathematica, some users provides a function called "NapoleonicMarchOnMoscowAndBackAgainPlot[]" (about 90 lines of code) to realize this chart as well. In this function, it includes the details of how to convert data, and how to draw the chart using the converted data. Such kind of function can be easily used but it request the Mathematica programmer to write all the codes to define this function for each new case.

5.2 An Example Chart Showing Production Sales

In this example, we first create a line chart to visualize the change in total sales of three products during half a year. The OOView tree and the VSDef tree are shown in Figure 10 (a) and (c). Now, in the resultant line chart, we want to add a small pie chart at each vertex of the polyline (Figure 10 (d)). Each pie chart visualizes the sale proportions of the three products in each month. To create it, we can first load a predefined pie chart from a library of charts, and drag and drop it onto the line chart. This will makes the system automatically add the VSDef tree used to define the pie chart as the child of the template node of the VSDef tree used to define the line chart (Part I of Figure 10 (b)). Next, we can open the binding editor of the pie chart and define two bindings, i.e., one between the horizontal position of the pie chart and the attribute Month of OOView, and the other between the vertical position of the pie chart and MonthSale (a derived attribute) of the OOView. These operations will make the system automatically copy the pie chart five times and put them at the five vertices of the polyline in the line chart . Next, users can use the Attribute window and Attribute Details window to define the two attributes, Occupancy and IntervalSum, using the subtrees in Part II of Figure 10 (b)). We click some sector of an arbitrary pie chart to open the binding editor to define two new bindings, one between the property SectorAngle and the attribute Occupancy, and the other between the property InnerRotationAngle and the attribute IntervalSum. This will make the system automatically generate the final visualization result as shown in Figure 10 (d).

6 CONCLUSIONS

We have introduced a new visualization framework which separates the visualization process into two different but related processes: the data querying and manipulating process and the visualization definition process. The Object-Oriented View Manipulation Model and the Object-Oriented Visualization Implementation Model are proposed corresponding to these two processes. Using the OOVM model, users can retrieve data from a database, guided by a user specified structure which matches the data structure of the visualization templates. The OOVI Model allows users to visually customize the chart components. After defining the bindings between the nodes of the two trees, the system can automatically generate the chart using the retrieved data according to the defined VS-

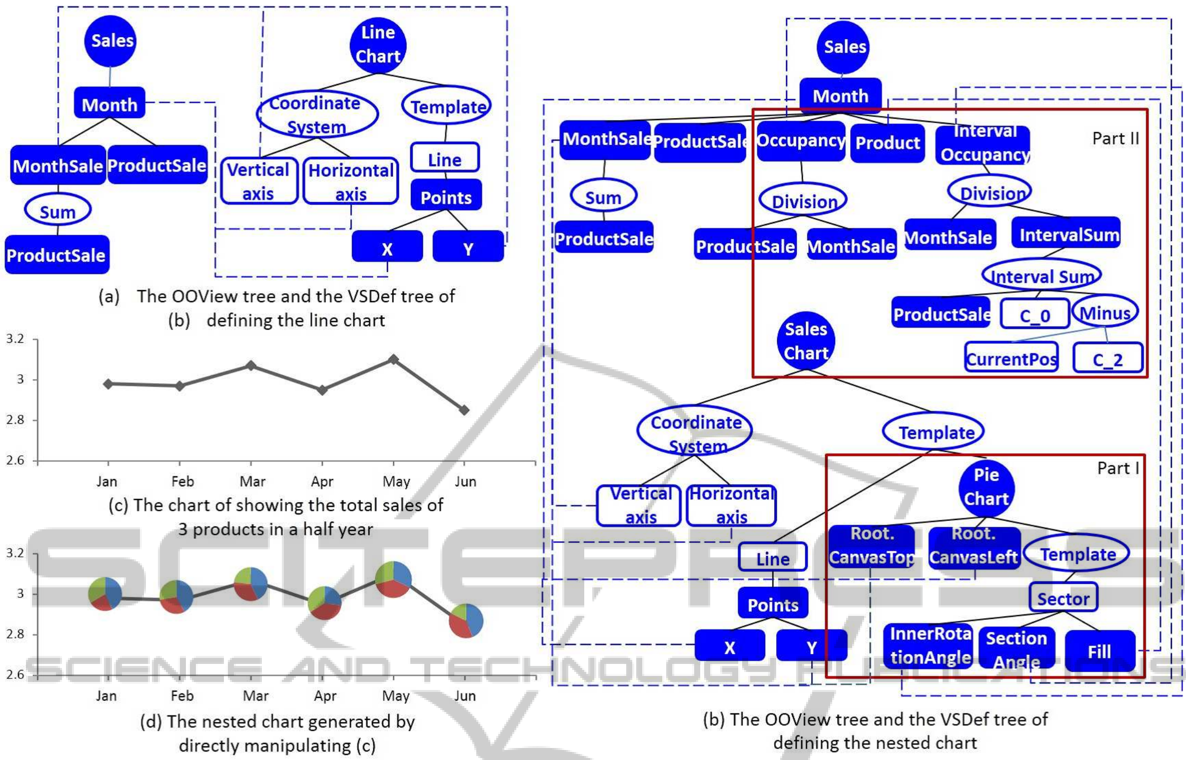


Figure 10: The Sales Chart in Section 5.2.

Def tree. Because both the OOVM model and the OOVI model use the same type of tree structures, the binding relations between the data side and the visualization side can be defined without explicit programming. Our framework allows users to directly manipulate the visualization results. These visualization operations directly correspond to the tree operations in the OOVM model and the OOVI model. Users can create arbitrary visualizations supported by our framework only through direct manipulation of existing visualizations.

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