Interactive Visual Analysis of Complex Data: Introduction, Families of Curves

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Focus and Context Visualization
Basic Problem

Many data sets are too large to visualize on one screen

- Too many cases
- Too many variables
- Highlight particular cases or particular variables, but viewer’s focus may change from time to time

How to work with, navigate through, and analyze a set of data that is too large to fit in the display?

Potential solutions lie in

- Representation
- Interaction
- Both

[Stasko Course Notes]
Overview

**Overview first, zoom-in, details on demand!**

Overview

- Starting point
- Very important
- Helps present overall patterns
- Needed for navigation
Overview first, zoom-in, details on demand!

Details

- Generally provided on demand
- Individual cases and variables
- How to allow user to find and focus on details of interest?
Pan and Zoom

Pan/Scroll

- Provide a larger, virtual screen by allowing user to move to different areas
- Still a problem
- Clunky interaction
- Only get to see one piece

Zoom

- Zoom out shows an overview of data space
- Zoom in allows viewer to examine details
- Getting lost - zoom in or out way too far can’t see anything

Long pan isn’t good - zoom out, pan a little, zoom in

[Stasko Course Notes]
Focus and Context 1

Combine overview + detail

- Via space - use different portions of screen to show overview and details
- Via time - alternate between overview and details sequentially in same place

No universal solution, many possibilities

Focus+context visualization: integration of (zoomed) focus & context within one view
Focus + Context 2

Various classification possible

Distorsion Oriented F+C
Views-/layers-based F+C
InPlace F+C
Focus + Context

Various classification possible

Distorsion Oriented F+C
Views-/layers-based F+C
InPlace F+C
Distortion-oriented F+C vis. 2

Hyperbolic tree view
[Lamping/Rao 1994]

3D hyperbolic space
[Munzner 1995]
Distortion-oriented F+C vis. 3

Generalized detail-in-context [Keahey 1998]
Fisheye views

Distortion oriented technique

Introduced by George Furnas in 1981 report, more famous article is 1986 SIGCHI paper

Definition:

“Provide[s] detailed views (focus) and overviews (context) without obscuring anything... The focus area (or areas) is magnified to show detail, while preserving the context, all in a single display.”

(Shneiderman, DTUI, 1998)
Fisheye views
Fisheye views terminology

- Focal point
- Level of detail
- Distance from focus
- Degree of interest function
Fisheye views terminology

Focal point
Level of detail
Distance from focus
Degree of interest function
Fisheye views Focal Point

Assume that viewers focus is on some item, some coordinate, some position,...
Fisheye views Level of Detail

Some intrinsic value or quantity on each data element

How important is it to you in a general sense?

Simplest example is that all data items have same level of detail
Fisheye views Distance from Focus

Calculation of how far each data item is from the focal point

Query position

Focal Point, (0.8, 0.1)

(0.0, 0.0)

(1.0, 1.0)
Fisheye views Degree of Interest Function

“DOI” - Function that determines how items in display are rendered

- DOI = Level of Detail - Distance from Focus

Level of Detail / Distance from Focus

Focal Point, (0.8, 0.1)

(0.0, 0.0)

(1.0, 1.0)
Fisheye views Degree of Interest Function

DoI Function

Can take on various forms

Continuous - Smooth interpolation away from focus

Filtering - Past a certain point, objects disappear

Step - Levels or regions dictating rendering $0 < x < 0.3$
  all same, $0.3 < x < 0.6$ all same

Semantic changes - Objects change rendering at
  different levels
Distortion-oriented F+C vis. 4

Perspective wall
[Mackinlay et al. 1991]

Document lens
[Robertson/Mackinlay 1993]
Distortion-oriented F+C vis. 5

Table lens [Rao/Card 1994]
Distortion-oriented F+C vis. 6

F+C Process Vis.  
[Matkovic et al. 2002]

Focus+Context Process Visualization

Using LODs for F+C  
3D Anchoring  
Collision Avoidance  
Focus+Context Rendering
Focus + Context

Various classification possible

Distortion Oriented F+C

Views-/layers-based F+C

InPlace F+C
**Views-/layers-based F+C vis. 1**

Information Mural  
[Jerding/Stasko 1998]

SeeSoft  
[Eick et al. 1992]
Views-/layers-based F+C vis. 2

Toolglass & Magic Lens  
[Bier et al. 1993]

[Fuhrmann et al. 1998]
Views-/layers-based F+C vis. 3

Macroscope [Lieberman 1994]
Focus + Context

Various classification possible

Distorsion Oriented F+C
Views-/layers-based F+C
InPlace F+C
In-place F+C vis. 1

GeoSpace [Lokuge/Ishizaki 1995]
In-place F+C vis. 2

Semantic Depth of Field (SDOF) [Kosara et al. 2001]
In-place F+C vis. 3

F+C Screen [Baudisch et al. 2001]
Generalized F+C Visualization

Focus+context visualization: uneven use of graphics resources for visualization

<table>
<thead>
<tr>
<th>Resource Space</th>
<th>Approach</th>
<th>Example</th>
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<tr>
<td>frequ.</td>
<td>smooth context</td>
<td>fisheye, ProcVis</td>
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<td>col.+α</td>
<td>glyph rendering</td>
<td>SimVis</td>
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</table>

Krešimir Matković

InfoVis, TU Wien, 14. 04. 2016
F+C visualization – comments

Very useful, often used (esp. in InfoVis)

Usually distortion-oriented, but more general concept (cf. generalization)

Requires interaction (focussing, navigation), smooth changes due to interaction

Aligns well with information drill-down, data analysis (visual information seeking mantra)

Also useable for presentation (e.g., SDOF)
Overview

Coordinated Multiple Views

- Engineering

Complex data: families of curves

- Engineering
- Traffic Surveillance
- Bio-Sygnals and ICU Data
  - Heart reinervation
  - IVA of ICU Data
- Animal Paths
- Image Collection
Multidimensional Multivariate Data

Conventional approach deals with n-dim. Euclidian spaces
Each item is a point in n-dim. Space (n-tuple)

\[ P_i = [x_1, \ldots, x_i, \ldots, x_n] \]

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<thead>
<tr>
<th>STATION</th>
<th>AVERAGE TEMP</th>
<th>PRESSURE</th>
<th>ELEVATION</th>
<th>...</th>
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<tr>
<td>2</td>
<td>20</td>
<td>1020</td>
<td>300</td>
<td>...</td>
</tr>
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Coordinated multiple views

Show various dimensions simultaneously

Use mostly simple 2D views

Interaction:
- Linking & brushing
- Select items in one view and they will be highlighted in all views
Complex Data

Engineering data does not always fit to this data model

Typical simulation:

- N control parameters
- n simulation runs (n ≤ 2^N)
- M output values which can be mappings (f(x), x is time, crankangle,...)

Point P_i is the same, but x_i can be a mapping
Complex Data

Control parameters: scalar values

$\mathbf{x}^i$

$X_1 \quad X_2 \quad \ldots \quad X_m$

Computed responses: scalar values, curves, and surfaces

$\mathbf{y}^i$

$Y_1 \quad Y_2 \quad \ldots \quad Y_k \quad \ldots \quad Y_n$

Features extracted from complex responses: scalar values

$\mathbf{z}^i$

$Z_1 \quad \ldots \quad Z_p$
First Success - Automotive Simulation
Automotive Simulation

Simulation is increasingly employed
- fluid/gas flow (engine, interior, exterior, etc.)
- crash simulation, etc.

Methods
- computational fluid dynamics (CFD)
- finite element methods (FEM)
- discrete simulation

Issues
- simulation often costly (€, time)
- datasets often large, multi-dim./-variate, etc.
Questions, Goals

More information from data
- cues for future improvements
- improving expertise

Optimization
- seeing the unexpected, reading between lines
- utilizing expertise

Analyzing failures
- answering „why“-/„how“-questions
- simulation debugging
- failure analysis
Special Challenges

Multi-variate data (many data columns)
- CFD simulation delivers dozens of attribute dims.
- Process simulation can deliver even more

Large datasets (many data rows)
- Simulation datasets: Gigabytes, ...

Spatiotemporal relations
- 3D space/object referenced
- time-referenced

Complex/nontrivial physical phenomena
Injection Design

Context:
- common rail Diesel technology
- optimization of Diesel injection

Simulation:
- simplified 1D simulation
- variational analysis wrt. boundary conditions (~$10^4$ sim. runs)
Simulation and Visualization 1

Common practice:

- define a model
- run simulation
- visualize results
- change the model
- run simulation …
Simulation and Visualization 2

Multiple runs:

- define a model
- define control parameters
- run simulation
  - for each combination of control parameters
  - for some of the combinations (steering)
- use interactive visual analysis
  - to understand (optimize) the model
  - to understand the phenomena
Common Rail Injection

Valve body goes up
P drops

Our example

Fast simulation

Main principle

Solenoid valve controls opening and closing (injection)

High P moves needle up

Pressure P

Krešimir Matković

InfoVis, TU Wien, 14. 04. 2016
Common Rail Diesel Injection 1st case

Control Parameters:
- R1 = inlet / outlet
- R2 = piston / needle
- R3 = inlet / piston
- $P_{\text{rail}}$ = common rail pressure
- $SV_{\text{open}}, SV_{\text{close}}$ = valve open./clos. vels.
Injection Simulation

Simulation with AVL HydSim

Variations:

- 9* R1
- 9* R2
- 5* R3
- 3* P_{rail}
- 4* SV_{open}
- 4* SV_{close}

- 19440 sim. runs, multi-variate res.
Simulation Results

Computed values:
- $m_{\text{inj}} = \text{inj. fuel mass}$
- $X_{\text{max}} = \text{max. needle lift}$
- $T_{\text{open}}, V_{\text{open}}, T_{\text{close}}, V_{\text{close}} = \text{shape params.}$

Goals:
- enough fuel (not too much)
- early inj. (not too slow)
- etc.
Analysis: Black Box Reconstruction
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Analysis: Black Box Reconstruction
Curves as Outputs 1

Simulations, Meteorology, Traffic, ...

Why rely on scalar features?

Our approach differs from conventional

- Mapping is a dimension of the space

Control parameters: scalar values

$x_1, x_2, \ldots, x_m$

$\mathbf{x}^i$

SIMULATION

Computed responses: scalar values, curves, and surfaces

$y_1, y_2, \ldots, y_k, \ldots, y_n$

$\mathbf{y}^i$

FEATURE EXTRACTION

Features extracted from complex responses: scalar values

$z_1, \ldots, z_p$

$\mathbf{z}^i$
Curves as Dimension

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<table>
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<td>(Jan,6);(Feb,10);...</td>
<td>1020</td>
<td>300</td>
<td>...</td>
</tr>
</tbody>
</table>
Curve View

If there are N points $P_i$

And dimension $k$ is a mapping

Each $x_k$ is a function graph

There are N function graphs for dimension $k$ – *A Family of Function Graphs*

Curve View displays such a family

45000 curves!
Interaction

Curve view in a multiple linked view setup

Need for efficient brush

Line brush
- Selects all curves which cross the line
- Very intuitive
- Easy to define
- Would be much more complex using SQL
Overview

Coordinated Multiple Views

Complex data: families of curves

- Engineering
- Traffic Surveillance
- Bio-Sygnals and ICU Data
  - Heart reinervation
  - IVA of ICU Data
- Animal Paths
- Image Collections
Families of curves – complex data

One record = one run

Various attributes

- scalar - control parameters and scalar aggregates of state parameters
- time series – state variables

Considering function graphs as resulting values

<table>
<thead>
<tr>
<th>Run</th>
<th>Flow resistance</th>
<th>Closing start</th>
<th>Pressure(t)</th>
<th>Velocity(t)</th>
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<td>...</td>
<td>...</td>
<td>...</td>
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</tr>
</tbody>
</table>
Next Step: Injection Graph Analysis

Dependent on engine speed & load:

- Design goal
- Engine speed
- Injection rate shaping

Simulated
Analysis: Parameter Influence (box)
Analysis: Parameter Influence (box)
Analysis: Parameter Influence (box)
Analysis: Parameter Influence (box)
Analysis: Parameter Influence (box)
Analysis: Parameter Influence (box)
Analysis: Parameter Influence (box)
Analysis: Shape „boot“
Analysis: Shape „boot“
Overview

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Traffic Sensor Network (Minneapolis, St. Pauls)

- 12 weeks (84 days)
- 564 sensors
- daily data, aggregated from measurements all 30 secs.
- $2 \cdot 47376 = 94752$ graphs (144 f(t)-values each, one per 10 mins.)
Typical Visualization Tasks

- Exploration
- Find the unknown, unexpected
- Hypothesis generation
- Analysis
- Confirm or reject hypotheses
- Information drill-down
- Presentation
- Communicate/disseminate results

[TVCG 2006]
Typical Visualization Tasks

- exploration
- find the unknown, unexpected
- hypothesis generation
- analysis
- confirm or reject hypotheses
- information drill-down
- presentation
- communicate/disseminate results

… 2 sensors, 2 days (Sun+Mon)!
Typical Visualization Tasks

- Exploration
- Find the unknown, unexpected
- Hypothesis generation
- Analysis
- Confirm or reject hypotheses
- Information drill-down
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- Communicate/disseminate results

... 293 outliers (out of 47376 ≈ 0.6%)!

... negative(!) volume-values brushed...
Typical Visualization Tasks

- Exploration: find the unknown, unexpected
- Hypothesis generation
- Analysis: confirm or reject hypotheses
- Information drill-down
- Presentation: communicate/disseminate results

[TVCG 2006]
Typical Visualization Tasks

- Exploration
- Find the unknown, unexpected
- Hypothesis generation
- Analysis
- Confirm or reject hypotheses
- Information drill-down
- Presentation
- Communicate/disseminate results

[TVCG 2006]

... again the same sensor!

... just 1 outlier!
Typical Visualization Tasks

- Exploration
- Find the unknown, unexpected
- Hypothesis generation
- Analysis
- Confirm or reject hypotheses
- Information drill-down

Presentation

Communicate/disseminate results

whole day no cars?!

why (just) here???
Electronic Unit Injector - EUI 1

One injector per cylinder

Used in Diesel engines:
- patent from 1911
- used since 1930s in trucks, locomotives, and ships
- EUI in 1990s
- mostly used in heavy vehicles

Injector design is very important
- emission reduction
- engine efficiency
Model (of an EUI Injector)

Model definition:
- standard building blocks are used
- each block has control parameters
- decide which will be varied
- state variables are computed for each block
- scalar and time series values

Needle Control Valve

Control parameters
- Closing start
- Opening start
- Flow resistance
- Time for opening
- Time for closing

Output:
- Volume-rate

This element serves to define a throttle controlled by timing of flow areas (switch valve). Flow area can be a function of time or crank angle.
Multiple simulation runs

AVL Hydsim tool used

1D CFD – fast simulation
- 10 simulation runs per minutes

7 parameters varied – 2880 runs

9 state variables considered in analysis (+ aggregates)
Interactive Visual Analysis

Results are available:

- use interactive visual analysis
  - to understand (optimize) the model
  - to understand the phenomena
- CMV system used
- many parameters – many views
- engineer has to know what is depicted in each view
The Model View

Engineers are familiar with model view

We want to show results and control parameters in blocks

Control and state variables

Multiple runs!
- various values for control parameters
- various values for state variables - time series

Limited space – three levels
Three Levels

Show control parameters on left, state variables on right

Up to 3 variables (user selects them)

Level one
- histograms used
- if state variables are time series – use aggregates

Level two
- double width and height
- up to six histograms, or fewer larger
- scatter plot also possible (not used in our case)
- aggregates of state variables still used

Level three
- block can not be larger
- floating view with map and time series data
Analysis

Data derivation and aggregation integrated in the system

Successfully used to analyze and tune EUI for different operation modes

Complex Interaction – Simple Data

vs.

Simple Interaction – Complex data
Analysis – the High Power Mode 1

Square shaped injection curve

High injection pressure
- we want a lot of fuel

Blocks C and D are of main interest

3rd level view configured using model view

3 families of curves
Analysis – the High Power Mode 2

Select curves with steep rise
- line brush with limited crossing angle

Refine selection
- only high pressure at the injection start
- stronger fuel penetration – higher power

Refine once more
- subtract too slow rising
- or change limit of the crossing
Analysis – the High Power Mode 3

Second needle opening
- undesired behavior
- can be seen in the curve view
- maybe additional curves are hidden

Use a derived family of function
- first derivative
- more curves detected
- explore why (see paper)
Analysis – the High Power Mode 4

Select curves with step rise
- line brush with limited crossing angle

Refine selection
- only high pressure at the injection start
- Stronger fuel penetration – higher power

Refine once more
- subtract too slow rising
- or change limit of the crossing angle

Exclude second needle opening
Analysis – the High Power Mode 5

Curves are selected
- corresponding control parameters can be explored
- B and E flow resistance most influential, low values desired

Refine selection once more
- high injected fuel mass wanted
- integral aggregate

2880 runs reduced to 147

All parameters are always highlighted in the model view
Unlimited Possibilities

Low Consumption mode

Instead of brushing curve view

Use histograms of min and max aggregates of 1\textsuperscript{st} derivative
Integration of Model view into CMV

Helps users in:

- figuring out the basic behavior based on aggregates
- identifying important elements for a given scenario
- configuring views, select what is displayed by one click
- connecting views to originating models

Very positive feedback from domain experts

- will be included in commercial software in near future
Overview

Coordinated Multiple Views

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  - IVA of ICU Data
- Animal Paths
- Image Collection
Heart Reinervation 1
Heart Reinervation 2
Overview

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ICU Data

Modern Intensive Care Unit

- a lot of high technology equipment
- routinely logging of
  - many physiological measurements
  - laboratory results
  - interventions information
- these information can help intensive care physicians to understand physiological, pathological and therapeutic processes and so, consequently, to improve medical care
Usage of Data

Huge amounts of data available

Great potential but:
- many proprietary formats, data bases rarely merged
- statistical models are complex and hard to develop without merged DBs
- communication between medical and statistics experts

State of the art
- various regression models and advanced statistics
- Protocols (researchers – daily practice)
- APACHE II Score, for example

Interactive Visual Analysis
- novel concept for ICU medical researchers
Data 1

~1500 patients

<table>
<thead>
<tr>
<th>Time</th>
<th>Patient</th>
<th>Age</th>
<th>apa</th>
<th>gsc</th>
<th>temp</th>
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Huge database
- complex processing and analysis

C-reactive protein concentration

Coordinated Multiple Views (CMV)
Coordinated Multiple Views (CMV)
Family of Curves

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<td>04:00</td>
<td>1404</td>
<td>43</td>
<td>18</td>
<td>12</td>
<td>40.4</td>
<td>1</td>
</tr>
<tr>
<td>04:00</td>
<td>2344</td>
<td>73</td>
<td>24</td>
<td>12</td>
<td>38.6</td>
<td>1.2</td>
</tr>
</tbody>
</table>

A family of curves
Workflow

- Prepare the data according to the new data model
- Derive data if necessary
- Domain Experts have to familiarize with the tool
- Add specific features needed by domain experts depending on their tasks
- More complex data exploration and analysis
Data preparation

- Prepare the data according to the new data model
  - Tedious task
  - Missing data
  - Double data!

- Interactive methods speed up the process

Improvements of curve view were necessary

- Support for different length of curves
- Support for gaps
  - Small and large gaps
- Depict start-end point
- Fill the missing part (optionally)
- Mouse-over highlighting
Additional Features

Introduction of box-plot into CMV

- experts were used to it
- in an interactive setup very powerful overview method

Inverse brush

- usual approach – show brushed records and all records
- inverse brush – show brushed records, non-brushed records, and all records

Brush summary view

- another summary view
Case Study 1 – Confirming a Hypothesis

We are exploring sodium concentration

Hyponatraemia – sodium too low – <130 mmol/L

Hypernatremia – sodium too high – >150 mmol/L

Sodium concentration available as a curve per patient

Known hypothesis

– patients with hypo- or hypernatremia have a higher mortality rate

Brushing hypernatremia patients

– Use curve view and a long horizontal brush

– Compute maximum aggregate – curve -> scalar and use conventional views
Case Study 2 – Exploring Variability

We suspect that not only absolute values, but rate of change has influence on mortality.

First derivation aggregate curve – curve.

Using standard techniques to explore the change.

Hypernatremia with rapid fall very dangerous.

Special care has to be taken when reducing sodium level.

We also explored patients with rapid fall or rise but no hyper or hyponatremia. 

 unexpected finding!

 high sodium level variability increases mortality!
Case Study 3 – Interactive drill down

New data model makes advanced drill down possible

The timing of fall/rise can be easily specified
Thank you!

Special thanks for used materials to H. Hauser, and colleagues from VRVis!