

Characteristics and Variants of Parallel Coordinates



Romana Gruber

706.414 Seminar/Project Interactive and Visual Information Systems 4SP WS 2023/2024

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Overview

- Basics
- Usage
- Clutter Reduction
- Variants and Extensions

Basics



Background

- Henry Gannett [1883]¹
- Alfred Inselberg [1985]²
- Multidimensional data.
- Predominantly for analysis.
- Identify relationships, patterns, outliers, trends, and variations.

¹ Hewes, Fletcher Willis and Henry Gannett [1883]. *Scribner's Statistical Atlas of the United States*. Charles Scribner's Sons, New York, USA: 1883. Plate 151.

² Inselberg, Alfred [1985]. *The Plane with Parallel Coordinates*. *The Visual Computer* 1.2 (Dec 1985), pages 69–91. doi:10.1007/BF01898350

GENERAL SUMMARY, SHOWING THE RANK OF STATES, BY RATIOS, 1880.

(Based on the Returns of the Tenth Census.)

POPULATION. (Count by State)	OCCUPATIONS. (Ratio to Total Population)	WEALTH. (Dollars Value per Capita)	MANUFACTURES. (Value of Product per Capita)	AGRICULTURE. (Value of Product per Capita)	LIVE STOCK. (Value of All Classes per Capita)	NET DEBT. (Dollars and Cents per Capita)	TAXATION. (Dollars and Cents per Capita)	EDUCATION. (Expenses for Primary Schools per Capita)	LITERACY. (Percent Value in Value)
1 DIST. COLUMBIA \$100	1 MONTANA \$100	1 CALIFORNIA \$100	1 RHODE ISLAND \$100	1 IOWA \$100	1 WYOMING \$100	1 NEW MEXICO \$100	1 NEW MEXICO \$100	1 WYOMING \$100	1 WYOMING 1.00
2 RHODE ISLAND \$99	2 ARIZONA \$99	2 MONTANA \$99	2 MASSACHUSETTS \$99	2 VERMONT \$99	2 MONTANA \$99	2 TEXAS \$99	2 NORTH CAROLINA \$99	2 CALIFORNIA \$99	2 CALIFORNIA 0.99
3 MASSACHUSETTS \$98	3 CHICAGO \$98	3 RHODE ISLAND \$98	3 CONNECTICUT \$98	3 VERMONT \$98	3 VERMONT \$98	3 MINNESOTA \$98	3 ALABAMA \$98	3 MASSACHUSETTS \$98	3 MASSACHUSETTS 0.98
4 NEW YORK \$97	4 NEW YORK \$97	4 NEW YORK \$97	4 NEW JERSEY \$97	4 NEW JERSEY \$97	4 IOWA \$97	4 WEST VIRGINIA \$97	4 TENNESSEE \$97	4 OHIO \$97	4 OHIO 0.97
5 CONNECTICUT \$96	5 ILLINOIS \$96	5 CONNECTICUT \$96	5 NEW HAMPSHIRE \$96	5 VERMONT \$96	5 VERMONT \$96	5 WASHINGTON \$96	5 SOUTH CAROLINA \$96	5 MONTANA \$96	5 MONTANA 0.96
6 NEW YORK \$95	6 CALIFORNIA \$95	6 NEW JERSEY \$95	6 NEW YORK \$95	6 ILLINOIS \$95	6 ILLINOIS \$95	6 IOWA \$95	6 OHIO \$95	6 OHIO \$95	6 OHIO 0.95
7 PENNSYLVANIA \$94	7 IOWA \$94	7 PENNSYLVANIA \$94	7 PENNSYLVANIA \$94	7 PENNSYLVANIA \$94	7 WASHINGTON \$94	7 IOWA \$94	7 MINNESOTA \$94	7 CONNECTICUT \$94	7 MINNESOTA 0.94
8 MARYLAND \$93	8 WYOMING \$93	8 SOUT. CAROLINA \$93	8 DELAWARE \$93	8 ILLINOIS \$93	8 ILLINOIS \$93	8 KANSAS \$93	8 MICHIGAN \$93	8 IOWA \$93	8 IOWA 0.93
9 OHIO \$92	9 RHODE ISLAND \$92	9 OHIO \$92	9 RHODE ISLAND \$92	9 OHIO \$92	9 VERMONT \$92	9 NEBRASKA \$92	9 ILLINOIS \$92	9 ILLINOIS \$92	9 OHIO 0.92
10 DELAWARE \$91	10 NEW HAMPSHIRE \$91	10 OHIO \$91	10 NEW HAMPSHIRE \$91	10 OHIO \$91	10 WASHINGTON \$91	10 ILLINOIS \$91	10 TEXAS \$91	10 NEBRASKA \$91	10 NEBRASKA 0.91
11 IOWA \$90	11 MASSACHUSETTS \$90	11 OHIO \$90	11 ILLINOIS \$90	11 ILLINOIS \$90	11 ILLINOIS \$90	11 TEXAS \$90	11 TEXAS \$90	11 ILLINOIS \$90	11 ILLINOIS 0.90
12 ILLINOIS \$89	12 WASHINGTON \$89	12 WYOMING \$89	12 MARYLAND \$89	12 WYOMING \$89	12 OHIO \$89	12 IOWA \$89	12 VERMONT \$89	12 RHODE ISLAND \$89	12 IOWA 0.89
13 KENTUCKY \$88	13 SOUTH CAROLINA \$88	13 NEW HAMPSHIRE \$88	13 OHIO \$88	13 OHIO \$88	13 KANSAS \$88	13 MINNESOTA \$88	13 VERMONT \$88	13 OHIO \$88	13 OHIO 0.88
14 NEW HAMPSHIRE \$87	14 DELAWARE \$87	14 DELAWARE \$87	14 DELAWARE \$87	14 KANSAS \$87	14 ILLINOIS \$87	14 KENTUCKY \$87	14 WEST VIRGINIA \$87	14 WYOMING \$87	14 WYOMING 0.87
15 VERMONT \$86	15 OHIO \$86	15 OHIO \$86	15 WYOMING \$86	15 WYOMING \$86	15 IOWA \$86	15 INDIANA \$86	15 INDIANA \$86	15 INDIANA \$86	15 INDIANA 0.86
16 TENNESSEE \$85	16 INDIANA \$85	16 INDIANA \$85	16 VERMONT \$85	16 OHIO \$85	16 KENTUCKY \$85	16 ARIZONA \$85	16 DELAWARE \$85	16 TEXAS \$85	16 TEXAS 0.85
17 VERMONT \$84	17 IOWA \$84	17 IOWA \$84	17 VERMONT \$84	17 OHIO \$84	17 OHIO \$84	17 MINNESOTA \$84	17 MINNESOTA \$84	17 VERMONT \$84	17 VERMONT 0.84
18 NORTH CAROLINA \$83	18 OHIO \$83	18 OHIO \$83	18 VERMONT \$83	18 OHIO \$83	18 TEXAS \$83	18 TEXAS \$83	18 MINNESOTA \$83	18 NORTH CAROLINA \$83	18 NORTH CAROLINA 0.83
19 MISSOURI \$82	19 DIST. COLUMBIA \$82	19 MISSOURI \$82	19 MISSOURI \$82	19 OHIO \$82	19 IOWA \$82	19 ARIZONA \$82	19 KANSAS \$82	19 MISSOURI \$82	19 MISSOURI 0.82
20 IOWA \$81	20 IOWA \$81	20 MISSOURI \$81	20 MISSOURI \$81	20 OHIO \$81	20 WYOMING \$81	20 MINNESOTA \$81	20 NEW JERSEY \$81	20 ILLINOIS \$81	20 ILLINOIS 0.81
21 NORTH CAROLINA \$80	21 NEW YORK \$80	21 MISSOURI \$80	21 MISSOURI \$80	21 OHIO \$80	21 MISSOURI \$80	21 MARYLAND \$80	21 MISSOURI \$80	21 OHIO \$80	21 MISSOURI 0.80
22 MISSOURI \$79	22 MISSOURI \$79	22 MISSOURI \$79	22 MISSOURI \$79	22 OHIO \$79	22 OHIO \$79	22 MISSOURI \$79	22 MISSOURI \$79	22 MISSOURI \$79	22 MISSOURI 0.79
23 VERMONT \$78	23 IOWA \$78	23 OHIO \$78	23 OHIO \$78	23 OHIO \$78	23 KENTUCKY \$78	23 OHIO \$78	23 WYOMING \$78	23 PENNSYLVANIA \$78	23 PENNSYLVANIA 0.78
24 WEST VIRGINIA \$77	24 VERMONT \$77	24 VERMONT \$77	24 VERMONT \$77	24 DELAWARE \$77	24 VERMONT \$77	24 VERMONT \$77	24 VERMONT \$77	24 MARYLAND \$77	24 MARYLAND 0.77
25 ALABAMA \$76	25 NEW JERSEY \$76	25 WYOMING \$76	25 WYOMING \$76	25 SOUTH CAROLINA \$76	25 SOUTH CAROLINA \$76	25 SOUTH CAROLINA \$76	25 SOUTH CAROLINA \$76	25 SOUTH CAROLINA \$76	25 SOUTH CAROLINA 0.76
26 MISSOURI \$75	26 MISSOURI \$75	26 MISSOURI \$75	26 MISSOURI \$75	26 OHIO \$75	26 OHIO \$75	26 ILLINOIS \$75	26 ILLINOIS \$75	26 ILLINOIS \$75	26 ILLINOIS 0.75
27 WYOMING \$74	27 WYOMING \$74	27 WYOMING \$74	27 WYOMING \$74	27 WYOMING \$74	27 OHIO \$74	27 OHIO \$74	27 OHIO \$74	27 OHIO \$74	27 OHIO 0.74
28 IOWA \$73	28 NORTH CAROLINA \$73	28 NORTH CAROLINA \$73	28 NORTH CAROLINA \$73	28 WYOMING \$73	28 KENTUCKY \$73	28 KANSAS \$73	28 IOWA \$73	28 IOWA \$73	28 IOWA 0.73
29 KANSAS \$72	29 NEW MEXICO \$72	29 KANSAS \$72	29 NEW YORK \$72	29 NEW YORK \$72	29 NEW YORK \$72	29 IOWA \$72	29 IOWA \$72	29 IOWA \$72	29 IOWA 0.72
30 ARIZONA \$71	30 PENNSYLVANIA \$71	30 ARIZONA \$71	30 ARIZONA \$71	30 IOWA \$71	30 NEW HAMPSHIRE \$71	30 MASS \$71	30 NEW YORK \$71	30 MARYLAND \$71	30 MARYLAND 0.71
31 KANSAS \$70	31 KANSAS \$70	31 KANSAS \$70	31 VERMONT \$70	31 VERMONT \$70	31 NEW YORK \$70	31 VERMONT \$70	31 VERMONT \$70	31 VERMONT \$70	31 VERMONT 0.70
32 MISSOURI \$69	32 VERMONT \$69	32 VERMONT \$69	32 VERMONT \$69	32 KANSAS \$69	32 MASS \$69	32 VERMONT \$69	32 VERMONT \$69	32 VERMONT \$69	32 VERMONT 0.69
33 TEXAS \$68	33 TEXAS \$68	33 TEXAS \$68	33 WEST VIRGINIA \$68	33 WEST VIRGINIA \$68	33 WEST VIRGINIA \$68	33 MISSOURI \$68	33 MISSOURI \$68	33 TEXAS \$68	33 TEXAS 0.68
34 MISSOURI \$67	34 MISSOURI \$67	34 MISSOURI \$67	34 TEXAS \$67	34 MARYLAND \$67	34 MARYLAND \$67	34 MISSOURI \$67	34 MISSOURI \$67	34 MISSOURI \$67	34 MISSOURI 0.67
35 CALIFORNIA \$66	35 VERMONT \$66	35 VERMONT \$66	35 VERMONT \$66	35 VERMONT \$66	35 PENNSYLVANIA \$66	35 PENNSYLVANIA \$66	35 PENNSYLVANIA \$66	35 PENNSYLVANIA \$66	35 PENNSYLVANIA 0.66
36 FLORIDA \$65	36 IOWA \$65	36 IOWA \$65	36 IOWA \$65	36 VERMONT \$65	36 ALABAMA \$65	36 MISSOURI \$65	36 MISSOURI \$65	36 MISSOURI \$65	36 MISSOURI 0.65
37 CHICAGO \$64	37 ILLINOIS \$64	37 ILLINOIS \$64	37 ILLINOIS \$64	37 ILLINOIS \$64	37 CONNECTICUT \$64	37 CONNECTICUT \$64	37 CONNECTICUT \$64	37 CONNECTICUT \$64	37 CONNECTICUT 0.64
38 OHIO \$63	38 ILLINOIS \$63	38 ILLINOIS \$63	38 ILLINOIS \$63	38 FLORIDA \$63	38 FLORIDA \$63	38 VERMONT \$63	38 VERMONT \$63	38 VERMONT \$63	38 VERMONT 0.63
39 TEXAS \$62	39 NEW JERSEY \$62	39 NEW JERSEY \$62	39 PAIDIA \$62	39 NEW JERSEY \$62	39 MARYLAND \$62	39 NEW HAMPSHIRE \$62	39 NEW HAMPSHIRE \$62	39 NEW HAMPSHIRE \$62	39 NEW HAMPSHIRE 0.62
40 MISSOURI \$61	40 MISSOURI \$61	40 MISSOURI \$61	40 SOUTH CAROLINA \$61	40 MISSOURI \$61	40 MISSOURI \$61	40 MISSOURI \$61	40 MISSOURI \$61	40 MISSOURI \$61	40 MISSOURI 0.61
41 NEW MEXICO \$60	41 MISSOURI \$60	41 MISSOURI \$60	41 MISSOURI \$60	41 TEXAS \$60	41 TEXAS \$60	41 SOUTH CAROLINA \$60	41 CONNECTICUT \$60	41 MISSOURI \$60	41 MISSOURI 0.60
42 IOWA \$59	42 WYOMING \$59	42 WYOMING \$59	42 NORTH CAROLINA \$59	42 TEXAS \$59	42 WYOMING \$59	42 NEW JERSEY \$59	42 NEW YORK \$59	42 IOWA \$59	42 IOWA 0.59
43 MONTANA \$58	43 ARIZONA \$58	43 ARIZONA \$58	43 ARIZONA \$58	43 TEXAS \$58	43 NEW MEXICO \$58	43 IOWA \$58	43 OHIO \$58	43 OHIO \$58	43 OHIO 0.58
44 IOWA \$57	44 OHIO \$57	44 OHIO \$57	44 SOUTH CAROLINA \$57	44 ARIZONA \$57	44 ARIZONA \$57	44 SOUTH CAROLINA \$57	44 NEW YORK \$57	44 NEW YORK \$57	44 NEW YORK 0.57
45 ARIZONA \$56	45 TENNESSEE \$56	45 SOUTH CAROLINA \$56	45 SOUTH CAROLINA \$56	45 ARIZONA \$56	45 ARIZONA \$56	45 MISSOURI \$56	45 MISSOURI \$56	45 MISSOURI \$56	45 MISSOURI 0.56
46 MONTANA \$55	46 WEST VIRGINIA \$55	46 MISSOURI \$55	46 MISSOURI \$55	46 ARIZONA \$55	46 MISSOURI \$55	46 MASSACHUSETTS \$55	46 MASSACHUSETTS \$55	46 MASSACHUSETTS \$55	46 MASSACHUSETTS 0.55
47 WYOMING \$54	47 TEXAS \$54	47 WEST VIRGINIA \$54	47 DIST. COLUMBIA \$54	47 DIST. COLUMBIA \$54	47 DIST. COLUMBIA \$54	47 DIST. COLUMBIA \$54	47 DIST. COLUMBIA \$54	47 DIST. COLUMBIA \$54	47 DIST. COLUMBIA 0.54

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Parallel Coordinate Plot

- Dimensions are parallel axes.
- Records are polylines.

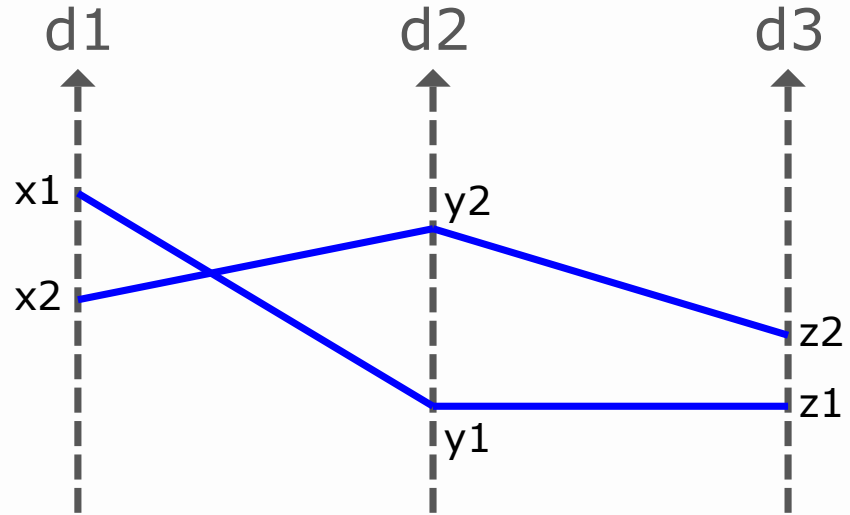


Image drawn by Romana Gruber.

Usage

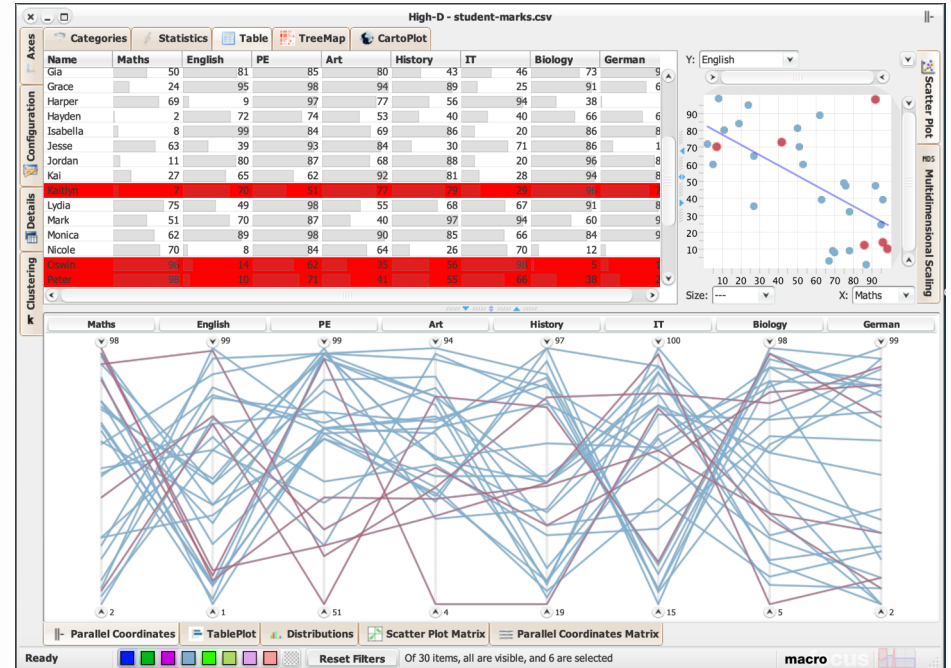


Interaction Techniques

- Brushing records
- Filtering records
- Selecting records
- Grouping records
- Hiding/showing dimensions
- Moving dimensions
- Inverting dimensions
- Showing histograms

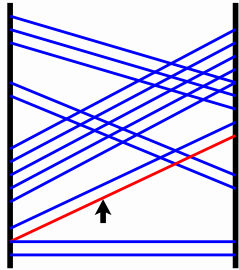
Brushing and Linking

- Multi-selection of records (brushing).
- Highlight records in synchronised views (linking).

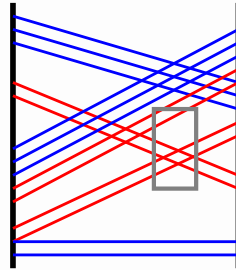


Screenshot by Romana Gruber from High-D www.high-d.com

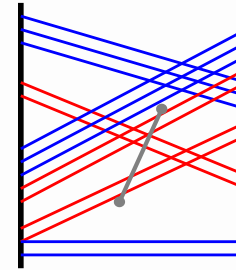
Brushing Techniques



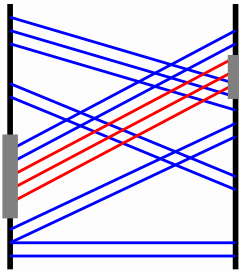
Selecting



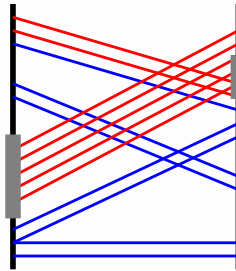
Area Brush



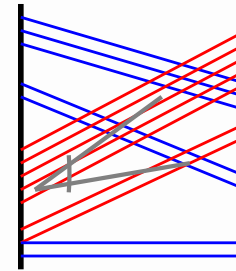
Lasso Brush



Composite AND
Brush



Composite OR
Brush



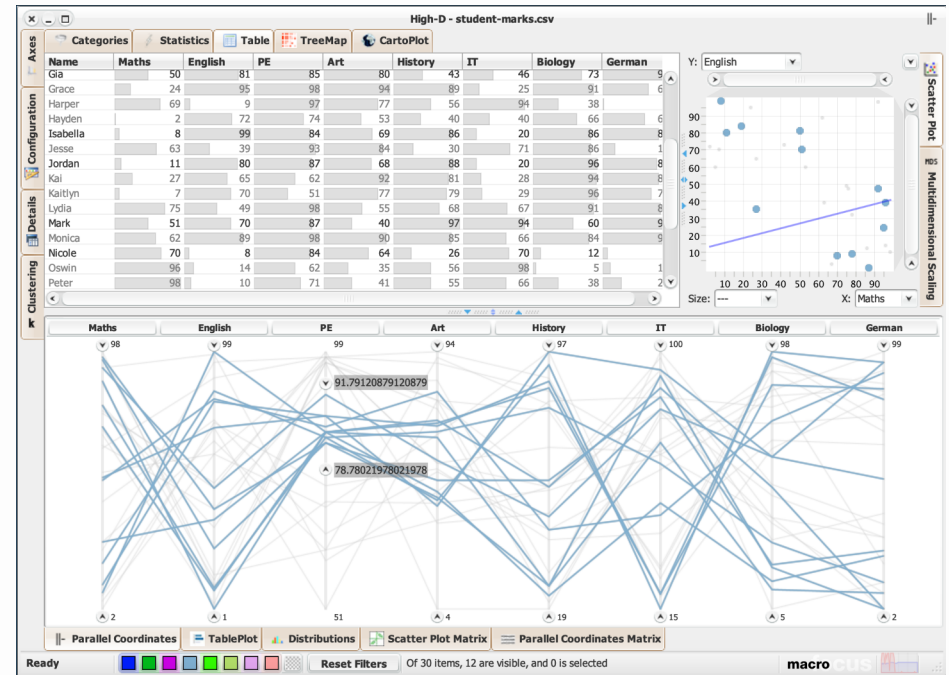
Angular Brush

Redrawn by Romana Gruber from the original by Raidou et al. [2016]¹

¹ R. G. Raidou, M. Eisemann, M. Breeuwer, E. Eisemann and A. Vilanova [2016]. *Orientation-Enhanced Parallel Coordinate Plots*. IEEE Transactions on Visualization and Computer Graphics, vol. 22, no. 1, 31 Jan 2016, pages 589-598, doi:10.1109/TVCG.2015.2467872

Filtering Records

- Apply filter on each dimension.
- Makes records inactive.
- To operate on subset of records.



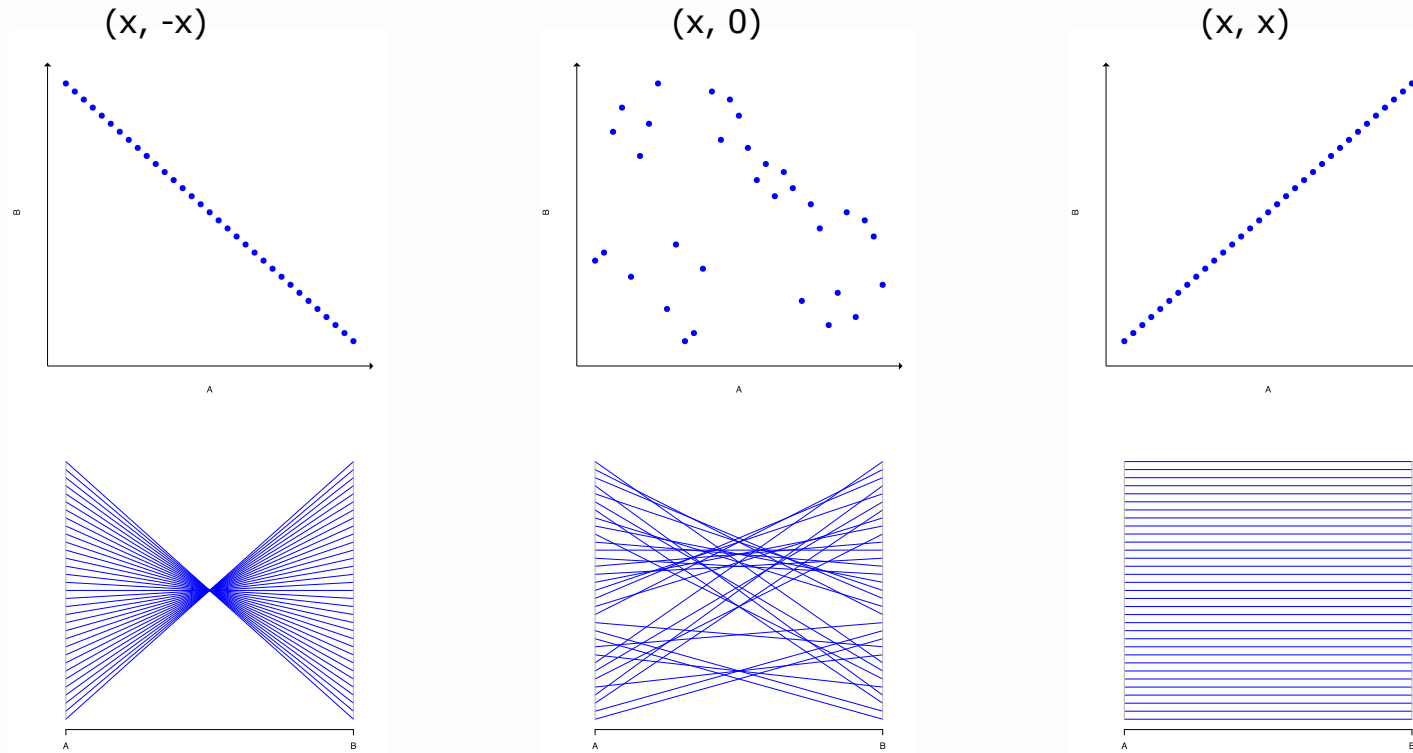
Screenshot by Romana Gruber from High-D www.high-d.com

Correlations

Types of correlation:

- Linear correlation.
- Non-linear correlation.

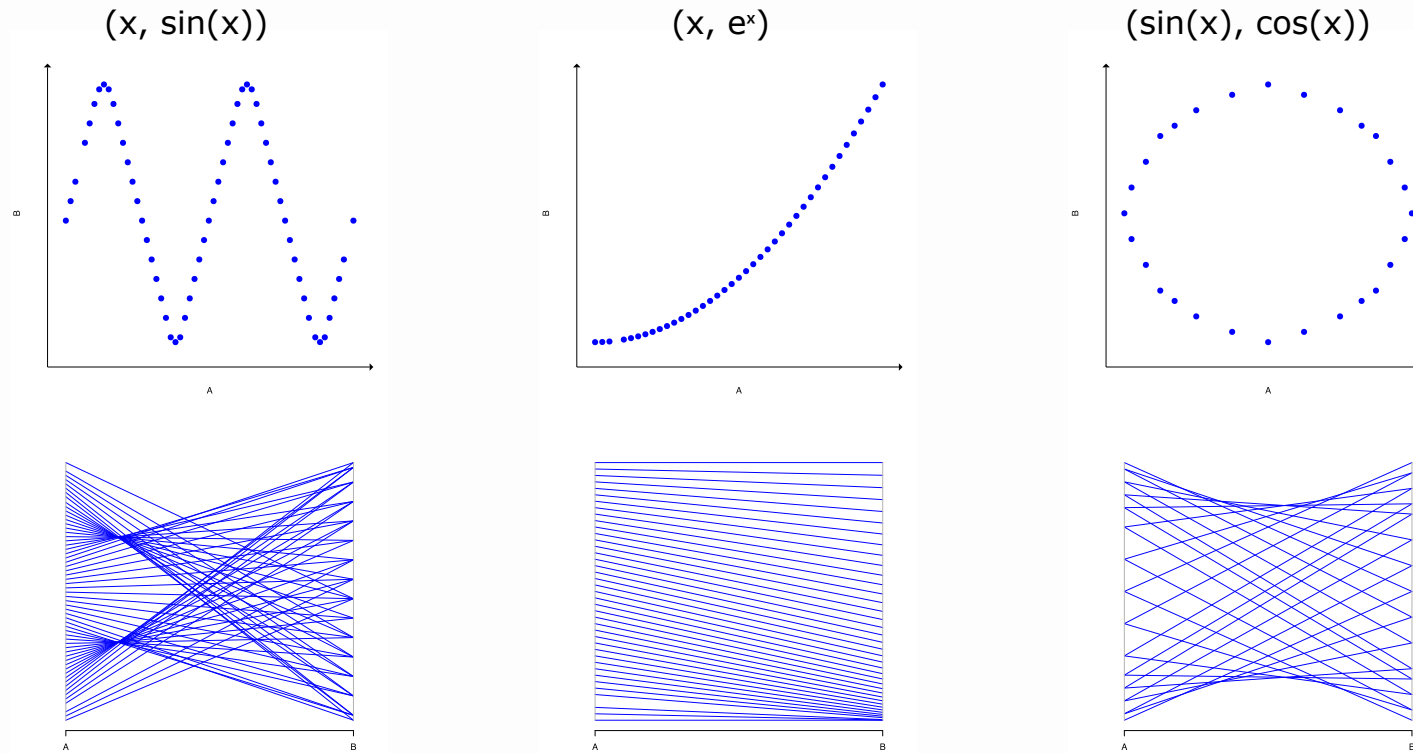
Correlation Example Plots



Images created by Romana Gruber with R from Figure 5 of Heinrich et al. [2012]¹

¹ Heinrich, Julian and Weiskopf, Daniel [2012]. *State of the Art of Parallel Coordinates*. Eurographics 2013 - State of the Art Reports, pages 95–116, doi:10.2312/conf/EG2013/stars/095-116

Correlation Example Plots



Images created by Romana Gruber with R from Figure 5 of Heinrich et al. [2012]¹

¹ Heinrich, Julian and Weiskopf, Daniel [2012]. *State of the Art of Parallel Coordinates*. Eurographics 2013 - State of the Art Reports, pages 95–116, doi:10.2312/conf/EG2013/stars/095-116

Outliers

Differ significantly from other data points.

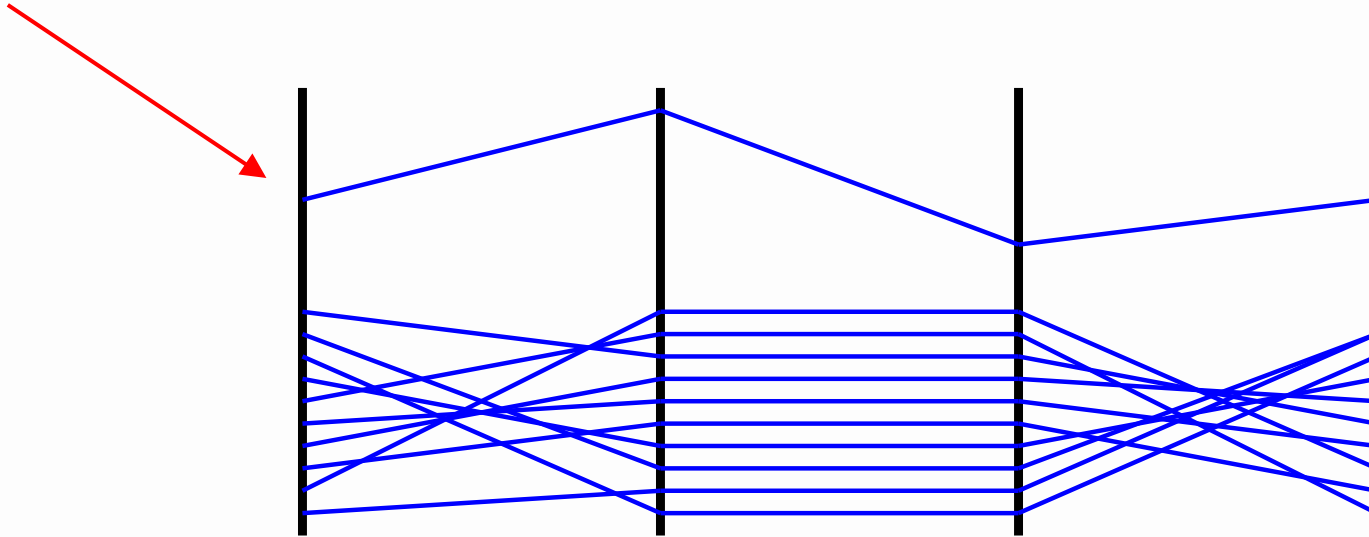
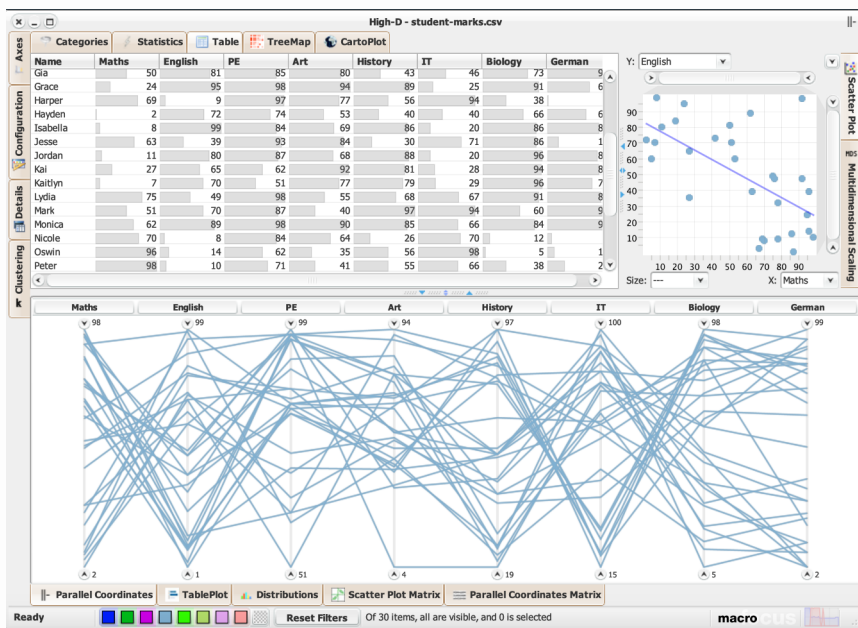
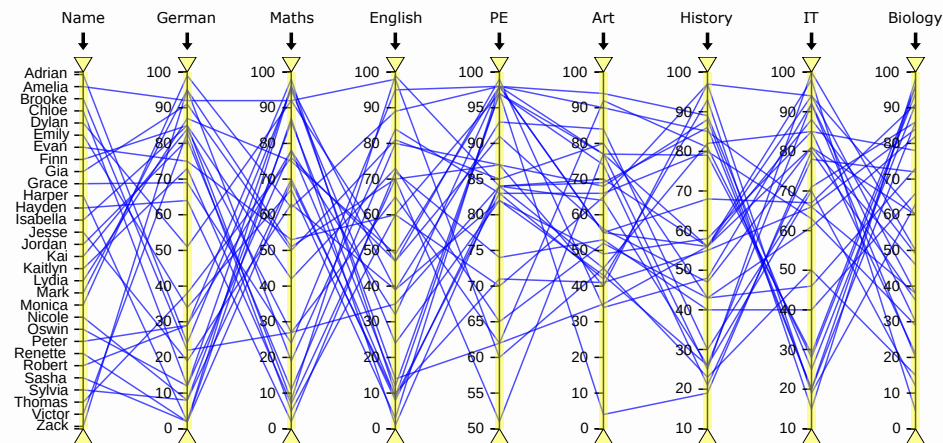


Image drawn by Romana Gruber.

Demo



High-D www.high-d.com 2019.9.3 on macOS Catalina 10.15.7



SPCD3 v1 www.spcd3.netlify.app with Google Chrome 123.0.6312.58 on macOS Catalina 10.15.7.

Showcase Video:
<https://youtu.be/ZYSEz1ceNSc>

Clutter Reduction



Dealing with Clutter

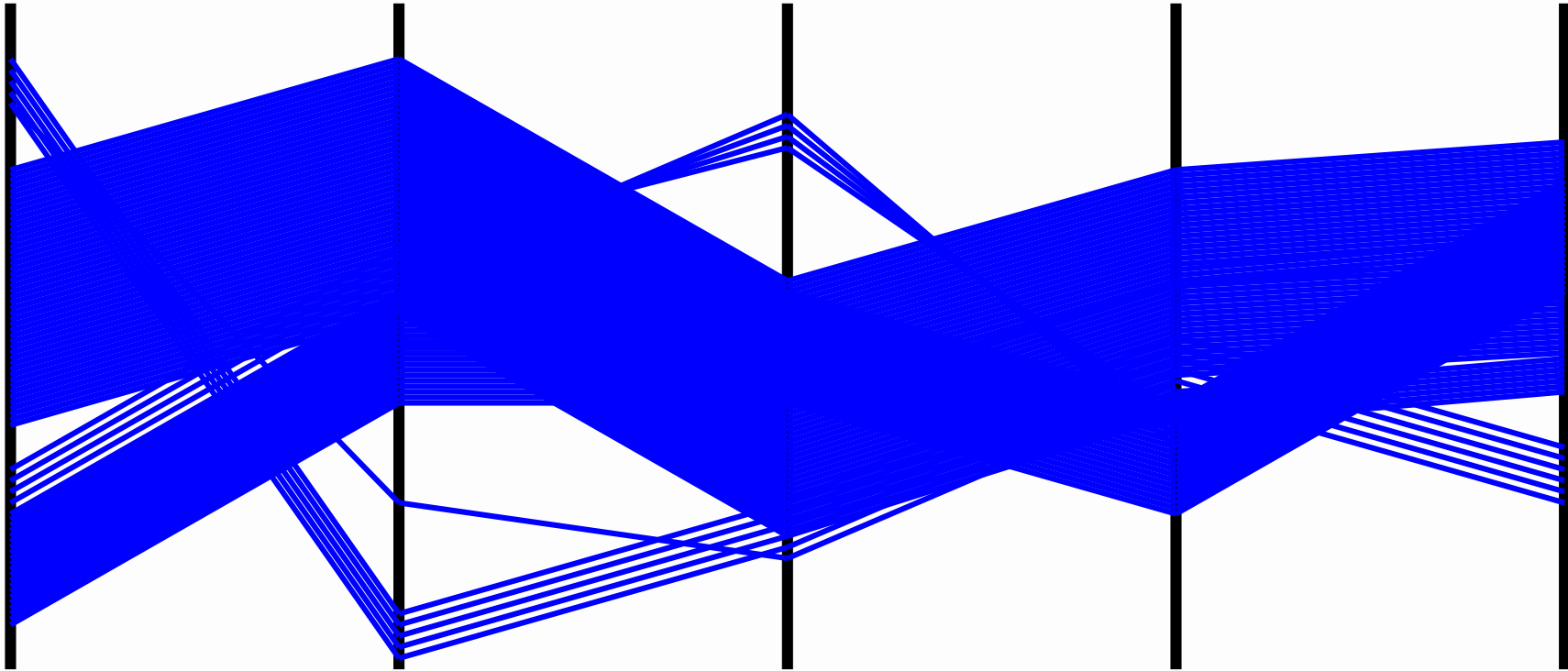
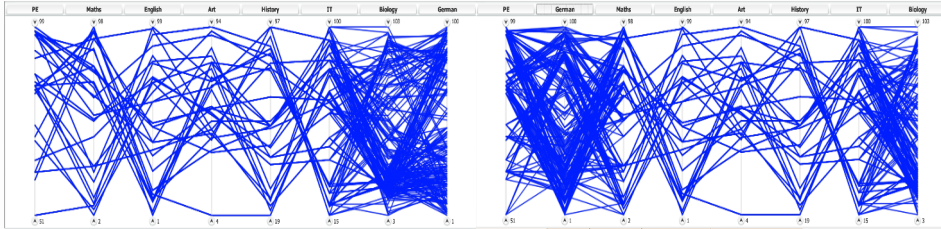
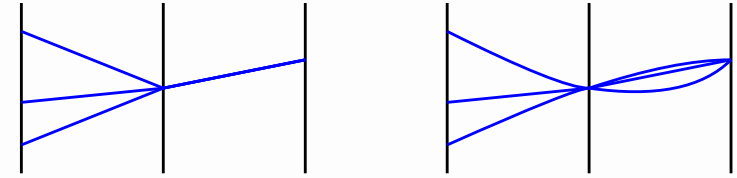


Image drawn by Romana Gruber.

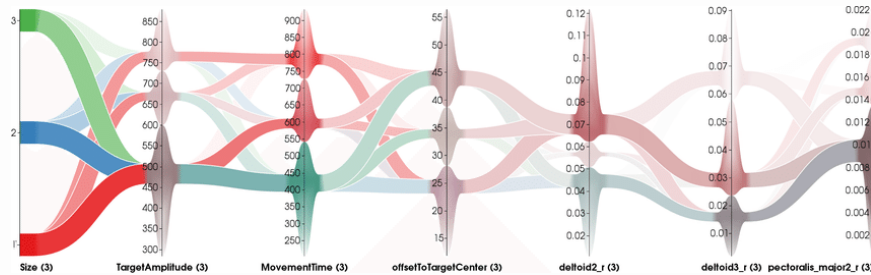
Clutter Reduction Techniques



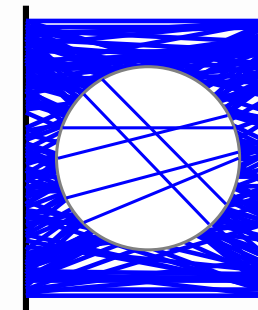
Axes Reordering¹



Using Curves²



Edge-bundling³



Sampling⁴

¹ Screenshot by Romana Gruber from High-D www.high-d.com

² Redrawn by Romana Gruber from the original by Graham, et al.; *Using Curves to Enhance Parallel Coordinate Visualisations*; Proc. 7th International Conference on Information Visualization (IV 2003), London, UK. 16-18 Jul 2003, pages 10–16. doi:10.1109/IV.2003.1217950

³ Extracted from Palmas et al.; *An Edge-Bundling Layout for Interactive Parallel Coordinates*; Proc. IEEE Pacific Visualization Symposium (PacificVis 2014), Yokohama, Japan. 04-07 Mar 2014, pages 57-64. doi:10.1109/PacificVis.2014.40

⁴ Redrawn by Romana Gruber from the original by Ellis et al. [2006], *Enabling Automatic Clutter Reduction in Parallel Coordinate Plots*, IEEE transactions on visualization and computer graphics. 12. 717-23. doi:10.1109/TVCG.2006.138

Variants and Extensions



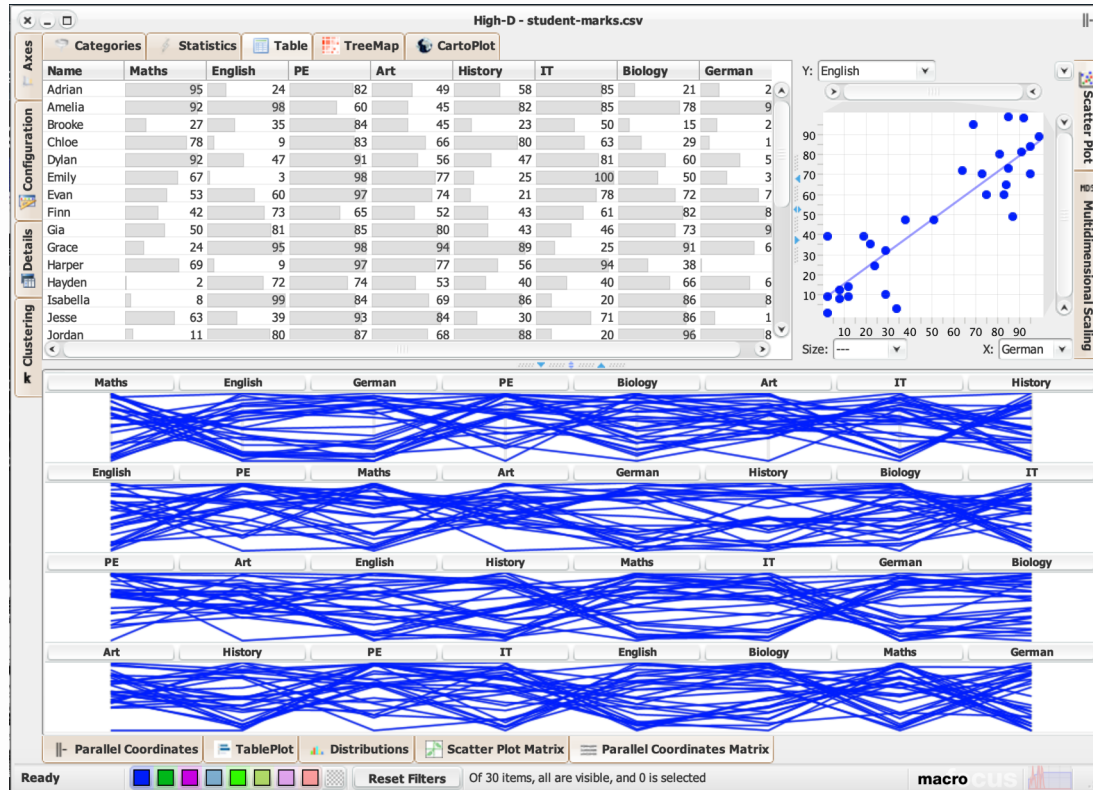
Grand Tour

- Daniel Asimov [1985]¹
- Edward Wegman [1996]²
- Tour through pairwise combinations of axes, to spot visual patterns.
- Most “interesting” pairs first.

¹ Asimov, Daniel [1985]. *The Grand Tour: A Tool for Viewing Multidimensional Data*. SIAM Journal on Scientific and Statistical Computing, 6(1), pages 128-143, doi: 10.1137/0906011

² Wegman, Edward and Luo, Qiang [1996]. *High Dimensional Clustering Using Parallel Coordinates and the Grand Tour*. Comput Sci Stat. 28, doi: 10.1007/978-3-642-59051-1_10

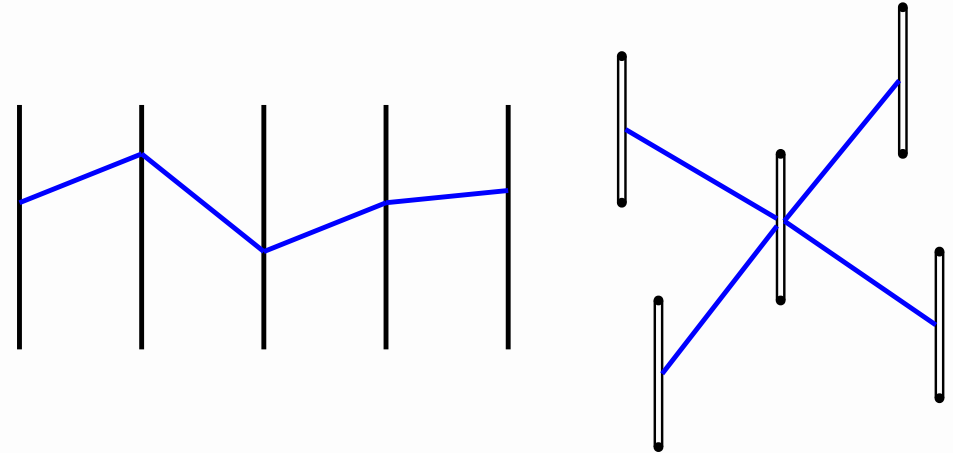
Parallel Coordinates Matrix



Screenshot by Romana Gruber from High-D www.high-d.com

3D Parallel Coordinates

- Axes are mapped onto a cylinder.
- One dimension in center.
- Multiple neighbours.



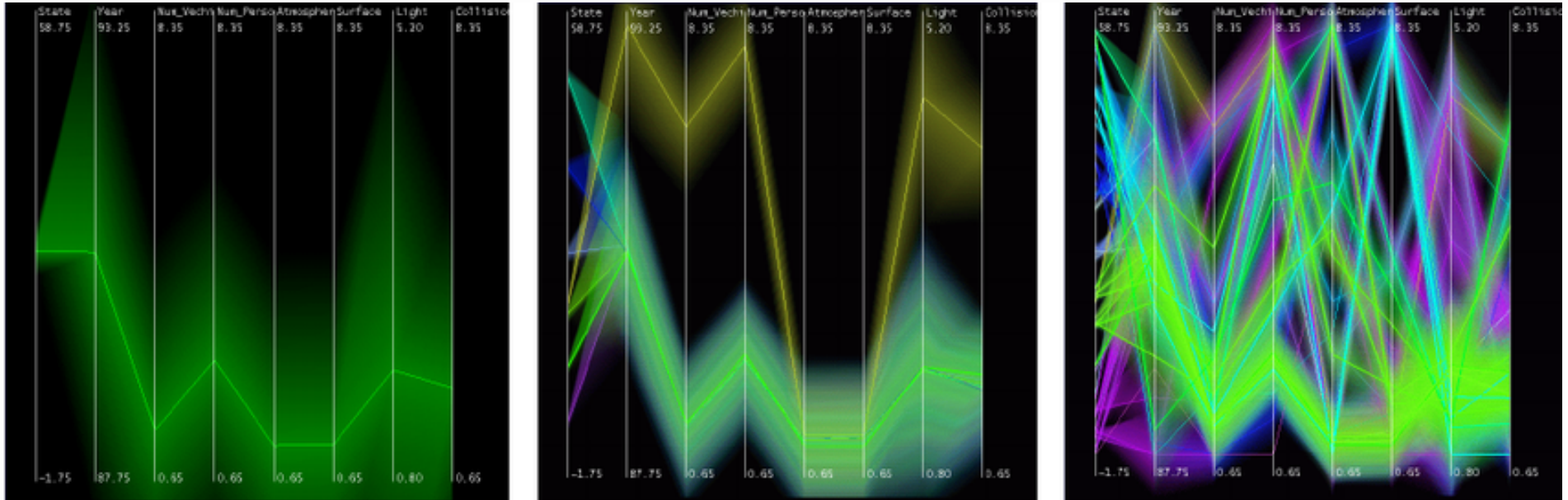
Redrawn by Romana Gruber from the original by Johansson et al. [2005]¹

¹ Johansson, Jimmy, Matthew Cooper, and Mikael Jern [2005]. *3-dimensional display for clustered multi-relational parallel coordinates*. 9th International Conference on Information Visualisation (IV 2005), London, UK. 06-08 Jul 2005, pages 188–193. doi:10.1109/IV.2005.1

Hierarchical Parallel Coordinates

- Hierarchical clustering of records.
- Colour-coding of clusters.
- Navigation of cluster hierarchy.

Hierarchical Parallel Coordinates



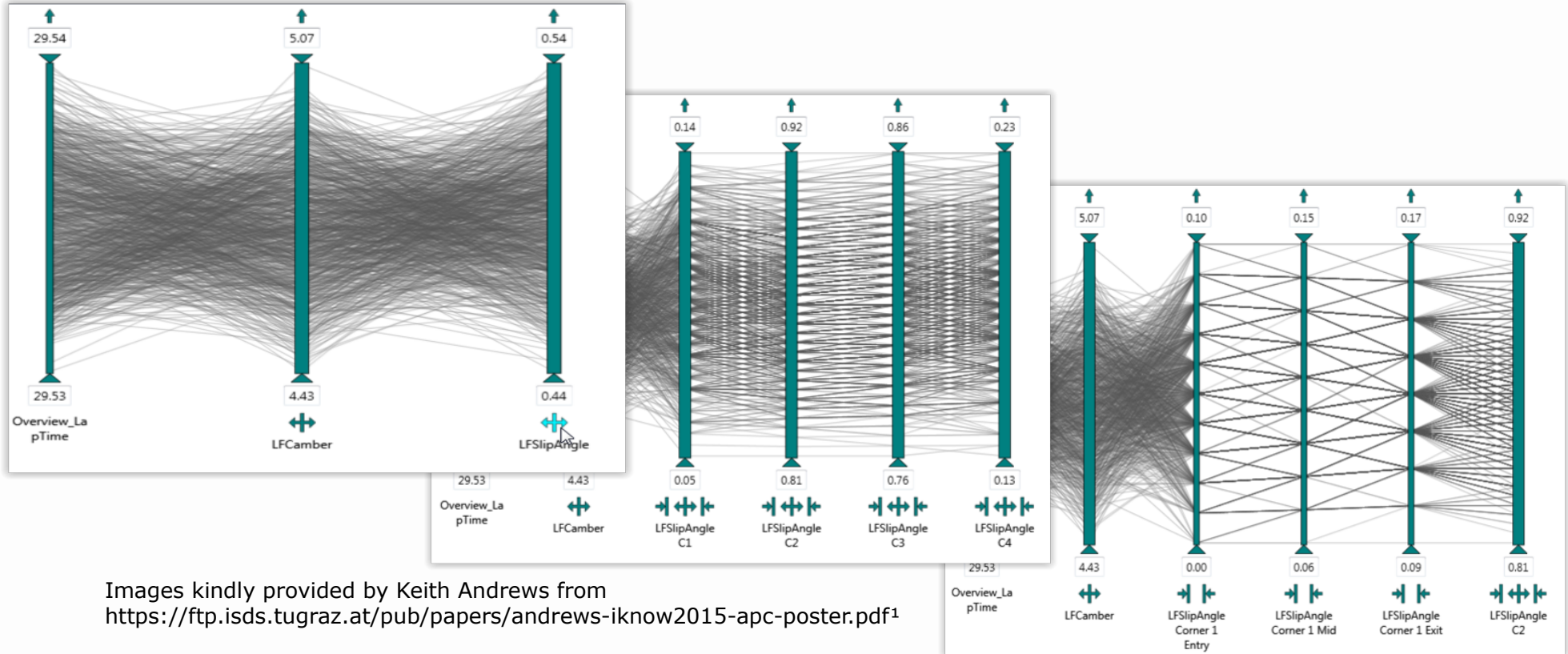
These images shows a dataset of 230.000 records at different level of details. The first image shows a cut across the root node. The middle image shows an intermediate cut and the last image shows the cut chaining all the leaf nodes.¹

¹ Extracted from Fua et al. [1999]; *Hierarchical parallel coordinates for exploration of large datasets*; Proc. Visualization 1999, San Francisco, CA, USA. 24-29 Oct 1999, pages 43–508. doi:10.1109/VISUAL.1999.809866

Aggregated Parallel Coordinates

- Dimensions can have inner hierarchy.
- Initially show aggregation.
- Dynamically expand and collapse dimension as needed.

Aggregated Parallel Coordinates



Images kindly provided by Keith Andrews from
<https://ftp.isds.tugraz.at/pub/papers/andrews-iknow2015-apc-poster.pdf>¹

¹Keith Andrews, Majda Osmić, and Gerhard Schagerl [2015]. *Aggregated Parallel Coordinates: Integrating Hierarchical Dimensions into Parallel Coordinates Visualisations*. Proc. 15th International Conference on Knowledge Technologies and Data-Driven Business. Article 37, Pages 1-4 doi: 10.1145/2809563.2809588

Questions?



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