A General Framework for Multi-Resolution Visualization (MRV)

Motivation

- Large data sets are common nowadays.
- MRV systems are widely used to handle large data sets, they share many common features.
- There lacks a framework that summarize these common features.
Semantic Abstraction Model

- Three levels of the abstraction model [SZ98]
  - perception of the world
  - memorization of the perception
  - description of the memories
- Reasoning context $R = (P(W), S, L)$ [SZ98]
  - World $W$: the world where the concrete objects reside.
  - Perception, View $P(W)$: the perception that an observer has of the world.
  - Structure $S$: an extensional representation of the perceived world
  - Language $L$: a language that allows reasoning about the perceived world and communication with others

Abstraction and Simplification [SZ98]

- An abstraction is a functional mapping: $Pg(W) \rightarrow Pa(W)$
- Abstraction is a mapping between the views (perceptions) of the world
- The modifications of the structures and the languages, which are called simplification, are side effects that are necessary for describing what happens at the level of the perceived world
Abstraction Hierarchy

Level of detail (LOD):
LOD of P1(W) > LOD of P2(W) > LOD of P3(W) > LOD of P4(W)

Definition of MRV System

- **MRV system**
  - A visualization system that visually represents abstraction hierarchies of views and allows users to interactively navigate among the views

- **Essential features of a MRV system:**
  - Abstraction hierarchies of views
    - Problem: they are often not provided to the MVT systems
  - Interaction visualization
General Framework for MRV

- **View simulation** - a MRV system simulates abstraction hierarchies of views through simplification if they are not provided
  - Simplification operators
  - Simplification operands (spaces)
- **Interactive visualization** - a MRV system visually presents the views and allows users to interactively navigate among them
  - MRV interfaces
  - MRV interactions

Simplification Overview

**Operators**
- Sampling
- Aggregation
  - Clustering
  - Histograms
- Approximation
  - Proximity positioning
  - Wavelet
- Generalization

**Operands**
- Data space (structure level)
  - Data item space
  - Dimension space
  - Topology space
- Visualization space (language level)
  - Visualization structure space
  - Visual encoding space
  - Screen space
Sampling Operator

- **Sampling** - the process of selecting some part of a population to observe so that one may estimate something about the whole population [Tho92].

- Example sampling techniques:
  - Simple random sampling
  - Biased sampling [KGKB03]
  - Dynamic sample selection [BCD03]
  - Multi-level sampling [HK04]

Sampling in MRV Application

Example: query results to a video library are represented using a collage of representative key frames [DCHW03]. Occlusion happens in this display. This figure is used without authors’ permission.
Sampling in MRV Application

Sampling is used to reduce the number of key frames shown in the display to make sure that there is no occlusion [DCHW03]. This figure is used without authors’ permission.

Aggregation Operators

- Aggregation - a simplification in which a relationship between objects is regarded as a higher level object [SS77].
- Aggregation operators include:
  - Clustering
  - Histograms
  - Other operators
Clustering Operators

- **Clustering** - a division of data into groups of similar objects. Each group, called a cluster, consists of objects that are similar among themselves and dissimilar to objects of other groups [Ber02].

- Example clustering approaches [Ber02]:
  - Hierarchical clustering
  - Partitioning clustering
  - Grid-based clustering
  - Human-computer clustering

Hierarchical Clustering in MV Vis

![Hierarchical Clustering Graph]

- MPG
- Cylinder
- Horsepower
- Weight
- Acceleration
- Year
- Origin

- Europe
- Japan
- USA
Histogram Operators

- A histogram partitions the data space into buckets. In each bucket, the data distribution is often assumed uniform and recorded using simple statistic data.

- Example histograms:
  - 1-D histograms
  - Multi-dimensional histograms
  - Dynamic histograms

1-D Histogram in MRV Application

An equi-width histogram of the SAT math scores of students in some colleges. These figures were captured from [NIS05].
M-D Histogram in MRV Application

A multi-dimensional histogram with equal sized bins visualized in Dimensional Stacking [WLT94].

Possible usage of M-D histograms in MRV systems:
- Generating approximate displays of multi-dimensional data sets
- Indicating potential interesting areas in the data sets to users
- Estimating extent of clutter of a display to be generated
Approximation Operators

- **Approximation** - a simplification in which objects and relationships are represented by fewer objects and simpler relationships without explicit many to 1 mappings.

- Approximation operators include:
  - Proximity positioning operators
  - Wavelet operators
  - Other operators

Proximity Positioning Operators

- **Proximity positioning**
  - Proximity positioning generates a topology preserving map of a collection that gives an overview of similarity among the objects within the collection. In the map, similar objects are positioned close to one another, and far from dissimilar ones [Bas01].

- Example proximity positioning operators:
  - Multi-Dimensional Scaling (MDS)
  - Principal Component Analysis (PCA)
  - Self Organizing Map (SOM)
  - Pathfinder Network Scaling (PNS)
Proximity Positioning Operators in MRV Application

A document collection visualized in the SPIRE Galaxies visualization [NHT01]. This figure is used without authors’ permission.

Wavelets Operators

- **Wavelets** - filter matrices that accept a data stream with items, and generate items of approximations and items of details. The approximation is a coarse summary of the original data, and details contain the data loss during the decomposition [WB96].
Wavelets Illustration

A fine data curve is downsized to a coarse one using wavelet decomposition [WB96]. This figure is used without authors’ permission.

Wavelets in MRV Application

The wavelet brushing example [WB96]. (a) The brush data is defined. (b) Fine brushed data is painted over a coarse data background. This figure is used without authors’ permission.
Generalization Operators

- Generalization - a simplification in which a set of similar objects is regarded as a generic object [SS77].

Generalization in MRV Application
Simplification Operands

- Data space (structure level)
  - Data item space
  - Dimension space
  - Topology space
- Visualization space (language level)
  - Visualization structure space
  - Visual encoding space
  - Screen space

Data Item Space

- Data items - individual objects contained in a data set

The clutter problem of data item space [YWR03b]. The Out5d data set (size: 16384 data items, 5 dimensions) visualized with parallel coordinates.
Data Item Space Simplification
Example – IHD framework

(a) Clustering. (b) Hierarchy generated. (c) Approximation display [FWR99a, FWR99b, YWR03b]
**Dimension Space**

- **Dimensions** - individual attributes of objects contained in a data set

The clutter problem of dimension space. The OHSUMED dataset (215 dimensions) visualized with a scatterplot matrix and parallel coordinates.

**Dimension Space Simplification**

**Example 1 - VHDR Framework**

- Key ideas of Visual Hierarchical Dimension Reduction (VHDR) framework [YWRH03]:
  - Build a dimension hierarchy by clustering the dimensions to convey dimension relationships
  - Allow users to navigate and modify the dimension hierarchy
  - Allow users to select dimensions or dimension clusters to form subspaces of interests
  - Simplification operator: clustering
Dimension Space Simplification

**Example 1 – VHDR Framework**

**Example 2 – VHDF Framework**

- Key ideas of Visual Hierarchical Dimension Filtering (VHDF) framework [YPWR03]:
  - Redundant dimensions can be removed
  - Unimportant dimensions can be removed
  - Simplification operator: sampling and clustering
Dimension Space Simplification
Example 2 – VHDF Framework

Dimension filtering in star glyphs [YPWR03]. Four data items in the OHSUMED data set are shown. (a) Before filtering (b) After filtering.

Dimension Space Simplification
Example 2 – VHDF Framework

Dimension filtering in scatterplot matrices [YPWR03]. The OHSUMED data set is shown. (a) Before filtering (b) After filtering.
Dimension Space Simplification
Example 3 - VaR Displays

- Key ideas of Value and Relation (VaR) display [YPH+04]:
  - Convey dimension relationships using MDS
  - Convey data values using pixel-oriented techniques
  - Visualize dimension relationships and data values in the same display
- Simplification operator: MDS

SkyServer dataset: 361 dimensions, 50,000 data items
Topology Space

- **Topology** - geometric, spatial, temporal, or logical relationships among objects in a data set.

A graph that contains 87,931 vertices and 87,930 edges [GKN04]. (a) The display is seriously cluttered. (b) The same graph displayed in lower levels of detail. This figure is used without authors’ permission. Simplification operator: hierarchical clustering.

Visualization Structure Space

- **Visualization structure** - the organization of a visualization.

The Compound Brush [Che03]. Users can easily modify the brushing process by manipulating visual entities in the right window. This figure is used without authors’ permission. Simplification operator: generalization.
**Visual Encoding Space**

- **Visual encoding** - the mappings between data and visual attributes

A basketball player statistics data set shown in the Table Lens [RC94]. This figure is used without authors’ permission.

**Screen Space**

- **Screen space** - the pixels composing a display

The Zoom Browser displays context web pages as tiles around the focus page [Hol97]. Each tile contains a thumbnail or a summary of a context web page. This figure is used without authors’ permission.
Interactive Visualization

- Common interfaces of MRV systems:
  - Zoomable interface
  - Overview + detail interface
  - Focus + context interface

- Common interactions of MRV systems:
  - Zooming/panning
  - Selection
  - Distortion
  - Overlap reduction
  - Preview, dynamic simplification, and others

Zoomable Interface and Zooming/Panning

- **Zoomable interface** - an interface in which objects are organized in space and scale and users directly interact with the information space mainly through panning and zooming [HBP02].
- **Zooming in** - the interaction that changes the current display from a view of a lower level of detail to a view of a higher level of detail.
- **Zooming out** - the interaction that changes the current display from a view of a higher level of detail to a view of a lower level of detail.
- **Panning** - the interaction that changes the current display from a subregion of a view to an adjacent sub-region of the same view. There can be overlaps between the two regions.
Interactive map from www.mapquest.com

Overview + Detail Interface and Selection

- **Overview + detail interface** - an interface composed of multiple windows. Some windows provide context and easy navigation (overview windows) for other windows (detail windows).

- **Selection** - the interaction that isolates a subset of entities on a display for further operations [Wil96].
Overview + Detail Interface and Selection in MRV Application

Focus + Context Interface and Distortion

- **Focus + context interface** - an interface where views of different levels of detail are mixed together in the same display.

- **Distortion** - an operation that increase the screen space allocated to some objects in the display while decreasing the screen space allocated to other objects.
Focus + Context Interface and Distortion in MRV Application

InterRing [YWR02, YWRP03]

Overlap Reduction in MRV Application

- VaR display [YPH+04]
  - Extent Scaling
  - Dynamic Masking
  - Zooming and Panning
  - Showing Names
  - Layer Reordering
  - Manual Relocation
  - Automatic Shifting
Usability Inspection for MRV Systems

- Usability inspection answers questions:
  - Which simplification operator and operand to be chosen?
  - Which interface and interactions to be chosen?
  - Does a MRV system really solve the problems for which it is intended?
  - Which existing MRV system to be chosen?

- Popular usability inspection methods:
  - User testing
  - Heuristic evaluation

Summary

A general framework for MRV systems

- View simulation
  - Simplification operators
    - Sampling, aggregation, approximation, and generalization
  - Simplification operands
    - Data space and visualization space

- Interactive visualization
  - MRV interfaces
    - Zoomable, overview + detail, and focus + context interfaces
  - MRV interactions
    - Zooming, panning, selection, distortion, overlap reduction, …