EuroVis 2017
M. Meyer, S. Takahashi, A. Vilanova
(Guest Editors)

Volume 36 (2017), Number 3
STAR – State of The Art Report

Survey of Surveys (SoS) - Mapping The Landscape of Survey Papers in Information Visualisation – SUPPLEMENTARY MATERIAL

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Author biographies

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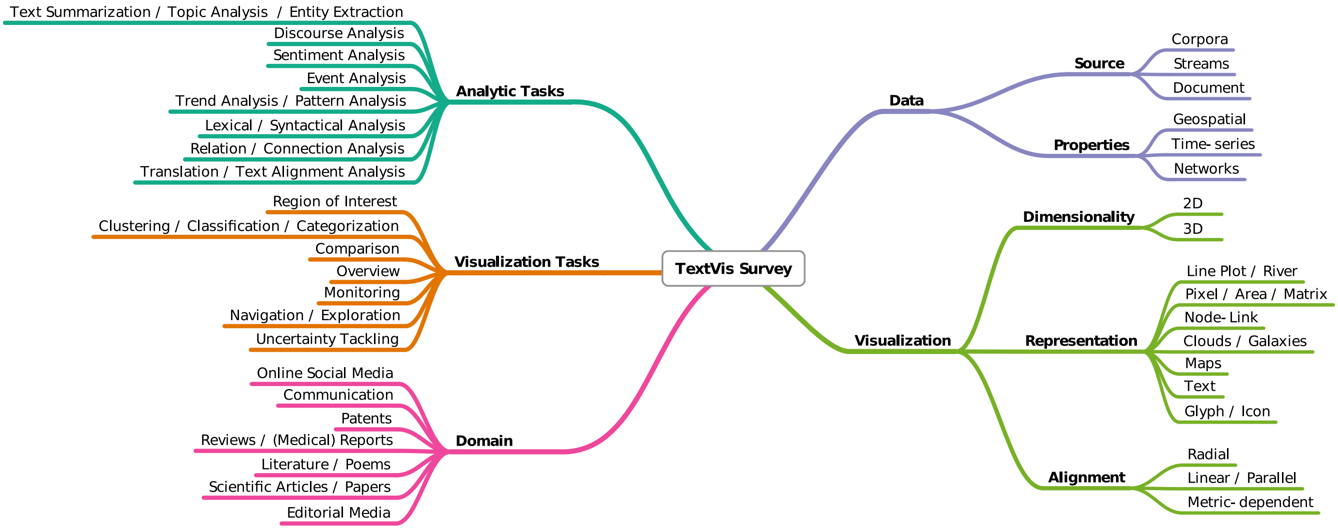

Figure 1: *Kucher et al. present a hierarchical taxonomy used to classify text visualisation techniques. Courtesy of Kucher et al. [KK15]*

	Elem. lookup & comparison	Elem. relation seeking	Synoptic (Patterns)	Synoptic (Temporal patterns)
Text	8	7	20	5 (6)
Citations	2	7	9	10
Authors	2	1	2	7
Metadata	2	5	8	2 (3)

a Approaches for data types: *Text*, *Citations*, *Authors*, and *Metadata* (supporting *Elementary* and *Descriptive Synoptic* tasks).

	Aggregation	Labelling	Composition	Multiple views	Tight integration
Multiple/Connectional	11 (6)	4 (3)	3 (1)	12 (3)	5 (2)

b Approaches for data type: *Multiple* (supporting *Connection Discovery* tasks), by level of integration.

Figure 2: *Table a presents the distribution of papers for each single data category, whilst b contains the distribution papers which look at multiple data-types. Both tables distribute papers based on tasks. Numbers in parentheses are papers identified as a secondary classification. Image courtesy of Federico et al. [FHKM16]*

Data structure	Visualization	Type	Aggregation	Visual aggregate	Metadata visualized
multidimensional	scatterplot	O/L	hierarchical clustering	points [19, 74]	average
multidimensional	scatterplot	O/L	hierarchical clustering	boxes [82]	extents (axis-aligned), average
multidimensional	scatterplot	O/L	space-filling subdivision	boxes [80]	extents (axis-aligned), average
multidimensional	scatterplot	O/L	hierarchical clustering	hulls [4]	extents (convex hull), average
multidimensional	scatterplot	O/L	hierarchical clustering	blobs [6, 15, 20, 44]	extents
multidimensional	parallel coordinates	O/L	hierarchical clustering	lines [75]	average
multidimensional	parallel coordinates	O/L	hierarchical clustering	bands [34, 82]	extents, average
multidimensional	parallel coordinates	O/L	hierarchical clustering	color histograms [29, 30]	distribution, extents
multidimensional	parallel coordinates	O/L	hierarchical clustering	beads [4]	distribution, extents
multidimensional	starglyphs	O/L	hierarchical clustering	lines [75]	average
multidimensional	starglyphs	O/L	hierarchical clustering	bands [34, 82]	extents, average
multidimensional	starglyphs	O/L	hierarchical clustering	color histograms [29, 30]	distribution, extents, average
tree	treemap	S/F	existing tree hierarchy	treemap nodes [63]	extents, average
tree	node-link diagram	O/L	existing tree hierarchy	thumbnails [17, 59]	extents, count, depth
graph	node-link diagram	O/L	hierarchical clustering	metanodes [2, 8]	extents, average
graph	node-link diagram	O/L	—	edge bundles [47]	link extents, average
graph	node-link diagram	O/L	data cube aggregation	metanodes [78]	node and link counts
graph	adjacency matrix	S/F	recursive edge merging	edge blocks [1, 28]	distribution, average
spatial	2D/3D geometric	—	recursive data merging	quad/octree blocks [4]	extents, average

Figure 3: *A hierarchical classification of aggregation strategies for Information Visualisation techniques. Image courtesy of Elmqvist and Fekete [EF10].*

	Technique	Element-related Tasks							Set-related Tasks														Attribute-related Tasks					Scalability	
		A1	A2	A3	A4	A5	A6	A7	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	C1	C2	C3	C4	C5	in # of sets	in # of elements
Euler-based	Euler diagrams	●	●	●	○			○	○	●	●	●	●	○	●	●	○	●	○	○	n/a	○	○	○	○			about 10	hundreds / ∞
	ComED	●	●	●	○			●	○	●	○	○	○	●	○	○			○	○	●							10 to 20	hundreds
	DupED	●	○	○	○			●	●	●	●	●	○			○			○	○	●							about 10	tens
Overlays	BubbleSets	●	●	○	○			●	○	○	○	○	○	○		○	○			○	○		○	○				about 10	tens
	LineSets	●	●	○	○			●	○					○		○				○	○		○					10 to 100	hundreds
	Kelp diagrams	●	●	○	○			●	○	○	○	○	○	○	○	○	○		○	○	○		○	○				about 10	tens
	Colored glyphs	○	●	○	○				○				○	○		○				○	○					○		10 to 20	hundreds
	Icon lists		●					●												○			●			○	○	tens	large list
Node-link	Linked lists	☞	☞	☞	☞	☞	☞	☞	●												○		●	○	○	☞	☞	hundreds	hundreds
	Anchored maps	○	○		○		○		●				○		○	○		○		●	☞		☞					20 to 50	hundreds
	PivotPaths	☞	☞		☞		☞		●					○						☞	●		☞					50 to 100	hundreds
Matrix	ConSet	●	●	○		☞	☞	☞	●			☞	☞	○							☞	☞	●					about 100	about 100
	PixelLayer	●	☞	☞					●			☞	☞									☞	☞					tens	hundreds
	Frequency grids	●	●	○	○	○	○	○	○	●			●	●	●	●	○	●		●	●		☞					3 to 5	hundreds
	Overlap matrix								●			●	●			●	●	○	○	○	●							about 100	not applicable
	KMVQL	☞		☞					●			○	○	○	●	●					●				●			4 to 6	not applicable
Aggregation	Mosaic displays			☞					●			○	○	○	●	●		○		○	●				●			up to 4 sets	large (agg.)
	Double-Decker	○		●					●	☞	☞		●	○	●	●		●		●	●			●	●			4 to 6	large (agg)
	Sets'o'grams	☞		☞	●	☞	●		●				☞	○	☞	☞				○						☞	☞	50 to 100	large (agg.)
	Radial Sets	☞		☞	●	☞	●		●			●	●	●	☞	☞	●	●	●	●	●	☞		☞	●	☞	☞	20 to 30	large (agg.)
Scatter	Scatter view								○										○									hundreds	not applicable
	Cluster view								○										●									hundreds	not applicable

● Task is supported

○ Task is partially supported

☞ Task requires interaction

A1: Find/Select elements of a specific set
A2: Find sets containing a specific element
A3: Find/Select elements by set memberships
A4: Find/Select elements by their degrees
A5: Filter out elements by set memberships
A6: Filter out elements by their degrees
A7: Create a set out of certain elements

B1: Find the number of sets in a family
B2/3: Inclusion relations / hierarchies
B4/5: Exclusion / intersection relations
B6: Identify intersections between k sets
B7: identify sets involved in an overlap
B8: Identify intersections of a set

B9: Identify the set with largest / smallest number of pair-wise set intersections
B10: Analyze & compare cardinalities
B11: Analyze & compare set similarities
B12: Analyze & compare set exclusiveness
B13: Highlight specific sets, subsets, etc.
B14: create a set by set-theoretic operation

C1: Find an element's attribute values
C2: Attribute distribution in a set / subset
C3: Compare attribute values between subsets
C4: Set memberships for specific attr. values
C5: Create a set of elements by attributes

Figure 4: *A 1-N taxonomy of set-types data showing a comparision between tasks and techniques. Courtesy of Alsallakh et al. [AMA*14]*

Paper Title	Visualization technique			What is measured						Where it is measured		Purpose					Inter-act-ion
	SP	PC	other	clustering	correlation	outliers	complex patterns	image quality	feature pres.	data (space)	image (space)	projection	ordering	abstraction	visual mapping	view optimization	
A Projection Pursuit Algorithm for Exploratory Data Analysis - Friedman & Tukey [21]	SP			clustering						data		projection					
A Rank-by-Feature Framework for Unsupervised Multidimensional Data Exploration Using Low Dimensional Projections-Seo & Shneiderman[44]	SP		histogram, matrix, list	clustering	correlation	outliers	complex patterns			data		projection					S
Finding and Visualizing Relevant Subspaces for Clustering High-Dimensional Astronomical Data Using Connected Morphological Operators**[20]	SP		histogram	clustering							image	projection					T
Graph-Theoretic Scagnostics - Wilkinson et al. [54]	SP			clustering		outliers	complex patterns				image	projection					
Selecting good views of high-dimensional data using class consistency - Sips et al. [46]	SP								class pres.	data		projection					T
Coordinating computational and visual approaches for interactive feature selection and multivariate clustering - Guo [22]			matrix		correlation					data		projection	ordering				
Exploring High-D Spaces with Multiform Matrices and Small Multiples - MacEachern et al. [35]			pixel based vis., matrix, small multiples		correlation					data		projection	ordering				
Improving the Visual Analysis of High-Dimensional Datasets Using Quality Measures - Albuquerque et al. [4]			jigsaw map, radvis, table lens	clustering	correlation	outliers				data	image	projection	ordering		visual mapping		
Interactive Hierarchical Dimension Ordering, Spacing and Filtering for Exploration of High Dimensional Datasets - Yang et al. [58]		PC	histogram, star glyphs		correlation					data		projection	ordering			view optimization	S, T
Interactive Dimensionality Reduction Through User-defined Combinations of Quality Metrics - Johansson & Johansson [30]		PC		clustering	correlation	outliers				data		projection	ordering				S, T
Pargnostics: Image-Space Metrics for Parallel Coordinates - Dasgupta & Kosara [15]		PC		clustering	correlation			image quality			image	projection	ordering				S
Combining automated analysis and visualization techniques for effective exploration of high-dimensional data - Tatu et al. [48]	SP	PC		clustering	correlation		complex patterns		class pres.	data	image	projection	ordering				
High-Dimensional Visual Analytics: Interactive Exploration Guided by Pairwise Views of Point Distributions - Wilkinson et al. [55]	SP	PC		clustering		outliers	complex patterns				image	projection	ordering				
Clutter Reduction in Multi-Dimensional Data Visualization Using Dimension Reordering - Peng et al. [39]	SP	PC	star glyphs, dim. stacking		correlation	outliers		image quality		data	image		ordering				
Similarity Clustering of Dimensions for an Enhanced Visualization of Multidimensional Data - Ankerst et al. [5]		PC	recursive pattern, circle segments		correlation					data			ordering				
Measuring Data Abstraction Quality in Multiresolution Visualizations - Cui et al. [14]	SP	PC	histogram						feature pres.	data				abstraction			T
Quality Metrics for 2D Scatterplot Graphics: Automatically Reducing Visual Clutter - Bertini & Santucci [9]	SP			clustering					feature pres.	data	image			abstraction			
A Screen Space Quality Method for Data Abstraction - Johansson & Cooper [28]		PC							feature pres.		image			sampling			
Enabling Automatic Clutter Reduction in Parallel Coordinate Plots - Ellis & Dix [12]		PC						image quality			image			sampling			T
Pixnostics: Towards measuring the value of visualization - Schneidewind et al. [42]			jigsaw map, pixel bar chart		correlation		complex patterns			data	image				visual mapping		

Figure 5: *A 1-N classification created to systemise quality metrics factors for high-dimensional data. Courtesy of Bertini et al. [BTK11]*

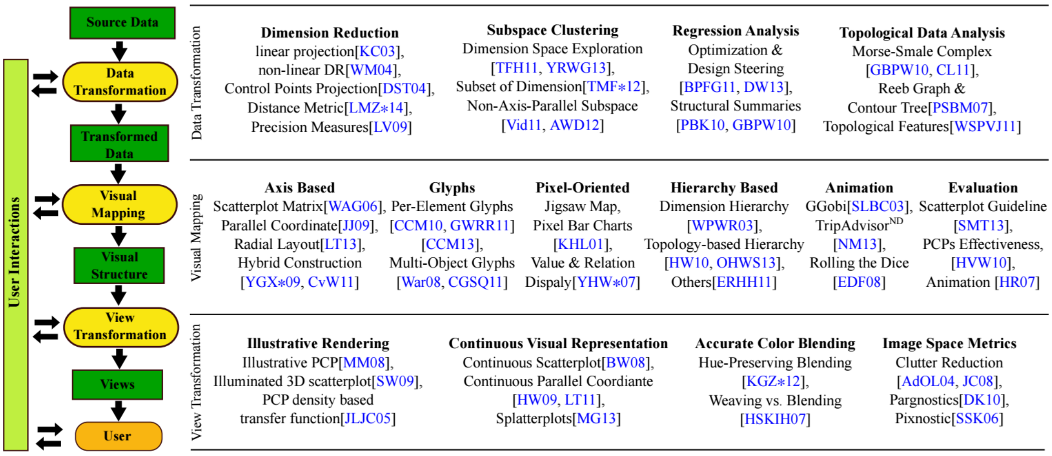

Figure 6: *A 2D classification designed using the information visualisation pipeline for the taxonomy of high dimensional data. Courtesy of Liu et al. [LMW*15]*

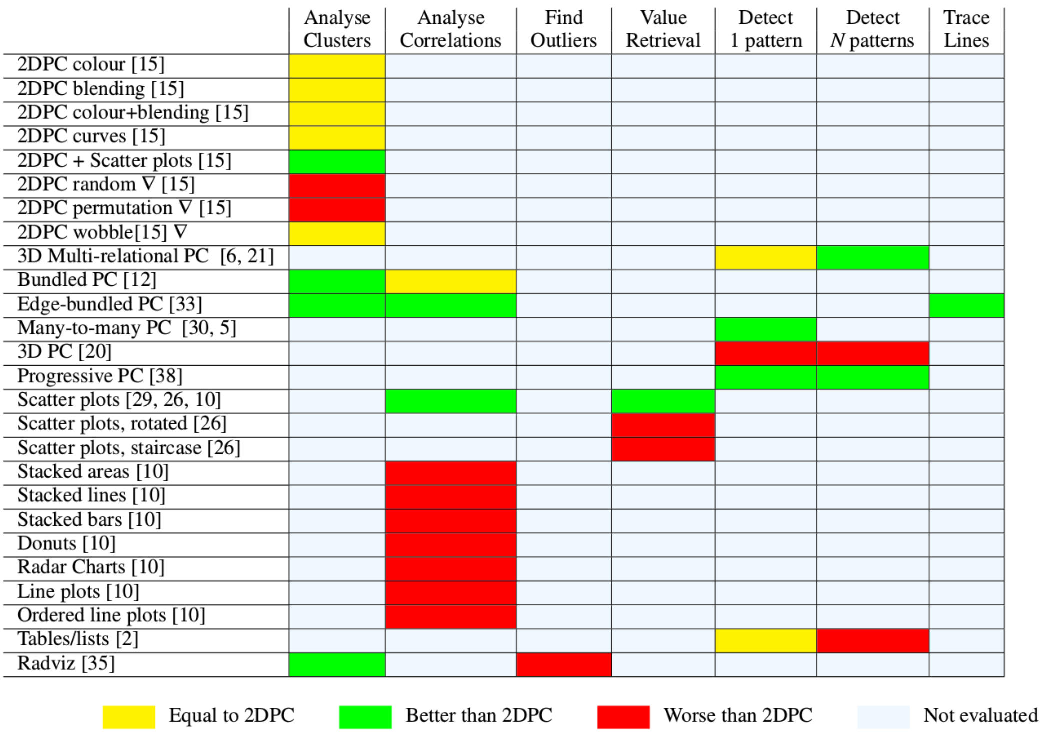

Figure 7: *A 1-N classification of 26 techniques performed in relation to standard 2D parallel coordinates. Yellow colour indicates no significant difference in performance. Green colour means that the technique outperforms 2DPC for the specific task. Red colour shows the technique performs worse than 2DPC. Light blue colour reveals no evaluation has been found in the literature. ∇ denotes that the technique is based on animation. Courtesy of Johansson and Forsell [JF16] .*

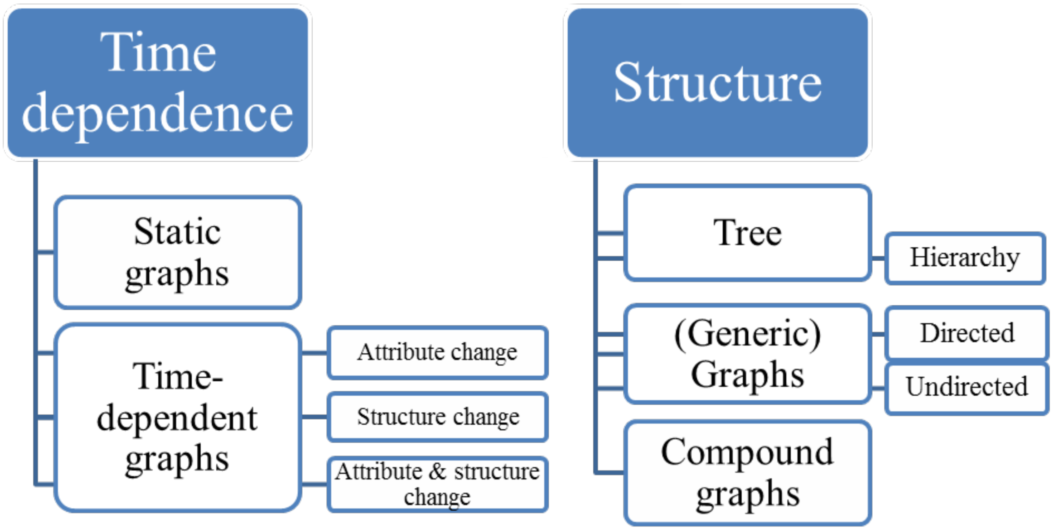

Figure 8: *Classification of graphs with respect to the temporal or structural characteristics. Courtesy of Von Landesberger et al. [VLKS*11]*
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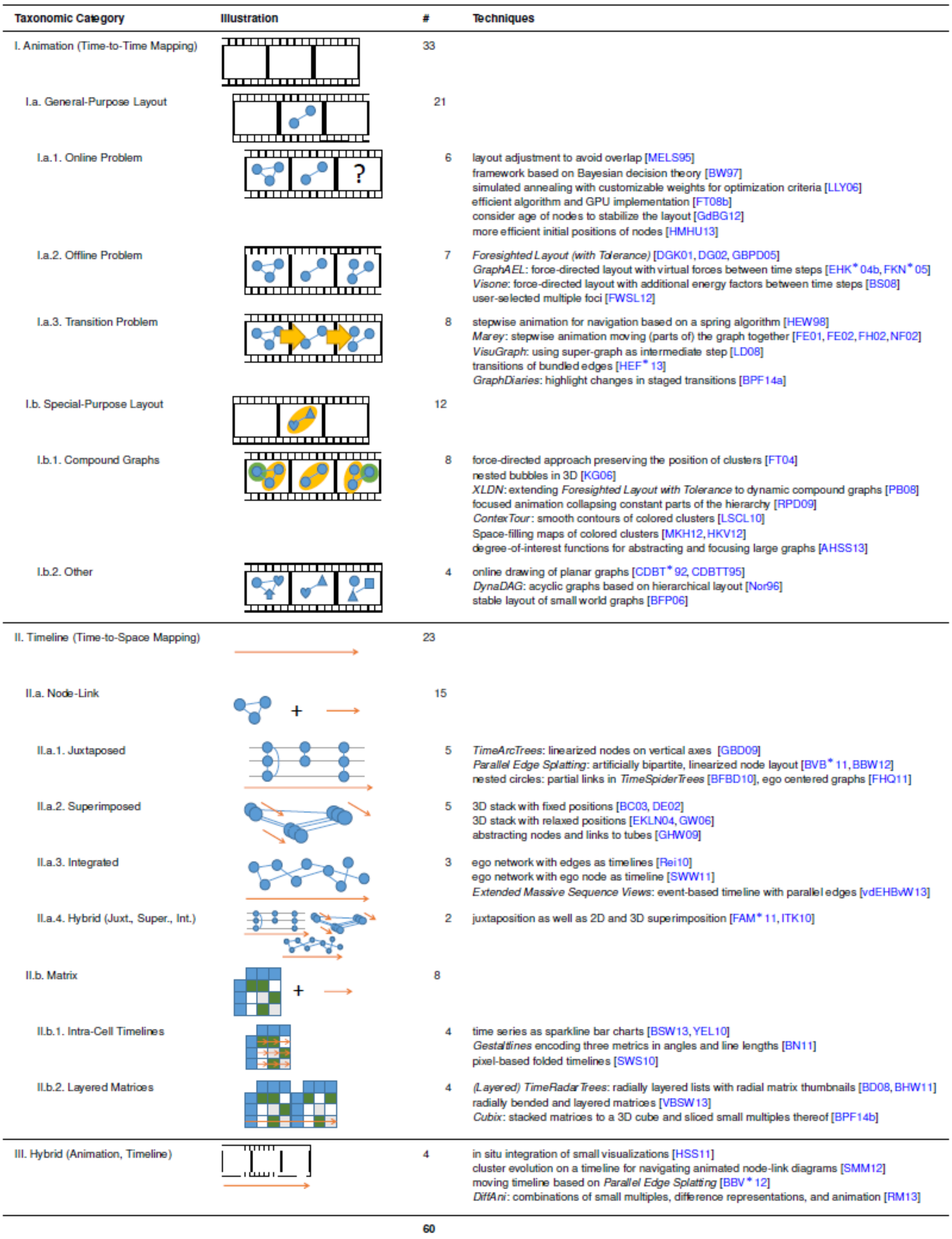
	Data	Properties	Data Types N	C	T	Representative Datasets
Trajectory	Shipping trajectories	Time	✓			Vessel traffic data [4]
		Location	✓			
		Ship type		✓		
		Destination			✓	
		Velocity	✓			
	Aircraft trajectories	Location	✓			Flight in France [5], Europe 24 [6]
		Flight level	✓			
		Time	✓			
		Velocity	✓			
		Aircraft ID			✓	
	Automobile trajectories	Time	✓			Taxi GPS data of Beijing [7], [8], Shenzhen [9], Shanghai [10], [11], [12], San Francisco [13], New York City [14], Wuhan [15], [16], and Sweden [17]; Traffic monitoring cells data in Nanjing [18]; GPS data in Louisiana [19]
		Location	✓			
		Direction		✓		
		Change of direction		✓		
		Velocity	✓			
		Acceleration	✓			
		Pick-up/drop-off		✓		
	Train/Metro trajectories	Location	✓			Train data in France [20], Boston's metro data [21]
		Time	✓			
		Station			✓	
	Pedestrian trajectories	Location	✓			Human mobility traces [22]
		Time	✓			
		Velocity	✓			
	Mixed trajectories	Object type		✓		Intersection count [23]
		Position	✓			
		Velocity	✓			
		Direction		✓		
		Time	✓			
Incident	Tunnel incident	Stateful events		✓		Incident detection system (IDS) data [24]
		Stateless events	✓			
		Video				
	Highway incident	Location	✓			Maryland highway & traffic information [25], Traffic Management Centers Data [26], traffic incident in Singapore [27]
		Time of date	✓			
		Weather conditions		✓		
		Vehicle involved			✓	
		Incident type		✓		
	Metro incident	Time	✓			Metro smartcard records in Shenzhen [28], urban rail transit system data [29]
		Station			✓	
		Check in/out		✓		

Figure 9: *The taxonomy displays different data types with their potential properties. These are then categorized into three data types: Numerical; Categorical; or Textual. Examples of related literature are also given. Courtesy of Chen et al. [CGW15]*



Taxonomic Category	Illustration	#	Techniques
I. Animation (Time-to-Time Mapping)		33	
I.a. General-Purpose Layout		21	
I.a.1. Online Problem		6	layout adjustment to avoid overlap [MELS95] framework based on Bayesian decision theory [BW97] simulated annealing with customizable weights for optimization criteria [LLY06] efficient algorithm and GPU implementation [FT08b] consider age of nodes to stabilize the layout [GdBG12] more efficient initial positions of nodes [HMHU13]
I.a.2. Offline Problem		7	*Foresighted Layout (with Tolerance)* [DGK01, DG02, GBPD05] *GraphAEL*: force-directed layout with virtual forces between time steps [EHK*04b, FKN*05] *Visone*: force-directed layout with additional energy factors between time steps [BS08] user-selected multiple foci [FWSL12]
I.a.3. Transition Problem		8	stepwise animation for navigation based on a spring algorithm [HEW98] *Marey*: stepwise animation moving (parts of) the graph together [FE01, FE02, FH02, NF02] *VisuGraph*: using super-graph as intermediate step [LD08] transitions of bundled edges [HEF*13] *GraphDiaries*: highlight changes in staged transitions [BPF14a]
I.b. Special-Purpose Layout		12	
I.b.1. Compound Graphs		8	force-directed approach preserving the position of clusters [FT04] nested bubbles in 3D [KG06] *XLDN*: extending *Foresighted Layout with Tolerance* to dynamic compound graphs [PB08] focused animation collapsing constant parts of the hierarchy [RPD09] *ContexTour*: smooth contours of colored clusters [LSCL10] Space-filling maps of colored clusters [MKH12, HKV12] degree-of-interest functions for abstracting and focusing large graphs [AHSS13]
I.b.2. Other		4	online drawing of planar graphs [CDBT*92, CDBTT95] *DynaDAG*: acyclic graphs based on hierarchical layout [Nor96] stable layout of small world graphs [BFP06]
II. Timeline (Time-to-Space Mapping)		23	
II.a. Node-Link		15	
II.a.1. Juxtaposed		5	*TimeArcTrees*: linearized nodes on vertical axes [GBD09] *Parallel Edge Splatting*: artificially bipartite, linearized node layout [BVB*11, BBW12] nested circles: partial links in *TimeSpiderTrees* [BFBD10], ego centered graphs [FHQ11]
II.a.2. Superimposed		5	3D stack with fixed positions [BC03, DE02] 3D stack with relaxed positions [EKLN04, GW06] abstracting nodes and links to tubes [GHW09]
II.a.3. Integrated		3	ego network with edges as timelines [Rei10] ego network with ego node as timeline [SWW11] *Extended Massive Sequence Views*: event-based timeline with parallel edges [vdEHBvW13]
II.a.4. Hybrid (Juxt., Super., Int.)		2	juxtaposition as well as 2D and 3D superimposition [FAM*11, ITK10]
II.b. Matrix		8	
II.b.1. Intra-Cell Timelines		4	time series as sparkline bar charts [BSW13, YEL10] *Gestaltlines* encoding three metrics in angles and line lengths [BN11] pixel-based folded timelines [SWS10]
II.b.2. Layered Matrices		4	*(Layered) TimeRadarTrees*: radially layered lists with radial matrix thumbnails [BD08, BHW11] radially bended and layered matrices [VBSW13] *Cubix*: stacked matrices to a 3D cube and sliced small multiples thereof [BPF14b]
III. Hybrid (Animation, Timeline)		4	in situ integration of small visualizations [HSS11] cluster evolution on a timeline for navigating animated node-link diagrams [SMM12] moving timeline based on *Parallel Edge Splatting* [BBV*12] *DiffAni*: combinations of small multiples, difference representations, and animation [RM13]
		60	

Figure 10: *Hierarchical taxonomy of dynamic graph visualisation courtesy of Beck et al. [BBDW14]*

		Graph elements (nodes, graph objects)		
		Both constraints	**One constraint, one target**	**Both are targets**
Time points	**Both constraints**	**Find connections between elements (comparison)** (How) is graph element $\mathbf{g_1}$ connected to graph element $\mathbf{g_2}$ at the given time, **t**? $?\lambda: (\mathbf{g_1}, \mathbf{t})\ \lambda\ (\mathbf{g_2}, \mathbf{t})$	**Find elements connected in the given way (relation seeking)** Find the graph element(s) to which graph element $\mathbf{g_1}$ is connected in the given way at time **t**: $?\ g_2 : (\mathbf{g_1}, \mathbf{t}) \wedge (g_2, \mathbf{t})$	**Find elements connected in the given way (relation seeking)** Find graph objects which are connected in the given way at the given time: $?g_1, g_2 : (g_1, \mathbf{t}) \wedge (g_2, \mathbf{t})$
	Both targets	**Hybrid** Find the time points at which two given graph objects were connected in the given way: $?\ t : (\mathbf{g_1}, t) \wedge (\mathbf{g_2}, t)$	**Find elements connected in the given way (relation seeking)** Find the graph element(s) to which graph element $\mathbf{g_1}$ is connected and the time(s) at which the connection(s) occur: $?\ g_2, t : (\mathbf{g_1}, t) \wedge (g_2, t)$	**Find elements connected in the given way (relation seeking)** Find graph objects (and their associated time points) at any time that are connected in the given way: $?\ g_1, g_2, t : (g_1, t) \wedge (g_2, t)$

Figure 11: *Classification of elementary structural task variations. Courtesy of Kerracher et al. [KKC15]*

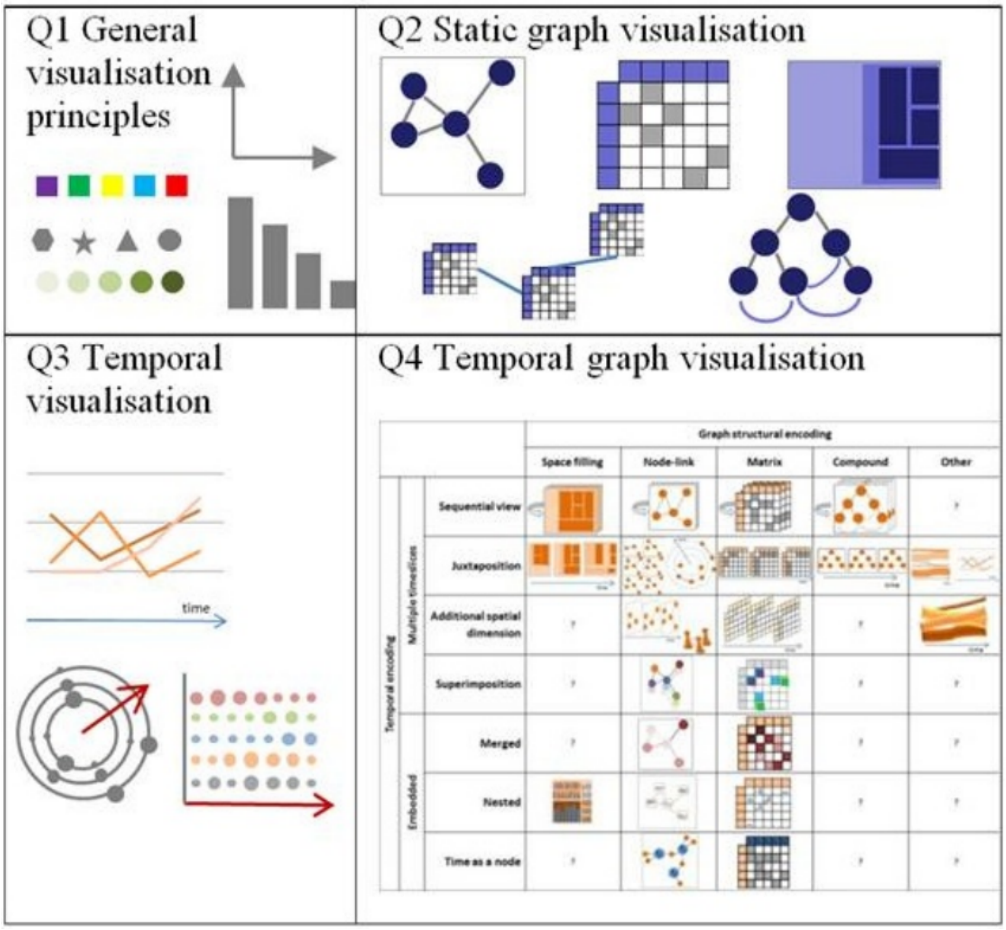


Figure 12: *Research areas and techniques associated with data items by quadrant. Courtesy of Kerracher et al. [KKCG15]*

Figure 13: *Taxonomy presented by Behrisch et al. classifying different matrices reordering algorithms [BBR*16]*

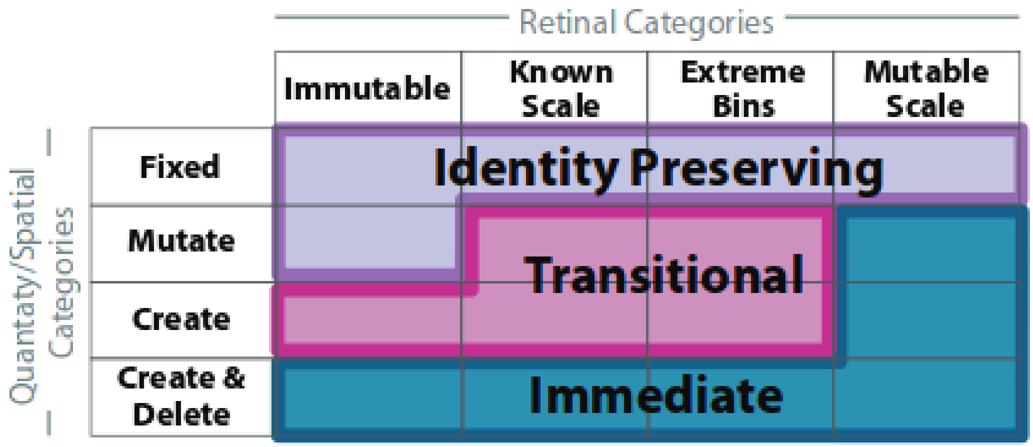


Figure 14: *A matrix created by Cottam et al. to classify different dynamic visualisation techniques [CLW12]*

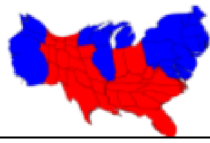
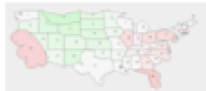
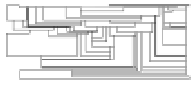
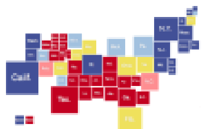
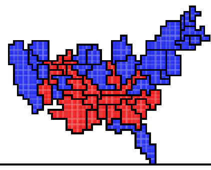
Type	Statistics	Contiguity	Geography	Topology	Example
Diffusion-based cartograms [GN04]	Almost accurate	Contiguous	Distorted	Topology-preserving	
Circular-arc cartograms [KKN13]	Not Accurate	Contiguous	Shape mostly preserved	Topology-preserving	
Optimal rubber sheet method [Sun13b]	Almost accurate	Contiguous	Distorted	Topology-preserving	
Fast, free-form rubber-sheet method [Sun13a]	Almost accurate	Contiguous	Distorted	Topology-preserving	
T-shape cartograms [ABF*13]	Accurate	Contiguous	Shape not preserved	Topology-preserving	
Non-contiguous cartograms [Ols76]	Accurate	Not contiguous	Shape preserved	Topology not preserved	
Demers cartograms [BDC02] (figure from [NYT12])	Accurate	Not contiguous	Shape not preserved (squares)	Topology not preserved	
Mosaic cartograms [CBC*15]	Not accurate	Contiguous	Shape mostly preserved	Topology-preserving	
Table cartograms [EFK*13]	Accurate	Contiguous	Shape not preserved	Topology not preserved	

Figure 15: *A 2D systematic overview of different types of cartograms, displayed with their categorisations. Courtesy of Nusrat and Kobourov [NK16].*

Technique	Visualization A	Visualization B	Spatial Relation	Data Relation
ComVis [24] (Figure 2)	any	any	juxtapose	none
Improvise [39] (Figure 3)	any	any	juxtapose	none
Jigsaw [36]	any	any	juxtapose	none
Snap-Together [30]	any	any	juxtapose	none
semantic substrates [34] (Figure 4)	node-link	node-link	juxtapose	item-item
VisLink [11] (Figure 5)	radial graph	node-link	juxtapose	item-item
Napoleon's March on Moscow [37]	time line view	area visualization	juxtapose	item-item
Mapgets [38] (Figure 6)	map	text	superimpose	item-item
GeoSpace [22] (Figure 7)	map	bar graph	superimpose	item-item
3D GIS [8]	map	glyphs	superimpose	item-item
Scatter Plots in Parallel Coordinates [45] (Figure 8)	parallel coordinate	scatterplot	overload	item-dimension
Graph links on treemaps [14] (Figure 9)	treemap	node-link	overload	item-item
SparkClouds [21]	tag cloud	line graph	overload	item-item
ZAME [13] (Figure 10)	matrix	glyphs	nested	item-group
NodeTrix [17] (Figure 11)	node-link	matrix	nested	item-group
TimeMatrix [44]	matrix	glyphs	nested	item-group
GPUVis [25]	Scatterplot	glyphs	nested	item-group

Figure 16: *Classification of common composite visualisation techniques. Image courtesy of Javed and Elmqvist [JE12].*

Category	Performance Visualization Techniques	Example applications and studies
Simple visual structures	Pie charts, distribution, box plots, kiviat diagrams	ParaGraph [2], PET [20], SvPablo [16], VAMPIR [21], Devise [22], AIMS [9]
	Timeline views	Paje [23], AIMS [9], Devise [22], AerialVision [24], Paraver [25], SIEVE [14], Virtue [13], utilization and algorithm timeline views in [17]
	Information typologies	SHMAP [26], Vista [4], Voyeur [27], processor and network port display in [28], hierarchical display in [12]
	Information landscape	Triva [29], Cichild [30]
	Trees & networks	Paradyn [18], Cone Trees [31], Virtue [13], [32]
Composed visual structures	Single-axis composition	AIMS [9], Vista [4]
	Double-axis composition	Devise [22], AerialVision [24]
	Case composition	Triva [29]
Interactive visual structure	Interaction through controls (data input, data transformation, visual mapping definition, view operations)	Paje[23], data input, filtering, and view manipulation in [28] and [32]
	Interaction through images (magnifying lens, cascading displays, linking and brushing, direct manipulation of views and objects)	Virtue [13], Cone Trees [31], Devise [22], direct manipulation of the 3D cone and virtual threads in [32]
Focus + context visual structures	Macro-micro composite view	Microscopic profile in [4], PC-Histogram in [24]

Figure 17: *A classification of performance visualisation techniques courtesy of Gao et al. [GZR*11]*

Visualization System	Visualization Technique(s)	Data Source(s)	Number of Citations	
Host / Server Monitoring				
Erbacher et al. [4][5]	Glyph	Server Logs	106 | 7	
Tudumi [6]	3D Node Link	Server Logs	38	
NVisionIP [7,8]	Scatter Plot	NetFlows	145 | 20	Available Online
Portall [9]	Node Link	Packet Traces	21	
HoNe [10]	Node Link	Packet Traces	8	
Perlman et al. [11]	Node Link | Glyph	Packet Traces	5	
Radial Traffic [12]	Radial Panel	Packet Traces	23	
Mansmann et al. [13]	Node Link	Packet Traces	2	
Internal/External Monitoring				
VISUAL [14]	Scatter Plot | IP Matrix	Packet Traces	93	
VizFlowConnect [15]	Parallel Coordinates	NetFlows	111	Available Online
Erbacher et al. [16]	Radial Panel	Packet Traces	8	
TNV [17]	IP Matrix | Color Map	Packet Traces	48	Available Online
Port Activity				
Abdullah et al. [18]	Histogram	Packet Traces	30	
Cube of Doom [19]	3D Scatter Plot	Packet Traces	99	Available Online
PortVis [20]	Scatter Plot	NetFlows	112	
NetBytes Viewer [21]	3D Scatter Plot	NetFlows	7	
Existence Plots [22]	Scatter Plot	Packet Traces	3	
Attack Patterns				
Giardin [29]	Color Map	Packet Traces	60	
NIVA [30]	Node Link | Glyph	Intrusion Alerts	51	
Snort View [31]	Scatter Plot | Glyph	Intrusion Alerts	67	Available Online
IDGraphs [32]	Scatter Plot	NetFlows	29	
IP Matrix [33]	Scatter Plot | Color	Intrusion Alerts	21	
Visual Firewall [34]	Scatter Plot	Packet Traces	24	
IDS Rainstorm [35]	Scatter Plot	Intrusion Alerts	60	
Vizalert [36][37][38]	Radial Panel	Intrusion Alerts	38 | 35 | 29	
Rumint [39][40]	Parallel Coordinates	Packet Traces	15 | 35	Available Online
Ren et al. [41]	Flying Term	DNS Traces	10	
Xiao et al. [42]	Scatter Plot	Packet Traces	23	
Svision [43]	3D Scatter Plot	Packet Traces	9	
Mansmann et al. [44]	Treemap	Packet Traces	20	
SpiralView [45]	Radial Panel	Intrusion Alerts	5	
NFlowVis [46]	Treemap	NetFlows	17	
Avisa [49]	Radial Panel	Intrusion Alerts	2	
Routing Behavior				
BGPlay [50]	Node Link	BGP Traces	22	
Wong et al. [51]	Node Link	BGP Traces	9	
LinkRank [52]	Node Link	BGP Traces	16	
Teoh et al. [53][54][55]	Histogram | Node Link	BGP Traces	54 | 28 | 35	
BGP Eye [56]	Color Map	BGP Traces	8	

Figure 18: *Taxonomy of Security Visualisation Systems, divided into different use-cases. Created by Shiravi et al. [SSG12]*

Relations	Major Tasks	Design Choices: Visual Representation	Design Choices: Supplementary Visual Technique	Design Choices: Interaction Design	Pros	Cons
Entity Level	1. Show an entity 2. Show a group of entities 3. Show entity level relations (a single case or multiple cases) 4. Show single entity vs. groups of entities level relations (a single case or multiple cases) 5. Find relevant entities for a specific entity 6. Verify relations between some entities 7. Discriminate some entities from others 8. Mark important entities or relations	The Node-Link Diagram	1. Edge bundling 2. Use spatial distance (e.g. the force-directed layout) 3. Use spatial distance + hiding links 4. Color coding to separate nodes of different domains or selected and unselected nodes or links 5. Visual marks (e.g., shapes) to separate nodes and/or links	1. Select nodes/links 2. Highlight nodes/links 3. Drag nodes/links	1. An intuitive way to show either an entity or multiple entities and relations between entities 2. Customizable spatial layout for users 3. Links clearly show specific relations between entities	1. Entities are randomly placed in the space, so it may be difficult to find an entity if there are many entities 2. The number of links exerts much impact on the readability of the diagram 3. Without links, relations between entities cannot be identified easily 4. Color coding and visual marks are not efficient to visually separate domains
		A Simple Matrix	1. A single cell to represent Entity 2. A row or a column to represent Group 3. Use a heatmap	1. Select cells 2. Highlight cells 3. Extract a cell 4. Merge cells	Avoid visual clutters caused by too many links	1. Not as easy as node-link diagrams to perceive 2. Columns or rows rearrangement is the only way to change the layout
		Parallel Coordinates with Two Domains	1. Edge bundling 2. Using curved lines to indicate links	1. Select entities 2. Highlight polylines/entities 3. Brushing 4. Axes rearrangement 5. Entities reposition in axes	1. Place entities of the same group together 2. Relatively easy to find entities 3. Efficiently select multiple entities/polylines	1. The number of links exerts much impact on the readability of the diagram 2. Without links, relations between entities cannot be identified easily 3. Sometimes entity reposition (e.g., moving relevant entities to the top) is necessary to understand grouping
Group Level		Tree Visualizations	1. Icicle 2. Bubble trees 3. Treemaps	1. Select nodes/links 2. Highlight nodes/links 3. Path extraction	Clearly represent hierarchical relations	1. Not all Groups are hierarchical relations 2. Cannot represent biclusters and bicluster-chains
Bicluster Level	1. Show a bicluster 2. Show all biclusters 3. Find biclusters of interest 4. Mark biclusters of interest	Matrices	1. Use a heatmap 2. Reorder rows or columns 3. Repeat rows or columns 4. Color coding the region of a bicluster	1. Reorder rows/columns 2. Select biclusters 3. Highlight biclusters 4. Replicate rows/columns	1. A visual representation that is easy to understand biclusters 2. Efficiently reduce visual clutters caused by many links	1. It is difficult to display all biclusters without replicating rows and/or columns 2. Replicated rows or columns may cause confusion 3. Overlaps may obscure biclusters with less entities
		Parallel Coordinates with Two Domains	1. Edge bundling 2. Use curved lines 3. Wrap entities with polylines 4. Tile-based parallel coordinates	1. Select entities 2. Brushing 3. Highlight polylines/entities/ribbons 4. Axes rearrangement 5. Entities reposition in axes	1. Place entities of the same group together 2. Relatively easy to find entities 3. Efficiently select multiple entities/polylines	1. The number of links exerts much impact on the readability of the diagram 2. Without links, relations between entities cannot be easily identified 3. Sometimes entity reposition (e.g., moving relevant entities to the top) is necessary to understand the relation
		Zoned Node-Link Diagram	1. Wrap nodes of a bicluster in a colored region 2. Use force-directed layout 3. Hide links between nodes	1. Select nodes/links 2. Highlight nodes/links 3. Drag nodes/links	1. Customizable spatial layout for users 2. Links clearly show relations between specific entities 3. Easily find entities that are shared between biclusters	1. Entities are randomly placed in the space, so it may be difficult to find an entity if there are many entities 2. Without links, relations between entities cannot be identified easily 3. Biclusters with less entities may be obscured in the overlapping region
Chain Level	1. Show a chain 2. Show all chains 3. Find chains of interest 4. Mark chains of interest	Node-link Diagram + Matrices	Combine all supplementary visual techniques that the node-link diagram and matrix based visualizations can use and the Bubble Sets technique	Combine all interactions that the node-link diagram and matrix based visualizations can use and path extraction	1. Efficiently reduce the number of links 2. A customizable spatial layout for users 3. Show the overview of the data based on bicluster-chains 4. By following links, users can find out how a bicluster-chain is formed	1. Entities may replicate many times in multiple matrices 2. Not a trivial visualization for users to understand connections across several biclusters 3. Which bicluster to choose to start a bicluster-chain is a problem
		Parallel Coordinates + Matrices	Combine all supplementary visual techniques that parallel coordinates and matrix based visualizations can use and the Bubble Set technique	Combine all interactions that parallel coordinates and matrix based visualizations can use and path extraction		
Schema Level	1. Show the overview of a dataset 2. Guide the exploration of chains or biclusters	The Node-Link Diagram	1. Clutter Map 2. The PivotGraph technique 3. Color coding to indicate different domains 4. Visual marks (e.g., shapes) to separate nodes and/or links 5. Use spatial distance (e.g. force-directed layout) 6. Use spatial distance + hiding links	1. Select nodes/links 2. Highlight nodes/links 3. Dynamic path extraction	1. An intuitive way to show relations between domains 2. The size of nodes and the thickness of links can be used to encode the information of biclusters and/or chains	1. The layout of PivotGraph cannot be easily changed by users 2. Depend on links to perceive relations across several specific domains
		The Chord Diagram	1. Color coding of chords to indicate different domains 2. Use ribbons between chords to indicate connections	1. Select chords/ribbons 2. Highlight chords/ribbons	1. An intuitive way to show relations between domains 2. The length of chords and the thickness of ribbons can be used to encode the information of bicluster and/or chains	1. Not efficient for a dataset with many domains 2. Ribbons inside the diagram may form visual clutters 3. Paths inside the diagram may be obscured by too many crossing ribbons

Figure 19: *Design framework associated with bicluster visualisation. Courtesy of Sun et al. [SNR14]*

InfoVis techniques	Examples
Empirical methodologies	
Model	[11,34,35,52,65,66,84,95,119,128,146,153]
Evaluation	[4,12,14,15,18,49,60,69,78,82,98,100,101,103,104,115,116, 131,156]
Interactions	
WIMP interactions	[37,55,135]
Post-WIMP interactions	[13,70,147]
Frameworks	
Systems and frameworks	[2,17,28,57,89,153]
Applications	
Graph visualization	[3,8,9,13,19,20,30,36,40,42,51,59,62,85,91,118,120,133,162,164, 167,170]
Text visualization	[1,5,22,31,32,83,92–94,154,159,163,169]
Map visualization	[1,44,71,102,106,117,125,136,144,148]
Multivariate data visualization	[21,48,68,72,108,112,134,139,140]

Figure 20: *A taxonomy of InfoVis techniques created by Liu et al. [LCWL14]*

Higher-Res Tables

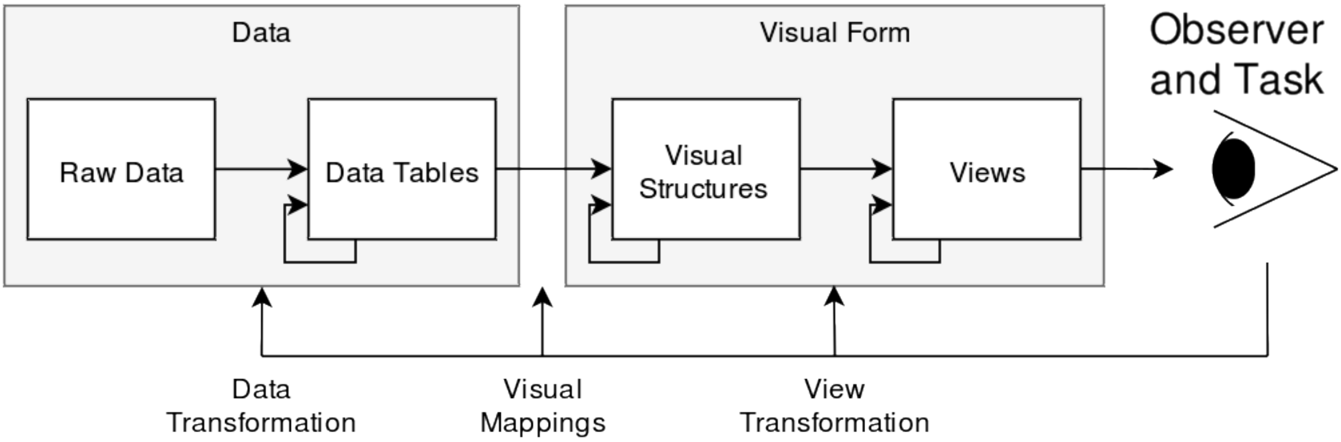


Figure 21: *The original Information Visualisation Pipeline model created by Card et al. [CMS99] which we adapt to design our modified classification.*

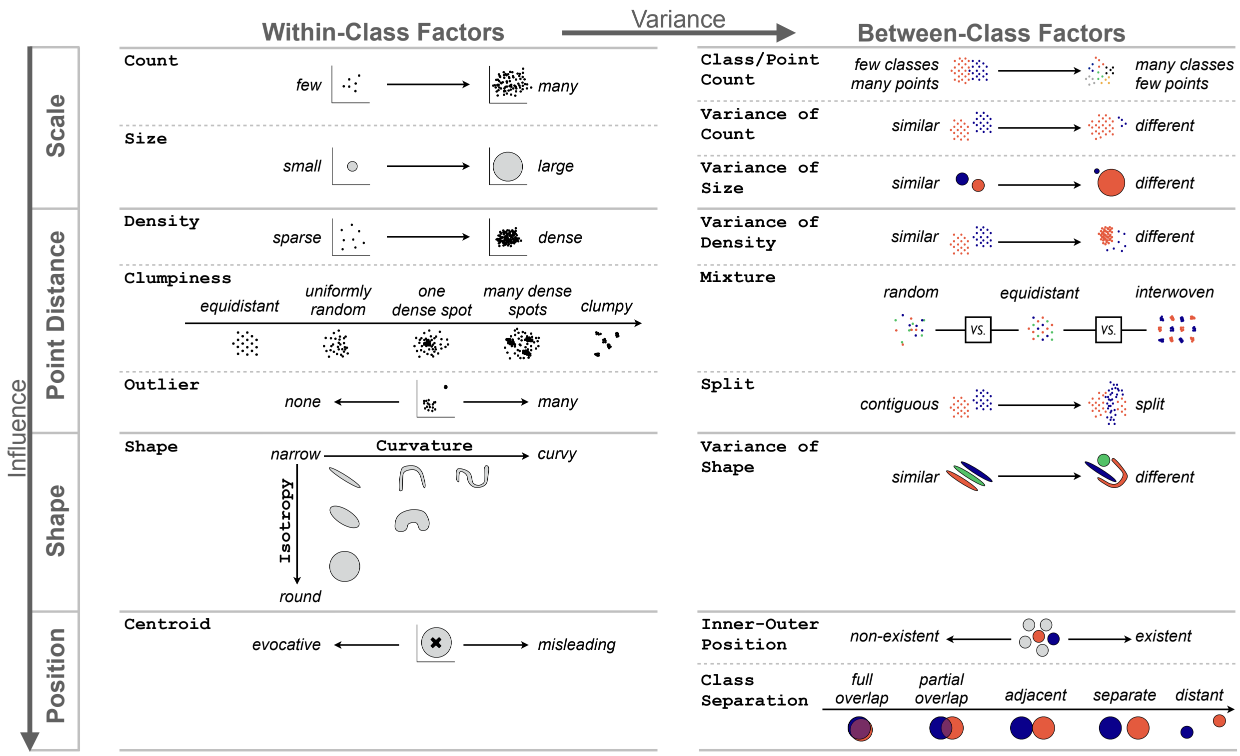


Figure 22: *An indirect mapping taxonomy of data characteristics with respect to class separation in scatterplots. Courtesy of Sedlmair et al. [STMT12]*

		Taxonomy				Demonstrated Scale*		Global Compre.		Problem Detection			Diagnosis/ Attribution	
Visualization Techniques	Papers	H	S	T	A	Data	Parallel	Program Structure	Resource Usage	Anomalies	Bottlenecks / Imbalance	Resource Misuse	Software	System
Radial Tree	Bhatele et al. [BGI*12]			X		NR	10^4 processes	X	X		X			
Node-Link Graph	Boxfish [LLBT12, ILGT12]	X				NR	10^4 nodes		X		X			X
Radial Tree, Animation	Choudhury and Rosen [CR11]	X	X			10^7 transactions	N/A	X	X		X	X	X	
Layered Node-Link	DOTS [BKS05]	X		X		NR	NR	X	X		X	X	X	
Clustered Node-Link, Animation	Frishman et al. [FT05]	X		X		NR	10^2 objects	X	X	X				
Node-Link Graph	Heapvis [AKGT10]		X			10^3 nodes		X	X				X	
Radial Tree	Kim et al. [KLJ07]		X	X		NR	10^3	X		X			X	
Node-Link Trees, Indented trees	Lin et al. [LTOB10]		X			NR	NR	X	X				X	
Node-Link trees	DeRose et al. [DHJ07]		X	X		NR	10^2 cores				X		X	
Node-Link graph, Animation	Sambasivan et al. [SSMG13]		X			NR	NR	X					X	
Radial Tree	Sigovan et al. [SMMT13a]	X				10^1 resources	10^3 processes		X	X		X		
Node-Link trees	STAT [AdSLT09]		X	X		NR	10^5 tasks	X			X		X	
Clustered Node-Link, Animation/Real Time	Streamsight [DPA09]		X	X		streaming	10^3 tasks	X	X	X	X			
Layered None-Link	Threadscope [WT10]	X		X		10^3 events	10^1 threads	X	X	X	X			
Node-Link Graph, Treemap	Weidendorfer et al. [WKT04]		X			NR	1	X					X	
Timeline, Stacked Graph, Small Multiples	de Pauw et al. [DPWB13]	X		X		streaming	10^3 tasks	X	X		X		X	
Shared Timeline	Muelder et al. [MGM09]			X		NR	10^4 processes	X			X			
Gantt Charts, Timeline, Matrix, Scatterplot	Muelder et al. [MSMT11]	X	X	X		NR	10^3 cores	X	X		X			
3D Parallel Gantt Chart, Treemap/Force-directed layouts	Triva [SHN10]	X		X		NR	10^3 processes	X	X		X			
Parallel Gantt Chart, Node-Link Tree, Bar Charts	Zinsight [DPH10]		X	X		10^5 events	10^2 processes	X	X		X		X	
1D Color-Coded Array, Histograms	Cheadle and Field [CFAT06]	X	X			10^1 memory groups	N/A	X					X	X
1D Color-Coded Array Stacked By Time	Moreta and Telea [MT07]		X			10^5 allocations	N/A	X				X	X	
Edge Bundling, Gantt Charts, Hierarchies	Extravis [CHZT07]		X			10^5 events	NR	X					X	
Parallel Gantt Chart, Indented Trees, Code view	HPCToolkit [ABF*10, TMCF*11, LMC13]	X	X	X		10^1 gigabytes	10^4 processes	X	X		X	X	X	X
Stacked Barcharts, Stacked Timelines	Lumière [BBH08]	X	X	X		10^6 decisions	NR	X	X	X	X		X	
Parallel Gantt Chart, Small multiples, Plots, Ensemble	Projections [KZKL06, LMK08]		X	X		gigabytes	10^4 processes	X	X		X	X	X	
Stacked Barcharts, Scatterplot, Histograms, Code Coloring	TraceVis [RZ05]	X	X			10^7 instructions	NR	X	X		X	X	X	
Icicle Timelines, Coordinated views	Trumper et al. [TBD10]		X	X		10^4 events	10^1 threads	X			X	X	X	
Parallel Gantt Chart, Icicle Timeline, Adjacency, Indented Trees, Ensemble Timeline, Plots	Vampir [NAW*96, BW12, ISC*12, VMa13]	X	X	X		terabytes	10^5 processes	X	X		X			
Abstract Diagram	Choudhury et al. [CPP]	X	X			10^1 buffers	N/A				X	X	X	
Dot Plot, Bar Charts	lviz [WYH10]		X	X		10^6 events	2 jobs	X			X		X	
Scriptable	ParaProf [SML*12]			X		NR	10^4 processes		X		X			
Indented Trees, Matrix	Scalasca [GWW*10, WG11]		X		X	terabytes	10^5 cores	X	X		X		X	
Color-coded 2D matrix, histograms, 3D graph layout	Schulz et al. [SLBT11]	X		X	X	NR	10^4 cores		X	X	X	X		
Bubble Chart, Animation	Sigovan et al. [SMM13]			X		NR	10^4	X	X		X			
City Metaphor	SynchroVis [WWF*13]		X	X		10^2 objects	10^1 threads	X		X			X	
Icicle Timeline, Bundles	SyncTrace [KTD13]		X	X		10^7 events	10^2 threads	X	X		X	X	X	
Sunburst, Matrix, Dendrogram	Trevis [AH10]		X			10^3 nodes	NR	X					X	

Figure 23: *Isaacs et al. present a 1-N design space that classifies literature based on the context, scale and goal of each paper. Image courtesy of Isaacs et al. [IGJ*14]*

			Close Reading					Distant Reading						
			Plain	Color	Font size	Glyphs	Connections	Structure	Heat maps	Tag clouds	Maps	Timelines	Graphs	Miscellaneous
Single Text Analysis	enhanced text views	[Pie10], [CGM*12], [Pie13], [GWFI14]				x								
		[PSA*06], [CTA*13], [Ben14], [BJ14]		x										
		[ARLC*13]				x	x							
		[WMN*14]		x	x									
	both	[VCPK09], [BGHJ*14], [KJW*14]		x				x		x				
		[WJ13b], [CMLM14], [KZ14]		x			x							
		[Cay05]	x					x						
		[CDP*07]		x					x					
		[WV08]		x									x	
		[MFM13]	x										x	
		[RSDCD*13]	x											x
	abstract text views	[KO07], [FS11], [CTA*13], [OKK13], [Ben14]							x					
		[Pie05]						x						
		[PBD14]												x
Parallel Text Analysis	section alignments	[WH11], [HKTK14]		x										
		[Cor13], [WJ13b]		x			x							
		[JRS*09]		x				x						
		[GCL*13]		x					x					
		[JGBS14b]		x			x		x					x
	sentence alignments	[BGHE10]		x			x							
		[JGBS14a]			x		x							
Corpus Analysis	statistics for textual entities	[Bea08], [Bea11], [Bea12], [BJ14]								x				
		[WJ13a], [HCC14]												x
		[CWG11]		x	x				x					
		[Mur11]		x					x					
		[FKT14]	x						x	x				
	relationships between texts	[EX10], [Gal11], [WH11], [Joc12], [CEJ*14], [Ede14]											x	
		[RRRG05]							x					
		[OST*10]		x										x
		[Wol13]		x									x	
	relationships between textual entities	[RRRG05], [AGL*07], [vHWV09], [KKL*11], [MLSU13], [WJ13a], [Arm14]											x	
		[GZ12], [RFH14]		x									x	
		[MH13]		x					x				x	
		[AKV*14]		x					x					
	social networks	[Cob05], [CSV08], [BDF*10], [RD10], [BHW11], [Kle12], [Boo13], [KOTM13], [Tót13], [Pet14]											x	
		[KLB14]	x										x	
	space and time	[JHSS12], [JW13], [DNCM14], [GDMF*14], [ÓML14]									x	x		
		[Wea08]							x		x	x		
		[BPBI10]		x							x	x		
		[DWS*12]	x							x	x	x		
		[HACQ14]		x						x	x	x		
	space	[MBL*06], [DFM*08], [Tra09], [GH11b], [EJ14]									x			
	time	[KBK11], [ARR*12], [LWW*13]										x		
		[CLT*11], [CLWW14]								x		x		
		[HSC08]	x									x	x	
		[DWS*12]	x							x	x	x		
		[ESK14]								x		x		x
		[HPR14]		x								x		

Figure 24: *A 1-N Taxonomy by Jänicke et al. to map reading techniqes found within different analysis methods. Image courtesy of Janicke et al. [JFCS15]*

	2D	3D	Adjacency	Overlap	Inclusion	Rectangles/Cuboids	Squares/Pyramid (Frustums)	Triangles/Trapezoids	Polygons	Circle(-segments)/Cylinders	Circle(-segments)/Spheres	Ellipses/Ellipsoids	1D Subdivision	2D Subdivision	3D Subdivision	1D Packing	2D Packing	3D Packing	Year Published	Figure in the Appendix
Treemap [10],[11]	■				■	■								■					1991	12(c)
Contrast Spiral Treemap [53]	■				■	■							■						2007	13(o)
2 1/2D Treemap [65]	■	■			■	■	■							■					1992	12(d)
Polar Treemap [15]	■				■					■	■			■					1993	12(e)
Jigsaw Map [59]	■				■				■				■						2005	13(g)
Generalized Treemap (Pie) [8]	■				■					■	■			■					2006	13(j) - left
Generalized Treemap (Pyramid) [8]	■				■			■						■					2006	13(j) - middle
Generalized Treemap (Pie+Pyramid) [8]	■				■					■	■			■					2006	13(j) - right
Tree Cube [30]		■			■	■									■				2003	13(c)
3D Treemap [15]		■			■	■									■				1993	12(h)
Cushion Treemap [51]	■				■	■								■					1999	12(m)
Voronoi Treemap [44]	■				■				■					■					2005	13(f)
Circular Partitions [45]	■				■				■					■					2008	13(q)
Quantum Treemap [66]	■				■	■								■			■		2001	12(q)
Data Jewelry Box [58]	■				■	■											■		2002	12(r)
Cascaded Treemap [19]	■			■		■								■					2008	13(p)
Ellimap [48]	■				■							■		■					2007	13(k)
Treemaps with Ovals [15]	■				■							■		■					1993	12(f)
Pebble Map [36]	■				■					■	■						■		2003	13(b)
CropCircles [37]	■				■					■	■						■		2006	13(h)
Lifted Treemap [68]		■			■	■								■					2009	13(r)
3D Nested Treemap [25]		■			■	■								■					1999	12(n)
Information Cube [29]		■			■	■												■	1993	12(i)
Nested Columns [15]		■			■					■							■		1993	12(g)
2D Icicle Plot [12]	■		■			■							■						1983	12(b) - left
Castles [17]	■		■					■					■						1981	12(a)
Cushioned Icicle Plot [52]	■		■			■							■						2007	13(l)
Triangular Aggregated Treemap [48]	■		■					■					■						1998	12(l)
Sunburst [40]	■		■							■	■		■						2000	12(p)
Interring [42]	■		■							■	■		■						2002	12(s)
PieTree [38]	■		■							■	■		■						2000	12(o)
Radial Edgeless Tree [46],[47]	■		■					■					■						2007	13(m)
Steptree [20]		■	■			■								■					2004	13(d)
3D Icicle Plot [12]		■	■			■							■						1983	12(b) - right
Nested Hemispheres [26]		■			■						■						■		2004	13(e)
3D Nested Cylinders and Spheres [21]		■	■							■	■						■		2006	13(i)
3D Sunburst [70]		■	■							■				■					2007	13(n)
3D Beamtree [23]		■	■		■					■			■						2002	13(a)
Information Pyramids™ [28]		■	■				■							■					1997	12(k)
Cheops™ [50]	■		■					■								■			1996	12(j)

Figure 25: *Design space for implicit hierarchy visualization created by Schulz et al. to compare techniques in the field. Image courtesy of Schulz et al. [SHS11]*

Authors / Technique	design guideline													visual channel					
	[DG1] visualization space	[DG2] complexity vs. density	[DG3] hybrid visualizations	[DG4] perceptually uniform properties	[DG5] redundant mapping	[DG6] importance-based mapping	[DG7] view point independence	[DG8] simplicity and symmetry	[DG9] orthogonality and normalization	[DG10] intuitive / semantical mapping	[DG11] balanced glyph placement	[DG12] facilitate 3D depth perception	[DG13] interactive occlusion control	color	shape	size / height / length	orientation	texture	opacity
Brewer [Bre99]: Color use guidelines				■		■				■				■					
Cleveland & McGill [CM84]: Graphical perception	2D/3D			■					■		■			■	■	■	■	■	
Crawfis & Max [CM93]: Vector field visualization	3D	2	■			■	■	■		■	■	■		■			■		■
de Leeuw & van Wijk [dLvW93]: Local flow probe	3D	-3	■			■			■	■				■	■	■	■		
Healey & Enns [HE99]: Combining textures and colors	2.5D	1	■	■				■	■	■	■			■	■	■	■	■	
Healey et al. [HBE96]: Preattentive processing	2D		■	■				■	■		■			■	■	■	■	■	
Kindlmann & Westin [KW06]: Glyph packing	3D	2	■			■	■	■	■	■	■	■		■	■		■	■	
Kindlmann [Kin04]: Superquadric tensor glyphs	2.5D	1.5	■				■	■	■	■					■		■	■	
Kirby et al. [KML99]: Concepts from painting	2D	1	■			■		■	■	■	■			■	■	■	■	■	■
Laidlaw et al. [LAK*98]: Stochastic glyph placement	2D	2	■			■		■	■	■	■	■		■	■	■	■	■	■
Li et al. [LMvW10]: Symbol size discrimination	2D			■					■						■	■			
Lie et al. [LKH09]: Design aspects of glyph-based 3D visualization	3D	2		■	■		■	■	■	■		■	■	■	■	■	■		■
McGill et al. [MTL78]: Variations of box plots	2D	-3		■	■	■		■	■	■					■	■			
Meyer-Spradow et al. [MSSD*08]: Surface glyphs	2.5D	0	■			■	■	■	■	■	■		■	■	■	■			■
Peng et al. [PWR04]: Clutter reduction using dimension reordering	2D	1		■	■			■	■		■				■	■			
Pickett & Grinstein [PG88]: Stick figures	2D	3		■	■			■	■								■	■	
Piringer et al. [PKH04]: Depth perception in 3D scatterplots	3D								■	■		■	■	■		■			■
Rogowitz et al. [RTB96]: How not to lie with visualization	3D		■	■		■			■	■				■					■
Tominski et al. [TSWS05]: Helix glyphs on geographic maps	2.5D	-2	■		■					■	■	■		■		■			
Treinish [Tre99]: Task-specific visualization design	2.5D	-2	■	■		■			■	■	■			■	■		■	■	
Ward & Guo [WG11]: Shape space projections	2D	3		■	■			■						■	■	■			

Figure 26: *A 1-N categorization of glyph-based approaches created by Borgo et al. In Desgin Guideline 2, -3 represents a small amount of complex glyphs with +3 displaying a large number of simple glyphs. Courtesy of Borgo et al. [BKC*13]*

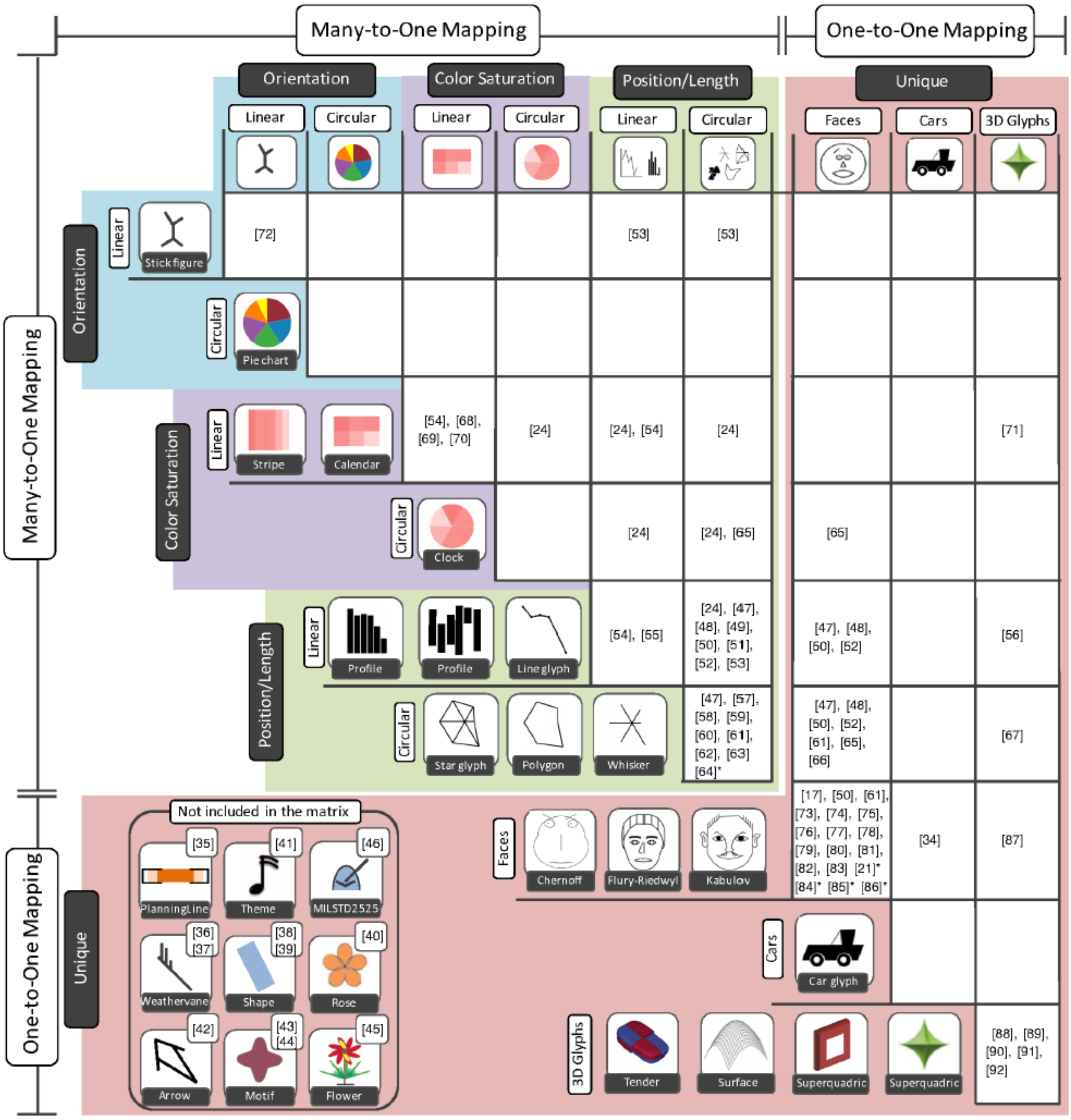


Figure 27: *A 2-Dimensional table showing the classification of the literature in the glyph-based user-study survey. Courtesy of Fuchs et al. [FIBK16]*

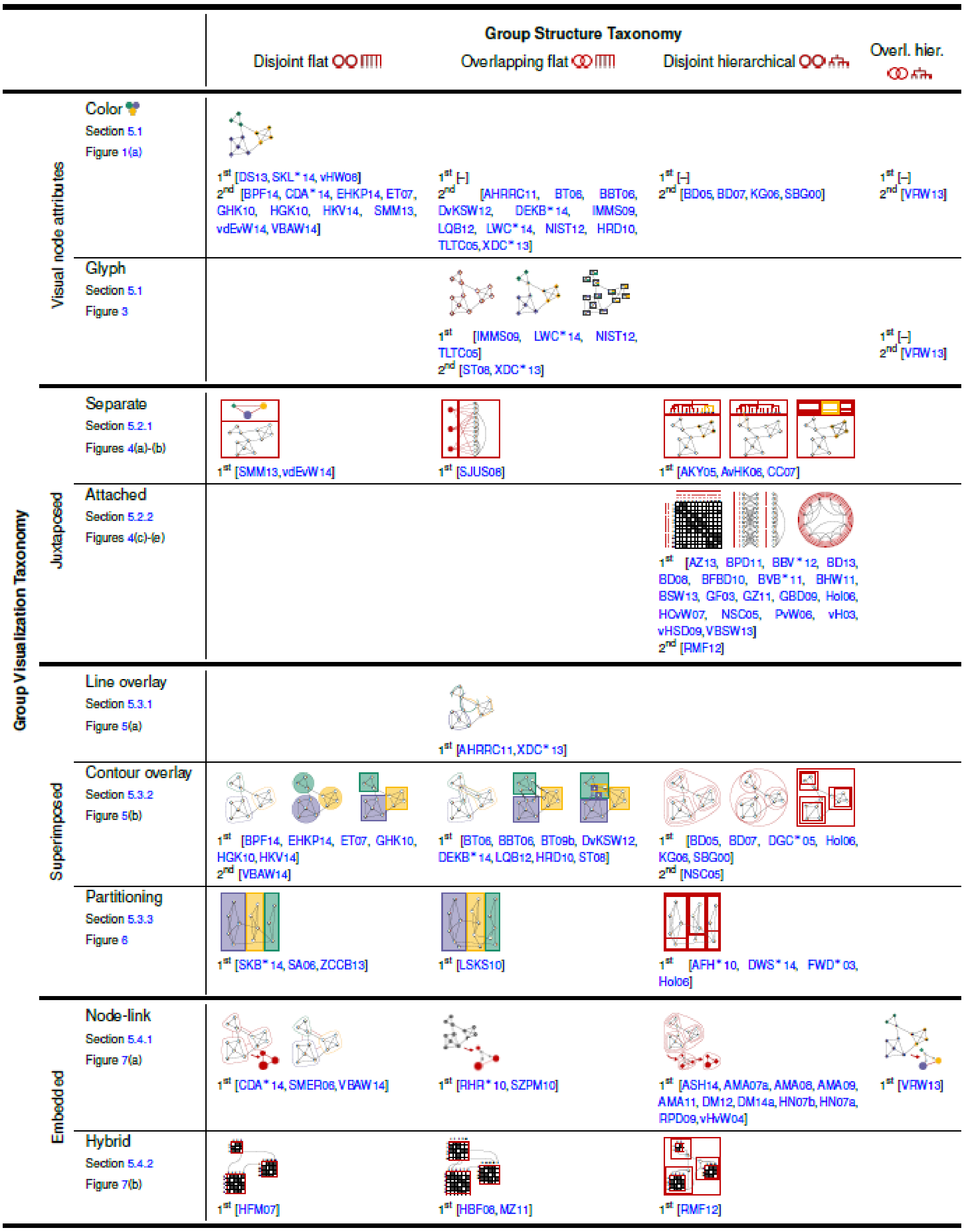


Figure 28: *Taxonomy table created by Vehlow et al. correlating group visualizations and group structures. Courtesy of Vehlow et al. [VBW15]*

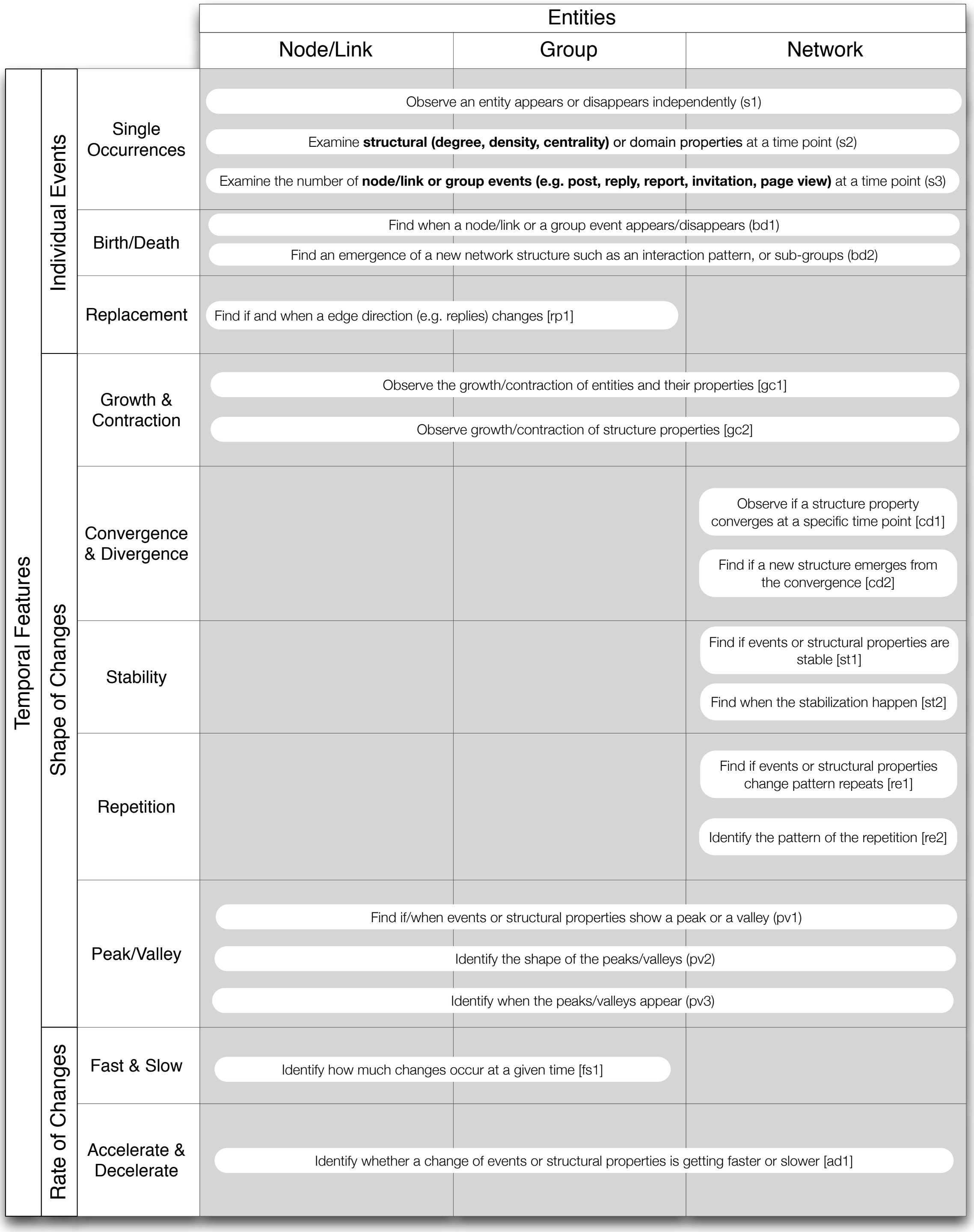


Figure 29: *Design Space of network temporal evolution tasks courtesy of Ahn et al. [APS14]*

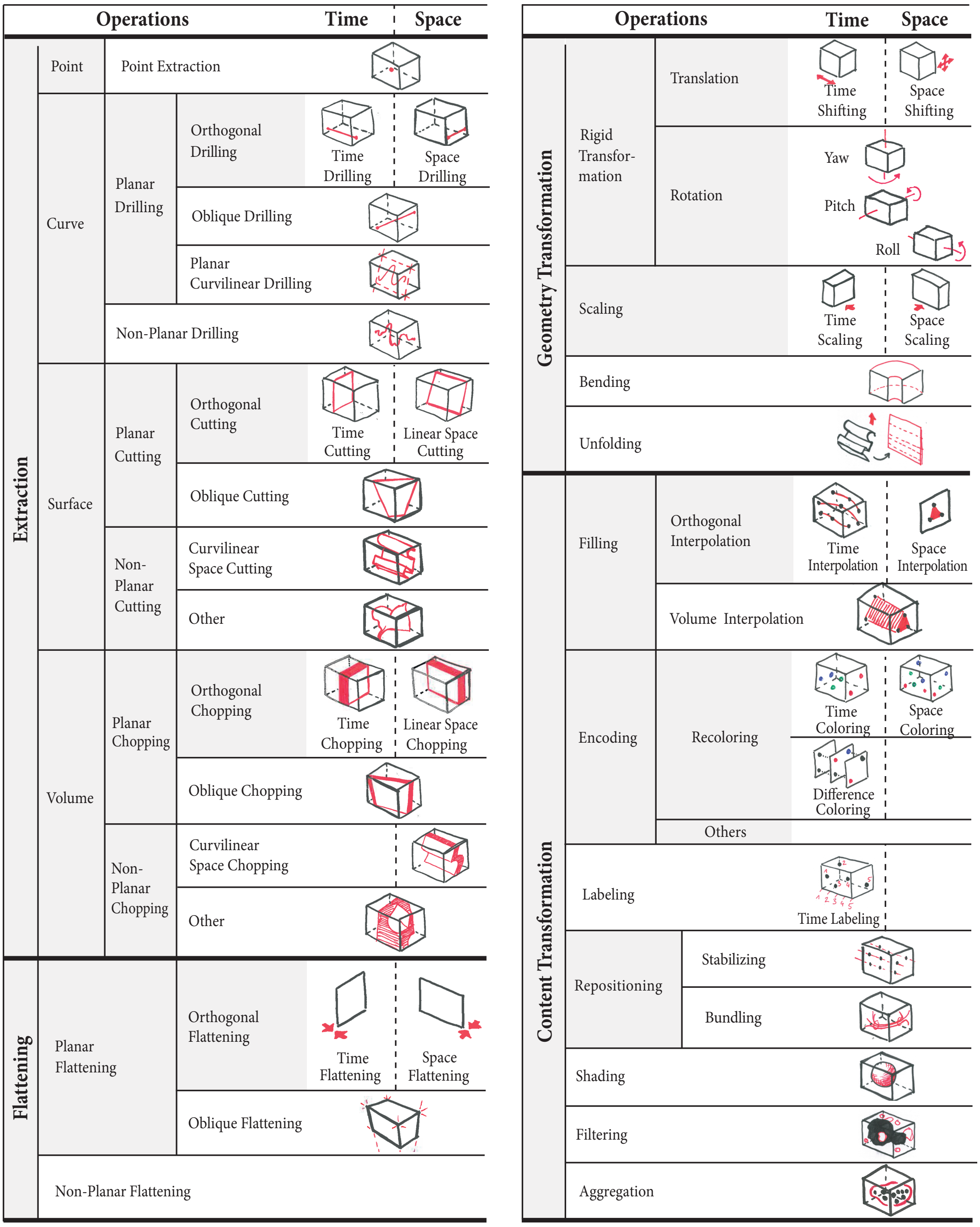


Figure 30: *Taxonomy of Space-Time cube operations created by Bach et al. [BDA* 14]. Each operation gives a representation of how the operation may work. Bold font indicates complete operations. Gray shading indicates non-leaf nodes. Image courtesy of Bach et al. [BDA* 14]*

	Level	Focus	Section	Visualization Technique	Representation	References	Year
Time T Visualization	Line	Line properties	2	Seesoft	2D colored pixel	[1], [2]	1992
				Sv3d	3D colored cuboid	[3], [4]	2003
	Class	Functioning, Metrics	3	Class BluePrint	2D layers and graph	[5], [6], [7]	1999
	Architecture	Organization	4.1	Treemap	2D/3D colored nested boxes	[8], [9], [10]	1991
				Circular Treemap	2D/3D colored nested circles	[8], [11]	1991
				City/Cities	3D city metaphor	[12], [13], [14], [15]	1993
				Sunburst	2D colored radial display	[16], [17], [18]	1998
				Solar System	3D solar system metaphor	[19], [20]	2003
				Voronoi Treemap	2D colored irregular shapes	[21]	2005
		Relationships	4.2	Dependency Structure Matrix	2D table	[22], [23], [24]	1981
				UML	2D diagrams	[25]	1996
				Geon	3D geon diagrams	[26], [27], [28]	1998
				Solar System	3D solar system metaphor	[19], [20]	2003
				Landscape	3D landscape metaphor	[29], [30]	2004
				Hierarchical Edge Bundles	2D graph with bundled edges	[31]	2006
				City/Cities	3D city metaphor with edges	[32], [33], [34]	2007
				3D Clustered Graph	3D clustered graph	[35]	2007
		Metrics	4.3	Polymetric views	2D graph	[5], [36], [37]	1999
				Solar System	3D Solar system metaphor with edges	[19], [20]	2003
				UML MetricView	2D UML diagrams with charts on top	[38]	2005
				Treemap metrics	2D nested boxes with color and texture	[39]	2005
				City	3D City metaphor	[40], [41], [42], [43]	2005
				UML Area Of Interest	2D diagrams with area of interest	[44], [45]	2006
Visualizing Evolution	Line	Changes	5.1	Code Flow	cable-and-plug wiring metaphor	[46], [47]	2007
	Class		5.2	TimeLine	3D building metaphor	[48]	2008
	Archi.	Organizational Changes	5.3.1	Hierarchical Edge Bundles	2D graph with bundled edges	[49]	2008
		Metrics Evolution		Evolution Matrix	2D matrix	[50], [51]	2001
			5.3.2	RelVis	2D Kiviat diagrams and graph	[52]	2005
				City/Cities	3D city metaphor with animation	[48], [53]	2008

Figure 31: *Caserta and Zendra present a table that classifies methods that visualise the static aspects of software, and the associated literature. Image courtesy of Caserta and Zendra [CZ11] .*

	Data							Tasks						
Techniques	Temporal	Geospatial	Flow	Volume	Multivariate	Graph	Document	Select	Explore	Reconfigure	Encode	Abstract & Elaborate	Filter	Connect
[SB92, SB94] Fisheye Views		●				●						●		
[RM93] Document Lens							●					●		
[CMS94] MagicSphere				●				●			●	●	●	
[RC94] Table Lens					●							●		
[VCWP96] 3D Magic Lenses				●								●	●	
* [FG98] Lenses for Flow Visualization			●								●	●		
[FP99] Excentric Labeling					●				●			●		●
[SHER99] Interactive 3D Lens			●	●	●		●				●	●	●	
[LHJ01] Volume Magnification Lens				●								●		
[SFR01] Time Lens	●								●					
[BCPS02] Fuzzy Lens, Base-Pair Lens, Ring Lens						●				●	●	●		
[MTHG03] 3D Flow Lens			●								●	●		
* [WCG03] EdgeLens						●				●				
* [vHvW04] Graph Abstraction Lens						●						●		
[RHS05] Magic Lenses in Geo-Environments		●									●		●	
* [EBD05, ED06b, ED06a] Sampling Lens					●								●	
[RLE05] Temporal Magic Lens	●								●					
* [WZMK05] The Magic Volume Lens				●								●		
[TAvHS06] Local Edge Lens						●							●	
[KSW06] ClearView				●								●	●	
[TGBD08] 3D Generalization Lenses		●										●		
* [TAS09] Layout Lens						●				●				●
[BRL09] Enhanced Excentric Labeling					●				●			●		●
* [MCH*09] Bring &Go						●				●				●
[ACP10] High-Precision Magnification Lenses	●	●	●	●	●	●	●	●				●		
[JDK10] Network Lens						●					●			
* [KCJ*10] Detail Lenses for Routes		●										●		●
[Kin10] SignalLens	●											●		
* [SNDC10] PushLens						●				●				
* [STSD10] Tangible Views		●			●	●		●	●	●	●	●	●	●
* [EDF11] Color Lens	●	●	●	●	●	●					●			
[GNBP11] FlowLens			●						●		●		●	
[HLTE11] SemLens					●						●		●	
[HTE11] MoleView		●			●	●				●				
[LWG11] Facet Lens							●				●		●	
[PBKE11] EdgeAnalyser					●	●					●	●		
[ZCB11] MagicAnalytics Lens	●													●
* [ZCPB11] ChronoLenses	●												●	●
[TSAA12] Time Lens		●							●		●			●
[PPCP12] JellyLens		●										●		
* [KTW*13] TrajectoryLenses		●											●	
[PPCP13] Gimlenses				●								●	●	
[UvK13] Magic Lenses for Hypergraphs						●							●	
* [CC13] Lens for Querying Documents							●						●	●
[AACP14] RouteLens		●										●		
[BHR14] PhysicLenses		●										●		
* [MW14] Bubble Lens					●			●				●		
[DMC14] VectorLens	●				●			●					●	
[KRD14] Multi-touch graph Lenses						●				●			●	●
[DSA15] 3DArcLens		●				●				●			●	

Figure 32: *Lens Techniques categorised according to data types and task. Courtesy of Tominski et al. [TGK*16]*