University of Reading

An abductive process of developing interactive data visualization: a case study of market attractiveness analysis

Book or Report Section

Accepted Version

Li, Q. and Liu, K. (2018) An abductive process of developing interactive data visualization: a case study of market attractiveness analysis. In: Liu, K., Nakata, K. ORCID: https://orcid.org/0000-0002-7986-6012, Li, W. (V.) ORCID: https://orcid.org/0000-0003-2878-3185 and Baranauskas, C. (eds.) Digitalisation, Innovation, and Transformation. Springer, pp. 289-298. ISBN 9783319945415 doi: https://doi.org/10.1007/978-3-319-94541-5_29 Available at https://centaur.reading.ac.uk/80525/

It is advisable to refer to the publisher's version if you intend to cite from the work. See Guidance on citing.
Published version at: http://dx.doi.org/10.1007/978-3-319-94541-5_29
To link to this article DOI: http://dx.doi.org/10.1007/978-3-319-94541-5_29

Publisher: Springer

All outputs in CentAUR are protected by Intellectual Property Rights law, including copyright law. Copyright and IPR is retained by the creators or other copyright holders. Terms and conditions for use of this material are defined in the End User Agreement.

University of Reading

www.reading.ac.uk/centaur

CentAUR

Central Archive at the University of Reading

Reading's research outputs online

Author's Draft

This document is the author deposited version. The final version of this paper can be found in https://link.springer.com/chapter/10.1007/978-3-319-94541-5_29

"Li, Q. and Liu, K., 2018, July. An Abductive Process of Developing Interactive Data Visualization: A Case Study of Market Attractiveness Analysis. In *International Conference on Informatics and Semiotics in Organisations* (pp. 289-298). Springer, Cham. "

An Abductive Process of Developing Interactive Data Visualization - A Case Study of Market Attractiveness Analysis

Qi Li[1] and Kecheng Liu[2]

[1] Henley Business School, University of Reading, Reading, RG6 6UD, UK
q.li5@pgr.reading.ac.uk
[2] Information Research Center, Henley Business School, University of Reading, Reading, UK.
k.liu@henley.ac.uk

Abstract

Data visualization has been widely utilized in various analytic scenarios in the ear of Big Data, especially helping novice readers make sense of a complex dataset with interactive functions. However, due to the insufficient theoretical support for an understanding of the process of developing interactive functions and visual presentations, interactive data visualization tools often offer an interactive playground where readers might be emerged by a huge amount of data, instead of generating the insight on readers' demand. Thus, this paper is intended to construct a process of developing interactive visualization with a specific focus on enabling the interoperation between design and interpretation. Stemmed from organizational semiotics, an abductive process will be portrayed in this paper to interpret the process of developing interactive data visualization. Especially the interactive functions will be employed in an iterative process, where producers can be aware of an answer to readers' information demands on semantic, pragmatic and social levels.

Keywords: Interactive Data Visualization; Organizational Semiotics; Abductive Reasoning Process

1. Introduction

Data visualization plays an important role in business analytic intelligence, in terms of help users make sense of a large amount of data and enable data to be eventually decision-making useful with visual aids (Chen, Ebert, Hagen, *et al.* 2009). Other scholars further extend the scope of contributions of data visualization to communication between readers and producers, exploration of the complex dataset and making sense of the information demanded decision-making (Segel & Heer 2010; Li & Liu 2016). With the development of in-memory computing and cloud techniques, data visualization can be agiler to adapt to users' demands, in other words, quickly responding to users' requests by the embedded interactive functions. In addition, the collaboration among different users will be promoted based on web-based visualization application, where different views from multiple users, producers and experts can be incorporated into the process of developing data visualization. In short, other than supporting individual's exploration and sense-making of the dataset, data visualization facilitates the communication by interactive functions.

However, according to the observation on the leading visualization tools, such Tableau, QlikView, and PowerBI, although 'interactive visualization exploration' has been listed as a critical capacity of business intelligence, the focus remains on the generation of various visual representations with automatic graphing and enabling users to analyse and manipulate data by interacting with the visual representations (Gartner 2017). This observation is also echoed by the prior research, which points out the concept of interactive data visualization remains unclearly defined and its development process is still vaguely

portrayed, even though the diverse technique is available and able to support users to interact with data (Shneiderman 1996; Strecker 2012). Without an appropriately designed process and methodology, data visualization producers cannot automatically understand users' demands (or requirements), intentions of using visualization and perceived pressure from the organizational and social environment. Directly or indirectly, the above elements would impact on users' sense-making of the dataset. Thus, this paper will stress the discovery of a process framework for developing interactive data visualization.

Therefore, this paper will construct a process for developing interactive data visualization with a specific focus on understanding readers' multi-levels of information demands and guiding the producers to fulfil them with employment of interactive functions. Organizational semiotics, the doctrine of sign research, which has been applied in the various prior research for understanding the process of information transfer among different parties, will be utilized at the theoretical foundation to understand of levels of interpretation. Also, the logical reasoning process will be referred to explain how a visualization will be interpreted and to discover the key interactions demanded during this process. Stemmed by the prior research of data visualization process, this research will propose a new process with more practical details for guiding the production of data visualization, followed by an illustrative case study where the process has been applied to help design a data visualization of market attractiveness analysis. Advance and weaknesses of this research will be discussed at the end of this paper, in order to offer more suggestions for the further research.

2. **Abduction in Organizational Semiotics**

Data visualization can be articulated as a process of communication with graphic means (SAS 2012; Chen, Ebert, Hagen, *et al.* 2009; Wang, Zhang, Ma, *et al.* 2016). Semiotic, as a theoretical ground of signs and signification, can help interpret the process where a sign as a carrier to deliver information among different parties and guides the discovery of implicit and explicit factors impact the efficacy of information transferring (Liu & Li 2014; Stamper 2001). By in-depth understanding the process and identifying the significant influencing factors, the producers can further work on improving the efficacy of communication, e.g. the right information can be communicated at the right time, by the right method and to the right people. Different from other branches of semiotic research, organisational semiotics, associating with the scope of business informatics, focuses on application and usefulness of signs in a business context, where the communication among individuals and business objects are driven by business purposes, serving for business objectives and influenced by organisational environments (Liu & Li 2014). Thus, in this research, the important conceptual components of organizational semiotics will be discussed in order to lay a theoretical foundation of understanding the process of designing and interpreting data visualization: semiosis for understanding the process of sign-signifying; semiotic ladder for identify potential influencing factors in multiple layers; norm-based method for eliciting, analysing, documenting and communicating users' demands for interactive data visualization.

2.1 Semiosis

Semiosis reveals the process of sense-making, where an individual understands a sign by interpreting it based on the link with a certain object (Stamper, Liu, Hafkamp, *et al.* 2000). It is a universal mechanism which can be utilized for all sign-processing activities, which helps people to recognize the importance of creating and using signs. Interactive data visualization can be regarded as a typical sign-based communication, where visual representations act as signs to facilitate the communication between producers and readers.

The whole process of semiosis can be articulated into the following triangular model (Figure 1). The firstness is a sign or representation which is utilised as a sign vehicle linking to a secondness. The secendness is an object in actuality, which should be reflected by the sign in the firstness. However, the

reflection might not be generic and spontaneous (see the dotted line in Figure 1), where readers cannot perfectly receive the information sent by producers without any deviation. Instead, the reflection will be impacted by the readers' interpretation based on prior knowledge, various purposes of interpretation and pressures from the organisational and social environment.

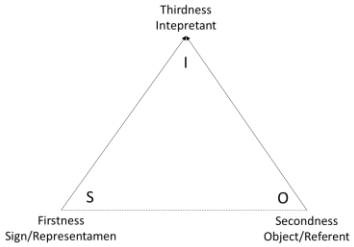

Figure 1 Semiosis Framework (Liu & Li 2014)

In the context of interactive data visualization, the meaning of three elements in semiosis framework can be further expended (Table 1):

Table 1 Elements in Semiosis in the Context of Visualization

Elements	Explanations in the context of visualization (Li & Liu 2016)
The sign, which is considered as a signifier	Visual representations, including a diagram, chart, map and table
The object, which is considered as signified	Business actuality reflected or implied by the visual representations, e.g. market size; sales trend
The interpretant, which is considered as the effect of signs on readers' action (incl. reading, interpreting and behaving upon)	A process and result of interpreting signs and identifying their reflection based on readers' subjective elements e.g. knowledge, experience and perception of environmental pressures e.g. driven by the sales-oriented strategy applied in the corporate, managers will focus more on the information related to current and potential sales when viewing the visualization of market data

Even though the semiosis portraits a general framework for discovering the visualization process where readers make sense of visual representation, the interpretant can be explained further, especially identifying the factors influencing interpretant on both technical and social aspects.

2.2 Semiotic Ladder

Interpretant has a broader scope than interpretation, which covers not only signifying a sign and identifying the meaning associating with the sign, but also involving readers' background knowledge, intentions and influences (incl. support and restrain) from social norms (Stamper 1973). Thus, semiotic ladder offers a framework of taxonomy to categorise the various influencing factors towards interpretant to 6 levels. By understanding the concepts and characteristics of different levels, visualization producers can have an in-depth understanding in terms of the barriers which hinders readers from making sense of visual representations.

Stemmed by the theory of organisational semiotics which suggests understanding the barriers hindering the communication in the context of business through the lens of semiotics, Stamper (2001) suggests analysing the sign effect through 6 levels, consisting of two aspects of human information function and IT platform. IT platform is closely related to the infrastructure, physical quality and structure of sign.

Different from the traditional semiotic framework which mostly focus on the meaning and interpretation, Stamper points out the physical quality and construction of sign will impact on human understanding of sign. On the aspect of human information function, the semiotic framework is intended to address the challenges of signifying signs in terms of transferring their meaning, fulfilling readers' intentions and responding to the social norms.

When it comes to interactive data visualization, the lower three layers encourages producers to incorporate the Gestalt Law and pre-attentive attributes into visualization design, in order to assist human brain perceptive system to visually identify the patterns e.g. size, proximity and colours. On the upper three layers of the semiotic framework, the focus shifts from visual representation (signs) to interpretant of visual representation (sign effect). As it is implied from the comment 'featureless data is equivalent to noise', there is a big challenge on the cognition aspect of interactive data visualization: to enable users to capture the pattern of the dataset, to make sense of them based on their background knowledge, intentions and to cope with social pressure. Since this paper mainly focuses on the sense-making aspect of interactive data visualization, the process framework will focus more on the key questions and norms on the upper three layers. However, the semiotic framework might have offered a comprehensive guideline for producers to recognise a series of social and technical factors which might affect sign effect – making sense of visual representations, but it does not offer a set of tangible methods to elicit and document the elements and come out a practical solution.

Table 2 Upper Three Levels of Semiotic Ladder

Factors	Explanation (Stamper, Liu, Hafkamp, *et al.* 2000)	In the context of interactive data visualization
Semantics	Meaning indicted by signs: the relationship between signs and objects	Do readers have a statistic or mathematic background to understand the algorithms behind? What factors will readers mainly consider for measuring market
Pragmatics	Intentions of readers to make sense of the dataset	What is the motivation(s) for readers to interpret the visual representations? What is
Social World	Context or environment where some factors might impact readers' focus and interpretation of visual representations	Based on what a reader can recognise, what are the major social and environmental factors which might impact on readers' opinions or focus? E.g. corporate strategy, tones from the top

2.3 Abduction

Liu and Tan (2015) state the process of developing data visualization can be depicted as a shared semiosis where the visual representation is used as a carrier to facilitate the communication between the producers and readers. Not only is it focusing on the artefact which carries the visual representation in the final stage, but also focusing on the process where a reader interprets the visualization. Also, Norm centric activities where norm can be used a powerful tool to help producer aware and document readers' explicit and implicit demands in various levels of interpreting.

Thus, this research, inspired by the three principles from Liu and Tan (2015), is intended to construct a framework for producing data visualization, especially empowering readers to implement abductive reasoning, guiding producers to place interactive functions based on norms and specifying the process of developing data visualization to steps.

The concept of abduction can be traced back to Peirce in 1930s, which can be demonstrated in semiosis where people explore signs with their prior knowledge, spots new (unmatched patterns with their prior knowledge) and refine the prior knowledge by proposing new propositions and hypothesis which might result in further actions, e.g. further discovery by other means (Kovács & Spens 2005; Thagard 2007). Dubois and Gadde (2002) claim that abduction can be used as an approach to push creativity and help the reader form a proposition by making sense of what their observed and contrast with what they understood. Other than abduction, induction and deduction are other two mainstream reasoning process.

In contrast, deduction encourages people to extract the logical conclusion from the prior theories, to form them up as hypothesises and propositions, and to test them in the form of an empirical study. Induction follows the opposite way compared with deduction (Ho 1994). Instead of obtaining knowledge from prior literature, induction will guide people to generalize a theoretical form based on an observation (Sowa 2000).

Different from induction and deduction, the method of abduction supports human to develop or refine their knowledge by systematizing the creativity and intuition into their logic reasoning process. The factors, such as prior knowledge and context, is also recognized to be influenced to the people's understanding, instead of purely relying on what people can observe in the empirical study. Also, it emphasizes that the aim of abduction is more than spotting the different of empirical study and prior understanding, but also including understanding the new phenomenon and generate/reframe new understanding.

3. Constructing a Process for Developing Interactive Data Visualization

In this research the logic reasoning process of abduction can be depicted as follows, consisting of 5 steps.

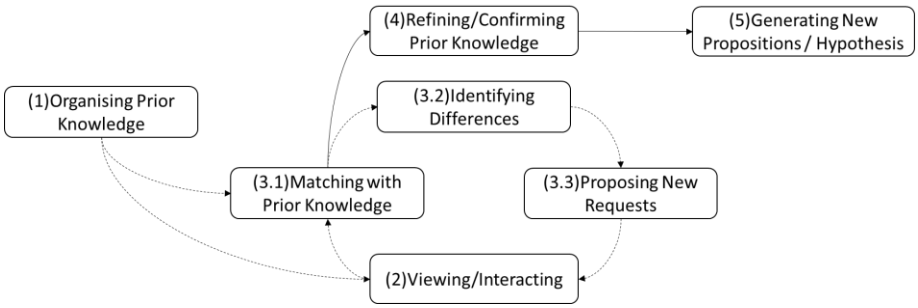

Figure 2 Abductive Process of Developing Data Visualization

Step one Capturing and organizing readers' prior knowledge
Stemmed from the framework of the semiotic ladder, readers' interpretant of signs can be impacted by their prior knowledge (semantic level), intentions (pragmatic level) and social context (social world level). Also, discussed in the concept of abduction, readers always intend to conduct their observation guided by a series of hypothesis generated from their prior knowledge. Thus, at the beginning of developing data visualization, producers are encouraged to grasp readers' requirements and prior understanding by incorporating six interrogatives. Then some information can be further made as a norm for guiding the design of interactive functions.

Step two Viewing the initial data visualization

Based on the information obtained from the previous step and dataset available on hand, the producer can draft the initial version of the data representation and present it to the user. Then the user can have the initial view of the data representation and try to extract the demanded information from it which can be used as input of further interpretation. The design of interactive function at this stage is based on the initial input of users' demand and data availability. Thus, the user can explore the dataset based on its initial understanding.
After step two, there are two possible routes. In the first route, the user might have already obtained sufficient information from through viewing the initial data visualization. For example, they might directly find a good answer from the initial data presentation and then they can connect to the step 4, such as confirming their prior knowledge or adding more new knowledge. In the other route, the users might find the difference between the observation and their prior knowledge and try to configure a new request for further information, which will be demonstrated in step 3.

Step three entering iteration loop
Once readers find the information revealed from the initial data visualization is different from their prior understanding, the readers might enter into an iterative process (s3.1, s3.2 and s3.3), which they can request further questions based on their information demands.

Based on the observation in step two, readers would compare the information derived from viewing the data visualization with the prior knowledge (s3.1). In other words, they will compare what they have seen from the visualization with what you have understood from the prior experience and identify the differences (s3.2), where they can further address new questions into data visualization by its interactive functions (s3.3).

Step four Refining the Prior Knowledge
Through continuously addressing different information demands, readers will be able to portrait an in-depth understanding of the domain question(s). Then they can add the information learnt from the interaction with data visualisation into the prior knowledge, and generate a new understanding of the specific domain questions, which can guide their following behaviours acting upon.

Step five Generating New Hypothesis
After refining the prior understanding, the readers can further generate a new proposition for their domain questions, which can be further articulated to be a solution for the domain questions they raised up at the very beginning. Also, the readers might generate a further hypothesis which they can test in the reality or in difference scenarios. By this way, they might enter another abductive process by other means to further renew their knowledge.

4. Illustrative Case Study: Market Attractiveness Analysis

In this research, an analysis of global market attractiveness of the energy drink industry will be referred to as an illustrative case study. The key domain question raised up by the target readers is to identify the most attractive market(s) to develop a new brand of energy drink, and they expect the delivery to be able to reveal the answer by graphics that they can easily understand. Thus, this case study illustrates all 5 steps of the abductive process of developing interactive data visualization.

Step one Capturing and organizing readers' prior knowledge
A semi-structured interview with the target readers takes place at the very beginning for the purpose of capturing the initial requests of developing data visualization. Information obtained from the interview will be mapped based on the framework of six interrogations, and then migrate to the 3-level of the semiotic framework. An example is shown in

Table 3 Initial Requirement Elicitation

Six Interrogation (Tan & Liu 2013)					
When	Who	What	How	Where	Why
Initially viewing data visualisation	Brand Director	Comparing different markets based on their attractiveness	Measuring attractiveness based on consumption volume and sales	Preferable in a workshop; also request to access to the data visualization online	Initial hypothesis: the market(s) with high volume and sales is generally attractive
3-level of the semiotic framework					
Semantic Level	To compare the market data among different markets				
Pragmatic Level	To identify the most attractive market for the new brand				
Social Level	'Sales-driven' corporate strategy – to boost the sales and volume				

Step two Viewing the initial data visualization

Based on the information obtained in step one, two bar charts are made for fulfilling the initial information requests – showing the market with the highest / lowest sales and volume. The advantage of bar chart including enabling readers to easily compare the data by bar length and to identify the highest / lowest data by ordering.

After viewing the initial presentation of data visualization, the target readers confirm some their initial hypothesis, such as the countries with a huge amount of population will have high sales and volume of energy drink, such as China, Japan and the United States. However, they also found the information which is different from the prior experience. For example, some markets like Brazil and UAE might not rank high in terms of sales but enter into the top tier of sales due to the high unit price.

Step Three entering iteration loop

Based on the questions generated from the initial view of data visualization in step two, the target readers enter into the iterative loop where they can address further requests for information based on their new hypothesis. A round of interview takes place to allow the target readers to compare the compared the information from data visualization and prior experience, to articulate the specific gaps and to reveal more details of their new requests and hypothesis. During the interview, the target readers express the idea of taking more variable from the non-sales aspects into the measurement of market attractiveness, since an attractive market should not merely be identified by the sales data in a short period. Instead, incorporating non-sales data might help reveal a view of long-term market development. Thus, more requests are added to the 3 levels of the semiotic framework. On the semantic level, more variables, such as demography, the projection of market growth, market competition and business environment are considered into the measurement of market attractiveness. On the pragmatic level, the focus on the target readers shifts from merely sales variables to both sales and sales-related variables. On the level of the social world, the target readers' interpretation is also influenced by the corporate strategies, such as 'sales-driven', 'blue ocean market', '100 million USD sales threshold' and '5-year long-term focuses'. Thus, after several rounds of iteration, the interactive functions have been added to the data visualization based on the requests from the target readers. Eventually, the visual presentation is able to response to the information demands address by the target readers.

Step Four Refining the Prior Knowledge

Once the target readers find the data visualization provides sufficient information for them to justify the prior hypothesis, they decided to end the iteration and tried to refine the prior understanding. The

information grasped from the data visualization would be added to the prior knowledge. For example, the target readers had thought to put the main focus on the western European market since it seems to be a mature market. However, with the aid the data visualization, they found that the new brand can be considered to launch in Brail and the Middle East where the less fierce competition might lead more room for a new brand to set up and grow. Also, instead of merely focusing on a single market, Hub-and-Spoke can be considered to apply in Middle East markets since some similarities can be found in data patterns of their energy drink consumption and market competition, e.g. setting UAE as the Hub and gradually expand the brand influence to its neighbor countries (spokes) as a new fashion.

Step Five Generating New Hypothesis

At the final step, a workshop took place to finalize the interactive data visualization based on documents of all hypothesis and information requests provided by the target readers. The format of 'context-content-conclusion' has been used for the final presentation, which can demonstrate the key questions and hypothesis (context), the filtered data in a graphic format with interactive function (content), and summary of data pattern (conclusion). The target readers can take the interactive data visualization as an input of their business strategy formation or a document to provoke a discussion of strategic decision.

5. Discussion and Conclusion

This paper portrays an abductive process of developing interactive data visualization, where different mechanisms have been used to facilitate the communication and interoperation between producers and target readers. The information demands from target readers will analyse by different level based on the semiotic framework, including semantic, pragmatic and social levels. Also, the iteration loop allows target readers continuously address the requests for more information in order to justify their hypothesis, which can be documented and analysis in the format of the norm and eventually lead the design of interactive functions. In the end, a case study of global market attractiveness analysis has been used to illustrate the proposed process of developing interactive data visualization.

In terms of contributions of this research, it further develops the statement from (Liu & Tan 2015) - visualization as a process of abduction, by demonstrating a detailed process where visualization producers can capture targets' multilevel information demands and elicit them into the design of interactive function. Also, further developed the idea of enabling the interoperation between producers and readers (Li & Liu 2016), the iteration loop enables both two parties to continuously synergize the understanding of information request, targets' purposes and potential influence from the corporate strategy (social environment).

However, there are two limitations which should be addressed in order to inspire further studies. Firstly, this research does not set criteria to measure the satisfaction of target readers about fulfilling their information demands. Without the criteria, the target readers might be trapped by 'confirmation bias' where they think they might have had sufficient information but actually not (Kodagoda, Attfield, Wong, *et al.* 2013; Lee, Kim, Hung, *et al.* 2016). Therefore, the following research can further work to specifying the criteria of measuring readers' satisfaction of information fulfilment. Secondly, this research does not compare the proposed process with the traditional way of developing visualization from the readers' perspective about the extent in which the new process helped them understand data better than the traditional approach. Thus, a comparative research between the abductive process and non-abductive process of developing interactive data visualization should be conducted to justify the helpfulness of the abductive process.

References

Chen, M., Ebert, D., Hagen, H., Laramee, R.S., et al. (2009) Data, Information, and Knowledge in Visualization. *Computer Graphics and Applications, IEEE*. [Online] 29 (1), 12–19. Available at:

doi:10.1109/MCG.2009.6.

Gartner (2017) Magic quadrant for business intelligence and analytics platforms. *Gartner*. [Online] (February 2017), 1–126. Available at: doi:10.1017/CBO9781107415324.004.

Ho, Y.C. (1994) Abduction ? Deduction ? Induction ? Is there a Logic of Exploratory Data Analysis ? *Proceedings of the the Annual Meeting of the American Educational Research Association*. [Online] 28. Available at: doi:http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.135.3507&rep=rep1&type=pdf.

Kodagoda, N., Attfield, S., Wong, B.L., Rooney, C., et al. (2013) Using Interactive Visual Reasoning to Support Sense-Making:\rImplications for Design. *IEEE Trans Vis Comput Graph*. [Online] 19 (12), 2217–2226. Available at: doi:http://dx.doi.org/10.1109/TVCG.2013.211.

Kovács, G. and Spens, K.M. (2005) Abductive reasoning in logistics research. *International Journal of Physical Distribution & Logistics Management*. [Online] 35 (2), 132–144. Available at: doi:10.1108/09600030510590318.

Lee, S., Kim, S.H., Hung, Y.H., Lam, H., et al. (2016) How do People Make Sense of Unfamiliar Visualizations?: A Grounded Model of Novice's Information Visualization Sensemaking. *IEEE Transactions on Visualization and Computer Graphics*. [Online] 22 (1), 499–508. Available at: doi:10.1109/TVCG.2015.2467195.

Li, Q. and Liu, K. (2016) *Interactive Data Visualisation : Facilitate the Accountability Disclosure through the Lens of Organisational Semiotics Interactive Data Visualisation : Basic Concept and Principle*.

Liu, K. and Li, W. (2014) *Organisational Semiotics for Business Informatics*. Routledge (ed.). [Online]. UK, Taylor & Francis. Available at: https://books.google.co.uk/books?id=1jCLBQAAQBAJ.

Liu, K. and Tan, C. (2015) *Semiotics in Visualisation*. In: ICEIS 2014 16th International Conference (ed.). [Online]. 2015 Lisbon, Portugal, Enterprise Information Systems. pp. 5–7. Available at: doi:10.1007/978-3-319-22348-3_1.

SAS (2012) Data Visualization: Making Big Data Approachable and Valuable. *Whitepaper, Source: IDG Research Services*. (August), 4.

Segel, E. and Heer, J. (2010) Narrative Visualization: Telling Stories with data. *Visualization and Computer Graphics*. [Online] 16(6) (March), 1139–1148. Available at: doi:10.1109/TVCG.2010.179.

Shneiderman, B. (1996) The eyes have it: a task by data type taxonomy for information visualizations. *Proceedings 1996 IEEE Symposium on Visual Languages*. [Online] 336–343. Available at: doi:10.1109/VL.1996.545307.

Sowa, J.F. (2000) *Knowledge Representation: Logical, Philisophical, and Computational Foundations*. (January 2000), 594.

Stamper, R., Liu, K., Hafkamp, M. and Ades, Y. (2000) Understanding the roles of signs and norms in organizations - a semiotic approach to information systems design. *Behaviour & Information Technology*. [Online] 19 (1), 15–27. Available at: doi:10.1080/014492900118768.

Stamper, R.K. (2001) *Information, Organisation and Technology: Studies in Organisational Semiotics*. Kecheng Liu, Rodney J Clarke, Peter Bøgh Andersen, and Ronald K Stamper (eds.). [Online]. Boston, MA, Springer US. Available at: doi:10.1007/978-1-4615-1655-2_5.

Stamper, R.K. (1973) *Information in Business and Administrative Systems*. Halsted Press book. [Online]. Wiley. Available at: https://books.google.co.uk/books?id=BXRkAAAAMAAJ.

Strecker, J. (2012) *Data Visualization in Review : Summary*.

Tan, C. and Liu, K. (2013) An organisational semiotics inspired information architecture: Pervasive healthcare as a case study. *ICISO 2013 - Proceedings of the 14th International Conference on Informatics and Semiotics in Organisations, IFIP WG8.1 Working Conference*. [Online] 35–44. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-84880322415&partnerID=tZOtx3y1.

Thagard, P. (2007) Abductive inference: From philosophical analysis to neural mechanisms. *Inductive reasoning: Cognitive, mathematical, and neuroscientific approaches.* [Online] 35. Available at: http://books.google.com/books?hl=en&lr=&id=08Ngh0olFRwC&oi=fnd&pg=PA226&dq=Abductive+inference:+from+philosophical+analysis+to+neural+mechanisms&ots=drGjuMEVI3&sig=zSaDvQkdme1WukWRA7041eZ0rnU.

Wang, X.M., Zhang, T.Y., Ma, Y.X., Xia, J., et al. (2016) A Survey of Visual Analytic Pipelines. *Journal of Computer Science and Technology*. [Online] 31 (4), 787–804. Available at: doi:10.1007/s11390-016-1663-1.