Systemic Visual Structures: Design Solution for Complexities of Big Data Interfaces

Suraya Ya'acob, Nazlena Mohamad Ali, Norshita Mat Nayan
Institute of Visual Informatics
Universiti Kebangsaan Malaysia,
43600 Bangi, Selangor, Malaysia
surayayaacob@gmail.com, nazlena@ivi.ukm.my, norshita@ivi.ukm.my

Abstract. The prime challenge for big data in handling variety, velocity and volume (3V) information is a complexity. In recent years, big data has been studied extensively from technology perspectives. However, far too little attention has been paid to the limited human cognitive to perceive and process the complexities, especially when the users as in the management team of organization need to digest the information collaboratively. The objective of this paper is to show how visual representation design can play an important role to facilitate this challenge. We term the challenge as collaborative complex cognitive activities (collaborative CCA) and is valuable for decision making, analytical reasoning, sense making, problem solving, learning and planning in the organization. In this research, we propose the systemic view as a fundamental to facilitate the collaborative CCA for big data. We attempt to extend the technical function of an overview to suffice the demonstration of systemic view through visual structure. By having this, we are able to view each information elements as part of the whole and giving them preparation to handle any emergence of ideas, information or tasks during the collaborative CCA. Finally, this paper also shows the result of the validation. We test the systemic view of visual structure demonstration through the experimental class with applying case studies in the real environment of the organization. The deductive qualitative analysis shows the benefits of the systemic view to clarify the main drivers and see the interconnection between various elements. Further than that, we find the potential of systemic visual structure to spark an innovation while performing collaborative CCA. Through this research, we hope to broaden the scope of visual representation to ensure the users are able to perceives, process and find values from the complexities of big data.

Keywords: big data interfaces, visual representation, complexities, systemic

1. Introduction

Organizations are facing information overloaded challenge. According to Lam et. al [1], digital data is increasing up to 35 ZB within the year of 2020. The big data era is evolving from business intelligence era to facilitate the world in handling the messy, massive, diverse and ever changing information [2] but in more immense volume.

Even though, there is yet no scientific definition and description for the big data but most of the big data scientist agree on three main criteria to be address – variety, velocity and volume (3V). Thus, the goal of big data is to ensure the users are capable to gain insight and create values from an immense 3V of data. Moreover, the big data technology must be able to handle the complexities of data that ranging in many different structure, relational, distributed sources, streaming and large data volume movement scale from terabytes to zetabytes [3]. In recent years, big data has been studied extensively on technology perspective, for instances - managing logistics, hardware and efficiency of the technology devices. The concept of capture, store, manage and analyze has been major interesting research to address the 3V of immense data [4]. However, far too little attention has been paid to the same capacity of brain and limited human cognitive to perceive and process the complexity of huge amount of information and data, especially when the users as in the management team need to digest the information collaboratively. From users and organization perspectives, they are less concern about how data is stored, processed or being taken care. The value of big data is when they are able to grab the relevant information collaboratively and used to facilitate them in making the decision, solving the problem or gaining insight in the sense making.

In the context of visualization-computational based, according to Sedig et. al [5] data and information are encoded and stored internally (eg, as magnetic patterns on a hard disk platter) and are not directly accessible to users. The only access that users have to this information is through the visual representation at the interface of a tool. Therefore, the design of visual representation for big data interface is fundamentally influences how users perceive and process the complexities of big data. Thus, in this study, we focus and term the collaborative users challenge to perceive and process the complexities of big data as collaborative complex cognitive activities (hereafter, simple the 'Collaborative CCA'). Previous studies have primarily concentrated on reductionism and determination approach to underpin the most of the visual representation interface design. Base on the reductionism conception, the visual representation is usually break a phenomena down into its constituent parts. The capacity of the visual representation support only a particular part of whole phenomena. It restrict the users in the organisation to observe and make sense from many perspectives. The management team is inadequate of holism view to facilitate them during the collaborative CCA. Furthermore, it limits the needs in complex situation to see the interconnection between each part as the big picture for the whole system. Without a complete perspective, the organisation have dificulties to move forward with clarity. They need a more comprehensive view that takes into account the whole system of causes and effects that have an impact on the problem. Hence, visual representation must go beyond the constituents part and capable to act as the systemic, centralized and explicit guidelines between different manager's mental model and departmental information.

Further than that, we observe a general trend in organisation toward an emerging information from internal (e.g knowledgeable workers, R&D findings, strong financial) and external (e.g trends for users demand and competitors). However, the determination approach in visual representation locks the collaborative CCA into a course that disregards any input other than information provided by the application. It cuts off the possibility of improvisation and deviation and the chance to adapt new input. Whereas, the management team need to have more flexible and open ended visual representation to handle their constructive knowledge and allign the emergence of information with their cognitive process goal while performing the CCA. Since current visualizations need to handle this kind of complexities, we believe it is timely to explore further the approach in providing solution must according to the complexities conditions. Using research from other areas to help us, we propose to shift the visualization design paradigm for handling collaborative CCA through the systemic approach. Based on systemic and General System Theory (GST), we tend to propose more holism and dynamic approach in handling complexities in big data.

This paper is presented according to the following structure. Section 2 describes the working background – challenges for big data. In section 3, we describe how the systemic approach is more relevant to underpin the visual representation design in handling collaborative CCA for the big data. Section 4 explains the importance of convergence properties for visual structure to form the systemic view for visual representation design that relevant to facilitate collaborative CCA. In Section 5, we validate the contributions of systemic view in handling collaborative CCA. Validation through an experimental class with applying case study shows the benefits of systemic visual structure demonstration while performing CCA in the management teams. Finally, section 6 provides a summary and some future research directions.

2. Challenges for Complexities of Big Data

The challenge for handling the big data is a complexity. The complexity information arises from the interconnectedness from multiple levels of depth and sources, different mental model in the collaboration and the emergence of information uncertainties. However, we need to understand in the case of big data, the complexity is not only arises from the complicated but also from the complex system. Broadly speaking, systems can be classified as being *simple*, *complicated*, and *complex* [6]. Simple systems are always straightforward and follow a linear process, such as installing the software by following a sequence of instructions. Being opposite of simple, complicated system is non-linear, might having multiple entities and a number of elements that interact with each other and difficult to understand. Their complicated nature is often related not only to the scale of the problem and number of interacting elements but also issues of coordination or specialized expertise (e.g., industrial production, network operational, robotic design and math equation). Finally, a complex system also has multiple interacting entities, many more than a complicated system, and their properties of self-organization, interconnectedness and evolution (e.g., solving problem for the human resource talent, organization strategy alignment with the government policies or making decision for product development).

The differences between complicated and complex can be subtle, yet are important to our discussion of visual representation for big data interface. Aside from the fact that complex systems have a lot more interacting elements, another key differences is based on their outcomes [7][8]. The outcomes of a complicated system are always determined, predictable, by things like good algorithms, calculations, specifications, and control structures. For instance, we can be certain of the success of designing the new production line if we are following one success coordination and specialized expertise of the previous architectural and design procedures. A complex system, on the other, cannot be understood solely by simple or complicated approaches. The outcomes of a complex system are not certain and predictable, but are rather *emergent*. For instance, the complex system is like solving the financial problems of an organization. The successful of handling one financial situation provide experience but no assurance of success with the next, as each financial context is very different than the other. Every financial context is unique and must be understood with constant adaptation in design, action and emergent situations.

Complicated systems can use the most sophisticated math technical and engineering expertise in mapping out the flow charts of the process to solve a problem [9]. But from time to time, this sophisticated approach is fails to solve complex problem in the organization. This same problem can transferred to visualizations. For visualizations to effectively facilitate users' exploration of heterogeneous and ever-changing, dynamic information, it is essential to identify what kinds of representations can support data that are complex rather than complicated. Misidentifying the correct type of visual support will result in an ineffective solution, and it is possible that the giving visualization solution might create a new problem and be somewhat misleading. We may be trying to use deterministic and complicated tools to handle a complex data set in the big data —a clear mismatch.

One of the obvious mismatches is that traditional computer science and engineering training has taught us that when dealing with a system, we need to reduce it into simpler constituents. It is based on the reductionism theory that holds that a system, complex or not, is the sum of its parts and that an account of it can be reduced to accounts of individual constituents. This approach is appropriate if we want to handle a complicated visualization, but it may not be suitable to handle a complex visualization. This is because a complex visualization, like any complex system, is much more than a sum of its parts. It is often characterized as having extreme sensitivity to initial conditions as well as having an emergent behavior that are not readily predictable or even completely deterministic—this is because of the evolving, dynamic nature of the data. Outcomes in a complex system usually emerge from the dynamic interaction of its constituent elements over time. When dealing with data that is "*massive, messy, diverse, and ever changing*" using a complex view to the creation of visualizations can represent a more suitable approach.

3. Systemic Approach to Handle the Complexities

We propose the systemic approach as a basis for visual representation structure to handle the complexities. The concept of systemic is closely related to understand the interconnection and provide the big picture in the sense of holism. Hence, from visualization-computational based perspective (for instance – information visualization, visual analytics, knowledge visualization and data visualization), an overview concept is the key element that should consider the systemic view for big data interfaces. Overview is the key element in the classical visual information-seeking mantra - O*verview first, zoom and filter then details on demand* by

Schneiderman [10]. However, the context of meaning for overview is incomplete for the systemic view. According to Hornbaek and Hertzum [11], the meanings and uses of the notion of overview from information visualization research mainly discuss a technical sense of systemic, in which an overview is a display that shrinks an information space and shows information about it at a coarse level of granularity. Although this mantra suggests the importance of a user's initial high-level view of the data in framing further analysis, but it seem to capture only modest parts of overview. In particular, their emphasis on getting an overview first and preferably pre-attentively is at odds with descriptions of overviewing as actively created throughout a task. By having the systemic view means the users should be able to understand the reality and overall situation. They should be clear of the main driver, capable to identify the key points and see the interconnections between various perspectives, understand the interconnection between various elements and finally, giving them readiness to handle any emergence of ideas, information or tasks during the collaborative CCA. Therefore, we attempt to extend the technical function of an overview to suffice the demonstration of systemic view. Thus, we need a cornerstone to make sure an overview concept design of visual representation design for big data interface is sufficient to provide the systemic view.

Since the inevitable of the systemic view in current visualization-computational based is rooted from the theory of analytical reductionism - states that the system is a 'sum of its parts' and account system can be broken down into different individual accounts. That theory is applicable for complicated system but clearly a mismatch for complex matters. Therefore it is important to implement the theory that can provide the big picture in the sense of systemic. Systemic concept has been mentioned by Aristotle 2000 years ago when he explained the significant holism is something over and above its parts and not just the sum of them all [12]. According to Mengis [13], the concept of the big picture is basically from system thinking which is rooted from General System Theory (GST). GST had been introduced by Von Bertalanffy in 1930s and under system science, GST evolved to System Thinking around 1950 to current date. Within that, Checkland, Ackoff and Senge are among the key persons that contribute to the significant of GST in handling the complex challenges especially for the organization and management perspectives. GST approach the problem like a supply chain. Rather that reacting to individual parts that arise, GST will understand the underlying interconnection between various elements within a system – looks for patterns over time and seek for the root case. One of the famous metaphors to describe GST is an Iceberg Model. There are four level of GST from Iceberg Model namely: i). Events as the reaction on what just happened, ii). Pattern and trends to anticipate what trends have there been over time, iii). Underlying structure is the design that influenced the pattern to understand the interconnection between parts and iv). Mental model as the platform to transform the assumptions, beliefs and values do people hold about the system.

Because of the large extent of the GST level to be examined, we propose to concentrate the systemic view for visual representation on level three – Underlying structure. Our study seeks an importance of underlying structure of Iceberg metaphor to clarify the interconnectedness between elements of information to represent system as a whole. Based on Mengis [14] and Ziemkiewicz [15], we are aware that presenting visualization for the systemic view must at least contain the interconnection between the higher level of information (for instance: abstraction, key points and perspectives) and lower level information (for instance: details). So far, literature review in visualization-computational field finds that visual representation design focus is sufficient in presenting data part by part for lower level details. Therefore, to achieve higher level of information, we argue to have a higher level structure to complement a lower level of object data in forming the cycle of expectation. This is because the visual structure encoding is similar to how human structure information in their cognitive thinking. Finally, the importance of metaphor has been highlighted as higher level visual structures to allow for the abstraction overviews for the visual representation. Through 'the cycle of forming expectations', users can interpret visualizations by making hypotheses at higher structural levels and later confirming the hypotheses. The confirmation can be done through checking the relevant details at a lower level. The process will recur iteratively until the users are satisfied and get a fuller understanding of the complex problem or the phenomena. We argue that lack of higher level visual structure as the primary challenge to handle complexities from visual representation perspective. Further than that, as we can see, the metaphor itself is insufficient to provide systemic structure. Thus, we intend to propose a convergence properties as a visual structure design solution to complement the concept of higher level information with the lower details to generate the systemic view of visual representation for big data interface.

4. Convergence Properties as Visual Design Solution

Complex interface enable us to explore patterns and relationships between elements and processes, beyond only focusing on individual entities or agents. As new data feeds in and are incorporated into a visual representation interface, it gives rise to emergent processes and patterns that analysts should be enabled to explore. In line with emergence is the idea of convergence. Emergence and convergence have often been studied together from many aspects. Research (e.g., [17][18][19]) has shown that convergence is an essential part of emergence. We can consider the convergence aspect as a starting point to the initial characterization and preparation to handle an emergence, especially when dealing with collaborative visualizations [20][21] and [22]. The adaptation of the convergence concept is important for the collaborative users be able to get the big picture of the collaboration system of interest. Further investigation by Mengis [23] argued that the big picture is strongly related to the ability of systemic thinking, thus is related to cognitive activities. Through the convergence structure, the users should be able to grab several criteria of the big picture. Among them are: Clear of the main drivers, capacity to identify the key points (main), capabilities to see and draw the interconnections between various perspectives (key points), find an adequate level of details, find an adequate level of abstraction, capacity to relate abstraction and details, aware if discussing irrelevant issues and understand how a specific contribution related to the more general topic of the discussion. By gaining the big picture of the situation means the users understand the reality and overall situation. They understand the interconnection between various elements and giving them preparation to handle any emergence of ideas, information or tasks. The adaptation of a convergence concept is use to centralize, synthesize and organize the structure of the visual representation for the big data interface. Thus, when discussing collaborative collaborations, there are three key aspects related to the concept of convergence [20]: (i) creating share understanding, (ii) eliminating redundancy, similarity and overlap, and (iii) creating overviews and structure/ organization in a set of contributions by identifying relations. The details for each of the aspects will be discusses in the following paragraphs.

(i) Creating shared understanding - one current problem that surrounds our discussion of goal setting is that we are often uncertain what the potential elements are that come into play, as the goal often also needs to be formulated dynamically, as in many cases the goal is only conceptualised during the exploration process in complex situations. That is, the goals for a complex condition is context dependent and time sensitive, and thus emergent. We propose the goals for collaborative CCA in emergence interaction should be in open ended condition. The user's goals and information needs might potentially play a role as the goal to create shared understanding in the emergence. Since the goals is open ended, the shared understanding from convergence perspectives should be able to facilitate and dynamically change according to the context. Convergence involves the movement from diversity to uniformity. If convergence comes from different directions, then it involves movement toward a common point. Therefore, it is important to create shared understanding between the elements. According to Kolfschoten and Brazier [20], to create shared understanding entails creating shared meaning of language symbols and labels, resolving asymmetry of information, and resolving differences in exploration directions. Groups of analysts can achieve shared understanding when they come to a common understanding of concepts and words that are related to the task at hand. In addition, when it comes to the collaboration situations, the goals may differ from individual to individual, but at some point they should all have one single commom goal to ensure that it can satisty the interests of every person [24]. In this research, we intend to use visual structure as the concept of common understanding to centralized guideline to achieve the goal. Structure should guide them to allign all the details information to the higher level of abstraction and then build up perspectives to achieve the main goal.

(ii) Synthesizing is combining different elements to form a coherent whole. As discussed earlier, people perform lower level actions on the visual representation, as a synthetic process so as to support their cognitive reasoning and analytical processes [25]. The approach is to consider processes at higher level as constructive and emergent, instead of reductive, and this will make it possible that processes at lower levels will underpin the development of more sophisticated emergent patterns at higher levels [26]. In the context of collaborative CCA, they will need to provide tools and structures to support the synthetic approach. To do this, we need to understand better the synthetic process, in both individuals and groups. It is been suggested that an important approach to support synthesis is that of summarization and abstraction to eliminate redundancy, similarity and overlap [20]. Summarization can be achieved by capturing the essence of information with fewer information elements and representing it with fewer information elements. Through summarization methods, we will select only unique information, merge similar contributions to keep only unique information and finally select an instance of similar pieces of information to represent multiple instances. Abstracting information can be performed by creating higher level concepts that encompass relevant information in the original set. The purpose of abstraction is to make content more cognitively manageable by allowing people to pay attention to relevant information and to ignore other details. Abstraction can be done by generalizing a set of similar objects regarded to a specific generic type / object. It can also be attained by aggregating the relationships between objects in a hierarchical manner. When dealing with visualizations, abstraction and summarization techniques can be automatic and carried out by users, and as such these techniques will need to developed and tested.

(iii). Organizing and Structuring - an emergent behavior or emergent property can appear when a number of simple elements (e.g., entities, agents, and data) operate in an environment, forming more complex behaviors as a collective. To form structural elements, one needs find ways to relate information, based on causality, a hierarchy, or group classification. The challenge is that in complex systems the relationships are not clear. And if one type of relationship is imposed artificially the exploration may not effective. In addition, as new data comes in, the relationships will need to be adjusted dynamically. This adjustment can change the entire structure of the visualization. There seems little research about dynamic structuring given new data feeds of visualization exploration in real time during the exploration process. Multiple views can help [27], but this is only explored in the context of complicated visualizations, and not complex ones where dynamic nature is not taken in account.

5. Validation of Systemic Visual Structure Solution.

We intend to demonstrate and then validate how the demonstration of systemic views able to facilitate the collaborative users to handle the complexities. The unit of analysis for this research is the interactivity process between the users and the visual representation design. To make an observation of the interactivity process, the methods requires the events must be within their real context. Thus, the qualitative method is the most relevant one [28]. However, since we are validating the framework, the qualitative analysis will be carried out deductively [28]. By having the deductive approach, our research question has become more specific – what are the capabilities of systemic visual structure in facilitating collaborative CCA?

We intend to see the impact of systemic view in handling complexities from different level of stakeholders. For this particular paper, we would like to see how it gives impact to the novice users and later on the expert users [29]. The differentiation is according to the management skills criteria. So far we had conducted two experimental classes for the novice category. We categorize and select the novice respondents - still new in the business domain and basically didn't have much experience, training and skill to handle management tasks. Thus with the help of Young Entrepreneur Programme by Malaysia Agricultural and Research Development Institute (MARDI), we manage to approach two novice group from the Small and Medium Enterprise category to be our respondents. In order to observe the interactivity process in natural way, we intend to run the experimental class by applying the case study. Since the validation is case study basis, the experimental class seems to be more flexible and open ended to adapt the real case necessities. After understand the users' requirements, we discussed and agreed for the CCA type and subject domain that is relevant to the respondents'context and contain complexities to be our case studies through experimental class (refer to Table 1).

Table 1: Respondents of the experimental class by applying case study

Group	CCA Type	Subject Domain
Novice 1 (4 respondents)	Product Development Strategy	Agriculture investment for 18 acres land at Nilai, Negeri Sembilan
Novice 2 (5 respondents)	Business Developement strategy	Business investment in 2500 squarefeet land at Kuala Lumpur

During the experimental class, we only provide two main elements for the validation. First is the goal of the CCA type (based on the respondents' subject domain). Second is the visual structure design that derived from the systemic approach to facilitate the respondents during the activities. Using this method, we appoint the date for the management teams to perform CCA in the mode of face to face collaboration (e.g: meeting, discussion and workgroup). The experimental class took around 90-120 minutes. Based on the goal, we suggest the group to discuss as in the normal meeting or discussion as long as they refer and utilize the provided visual representation. Then we observe the interactivity process on how the visual structure design is able to facilitate the group of people while performing complex cognitive activities.

We bear in mind that the main goal for validation is to see how the visual structure design is able to facilitate the users to gain the systemic view while handling the CCA. Thus, the data collection must ensure to capture the data related to the visual structure. In order to do that, we intend to triangulate the analysis from three sources of data collection to capture the interactivity process. Three data collection methods were applied during the experimental class observation, which are: i) audio recording for discussion among the collaborators, ii) video recording for action observation during the experiment and iii) content record in the visual representation structure [28]. Thematic analysis was carried out after the transcription for the two cases. Analysis will be conducted based on the deductive qualitative analysis - DQA [30] in order to answer the research question-What are the capabilities of the systemic view of visual structure to facilitate the Collaborative CCA? Through the DQA, thematic analysis process based on open coding will be carried out as usual, but analysis codes for the themes have been assigned based on the unit of data analysis of interactivity process. Firstly, clear of the main drivers and secondly, capabilities to see and draw the interconnections between various elements.

First, we read and capture the relevant quotation from the script. Each quotation will be group according to the similarities and the new subthemes will emerge from the group. Then the collection of subthemes should support the systemic view themes. Since we are validating the visual structure, triangulation is essential to complement each of the quotation with the video on action observation that related to visual representation instruments. The findings based on the analysis will be discussed in the next section. For the findings, we found the demonstration of systemic view for visual structure is valid to handle complexities in the collaboration. Through the interactivity process between the users and the systemic view of visual structure, we found that the users are managed to understand the main drivers and able to see and draw the interconnection between various elements to construct the new perspectives. The subthemes emerge from the deductive qualitative analysis support the systemic visual structure themes as the following table 2:

Table 2: Unit and Subthemes for the systemic visual structure themes

Unit	Subtheme	Theme
• Know what are the important strategy phases and elements. • Know what to further investigate	i. Know what to do in order to develop strategy planning	Clear of the main drivers
• Value of long term (overall business development) • Value of short term (specific discussion)	ii. Understand the value of performing the discussion	
• Capacity to relate abstraction and details • Capacity to construct new perspective	i. Abstraction	Can see and draw the interconnections between various elements

By gaining these two elements of systemic – it provide the real understanding of the situations and overall situation. The first one, by understanding the interconnection between various elements gives the users preparation to handle any emergence of information, ideas or tasks. Most importantly, they are able to find an adequate level of details and abstraction. The capacity to relate abstraction and details, also the interconnection from various elements provide the basis to construct new perspectives – innovation. Whereas for the second one, clear of the main drivers - let the users understand the CCA goal. It gives the awareness if they were discussing irrelevant issues and understand how a specific contribution related to the more general topic of the discussion in order to accomplish the goal.

6. Conclusions and Future Works

Throughout this paper, we have been concerned with two overlapping themes: the visual representation to facilitate the complexities of the big data, and the role of systemic view for the visual structure to promote the creation of a whole that is greater than the sum of its part. To this end, we have validated the benefits of systemic view while handling the collaborative CCA through the visual structure demonstration. The findings from this research contribute to a better understanding of the visual representation design to handle the complexities of big data particularly from the management teams and organization perspectives. It demonstrate how the systemic approach is capable to play an important roles to facilitate and utilize complexities of big data for collaborative CCA such as decision making, sense making, learning, problem solving and analytical reasoning. Within this approach, visual representation design is capable to give clarity in the interactivity process of gaining the big picture and more responsive to the emergence of information in the organization.

Finally, this paper also shows the result of the systemic approach validation. The results are not yet conclusive on all elements of systemic view. But some first tentative conclusion can be drawn. With regards to the capability of the users to gain the systemic view, it becomes clearer for the collaborators to appreciate the values of main drivers and capable to see the interconnection between various element to construct new perspectives during the performance of collaborative CCA. Further than that, we noticed the systemic visual structure is potential to be an epistemic artefact to spark an innovation while performing collaborative CCA. Even though we value the effectiveness of current visualization computational-based approach to handle simple, linear and ideal situation, however, we need a cornerstone in the visual representation design approach to ensure it is applicable to facilitate the collaborative CCA especially to handle the velocity, variety and volume of the big data. To enrich, filter, map, render, display and view from information to visualization is an insufficient goal. Visualization in handling big data must also broaden the scope to ensure the users are able to perceive and find values of the presented visualization.

7. References

1. Lam, H., Bertini, E., Isenberg, P., Plaisant C., Carpendale, S.: Seven Guiding Scenarios for Information Visualization Evaluation Seven Guiding Scenarios for Information Visualization Evaluation. Technical Report, University of Calgary (2011)
2. James, K. A. C., Thomas, J.: Illuminating the Path: the Research and Development Agenda for Visual Analytics. IEEE Comput. Soc, Los Amitos, CA (2005)
3. Sitohang, B.: Big Data is a Big Challenges. In: The 4th International Conference on Electrical Engineering and Informatics, (2013)
4. Ng, Irene, C. L., Parry, Glenn, Maull, Roger and McFarlance, Duncan: Complex engineering service systems: a grand challenge. In: Ng, Irene, C. L., Parry, Glenn, Maull, Roger and McFarlance, Duncan (eds) Complex Engineering Service Systems: Concepts and Research. Decision Engineering, Part 5. pp 439--454. Springer, Verlag London (2011)
5. Sedig, K., Parsons, P., Babanski, A.: Towards a Characterization of Interactivity in Visual Analytics, J. Multimed. Process. Technol., vol. 3, no. 1, pp. 12--28, (2012)
6. Glouberman, S., Zimmerman, B.: Complicated and Complex Systems : What Would Successful Reform of Medicare Look Like ?, In: Discuss. Pap. Comm. Futur. Heal. Care Canada, vol. 8 (2002)
7. Ng, T.P., Irene, C. L.: Innovating on Value An SD Logic Approach, Presentation of Wolfson College Cambridge (2011)
8. Blamey, A., Mackenzie, M.: Theories of Change and Realistic Evaluation: Peas in a Pod or Apples and Oranges?. In: SAGE Publ., vol. 13, no. 4, pp. 439--455 (2007)
9. Byrne, E. P.: Educating engineers to embrace complexity and context. In: Proceedings of the institution of Civil Engineers, pp. 1--8 (2014)
10. Shneiderman, B.: "The Eyes Have It : A Task by Data Type Taxonomy The Eyes Have It : A Task by Data Type Taxonomy for Information Visualizations. In: Proceedings 1996 IEEE Symposium on Visual Languages (1996)

11. Hornbæk, K., Hertzum, M.: The notion of overview in information visualization. In: Int. J. Hum. Comput. Stud., vol. 69, no. 7–8, pp. 509--525 (2011)
12. Corning, P. A., Alto, P.: The Re-emergence of emergence: A Venerable Concept in Search of a Theory. In: Complexity 7, no 6 pp. 18--30 (2002)
13. Eppler, M. J., Linda, A., Adorisio, M., Mengis. J.: Communicating to See (and Keep) the Big Picture. A Challenge in the Interaction of Managers and Specialist. In: ICA Working Paper #3/2004, University of Lugano, Lugano (2004)
14. Mengis, J.: Integrating Knowledge Through Communication-The Case of Experts and Decision Makers. In: Proceedings OKLC 2007, the International Conference on Organizational Knowledge, Learning and Capabilities, vol. 44, pp. 699--720 (2007)
15. Ziemkiewicz, C., Kosara, R.: Implied Dynamics in Information Visualization. In Proceedings of the International Conference on Advanced Visual Interfaces, pp. 215--222, ACM (2010)
16. Ziemkiewicz, C., Kosara, R.: Embedding Information Visualization Within Visual Representation. In: Ras, Z, W., Ribarsky, W (eds).: Advances in Information and Intelligent Systems. Studies in Computation Intelligence, vol 251, pp 307--326, Springer Heidelberg (2009)
17. Waldrop, M. M.: The emerging Science at the edge of Order and Chaos. Simon and Schuster, New York: (1992)
18. David, G.: The Convergence between For-Profit and Nonprofit Hospitals in the United States, in: Int. J. Health Care Finance Econ., vol. 9, no. 4, pp. 403--428 (2009)
19. Scheffer, M.,Van Nes, E. H.: Self-organized similarity , the evolutionary emergence of groups of similar species. In: Proc. Natl. Acad. Sci. United States Am., vol. 103, no. 16, pp 6230--6235 (2006)
20. Kolfschoten, G. L., Brazier, F.: Cognitive Load in Collaboration-Convergence, in: 2012 45th Hawaii Int. Conf. Syst. Sci., pp. 129--138 (2012)
21. Kolfschoten, G.L.:Introduction to the ‘ Cognitive Perspectives on Collaboration ’ Minitrack. In: 38th Euromicro Conf. Softw. Eng. Adv. Appl. (2012)
22. Isenberg, P, Niklas, E.: Collaborative Visualization:Definition, Challenges, and Research Agenda. In: IEEE Symp. Inf. Vis., vol. 10, no. 4, pp. 310--326 (2011)
23. Mengis, J.: “Integrating Knowledge through Communication : An Analysis of Expert-Decision Maker Interactions. In Disertation of Institute of Corporate Communication, University of Lugano (2007)
24. Comi, A., Eppler, M. J.: Visual representations as carriers and symbols of organizational knowledge. In: i-Know ’11 Proceedings of the 11th International Conference on Knowledge Managemnt and Knowledge Technologies (2011)
25. Sedig, K., Parsons, J.: Interaction Design for Complex Cognitive Activities with Visual Representations: A Pattern-Based Approach. In: AIS Trans. Human-Computer Interact., vol. 5, no. 2, pp. 84--133, (2013)
26. Bates, M. J.: Information and knowledge: an evolutionary framework for information science. In: Inf. Res., vol. 10, no. 4, (2005)
27. Morey, J., Sedig, K.: Adjusting degree of visual complexity: an interactive approach for exploring four-dimensional polytopes. In: Vis. Comput. Int. J. Comput. Graph., vol. 20, pp. 1--21(2004)
28. Yin, R.: Case Study Research Design 5th edition, 5th edition. The guilfort Press, New York (2011)
29. Craft, B., Cairns, P.: Beyond Guidelines : What Can We Learn from the Visual Information Seeking Mantra ? In: IV ’05 Proceedings of Ninth International Information Visualisation Conference, pp. 110–118 (2005)
30. Carbone, E. T.: Using Qualitative & Quantitative Research Methods to Answer your Research Questions. In: Presentation of University of Massachusetts Medical School (2010)