Web-Based Interactive Visualization of Data Cubes

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Abstract

Data Cube is an effective technique for data mining. Because of the complex relationships among aggregation values of a data cube, designing an efficient method or tool to visualize the complex relationships becomes a challenging work in the data cube technique. Information visualization with computer graphics can help improving this process. Recently, we developed a Web-based interactive data cube visualization system that can be applied to visualize a single data cube or parallel data cubes conveniently on the Web. This paper presents the basic principle, structure and features of the system.

Keywords: Data Cube, Information Visualization, Web-based Graphics

1. Introduction

Data cube is an aggregation operator presented by Gray et al. in 1995 [4]. The data cube operator CUBE is a generalization of the traditional GROUP BY syntax in SQL. Traditional GROUP BY operator has problems for constructing histogram, cross-tabulation, roll-up, drill-down and sub-total. With CUBE operator, we can easily generate all these data reports. However, when the number N of the attributes (data dimensions) in a data table becomes large, the total number of the aggregation groups (or views) increases significantly, which is 2^N. Furthermore, when an attribute of the data table has multiple distinct values (cardinality), the number of the aggregation values in the aggregation groups that are related to the attribute will increase in multiple. Therefore, the total aggregation values in a data cube may be dramatically larger than 2^N.

Data Cube is an effective technique for data mining that is widely applied in decision support systems, Online Analytical Processing (ONAP) systems, and other data analytical systems. In data mining, a data cube is usually built to represent the data at different levels of abstraction. Because of the huge numbers of aggregation groups and values, building data cubes is still challenging for large datasets in data mining today. Many different methods have been presented to improve the efficiency of building data cubes [3, 5, 7, 8].

After creating a complex data cube, how to visualize the data components – aggregation groups and aggregation values and the relationships among the data components in the data cube presents another challenging work. Visualization of data cubes is to utilize computer graphics technology to display the data components as different visual objects in different styles so that people can intuitively observe the data components and easily discover the complicated relationships among the data components. Data visualization plays an important role in the data cube technique. Various approaches have been proposed to fulfill this objective [1, 2, 6, 9, 10, 11]. These proposed approaches presented different visualization spaces, structures and techniques for visualizing data cubes for different datasets at different levels.

Recently, we developed an interactive data cube visualization system. This system is lightweight and can be run on the Web. It uses colors and simple two-dimensional (2D) graphics shapes to represent the data components in a data cube. The system can also dynamically display the data components in a Group-By list that is similar to the Group-By result in SQL. This system can be used to visualize data cubes in small sizes currently. In this paper, we will discuss the basic structure of a data cube first. Based on this structure, we will present the basic principle, structure and feathers of our data cube visualization system.

2. Data Cube Structure

Gray et al. introduced the Data Cube operator in detail in their paper [4]. To illustrate the data cube structure, we use the similar data for a car sales table used by Gray et al. Table 1 lists the base data values for the car sales. It has three data attributes or dimensions Model, Year and Color, and one value column Sales. The cardinalities of the Model, Year and Color attributes are 2, 3, and 3, respectively. Totally, there are 2×3×3 = 18 base sales values. After the CUBE operator, we will obtain (2+1)×(3+1)×(3+1) = 48 values that contains 18 base sales values and 30 new aggregation values. Here we only list 30 aggregation values in Table 2.

Sales			
Model	Year	Color	Sales
Ford	2002	Red	5
Ford	2002	White	87
Ford	2002	Blue	62
Ford	2003	Red	54
Ford	2003	White	95
Ford	2003	Blue	49
Ford	2004	Red	31
Ford	2004	White	54
Ford	2004	Blue	71
GE	2002	Red	64
GE	2002	White	62
GE	2002	Blue	63
GE	2003	Red	52
GE	2003	White	9
GE	2003	Blue	55
GE	2004	Red	27
GE	2004	White	62
GE	2004	Blue	39

Table 1: Car sales table

Aggregation values for Sales			
Model	Year	Color	Sales
Ford	2002	ALL	154
Ford	2003	ALL	198
Ford	2004	ALL	156
Ford	ALL	Red	90
Ford	ALL	White	236
Ford	ALL	Blue	182
Ford	ALL	ALL	508
GE	2002	ALL	189
GE	2003	ALL	116
GE	2004	ALL	128
GE	ALL	Red	143
GE	ALL	White	133
GE	ALL	Blue	157
GE	ALL	ALL	433
ALL	2002	Red	69
ALL	2002	White	149
ALL	2002	Blue	125
ALL	2002	ALL	343
ALL	2003	Red	106
ALL	2003	White	104
ALL	2003	Blue	104
ALL	2003	ALL	314
ALL	2004	Red	58
ALL	2004	White	116
ALL	2004	Blue	110
ALL	2004	ALL	284
ALL	ALL	Red	233
ALL	ALL	White	369
ALL	ALL	Blue	339
ALL	ALL	ALL	941

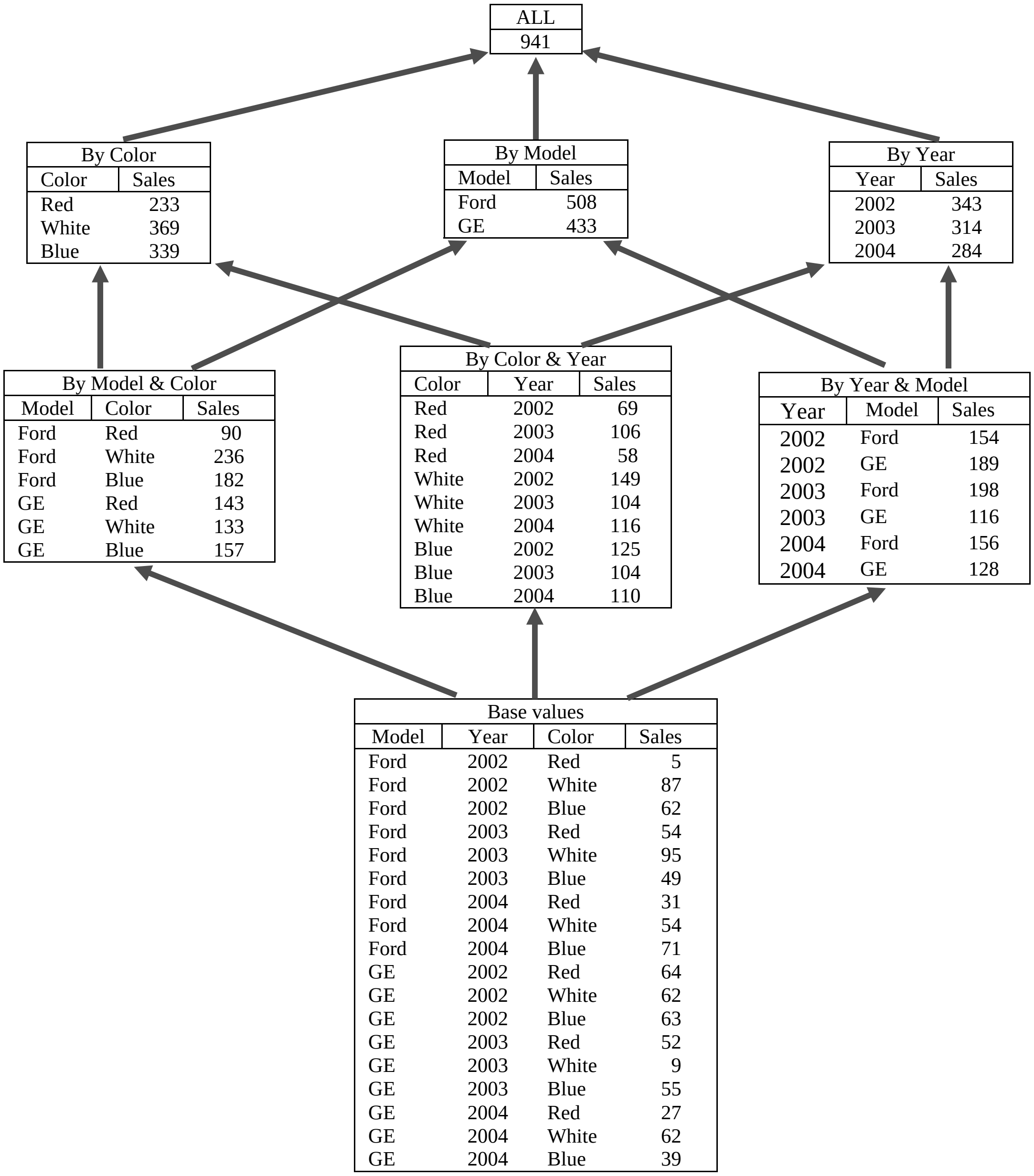
Table 2: Aggregation values for the car sales

The aggregation values in Table 2 do not show the hierarchical relationship among the values. Actually, these values are derived from the base values, and there exists a hierarchical relationship. If we rearrange the values in both Table 1 and Table 2 and create a hierarchical structure as Figure 1, the relationships among all values can be revealed clearly.

We can see that all values can be divided into eight groups. The number of groups is just equal to two to power of the number of dimensions that is three. Furthermore, the eight groups can be arranged into four levels according to their derivation process. The number of levels is equal to the number of dimensions plus one. The bottom group contains only base values. The second level derived from the bottom includes three groups. Each group contains aggregation values that are aggregated by removing one dimension from the bottom level. The third level is derived from the second level. It has three groups too. The values in the groups on this level are aggregated by removing one more dimension from the lower level – the second level. Finally, the top level is derived from the third level. It generates only one total aggregation value for all dimensions.

Figure 1 is actually a hierarchical directed graph structure, not a tree structure. When the number of dimensions of a data cube is large, the hierarchical graph structure of the data cube will become very complicated, which is very difficult to be represented as that in Figure 1. If we can create a visualization space that uses a tree structure to represent a data cube, the data values and relationships in the cube will be represented more clearly. Tree is a hierarchical structure. We can easily maintain the similar hierarchical structure presented in Figure 1 using a tree-based structure. To create a cube tree, the aggregation groups will be used as nodes in the tree. For those aggregation groups that are below the middle level and have more than one leaving arrowed-lines, we may need to split them into multiple nodes for the cube tree.

Based on this idea, we developed a Web-based data cube visualization system. Besides maintaining the hierarchical structure, the developed system uses pies to represent nodes in the tree, and colored fans in a pie to show the aggregation values in a node. Users can also interactively control many display features to visualize a data cube in different details.



ALL
941

By Color

Color	Sales
Red	233
White	369
Blue	339

By Model

Model	Sales
Ford	508
GE	433

By Year

Year	Sales
2002	343
2003	314
2004	284

By Model & Color

Model	Color	Sales
Ford	Red	90
Ford	White	236
Ford	Blue	182
GE	Red	143
GE	White	133
GE	Blue	157

By Color & Year

Color	Year	Sales
Red	2002	69
Red	2003	106
Red	2004	58
White	2002	149
White	2003	104
White	2004	116
Blue	2002	125
Blue	2003	104
Blue	2004	110

By Year & Model

Year	Model	Sales
2002	Ford	154
2002	GE	189
2003	Ford	198
2003	GE	116
2004	Ford	156
2004	GE	128

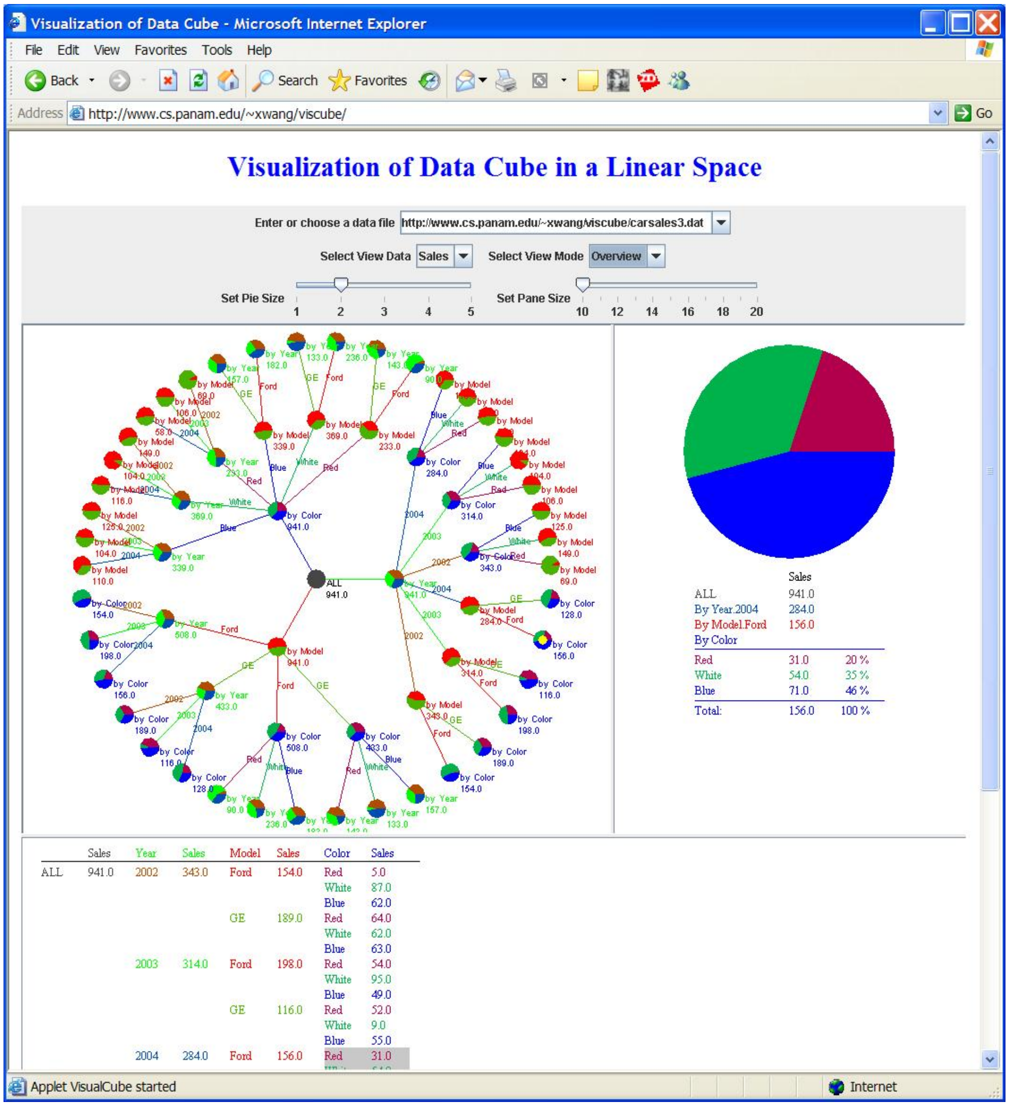
Base values

Model	Year	Color	Sales
Ford	2002	Red	5
Ford	2002	White	87
Ford	2002	Blue	62
Ford	2003	Red	54
Ford	2003	White	95
Ford	2003	Blue	49
Ford	2004	Red	31
Ford	2004	White	54
Ford	2004	Blue	71
GE	2002	Red	64
GE	2002	White	62
GE	2002	Blue	63
GE	2003	Red	52
GE	2003	White	9
GE	2003	Blue	55
GE	2004	Red	27
GE	2004	White	62
GE	2004	Blue	39

Figure 1: The hierarchical structure of a data cube

3. Web-Based Data Cube Visualization and Features

Figure 2 is a snapshot of our data cube visualization system from a Web browser. The demo system is posted at `http://www.cs.panam.edu/~xwang/viscube/`. The system contains four panels: Control Panel, Cube Display Panel, Focused Node Panel and Group-By Panel.


Visualization of Data Cube - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Search Favorites
Address http://www.cs.panam.edu/~xwang/viscube/
Go
Visualization of Data Cube in a Linear Space
ALL
941.0
by Color
941.0
by Model
941.0
by Year
941.0
Internet

Enter or choose a data file: http://www.cs.panam.edu/~xwang/viscube/carsales3.dat

Select View Data: Sales

Select View Mode: Overview

Set Pie Size: 1 2 3 4 5

Set Pane Size: 10 12 14 16 18 20

	Sales	
ALL	941.0	
By Year.2004	284.0	
By Model.Ford	156.0	
By Color		
Red	31.0	20 %
White	54.0	35 %
Blue	71.0	46 %
Total:	156.0	100 %

	Sales	Year	Sales	Model	Sales	Color	Sales
ALL	941.0	2002	343.0	Ford	154.0	Red	5.0
						White	87.0
						Blue	62.0
				GE	189.0	Red	64.0
						White	62.0
						Blue	63.0
		2003	314.0	Ford	198.0	Red	54.0
						White	95.0
						Blue	49.0
				GE	116.0	Red	52.0
						White	9.0
						Blue	55.0
		2004	284.0	Ford	156.0	Red	31.0

Applet VisualCube started

Figure 2: A snapshot of the data cube visualization system

3.1 Control Panel

Control panel is at the top of the user interface of the system. It consists of five control tools to allow users to load the base data values of a data cube, select view attribute, select view mode and control the view size.

The first control tool is a combobox for users to select a data cube file URL. Once a file URL is selected, the file will be downloaded from the specified Web server to the visualization system. The file only contains the base data of a data cube or with parallel cubes.

The first line of the file must be two numbers to specify the number of dimensions and the number of parallel date cubes. This system allows visualizing parallel data cubes. Each parallel data cube is saved as a separate value column in the base data file. The following List 1 is a data cube source file that contains the previous Sales data cube with other two parallel data cubes: Profit and Cost. The first number 3 specifies that the data cubes have three dimensions Model, Year and Color, and the second number 3 specifies that there are three parallel data cubes Sales, Profit and Cost in this file.

The second line of the file gives the names of all dimensions and parallel data cubes. These names will be used to mark the graphics objects in the visualization system later on.

```
3   3
Model   Year   Color   Sales   Profit   Cost
Ford    2002   Red       5       40      25
Ford    2002   White    87      860     550
Ford    2002   Blue     62      610     420
Ford    2003   Red      54      530     360
Ford    2003   White    95      940     670
Ford    2003   Blue     49      480     310
Ford    2004   Red      31      300     200
Ford    2004   White    54      530     340
Ford    2004   Blue     71      700     450
GE      2002   Red      64      630     435
GE      2002   White    62      610     410
GE      2002   Blue     63      620     420
GE      2003   Red      52      510     330
GE      2003   White     9       80      55
GE      2003   Blue     55      540     350
GE      2004   Red      27      260     150
GE      2004   White    62      610     400
GE      2004   Blue     39      380     230
```

List 1: Data cube source file format

The second control tool is a selection menu that allows users to select a data cube to be viewed if more than one parallel data cubes are stored in a file. Choosing different data cube name from the menu will bring the corresponding data cube to be displayed in the system. When the ALL item is selected from the menu, all parallel data cubes will be displayed in parallel in the system. This parallel data cube display mode provides a way for users to observe and compare the data relationships among different parallel data cubes. Figure 3 shows how the parallel data cubes are visualized in the system.

The third control tool is another selection menu that allows users to choose the view modes. The system provides two view modes: Local and Overview. In the Local view, users can drag the tree-based data cube displayed in the Cube Display Panel, and focus on a magnified special area to see aggregation values in detail. The Overview view displays the current data cube or parallel data cubes in the Cube Display Panel completely. Both Figure 2 and Figure 3 show data cubes in the Overview view.

The other two control tools are two sliders that allow users to set the Pie size and the data cube display pane size.

3.2 Cube Display Panel

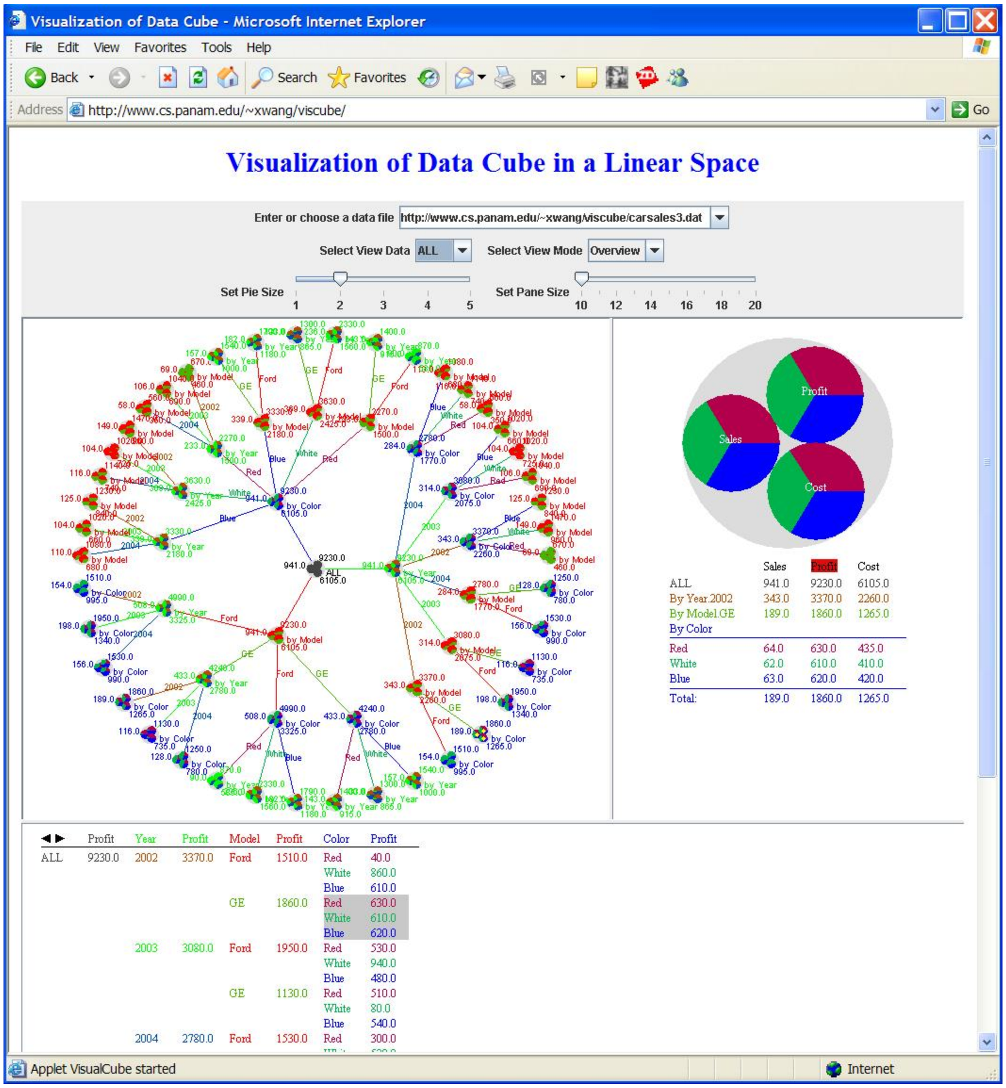
The Cube Display Panel is the most important panel in the system, and located at the middle left area. The size of this panel can be adjusted by dragging the vertical separate bar on the left side of the panel or the horizontal separate bar at the bottom of the panel.

The Cube Display Panel uses a tree-based structure to represent the current data cube. Each node in the cube tree represents an aggregation group or a splitted aggregation group, and is displayed with a colored pie. The ALL total group in the top aggregation level of a data cube always becomes the root node of the cube tree, and is displayed at the center of the data cube tree in a gray color. The groups in other levels are displayed as colored nodes around the root node and from the center toward the outside of the cube tree. The base values in the bottom level of a data cube are grouped into many leaf nodes that are displayed at the most outer loop of the tree.

Each node is also related to a dimension of the data cube. The dimension name and the corresponding aggregation value of a node are displayed next to the colored node pie. A node pie contains several fans with different colors. The number of fans in a pie represents the cardinality of the dimension. The colors of fans in a pie represent the different values in the current dimension. The system automatically assigns an individual color to every dimension and every data value in each dimension. The size of a fan represents the percentage of a dimension value to the aggregation value in the current node.

Every node in the cube tree is selectable. When the mouse cursor moves up a node, the cursor becomes a hand. This means that the current node can be selected by a single clicking. When a node is selected, a small yellow circle will be flashing on the node pie, and the corresponding node pie is magnified and displayed in the Focused Node Panel with all related aggregation values and percentage values. Moreover, the Group-By values from the root node to the current node will also dynamically be displayed with a Group-By list in the Group-By Penal.

If all parallel cubes are selected from the Control Panel, the aggregation values corresponding to a node for all parallel cubes will be displayed as separate small pies on the node. Figure 3 shows that every node has three separate pies to represent the three parallel data cubes Sales, Profit and Cost.



Visualization of Data Cube in a Linear Space

Enter or choose a data file: http://www.cs.panam.edu/~xwang/viscube/carsales3.dat

Select View Data: ALL

Select View Mode: Overview

Set Pie Size: 1 2 3 4 5

Set Pane Size: 10 12 14 16 18 20

	Sales	Profit	Cost
ALL	941.0	9230.0	6105.0
By Year.2002	343.0	3370.0	2260.0
By Model.GE	189.0	1860.0	1265.0
By Color			
Red	64.0	630.0	435.0
White	62.0	610.0	410.0
Blue	63.0	620.0	420.0
Total:	189.0	1860.0	1265.0

◀ ▶	Profit	Year	Profit	Model	Profit	Color	Profit
ALL	9230.0	2002	3370.0	Ford	1510.0	Red	40.0
						White	860.0
						Blue	610.0
				GE	1860.0	Red	630.0
						White	610.0
						Blue	620.0
		2003	3080.0	Ford	1950.0	Red	530.0
						White	940.0
						Blue	480.0
				GE	1130.0	Red	510.0
						White	80.0
						Blue	540.0
		2004	2780.0	Ford	1530.0	Red	300.0

Figure 3: A snapshot of visualization with parallel data cubes

3.3 Focused Node Panel

The Focused Node Panel is used to visualize the currently selected node in detail. This panel is located on the right of the Cube Display Panel. Its size will also be changed when dragging the vertical separate bar or the horizontal separate bar.

When a user selects a node in the Cube Display Panel, the selected node will be magnified and displayed in the Focused Node Panel immediately. The detailed data about the node will also be listed below the colored node pie.

For a node, the colored pie visually shows the relative percentages of all individual aggregation values to the total aggregation value in the current node with colors and sizes of the fans in the pie. Sometimes, users may want to know the exact numbers about all aggregation values and their percentages to the total aggregation value in the node. Besides displaying the magnified node pie, the Focused Node Panel also lists all these numbers below the magnified node pie. The super-aggregation values for all dimensions from the root node to the current node are also listed to show the relative relationships from the root node to the current node.

3.4 Group-By Panel

Many users are very familiar with the Group-By operation in SQL. The result from the Group-By operation shows aggregation values for certain attributes or dimensions clearly. Although a data cube provides all aggregation values, users may still like to read aggregation values in the Group-By list form. Our data cube visualization system provides a special panel – the Group-By Panel to display the Group-By list dynamically. The Group-By Panel is located at the bottom of the system. Both Figure 2 and Figure 3 show this panel.

As we know, a data cube generates all aggregation values that can be projected into many different Group-By lists. Which Group-By list should be displayed in the Group-By Panel at a time? Actually, when a user selects a node from the Cube Display Panel, the user usually concerns only the Group-By list from the root node to the selected node. So our system uses this principle to dynamically generate the Group-By list and displays the list in the Group-By Panel.

When a node is selected, a path from the root node to the selected node is created. Based on the nodes on this path, we can determine the selected dimensions and their order, and then we can generate the Group-By list according to the selected dimensions and their order.

The data items in the Group-By list are displayed with the corresponding colors that appear in the Cube Display Panel. In particular, the data item for the selected node is displayed with a gray background color.

If the parallel cubes are selected, a Group-By list should include all related parallel values. Because of the space limitation in the Group-By Panel, our system does not display all parallel values in the Group-By list at a time. Instead, we add two triangle buttons at the top-left corner of the Group-By Panel to allow users to select one parallel values for the Group-By list at a time.

In Figure 3, the Group-By list only shows the Profit values. We can see there are two triangle buttons at the beginning of the Group-By Panel. By clicking the left-oriented triangle button, the Group-By list will display the Sales values. In opposite, clicking the right-oriented triangle button will cause to display the Cost values in the Group-By list.

4. Conclusions and future work

In this paper, we presented our newly developed data cube visualization system. This system uses tree-based structure, simple 2D pies and colors to represent a data cube or parallel data cubes. The tree-based data cubes are only displayed in a linear space. A linear space is natural and easy to be understood by users. But when dimensions and/or cardinalities of a data cube are very large, the generated cube tree will not be able to be displayed in a linear space. So at this time, the system can only be used to visualize small datasets.

Currently, this system is still under development. We will reorganize the tree structure and move the tree-based data cubes into a hyperbolic nonlinear space so that the system can be used to visualize the data cubes for large datasets. We also consider combining the hyperbolic nonlinear space with three-dimensional (3D) graphics to create a 3D data cube visualization system. We believe that a 3D hyperbolic space will allow displaying a big enough data cube.

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